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New Mexico Copper Corporation

PROBABLE HYDROLOGIC CONSEQUENCES OF THE COPPER FLAT PROJECT SIERRA COUNTY NEW MEXICO

JOHN SHOMAKER & ASSOCIATES, INC.
WATER-RESOURCCE AND ENVIRONMENTAL CONSULTANTS
PREPARED BY JSAI

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PROBABLE HYDROLOGIC CONSEQUENCES OF THE COPPER FLAT PROJECT, SIERRA COUNTY, NEW MEXICO

prepared by

Michael A. Jones

Steven T. Finch, CPG, PG

JOHN SHOMAKER & ASSOCIATES, INC.
Water-Resource and Environmental Consultants
2611 Broadbent Parkway NE
Albuquerque, New Mexico 87107
505-345-3407
www.shomaker.com

prepared for

NEW MEXICO COPPER CORPORATION
a wholly owned subsidiary of THEMAC Resources Group, Ltd.
4253 Montgomery Blvd NE, Suite 130
Albuquerque, NM 87109

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PROBABLE HYDROLOGIC CONSEQUENCES OF THE COPPER FLAT PROJECT, SIERRA COUNTY, NEW MEXICO

EXECUTIVE SUMMARY

The proposed Copper Flat Project includes a mine pit, supply wells, tailings facility, and waste rock facilities (Fig. 1.1) located in the Hillsboro Mining District, Sierra County, New Mexico.

Presented in this report is the evaluation of the hydrologic consequences of the proposed operating plan detailed in the New Mexico Copper Corporation (NMCC) Updated Mining Operation and Reclamation Plan for Copper Flat Mine, Rev. 1 (THEMAC, 2017a) and in the New Mexico Copper Corporation Discharge Permit Application, Rev. 1 (THEMAC, 2017b). The operating plan reviewed herein reflects a nominal processing rate of 30,000 tons of ore per day for 11.5 years and aligns with “Alternative 2” in the Copper Flat Draft Environmental Impact Statement (BLM, 2015).

The objective of this report is to develop a determination of the probable hydrologic consequences of the operation and reclamation on both the permit and affected areas with respect to the hydrologic regime, quantity and quality of surface and groundwater systems that may be affected by the proposed operations (NMAC 19.10.6.602.(13)(g)(v)) of the Mining Act regulations.

Groundwater systems include:

- The regional Santa Fe Group (SFG) aquifer.
- Quaternary-age alluvial aquifers along Animas Creek and Percha Creek.
- The crystalline bedrock of the Animas Uplift.

Surface water includes:

- Perennial flow in the Rio Grande and Caballo Reservoir that is supplied in part by discharge from the SFG aquifer.
- An area of perennial flow and riparian vegetation along Animas Creek where the Quaternary-age alluvial aquifer discharges to the surface.
- An area of perennial flow and riparian vegetation along Percha Creek, atop the crystalline bedrock.
- Springs discharging from the crystalline bedrock.
- Storm-water flows in Grayback Arroyo.

“Consequences” considered here are the resulting effects on the hydrologic regime of NMCC’s proposed operation and reclamation including both water use, and surface and groundwater impact mitigation measures.

The sources of possible hydrologic consequences of the Project include:

1. Groundwater withdrawals from the SFG aquifer: The mine water supply will be withdrawn from pumping wells PW-1, PW-2, PW-3, and PW-4. Water level in the SFG aquifer will be lowered around the well field and then gradually recover after mining. Secondary effects evaluated include:
    a. Reduced groundwater discharge to Rio Grande and Caballo Reservoir.
    b. Reduced flow to artesian wells and other effects to local groundwater users.
    c. Potential reduced discharge to shallow aquifers along Animas Creek and Percha Creek, leading to lower alluvial water levels and reduced discharge to the perennial flow and riparian areas along Animas Creek.
    d. Potential ground subsidence.
2. Groundwater withdrawals from the crystalline bedrock associated with the open pit. Water levels in the bedrock around the pit will be permanently lowered, and groundwater will flow to the pit and evaporate. Groundwater flow rates to the pit and the future open pit water level and water balance area assessed. Secondary effects evaluated include:
    a. Potential groundwater discharge from the open pit.
    b. Potential effects on springs discharging from the crystalline bedrock and on the Percha Creek perennial (riparian) area.
3. Potential for groundwater discharge from the tailings storage facility (TSF) and waste rock stockpiles (WRSPs).

The consequences were evaluated using the numerical groundwater flow model (JSAI, 2014) developed for the Copper Flat Project. Effects include the following:

Santa Fe Group (SFG) Aquifer

- Water-level drawdown in the SFG aquifer is projected to reach a maximum of about 70 ft at the well field, at the end of mining. Drawdown will decrease with distance from the well field. Water levels will then recover over a period of about 20 to 30 years.
- Total reductions in discharge to the system from the SFG aquifer are projected to peak at a total of about 3,100 acre-feet per year (ac-ft/yr) shortly after the end of mining, then diminish to near-zero over about 30 years (Fig 3.3; Table 3.1).
- Flow induced from the Palomas Graben north of the study area is projected to reach a maximum of less than 800 ac-ft/yr at the end of mining, which is estimated to result in an additional reduction of discharge to the Rio Grande by a maximum of 275 ac-ft/yr.
- Potential impairment of existing water rights from reduced discharge to flowing wells may occur.
- Effects on shallow groundwater (riparian) systems along Las Animas Creek and Percha Creek are projected to be minimal, with a maximum of less than 2 ft of groundwater-level change on Percha Creek, less than 1 ft of groundwater-level change on Animas, and non-measureable small changes in surface flow and riparian evapotranspiration.
- Depletion to the Rio Grande is projected to peak around 2,080 ac-ft/yr at the end of mining, then reduce to 28 ac-ft/yr 100 years after mining (Fig. 3.3; Table 3.1)

    As required by New Mexico Office of the State Engineer (NMOSE), NMCC will mitigate the effects of pumping of the SFG aquifer by offsetting reductions in discharge to the Rio

Grande by lease or purchase of additional water rights in the amount of the model-simulated reductions to flow.

NMCC will work with the NMOSE to ensure that impairment to existing water rights (including permitted wells) according to NMOSE criteria, by NMCC pumping, will be appropriately mitigated.

- Pumping of the production water-supply wells is not expected to result in measurable ground subsidence. No water-quality effects are expected from pumping the proposed supply wells in the affected area.

Crystalline Bedrock

- At the end of mining, groundwater-level drawdown in the bedrock around the open pit is projected to reach a maximum of about 800 ft at the pit.
- A permanent cone of depression will form around the pit, with maximum drawdown of about 600 ft at the edge of the pit.
- The pit, which currently is an evaporative hydrologic sink, will form an evaporative hydrologic sink again in the future.

After mining, the pit will be filled with fresh water from the production water-supply wells to inundate portion of the pit walls and create a steady-state hydraulic sink with the surrounding groundwater system (rapid fill). The rapid fill will begin immediately after mining and will be completed in approximately 6 months. The rapid fill requires pumping 2,200 ac-ft into the pit and will fill the pit to elevation 4,894 ft amsl. At hydrologic equilibrium, the final pit water level is projected to be about 4,897 ft amsl, about 580 ft below the pit crest at the haul road entrance. The post-mining pit water body that forms after mining from rapid fill remediation will be about 250 ft in depth and have a steady-state surface area of about 22 acres. Steady state groundwater inflow is estimated at 36 ac-ft/yr and captured storm-water runoff is estimated at 57 ac-ft/yr. Pit water evaporation is projected to be about 93 ac-ft/yr. Evaporation will maintain the hydraulic sink in perpetuity.

Long-term, indirect effects to springs discharging in and around the Animas Uplift are projected to be minimal and not measureable. Water quality effects for the open pit water body are addressed in a separate report prepared for the project.

Storm-Water Flows

Storm-water flow through Grayback Arroyo will not be affected. During operations and after reclamation, storm-water flows from Grayback Arroyo will be conveyed around the open pit in existing bypass channel and through the mine area with no expected hydrologic consequences.

TSF and WRSPs

Net percolation to groundwater from the tailings and waste rock storage areas is not expected due to installation of liner under the TSF, placement of WRSPs on low permeability crystalline bedrock, and storm-water controls. Furthermore, proposed reclamation efforts are designed to limit infiltration and be protective of groundwater. In the event of a liner defect, the impact to groundwater chemistry is expected to be minimal and remain localized.

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PROBABLE HYDROLOGIC CONSEQUENCES OF THE COPPER FLAT PROJECT, SIERRA COUNTY, NEW MEXICO

1.0 INTRODUCTION

This report presents an evaluation of the probable hydrologic consequences of the proposed Copper Flat Project (Project) in Sierra County, New Mexico. Hydrologic consequences refer to any changes, resulting from the Project, to groundwater and surface water systems, including changes to flow, water level, or chemical composition.

The Project is located in the Hillsboro Mining District, shown on Figure 1.1. Effects on both the mine permit area (Fig. 1.1) and the surrounding affected area are evaluated with respect to the hydrologic regime, quantity, and quality of surface and groundwater systems that may be affected by the proposed operations (NMAC 19.10.6.602.(13)(g)(v)).

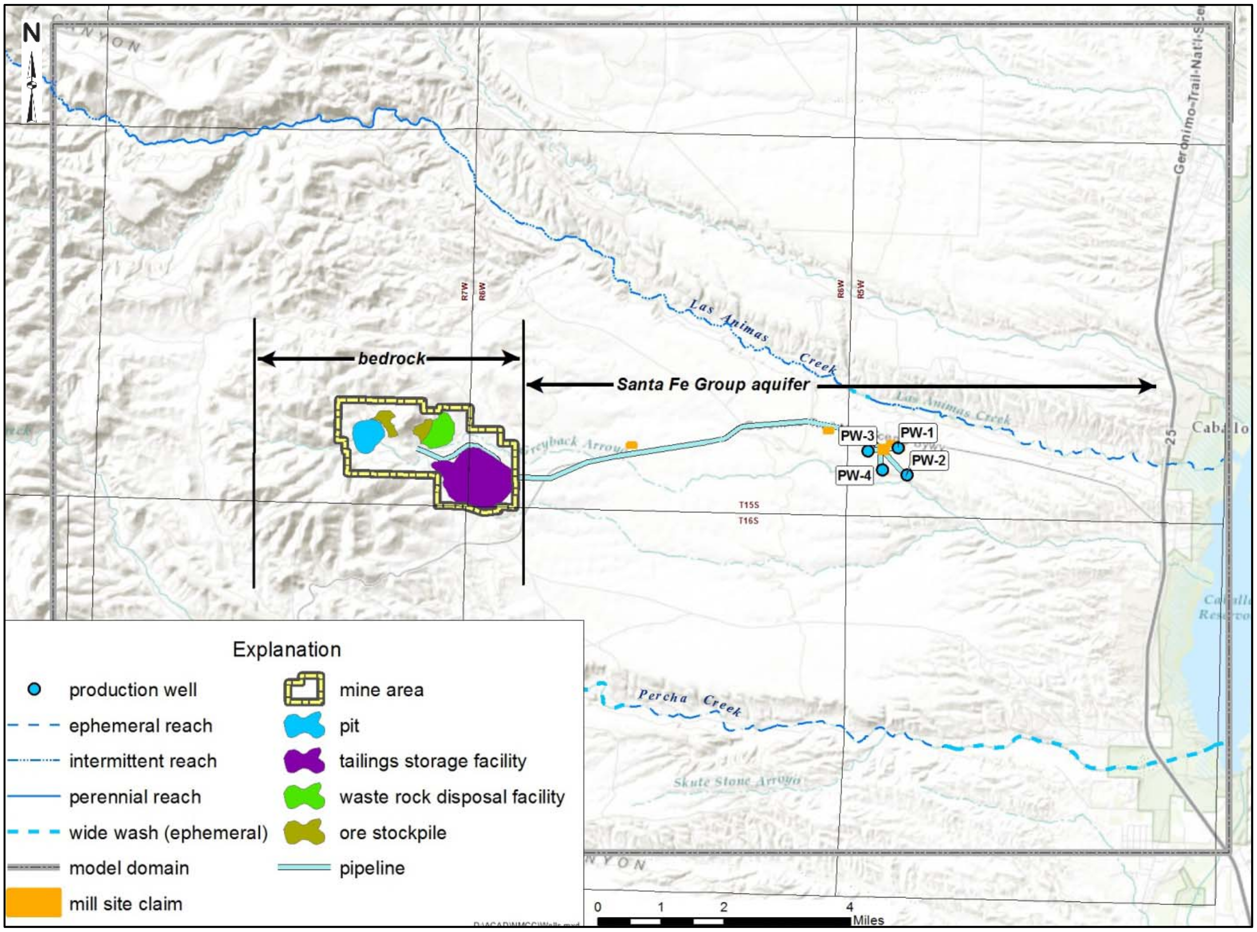

Figure 1.1. Map showing New Mexico Copper Corporation proposed mine facilities, mine area, and the affected area evaluated, Sierra County, New Mexico.

For the analysis of probable hydrologic consequences, the affected area includes the mine permit area containing the open pit and surrounding facilities, located on the andesite and quartz monzonite crystalline bedrock of the Animas Uplift (Fig. 1.1), as well as the affected area including the Santa Fe Group (SFG) aquifer around water supply wells PW-1 through PW-4 and surface and groundwater under Las Animas and Percha Creeks. The area evaluated for potential effects was the “model domain” shown on Figure 1.1.

1.1 Project Description

NMCC proposes to expand the existing open pit, previously developed by Quintana Minerals Corporation (Quintana) during a brief period of operation in 1982.

The existing pit was excavated to about 100 ft below original ground surface, with bottom elevation at about 5,400 feet above mean sea level (ft amsl). A permanent pool of water is present in the existing pit. The current water body has a surface area of about 5 acres, ranges from 10 to 35 ft deep, and contains 60 to 80 ac-ft of water. A diversion channel routes Grayback Arroyo around the pit.

Other facilities from 1982, including processing plant, waste rock storage and tailings storage, have been partially reclaimed. Water-supply wells PW-1, PW-2, PW-3, and PW-4 (Fig. 1.1) have been unused since 1982, except for pumping tests conducted by NMCC in 2012 to 2013.

Features of the Project include (Fig. 1.1) an expanded pit, processing plant, a lined tailings storage facility (TSF), and waste rock stockpiles (WRSPs). The water-supply wells will be re-activated. The Grayback Arroyo diversion would be maintained. Other diversions will route surface runoff around the processing plant and waste rock and tailings storage facilities.

The proposed operating scenario is detailed in NMCC’s Updated Mining Operation and Reclamation Plan for Copper Flat Mine (MORP; THEMAC, 2017a, Rev. 1) and in NMCC’s Discharge Permit Application (DP: THEMAC, 2017b, Rev 1). The planned scenario reflects a processing rate of 30,000 tons of ore per day for 11 to 12 years, and aligns with “Alternative 2” in the Copper Flat Draft Environmental Impact Statement (BLM, 2015). Upon receiving the required permit approvals, the Project will begin site preparation and construction, which will last approximately 2 years.

The operating life (period of mining) of the project is anticipated to be 11 to 12 years as noted in the MORP. NMCC will mine approximately 113 million tons of ore and 45 million tons of waste rock during the operating life of the mine (158 million tons). Depending on operational conditions, the mining operation will supply 8.9 to 10.8 million tons per year of copper ore to the mill for processing.

The pit will be expanded to occupy a footprint of 129 acres, reaching an ultimate bottom elevation of 4,650 ft amsl, about 825 ft below original ground surface. At the end of mining, the pit would be rapid-filled with good quality water from the production wells to the projected long-term stable water level and prevent oxidation of sulfates below the pit lake water line, thus optimizing pit water quality.

The WRSPs will be placed completely on crystalline bedrock, which provides a natural low-permeability liner. During operations, surface-water runoff collection trenches will be constructed, as needed, to collect and route runoff from the WRSPs to storm-water impoundments at the toe. These trenches will be constructed into the andesite bedrock to prevent water from entering the alluvial surface material down-gradient of the WRSPs. After mining ceases, the WRSPs will be reclaimed and covered with a 3-ft-thick engineered layered system of fill materials designed to store precipitation until it evaporates and prevent infiltration into the underlying WRSPs.

The TSF will be placed on an engineered liner system to prevent subsurface infiltration. The lined TSF will include an over-liner drainage system to maximize reclaim of water and minimize pressure on the liner. Underdrains beneath the dam will collect seepage and preserve dam stability. Water will be reclaimed from the surface of the tailings in a supernatant pond. After mining, the facility will be drained down reclaimed and covered with a 3-ft-thick layered system of fill materials to prevent infiltration into the tailings.

Ore will be trucked from the pit to the processing plant for crushing, grinding, and flotation recovery of copper. The mill will process ore at an average rate of 27,890 tons per day over the life of the operation. Milling will also include a molybdenum processing circuit and a gravity gold recovery circuit.

After mining, the site will be closed and reclaimed per an approved Reclamation and Closure Plan. NMCC has prepared a Reclamation and Closure Plan described in the Mine Operation and Reclamation Plan submitted to the Mining and Minerals Division as part of NMCC's Permit Application Package (THEMAC, 2017a; Golder, 2017).

The objective of the Reclamation and Closure Plan is to reclaim and close the facility in a manner protective of groundwater in conformance with the NM Copper Rules, meet the reclamation requirements of the New Mexico Mining Act, and return the mine area to conditions similar to those present before NMCC's re-establishment of the mine. The Reclamation and Closure Plan is designed to re-establish grazing in the area and allow for long-term use of the reclaimed areas by wildlife known to historically use the area without affecting the potential for other uses such as mining and recreation.

1.2 Analysis Method

The model of groundwater flow in the Animas Uplift and the Palomas Basin (JSAI, 2014) was used to project the hydrologic consequences of development of the Copper Flat Project. The numerical model was peer reviewed and adopted by the New Mexico Office of the State Engineer (NMOSE) in its deliberations regarding NMCC water rights declarations, and used for the Copper Flat Draft Environmental Impact Statement (BLM, 2015).

The mine site water balance developed for the proposed Mining Operation and Reclamation Plan (THEMAC, 2017a) was simulated in the numerical model to estimate potential effects on groundwater and surface-water levels and flows for the pre-mining, mining, and post-mining periods.

This analysis meets the requirements of NMAC 19.10.6.602.(13)(g)(v) by evaluating the probable hydrologic consequences of the operation and reclamation on both the permit and affected areas, with respect to the hydrologic regime, quantity, and quality of surface and groundwater systems that may be affected by the proposed operations.

The analysis takes into account both water use by the proposed operation and proposed mitigation strategies to reduce or eliminate the effects of the proposed operation. The "hydrologic regime" is considered to be surface and groundwater systems potentially affected by NMCC's proposed operation and reclamation of Copper Flat.

Surface and groundwater systems in the area include the following.

Groundwater is found in:

- The regional Santa Fe Group (SFG) aquifer.
- Quaternary-age alluvial aquifers along Animas Creek and Percha Creek.
- The crystalline bedrock of the Animas Uplift.

Surface water includes:

- Perennial flow in the Rio Grande and Caballo Reservoir that is supplied in part by discharge from the SFG aquifer.
- An area of perennial flow and riparian vegetation along Animas Creek where the Quaternary-age alluvial aquifer discharges to the surface.
- An area of perennial flow and riparian vegetation along Percha Creek, atop the crystalline bedrock.
- Springs discharging from the crystalline bedrock.
- Storm-water flows in Grayback Arroyo.

"Consequences" considered here are the resulting effects on the hydrologic regime of NMCC's proposed operation and reclamation including both water use, and surface and groundwater impact mitigation measures.

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The sources of possible hydrologic consequences of the Project include:

1. Groundwater withdrawals from the SFG aquifer: The mine water supply will be withdrawn from pumping wells PW-1, P W-2, P W-3, and P W-4. Water level in the SFG aquifer will be lowered around the well field and then gradually recover after mining. Secondary effects evaluated include:
   a. Reduced groundwater discharge to Rio Grande and Caballo Reservoir.
   b. Reduced flow to artesian wells and other effects to local groundwater users.
   c. Potential reduced discharge to shallow aquifers along Animas Creek and Percha Creek, leading to lower alluvial water levels and reduced discharge to the perennial flow and riparian areas along Animas Creek.
   d. Potential ground subsidence.

2. Groundwater withdrawals from the crystalline bedrock associated with the open pit. Water levels in the bedrock around the pit will be permanently lowered, and groundwater will flow to the pit and evaporate. Groundwater flow rates to the pit and the future open pit water level and water balance are assessed. Secondary effects evaluated include:
   a. Potential effects on springs discharging from the crystalline bedrock and on the Percha Creek perennial (riparian) area.

3. Potential for groundwater discharge from the WRSPs and TSF.

The consequences were evaluated using the numerical model (JSAI, 2014), which was developed using the United States Geological Survey (USGS) groundwater-flow modeling code MODFLOW (McDonald and Harbaugh, 1988).

Water supply pumping from the SFG aquifer was simulated at rates specified in the mine-site water balance using the MODFLOW module WEL. Pumping was simulated for the pre-mining period of construction, for the period of mining and for post-mining filling of the open pit. The period-of-pumping simulation is followed by simulation of the post-pumping recovery of water levels.

Pit-area dewatering is simulated initially as pumping from the open pit, represented using MODFLOW module LAK2 (JSAI, 2014, appendix D). After the initial dewatering of the existing pit, a set of drain boundary conditions (MODFLOW module DRN) simulate a lowering of groundwater levels as the open pit depth increases. The simulated drain elevations initially represent the extent and elevation of the current pit. The drain elevations are then lowered and new drains are added through the simulation time, to transform the boundary conditions to represent the ultimate pit. The post-mining pit filling and pit water balance is simulated using module LAK2.

Potential for groundwater discharge from the WRSPs and TSF are estimated independently of the numerical model.

1.3 Report Structure

The contents of the report are organized as follows:

Section 1.0 – Describes the Project and analysis methods and outlines the report

Section 2.0 – Projected water demand for mine water supply and rapid-filling in mine area, and estimated open-pit dewatering

Section 3.0 – Probable hydrologic consequences for mine area including the following:

- 3.1 Groundwater withdrawals from the SFG aquifer
  - 3.1.1 Regional groundwater level drawdown
  - 3.1.2 Effects on water balance
  - 3.1.3 Flow from north Palomas Graben
  - 3.1.4 Operational plans for no net effect on the Rio Grande
  - 3.1.5 Other water rights
  - 3.1.6 Effects of reduced flowing well pressure
  - 3.1.7 Effects on Quaternary-age alluvial aquifers and Animas Creek perennial flow and riparian zones
  - 3.1.8 Ground subsidence
- 3.2 Groundwater withdrawals from the crystalline bedrock
  - 3.2.1 End-of-mining groundwater drawdown
  - 3.2.2 Open pit water balance
  - 3.2.3 Potential open pit discharge to groundwater
  - 3.2.4 Effects on springs and on the Percha Creek perennial (riparian) area
- 3.3 Potential groundwater discharge from tailings and waste rock
  - 3.3.1 Tailings infiltration
  - 3.3.2 Waste rock infiltration
  - 3.3.3 Groundwater flow paths and travel times

Section 4.0 – Report conclusions with a summary of results

Section 5.0 – References

Appendix A – Additional results regarding projected groundwater-level hydrographs at different locations

Appendix B – Technical Memorandum regarding the analysis of liner leakage rates

2.0 PROJECT WATER DEMAND

The projected water demand is based on the proposed mine plan for Copper Flat as detailed in the Mining Operation and Reclamation Plan, Rev. 1 (THEMAC, 2017a), which includes a water balance accounting for seasonal effects of climate, recycled process water, makeup water from supply wells, open pit dewatering, and diverted and captured storm-water runoff from the mine area.

The projected monthly water demand was obtained in electronic form (spreadsheet file "Nov 2016 Water Balance Prod Well GPM.xlsx," NMCC personal communication, February 2017). Operational demand increases in summer and decreases in winter, averaging 6,105 acre-feet per year (ac-ft/yr) over the 11.5-year life of the mining operation.

Water will be withdrawn from the SFG aquifer to provide the main water supply for the mine. Water will also be withdrawn from the crystalline bedrock, to dewater the pit. After mining, water will be withdrawn from the SFG aquifer to rapid-fill the open pit.

2.1 Water-Supply Pumping

The estimated rates of groundwater use are summarized on Table 2.1. Project water demand includes the mine construction and start up, 11.5-year mining period, and post-mining reclamation water demand requirements. Pumping for rapid fill reclamation of the open pit will require 2,200 ac-ft over 0.5 year.

Table 2.1. Projected water-supply pumping

component	unit	result
pumping duration (includes construction, operation, reclamation)	years	23.0
average pumping rate over full project duration	gpm	2,180
summer maximum pumping rate	gpm	4,224
winter minimum pumping rate	gpm	3,388
water removed from aquifer over pumping duration	ac-ft	73,856
average annual pumping rate over pumping duration	ac-ft/yr	3,211
maximum annual withdrawal rate	ac-ft/yr	6,095

gpm - gallons per minute ac-ft/yr - acre-feet per year

The Project water use is presented in more detail in Table 2.2, showing year-by-year projections of water needs. The table presents the water balance for the mine operation that has been provided to the U.S. Bureau of Land Management in response to comments on the Draft Environmental Impact Statement, with the exception in listing a smaller volume of water (2,200 ac-ft instead of 2,800 ac-ft) used for post-mining filling of the pit.

Table 2.2. Projected water-supply pumping (acre-feet per year)

year	production wells	operation	construction	startup	rapid fill	reclama-tion
1	132	0	132	0	0	0
2	673	0	233	440	0	0
3	6,081	6,081	0	0	0	0
4	6,087	6,087	0	0	0	0
5	6,071	6,071	0	0	0	0
6	6,088	6,088	0	0	0	0
7	6,078	6,078	0	0	0	0
8	6,086	6,086	0	0	0	0
9	6,090	6,090	0	0	0	0
10	6,095	6,095	0	0	0	0
11	6,095	6,095	0	0	0	0
12	6,090	6,090	0	0	0	0
13	6,093	6,093	0	0	0	0
14	5,472	2,621	0	0	2,200	651
15	321	0	0	0	0	321
16	97	0	0	0	0	97
17	97	0	0	0	0	97
18	50	0	0	0	0	50
19	24	0	0	0	0	24
20	15	0	0	0	0	15
21	10	0	0	0	0	10
22	6	0	0	0	0	6
23	5	0	0	0	0	5
24	0	0	0	0	0	0
25	0	0	0	0	0	0
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total	73,856	69,575	365	440	2,200	1,276

This smaller post-mining filling of the pit volume is a refinement of the plan that does not measurably change the effects of the Project. The revised pit water balance is reflected in the analysis of pit water (SRK, 2017). Other, smaller adjustments to the estimated water balance may arise as the Project develops, with no measureable change to the effects of the Project.

2.2 Open-Pit Dewatering and Refilling

Pit dewatering is simulated assuming initial pit sump pumping of 100 gallons per minute (gpm), projected to empty the existing pit, with a water volume of about 60 ac-ft (INTERA et al., 2012), in about 4-1/2 months. During operations, groundwater and runoff flowing to the pit will be collected in sumps and pumped out. Projected pit dewatering during mining is summarized in Table 2.3.

Table 2.3. Pit dewatering

pit dewatering duration	years	11.4
average pit dewatering rate	gpm	28
total water withdrawn by pumping over full project duration	ac-ft	499

gpm - gallons per minute ac-ft – acre-feet

The schedule of dewatering is shown on Figure 2.1 including projected pit bottom elevation, pit-area groundwater elevation, and dewatering rates. Long-term total flow is expected to range between about 35 and 65 gpm (56 and 105 ac-ft/yr) with an initial minimum of about 20 gpm (32 ac-ft/yr) and a maximum of about 70 gpm (113 ac-ft/yr), as the pit bottom approaches final elevation of 4,650 ft amsl.

After mining is complete, the pit will be rapid filled to the projected steady-state post-mining equilibrium water level.

Current and projected final pit geometry are summarized on Figure 2.2 showing the water surface area as a function of water level. The existing pit currently has a water surface area of about 5.2 acres. The proposed pit would have water surface area of about 22 acres, with a final water level near 4,897 ft amsl. Rainfall, runoff, and groundwater inflows to the ultimate pit are projected (Section 3.2 below) to be about 100 ac-ft/yr, sufficient to sustain evaporation from a water surface of about 22 acres.

