FREEPORT-McMoRAN
COPPER & GOLD

Chino Mines Company
Box 10
Bayard, NM 88023

February 29, 2012

**Certified Mail #70101670000114199184**
**Return Receipt Requested**

Mr Kurt Vollbrecht
Mining Environmental Compliance Section
Ground Water Quality Bureau
New Mexico Environment Department
P O Box 5469
Santa Fe, New Mexico 87502

Dear Mr Vollbrecht.

**Re: Submittal of Tyrone Site Wide Stage 2 Abatement Plan Proposal, DP-1341,Condition 34 and Settlement Agreement and Stipulated Final Order**

Under Condition 34 of Discharge Permit 1341 and the Settlement Agreement and Stipulated Final Order (Settlement Agreement) signed in December 2010, Freeport-McMoRan Tyrone Inc. (Tyrone) is required to submit an abatement plan in accordance with 20.6.2.4101 to 4115 of the New Mexico Administrative Code (NMAC) This Stage 2 abatement plan proposal (APP) was completed in accordance with the terms of DP-1341, the Settlement Agreement and the regulatory requirements in Section 20.6.2.4106.E NMAC NMED previously approved a stage 1 abatement plan report that evaluates the nature and extent of groundwater impacts in the vicinity of the Tyrone Mine. This APP describes Tyrone's evaluation of abatement options and Tyrones' proposed abatement activities to attain the abatement standards and requirements set forth in 20 6.2.4103 NMAC at the Tyrone Mine. The APP assessed three study areas. the Mangas Valley APP, the Mine/Stockpile Unit APP, and the Brick Kiln Gulch/Oak Grove Wash. Also included in this Stage 2 APP is an analysis of background concentrations for selected constituents of interest at Tyrone.

As specified in the Settlement Agreement, Tyrone consulted with New Mexico Environmental Department over the course of model and APP development to facilitate its approval. As specified in the Settlement Agreement, Tyrone also plans to submit a petition for alternative abatement standards under 20.6.2.4103.F NMAC based on the results of groundwater modeling presented herein, empirical data, and other information relevant to the Tyrone Mine presented in this and other abatement plan documents.

In accordance with NMAC 20.6.2.4108 B and C, Tyrone will provide the NMED Secretary proof *of public notice within 30 days of filing this Stage 2 APP The public will be notified through* publication of a notice in newspapers of general circulation in New Mexico and in Grant County Additionally, if NMED requires, the notice will be provided in both English and Spanish and will be provided to a bilingual radio station serving the area. The notice will also be provided by certified mail to the following:

- Any persons who have specifically requested notification from the NMED Secretary
- The New Mexico Trustee for Natural Resources and other local, state and federal governmental agency affected by this plan
- Owners and residents of surface property located inside and within 1 mile from the perimeter of the geographic area where the standards are exceeded at the site
- The Governor or President of each Indian tribe, Pueblo, or Nation within the state of New Mexico

An example of the general form of the notice is provided with this transmittal letter

Three hard copies and one electric copy are enclosed. If you have any questions or require additional information regarding this report, please contact Lynn Lande at 575-912-5235

Sincerely,

Thomas J. Shelley

Thomas L Shelley, Manager
Reclamation

TLS ll
Attachment
20120229-001

c Mary Ann Menetrey
Joe Marcoline
Holland Shepherd

# NOTICE OF SUBMITTAL OF
# STAGE 2 ABATEMENT PLAN PROPOSAL
## Date of Notice: To Be Determined, 2012

Notice is hereby given by Freeport-McMoRan Tyrone, Inc. (Tyrone) of the submittal to the New Mexico Environment Department (NMED) of a Stage 2 Abatement Plan Proposal for the Tyrone Mine site near Silver City, New Mexico, as follows:

1. The responsible party is:

    Freeport-McMoRan Tyrone, Inc.
    P.O. Box 571
    Tyrone, NM  88065

2. The site is located approximately 10 miles south of Silver City, New Mexico.

3. Tyrone holds multiple ground water discharge permits for Tyrone, including Closure Permit DP-1341, which requires Tyrone to implement specified closure actions following the conclusion of mining operations and requires abatement of ground water contamination related to discharges from mining operations in accordance with the regulations adopted by the Water Quality Control Commission. NMED has approved Tyrone's Stage 1 Final Site Investigation Report for investigation of the impacted groundwater, and has authorized Tyrone to develop a Stage 2 Abatement Plan Proposal. The Stage 2 Abatement Plan Proposal provides an overview of current site conditions and proposes abatement measures for different areas with impacted groundwater at the site to be implemented in addition to the closure activities required by DP-1341. The closure activities already specified under DP-1341, and not changed by the Stage 2 Abatement Plan Proposal, include regrading and installation of covers on mine stockpiles and tailing piles. These closure measures already have been implemented on all tailing impoundments at the Tyrone Mine and some stockpile areas. The additional proposed abatement activities include installation of new structures to control water contaminants in some areas, enhanced pumping of impacted groundwater in some areas, and groundwater monitoring to assess the results.

4. The Secretary of the NMED will review the Stage 2 Abatement Plan Proposal following an opportunity for public comment, including a possible public meeting or a hearing as described below, and will either approve the proposal or notify the responsible person of any deficiencies. If no public meeting or hearing is held, the Secretary shall notify the responsible person of approval or any deficiency within ninety (90) days of receiving the proposal. If a public meeting or hearing is held, then the Secretary shall notify the responsible person of approval of the proposal or of any deficiencies, based on the information contained in the proposal and information submitted at the meeting or hearing, within sixty (60) days of receiving all required information. If the Secretary notifies the responsible person of deficiencies in the proposal, the responsible person is required to modify the proposal to cure the specified deficiencies within thirty (30) days of receipt of notice of the deficiency. If the requirements of the abatement regulations are met, the Stage 2 Abatement Plan Proposal will result in the standards and requirements of section 20.6.2.4103 NMAC being met within a schedule that is reasonable, given the particular circumstances of the site, and the Secretary shall approve the Stage 2 Abatement Plan Proposal.

5. This notice is intended to notify the public that the Stage 2 Abatement Plan Proposal is being made available for public comments and requests for a public meeting or hearing. Written comments or requests for a public meeting or hearing will be accepted and considered if provided by the deadline set forth below.

6. A copy of the Stage 2 Abatement Plan Proposal can be viewed by interested parties at the following NMED offices:

   NMED Ground Water Quality Bureau
   3082 E. 32nd Street Bypass, Suite D
   Silver City, NM 88061

   NMED Ground Water Quality Bureau
   Harold Runnels Building Room N2250
   1190 Saint Francis Drive
   Santa Fe, NM 87502

7. Written comments on the Stage 2 Abatement Plan Proposal and requests for a public meeting or hearing that include a statement of the reasons why a public meeting or hearing should be held, will be accepted for consideration if sent to the Secretary, at the address below, within sixty (60) days after the Secretary determines that the Stage 2 Abatement Plan Proposal is administratively complete.

8. Interested persons may obtain further information by contacting:

   Mr. Kurt Vollbrecht
   Mining Environmental Compliance Section
   Ground Water Quality Bureau
   New Mexico Environmental Department
   P.O. Box 5469
   Santa Fe, New Mexico 87502
   505-827-0195

# Tyrone Mine Facility
# Stage 2 Abatement Plan Proposal

**Prepared for** **Freeport McMoRan Tyrone, Inc.**
**Tyrone, New Mexico**

**February 29, 2012**

*Daniel B. Stephens & Associates, Inc.*
6020 Academy NE, Suite 100 • Albuquerque, New Mexico 87109

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# Executive Summary

Freeport-McMoRan Tyrone Inc. (Tyrone) submits this Stage 2 abatement plan proposal under the terms of Condition 34 of Supplemental Discharge Permit for Closure DP-1341 (DP-1341), a Settlement Agreement and Stipulated Final Order, and the Abatement Plan Rules, 20.6.2.4101 to 4115. Tyrone and the New Mexico Environment Department (NMED) entered into the Settlement Agreement and Stipulated Final Order (Settlement Agreement) in December 2010. The Settlement Agreement was entered into in response to the Decision and Order on Remand issued by the New Mexico Water Quality Control Commission (NMWQCC) on February 4, 2009 and Tyrone's appeal thereof. The Settlement Agreement addresses a number of issues regarding site-specific closure requirements, applicable groundwater standards, Stage 1 and Stage 2 abatement plans and alternative abatement standard development, and guidelines for variances and permitting of new and existing facilities at the Tyrone Mine, located about 10 miles southwest of Silver City, New Mexico.

Under the Settlement Agreement, Tyrone is required to submit an abatement plan in accordance with 20.6.2.4101 to 4115 of the New Mexico Administrative Code (NMAC). The Stage 1 Abatement Plan Final Site investigation Report (FSIR) was submitted as required by Condition 34 of DP-1341 and the Settlement Agreement, and approval of the FSIR was granted in a letter from NMED dated January 20, 2012. The FSIR provided a review of the previous Stage 1 abatement plan submittals, the results of additional field investigations not previously documented, and updated water quality figures and maps of the extent of groundwater impacts based on 2010 monitoring data.

This Stage 2 abatement plan proposal (APP) was completed in accordance with the terms of DP-1341, the Settlement Agreement, and the regulatory requirements in Section 20.6.2.4106.E NMAC. This APP discusses groundwater impacts and abatement of groundwater pollution at the Tyrone Mine relative to three APP study areas: the Mangas Valley APP, the Mine/Stockpile Unit APP, and the Brick Kiln Gulch/Oak Grove Wash APP study areas.

Also included in this Stage 2 APP is an analysis of background concentrations for selected constituents of interest at Tyrone. The Stage 1 abatement plan specified that a background study would be undertaken, and the potential for elevated background concentrations is recognized in the Settlement Agreement. The background study proposes elevated background standards for manganese and fluoride, two constituents that are ubiquitous in the Tyrone area and are naturally elevated above the numerical groundwater quality standards of 20.6.2.3103 NMAC (Section 3103 standards) at some Tyrone monitor wells. Whereas the Section 3103 standards for fluoride and manganese are 1.6 and 0.2 milligrams per liter (mg/L), respectively, the proposed background standard for fluoride and manganese, based on naturally elevated concentrations observed in groundwater at Tyrone, are 2.9 and 3.1 mg/L, respectively.

Tyrone plans to submit a petition for alternative abatement standards that meets the criteria of 20.6.2.4103.F NMAC based on the results of groundwater modeling presented herein, empirical data, and other information relevant to the Tyrone Mine presented in this and other abatement plan documents. This action is also required as part of the Settlement Agreement.

### *Source Controls*

The most significant components of abating groundwater contamination at Tyrone are the source control measures that will be applied. At Tyrone, source control will be achieved primarily through regrading leach and waste rock stockpiles and tailing impoundments and constructing a vegetated store and release cover over the stockpile and tailing material designed to minimize the infiltration of precipitation through the cover to the extent practicable. Other important components of source control include management of stormwater runoff and seep collection at stockpile toes.