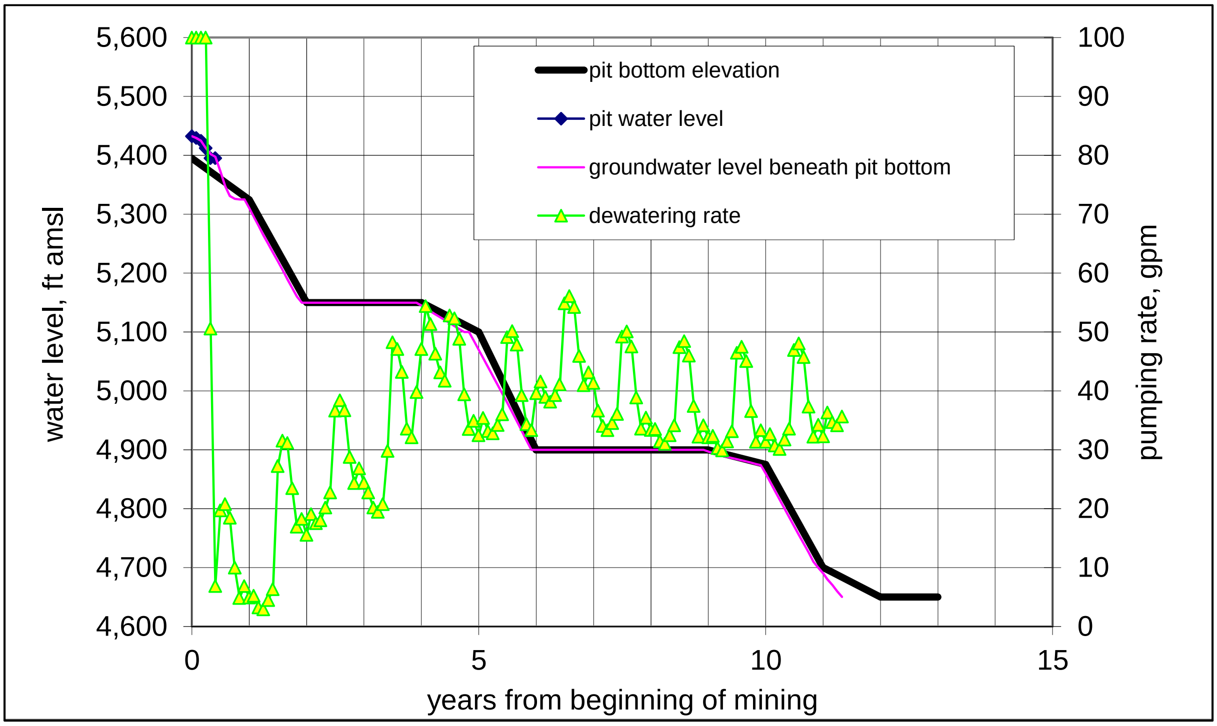

Figure 2.1. Projected pit bottom elevation, groundwater level, and dewatering rate.

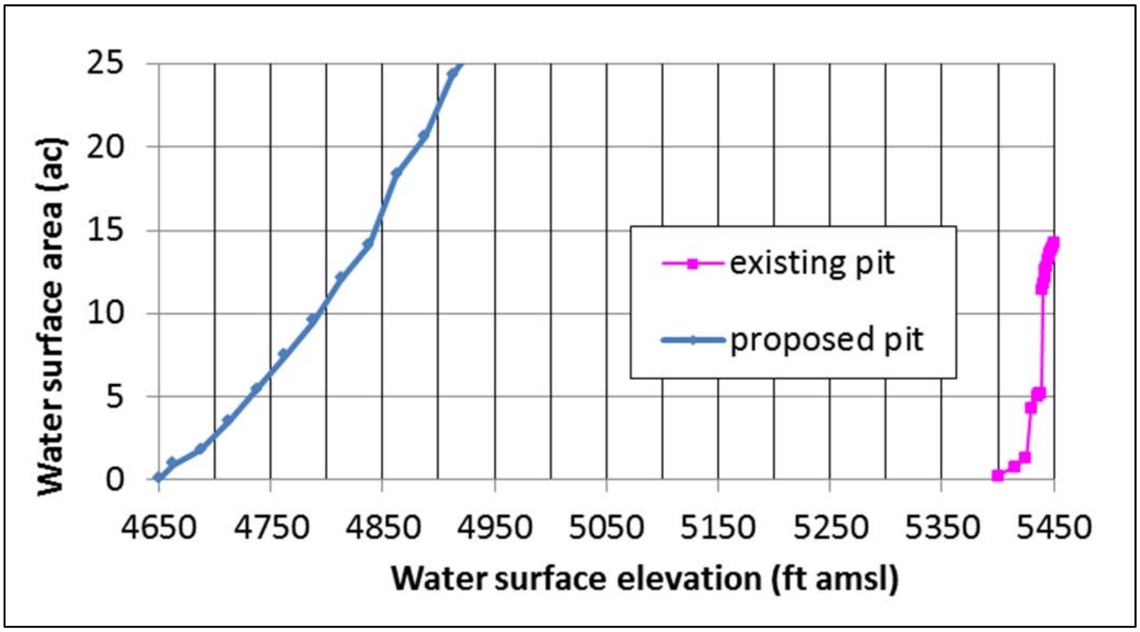

Figure 2.2. Current pit and final pit elevations and water-surface areas.

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3.0 PROBABLE HYDROLOGIC CONSEQUENCES

Probable hydrologic consequences are related to the direct hydrologic consequences of the Project:

1. Groundwater withdrawal from the SFG aquifer for mine water supply.
2. Groundwater withdrawal from the crystalline bedrock around the open pit.
3. Potential for infiltration of water from the TSF and WRSPs to groundwater systems.

3.1 Groundwater Withdrawals From the SFG Aquifer

The most direct consequence of groundwater withdrawal from the SFG aquifer will be groundwater-level drawdown in the aquifer (Sec. 3.1.1). This will in turn result in changes to the aquifer water balance (Sec. 3.1.2), including increased inflow from the north Palomas Graben (Sec. 3.1.3), reduced discharge to the Rio Grande and Caballo Reservoir, reduced discharge to flowing wells, and reduced discharge to the Quaternary-age alluvial aquifers.

The consequences of reduced discharge to the Rio Grande and Caballo are discussed in Section 3.1.4. Potential consequences to other groundwater rights are discussed in Section 3.1.5, with the consequences of reduced discharge to flowing wells discussed in Section 3.1.6.

The potential consequences of reduced discharge to Quaternary-age alluvial aquifers, including reduced discharge to the perennial and riparian zone along Animas Creek, are discussed in Section 3.1.7.

Potential land subsidence, another possible consequence of groundwater drawdown, is discussed in Section 3.1.8.

3.1.1 Regional Groundwater Level Drawdown

Contours of projected groundwater-level drawdown at the end of mining in the SFG aquifer around the water-supply wells are shown on Figure 3.1. After the end of mining, water levels in the SFG aquifer will gradually recover to pre-mining levels over about 20 to 30 years.

The groundwater-level drawdown over time will in turn cause reduced discharge from the SFG aquifer to the Rio Grande and Caballo, and reduced discharge to other related hydrogeologic systems.

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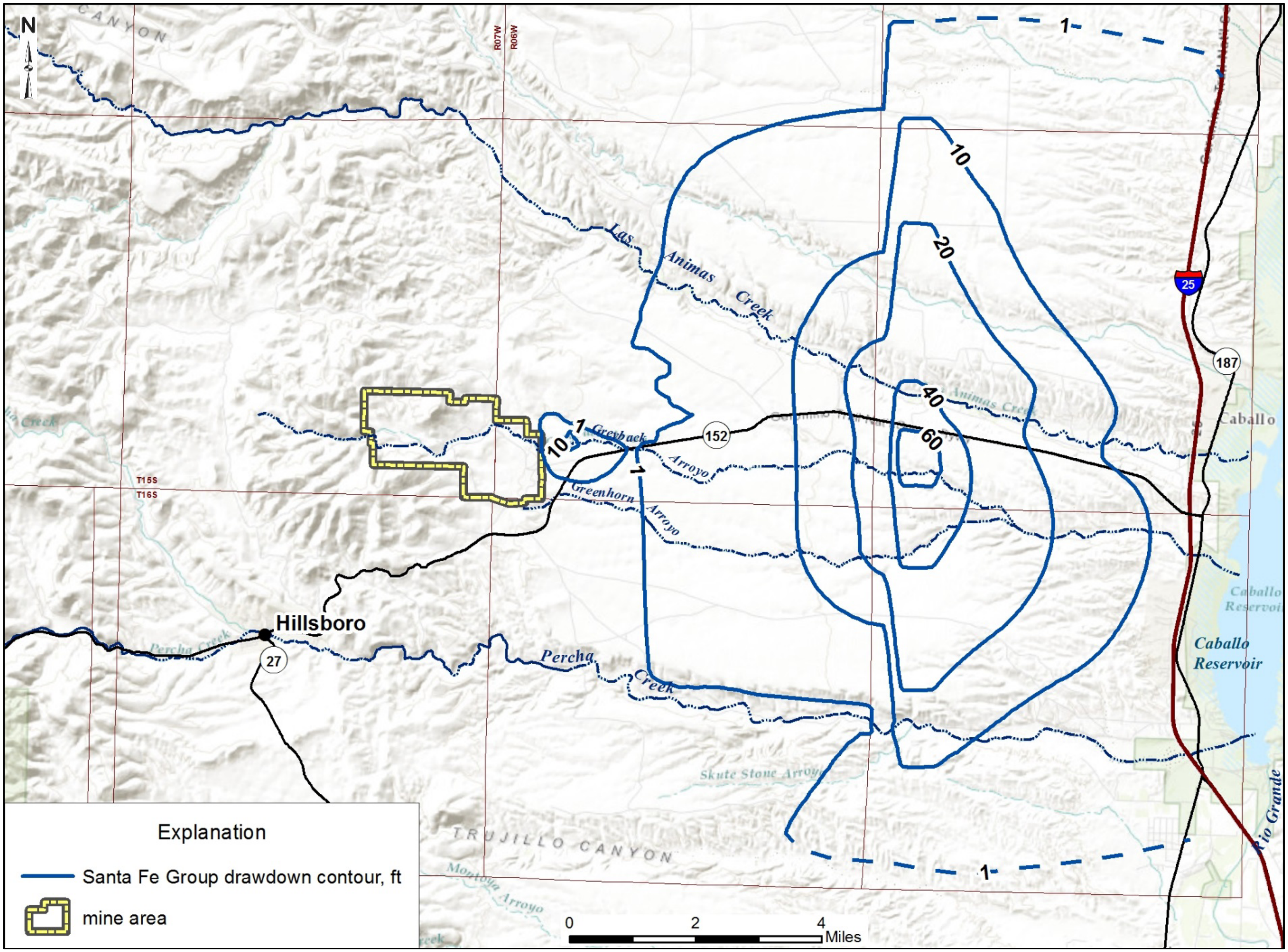


Figure 3.1. Projected end-of-mining groundwater drawdown in the SFG aquifer.

3.1.2 Effects on Water Balance

The groundwater pumped is initially removed from aquifer storage. Over time, more water is provided by increased inflow from the Palomas Graben north of the study area and by reduced discharge out of the study area. The sources of the water pumped are shown on Figure 3.2.

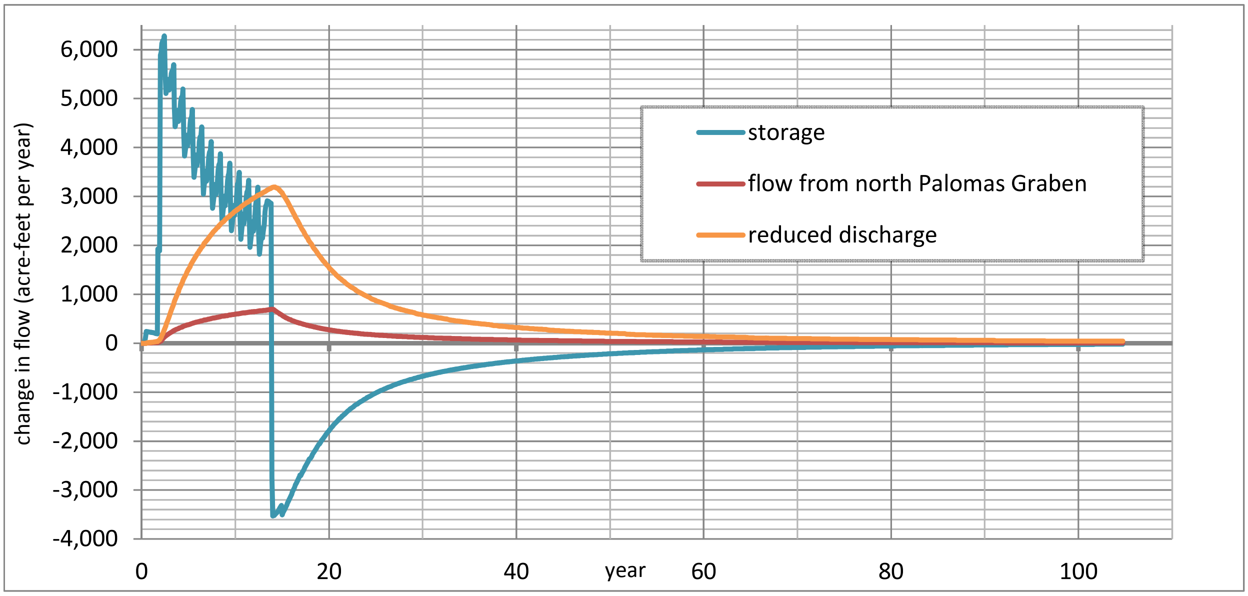


Figure 3.2. Projected sources of water pumped.

The hydrologic effect of additional inflow from the north Palomas Graben on the Rio Grande is estimated in Section 3.1.3.

The reductions in discharge are presented in detail on Figure 3.3, and include components of (1) reduced discharge to the Rio Grande both above and below Caballo Reservoir, (2) reduced discharge to flowing wells, and (3) reduced discharge to Quaternary-age alluvial aquifers and the Animas Creek perennial (riparian) zone.

The effects of reduced discharge to Caballo Reservoir and the Rio Grande are discussed in Section 3.1.4. The potential effects on other groundwater rights are discussed in Section 3.1.5. The potential hydrologic effects of reduced discharge to flowing wells are discussed in Section 3.1.6.

The potential hydrologic effects of reduced discharge to Quaternary-age alluvial aquifers and the Animas Creek perennial (riparian) zone are discussed in Section 3.1.7.

The projected water balance changes are summarized in Table 3.1.

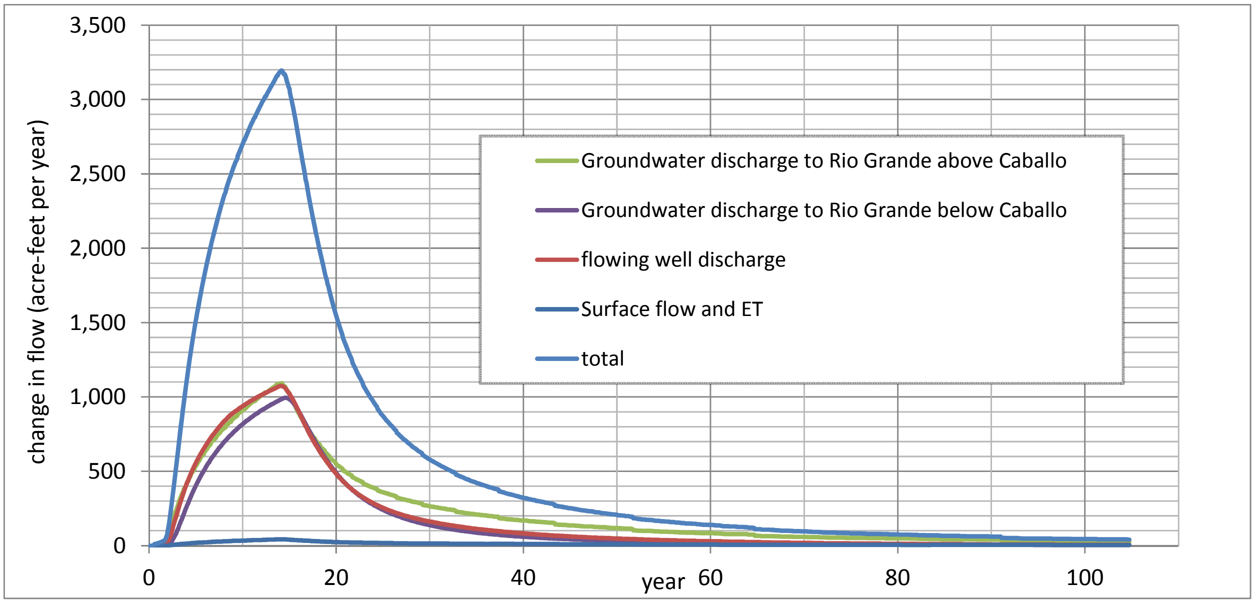


Figure 3.3. Projected reductions in discharge.

Table 3.1. Summary of results

change in flow, acre-feet/year		
parameter	rate 3 months after pit filling	rate 100 yrs after mining
storage	-3,525	-12
groundwater discharge to Rio Grande above Caballo Dam	1,089	25
groundwater discharge to Rio Grande below Caballo Dam	983	3
discharge from flowing wells	1,075	5
Animas Creek evapotranspiration and flow reduction	18	0
Percha Creek evapotranspiration and flow reduction	25	2
flow to open pit	28	29
inflow from graben north of study area	686	3

cumulated change in volume, acre-feet	
parameter	volume change 3 months after pit filling
storage	42,813
Rio Grande above Caballo Dam	8,878
Rio Grande below Caballo Dam	7,504
flowing wells	9,007
Animas Creek flow and evapotranspiration	147
Percha Creek flow and evapotranspiration	180
flow to open pit	-467
inflow from graben north of study area	5,924
total	**73,987**

3.1.3 Flow From North Palomas Graben

Induced groundwater flow from the Palomas Graben (Fig. 3.2) north of the study area would result in reduced discharge to the Rio Grande, beyond the reductions shown in Figure 3.3.

Based on discussions with the NMOSE, the effect of increased flow from north of the study area on the Rio Grande is estimated here using an analytical solution (Glover and Balmer, 1954; Theis, 1941) for the effect on streamflow of pumping a well.

The solution applied here simulates an impermeable barrier west of the Palomas Graben, reflecting the fault barrier and lack of aquifer transmissivity west of the graben.

A computer program employed by NMOSE (E. Keyes, personal communication, 2015) was used to compute the effect on the Rio Grande from removal of (the numerical model-computed) water from the graben, using assumptions listed in Table 3.2.

Table 3.2. Parameters for Glover-Balmer solution

transmissivity (ft^2/day)	3,700
storage coefficient (percent)	10
distance from well to river (miles)	6
distance from well to barrier (mile)	1

Results are shown on Figure 3.4 for a scenario pumping a constant 6,100 ac-ft/yr for 12 years. The computed effect on the Rio Grande would be added to the "Rio Grande above Caballo" effect shown on Figure 3.3.

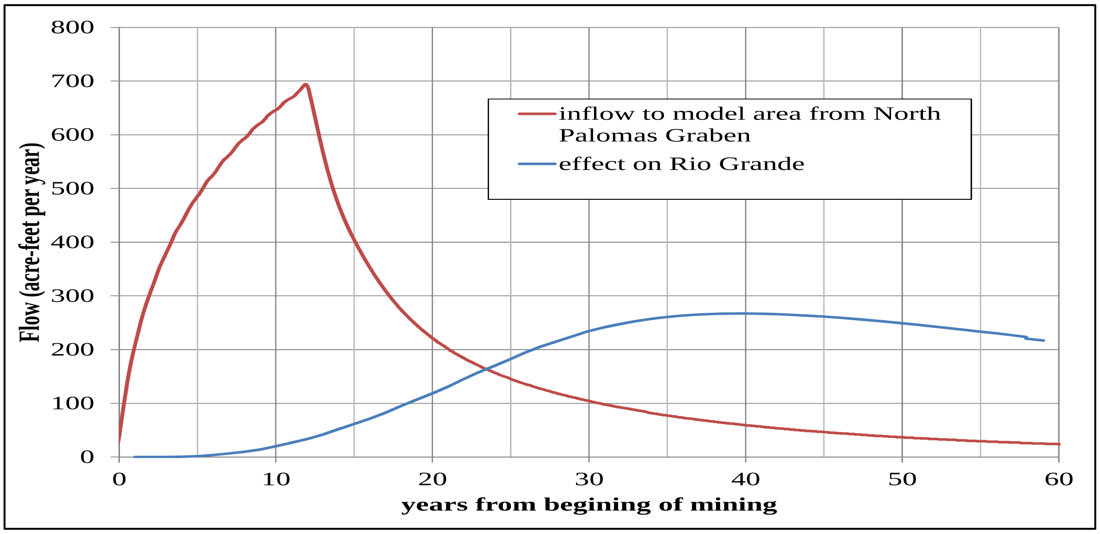


Figure 3.4. Projected effect on Rio Grande of increased flow from north Palomas Graben.

3.1.4 Operational Plans for No Net Effect on the Rio Grande

NMCC has committed to offset the effects of reduced discharge to the Rio Grande system (Figs. 3.3 and 3.4) during and after the operation of the Copper Flat Mine to ensure no net reduction in flows of the Rio Grande, in a manner approved by the NMOSE.

NMCC has procured a lease for water from the Jicarilla Apace Nation (Nation) that has been approved by the United States Secretary of the Interior.

The Nation is the owner of water rights through a water rights settlement agreement authorized and adopted by the United States Congress and the State of New Mexico in the Jicarilla Apache Tribe Water Rights Settlement Act of October 23, 1992 (Settlement Act).

The Settlement Act expressly permits trans-basin transfers and the Nation currently has the right to lease 6,500 ac-ft/yr. The Jicarilla lease water is diverted from three tributaries in Colorado, diverted through the San Juan Chama project tunnels and is stored in Heron Reservoir in northern New Mexico.

The water purchased by NMCC for offset purposes will travel down the Chama River and into the Rio Grande in the same manner that other Jicarilla-leased water is allowed with the approval of the Secretary of Interior and NMOSE.

Flow of Jicarilla lease water arriving at Caballo Reservoir will be computed based on agreed-upon evaporation and conveyance losses between Heron Reservoir and Caballo Dam. NMCC will provide sufficient water arriving at Caballo Dam to offset the groundwater-flow model-computed effects (Figs. 3.3 and 3.4) both above and below Caballo Dam.

The Jicarilla lease has been executed by NMCC and the Nation, and the agreement has been reviewed and approved by the United States Bureau of Reclamation action with the full authority of the United States Secretary of Interior. The lease specifically allows water to be utilized at the locations where NMCC pumping effects on the Rio Grande are predicted to take place.

All that remains to allow the diversion of Jicarilla lease water is NMOSE approval of the NMCC plan to use wells LRG-4652 through LRG-4652-S-3 (PW-1 through PW-4), which is pending an on-going proceeding and negotiation. NMCC is working with NMOSE to incorporate into the permit all monitoring, offsets, and replacement requirements deemed necessary to avoid impairment to other water users and impacts to the Rio Grande.

When the permit is issued, the conditions of approval will include an express condition by NMOSE, that the pumping effect on the Rio Grande will be offset by the water purchased under the lease from the Nation. The permit will address the length of time offsets and monitoring are necessary to protect the Rio Grande and existing water users after mine operations cease.

EBID
Exhibit 21

If NMCC, at some point after mine operation ceases and impacts to the river are decreasing, elects to stop leasing water from the Nation to provide for offsets on the river, NMCC will either secure another lease of equally effectual water or secure and permanently retire water rights. NMCC will supply the offset water in the quantity and location sufficient to offset the effects of NMCC pumping, in a manner agreed by NMOSE.

In the case of the permanent retirement of water rights, the offset would continue to have a positive effect on the Rio Grande even after the NMCC effect ceases. In any case, NMCC will take steps to ensure that no net reduction of flow to the Rio Grande occurs.

3.1.5 Other Water Rights

The SFG aquifer will have a limited area of significant drawdown, which may directly affect a small number of private wells. During the operation of its production wells, NMCC will work with NMOSE to ensure that impairment to existing water rights, according to NMOSE criteria, shown to be caused by NMCC pumping, will be mitigated, as appropriate, so that there is no net loss of available water to the existing water right.

Flowing wells along the eastern ends of Animas Creek and Percha Creek will experience a reduction in artesian pressure and reduced flow, as described in Section 3.1.6.

Groundwater model projections indicate that private wells in the shallow aquifer along Animas Creek and Percha Creek will not be affected by the pumping of the NMCC production wells, as described in Section 3.1.7.

3.1.6 Effects of Reduced Flowing Well Pressure

The model estimates a peak reduction in discharge to flowing wells of 1,054 ac-ft/yr, out of a pre-mining discharge of 2,030 ac-ft/yr (Table 3.1). The effect builds gradually from zero, to a maximum of 1,054 ac-ft/yr shortly after the end of mining, then gradually diminishes to near-zero over 30 years (Fig. 3.3). The possible consequences of reduced discharge to flowing wells are discussed below.

The flowing wells are located in the lower (eastern) section of the study area, upstream of Caballo Reservoir. Most of the wells are located along Animas Creek, with the remainder along Percha Creek. Estimated pre-mining discharge to flowing wells of 2,030 ac-ft/yr consists of 1,750 ac-ft/yr of discharge to Animas Creek wells and 280 ac-ft/yr to wells along Percha Creek.

In general, discharge from the flowing wells is used to fill unlined ponds, which in turn serve as reservoirs for irrigation systems. Most wells are allowed to flow continually, maintaining permanent ponds; these are visible in Google Earth images taken both inside and outside the irrigation season.

The discharge from flowing wells to ponds can evaporate from the pond, infiltrate into the shallow groundwater system or be pumped to irrigate fields. Water applied to the fields may be discharged as evapotranspiration or infiltrate to the shallow groundwater system.

Discharge from the flowing wells does not contribute significantly to streamflow, as there are no perennial stream sections in the artesian zone of the lower Animas and Percha Creek basins (INTERA et al., 2012). Flowing well discharge instead contributes to the shallow groundwater systems along Animas Creek and Percha Creek.

The pond and field areas along Animas Creek were estimated based on Google Earth, at 3.9 and 125.8 acres, respectively. By comparison, the 1966 hydrographic survey indicates 8.4 acres of pond and 191.2 acres of field. The estimated discharge from flowing wells is larger than would be required to irrigate the areas indicated. Pond and field areas are listed in Table 3.3, along with the maximum rate of evaporation and evapotranspiration (JSAI, 2014, section 2.4) that could occur from the given areas.

Table 3.3. Areas and potential evapotranspiration for Animas Creek ponds and fields

	area (acres)	**maximum ET (in./yr)**	**ET (ac-ft/yr)**
ponds	3.9	65	21
fields	125.8	65	681
total	**130**		**703**

ac-ft/yr - acre-feet per year

As indicated in Table 3.3, the maximum evaporation and evapotranspiration that could occur from the given areas of pond and field is 703 ac-ft/yr. This implies that most of the 1,750 ac-ft/yr of flowing well discharge along Animas Creek infiltrates to the shallow aquifer, either from the fields or through the ponds.

Current water balance for Animas Creek flowing wells was estimated assuming (1) typical application of irrigation water, with 70-percent evapotranspiration of the water applied and 30-percent infiltration to the shallow groundwater system, and (2) infiltration of any remaining flowing well discharge through the ponds. Results are presented in Table 3.4.

Some wells with reduced artesian pressure may be pumped in order to maintain water supply. Model-projected additional drawdown at the end of mining, due to pumping flowing wells at pre-mining rates, is shown on Figure 3.5. Incremental drawdown reaches a maximum of less than 10 ft in the lower reach of Animas Creek basin.