Significant source controls have already been instituted at Tyrone. All six tailing impoundments in the Mangas Valley APP study area have been reclaimed as of 2009. In addition, the tailing repositories from a 1980 release from the No. 3 tailing impoundment have been reconsolidated and reclaimed. In the Mine/Stockpile Unit APP study area, portions of the 1C and 7A waste rock piles have been reclaimed, as has the former concentrator area. In the Brick Kiln Gulch/Oak Grove Wash APP study area, the No. 1 leach stockpile and the historical Burro Mountain tailing impoundment have been reclaimed. All of these actions have been conducted in accordance with requirements detailed in DP-1341. Test plots on reclaimed tailing and stockpile material are in place to monitor field-scale cover performance.

The additional source control measures that will be required at Tyrone are stipulated in the Settlement Agreement, and therefore alternatives for stockpile and tailing source controls are not considered in this Stage 2 APP. The stipulated conditions are the result of more than 15 years of technical studies and associated dialogue and negotiation with the NMED and Mining and Minerals Division (MMD). The NMED and MMD technical staff are very familiar with this body of existing work, as are Tyrone technical staff.

### *Mangas Valley APP Study Area*

Source controls have already been implemented throughout the Mangas Valley APP study area. Groundwater in this area occurs in Gila Conglomerate or in alluvium that is contiguous with groundwater in the underlying Gila Conglomerate. Most monitor wells in this study area meet all Section 3103 standards. Groundwater standards for sulfate and total dissolved solids (TDS) are exceeded within limited areas at or immediately adjacent to the toe of several reclaimed tailing impoundments.

One existing groundwater capture system is present within this APP study area, at the toe of the No. 1X tailing impoundment. Source controls implemented to abate impacts to groundwater at the No. 1 tailing complex include (1) reclamation of the Nos. 1X, 1, and 1A tailing impoundments, completed in 2009, and (2) elimination of discharge of water to the No. 1X tailing impoundment from mine dewatering, capture system discharge, and Little Rock Mine discharge, completed as of 2004. Existing monitoring data indicate that constituent concentrations are generally stable or declining in the vicinity of the No. 1X capture system. The proposed abatement action for the No. 1X capture system, therefore, is to continue the extraction of impacted groundwater as long as Section 3103 standards are exceeded. The extracted water will be added to the mine operational circuit during active mining operations. Following closure, if operation of the system is still required based on observed water quality, the extracted water will be treated at the water treatment plant to meet Section 3103 standards prior to discharge.

Four wells (27-2005-06, 27-2010-02, MVR-1, and 46) located at or very near the toes of existing tailing impoundments exceed Section 3103 standards for sulfate and TDS. These wells are believed to have been impacted by seepage of stormwater that collected in drainages or ponds constructed at the toe of the tailing impoundments to manage runoff from the tailing. These collection ponds were reclaimed concurrent with the tailing and eliminated as potential sources of impacts to groundwater. The proposed abatement approach for impacted water at and in the vicinity of these wells is monitored natural attenuation. With the source controls recently completed adjacent to these wells, the observed TDS and sulfate concentrations should decrease through time, although the decline may not be immediate and the time frame required to reach Section 3103 standards is unknown. Nevertheless, this approach is appropriate because the impacts are of limited extent and magnitude, source controls have been implemented, elevated concentrations appear to be leveling out, and there are multiple observation wells that meet Section 3103 standards downgradient of the wells that exceed standards.

### *Mine/Stockpile Unit APP Study Area*

The Mine/Stockpile APP study area is conceptually divided into two regions denoted as interior and peripheral. The interior region consists of the majority of the Mine/Stockpile APP study area, including numerous mine facilities such as leach stockpiles, waste rock piles, and open pits. Within this region, all groundwater will eventually flow to one of the open pits. The peripheral portions of the Mine/Stockpile APP study area are considered separately because either perched groundwater, regional groundwater, or both have the potential to move away from the Mine/Stockpile area and not be captured at one of the mine pits.

Groundwater in this study area occurs primarily in fractured igneous rock (either quartz monzonite or granite). In some limited areas, such as the northern portion of the No. 3 leach stockpile, the former concentrator area, and the No. 5A waste stockpile, groundwater occurs in Gila Conglomerate that overlies igneous rock. Throughout most of the Mine/Stockpile APP study area, regional groundwater flows to one of the open pits (Main, Gettysburg, or Copper Mountain). Observation wells in this study area often exceed Section 3103 standards for sulfate and TDS, and wells near leach stockpiles often exceed Section 3103 standards for multiple other constituents such as aluminum, cadmium, cobalt, copper, fluoride, iron, manganese, pH, and zinc.

*Groundwater Modeling for Alternative Abatement Standards*

Groundwater flow and geochemical transport modeling was conducted for the Mine/Stockpile APP study area to predict future constituent concentrations in regional groundwater beneath the leach and waste rock piles under closure conditions. The simulation results will be used to assist with a petition for alternative abatement standards that will be provided as a separate document. The modeling was conducted following an overall approach agreed to with the NMED, and Tyrone met with NMED staff on several occasions during model development to discuss the simulation approach and results.

The Tyrone groundwater flow model developed under Condition 83 of DP-1341 was used as the basis of the alternative abatement standard modeling with appropriate updates to account for new site-specific information and modeling objectives. The model was used to predict water levels at Tyrone 50 years in the future, which were then used as the basis for developing cross section (vertical slice) models coincident with groundwater flow paths.

Combined solute transport and geochemical modeling was used to simulate future constituent concentrations along seven defined groundwater flow paths, subject to the predicted groundwater flow field, the mineralogy present within the aquifer, and the chemical quality of recharge water from upgradient groundwater inflow and from stockpiles. The groundwater flow and solute transport portions of the model simulated the direction and magnitude of groundwater fluxes within the flow path and the effects of hydrodynamic dispersion on solute concentrations. The geochemical portion of the model predicted the effects of mineralogical composition of the aquifer on constituent concentrations in groundwater, mineral saturation status, and geochemical reactions that may occur through the mixing of different source waters.

Simulated future constituent concentrations vary widely across the Mine/Stockpile Unit APP study area. For example, maximum simulated sulfate concentrations in the upper 400 feet of aquifer range from 926 mg/L to 48,819 mg/L while minimum sulfate concentrations range from 70 to 975 mg/L, and maximum simulated copper concentrations range from 19 mg/L to 621 mg/L while minimum copper concentrations range from 0 to 2.79 mg/L. (The Section 3103 standards for sulfate and copper are 600 and 1.0 mg/L, respectively.) Maximum simulated concentrations are dependent primarily on (1) the length of leach or waste rock stockpile that overlies the simulated cross section and (2) aquifer hydraulic properties. As would be expected, the highest simulated concentrations occur in the shallowest portions of the aquifer immediately below leach stockpiles.

Consistent with the terms of the Settlement Agreement, Tyrone intends to petition the NMWQCC for alternative abatement standards for groundwater at Tyrone in certain areas beneath the mine. The specific petition will be developed in consultation with the NMED. Requested alternative standards are expected to be the highest simulated values of each constituent for the Mine/Stockpile area, since monitor wells that will be used to determine compliance with standards are screened across the water table or the first water-producing zone encountered in the fractured rock.

*Proposed Abatement Approaches for Mine/Stockpile APP Study Area Peripheral Regions*

Specific Stage 2 abatement measures are proposed in four areas along the periphery of the Mine/Stockpile APP study area: Deadman Canyon, the No. 3A leach stockpile, the former concentrator area, and the area bordering the south and east sides of the mine. These areas are considered individually because either perched and/or regional groundwater that exceeds Section 3103 standards for one or more constituents has the potential to move away from the Mine/Stockpile area and not be captured at one of the mine pits.

*Deadman Canyon.* Deadman Canyon perched groundwater refers to shallow water in the alluvium (about 10 feet deep or less) of Deadman Canyon, which borders the western side of the Mine/Stockpile APP study area. The alluvium overlies quartz monzonite.

Additional source controls that will be implemented at the outset of closure under DP-1341 consist of regrading and covering the stockpiles in the Deadman Canyon area as described in the Settlement Agreement. In addition, existing seep collection and groundwater extraction from the collector trench in the Seep 5E tributary drainage will continue as long as water that exceeds Section 3103 standards collects there. The reduced infiltration through the stockpiles adjacent to Deadman Canyon is expected to substantially reduce or eliminate the seepage that drains to the current seepage collection points.

In addition to these measures, the construction and operation of one to three additional collection trenches is proposed. A northern Deadman Canyon collection trench is proposed for the north portion of Deadman Canyon at the entrance to the narrows near Seep 5. The purpose of this collection trench is to capture impacted perched water that reaches the northern extent of the alluvium. Collection of perched groundwater at this location would serve to contain impacted water at a natural collection point, where the alluvium is constricted both vertically and laterally and the water is forced to the surface. All impacted shallow groundwater in Deadman Canyon not captured at other seepage collection trenches can be captured at this location.

Two additional seepage collection trenches may be constructed based on the results of future monitoring data. One collection trench will be considered immediately downgradient of the DC2-1 lined collection impoundment in what is referred to as the DC2-1 tributary canyon, and a second collection trench is proposed for the Seep 3 tributary. All of these measures would be in addition to existing abatement activities, which include six active seep collection systems and an interceptor/barrier trench in the Seep 5E tributary canyon.

*No. 3A Leach Stockpile.* Perched and regional groundwater in the No.3A leach stockpile area, north of the Main Pit, has been impacted by seepage of pregnant leach solution (PLS). In this area, Quaternary alluvium has filled drainage channels eroded into the Gila Conglomerate. The channels are referred to as “canyons” at the No. 3A leach stockpile because the stockpile was built on top of the pre-existing drainage pattern and the canyons (drainages) are the mechanism used to channel and collect PLS at the base of the stockpile. Perched fluids exist in the alluvium; most of these fluids appear to be PLS, although there is some limited mixing with meteoric water that may infiltrate into the channels. Regional groundwater occurs about 100 to 200 feet below the base of the alluvial channels in Gila Conglomerate.

The proposed abatement approach for perched fluid in the No. 3A leach stockpile area is to continue operating the existing interceptor/barrier trenches during operations and closure. The existing seepage collection facilities have been effective in capturing perched seepage and limiting the downgradient extent of perched fluids. When the No. 3A leach stockpile is reclaimed, push-down of the stockpile to the north and west for regrading will bury some of the existing capture systems. The buried trenches will be plumbed so that seepage can be collected and routed by gravity flow to the edge of the reclaimed stockpile. In addition, a number of new shallow toe seepage collection facilities and four new seepage collection and cutoff trenches will be constructed. The new seepage collection and cutoff trenches will be constructed across the full extent and depth of the alluvial channels so that perched seepage exceeding Section 3103 standards that reaches these locations will be collected and sent to the water treatment plant.

Regional groundwater in the No. 3A leach stockpile area occurs in Gila Conglomerate except on the far eastern and southern sides of the stockpile, where it occurs in granite. Regional water beneath and adjacent to the No. 3A leach stockpile has been impacted by downward seepage of PLS either from the base of the stockpile or from the base of alluvial channels where seepage is collected.

The proposed abatement approach for regional groundwater at the No. 3A leach stockpile area is continued operation of the existing groundwater extraction systems as needed. This approach is appropriate because (1) the existing systems have effectively contained and diminished groundwater impacts adjacent to the stockpile, (2) source controls will be implemented as required by the Settlement Agreement and DP-1341, and (3) multiple monitor wells exist downgradient of the zone of impacted water adjacent to the No. 3A leach stockpile. Sampling of these wells will continue to allow Tyrone to confirm the effectiveness of the abatement measures.

*Former Concentrator Area.* Soil and groundwater contamination by diesel fuel was discovered in the former concentrator area and adjacent to the Tyrone power plant in 1997. The source of the diesel contamination was determined to be leaks from an underground pipeline that runs from a storage tank on the eastern side of Mangas Wash to the pump house near the power plant. Diesel fuel released at the leaking pipeline migrated through the Mangas Wash alluvium, impacting soil and perched groundwater approximately 30 to 50 feet below the surface. Regional groundwater in Gila Conglomerate was also impacted by downward migration of diesel fuel along the annulus of two regional monitor wells that did not have annular seals. Both of these wells were drilled out in 1998 and recompleted with proper seals.

Tyrone proposes that monitored natural attenuation and plume-front containment be conducted for impacted groundwater in the former concentrator area. Monitored natural attenuation for the impacted groundwater is an appropriate abatement approach because the downgradient extent of diesel-impacted perched groundwater is contained by the Canyon 4/Mangas Wash interceptor/barrier trench, and impacted regional groundwater will ultimately be captured at the Main Pit. Furthermore, diesel contamination will degrade naturally over long time periods (e.g., decades).

*South Side and Upper East Side Areas.* Perched groundwater exists in the shallow alluvium of Upper Oak Grove Wash and some if its tributaries in the South Side area due to infiltration of precipitation and runoff and, at some locations, seepage from waste rock stockpiles along the south side of the mine. The alluvium is about 30 to 40 feet deep and overlies quartz monzonite or granite. Where perched groundwater occurs on the south side of the mine adjacent to stockpiles, it generally exceeds Section 3103 standards for one or more constituents. Perched fluid (predominantly PLS) also occurs in alluvium at the toes of the Nos. 1A and 1B leach stockpiles in the Upper East Side area, where it is collected at interceptor/barrier trenches. The alluvium in these areas occurs in drainages that are tributary to either Upper Oak Grove Wash or Brick Kiln Gulch.

Regional groundwater in the same area exists in quartz monzonite and granite. In the far southwest corner of the mine, regional water quality generally meets all Section 3103 standards or exceeds only a single standard, such as that for fluoride or manganese, due to natural background conditions. Immediately south of the mine, several wells adjacent to waste rock stockpiles exceed standards for TDS and sulfate, and farther to the east, in a limited area near the former corner of the No. 1C waste stockpile, regional groundwater exceeds Section 3103 standards for TDS, sulfate, aluminum, cadmium, cobalt, copper, fluoride, manganese, pH, and zinc. A former well near the toe of the 1B leach stockpile exceeded Section 3103 standards for TDS and sulfate before it was plugged and abandoned due to reclamation activities in 2006.

A significant amount of reclamation activity has been ongoing in the South Side area and a portion of the Upper East Side area over the past several years. The Nos. 1C and 7A waste rock piles are partially reclaimed and expected to be completely reclaimed in 2012. A portion of the No. 1C waste rock pile formerly covered Oak Grove Wash, but the pile was pulled back and the original course of Upper Oak Grove Wash is being restored. As part of these reclamation activities, new toe drains and seepage collection trenches have been installed to collect impacted water before it reaches the perched groundwater zone beneath Upper Oak Grove Wash.

The proposed abatement approach for perched groundwater in the South Side area is monitored natural attenuation. This approach is proposed because source controls are partially in place and will be fully in place by 2012, and implementation of these controls should lead to improvement of water quality through time. In addition, impacted water will eventually flow down the Upper Oak Grove Wash perched zone and be extracted at the Upper Oak Grove interceptor/barrier trench; therefore, the downgradient extent of impacted perched water is contained, and the effectiveness of the containment is monitored. In the Upper East Side area, operation of existing interceptor/barrier trenches will be continued. The effectiveness of these capture systems is monitored.

The proposed abatement approach for regional groundwater in the South and Upper East Side areas is monitored natural attenuation, supplemented by regional groundwater extraction. Continued monitoring is appropriate because significant reclamation and other source control measures have recently been implemented and will be completed in 2012. In addition, multiple monitor wells that meet Section 3103 standards are downgradient of the wells that exceed Section 3103 standards.

In addition to monitored natural attenuation, a regional groundwater extraction system is proposed for the general vicinity of the former 1C waste stockpile toe, where groundwater exceeds Section 3103 standards for multiple constituents. This area has been characterized by significant historical groundwater impacts, and there may be some seepage of regional groundwater across the Sprouse-Copeland Fault into the Brick Kiln Gulch/Oak Grove Wash APP study area at this location. Preliminary simulations conducted using the Tyrone groundwater flow model indicated that three extraction wells with a combined total extraction rate of about 50 to 60 gpm would create a zone of capture large enough to capture the potential region of impacted water. Tyrone proposes to operate the extraction system so long as the extracted groundwater exceeds Section 3103 standards.

A second regional groundwater extraction system will be implemented in the Upper East Side area if conditions warrant. The need for the second extraction system will be based on observed constituent concentrations at wells MB-12 and MB-35 and the MB-36 replacement well. If monitoring data from these wells, or potentially other monitor wells constructed in the future, indicate that a plume of regional groundwater exceeding Section 3103 standards is migrating unabated to the east-southeast beneath Brick Kiln Gulch/Oak Grove Wash, then the second regional groundwater extraction system will be considered. This second system could be operated in conjunction with, or in lieu of, the first system, depending on the results of future groundwater monitoring. If a second regional groundwater extraction system is implemented, it would likely be placed on the west (upgradient) side of the Sprouse-Copeland Fault due east of the No. 1B leach stockpile. Preliminary simulations conducted using the Tyrone groundwater flow model indicated that three to four pumping wells with a combined total extraction rate of about 30 to 50 gpm would create a zone of capture large enough to capture the potential region of impacted water.

### *Oak Grove Wash/Brick Kiln Gulch APP Study Area*

The Oak Grove Wash/Brick Kiln Gulch APP study area is separated from the adjacent Mine/Stockpile APP study area by the Sprouse-Copeland Fault, which is approximately coincident with Highway 90 as it runs north-south past the mine. This APP study area consists of what is referred to as the East Side of the Tyrone Mine. Perched water occurs in this area in the wash alluvium within about 30 to 90 feet of land surface; the alluvium gets thicker moving downstream. Regional groundwater occurs in Gila Conglomerate, and the regional aquifer water table is about 400 to more than 500 feet below the base of the perched water in the alluvium.

Known or potential sources of groundwater impacts in this area include the No. 1 leach stockpile (reclaimed in 2009), the Burro Mountain tailing impoundment (reclaimed in 2004), and seepage from the Nos. 1A and 1B leach stockpiles and the No. 1C waste rock pile (partially reclaimed during 2011). In addition, studies carried out under the Stage 1 APP indicated that impacted water migrates through alluvium within the washes subsequent to recharge events. The source of the impacted water is runoff that infiltrates into the alluvium; at some locations the impacted recharge water likely comingles with residual seepage within the alluvium from previous recharge events or residual seepage from adjacent mine facilities. It appears that a significant source of impacts to the perched water is remobilization of residual salts and metals within the alluvium from former PLS seepage.

The proposed abatement approach for the East Side perched groundwater is to construct a low-permeability barrier (commonly called a slurry wall) within the alluvium below the confluence of Upper Oak Grove Wash and Brick Kiln Gulch. Impacted water that collects behind (upgradient of) the barrier would be extracted using a dedicated pumping well and added to the mine operational circuit or (at closure) sent to the water treatment plant. Downstream of the proposed barrier, existing abatement pumping at two well transects will be continued, while pumping at two well transects upstream of the barrier will be discontinued.

This proposed approach was selected because:

- The low-permeability barrier below the confluence of the washes will capture storm surges of perched water from Upper Oak Grove Wash and residual seepage and/or storm surges from Brick Kiln Gulch. In addition, the proposed location is downgradient of the reclaimed No. 1 leach stockpile and the majority of the reclaimed Burro Mountain tailing impoundment and is therefore positioned to capture potential subsurface seepage from either of these facilities.

- The low-permeability barrier will pond water behind it in the subsurface, thereby creating storage capacity. Surges in perched water can thus be stored and extracted over a period of time, which is a more tractable and efficient approach than trying to extract surges of perched water as they occur during or shortly after precipitation events.

- The selected location for the low-permeability barrier is upgradient of the location where the Mangas Fault crosses Oak Grove Wash, and therefore impacted water will not be ponded at the fault location. Ponding water on top of the fault is not desirable because the downward seepage of impacted water could be enhanced if in fact the fault is a pathway for vertical seepage.

Implementation of the low-permeability barrier will effectively capture perched zone flows, and the resulting effects on perched zone water levels downstream in Oak Grove Wash will be readily apparent. Continued monitoring will provide the basis to make informed decisions concerning any additional abatement measures required for this area in the future.

The proposed abatement approach for impacted regional water in the East Side area east of the Sprouse-Copeland Fault is monitored natural attenuation continued monitoring of all East Side wells as required by the operational DPs and DP-1341. With source controls recently completed in the area (i.e., reclamation of the No. 1 leach stockpile and the Burro Mountain tailing impoundment and partial reclamation of the No. 1C waste rock pile), abatement of impacted perched water through pumping and capture trenches, and the proposed additional perched zone abatement actions discussed above, the observed TDS and sulfate concentrations should decrease through time. This approach is appropriate because the extent of impacted water that exceeds one or more Section 3103 standards is limited, significant source controls are in place and additional source controls will be implemented as part of this Stage 2 APP, and there are multiple monitor wells that meet Section 3103 standards downgradient of all wells that exceed standards.