Table 3.4. Estimated water balance for Animas Creek flowing wells

flowing well discharge	**1,750**
evapotranspiration (ET)	703
infiltration (fields)	301
infiltration (ponds)	746
Total (ac-ft/yr)	**1,750**

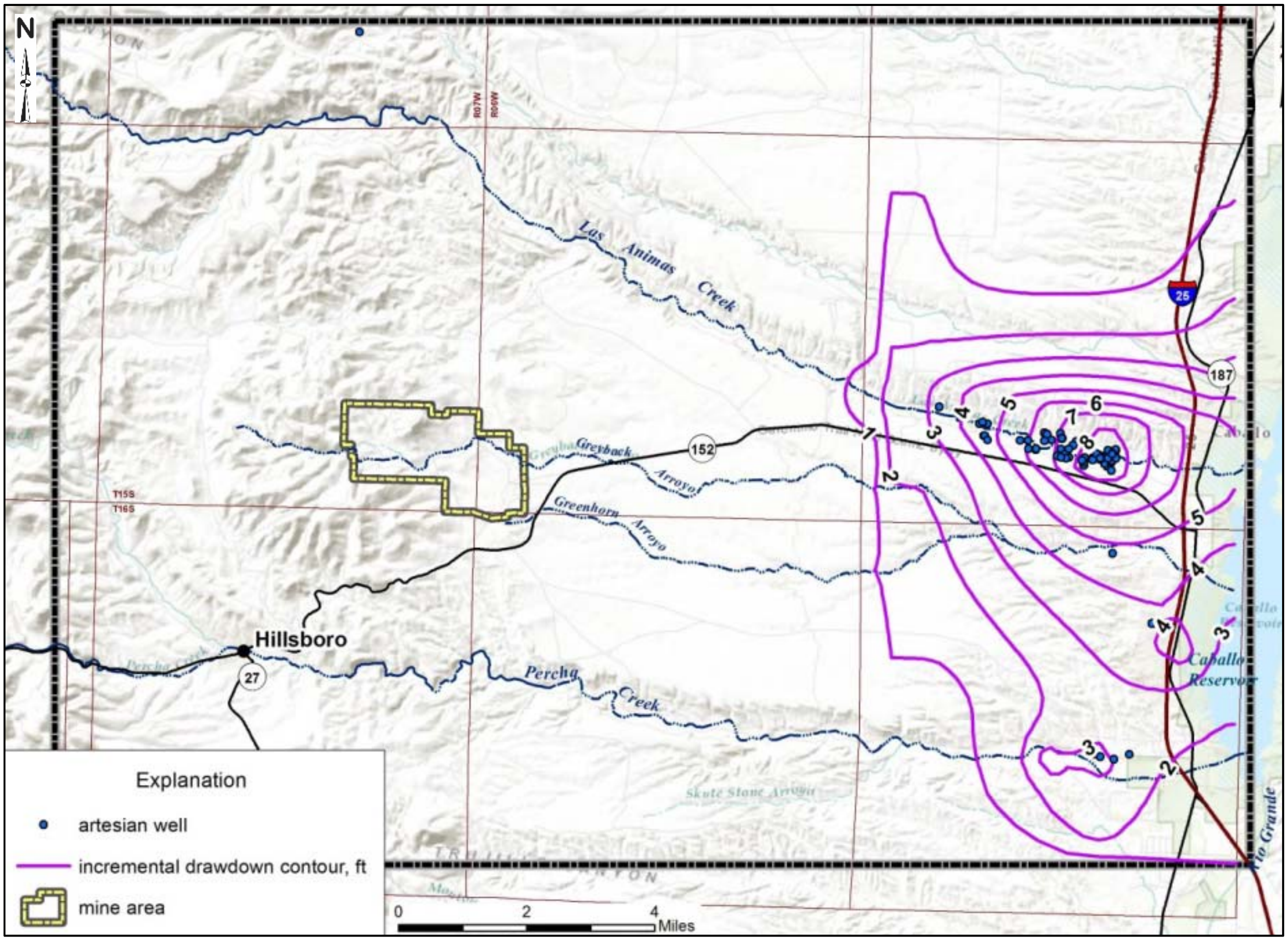


Figure 3.5. Projected incremental drawdown due to pumping of flowing wells at current flow rates.

3.1.7 Effects on Quaternary-Age Alluvial Aquifers and Animas Creek Perennial Flow and Riparian Zone

The shallow groundwater and riparian systems along Animas Creek and Percha Creek overlie the SFG sediments. Geology of the study area is shown on Figure 3.6, showing faulting within the SFG. An important fault-bounded feature is the Palomas Graben, in which the Copper Flat water-supply wells are completed.

West of the graben, the SFG sediments are thinner and less permeable, and do not yield substantial flow to wells. Within and east of the graben, the SFG forms an aquifer capable of yielding substantial flow. The hydrologic relationship of the shallow alluvial systems to the SFG is illustrated in cross-section C-C' (Fig. 3.7) along Animas Creek.

West of the graben, the low transmissivity of the SFG results in elevated water levels reaching the level of the shallow alluvium. Flow between the SFG and the alluvium is limited by low transmissivity and the small water-level gradient between the two.

Near the graben, the increased transmissivity of the SFG results in water levels dropping below the bottom of the alluvium, forming a hydraulic disconnection between the SFG aquifer and the alluvial groundwater system (Fig. 3.8). As a result, water flows from the alluvium to the SFG, through low-permeability clay beds, only by gravity; pumping from the SFG does not increase the flow or change water levels in the alluvium.

East of the graben, water flows down-dip along the permeable SFG beds. In the lower part of the basin, water level in the SFG pressurizes the confining clay beds from below. Water discharges from the SFG to the alluvium and to Caballo reservoir by flowing slowly across the resistant clay beds, or by discharging to flowing wells.

As a result, groundwater-level changes in the shallow alluvium, due to pumping in the SFG, will be highly attenuated. The main area of groundwater drawdown in the SFG (Fig. 3.1) will be in the graben, where the alluvium is disconnected from the SFG (Fig. 3.7).

Away from the graben, SFG drawdown will be smaller, and the connection to the alluvium is limited by low-permeability clay beds (Fig. 3.8).

A contour map of projected groundwater-level drawdown within Quaternary-age alluvial aquifers at the end of mining is shown on Figure 3.9. The figure indicates that peak groundwater-level drawdown along Animas Creek and most of Percha Creek will be less than 1 ft. Drawdown in a small area along lower Percha Creek is projected to be greater than 1 ft and less than 2 ft. The projected effects on evapotranspiration and surface discharge from the shallow aquifers are correspondingly small (Table 3.1). After mining ends water levels will slowly recover to pre-mining levels.

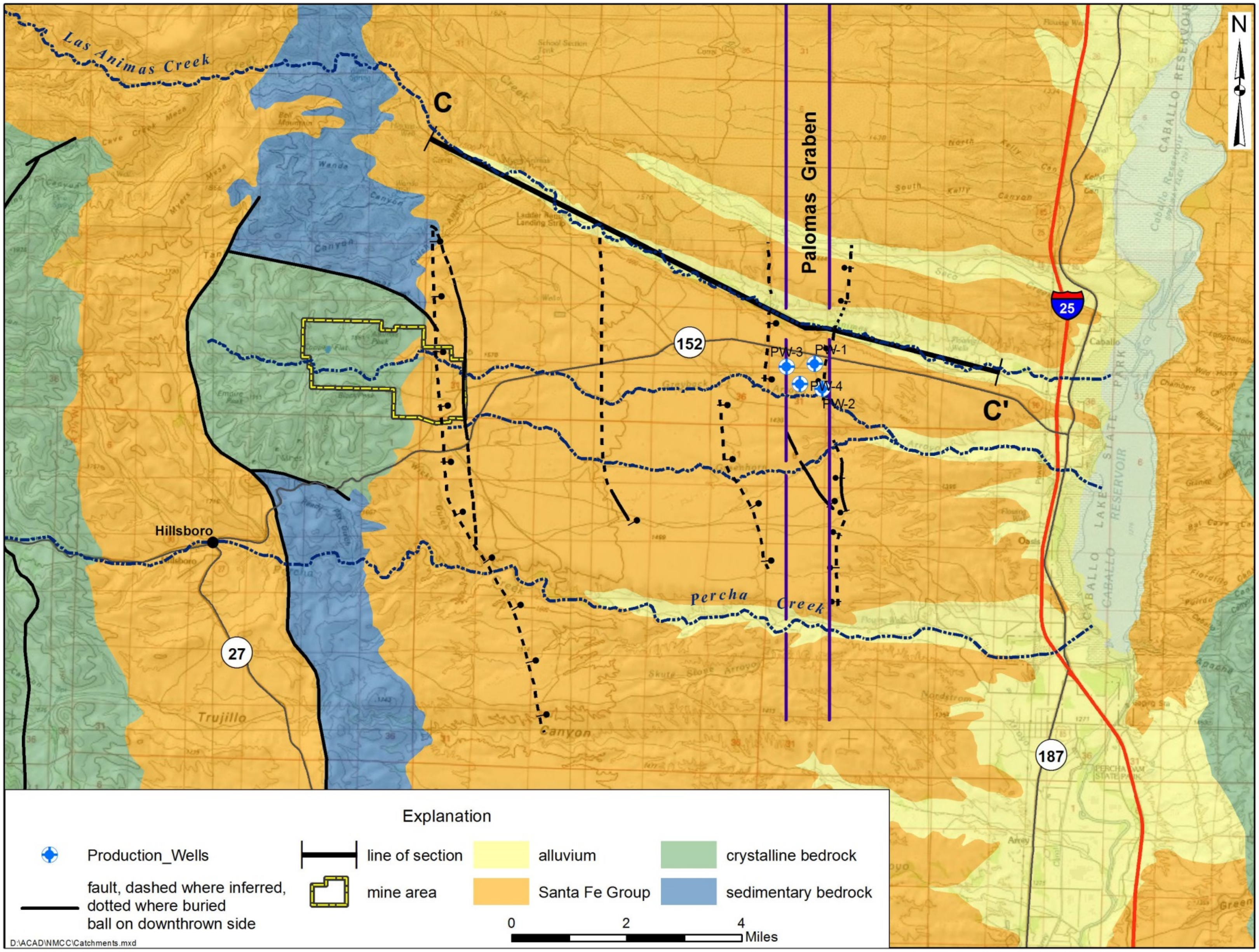
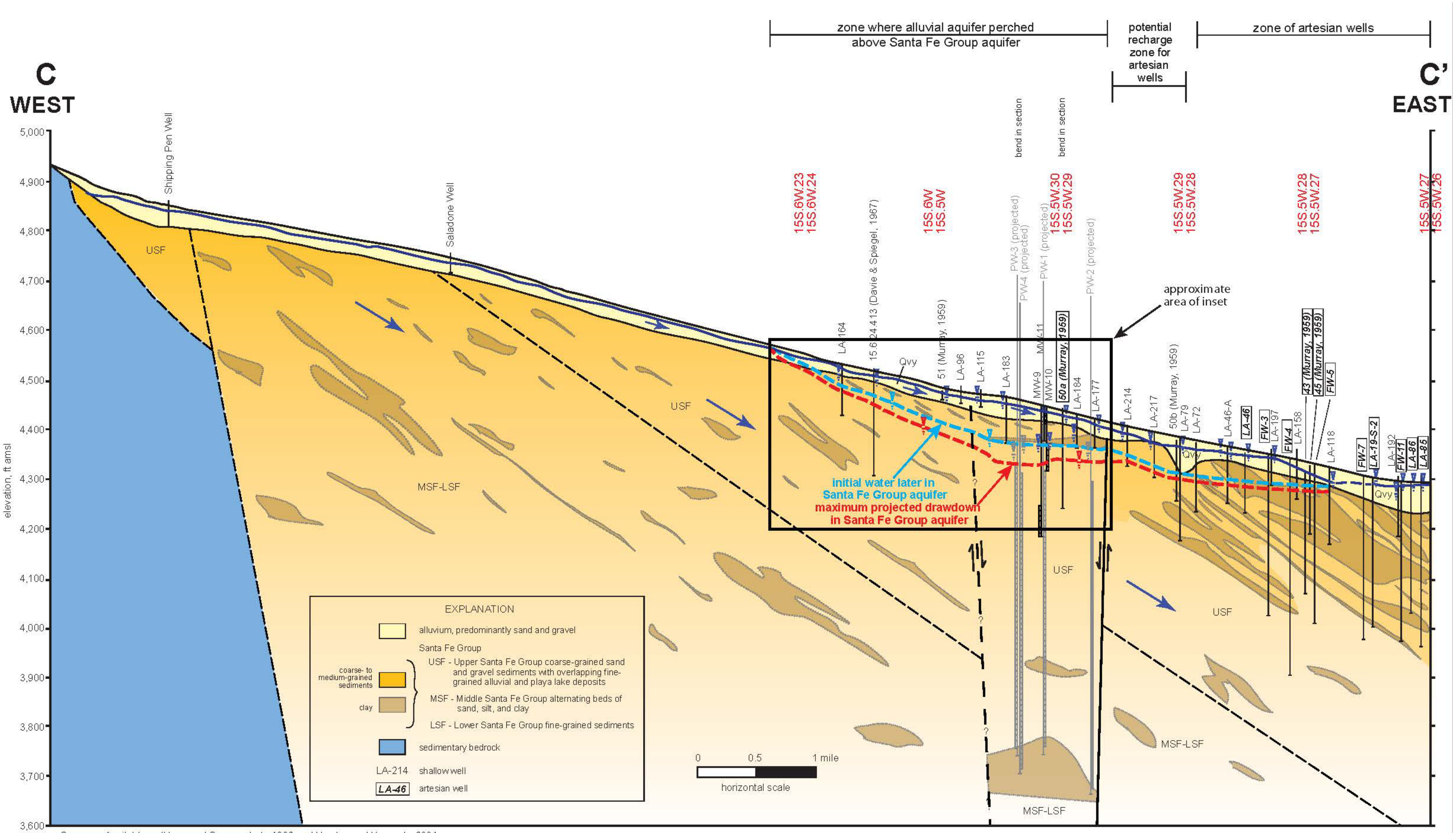


Figure 3.6. Geologic map.



Sources: Available well logs and Seager et al., 1982 and Hawley and Kennedy, 2004.

Figure 3.7. Cross-section C-C'.

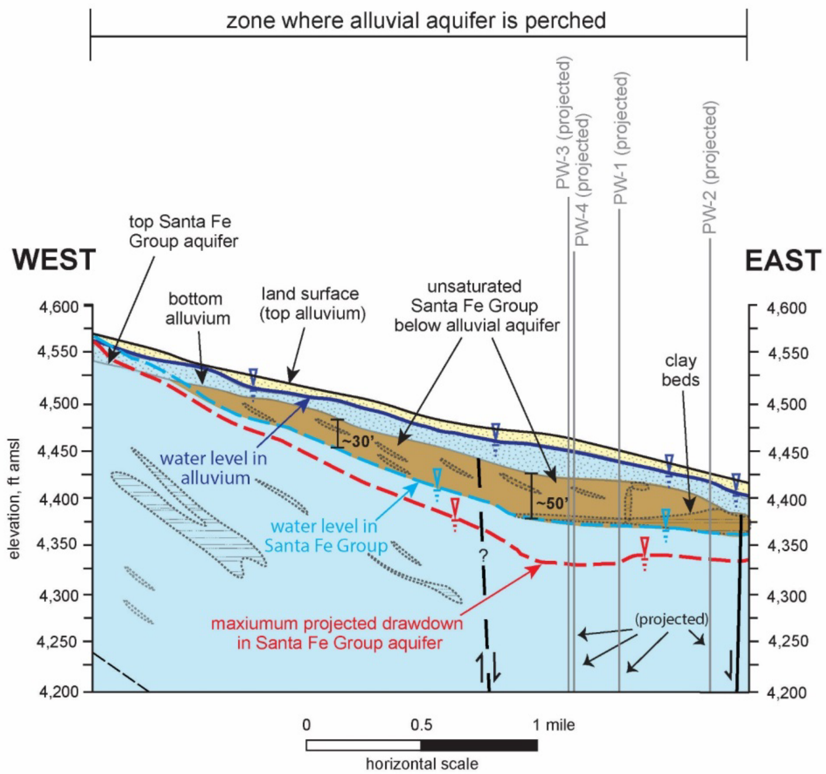


Figure 3.8. Section C-C', inset area of perched shallow aquifer.

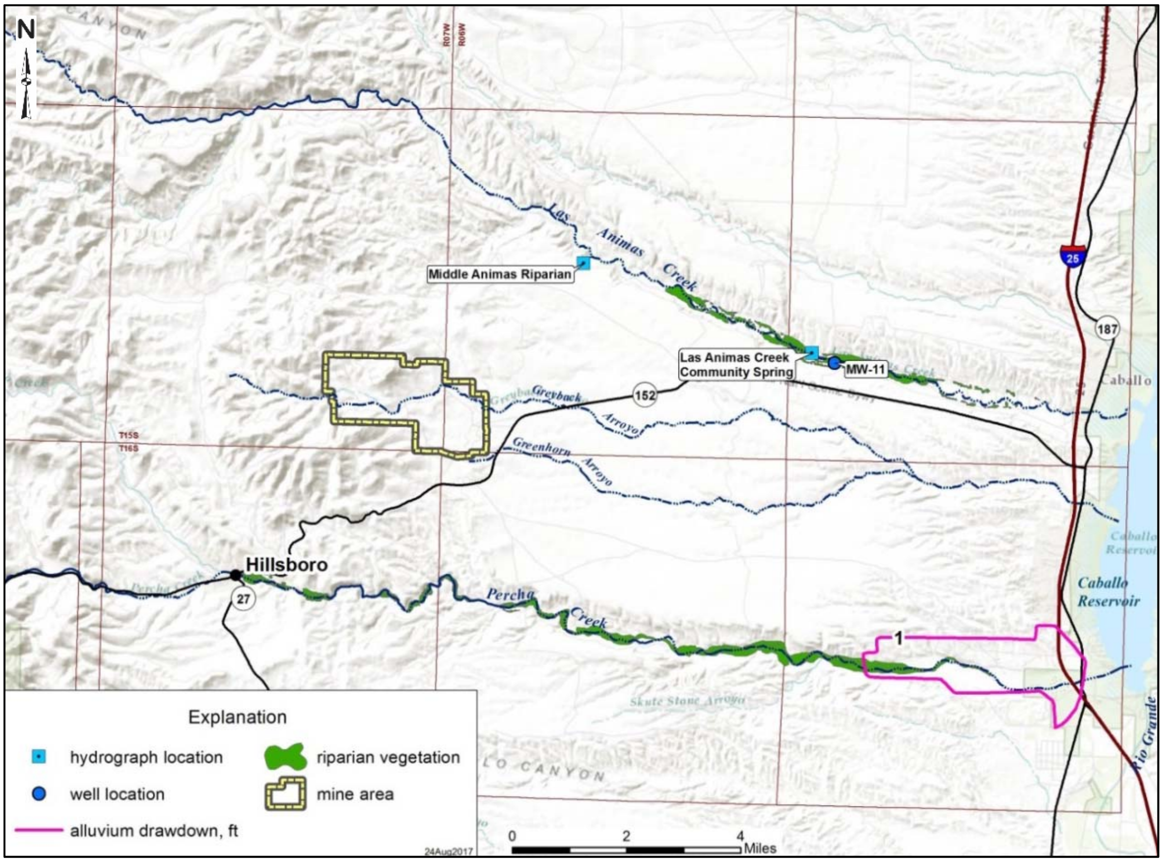


Figure 3.9. Projected end-of-mining groundwater drawdown, shallow aquifers.

3.1.8 Ground Subsidence

The potential for land surface subsidence due to groundwater-level drawdown was evaluated using the method of Hoffman and others (Hoffman et al., 2003). Potential subsidence due to dewatering of the crystalline bedrock is negligible; therefore, subsidence potential was evaluated only for the SFG aquifer around the well field.

Projected maximum drawdown (maximum drawdown near the well field occurs at the end of mining; maximum drawdown farther away may occur later) is shown on Figure 3.10, with an area-wide maximum drawdown of about 70 ft occurring at the well field.

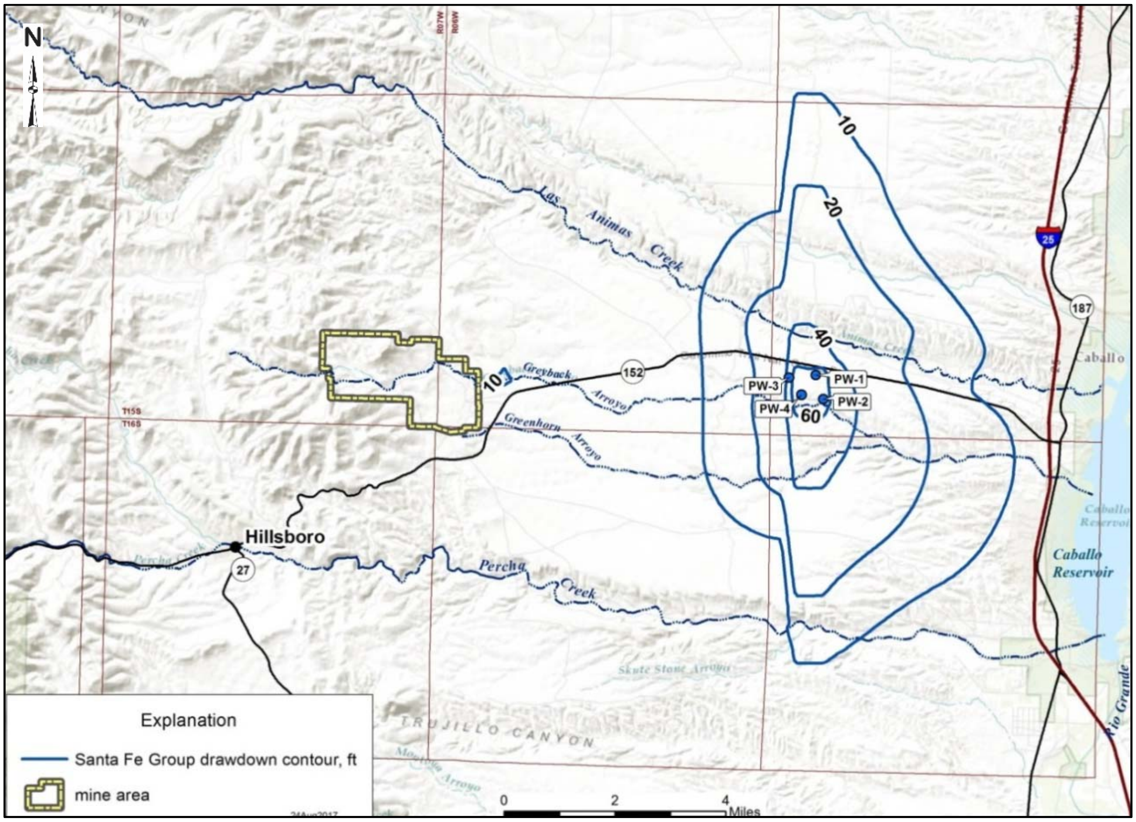


Figure 3.10. Projected maximum drawdown in Santa Fe Group aquifer.

Subsidence is estimated using equation (1) (Hoffman et al., 2003, equation 9):

$$\Delta b = S_S b \Delta h \qquad (1)$$

where,
b is the saturated thickness of compressible beds
Δb is land surface subsidence
S_S is the specific storage of the compressible beds
Δh is drawdown

Thickness of compressible beds is assumed at 5,000 ft. Specific storage (storage coefficient per unit aquifer thickness) for SFG is modeled at 2.0 x 10-6/ft. Maximum subsidence is then estimated using equation (2):

$$\Delta b = (2 \times 10^{-6}\ /\text{ft}) \times (5{,}000\ \text{ft}) \times (70\ \text{ft}) = 0.70\ \text{ft} \qquad (2)$$

By using conservative assumptions, a maximum potential subsidence of 0.7 ft is calculated for the immediate area of the well field, where drawdown reaches a maximum. Subsidence decreases with distance from the well field area in proportion to drawdown. Contours of maximum potential subsidence are illustrated on Figure 3.11.

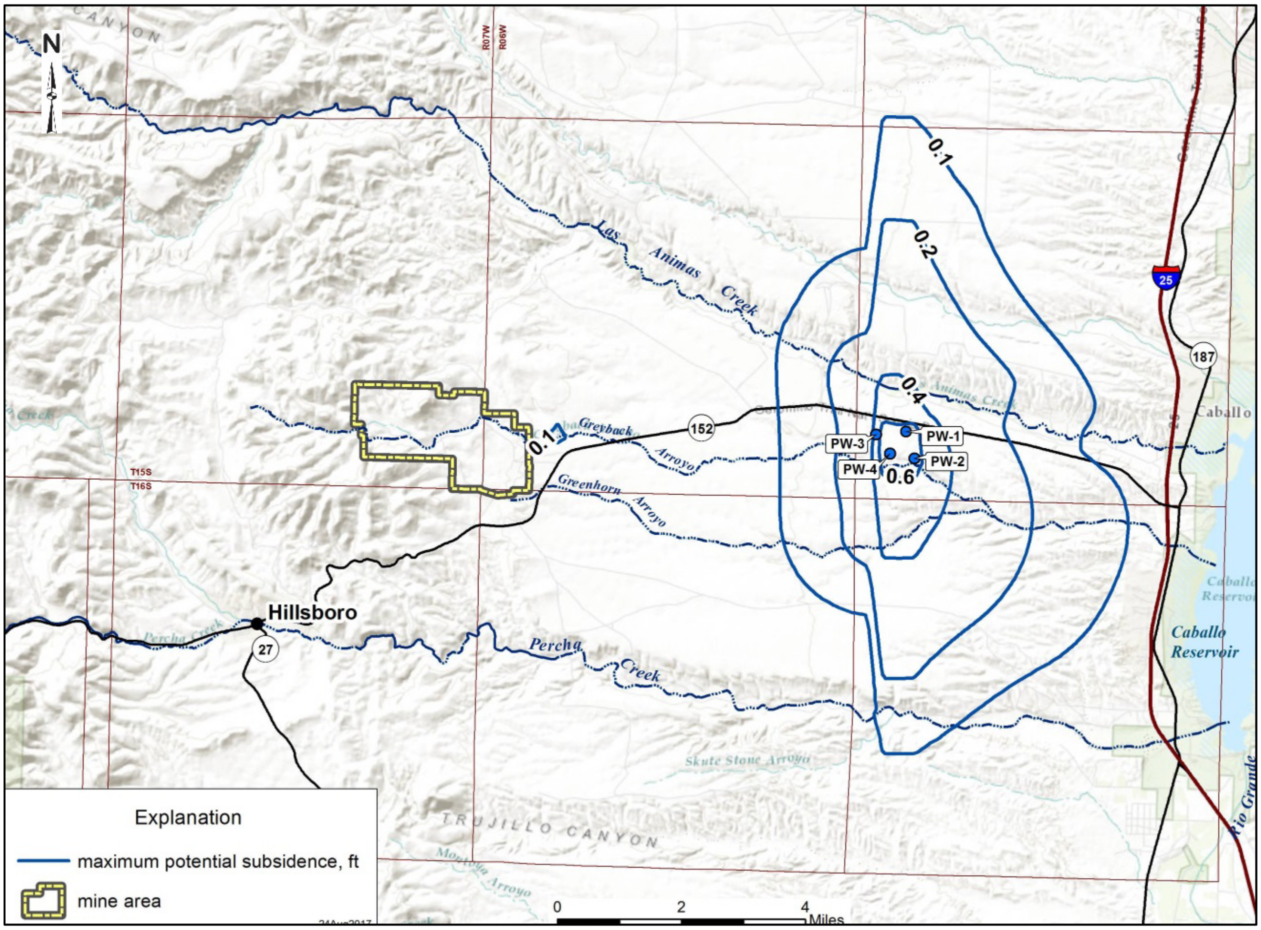


Figure 3.11. Projected worst-case potential maximum subsidence.

Outside of the well field area, the maximum potential subsidence shown on Figure 3.11 is less than about 0.4 ft (less than 5 in.), not noticeable over many years, but still over-estimated; it represents the total long-term subsidence that might be expected if groundwater drawdown is maintained.

Because the maximum groundwater drawdown would only occur near the end of mining, and would be immediately followed by post-mining water-level recovery, the drawdown would not persist for an extended period, and most of the potential subsidence would not occur. Actual subsidence is expected to be minimal at the well field and nil elsewhere.

3.2 Groundwater Withdrawals From the Crystalline Bedrock

Groundwater withdrawals from the crystalline bedrock will occur during dewatering of the open pit and after mining as groundwater flows into the pit. Consequences considered below include the following:

- Groundwater drawdown occurring during dewatering of the open pit is presented in Section 3.2.1.
- Groundwater discharge to the pit and the post-mining pit water balance are presented in Section 3.2.2.
- Potential discharge of groundwater from the open pit is discussed in Section 3.2.3.
- Long-term groundwater drawdown and potential effects on springs discharging from the crystalline bedrock are discussed in Section 3.2.4.

3.2.1 End-of-Mining Groundwater Drawdown

Groundwater drawdown in the crystalline bedrock at the end of mining is shown on Figure 3.12. Drawdown approaches a maximum of about 750 ft at the bottom of the dewatered pit. Drawdown of 1 ft extends for an approximately 2-mile radius around the pit.

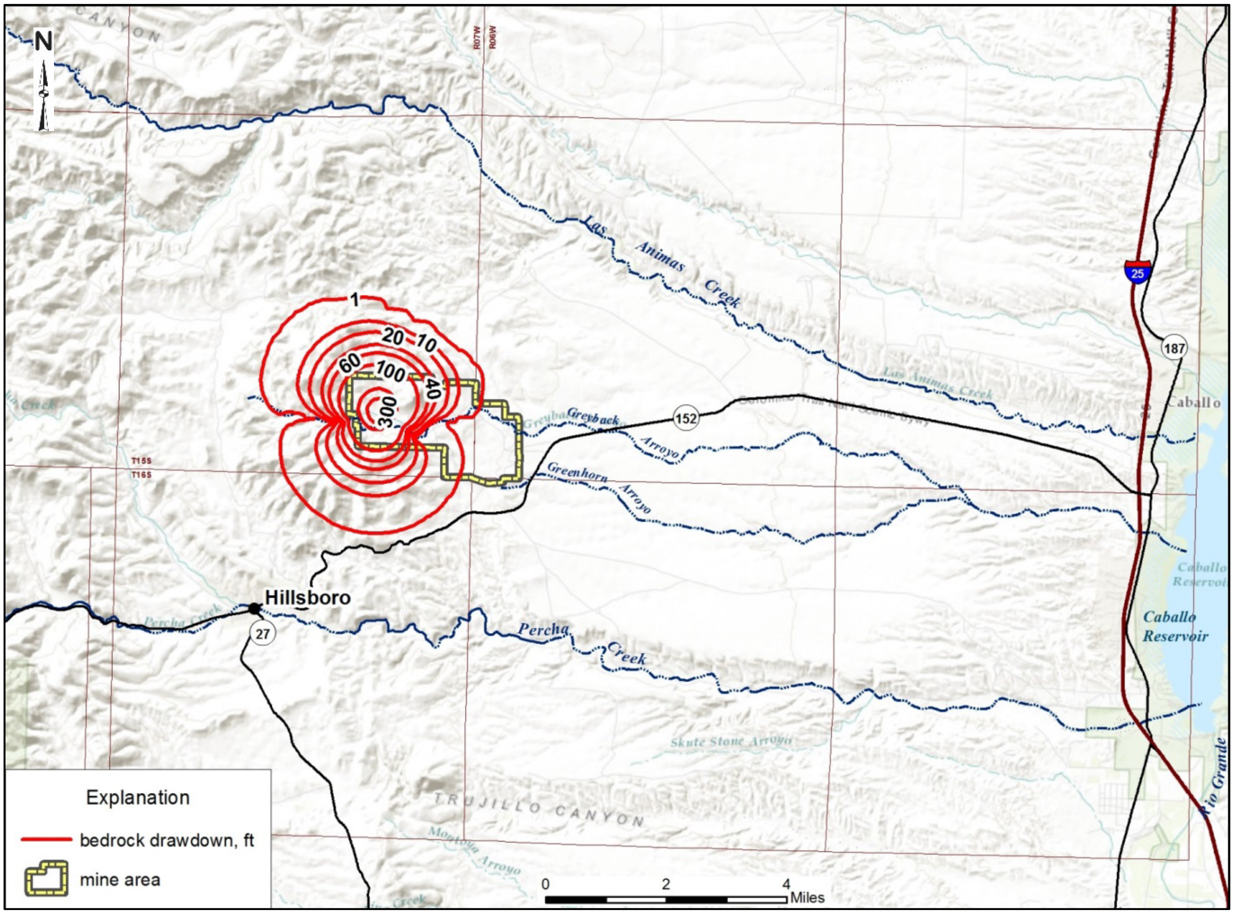


Figure 3.12. Projected end-of-mining groundwater drawdown in the crystalline bedrock.

3.2.2 Open Pit Water Balance

The post-mining pit water level and water balance were simulated assuming the pit geometry and watershed shown on Figure 3.13. The area within the pit highwall is about 129 acres, and the total pit watershed area is about 314 acres.

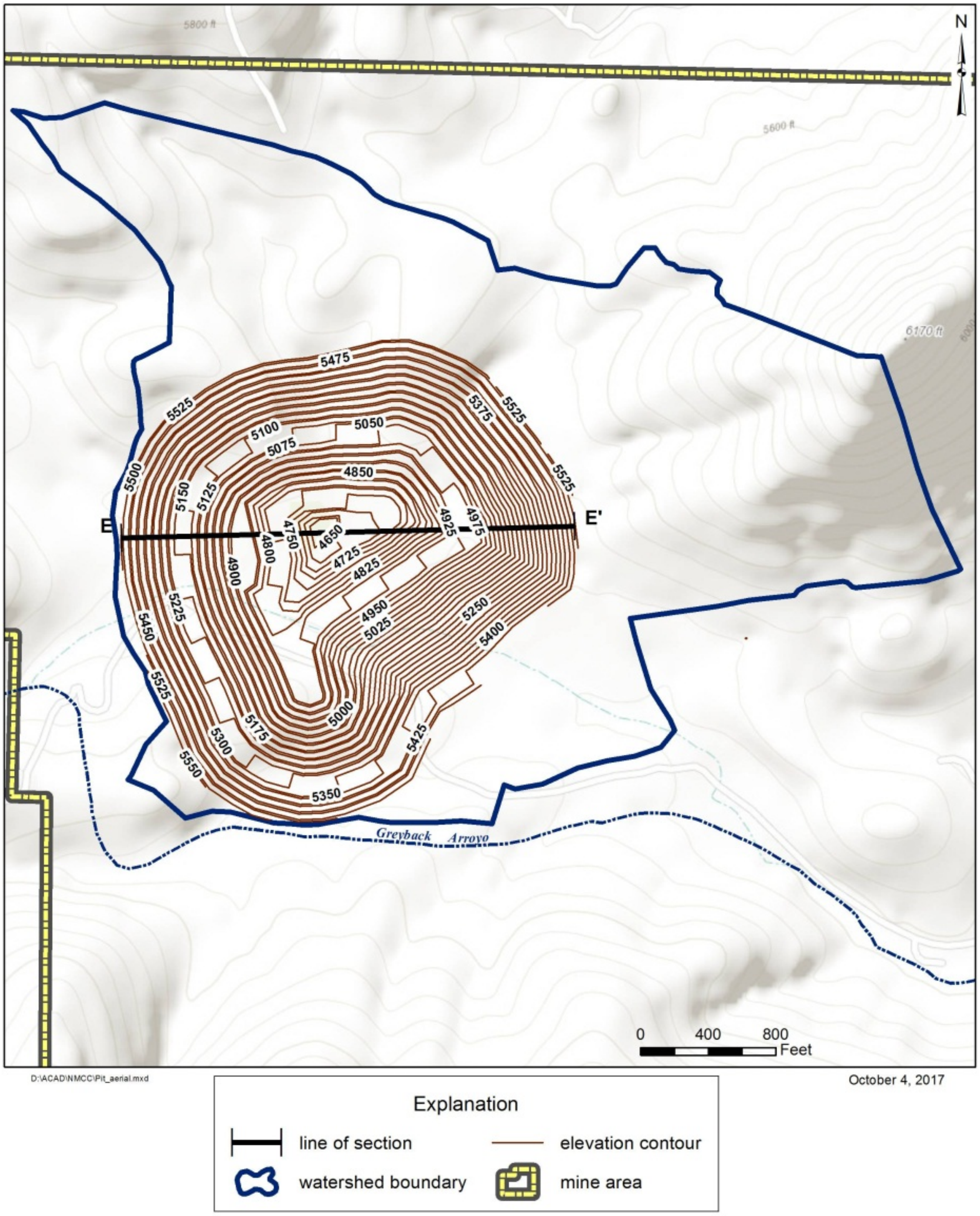


Figure 3.13. Ultimate open pit and watershed area.

Precipitation on the pit area was estimated for each month based on the record at Hillsboro (JSAI, 2014, section 2.0), with annual average precipitation of 12.5 in. Runoff from the un-reclaimed sections of the pit was simulated at 12.6 percent of precipitation, and runoff from reclaimed sections of the pit was simulated at 30.3 percent. Runoff from the remainder of the watershed was simulated at 7.1 percent of precipitation.

Evaporation from the open pit was assumed at 50 in./yr, less than the 65 in./yr estimated potential evaporation (JSAI, 2014, section 2.4) for the area. The lower rate reflects the wind and sun sheltering effects of the deep pit. Monthly evaporation rates based on the record at Hillsboro were scaled to match the annual rate of 50 in./yr.

Post-mining reclamation would include use of the water-supply wells PW-1 through PW-4, and a temporary pipeline to the bottom of the pit, to rapidly fill the pit to the expected long-term post-mining equilibrium water level. The post-mining simulation assumes this “rapid fill” scenario. Rapid filling will result in better water quality in the open pit by filling it with clean water and inhibiting oxidation of sulfide by submerging potential acid-generating sections of the pit wall (SRK, 2017).

A pumping rate of 2,726 gpm is simulated in the model, sufficient to fill the pit to elevation 4,894 ft amsl in 6 months. Total volume pumped from the supply wells will be 2,200 ac-ft. The open pit water body elevation of about 4,894 ft amsl corresponds to a water-surface area of about 21.7 acres. Simulated water level in the pit after the end of mining is presented on Figure 3.14. The final long-term water level of about 4,897 ft amsl corresponds to a water-surface area of about 22.3 acres. Water levels will fluctuate around this mean, rising and falling seasonally and with wet and dry climatic conditions. The largest potential effect on pit water levels would result from environmental circumstances such as a 100-year flood event or the occurrence of a prolonged drought. Probability is an indicator for the likelihood of an event’s occurrence. As such, the probability is 1 in a 100 that it will be higher. Similarly, the probability that it will be lower than 4,897 ft is based on a worst-case drought of zero precipitation for 1 year. The historical precipitation record at Hillsboro indicates that a 100-year 24-hour precipitation event is 3.29 in. (JSAI, September 25, 2017 Technical Memorandum regarding OPSDA runoff). This event would generate 36 ac-ft of runoff to the pit (JSAI, September 25, 2017.). For a 22-acre water surface, the water level would rise 1.6 ft. Conversely, if there was zero runoff for 1 year, the water level would decline 2.6 ft. Therefore, the bracket for maximum short-term potential rise and decline would be 4,898.6 ft to 4,891.4 ft amsl.

The simulated annual pit water balance is presented on Figure 3.15, showing a final pit water balance of about 93 ac-ft/yr, with about 57 ac-ft/yr from precipitation and runoff, and 36 ac-ft/yr from groundwater inflow, all discharging as evaporation from the pit water surface.

After reclamation, groundwater levels in the bedrock around the open pit will remain below pre-mining levels, due to groundwater flowing to the open pit and discharging as evaporation from the hydrologic sink. Future water-level patterns can be seen in the hydrographs at selected locations, presented in Appendix A.

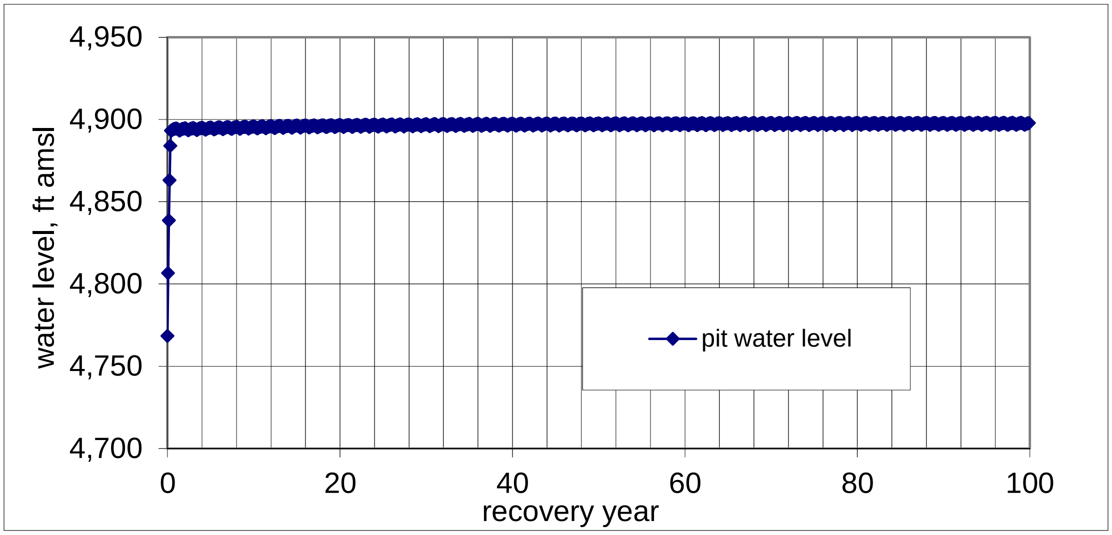


Figure 3.14. Projected open-pit water level (rapid fill in year 1).

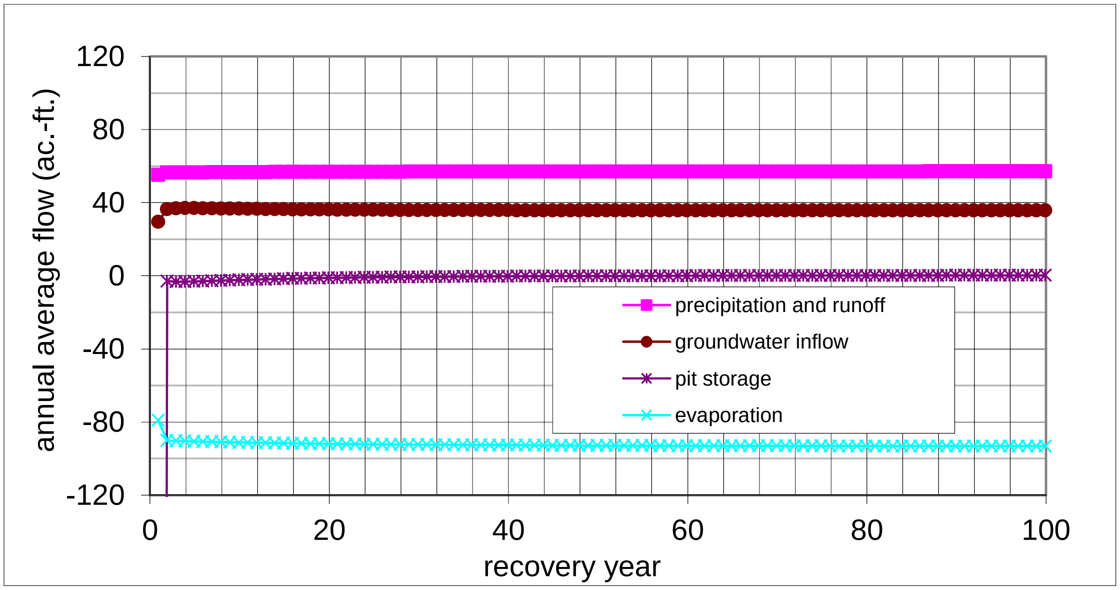


Figure 3.15. Projected open-pit water balance (rapid fill in year 1).

3.2.3 Potential Open Pit Discharge to Groundwater

The post-mining pit will be a groundwater sink, with the open pit water level below surrounding groundwater levels in the crystalline bedrock. The pit will remain a hydraulic sink after rapid filling of the pit during reclamation, and after precipitation events that raise the pit water level.

For a short period immediately following rapid fill, water may flow out of the pit into the dewatered space around it, then return to the pit as conditions equilibrate. Model-simulated flow to this dewatered space during the 6-month rapid filling totals 0.74 ac-ft. This water remains in the immediate vicinity of the pit wall before returning to the pit.

The hydraulic conditions around the pit are shown in cross-section on Figure 3.16 for pre-mining, end-of-mining, and 100-year post-mining conditions. The pit will remain as a hydraulic sink during temporary water level fluctuations because of the deep cone of depression caused by dewatering and maintained by water surface evaporation.

In order for it to be possible for water to flow from the pit to groundwater, the open pit water level would have to be higher than surrounding groundwater (>5,100 ft elevation). No conceivable storm event, wet year, or even wet decade could possibly add enough water to the pit to reach the water level required to achieve flow-through.

The projected post-mining potentiometric surface, including the closed contours around the hydraulic sink of the open pit, is shown in plan view on Figure 3.17.

3.2.4 Effects on Springs

Spring locations identified in the area (INTERA et al., 2012; BLM, 2015) are shown on Figure 3.18. The springs fall into several groups: (1) springs discharging on the Animas Uplift, (2) springs discharging in the Animas graben west of the uplift, and (3) springs discharging to the Palomas Basin, at the eastern edge of the uplift and along parallel fault trends stepping down from the uplift into the Basin.

The springs of the Animas Uplift (BG1, BG2, and other occasional seeps) are fed by local, perched groundwater systems or by near-surface circulation of local precipitation, and are ephemeral (INTERA et al., 2012), flowing only after precipitation events. These would not be affected by the flow of groundwater toward the open pit within the crystalline bedrock.

Springs of the Animas Graben, including Warm Spring (WS), WSCS-A, CSCS-B, CSCS-C and Cave Creek Spring, discharge from the SFG deposits west of the Animas Uplift. The source of their water is the Las Animas Creek and Percha Creek watersheds west of the Animas Uplift. The andesite of the uplift acts as a barrier to flow at depth (JSAI, 2014, p. 24) and the groundwater systems of the graben and the uplift are separate. Flow at springs in the Animas Graben will therefore not be directly affected by the movement of groundwater in the Animas Uplift toward the open pit.

Springs discharging at the east edge of the Animas Uplift include Warm Spring on Animas Creek and PCS-A on Percha Creek. In the Palomas Basin east of the uplift, springs discharge from alluvium along Las Animas Creek, along a set of fault structures parallel to the uplift.

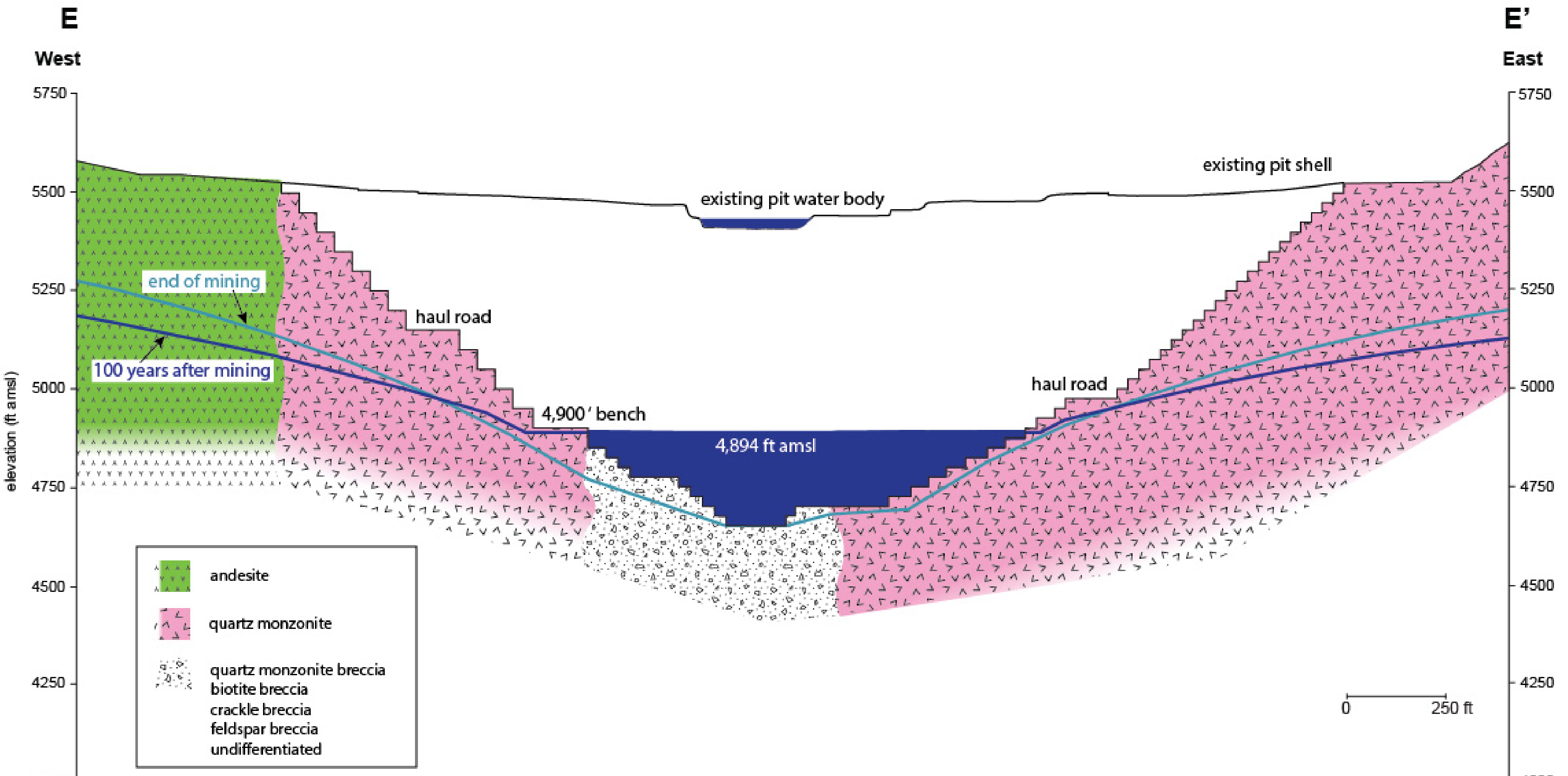


Figure 3.16. West-to-east hydrogeologic cross-section E-E' showing water-level profile across existing pit and proposed open pit after rapid fill.

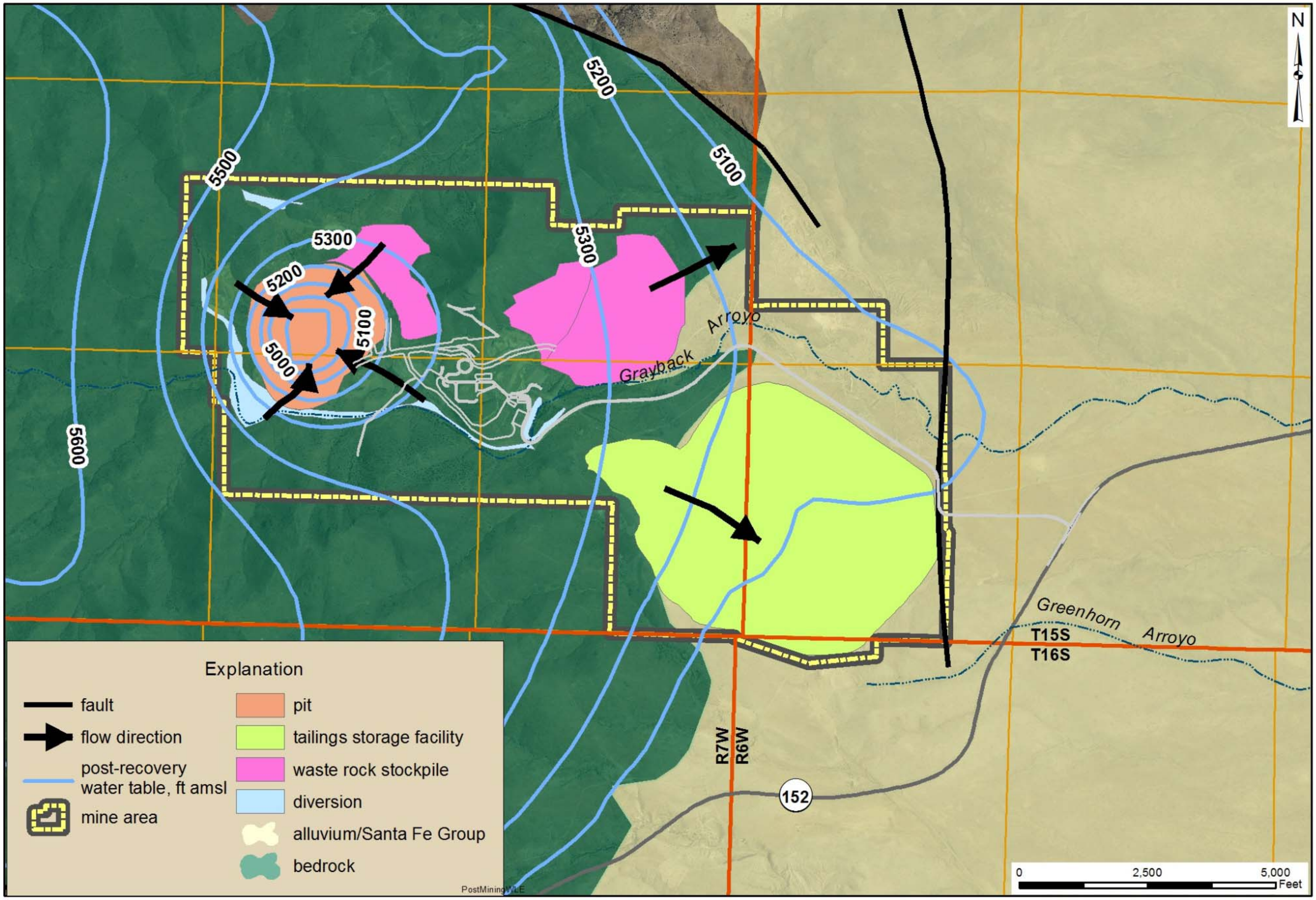


Figure 3.17. Proposed mine facilities and projected post-mining groundwater elevation.

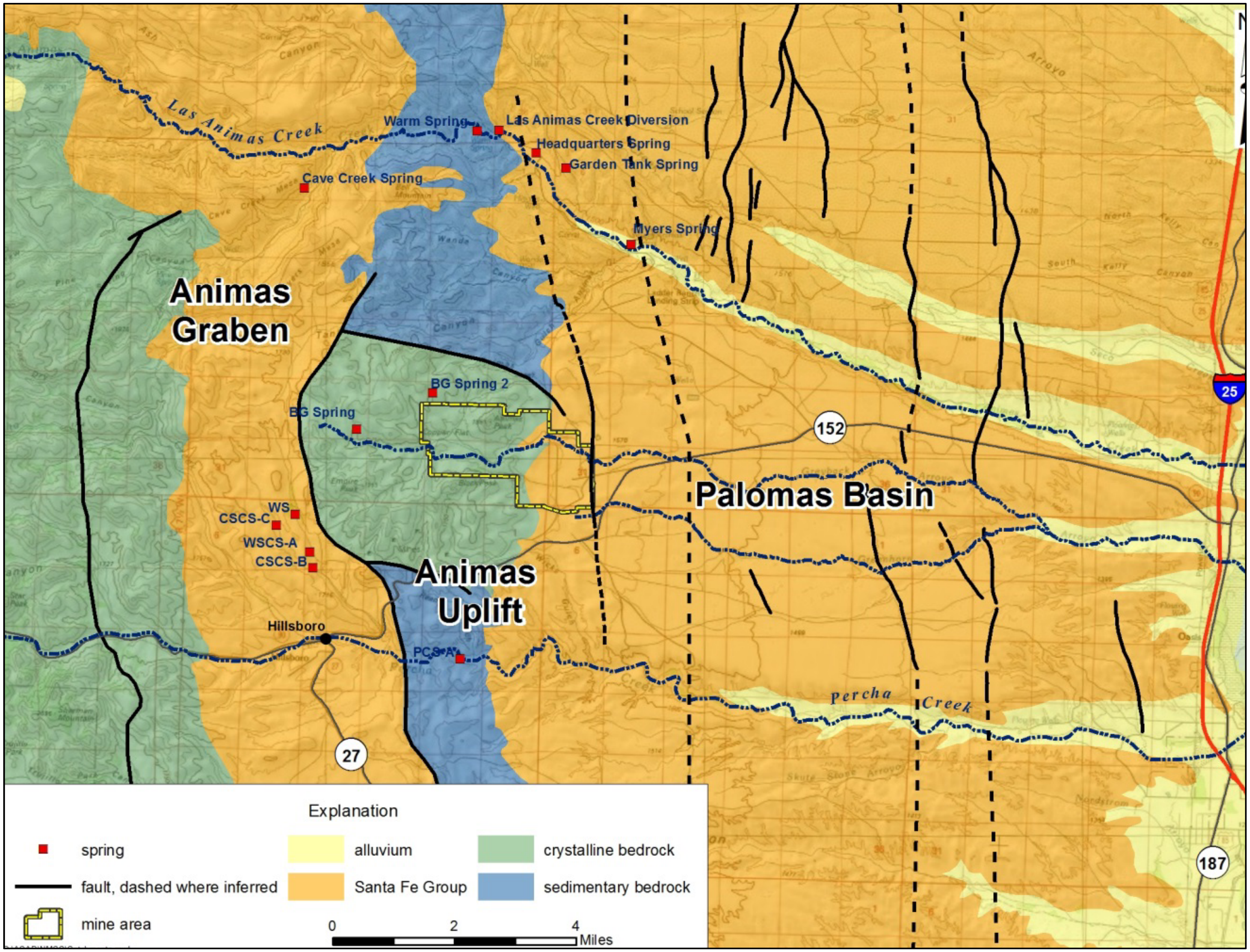


Figure 3.18. Locations of springs in and around the Animas Uplift.