# 1. Introduction

Freeport-McMoRan Tyrone Inc. (Tyrone) submits this Stage 2 abatement plan proposal under the terms of Condition 34 of Supplemental Discharge Permit for Closure DP-1341 (DP-1341), a Settlement Agreement and Stipulated Final Order, and the Abatement Plan Rules, 20.6.2.4101 to 4115. Tyrone and the New Mexico Environment Department (NMED) entered into a Settlement Agreement and Stipulated Final Order (Settlement Agreement) in December 2010. The Settlement Agreement was entered into in response to the Decision and Order on Remand issued by the New Mexico Water Quality Control Commission (NMWQCC) on February 4, 2009 and Tyrone's appeal thereof. The Settlement Agreement addresses a number of issues regarding site-specific closure requirements, applicable groundwater standards, Stage 1 and Stage 2 abatement plans and alternative abatement standard development, and guidelines for variances and permitting of new and existing facilities at the Tyrone Mine, about 10 miles southwest of Silver City, New Mexico (Figure 1-1).

Under the Settlement Agreement, Tyrone is required to submit an abatement plan in accordance with 20.6.2.4101 to 4115 of the New Mexico Administrative Code (NMAC). The Stage 1 Abatement Plan Final Report (DBS&A, 2011b) was submitted by June 30, 2011 as required by the Settlement Agreement. The report provided a review of the previous Stage 1 abatement plan submittals, the results of additional field investigations not previously documented, and updated water quality figures and maps of the extent of groundwater impacts based on 2010 monitoring data. The Stage 1 Final Report was approved by the NMED in a letter dated January 20, 2012. In an earlier comment letter dated November 8, 2011, the NMED granted Tyrone permission to proceed with development of the Stage 2 abatement plan.

This report is the Stage 2 abatement plan proposal (APP), completed in accordance with the terms of the Settlement Agreement and the regulatory requirements listed in Section 20.6.2.4106.E NMAC. As with the previous Stage 1 abatement plan reports, this report is organized according to the APP study areas designated in DBS&A (2004) and illustrated on Figure 1-1. These areas serve as a basis for discussing groundwater impacts and abatement of groundwater pollution at the Tyrone Mine in an orderly fashion.

Included with this Stage 2 APP is an analysis of background concentrations for selected constituents of interest at Tyrone. The Stage 1 abatement plan (DBS&A, 2004) specified that a background study would be undertaken, and the potential for elevated background concentrations is recognized in the Settlement Agreement. The background study, provided in Appendix A, proposes elevated background standards for manganese and fluoride, two constituents that are ubiquitous in the Tyrone area and are naturally elevated above the numerical groundwater quality standards of 20.6.2.3103 NMAC (Section 3103 standards) at some Tyrone monitor wells. Whereas the Section 3103 standards for fluoride and manganese are 1.6 and 0.2 milligrams per liter (mg/L), respectively, the proposed background standard for fluoride and manganese, based on naturally elevated concentrations observed in groundwater at Tyrone, are 2.9 and 3.1 mg/L, respectively.

Tyrone plans to submit a proposal for alternative abatement standards that meets the criteria of 20.6.2.4103.F NMAC based upon the results of groundwater modeling presented herein, empirical data, and other information relevant to the Tyrone Mine. This action is also required as part of the Settlement Agreement.

# 2. Report Structure and Overview

In an effort to structure this Stage 2 APP in a manner consistent with the Stage 1 APP and the appropriate section of the regulations (20.6.2.4106E NMAC), the report is structured as described below.

First, many of the source control measures (i.e., covering and regrading of stockpiles and tailing) already implemented at Tyrone under the DP-27 Settlement Agreement (Mangas Valley tailing impoundments) and DP-1341 (No. 1 leach stockpile and portions of the Nos. 1C and 7A waste stockpiles), as well as those that will be implemented at closure in accordance with DP-1341 and the Settlement Agreement, were developed, analyzed, and considered in detail over the past 15 years. This prior body of work is not reproduced in this Stage 2 APP. However, some of the more important and recent studies, agreements, and findings that led to the source control measures called out in the Settlement Agreement are summarized in Section 3.

Sections 4 through 7 address Items 20.6.2.4106E NMAC (1) through (3) for each of the three APP study areas as delineated in the Stage 1 APP (DBS&A, 2004) and shown in Figures 2-1 and 2-2. These sections describe current water quality conditions in the applicable study area (20.6.2.4106E [1] NMAC), the development and assessment of abatement options (20.6.2.4106E [2] NMAC), and the proposed abatement option (20.6.2.4106E [3] NMAC). Perched and regional groundwater are discussed separately if there is such a distinction for the given area, as the depth and nature of the groundwater generally has a substantial influence on the existing or proposed abatement measures relative to effectiveness and technical feasibility. In many areas at Tyrone where constituent concentrations in groundwater exceed Section 3103 standards, effective abatement measures have already been instituted and the assessment of alternative abatement measures (particularly source controls) is not needed. In other areas, new or additional alternatives have been developed and considered, and the preferred alternative for implementation under the Stage 2 APP is identified.

Due to the size and importance of the Mine/Stockpile Unit APP study area, the discussion of it is divided into two sections:

- Section 5 presents the results of predictive groundwater flow and geochemical transport modeling to determine future constituent concentrations in groundwater as required by the Settlement Agreement. The modeling focuses specifically on regional groundwater below leach and waste rock stockpiles in the Mine/Stockpile APP study area.

- Section 6 presents the analysis for what are termed the “peripheral areas” of the Mine/Stockpile APP study area. These peripheral areas, illustrated in Figure 2-2, are designated as such because either perched and/or regional groundwater that currently exceeds, or is likely to exceed, Section 3103 standards will not flow to one of the mine pits. Consequently, impacted groundwater in these areas requires special consideration in terms of abatement options.

The remaining sections of the report present the proposed plan for the following items:

- Section 8: Monitoring program in accordance with 20.6.2.4106E (4) NMAC
- Section 9: Site maintenance activities to be performed after termination of abatement activities in accordance with 20.6.2.4106E (5) NMAC
- Section 10: Schedule for duration of abatement activities in accordance with 20.6.2.4106E (6) NMAC
- Section 11: Proposed public notification in accordance with 20.6.2.4106E (7) NMAC.

# 3. Overview of Previous Studies and Agreements

This section provides a brief overview of the previous studies, plans, and settlement agreements most applicable to the primary closure requirements of the cover/capping and regrading requirements for stockpiles and tailing impoundments at Tyrone. Closure requirements for the tailing impoundments (already reclaimed) were stipulated in the DP-27 Settlement Agreement (Section 3.4). Closure requirements for remaining facilities related to regrading and cover/capping requirements are stipulated in the Settlement Agreement. The stipulated conditions for the stockpile source control measures are based on substantial prior evaluation and analysis, including field scale tests and monitoring. The NMED and Mining and Minerals Division (MMD) technical staff are very familiar with this body of existing work, as are Tyrone technical staff and Tyrone's consultants. These conditions were agreed to in the Settlement Agreement based on previous studies and analyses familiar to all parties to the agreement, and therefore other alternatives for source controls for the stockpiles and tailing impoundments are not considered in this Stage 2 APP.

## 3.1 Previous Cover Studies

Cover design is an important component of the reclamation plans for the Tyrone facilities and is the primary component of long-term source control. Tyrone has conducted many cover studies, the results of which have served as the basis for key components for other closure and feasibility studies that followed.

Tyrone identified the need for cover design studies in the development of its closure/closeout plans (DBS&A, 1997b). Following discussions with the NMED and MMD during the spring of 1998, Tyrone prepared and submitted cover design work plans for regulatory review. Based upon agency comments, a revised work plan was submitted on October 23, 1998, and work was initiated on the cover design studies in early November 1998.

Implementation of the initial work plan and subsequent work led to the development of a *Cover Design Study Status Report* (CDSSR) for Tyrone (DBS&A, 1999b). The CDSSR presented the results of material characterizations, soil-water balance simulations, and technical reviews of various types of cover systems. Based on this work and subsequent interactions with the NMED and MMD, a capacitive (store and release) type cover was selected as the most appropriate for use in this region.

Tyrone submitted a work plan to address Condition 76 of DP-1341 in December 2003 (TTEMI, 2003). The original designs called for top surface and 2.5:1 and 3:1 outslope plots to be constructed with Gila Conglomerate cover materials on the south side of the No. 1 leach stockpile and for 2:1 test plots to be built on the No. 1C stockpile. Ultimately, alternative designs for reclamation of the No. 1C stockpile resulted in the abandonment of the 2:1 Gila Conglomerate test plots, and the No. 1 test plots were relocated to the west face of the stockpile. The NMED conditionally approved the Tyrone stockpile test plot work plan on February 17, 2005. The MMD officially approved the test plot work plan, including provisions associated with compliance with Condition 9.L.1 (Permit GR010RE), in February 2006.

The test plots on the No. 1 leach stockpile were constructed and seeded in the summer of 2005, and the meteorological and vadose zone monitoring instrumentation were fully installed by December 2005. Data from the test plot have been reported to the NMED and MMD on an annual basis. Final determination of cover thickness was intended to be based on the analysis of scientific studies evaluating the relative performance of the proposed and alternative covers. Although the scientific analysis is not complete, Tyrone has agreed to provide a 3-foot-thick cover on the stockpile areas as part of the Settlement Agreement.

Infiltration analysis based on data collected at the No. 1 leach stockpile test plots to date is documented by Golder Associates (2012a) (Appendix B). The infiltration rates determined based on the collected data, extrapolated to long-term conditions, were used as the infiltration rates for uncovered and covered stockpile scenarios used in the predictive modeling presented in Section 5 of this Stage 2 APP.

## 3.2 Closure Closeout Plan

The most recent Closure Closeout Plan (CCP) for the Tyrone Mine was prepared in 2007 (Golder, 2007b) and was submitted as a 5-year update to the CCP submitted in 2001 and approved by NMED in 2003. The 2007 CCP, prepared in accordance with NMED (DP-1341) and MMD (revision 01-1 to GR010RE) permit conditions, is based on the end of year 2007 mine conditions and conceptual designs.

The CCP is based on multiple previous studies completed for Tyrone. Mining activities, including mining and hauling of ore to the various active leach stockpiles and continued operation of the solution extraction/ electrowinning (SX/EW) plant, are expected to continue for many years. For purposes of the CCP, the mine area was grouped into three mining units:

- Mangas Valley Tailing Unit, regulated under the DP-27 Settlement Agreement and Stipulated Final Order (NMED, 2003). The majority of this area has been completely reclaimed.
- Mine/Stockpile Unit, regulated under eight operational discharge permits (DPs). In this area, the south perimeter stockpiles and the former mill have been reclaimed.
- East Mine Unit, regulated under DP-896. This area has been completely reclaimed.

The extensive reclamation already conducted at Tyrone (i.e., all tailing impoundments, the Tyrone mill and concentrator, and three stockpile units) has been accomplished in accordance with the permit conditions and the Settlement Agreement terms cited above.

A revised CCP that fulfills the following objectives will need to be prepared and submitted to facilitate NMED's reissuance of DP-1341 by the end of 2012:

- Incorporate closure activities documented in the Settlement Agreement.
- Include and reflect the action proposals and predictions in this Stage 2 APP.
- Take into account reclamation already accomplished at Tyrone.
- Serve as the basis for an updated reclamation cost estimate.

## 3.3 Feasibility Study

The Tyrone Feasibility Study was conducted as a requirement under Condition 89 of DP-1341 to evaluate closure alternatives for the mine for their relative performance based on the water quality regulation requirements and technical and economic criteria. The study relied heavily on a multitude of previous studies and activities conducted over the prior 10 years and integrated the results of these studies in order to complete the evaluation.

### *3.3.1 Closure Alternatives*

Eight different closure alternatives were considered in the Feasibility Study, based on consultation with NMED and MMD:

1. Minimal action
   - No stockpile regrading
   - No stockpile cover
   - Impacted water contained and treated
   - Open pits pumped to maintain groundwater capture zone

2. DP-1341 option
   - Stockpile outslopes (except inside waiver area) regraded 3:1 or 2.5:1 where constrained
   - Stockpile tops and outslopes covered with 36 inches of material and revegetated
   - Impacted water contained and treated
   - San Salvador and South Rim pits backfilled with waste rock and covered

3. DP-1341 option with thicker cover
   - Stockpile outslopes (except inside waiver area) regraded 3:1 or 2.5:1 where constrained
   - Stockpile tops and outslopes covered with 48 inches of material and revegetated
   - Impacted water contained and treated
   - San Salvador and South Rim pits backfilled with waste rock and covered

4. DP-1341 option with thinner cover
    - Stockpile outslopes (except inside waiver area) regraded 3:1 or 2.5:1 where constrained
    - Stockpile tops and outslopes covered with 24 inches of material and revegetated
    - Impacted water contained and treated
    - San Salvador and South Rim pits backfilled with waste rock and covered

5. DP-1341 option with partial pit backfill
    - Stockpile outslopes (except inside waiver area) regraded 3:1 or 2.5:1 where constrained
    - Stockpile tops and slopes covered with 36 inches of material and revegetated
    - Impacted water contained and treated
    - San Salvador, South Rim, and Savanna pits backfilled with waste rock and covered; Copper Mountain Pit partially backfilled (above water table)

6. DP-1341 option with complete backfill
    - Open pits backfilled with stockpile material
    - Remaining stockpile outslopes (except inside waiver area) regraded 3:1
    - Stockpile outslopes and backfilled pits covered with 36 inches of material and revegetated
    - Impacted water contained and treated

7. Tyrone proposed plan
    - Stockpile outslopes (except inside surface water capture zone) regraded 2.5:1; stockpile top surfaces within the surface water capture zone not regraded
    - Stockpile tops and outslopes (outside the surface water capture zone only) covered with 24 inches of material and revegetated

   - Impacted water contained and treated
   - Open pits pumped to maintain capture zone

8. Tyrone proposed plan with thicker cover
   - Stockpile outslopes (except inside surface water capture zone) regraded 2.5:1; stockpile top surfaces within the surface water capture zone not regraded
   - Stockpile tops and outslopes (outside the surface water capture zone only) covered with 36 inches of material and revegetated
   - Impacted water contained and treated
   - Open pits pumped to maintain groundwater capture zone

These closure alternatives were evaluated using a dynamic systems model to address the following items (Golder, 2007b):

- Quantity and quality of impacted water associated with mine facilities
- Changes resulting from reclamation and closure activities
- Potential effects to groundwater quality
- Time frame for mining impact and post closure remedial activities

Each of the reclamation alternatives were evaluated for 100 years following the end of mining activity. Reclamation at the tailing impoundments was in progress at the time the Feasibility Study was conducted but was not included in the study. Reclamation of the tailing impoundments has since been completed.

### *3.3.2 Reclamation Alternative Evaluation*

The systems model was developed to consider the combined effects of a range of factors (environmental, operational, and economic) for each alternative based on conceptual models of the following processes occurring at the mine site:

- Climate
  - Rainfall simulation

- Water balance
  - Impacted runoff
  - Infiltration through stockpiles
  - Groundwater flow toward open pits and interceptor wells

- Water treatment
  - Reagent consumption
  - Energy consumption
  - Sludge production

- Cost estimate
  - Water treatment
  - Stockpile reclamation (regrading, cover, etc.)

The conceptual models were developed with NMED oversight and review to best represent each of the processes.

### *3.3.3 Projected Performance*

The relative performance of each reclamation alternative was estimated based on the system model output for the following variables:

- Impacted water volume
- Sulfate mass
- Life cycle cost analysis

A sensitivity analysis was conducted to determine the effect of varying systems model input parameters on the three above performance criteria. Alternative 7 (Tyrone proposed plan) was the proposed course of action resulting from the study.

## 3.4 DP-27 Settlement Agreement

The final settlement agreement regarding closure of DP-27, referred to as the DP-27 Settlement Agreement and Stipulated Final Order of October 10, 2003 (DP-27 Settlement Agreement), was signed by Tyrone in October 2003. The agreement is between NMED and Tyrone and resolved issues regarding alleged violations of the water quality act and Section 3103 standards at the Mangas Valley tailing impoundments (NMED, 2003). DP-27 was originally issued to Tyrone on November 9, 1978 for tailing impoundment discharges in the Mangas Valley. Tailing deposition stopped in 1992, but at the time of the DP-27 Settlement Agreement, some of the tailing impoundments received authorized discharges of water from Little Rock Mine, the Tyrone Main Pit, and several other minor sources. DP-27 was not renewed in 2003, and a notice of violation was issued. Negotiations were conducted, resulting in the DP-27 Settlement Agreement. Sections 3.4.1 through 3.4.4 summarize the key components of this agreement.

### *3.4.1 Discharge Elimination Schedule*

The DP-27 Settlement Agreement required all discharges to the tailing impoundments to cease, and requested that a work plan be submitted regarding an alternative evaluation process to eliminate discharge of:

- Mine dewatering water
- No. 1X capture system water
- Little Rock Mine seepage
- Sanitary effluent
- Municipal (Town of Silver City) sewage sludge

Based on work plans and an alternatives evaluation report submitted to address these five discharges, the discharges were eliminated as of February 2004.

### *3.4.2 Tailing Impoundment Reclamation Requirements*

The tailing impoundments were required to be reclaimed within 8 years of the effective date in accordance with DP-1341 and the DP-27 Settlement Agreement. Reclamation has included the following measures:

- Regrading of tailing impoundment surfaces
- Installation of stormwater controls
- Placement of a minimum of 24 inches of non-acid-generating cover material
- Establishment of vegetation on covered surfaces

Tyrone was required to submit for NMED approval Basic Engineering Reports detailing the closure design and analysis along with a schedule for reclamation of each tailing impoundment. Once the basic reports were approved, a detailed design for each impoundment was required to be submitted. Following completion of the reclamation, a Construction Quality Assurance Report was submitted for each facility. NMED and MMD have inspected the reclaimed areas routinely.

All of the foregoing activities were conditions of the DP-27 Settlement Agreement and closure and closeout permits. These conditions have been fulfilled. Tyrone completed reclamation of the last tailing impoundment in 2009. The six primary tailing impoundments account for more than 3,200 acres of reclamation at Tyrone (including reclaimed borrow areas).

NMED and MMD have reviewed and approved the Construction Quality Assurance Reports and released a significant portion of the financial assurance for these facilities. Regular inspections (at least quarterly) are performed on the reclaimed tailing facilities, and repairs to the reclamation are performed as needed based on the results of these inspections.

Figure 3-2 provides some photographs of the No. 2 and 3X tailing impoundments taken before and after reclamation (2005 and 2009, respectively). Figure 3-3 provides an equivalent series of photographs for the Nos. 1, 1X, and 1A tailing impoundments. The regrading and covering of the tailing impoundments is clearly portrayed in the photographs, as are various stormwater controls and the establishment of vegetation on the tailing cover (Figure 3-2).

#### *3.4.3 Reclamation Evaluation*

Tyrone was required to conduct a test plot study to evaluate cover performance for the various Gila Conglomerate cover thicknesses on both the tops and side slopes of the tailing impoundments. The study is intended to evaluate the net infiltration rate through the cover, erosion potential, and vegetation establishment for four cover thicknesses (1.5, 2, 3, and 4 feet). A report that summarizes test plot performance is submitted annually to NMED and MMD.

#### *3.4.4 Water Quality Monitoring and Quarterly Progress Reports*

A summary of activities, precipitation data, and water quality at multiple monitor wells is provided quarterly to the NMED under Condition 34 of the DP-27 Settlement Agreement.

### 3.5 Tyrone Settlement Agreement

Tyrone and NMED entered into a Settlement Agreement and Stipulated Final Order (Settlement Agreement) in December 2010. The Settlement Agreement was entered into in response to the Decision and Order on Remand issued by the NMWQCC on February 4, 2009 and Tyrone’s appeal thereof and the agreement is the result of months of negotiations between Tyrone, NMED, and Gila River Information Project (GRIP) representatives. GRIP declined to be a party to the final agreement.

The Settlement Agreement addresses a number of issues regarding site-specific closure requirements, applicable groundwater standards, Stage 1 and Stage 2 abatement plans and alternative abatement standard development, and guidelines for variances and permitting of new and existing facilities. One of the most important aspects of this agreement is the approach to source controls at Tyrone; the agreement was developed based on the numerous prior studies completed for Tyrone, including the Feasibility Study summarized in Section 3.3. A summary of each of these issues as agreed to in the settlement are provided in Sections 3.5.1 through 3.5.4.

### *3.5.1 Closure Requirements and Source Control*

The slopes of leach and waste rock piles outside the open pit surface drainage area (Figure 3-1) are required to be regraded to 3:1 slopes and are allowed to be no steeper than 2.5:1 in locations where the slope would intersect a highway or surface drainage. A store and release cover is to be put in place following the regrading activities on leach and waste rock stockpiles and other required locations such as surface impoundments. The cover will consist of non-acid generating material at least 36 inches thick. Tyrone may request approval of an alternative cover design from NMED if the alternative design will provide the same or greater protection of groundwater.

Within the open pit surface drainage areas (where stormwater drains to an open pit and groundwater flow is toward the pit), the settlement agreement requires regrading of the top surfaces to between a 1 and 5 percent grade and installation of a store and release cover, but regrading of the side slopes is not be required. In addition, run-on controls must be put in place to divert stormwater from these locations. All water collected in the open pits will be pumped and treated to meet Section 3103 standards prior to discharge.

The regrading and cover requirements for reclamation at Tyrone required by the Settlement Agreement have been studied in detail in multiple efforts. The conditions stated in the Settlement Agreement are also well studied, as a number of options were considered over the past 10 years. The source controls agreed upon in the Settlement Agreement are appropriate and protective of groundwater quality.