The active springs of the Animas Graben and of the eastern edge of the uplift and the Palomas basin could be indirectly affected by the project if groundwater levels were lowered through indirect connection to the Animas Uplift. Future groundwater level change at each potentially affected location was evaluated using the numerical model. Results are summarized on Table 3.5.

Table 3.5. Projected groundwater-level change (in feet) at spring locations

	end of mining	100y post-mining
CSCS-C	0.01	0.16
WS	0.02	0.19
WSCS-A	0.01	0.13
CSCS-B	0.01	0.12
Cave Creek	0.05	0.15
PCS-A	0	0
(Animas) Warm	0.02	0.05
Myers	0.01	0.01

For the Animas Graben springs, groundwater level is projected to decline by up to 0.19 ft (2.3 in.), 100 years after the end of mining. Discharge is not expected to decrease because the source of water for these springs is west of the Animas Uplift (JSAI, 2014, p. 24). However, discharge locations could move a short distance due to a change in water level.

In the eastern part of the uplift, projected maximum change in water level is 0.05 ft (0.6 in.) at Animas Warm Spring. On Percha Creek, no water level change is projected at PCS-A, either during mining or in the 100 years following the end of mining. In the Palomas Basin, water level at Myers Spring is projected to decline by 0.01 ft (0.12 in.).

No direct effects to identified springs are predicted to occur as a result of the project, because (1) the springs of the Animas Uplift are ephemeral, precipitation-event-fed springs unrelated to the bedrock groundwater system, (2) the springs of the Animas Graben are fed by groundwater from the west and from depth, chemically unrelated to groundwater of the uplift.

Small indirect effects may occur, however, due to lowering of groundwater levels in the Animas Graben or in the western edge of the Palomas Basin, due to an attenuated connection with the crystalline bedrock of the Animas Uplift. The small, long-term projected effects presented on Table 3.5 conservatively assume that these attenuated connections exist, although they have not been observed in reality.

In conclusion, the direct effects of the Project on mapped springs are projected to be zero. The long-term indirect effects presented (maximum of 2.3 in. over 100 years) are too small and manifest too slowly to be measureable or significant.

3.3 Potential Discharge From Tailings Impoundment and Waste Rock Stockpiles

Potential for net percolation to groundwater from the TSF is evaluated in Section 3.3.1. Potential for net percolation to groundwater from the WRSPs is evaluated in Section 3.3.2. Groundwater flow paths and travel times down-gradient from the facilities are evaluated in Section 3.3.3.

The area of the mine including the open pit, waste rock storage facilities, and the tailings impoundment are shown above on Figure 3.17. The WRSPs lie on crystalline bedrock, while the TSF lies partially on SFG sediments.

Any net percolation through the WRSP around the pit would flow into the pit, while any net percolation to groundwater from the eastern-most WRSP or from the TSF would flow northeast and southeast, respectively.

3.3.1 Tailings Impoundment

Because the tailings impoundment will be lined, net percolation to groundwater from the tailings impoundment is not expected. However, unexpected sources of potential infiltration through the liner include manufacturing defects in the liner and other holes, in the liner and along the seams, developed during placement.

NMCC considers the potential for leaks in the liner to be very unlikely. Nonetheless, the potential occurrence of leaks in the tailings facility liner was evaluated based on previous analyses presented in Appendix B. An assumed liner leak occurrence for the purpose of evaluation is one circular defect per acre, with a standard defect area of 1.0 cm^2 (corresponding to a round hole diameter of 1.128 cm).

The rate of leakage through the defect, assuming a compacted bedding layer beneath the liner and an underdrain system above the liner (Golder, 2016), is given (Appendix B, equation 1) by

$$q=\beta_c[1+0.1(h_w/L_s)^{0.95}]a_d^{0.1}h_w^{0.9}K_s^{0.74}$$

where, q is flow through a circular defect

β_c is the coefficient relating to liner contact with bedding material (0.21 for good contact)

h_w is the depth of water above the geomembrane

L_s is the thickness of bedding material

a_d is the area of the defect (1 cm^2)

K_s is the saturated hydraulic conductivity of bedding material

Because the impoundment is designed with a 1.5-ft-thick drainage layer above the liner (Golder, 2016), head on the liner h_w will be less than 1.5 ft. Assuming the standard defect size (a_d = 1.0 cm^2) occurring once per acre and the design bedding layer conductivity (K_s =10^{-6} cm/s), leakage from the lined 536-acre (Golder, 2016) tailings storage facility is estimated in Table 3.6 at about 0.5 gpm. The total area of the tailings storage including surrounding facilities is approximately 630 acres, but the active storage area is 536 acres.

Table 3.6. Potential tailings liner leakage

B_c	0.21
h_w	1.5 ft
L_s	1 ft
a_d	1.0 cm^2
K_s	1x10^{-6} cm/s
q	0.0009 gpm/acre
total flow	0.5 gpm

The probable hydrologic consequence from a potential leak in the liner, of realistic magnitude, is nil. Not only is the projected rate of potential leakage insignificant, the groundwater beneath the tailings has a low travel velocity (JSAI, 2014, Section 5.3); any leakage from the tailings will remain beneath the tailings for hundreds of years.

3.3.2 Waste Rock Stockpiles

The probable hydrologic consequences during operation of the WRSPs are related to (1) surface runoff from the facility and (2) subsurface infiltration through the waste rock. The probable hydrologic consequences after reclamation and covering of the WRSPs are only related to subsurface infiltration through the waste rock.

Subsurface infiltration into the waste material or the cover has the potential to (1) evaporate or be transpired by vegetation, (2) remain held in storage, or (3) percolate downward through the waste material. Net infiltration is water infiltrated from surface past the effects of evapotranspiration. Percolation is water movement in the WRSPs.

The component of “surface infiltration” that makes it to groundwater can be said to be “net percolation” to groundwater. The potential impacts of net-percolation during the operation of the project and the post-closure phase are discussed as follows.

3.3.2.1 WRSP Hydrologic Setting

As detailed in the MORP (NMCC, 2017) and Discharge Permit Application (THEMAC, 2017), WRSPs 2 and 3 will be built in stages consisting of 75 ft lifts using the end-dumping method.

The end-dumping method partially sorts the waste rock, with the coarser material at the bottom of each lift. The crest of each lift will contain finer-grained material and will be compacted from vehicle traffic; as a result, most of the WRSP surface will limit infiltration of water. The coarser-grained base allows for a free draining toe to the collection system, if saturation were to occur.

As described in Section 1.1, the operating life will be 11 to 12 years. The areal extent of the WRSP 2 and 3 footprints will be fully built out by year 7. Waste rock produced from the mine beyond year 7 will be stockpiled in lifts within that footprint. WRSP 2 and 3 are conceptually illustrated on Figure 3.19.

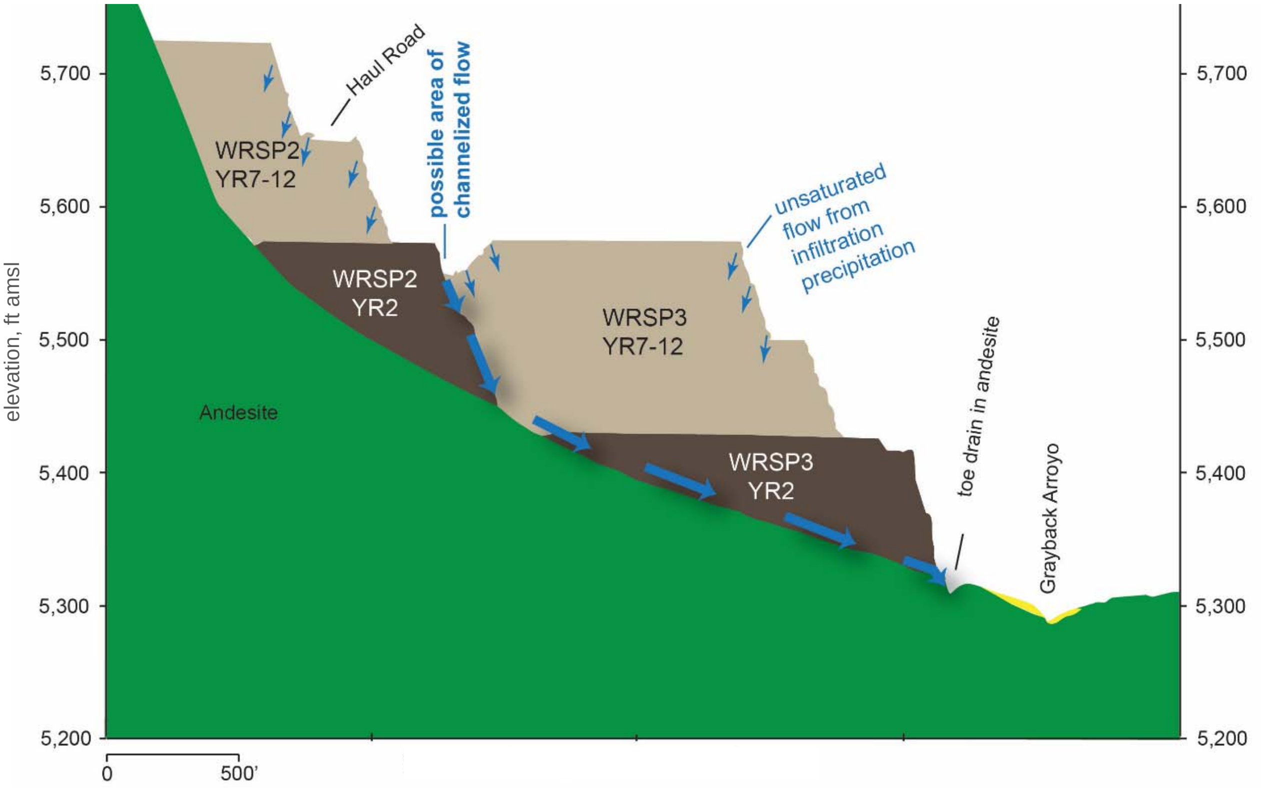


Figure 3.19. Waste rock stockpiles conceptual model.

Surface-water collection trenches will be constructed to collect and route surface runoff and subsurface seepage from the WRSPs as discussed in Section 2.4.2 of the MORP and 20.6.7.J.(6) of the Discharge Plan. Because the WRSP sits on sloping low-permeability andesite ($<1.0\times10^{-6}$ cm/s), net percolation to groundwater is not expected.

The WRSP slope areas, which concentrate and channelize the flow of storm water, will be the primary source of water for surface runoff and infiltration along preferential subsurface pathways. Both surface runoff and preferential subsurface flow will drain to the collection system.

The flat WRSP bench areas will be the primary source of water for subsurface infiltration into the main mass of the waste rock. Infiltrated water may be subsequently evaporated, continue to be held in storage in the pore space of the waste rock, or percolate through WRSP preferential pathways.

3.3.2.2 WRSP Operational Conditions

The water balance of the WRSP was evaluated for the period of operations considering climate inputs (precipitation, evaporation, and temperature), surface runoff from the WRSP, preferential subsurface flow, and net percolation through the mass of the waste rock.

Climate inputs were obtained from the record at Hillsboro and used to evaluate runoff and subsurface flow. A total of 67.8 years of complete daily data including precipitation, potential evaporation, and maximum and minimum temperature were available.

Runoff was estimated based on the U.S. Soil Conservation Service Curve Number method (USDA, 1986). A curve number of 80 was chosen based on the recommended range for unvegetated, and compacted surface of finer-grained material representative of the WRSP during operations.

Small precipitation events do not generate runoff, due to evaporation and subsurface infiltration. In addition, daily potential evaporation will likely be greater than the potential for surface infiltration, so stored infiltration from previous days' precipitation will also evaporate.

Based on the selected curve number of 80, precipitation events greater than 0.5 in. are expected to generate runoff. Daily precipitation data indicate an average of 1.4 runoff events per year, averaging 0.73 in./yr of runoff, or 9.6 ac-ft over the 158-acre maximum area.

The 68-year dataset indicates annual runoff ranging from zero to 2.3 in., or zero to 30.3 ac-ft over the 158-acre maximum catchment of the WRSP footprint. This water will be collected in the surface-water collection system.

The estimated daily runoff was subtracted from daily precipitation to obtain the precipitation available for infiltrating the subsurface, as preferential flow or as net infiltration into the main mass of waste rock.

Because the waste rock will be deposited dry, water infiltrating the waste rock will be initially held in void space and will not move downward due to the low moisture content and high negative soil pore-water pressure of the coarse-grained material. Most of this infiltration will be evaporated. Downward percolation can only occur when enough net infiltration has accumulated in the waste rock and the moisture storage potential is depleted. Until there is a minimum level of saturation throughout the thickness of waste rock, piston flow (where infiltration to the top of the pile pushes water out the bottom) cannot occur (Swanson and O'Kane, 1999).

The existing WRSPs at Copper Flat have been in place and un-reclaimed for approximately 30 years, with no observed net percolation through the WRSP or outflow at the base. Climate conditions (low precipitation, high potential evaporation) and waste rock properties (hydraulic conductivity and volumetric water content) ensure that flow through the waste rock could only occur, if at all, after a much longer period of time.

Therefore, infiltration of flow through the proposed WRSPs is not expected during operations. However, channelized (preferential) flow is a common phenomenon for un-reclaimed WRSPs (Smith et al., 1995), and the possibility for preferential flow was considered.

The potential for both preferential flow and for infiltration through the mass of the waste rock were evaluated following a similar example (Keller et al., 2015), utilizing a computer program (MACRO5; Larsbo et al., 2005) developed as a dual-porosity vadose zone model representing both preferential (macropore) flow and normal (micropore) infiltration. Input parameters are presented in Table 3.7.

Table 3.7 Summary of input parameters for MACRO5 model of WRSP operational conditions

property	symbol	unit	macropore value	micropore value
Soil Matrix Potential	Ψb	-cm	1	10
saturated hydraulic conductivity	Ks	cm/s	a	4.5×10^{-2}
unsaturated hydraulic conductivity	Kb	cm/s	a	1.06×10^{-4}
residual volumetric water content	θr	cm^3/cm^3	0.048	0.048
saturated volumetric water content	θs	cm^3/cm^3	0.215	0.315

a see Keller et al., 2015

Based on Hillsboro climate data and typical hydraulic properties of coarse waste rock from Keller et al. (2015) (see Table 3.7), net infiltration into the waste rock (below effects of evaporation) during operations is expected to range from zero to 6.7 in./yr, and average 1.4 in./yr. Of this infiltration, about 60 percent will be held in waste rock void space, with the remainder discharging to the collection system along preferential pathways. The waste rock saturation level is not expected to generate seepage during the 12-year period of operations for any plausible precipitation scenario. A summary of model-predicted water balance for WRSP operational period is presented as Table 3.8

Table 3.8. Model-predicted water balance for WRSP operational period

component	average rate (in./yr)	percent of total precipitation
total precipitation	12.50	
runoff	0.73	6
net infiltration	1.40	11
evaporation	10.37	83

The preferential flow path analyzed included simulating annual discharge from these pathways ranges from zero to 2.9 in. (39 ac-ft), averaging 0.5 in./yr (7 ac-ft/yr over the 158-acre catchment). As noted above, this water will be collected in the WRSP water collection system.

3.3.2.3 WRSP Post Reclamation Conditions

The Copper Rule (20.6.7 NMAC), requires that a 36-in.-thick store-and-release cover be placed on top of the WRSPs as part of reclamation of the waste rock storage facilities. NMCC's Closure Plan contains such a proposal, therefore, meeting the regulatory requirement.

A store-and-release cover is designed to control infiltration into the underlying waste rock by storing precipitation during storm and snowmelt events and releasing it to the atmosphere (by evapotranspiration) between events. It typically consists of a single well-graded soil layer, but it can also be a two-layer system that features a fine-grained soil layer overlying a coarser-grained layer, which forms a capillary break between the cover and the waste rock.

The effectiveness of a 36-in.-thick cover on water entering the waste rock was evaluated using a numerical model of vadose zone hydraulics (Niswonger et al., 2006) employing the Richards Equations for unsaturated flow and the Hillsboro climate data. Results for the worst-case scenario (without transpiration from vegetative cover) indicate that infiltration to the waste rock would be less than 2 percent of precipitation, or about 0.25 in./yr.

A sample set of cover material hydraulic properties for a single-layer cover that limits infiltration of precipitation, consistent with that proposed by NMCC, is presented as Table 3.9. Storm-water runoff controls and re-vegetation proposed in the Closure Plan further reduce infiltration potential.

Table 3.9. Sample single-layer waste rock cover properties

saturated water content (percent)	20
initial water content (percent)	6
residual water content (percent)	6
Brooks-Corey exponent	2.5
cover thickness (ft)	3.0
saturated hydraulic conductivity (cm/s)	1.0E-04
specific storage (ft^{-1})	1.00E-06

cm/s - centimeter per second

Of the estimated infiltration through the cover, almost all is expected to be released by evapotranspiration or retained in the cover and waste rock. Discharge to groundwater after reclamation will be nil, when considering the reclaimed cover system and low permeability andesite underlying the WRSP.

NMCC has committed to conduct a more detailed analysis of net infiltration when data are available on the material properties of the waste rock and the hydraulic properties of the cover materials. As noted by NMED, the draft DP-1840 requires that additional soil/water characteristic curves for reclamation cover material.

4.0 CONCLUSIONS

The probable hydrologic consequences from development of the Copper Flat Project were evaluated for the mine area and affected area using the numerical model of groundwater flow developed by JSAI (2014).

The objective of this report was to develop a determination of the probable hydrologic consequences of the operation and reclamation, on both the permit area and the affected area, with respect to the hydrologic regime, quantity and quality of surface and groundwater systems that may be affected by the proposed operations (NMAC 19.10.6.602.(13)(g)(v) of the Mining Act regulations).

Groundwater systems include:

- The regional SFG aquifer.
- Quaternary-age alluvial aquifers along Animas Creek and Percha Creek.
- The crystalline bedrock of the Animas Uplift.

Surface water includes:

- Perennial flow in the Rio Grande and Caballo Reservoir that is supplied in part by discharge from the SFG aquifer.
- An area of perennial flow and riparian vegetation along Animas Creek where the Quaternary alluvial aquifer discharges to the surface.
- An area of perennial flow and riparian vegetation along Percha Creek, atop the crystalline bedrock.
- Springs discharging from the crystalline bedrock.
- Storm-water flows in Grayback Arroyo.

The sources of possible hydrologic consequences of the Project include:

1. Groundwater withdrawals from the SFG aquifer: The mine water supply will be withdrawn from pumping wells PW-1, PW-2, PW-3, and PW-4. Water level in the SFG aquifer will be lowered around the well field and then gradually recover after mining. Secondary effects evaluated include:
    a. Reduced groundwater discharge to Rio Grande and Caballo Reservoir.
    b. Reduced flow to artesian wells and other effects to local groundwater users.
    c. Potential reduced discharge to shallow aquifers along Animas Creek and Percha Creek, leading to lower alluvial water levels and reduced discharge to the perennial flow and riparian areas along Animas Creek.
    d. Potential ground subsidence.

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2. Groundwater withdrawals from the crystalline bedrock associated with the open pit. Water levels in the bedrock around the pit will be permanently lowered, and groundwater will flow to the pit and evaporate. Groundwater flow rates to the pit and the future open pit water level and water balance area assessed. Secondary effects evaluated include:
   a. Potential groundwater discharge from the open pit.
   b. Potential effects on springs discharging from the crystalline bedrock and on the Percha Creek perennial (riparian) area.
3. Potential for groundwater discharge from the WRSPs and TSF.

4.1 Groundwater Withdrawals From the SFG Aquifer

Water-level drawdown in the SFG aquifer is projected to reach a maximum of about 70 ft at the well field, at the end of mining. Maximum drawdown decreases with distance from the well field. Water levels will then recover over a period of about 20 to 30 years.

Total reductions in discharge to the system are projected to peak at a total of about 3,100 ac-ft/yr shortly after the end of mining, then diminish to near-zero over about 30 years (Fig. 3.3).

- Flow induced from the Palomas Graben north of the study area is projected to reach a maximum of less than 800 ac-ft/yr at the end of mining, which is estimated to result in an additional reduction of discharge to the Rio Grande by a maximum of 275 ac-ft/yr.
- Effects on the shallow groundwater (riparian) systems along Las Animas Creek and Percha Creek are projected to be minimal, with a maximum of less than 2 ft of groundwater-level change on Percha Creek, less than 1 ft of groundwater-level change on Animas, and non-measureable small changes in surface flow and riparian evapotranspiration.
- Depletion to the Rio Grande is projected to peak around 2,080 ac-ft/yr at the end of mining, then reduce to 28 ac-ft/yr 100 years after mining (Fig. 3.3; Table 3.1)
- Groundwater withdrawals for water supply are not expected to result in measurable ground subsidence.

As required by NMOSE, NMCC will offset any reductions in discharge to the Rio Grande by lease or purchase of additional water rights in the amount of the model-simulated reductions to flow.

NMCC will work with the NMOSE to ensure that impairment to existing water rights by NMCC pumping, according to NMOSE criteria, will be mitigated, as appropriate, so that there is no net loss of available water to existing water rights.

No water-quality effects are expected from pumping the proposed supply wells in the affected area.

4.2 Groundwater Withdrawals From the Crystalline Bedrock

At the end of mining, groundwater-level drawdown in the bedrock around the open pit reaches a maximum of about 800 ft at the pit. A permanent cone of depression will form around the pit, with maximum drawdown of about 600 ft at the edge of the pit. The pit, which currently is an evaporative hydrologic sink, will form an evaporative hydrologic sink again in the future.

Final pit water level after mining is projected to be about 4,894 ft amsl, about 640 ft below the pit rim. The open pit water body that forms after mining and rapid fill remediation will be about 250 ft in depth and have a steady-state surface area of about 22 acres. Steady state groundwater inflow is estimated at 36 ac-ft/yr and captured storm-water runoff is estimated at 57 ac-ft/yr. Pit water evaporation is projected to be about 93 ac-ft/yr.

During operations and after reclamation, storm-water flows from Grayback Arroyo will be conveyed around the open pit in the existing bypass channel and through the mine area with no expected hydrologic consequences. Water quality effects for the open pit water body are addressed in a separate report prepared for the project.

Long-term, indirect effects to springs discharging in and around the Animas Uplift are projected to be minimal and not measureable.

4.3 Potential Groundwater Discharge From Tailings and Waste Rock

Infiltration to groundwater from the tailings and waste rock storage areas is not expected. The meteoric water that may infiltrate is expected to remain in the immediate area for centuries, due to the low permeability of the SFG sediments near the Animas Uplift and due to the presence of flow-inhibiting faults. The impact to groundwater chemistry is expected to be minimal.

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APPENDICES

Appendix A.

Projected Groundwater-Level Hydrographs at Selected Locations

APPENDIX A.

HYDROGRAPHS

Projected groundwater drawdown 100 years after mining is shown on Figure A1. Water-level change in the bedrock will be about 580 ft near the bottom of the pit. Water levels in the bedrock near the pit rapidly equilibrate to the pit water level. The rate of propagation of the drawdown away from the pit is a function of the low permeability of the andesite bedrock. Locations closer to the pit reach equilibrium sooner (see Fig. A20) than locations farther from the pit (see Fig. A22). By 100 years post-mining, the propagation of drawdown has essentially stopped; the contours in Figure A1 represent the post-mining equilibrium condition.

Projected water-level hydrographs for most well locations shown on Figure A1 are shown on Figures A2 through A23.

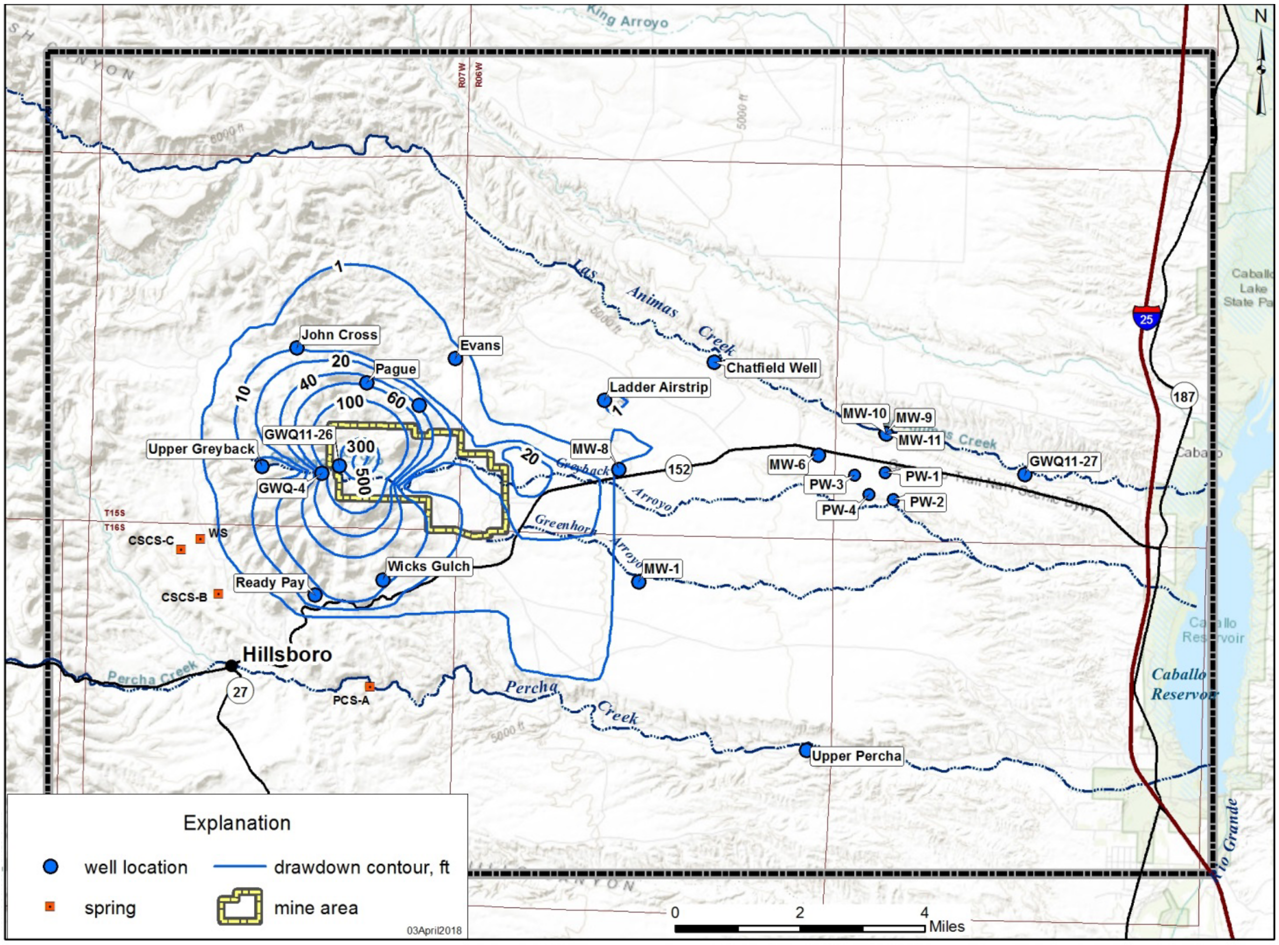

Figure A1. Projected groundwater drawdown 100 years after mining.

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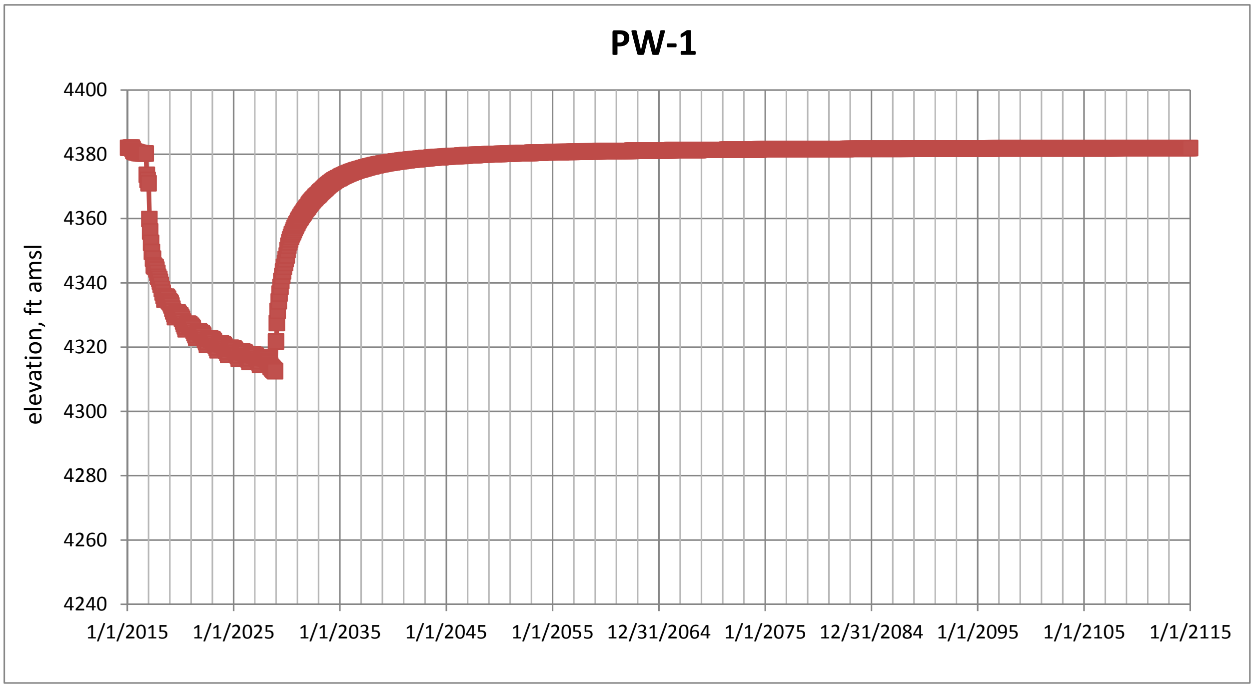


Figure A2. Projected water levels at PW-1.

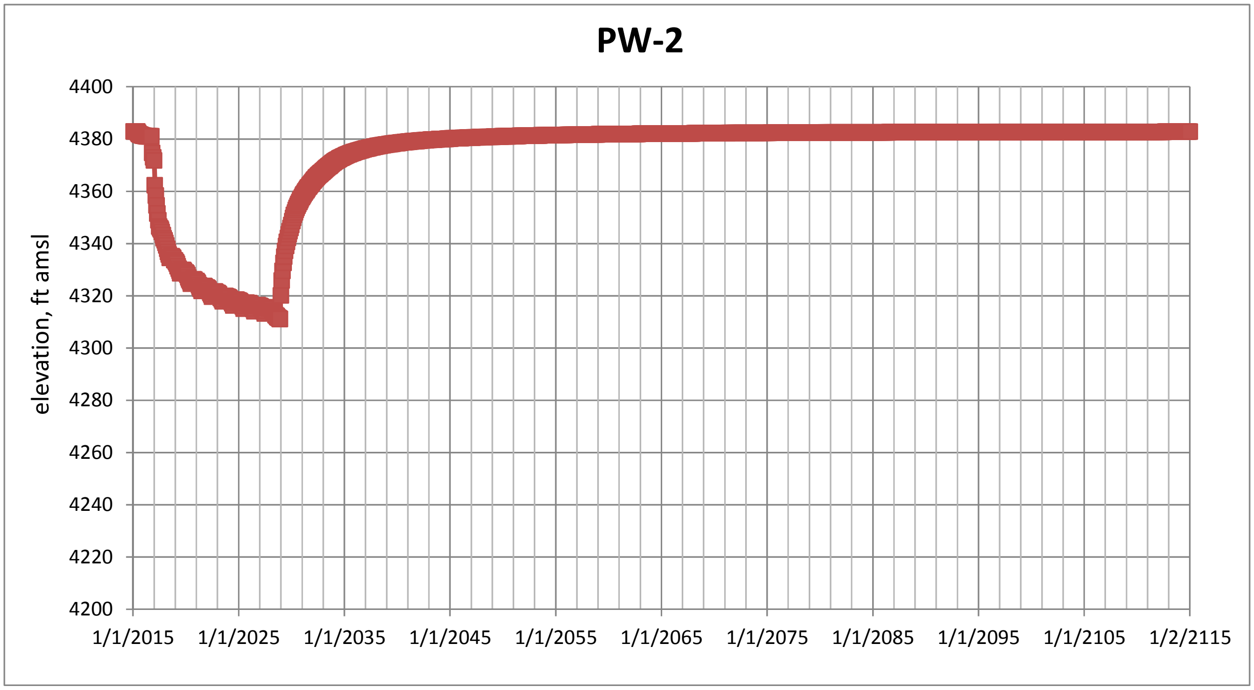


Figure A3. Projected water levels at PW-2.

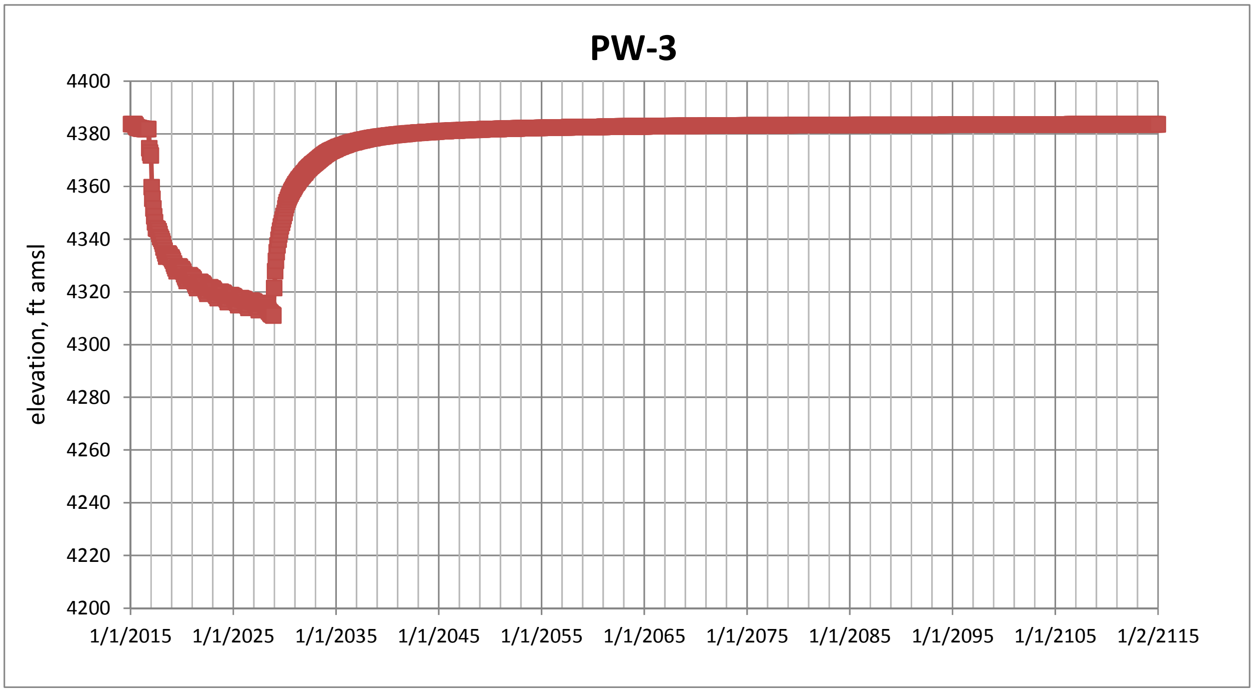


Figure A4. Projected water levels at PW-3.

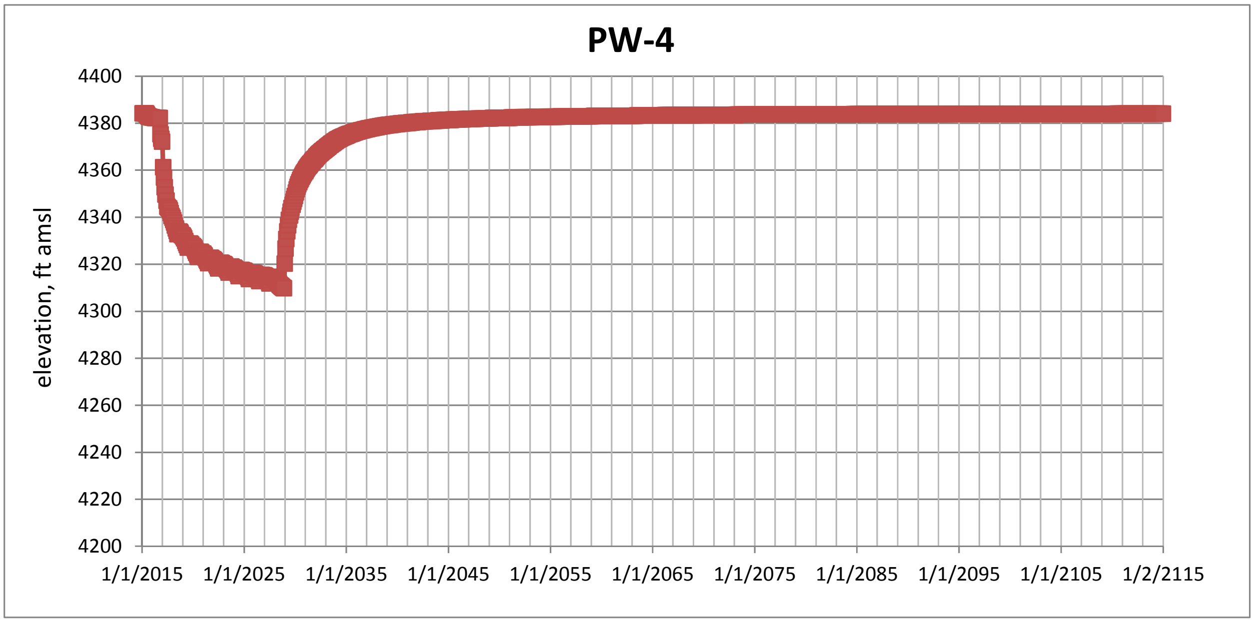


Figure A5. Projected water levels at PW-4.

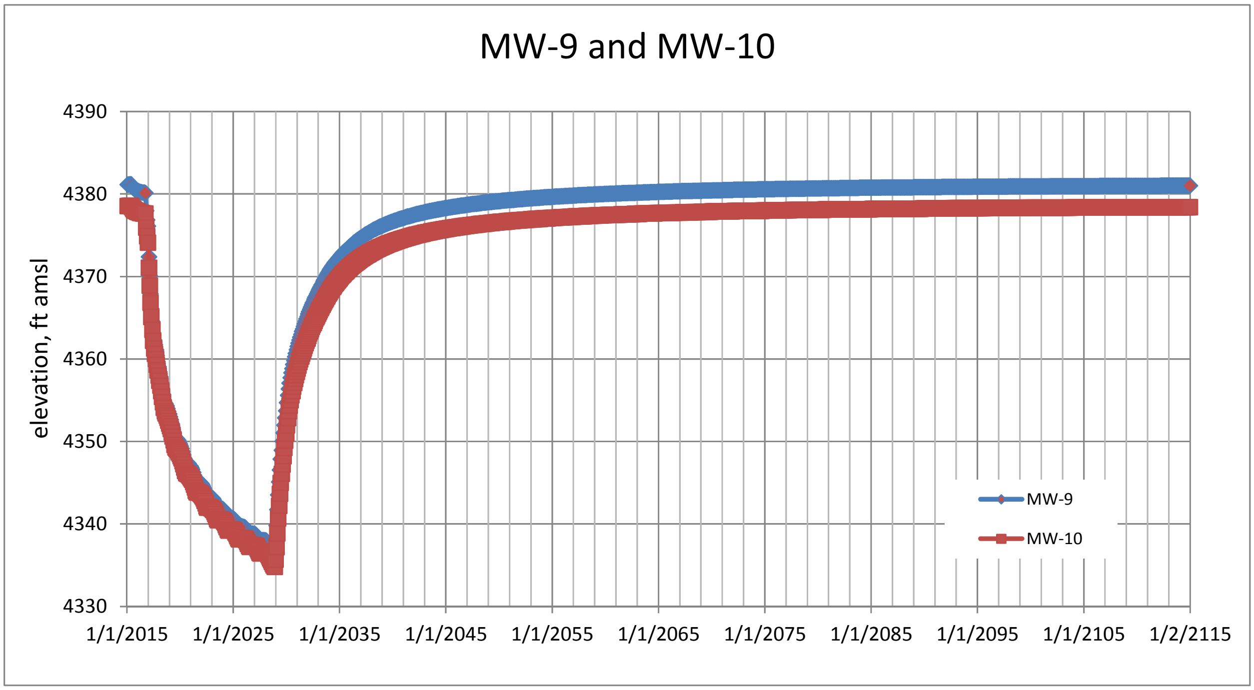


Figure A6. Projected water levels at MW-9 and MW-10.

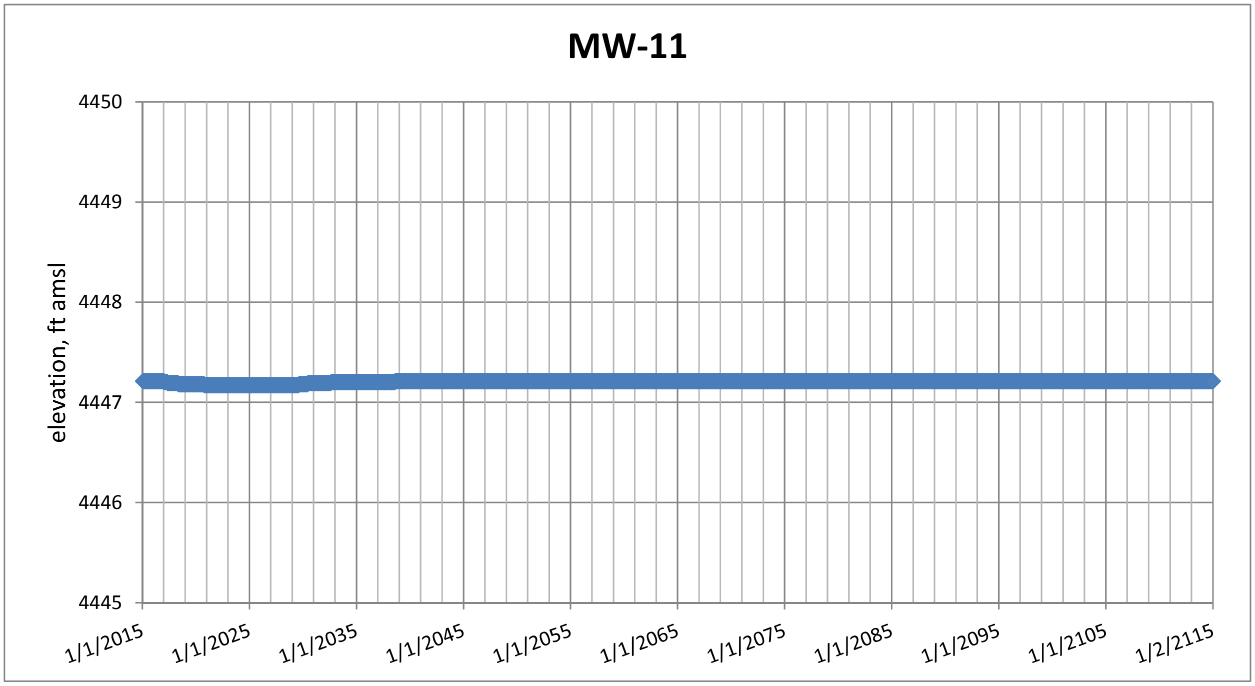


Figure A7. Projected water levels at MW-11.

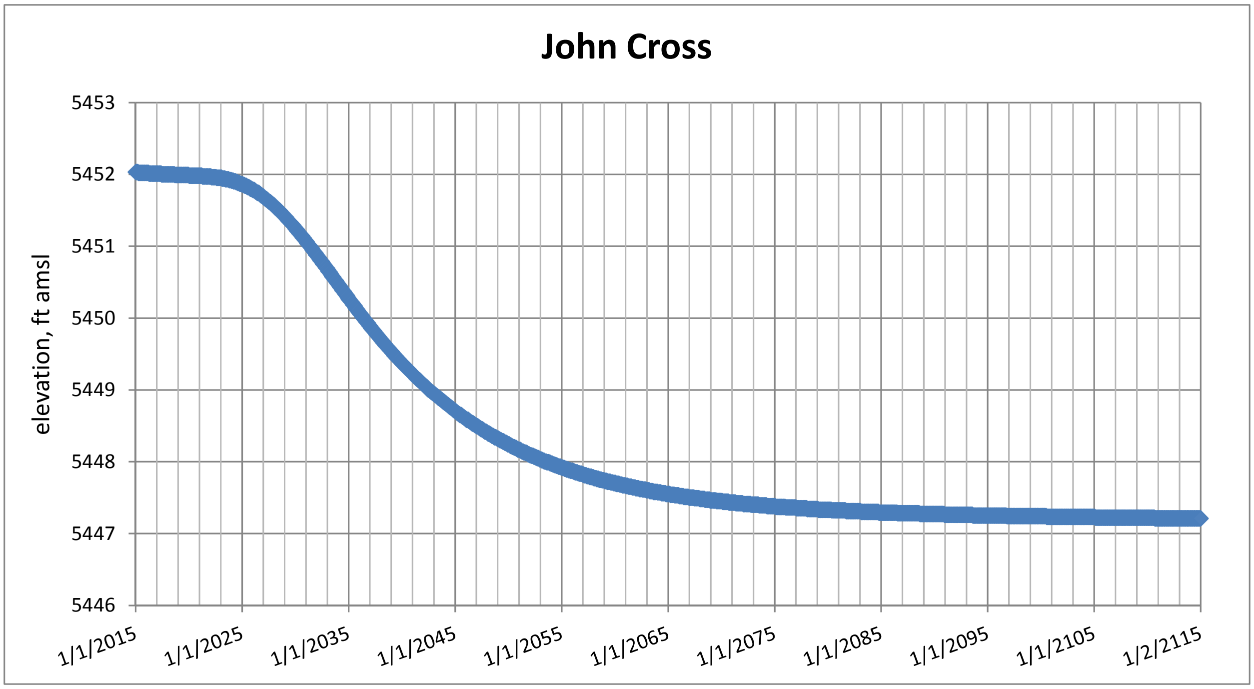


Figure A8. Projected water levels at John Cross.

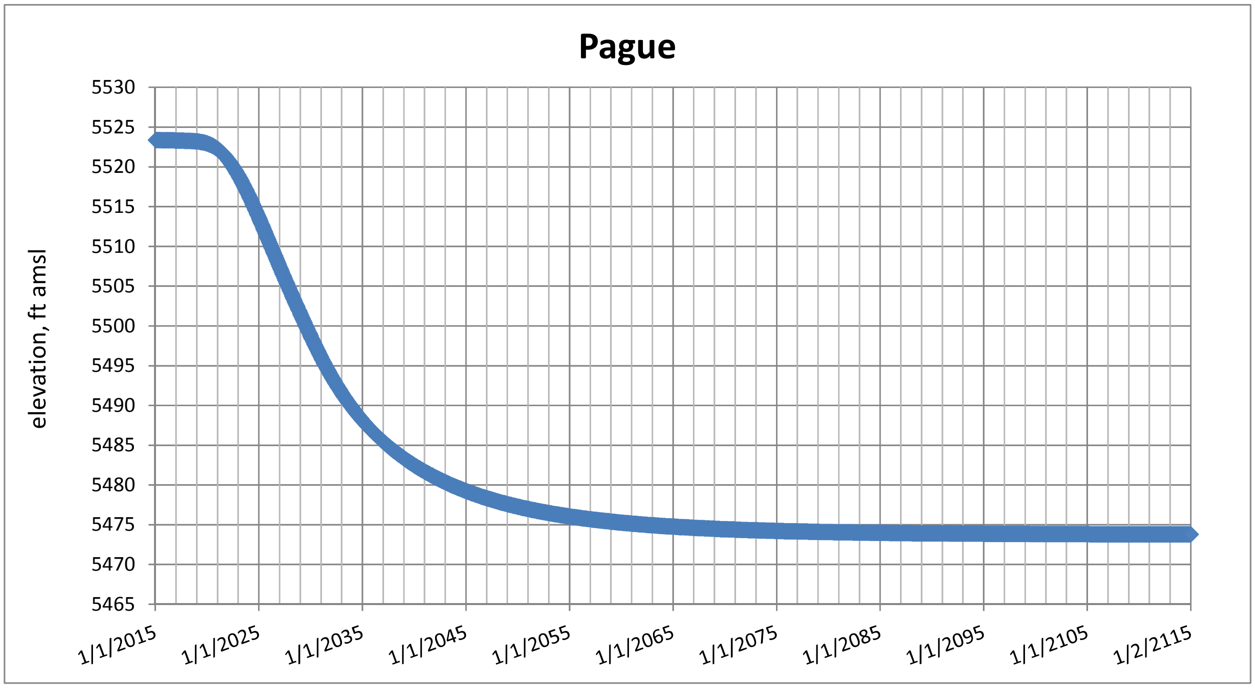


Figure A9. Projected water levels at Pague.

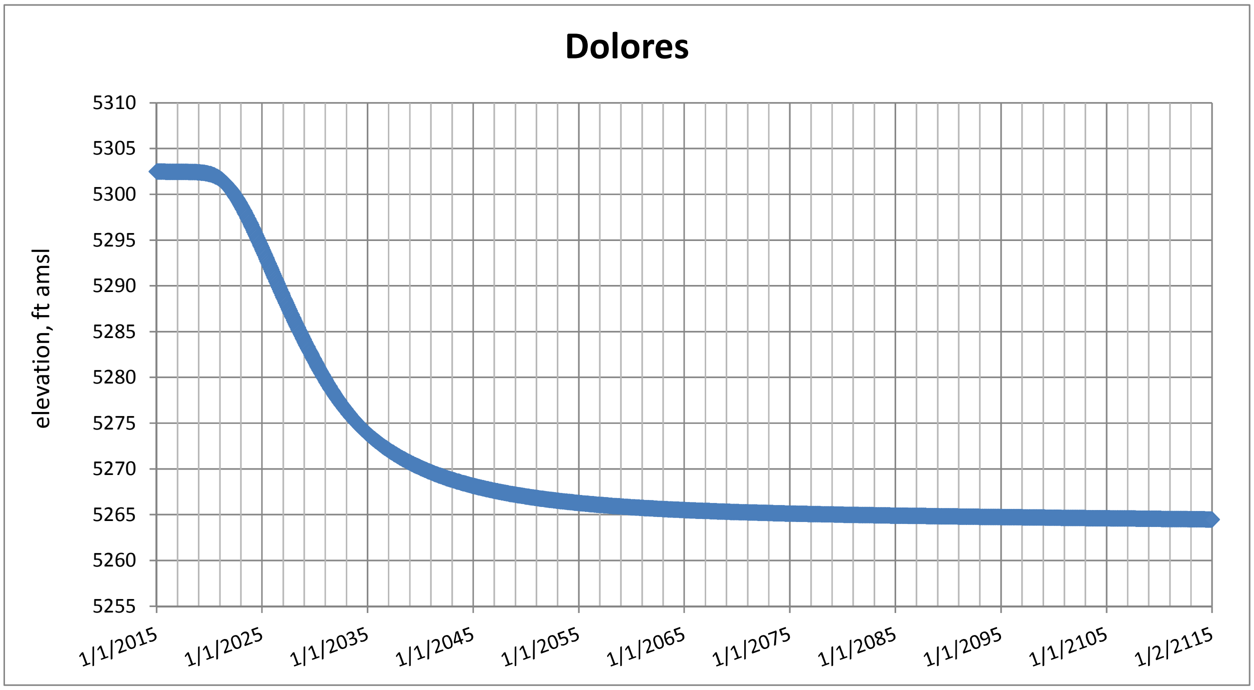


Figure A10. Projected water levels at Dolores.

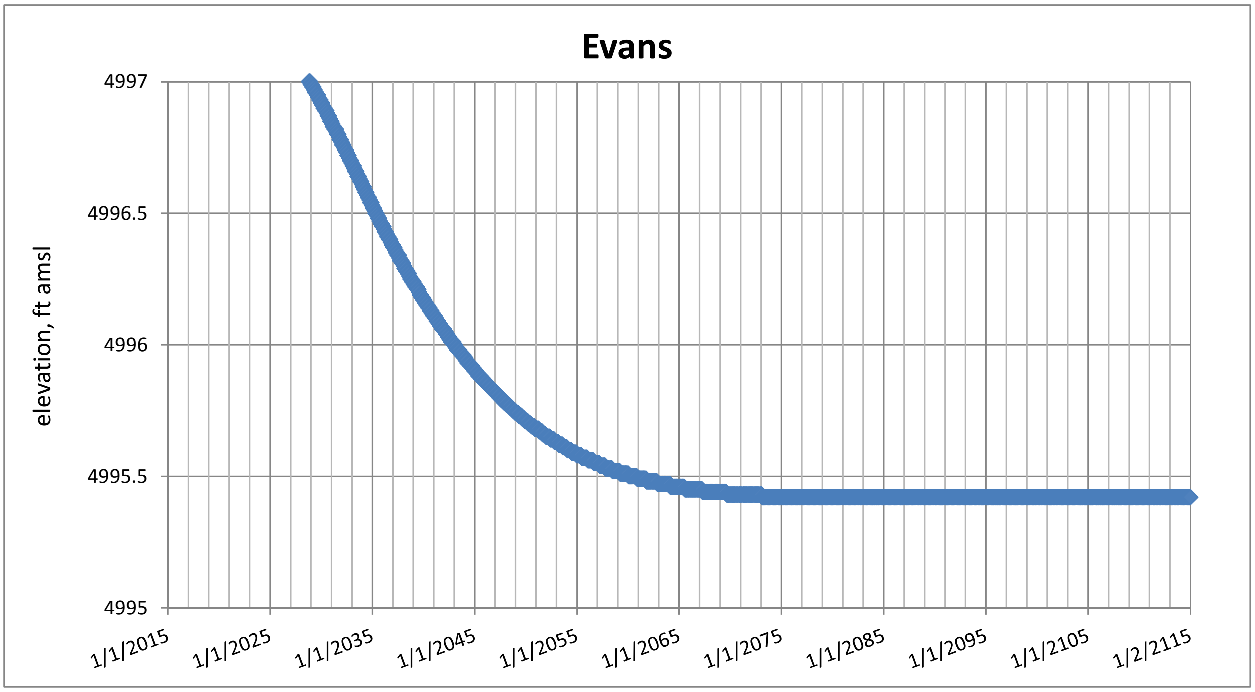


Figure A11. Projected water levels at Evans.