### *3.5.2 Groundwater Standards*

The applicable groundwater standards in the Settlement Agreement are those established in Section 20.6.2.3103 NMAC, referred to in this Stage 2 APP as Section 3103 standards. Additional site-specific groundwater standards may include any background concentrations approved by NMED as well as alternative abatement standards approved by the NMWQCC for Tyrone. Appendix A of this Stage 2 APP suggests that application of local background concentrations for fluoride and manganese be used as the quality standards for these two constituents at Tyrone. Although alternative abatement standards are not proposed in this report, Tyrone intends to file a petition for alternative standards with the NMWQCC based on the information and modeling results contained in this report and the Stage 1 APP, as outlined in the Settlement Agreement.

### *3.5.3 Abatement Plan and Alternative Abatement Standards*

Tyrone is required to submit an abatement plan in accordance with NMAC 20.6.2.4101 to 4115. The Stage 1 APP final report, including additional site characterization, was due on June 30, 2011 and was submitted as required. This report provided a review of the Stage 1 APP submittals to date, the results of additional field investigations not previously documented, and updated figures showing water quality and extent of groundwater impacts based on 2010 monitoring data (DBS&A, 2011b). The NMED provided comments on the Stage 1 final report in a letter dated November 8, 2011, and granted Tyrone permission to proceed with development of this Stage 2 APP. Approval of the Stage 1 final report was granted in a letter from NMED dated January 20, 2012.

Tyrone is also required to provide a written analysis of selected abatement options and to estimate concentrations of constituents in groundwater after implementation of closure measures using a systems model or other equivalent model. A detailed summary and description of the model, input data, and assumptions was required to be submitted to NMED by June 20, 2011, which was 180 days after the effective date of the agreement. The required detailed summary was submitted to and approved by the NMED. The written analysis of selected abatement options and the results of the modeling conducted to estimate constituent concentrations in groundwater are presented in Sections 4 through 7 herein, organized by APP study area. The modeling conducted for the Stage 2 APP is based on the closure requirements as set forth in the Settlement Agreement.

Tyrone is required to submit to NMED a petition for alternative abatement standards within 120 days of approval of the Stage 2 APP. The petition will be based on the model and analysis contained in this Stage 2 APP and may include additional analysis to further support the petition. For any constituents that are estimated to exceed Section 3103 standards post-closure, Tyrone will propose alternative abatement standards based on the Stage 2 APP model and analysis or the presence of background concentrations (Appendix A). These alternative abatement standards may be modified in the future based upon the results of post-closure monitoring. The alternative abatement standard petition will be presented first to NMED for review, then to NMWQCC for consideration and action, similar to a variance petition.

### *3.5.4 Variances and Permitting for New and Existing Facilities*

For the purposes of the Settlement Agreement, a new facility is defined as a facility that was not included in a DP prior to February 4, 2009. Tyrone is required to employ “full technological controls” at these locations to ensure that groundwater is protected. An exception can be made for facilities if they are (1) located within an open pit, (2) in an area that already exceeds standards, or (3) covered by an approved variance.

Existing facilities must comply with applicable groundwater standards (Section 3.5.2) or obtain a variance for the facility during operations. The following guidelines were established for NMED approval of a variance for an existing facility:

- It is not feasible to prevent groundwater contamination above applicable groundwater standards, but groundwater standards will be met after closure.
- Source controls are planned and implemented.
- Groundwater is contained by flow toward the open pits.
- The facility footprint will not expand without prior modification of the applicable DP.

# 4. Mangas Valley APP Study Area

This section provides an overview of the current conditions and the proposed abatement approach for regional groundwater in the Mangas Valley APP study area that exceeds Section 3103 standards. Persistent, extensive zones of perched groundwater have not been identified in this APP study area, although perched water may exist from time to time, following precipitation events, in shallow alluvial channels of tributary drainages. In the central portion of the valley, groundwater in the alluvium is contiguous with groundwater in the underlying Gila Conglomerate.

## 4.1 Description of Current Water Quality Conditions

As previously documented by DBS&A (2011b), most monitor wells in the Mangas Valley meet all Section 3103 standards, and most wells that do not meet standards exceed only the standards for total dissolved solids (TDS) and sulfate (Plate 4-1). Well 27-2005-03, upgradient of the reclaimed No. 2 tailing impoundment, and well 27-2005-05, upgradient of the reclaimed No. 3 tailing impoundment, exceed only the Section 3103 standard for fluoride, by less than a factor of two. The elevated fluoride in these two wells is believed to be attributable to naturally occurring background concentrations.

Source controls have already been implemented throughout the Mangas Valley area in accordance with the DP-27 Settlement Agreement (Section 3.4 and Figures 3-2 and 3-3). The six primary tailing impoundments account for more than 3,200 acres of reclamation in the Mangas Valley (including associated reclaimed borrow areas). The Tyrone mill site and tailing repositories (from the 1980 Dam 3 tailing release) account for more than 300 acres of additional reclamation that has been completed in the Mangas Valley.

The Mangas Valley APP study area contains one groundwater extraction system: the No. 1X capture system, located at the toe of the No. 1X tailing impoundment, which was reclaimed in 2009. Plate 4-2 shows the locations of the reclaimed No. 1X tailing impoundment and capture system wells, as well as the locations of the reclaimed Nos. 1 and 1A tailing impoundments and other nearby monitor wells. The No. 1X capture system has been in operation since August

1991 to capture impacted water from the saturated alluvium of Deadman Canyon, which was covered by the No. 1X tailing impoundment. In this area, water in the alluvium is not perched, but is contiguous with regional groundwater that exists in the Gila Conglomerate adjacent to and below the alluvium (DBS&A, 2004, 2006).

Impacted water at the toe of the No. 1X tailing impoundment is believed to be attributable to a combination of possible historical sources on or near the impoundment. Similar to other tailing dams with local impacts, stormwater runoff from the 1X tailing outslope was contained in a stormwater retention pond near the toe (north perimeter) of the impoundment. Tyrone was authorized for many years to dispose of Tyrone Mine dewatering water and impacted water collected at the Little Rock Mine southwest of the No. 1X tailing impoundment. In addition, impacted water pumped at the capture system was put back on the tailing impoundment until January 2004.

Impacted water beneath the No. 1X tailing impoundment and at the No. 1X capture system could also be attributable, to a lesser degree, to impacted water in the alluvium of Deadman Canyon south of the No. 1X tailing impoundment, as evidenced by wells TWS-42 (TDS and sulfate concentrations are elevated but meet standards) and TWS-19 (in addition to TDS and sulfate levels that are similar to well TWS-42, standards for copper, iron, and manganese are exceeded). This portion of Deadman Canyon, including water quality, is described in detail in the response to comments on the Stage 1 abatement plan final report (DBS&A, 2011c).

In addition to the impacts at the No. 1X tailing impoundment, groundwater in three other local areas in the Mangas Valley exceeds TDS and sulfate standards:

- *At well 27-2005-06 near the toe of the reclaimed No. 3X tailing impoundment*. The extent of water that exceeds Section 3103 standards at this well is defined by downgradient well 47, which contains elevated TDS and sulfate concentrations but meets standards, and cross-gradient well 19, which has no apparent impacts (Figure 4-1). The observed TDS and sulfate concentrations at impacted wells 27-2005-06 and 47 appear to have leveled out and may be declining slightly.

- *At well 27-2010-02 near the toe of the reclaimed No. 2 tailing impoundment*. The extent of water that exceeds Section 3103 standards at this well is defined by downgradient well 27-2010-03, which contains elevated TDS and sulfate concentrations but meets standards, and downgradient well 27-2010-01, which also contains elevated TDS and sulfate concentrations but meets Section 3103 standards (Figure 4-2). The observed TDS and sulfate concentrations at impacted well 27-2010-03 appear to be increasing (but are still below Section 3103 standards), while the observed TDS and sulfate concentrations at well 27-2010-01, farthest from the tailing impoundment, are steady. Note that in Figure 4-2 the three replacement wells constructed in 2010 (i.e., 27-2010-01, -02, and -03) are plotted with the prior TDS record of the well that they replaced. The original wells were plugged and abandoned due to reclamation activities, and the replacement wells were constructed once reclamation was complete.

- *At wells MVR-1 and 46 near the eastern toe of the No. 1 tailing impoundment.* Well MVR-1 exceeds Section 3103 standards for TDS and sulfate, and well 46 exceeds the standard for TDS. The extent of these impacts is defined at downgradient well MVR-3, which exhibits elevated TDS and sulfate concentrations but meets Section 3103 standards (Figure 4-3). Observed TDS and sulfate concentrations at well 46 have been trending downward since about 2005. The TDS and sulfate at wells MVR-1 and MVR-3 have been trending upward since about 2001; recent sampling results indicate that concentrations may be leveling out, but there are insufficient data points to make a definitive determination at this time.

These wells are believed to be impacted by seepage of stormwater that collected in drainages (well 27-2010-02) or former stormwater collection ponds constructed at the toe of the tailing impoundments to manage runoff from the tailing (wells 27-2005-06, MVR-1, and 46). The collection ponds retained impacted runoff from the tailing impoundments, some of which likely seeped into the regional aquifer prior to reclamation of the ponds and tailing impoundments.

All four of the areas where groundwater exceeds standards for TDS and sulfate were the subject of additional investigation conducted under the Stage 1 APP documented by DBS&A (2011b). At the toe of the No. 3X tailing impoundment, perched seepage in the alluvium was not detected at two temporary borings, 27-2011-11 and 27-2011-12 (Figure 4-1). At the toe of the No. 2 tailing impoundment, perched seepage in the alluvium was not detected at temporary boring 27-2011-13 (Figure 4-2). About 600 feet downgradient of the No. 1X capture system, groundwater collected from temporary boring 27-2011-02 was found to meet all Section 3103 standards with the exception of manganese (Plate 4-2), and groundwater samples routinely collected from monitor well 27-2005-01 and recently constructed well 27-2011-15, about 2,500 and 1,750 feet upgradient of well MVR-1, respectively, meet all Section 3103 standards (Figure 4-3 and Plate 4-1).

## 4.2 Proposed Abatement Approach

The proposed abatement approach for groundwater that exceeds one or more Section 3103 standards in the Mangas Valley is provided in Sections 4.2.1 and 4.2.2. As noted in Section 4.1, source controls have already been implemented in accordance with the DP-27 Settlement Agreement, with completion of the most recent reclamation occurring in 2009. The entire footprint of the historical tailing impoundments has been reclaimed, along with the associated stormwater runoff containments that are believed to be a likely historical source of groundwater impact near these facilities. Sufficient time has not passed such that the full expected benefit of the tailing reclamation can be documented through the observation of groundwater concentrations. Some recent declines in groundwater concentrations may be attributable to the reclamation, but more observation is needed to confirm this hypothesis.