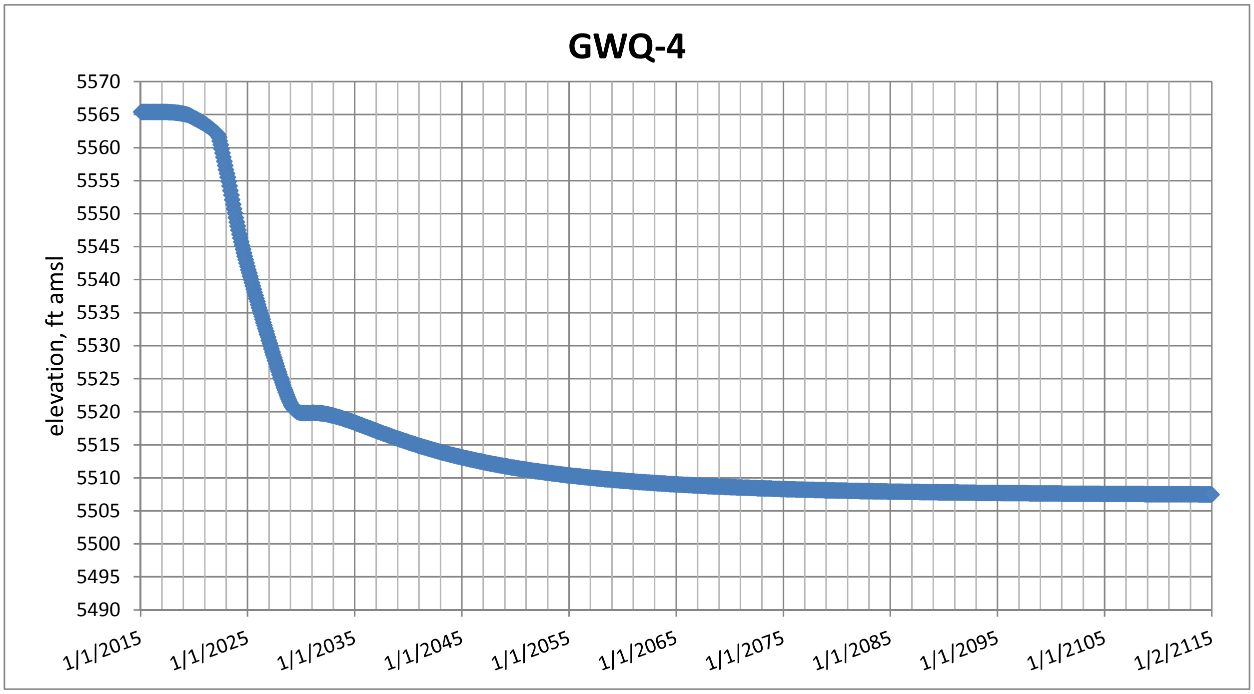


Figure A12. Projected water levels at GWQ-4.

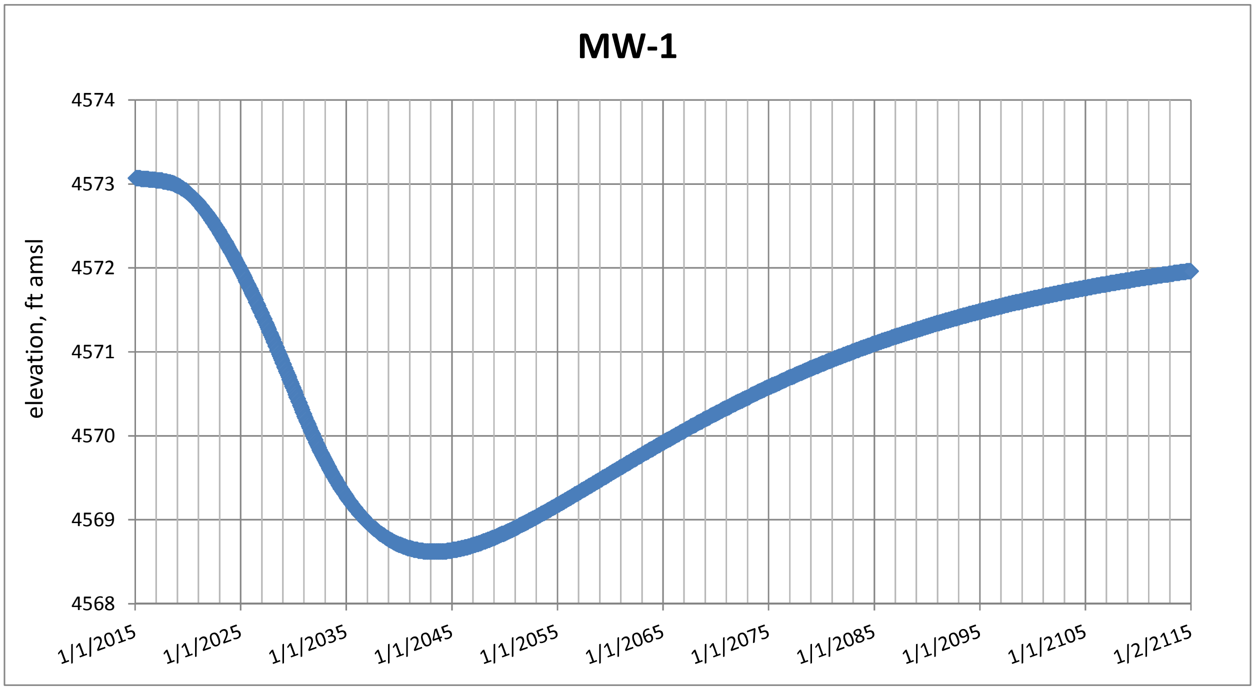


Figure A13. Projected water levels at MW-1.

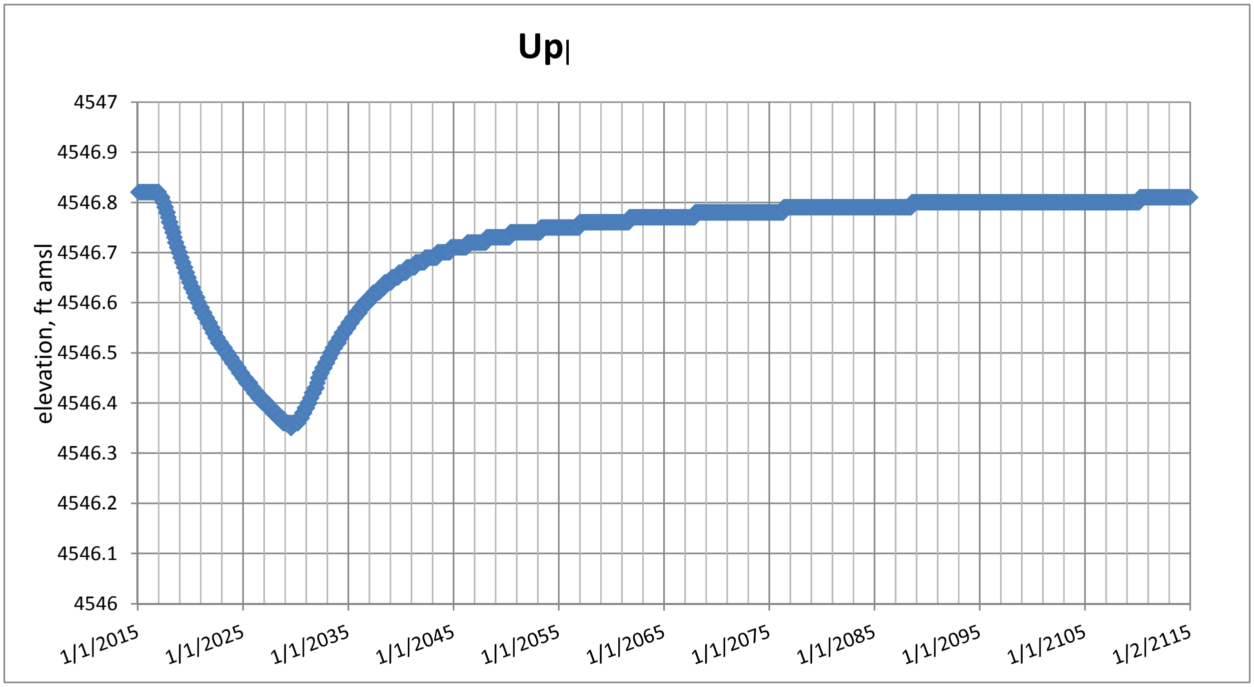


Figure A14. Projected water levels at Upper Percha.

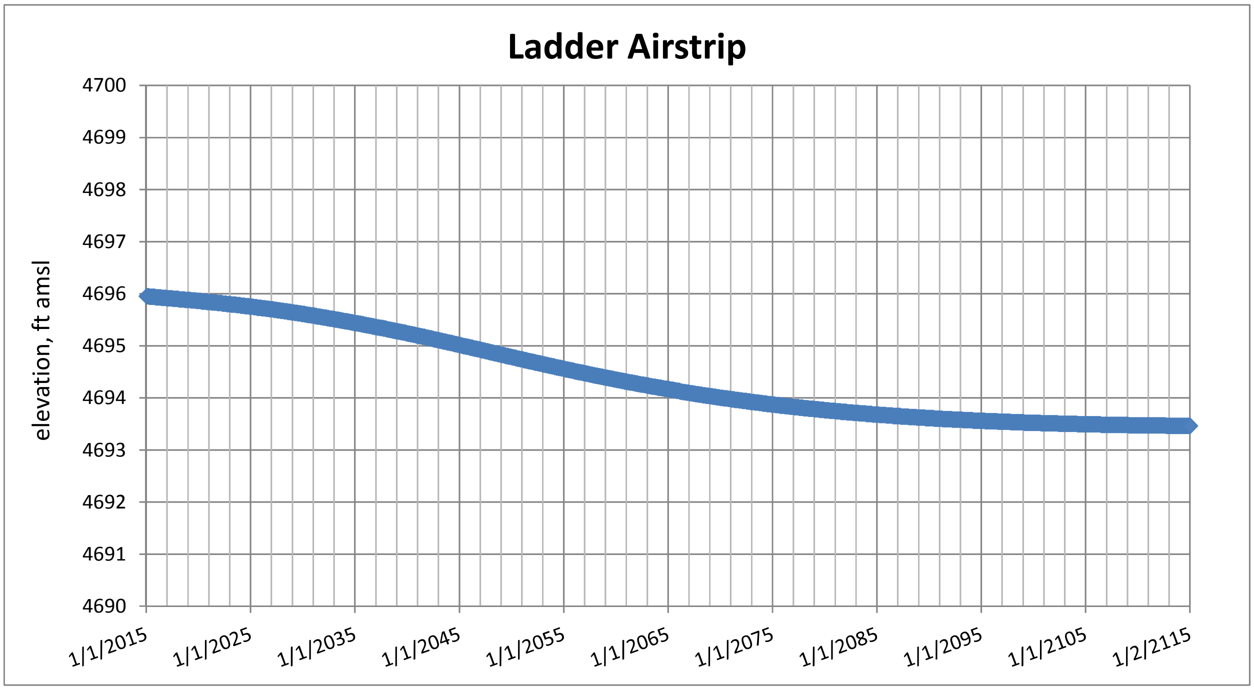


Figure A15. Projected water levels at Ladder Airstrip.

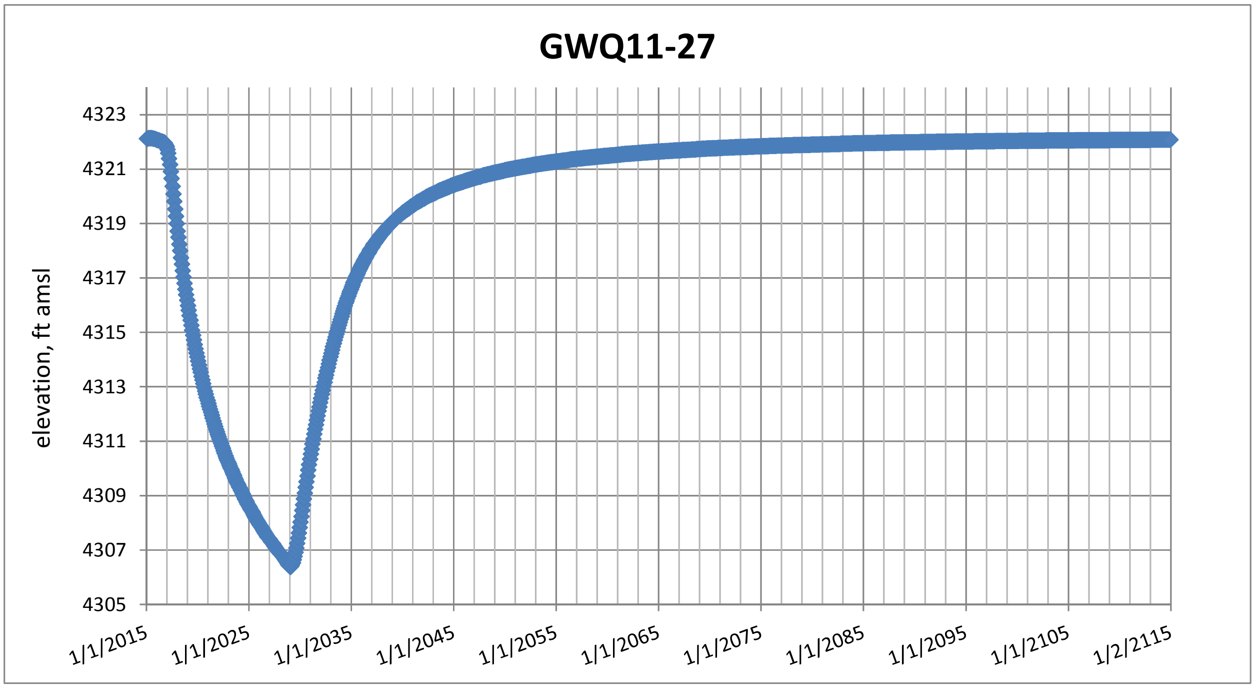


Figure A16. Projected water levels at GWQ11-27.

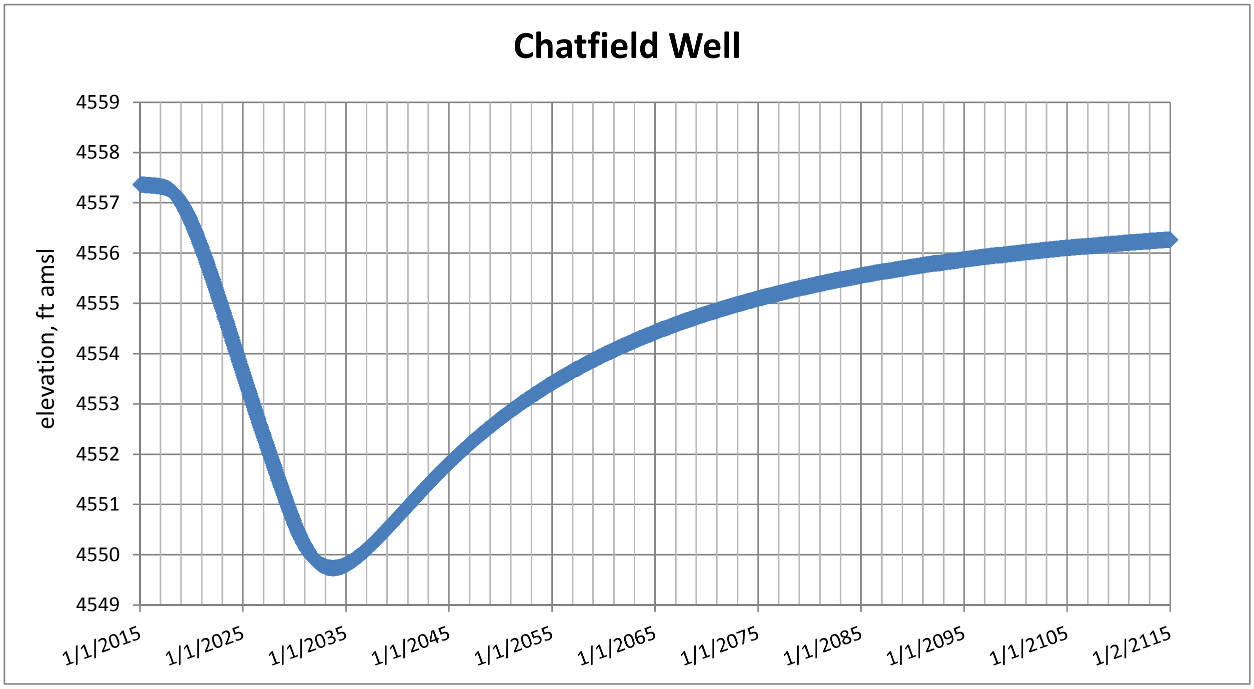


Figure A17. Projected water levels at Chatfield Well.

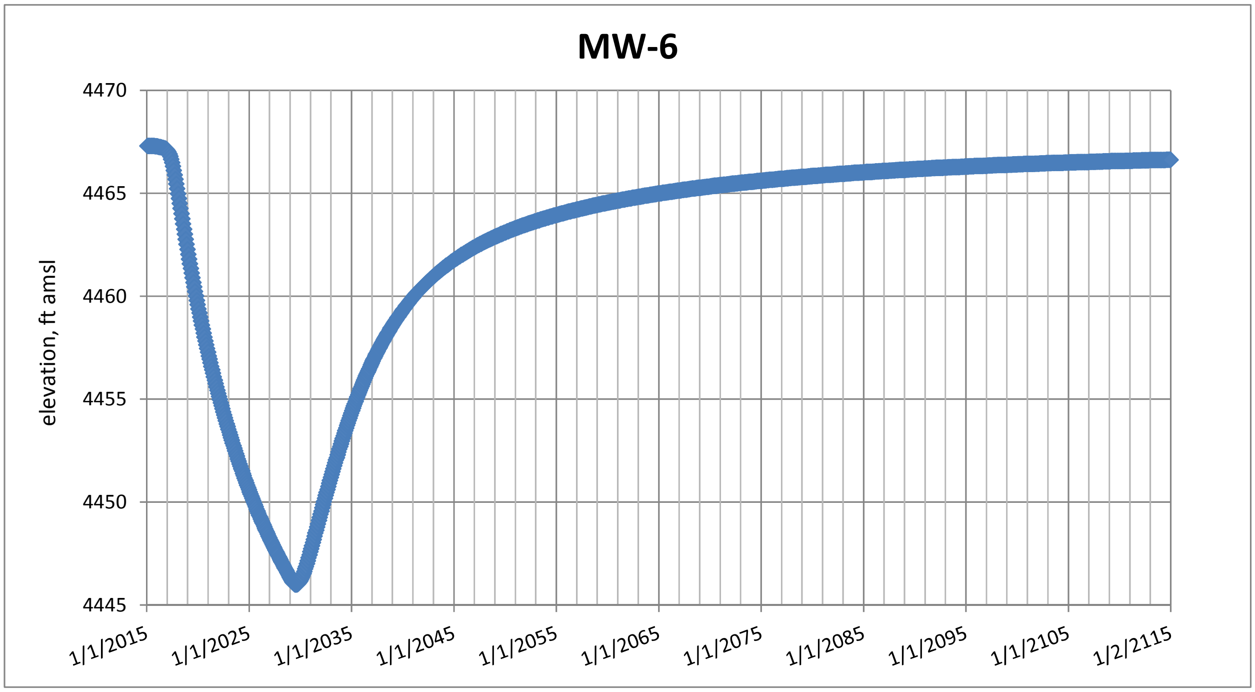


Figure A18. Projected water levels at MW-6.

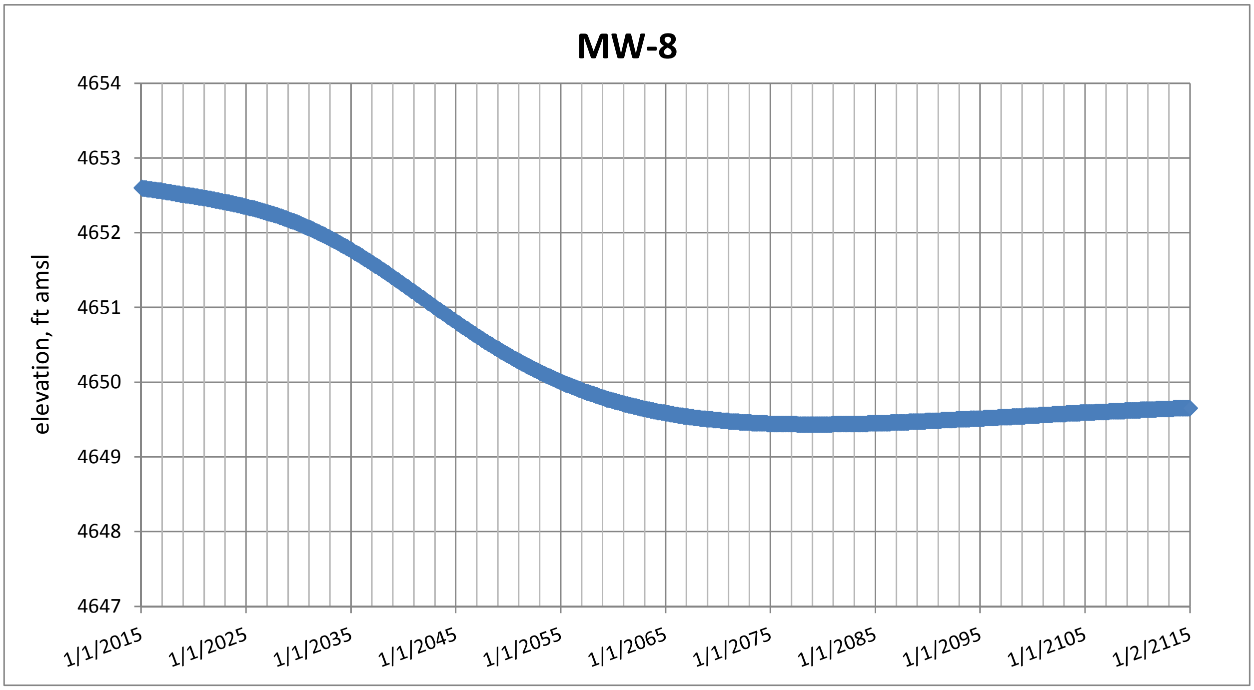


Figure A19. Projected water levels at MW-8.

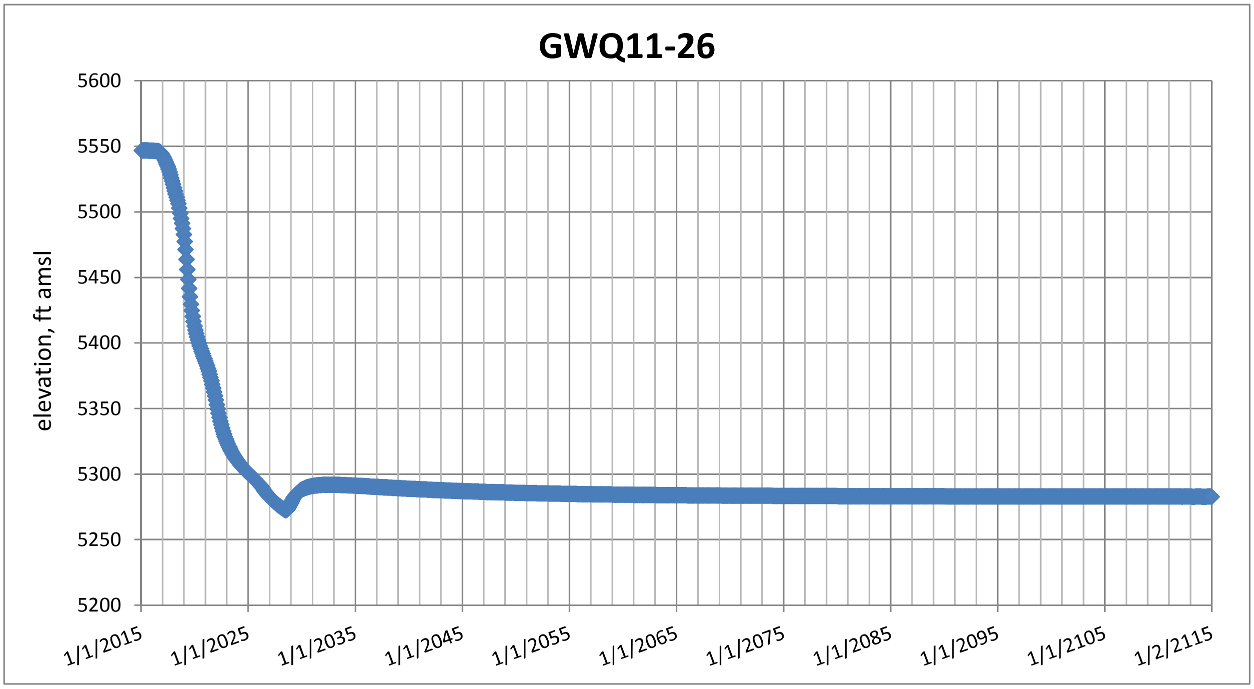


Figure A20. Projected water levels at GWQ11-26.

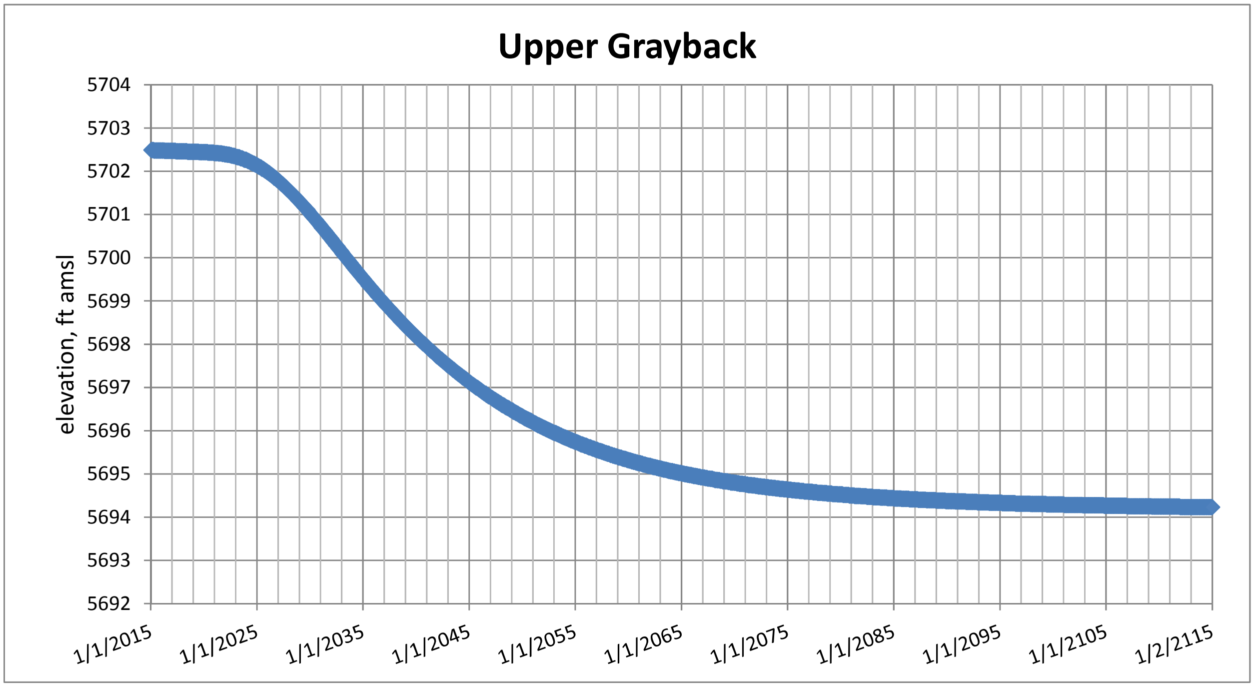


Figure A21. Projected water levels at Upper Grayback.

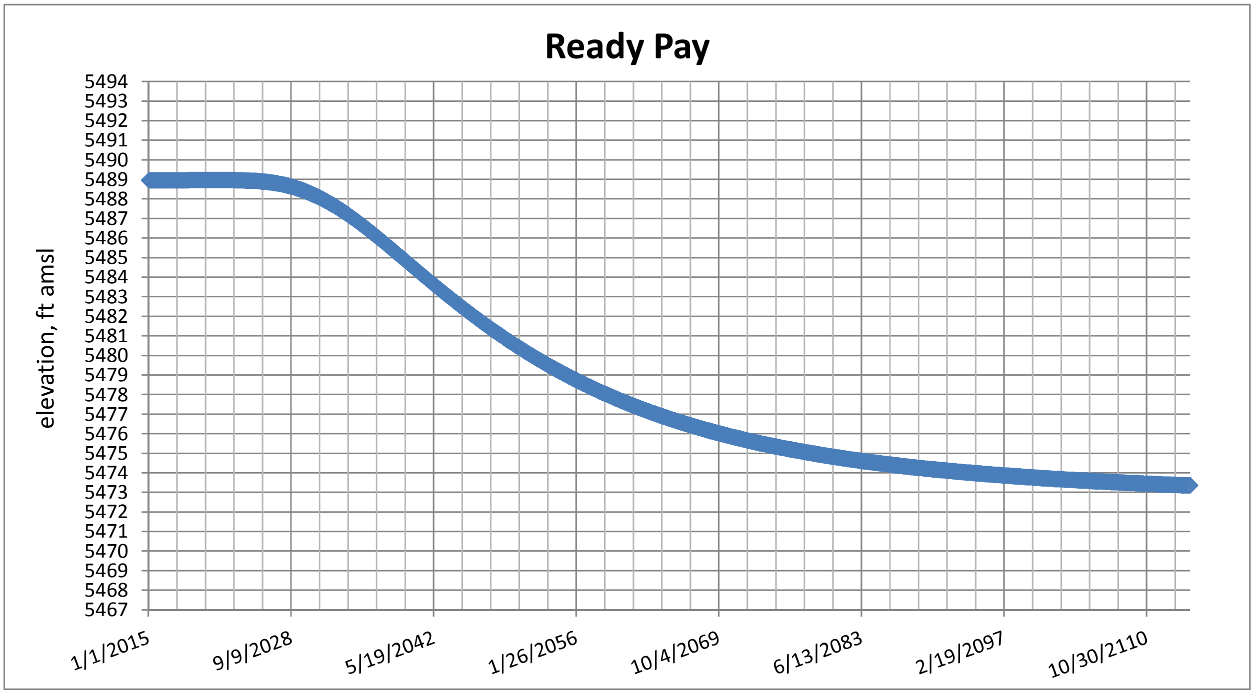


Figure A22. Projected water levels at Ready Pay.

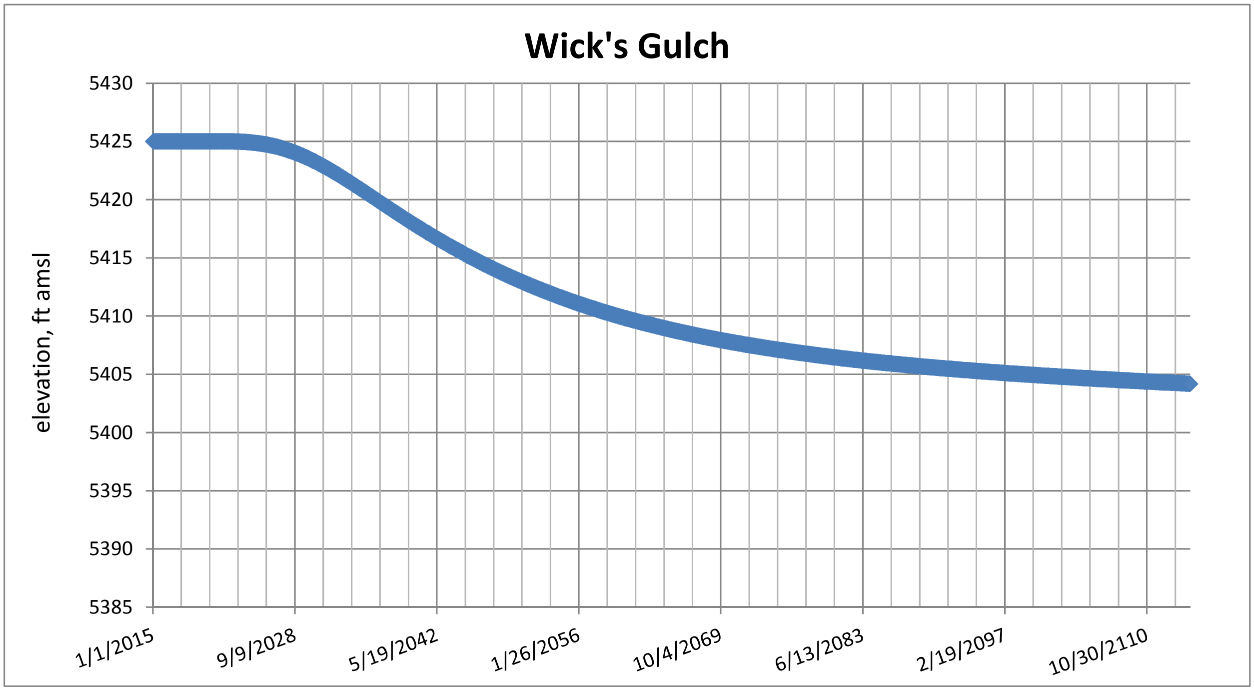


Figure A23. Projected water levels at Wick’s Gulch.

Appendix B.

Technical Memo Regarding Liner Leakage Rates

JOHN SHOMAKER & ASSOCIATES, INC.
WATER-RESOURCE AND ENVIRONMENTAL CONSULTANTS
2611 BROADBENT PARKWAY NE
ALBUQUERQUE, NEW MEXICO 87107
(505) 345-3407, FAX (505) 345-9920
www.shomaker.com

MEMORANDUM

To: JSAI Internal Memo

From: Michael A. Jones, Principal Hydrologist

Date: December 8, 2010

Subject: liner leakage projection

Introduction

Synthetic liners have been widely used in the modern mining industry to minimize/eliminate mine contact water intrusion to the surrounding surface water and groundwater systems. Even though the liner materials are virtually impermeable, holes and tears regularly occur and synthetic liners leak. In general, the leakage rates depend on many factors including liner quality, installation quality, stress due to weight of the impounded material and traffic, water pressure on the liner, over-liner/under-liner material hydrogeologic and geotechnical properties and conditions, and so on.

Environmental Impact Assessment (EIS) on any new project always requires estimating leakage through the lined mine facilities including leach pads, tailing storage facilities (TSF), contact water ponds, and waste rock dumps. Based on the estimated seepage (source) and hydrologic properties of the underlying aquifers (receiver), evaluation of solute transport downstream can be carried out using numerical or analytical methods. In certain circumstances, the liner leakage must be estimated in order to properly design the seepage collection systems.

Various assumptions and methods have been used by different professionals to estimate liner leakage. Depending on which firm is contracted, different seepage estimates can be obtained for the same facility.

This memorandum intends to provide guidance on how to estimate liner leakage for future projects. Standardizing the approach will make the liner leakage estimates more defendable and irrelevant to the selection of consulting firm.

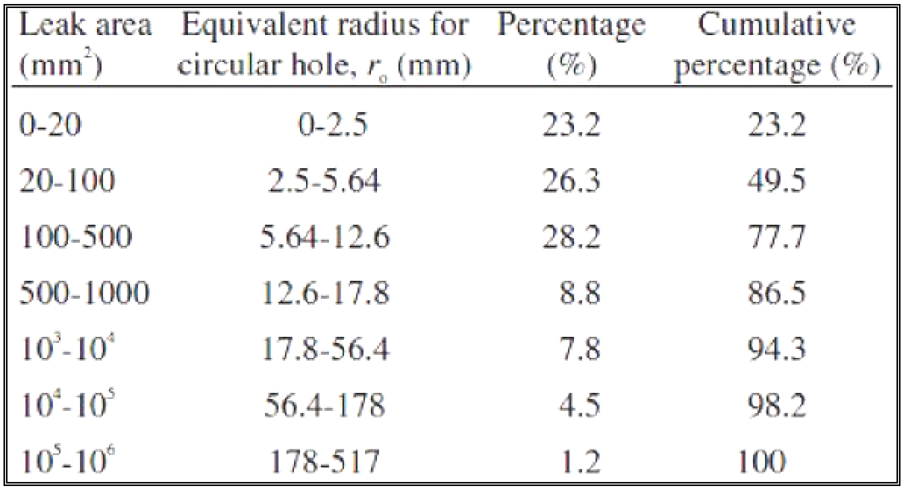
Liner Defect Assumptions

There are few papers on the size and frequency of occurrence of defects in liners (Erickson and Thiel, 2002; Colucci and Lavagnolo,1995; Rowel, 2005). The studies are generally in agreement. In a 3-year field study, Colucci and Lavagnolo (1995) found that the size of liner defects in waste landfills varies substantially with a median hole area of about 1 cm2 (Table 1).

Holes can be detected by electrical leak survey. Rowel et al. (2005) found that (1) no holes were detected for 30% of electrical leak surveys, and (2) fewer than 5 holes/ha were detected for 50% of the surveys with remaining 20% surveys having more than 5 holes/ha.

Some analyses have assumed a more frequent occurrence of smaller defects. In an EPA funded study, defect hole diameters were assumed to be 0.3 and 1 cm, but the corresponding numbers of holes were assumed to be 9 and 3.6 hole/ha, respectively (Barlaz et al., 2002).

Table 1. Reported size of holes in geomembranes
(after Colucci & Lavagnolo, 1995)



Leak area (mm^2)	Equivalent radius for circular hole, r_o (mm)	Percentage (%)	Cumulative percentage (%)
0-20	0-2.5	23.2	23.2
20-100	2.5-5.64	26.3	49.5
100-500	5.64-12.6	28.2	77.7
500-1000	12.6-17.8	8.8	86.5
10^3-10^4	17.8-56.4	7.8	94.3
10^4-10^5	56.4-178	4.5	98.2
10^5-10^6	178-517	1.2	100

For estimating liner leakage, we recommend using the following assumptions for the occurrence and size of liner defects:

- 1 circular defect per acre (or 2.5 defects per hectare)
- Area of defect = 1 cm^2 (equivalent hole diameter of about 1.13 cm)

These recommendations are in agreement with Giroud and Bonaparte (1989) for calculations to size the components of the lining system, and have been used by some consulting firms.

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Exhibit 21

Liner Leakage Equation 1 (for non TSF Facility)

We recommend an equation (Giruoud et al., 1997) to estimate liner leakage for non TSF facilities. The equation represents an impeded flow condition with a geomembrane underlain by a low permeable medium such as a (compacted) soil foundation.

The Giruoud et al. (1997) Equation is listed below:

$$q = \beta_c \left[1 + 0.1 \left(\frac{h_w}{L_s} \right)^{0.95} \right] a_d^{\ 0.1} h_w^{\ 0.9} K_s^{\ 0.74}$$

q = leakage through a circular defect in composite liner (m^3/sec)
β_c = coefficient relating to liner contact (0.21 for good and 1.15 for poor)
h_w = depth of water above the geomembrane (m)
L_s = thickness of soil liner (m)
a_d = area of defect (m^2)
K_s = saturated hydraulic conductivity of soil liner (m/s)

It should be noted that, in the above equation, the leakage rate has a non-linear relationship with the area of the defect. Therefore, the leakage through a single hole should be calculated first; then total leakage through the facility should be calculated based on the total number of defect holes within the facility footprint.

Liner Leakage Equation 2 (for TSF Facility)

The Giruoud et al. (1997) Equation is only suitable for lined leach pads, waste dumps and landfills where leakage is only impeded by defect size and conductance of the underlying soil liner. In a TSF, however, seepage through a liner defect will be most likely restricted by the permeability of tailings around the hole. In other words, hydraulic properties of both the over-liner tailings and the under-liner soil restrict the flow of water through the defect.

Coffey (Appendix A) has proposed an analytical solution to calculate liner leakage through a defect confined by both aquifers:

$$Q = (h_T - h_A)\ \pi D_H / (1/k_T + 1/k_A) \tag{1}$$

Where, Q is leakage rate through a defect; hT and hA are, respectively, total head in the tailings and in the underlying soil; kT and kA are, respectively, hydraulic conductivity of the tailings and underneath soil; and DH is the diameter of the defect.

If the underlying soil is not pressurized, i.e., in an unsaturated condition, the above equation can be simplified to:

$$\boldsymbol{Q} = h_T \pi D_H k_T \tag{2}$$

Derivation of equations is provided in Appendix A. We have reviewed and verified the Coffey work and found it is correct mathematically.

The analytical solution proposed by Coffey was also validated by John Shomaker & Associates, Inc. (JSAI) using a spreadsheet-based numerical model and U.S. Geological Survey (USGS) finite difference code MODFLOW. Results obtained for an example problem, using both analytical and numerical solutions, are compared in Table 2. Apparently, they are in close agreement.

Table 2. Calculated seepage through a defect - numerical and analytical solutions

	Case
D_H (cm)	1.128
A (cm^2)	1.000
h_T(m)	30
K_T (cm/s)	1.00E-06
Coffey - Eq2 Q (cm^3/s)	0.011
JSAI - Spreadsheet Q (cm^3/s)	0.011
JSAI - MODFLOW Q (cm^3/s)	0.012

Discussion

Rowe (2005) reports landfill liner seepage as detected by liner detection systems (LDS) for various liner configurations (Table 3). It was found that (1) average leakage rates through single geomembrane liners were between 130-190 liters per ha per day (lphd), and (2) average leakage rates through geomembrane plus compacted clay liners were between 50- 90 lphd.

The following assumptions were used in an example calculation:

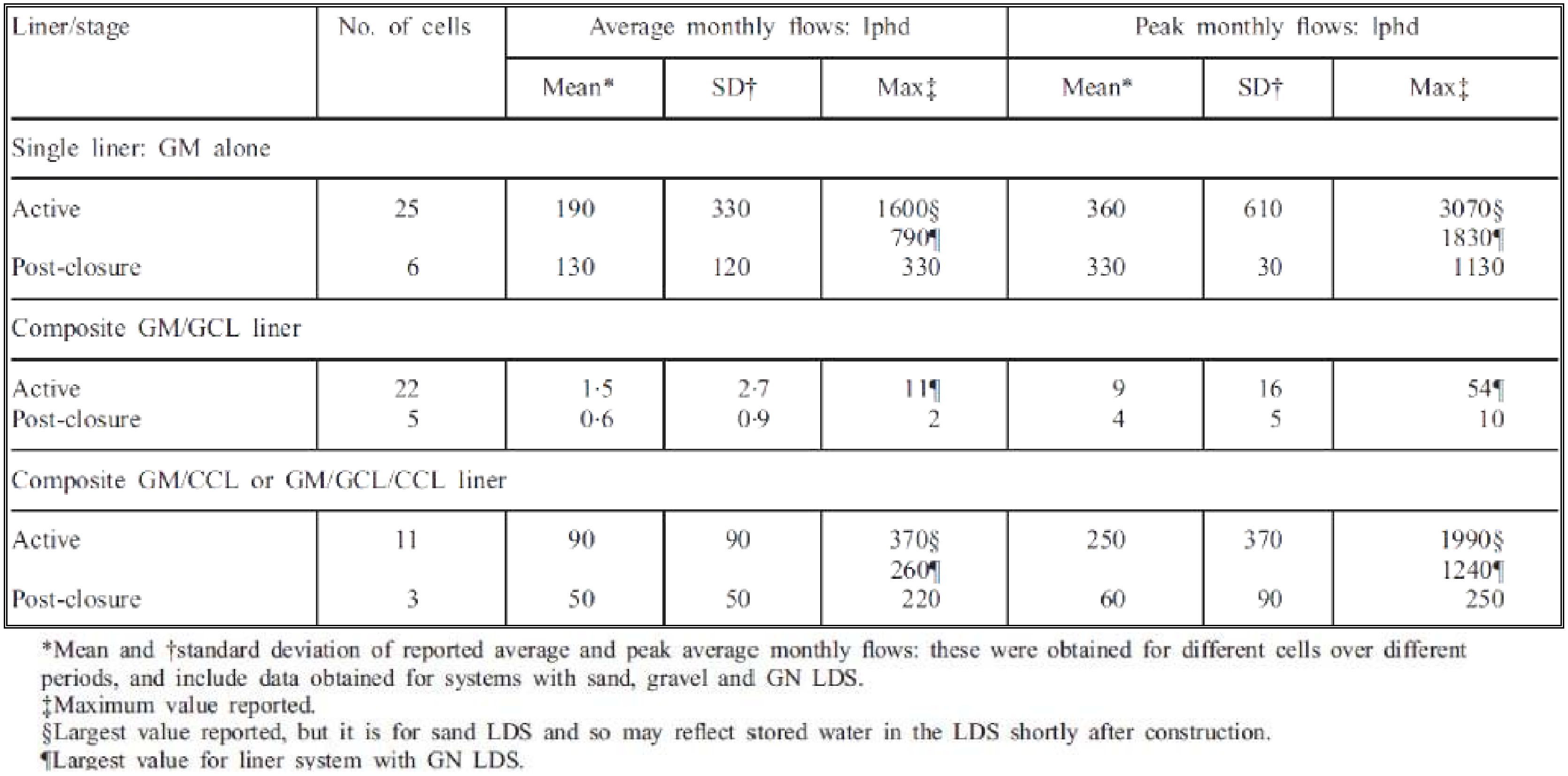
> $\beta_c = 0.21$, $h_w = 60$ cm, $L_s = 30$ cm, $a_d = 0.0001$ m^2, K_s =1.00E-7 m/s, and defect frequency (n) is 1 hole/acre,

Estimated liner leakage from the Giruoud et al. (1997) Equation is:

$$Q = n \times q = 36 \text{ liters/acre/day} = 89 \text{ liters/ha/day (lphd)}$$

The calculated result is in close agreement with the Rowe (2005) field measurements. Therefore, we suggest a general rule that leakage of a lined leach pad (or waste dump) is likely about 100 lphd.

Table 3. Field-measured liner seepage (after Rowe, 2005)



Liner/stage	No. of cells	Average monthly flows: lphd			Peak monthly flows: lphd		
		Mean*	SD†	Max‡	Mean*	SD†	Max‡
Single liner: GM alone							
Active	25	190	330	1600§ 790¶	360	610	3070§ 1830¶
Post-closure	6	130	120	330	330	30	1130
Composite GM/GCL liner							
Active	22	1·5	2·7	11¶	9	16	54¶
Post-closure	5	0·6	0·9	2	4	5	10
Composite GM/CCL or GM/GCL/CCL liner							
Active	11	90	90	370§ 260¶	250	370	1990§ 1240¶
Post-closure	3	50	50	220	60	90	250

*Mean and †standard deviation of reported average and peak average monthly flows: these were obtained for different cells over different periods, and include data obtained for systems with sand, gravel and GN LDS.

‡Maximum value reported.

§Largest value reported, but it is for sand LDS and so may reflect stored water in the LDS shortly after construction.

¶Largest value for liner system with GN LDS.

References

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Colucci, P., and Lavagnolo, M.C., 1995, Three years field experience in electrical control of synthetic landfill liners: Proc. 5th Int. Landfill Symp., Cagliari, pp 437-452.

Erickson, R.B., and Thiel, R., 2002, Design and application of the geomembrane supported GCL in one-product and encapsulated composite liner systems: Clay Geosynthetic Barriers, Zanzinger, Koerner & Gartung (eds), Swets & Zeitlinger, Lisse, ISBN 90 5809 380 8, pp 31-40.

Giroud, J.P., and Bonaparte, R., 1989, Leakage through liners constructed with geomembranes – Part I. Geomembrane liners, geotextiles and geomembranes Vol 8, pp 27-67.

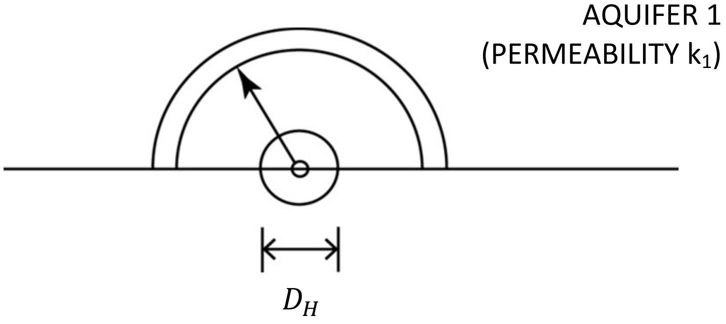
Giroud, J.P., Khire, M.V., and Soderman, K.L., 1997, Liquid migration through defects in a geomembrane overlain and underlain by permeable media: Geosynthetics International, Vol. 4, Nos. 3-4, pp 293-321.

Rowe, R.K., 2005, Long-term performance of contaminant barrier systems: Ge´otechnique 55, No. 9, pp 631-678.

Appendix A

Seepage Loss through a Circular Hole in Geomemberance
(Coffey, 2010)

CONSIDER SEEPAGE LOSS THROUGH A CIRCULAR HOLE OF DIAMETER D_H
IN A MEMBRANE SEPARATING TWO MATERIALS OF DIFFERENT PERMEABILITY.

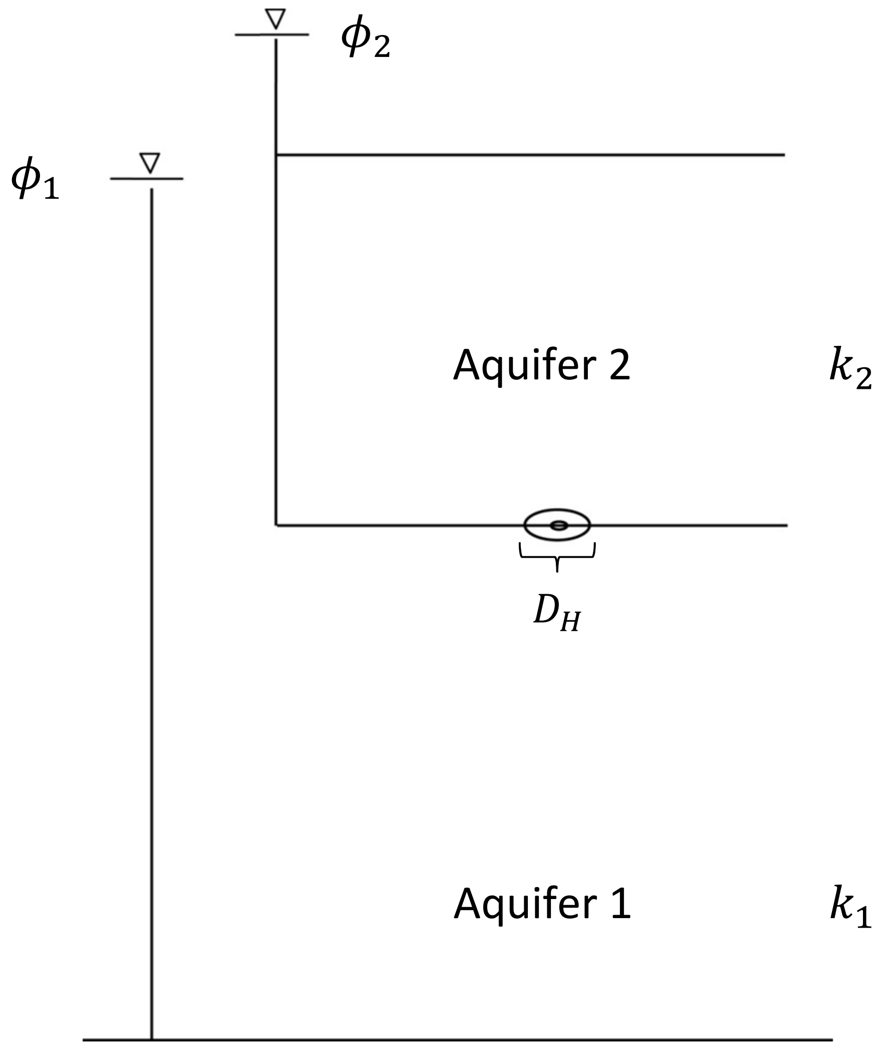


$$Q = k \, \overbrace{2\pi r^2}^{\textit{area of half sphere}} \, \frac{d\phi}{dr}$$

Under steady state, Q is uniform over r

$$\phi = \int_{r_a}^{\infty} \frac{Q}{2\pi k r^2} \, dr = -\left[\frac{Q}{2\pi k r}\right]_{r_a}^{\infty} = \frac{Q}{2\pi k r_a}$$

Head loss to hole: $\Delta\phi = \frac{Q}{\pi k D_H}$ (noting $2r_H = D_H$)



$$\phi_2 - \phi_1 = \frac{Q}{\pi D_H k_2} + \frac{Q}{\pi D_H k_1} = \frac{Q}{\pi D_H}\left(\frac{1}{k_2} + \frac{1}{k_1}\right)$$

$$Q = \frac{\pi D_H(\phi_2 - \phi_1)}{\left(\frac{1}{k_2} + \frac{1}{k_1}\right)}$$

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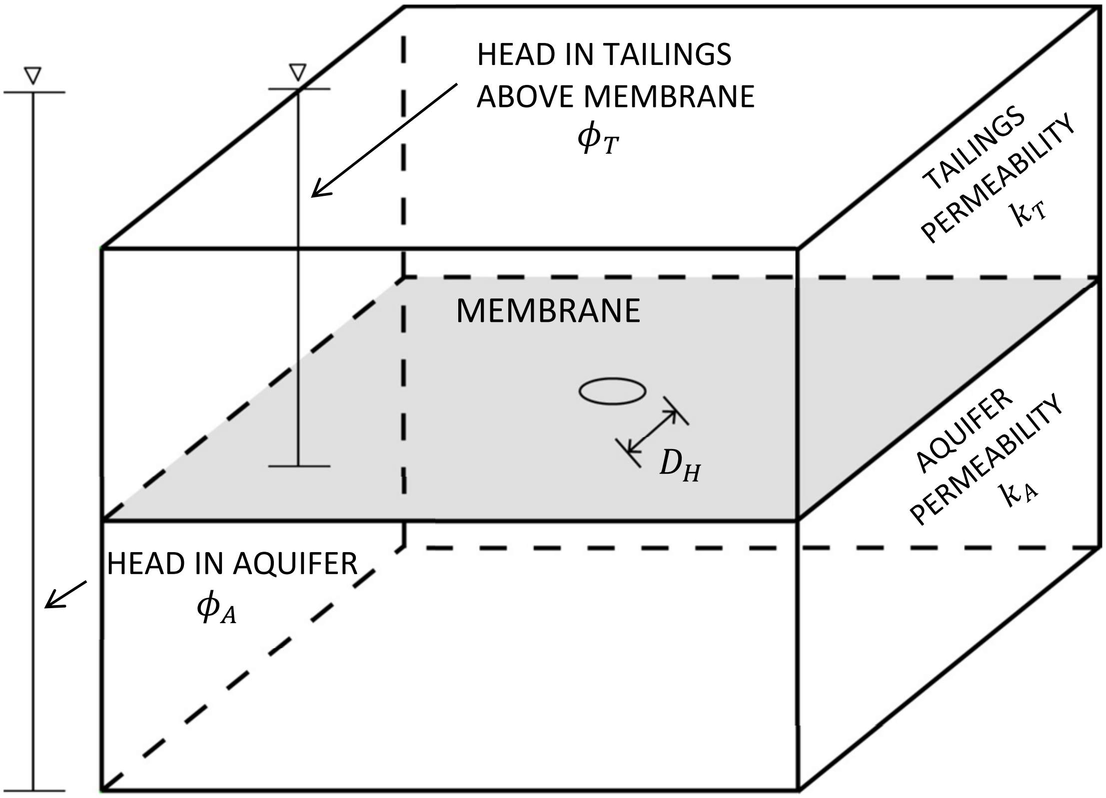

LEAKAGE THROUGH HOLE OF DIAMETER D_H:

$$\boxed{Q = \frac{\pi D_H(\phi_T - \phi_A)}{\left(\frac{1}{k_A} + \frac{1}{k_T}\right)}}$$

$Q = \pi \phi_T k_T D_H$ for fully drained layer below

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18382 **Exhibit 21**