### *4.2.1 No. 1X Capture System*

Source controls implemented to abate impacts to groundwater at the No. 1 tailing complex area include reclamation of the Nos. 1X, 1, and 1A tailing impoundments, completed in 2009, and elimination of discharge of water to the No. 1X tailing impoundment from mine dewatering, capture system discharge, and Little Rock Mine discharge, completed as of 2004. Positive effects of these actions on groundwater quality may already be indicated by downward trends in TDS and sulfate concentrations in wells PZ-1 and 18, at the No. 1X capture system and in wells 45 and 27-2005-02 adjacent to the reclaimed Nos. 1X and 1 tailing impoundments (Plate 4-2). In addition, Section 3103 standards are met at monitor wells 10, 42, and 11, downgradient from the No. 1X capture system, and a groundwater sample collected during

Stage 1 APP investigation activities in March 2011 from a temporary boring completed about 600 feet downgradient of the system indicated that all Section 3103 standards were met except for manganese (DBS&A, 2011b) (Plate 4-2).

Consequently, the proposed abatement action for the No. 1X capture system and impacted water that lies beneath the tailing impoundments upgradient of the system is to continue the capture and extraction of impacted groundwater as long as Section 3103 standards for TDS and sulfate are exceeded. The extracted water will be added to the mine operational circuit during active mining operations. During closure, if operation of the system is still required based on observed water quality, the extracted water will be treated at the water treatment plant to meet Section 3103 standards prior to discharge.

#### *4.2.2 Wells 27-2005-06, 27-2010-02, MVR-1, and 46*

The proposed abatement approach for impacted water at and in the vicinity of these wells is monitored natural attenuation. With the source controls recently completed adjacent to these wells, and no additional sources identified through the Stage 1 APP field investigations, the observed TDS and sulfate concentrations should decrease through time, although the decline may not be immediate and the time frame to reach Section 3103 standards is unknown. Tyrone proposes to continue monitoring these and other wells as required by the DP-27 Settlement Agreement. This approach is appropriate because the impacts are of limited extent and magnitude, source controls have been implemented, elevated concentrations appear to be leveling out, and multiple observation wells that meet Section 3103 standards exist downgradient of the wells that exceed standards.

# 5. Mine/Stockpile APP Study Area Interior Region

This section presents the methodology followed and results obtained for groundwater flow and geochemical transport modeling within the Mine/Stockpile APP study area (Figure 2-2). The purpose of the modeling was to predict future constituent concentrations in regional groundwater beneath the leach and waste rock piles under closure conditions. The simulation results will be used to assist with a petition for alternative abatement standards that will be provided as a separate document from the Stage 2 APP.

Throughout most of the Mine/Stockpile APP study area, regional groundwater flows to one of the open pits (Main, Gettysburg, or Copper Mountain). Regions where groundwater does not flow to one of the open pits (i.e., the south side and the northern portion of the No. 3 leach stockpile) are discussed in Section 6. Observation wells in this study area generally exceed Section 3103 standards for sulfate, TDS, and multiple other constituents (Plate 5-1).

## 5.1 Tyrone Groundwater Flow Model

The Tyrone groundwater flow model was originally developed in 1999 (DBS&A, 1999a) to:

- Estimate the post-closure recovery period of water levels in the mine pits and surrounding aquifers and project the post-closure steady-state pit lake(s) surface elevation(s)

- Examine the potential for pit lake outflows

- Evaluate the potential interactions of pit lake(s) with other mine facilities, hydrologic features, and geologic structures

- Provide supporting groundwater flow information for the pit lake water quality study

The model focused primarily on the regional groundwater flow system in the Mine/Stockpile Unit, although portions of the East Mine Unit and the Mangas Valley Tailing Unit are also included within the model boundaries. The original model was based on the 1998 mine configuration and was used to simulate both current and future groundwater conditions. Predictive model simulations are documented in pit lake formation modeling report (DBS&A, 1999a), and a detailed model sensitivity analysis and verification study was also conducted (DBS&A, 2002).

The original groundwater flow model was updated as part of Condition 83 of DP-1341 (DBS&A, 2007). The purpose of the updated model was to

- Estimate the post-closure recovery period of water levels in the mine pits and surrounding aquifer, and evaluate the potential for pit lake outflows in the future

- Serve as a simulation tool to assist with the evaluation of potential closure alternatives, such as interceptor well pumping or partial backfill of certain open pits

This latest version of the Tyrone groundwater flow model was updated as part of the Stage 2 APP modeling, as detailed in Appendix C. The purpose of the model update was to (1) include some additional faults in the model that are believed to affect groundwater flow but were not included in the previous version of the model (e.g., the Townsite Fault), (2) extend the historical simulation period in the model from 2005 to 2010, and (3) develop a better representation of some other features in the Mine/Stockpile Unit, such as observed water levels on the south side of the mine.

The Tyrone groundwater flow model is a transient model that simulates water levels from 1950 through 2010 in the Tyrone Mine area; the extent of the model and the model grid is illustrated in Figure 5-1. The model consists of 4 model layers (Figure 5-2) and is therefore a fully three-dimensional model. The simulated 2010 water table from the model is presented in Figure 5-3. The Tyrone groundwater flow model was used as the basis for developing the cross-sectional models of groundwater flow and solute transport presented below. The aquifer hydraulic properties in the regional model, such as hydraulic conductivity, were used for the equivalent location in each simulation cross section. For example, the hydraulic conductivity for model layer 1 in the Tyrone groundwater flow model (Figure 5-4) would be applied to the model layers in each cross-sectional model that are of equivalent depth. The hydraulic conductivity field in the model is complex and accounts for the effects of multiple faults on groundwater flow (Appendix C).

The calibration period for the groundwater flow model is from 1950 through 2010, and the predictive period is 2011 through 2060. The 50-year predictive simulation time frame was selected because at the end of that period the simulated groundwater flow field, including the simulated groundwater discharge to the Main and Gettysburg Pits, is not changing significantly. Predictive simulations were conducted by adjusting the applied recharge in the model from current operational values to predicted future values based on the test plot studies summarized in Section 3. The simulated current recharge in the disturbed portions of the Mine/Stockpile APP study area was set to 1.81 inches per year (in/yr) in the groundwater flow model, which is the value of infiltration for uncovered stockpiles determined by Golder (2012a) (Appendix B). This magnitude of recharge is confirmed by observed water level rises at some monitor wells in the Mine/Stockpile Unit (e.g., well 2-5A), which generally indicate about 1.2 to 2 in/yr of recharge under operational conditions. For facilities that will be covered in the future, the estimated long-term recharge is 0.22 in/yr based on the cover test plot simulation results provided in Appendix B. Recharge is assumed to be the same on the tops and side slopes of uncovered and covered stockpiles.

The recharge was assumed to transition from operational to covered values over a period of 20 years. The long-term predictive recharge applied in the groundwater model is illustrated in Figure 5-5. Comparison of Figures 5-5 and 3-1 illustrate that in the Mine/Stockpile APP study area, the recharge applied in the predictive simulation is consistent with the closure measures detailed in the Settlement Agreement and summarized in Section 3.5.1.

The simulated water level at year 2060 and simulated groundwater flow to the Gettysburg and Main Pits are provided in Figures 5-6 and 5-7, respectively. Pumping of the pits is assumed to continue during closure in accordance with DP-1341. As indicated in Figure 5-7, the simulated groundwater inflows at 2060 are about 570 and 35 gallons per minute (gpm) to the Main and Gettysburg Pits, respectively. Simulated groundwater inflow to the Copper Mountain Pit averages about 70 gpm during the first decade of the predictive simulation, but declines to about 5 gpm by 2060.

### 5.1.1 Cross-Sectional Groundwater Flow Models

The cross-sectional models developed to simulate solute transport and geochemical effects are based on the Tyrone three-dimensional groundwater flow model. The cross-sectional models are two-dimensional in that they simulate groundwater flow and solute transport along a groundwater flow pathline. Therefore, water flows from one end of each section to the other end and can move up or down within the section, but groundwater cannot enter or leave the sides of the simulated section.

The cross sections were developed by conducting particle tracking in the three-dimensional model to determine a groundwater flow pathline assuming steady-state conditions. For the comparison to current conditions (Section 5.2.2), the prescribed hydraulic heads at each end of the cross section were taken from the 2010 simulation results of the groundwater flow model. For the predictive cross section simulations (Section 5.2.3), the prescribed heads for the cross section were taken from the simulated 2060 simulation results (50 years in the future).

The grid size for the cross sections is finer than that in the groundwater model to facilitate model convergence and more accurate simulation results. The model cell lengths are 100 feet and the model layer thicknesses are 25 feet. The hydraulic properties for the model cells in the cross sections were taken from the groundwater flow model. For example, the hydraulic conductivity values along the cross section for the section layers equivalent to layer 1 in the groundwater model are those illustrated in Figure 5-4. The effective porosity for the geochemical transport simulations was assumed to be equivalent to the specific yield used in the groundwater modeling, which is either 0.015 or 0.03 (Appendix C). The longitudinal and vertical dispersion coefficients were set to 100 feet and 10 feet respectively based on professional judgment and the results of the comparison to current conditions presented in Section 5.2.2.

## 5.2 Cross-Sectional Flow and Geochemical Transport Modeling

Combined solute transport and geochemical modeling was used to simulate future constituent concentrations within seven defined flow paths, subject to the defined groundwater flow field, the mineralogy present within the aquifer, and the chemical quality of recharge water from upgradient groundwater inflow and recharge from stockpiles. The groundwater flow and solute transport portions of the model simulated the direction and magnitude of groundwater fluxes within the flow path and the effects of hydrodynamic dispersion on solute concentrations. The geochemical portion of the model predicted the effects of mineralogical composition of the aquifer on constituent concentrations in groundwater, mineral saturation status, and geochemical reactions that may occur through the mixing of different source waters.

An overview of the geochemical simulation approach is provided in Section 5.2.1, and the comparison of an example set of cross-sectional solute transport and geochemical simulations to observed conditions is discussed in Section 5.2.2. The observed conditions are reflective of current and past mine operations. The results of predictive simulations for seven representative cross sections are presented in Section 5.2.3.

### *5.2.1 Overview of Geochemical Simulation Approach*

Geochemical equilibrium conditions were assumed in all transport simulations. The primary reactions simulated by the geochemical model were dominated by transport and precipitation of major and minor constituents as a function of pH. The effects of sorption (retardation) on constituent concentrations were expected to be minimal in the fractured rock aquifers and sorption was therefore not simulated in the model. Additional assumptions include:

- Standard temperature and pressure (i.e., 25 degrees Celsius [°C] and 1 bar of pressure) were used.
- Mineral assemblages present in the aquifer are homogeneous within the zone represented by each cross-sectional flow path.
- Specification of kinetic rate laws for mineral reactants was based on published studies, considering previous geochemical modeling efforts at Tyrone.

The computer code PHT3D (Prommer and Post, 2010) was used to conduct the simulations. PHT3D uses a groundwater flow field simulated by the U.S. Geological Survey (USGS) code MODFLOW-2000 (Harbaugh et al., 2000), and it simulates solute transport using the MT3D (Zheng and Wang, 1999) model. Geochemical reactions are simulated in PHT3D using the USGS code PHREEQC (Parkhurst and Appelo, 1999). Application of the PHT3D model to the simulated cross sections allowed for the simulation of advective transport, hydrodynamic dispersion, aqueous speciation, and mineral precipitation and dissolution.

As outlined in the proposed modeling approach (DBS&A, 2011a), model simulations were conducted for a selected groundwater flow path in the Mine/Stockpile Unit for which upgradient and downgradient observed water quality was available for comparison to the geochemical model simulation results. The purpose of this effort was not to conduct a detailed calibration of the geochemical model simulation results to observed data, but rather to assist with the selection of appropriate chemical reactions and other decisions that had to be made in order to conduct the post-closure geochemical modeling simulations. A cross section within the southern part of the Mine/Stockpile Unit, approximately between monitor well 2-5A (San Salvador Pit area) on the upgradient end and monitor wells 2-7 and 6-5 (west of the Savanna Pit) on the downgradient end, was selected to conduct the model comparison and adjustment based on observed conditions (Figure 5-3, Plate 5-1). The results of this effort are discussed in detail in Section 5.2.2; much of the overall approach presented in this section was determined through the model comparison exercise described therein.

The geochemical simulations included 25 constituents, 23 of which are mobile constituents and 2 of which are immobile constituents as follows:

- Mobile constituents include bicarbonate, calcium, chloride, fluoride, ferric iron, ferrous iron, potassium, magnesium, manganese, sodium, sulfate, sulfide, zinc, aluminum, cadmium, copper, lead, silica, arsenic, cobalt, chromium, nickel, and dissolved oxygen. Dissolved oxygen was modeled as a mobile phase but concentrations were kept low because the groundwater system is not expected to reach oxygen saturation in the groundwater or recharge components. Although shallow or peripheral portions of a leach stockpile may reach equilibrium with atmospheric oxygen, the leachate emanating from the bottom of the stockpile will likely have very little or no dissolved oxygen because the oxygen will have been consumed in oxidation reactions occurring in the stockpile. For the simulations, therefore, dissolved oxygen concentrations were set to zero in the recharge fluid from leach and waste rock stockpiles. For groundwater inflow or recharge of non-impacted groundwater, the dissolved oxygen concentration was set at 2 mg/L ($1.25 \times 10^{-4}$ moles per liter [mol/L]).

- The two simulated immobile constituents are pH and electron activity (pe). The pH represents the hydrogen ion concentration (acidity) of the water and is based on field measurements. The pe represents the electron activity in a solution and is a measurement of the reducing capacity of a solution. The pe corresponds to the general reduction-oxidation (redox) state of the system and is controlled by oxygen in the groundwater system as well as elements that are sensitive to redox reaction, such as iron and sulfur.

PHT3D has a low tolerance for poor charge balance in the input water quality data. The model input files, therefore, were set to link the charge balance to sulfate concentrations, which means that the prescribed constituent concentration input data were adjusted to correct the charge balance by changing the sulfate concentration. The charge balance was calculated by PHREEQC for each simulation.

The PHREEQC database, modified with additional components added from the MINTEQ.V4 database (Allison et al., 1990), was used for all model simulations. The additional MINTEQ.V4 components included the elements arsenic, chromium, cobalt and nickel. Data from the MINTEQ.V4 database were added to represent equilibrium phase and kinetic minerals.

Equilibrium phases or mineral species were included in the simulations to represent (1) mineralogical controls on water quality and (2) mineral phases within the aquifer matrix. Each simulation included 11 equilibrium phases: gypsum, fluorite, amorphous silica, gibbsite, amorphous iron oxide, potassium jarosite, alunite, pyrolusite, goethite, sphalerite, and chalcocite. Based on the results of the current period comparison simulations, initial concentrations for fluorite and chalcocite of $2.15 \times 10^{-4}$ and $1.72 \times 10^{-4}$ mol/L of rock volume, respectively, were applied in each simulated cross section. This approach assisted with obtaining a better match to observed fluorite and copper concentrations in the current period simulation.

Three of the equilibrium phases, pyrolusite, sphalerite and chalcocite, were not modeled to reach equilibrium in the simulations. These minerals are not expected to reach equilibrium or saturation in the groundwater system at the assigned pH and pe values and were therefore set to remain under-saturated by assigning a target saturation index (SI) of –0.5. This decision was based on review of geochemical pe-pH diagrams for mineral stability and expected reactions in the simulated Tyrone groundwater environment (Nordstrom and Alpers, 1999). For example, potassium jarosite has a stability field in pe-pH space with pe values greater than 10 and a pH range of 1 to 2. These conditions do not exist in the Tyrone groundwater system because the pH is generally greater than 2 and the pe is expected to be less than 10, which means it is unlikely that potassium jarosite would reach equilibrium (SI = 0) or saturation (SI > 0) under the simulated groundwater conditions.

Three surface exchangers were defined to simulate cation-exchange reactions. These reactions represent the ability of minerals in the aquifer matrix to exchange cations, such as sodium, from the mineral's surface with a different cation in solution, such as calcium. The surface-exchange cations in the model are calcium, sodium, and potassium at concentrations of $1.4 \times 10^{-4}$, $1.79 \times 10^{-6}$, and $4.68 \times 10^{-6}$ mol/L of rock volume, respectively. These concentrations were based on synthetic precipitation leachate procedure (SPLP) results for rock samples collected from Tyrone (DBS&A, 1997a). The SPLP data represent “reactive” components that are included in the model as cation-exchangers.

During the model setup, minerals were also incorporated into the model as kinetic minerals with reaction rates based on published values. Both pyrite and plagioclase were simulated as kinetic minerals. By using the rate law, these minerals tend to dissolve slowly over time, and the calculated dissolution rates are dependent on variables such as dissolved oxygen content for pyrite and pH ($H^+$ and $OH^-$ concentrations) for plagioclase. The low reaction rates defined for the kinetic minerals constrained their dissolution to very low values. Pyrite was almost non-reactive at the dissolved oxygen contents simulated in the model, even when 4.8 percent pyrite (a high value based on observed rock compositions for Tyrone) was included in the aquifer matrix. The simulated concentrations of iron and sulfate released by the kinetic pyrite reaction were quite minor compared to the PLS input concentrations, so pyrite was not simulated as a kinetic mineral in the final simulations. Plagioclase hydrolysis was also included as a kinetic reaction in several simulations, but the simulated reaction consumed hydrogen ions ($H^+$), resulting in an increase in pH within the aquifer matrix. These plagioclase reactions seemed potentially unrealistic given previous mineralization and alteration events that have altered primary mineralogy at Tyrone, as shown by petrographic evidence indicating that many of the primary feldspar grains have undergone argillic alteration, forming clay minerals such as kaolinite. Consequently, kinetic plagioclase reactions were not incorporated in the final simulations either.

### 5.2.2 Model Comparison to Observed Groundwater Conditions

A current condition cross section was developed based on the simulated 2010 hydraulic head field obtained from the groundwater flow model (Figure 5-3). The details of the cross section are provided in Figure 5-8. The simulation results from the cross section were compared to observed water quality data from monitor wells 2-7 and 6-5, which are located near the downgradient end of the simulated current condition cross section and provide a dataset back to the early 1980s (for well 6-5) for comparison with model results (Figure 5-3). These two wells are located very close to one another but often have quite different water quality, perhaps caused by variable connectivity through local fracture patterns to adjacent recharge sources. Based on the observed constituent concentrations, well 6-5 appears to be better connected to groundwater influenced directly by stockpile seepage.

The cross section comparison simulation was developed as discussed in Section 5.1.1. In order to better replicate observed conditions at well 6-5, the length of leach stockpile that contributed PLS seepage to the section was set to 1,300 feet, and the length of recharge between the stockpile toe and the well locations was set to 1,900 feet. This approach was based on review of historical photographs and leach operations and consideration of the location of the simulated cross section versus the mapped flow paths based on observed data, which were slightly different at the upgradient end of section. The water quality for groundwater inflow and recharge not beneath a stockpile was set to the average observed water quality at well 2-5A over the period 2001 through 2009 (Appendix D). Well 2-5A is an upgradient well in the Mine/Stockpile Unit near the starting point of the cross section that is not on the downgradient portion of a leach stockpile (Figure 5-3, Plate 5-1).

The simulation results for all of the constituents plotted against the observed concentration data at wells 2-7 and 6-5 are provided in Appendix D. For most of the constituents considered, the simulated values agree well with observed values and trends in well 6-5 (Appendix D). The time scale begins at 1981 (year 0) when open pit mining and leaching operations were underway. Observed data in wells 2-7 and 6-5 include data from 2011 (year 30). These wells were dewatered for a period of time during the 1980s and 1990s, and water quality data are not available for sampling events when the wells were dry. The plots in Appendix D include the simulation results for different depths in the aquifer; since the observed data at wells 2-7 and 6-5 are representative of water table or near-water table conditions, the simulation results for the shallowest two observation points in the model should be used for comparison to the observed data. The simulation results and the observed data for wells 2-7 and 6-5 are provided in Figure 5-9 for sulfate and copper and in Figure 5-10 for manganese and pH.

The model results tend to match the early time observed concentrations in monitor wells 6-5 and 2-7, which are generally low. The model then predicts an increasing concentration trend similar to the observed trends for many constituents. The behavior of various elements and minerals during the verification modeling is described below. For the simulated and observed values of constituents other than sulfate and copper (Figure 5-9) and manganese and pH (Figure 5-10), refer to the plots in Appendix D.

Alkalinity, represented by the bicarbonate ion ($HCO_3$), is modeled as a mobile constituent. Concentrations are greater than the highest observed values in well 2-7, but maintain a relatively steady state from year 10 to 50. An equilibrium phase such as calcite ($CaCO_3$) was not included in the modeled scenarios to attenuate the bicarbonate.

Calcium is modeled as a mobile phase and cation-exchanger and matches well with the observed data for wells 6-5 and 2-7. The late time data for well 6-5 shows an elevated trend (relative to early time data, which is highly variable) that is matched closely by the model results.

Fluoride concentrations under equilibrium conditions are generally controlled by the mineral fluorite ($CaF_2$). As the calcium concentration increases, fluoride will precipitate from solution, lowering both calcium and fluoride concentrations. In the simulation, fluoride and calcium vary together. Fluoride has a spike in concentration at approximately 10 to 15 years (depending on depth in the profile) due to fluorite dissolution in the model, but the concentrations quickly decrease to values more in line with observed data from wells 2-7 and 6-5. The observed data for well 6-5 appear to indicate a similar decreasing trend in fluorite at this well location.

Chloride ($Cl^-$) concentrations in groundwater are relatively low, varying from about 2 mg/L to 50 mg/L. The simulation results match this magnitude of observed chloride concentrations reasonably well, ranging from about 15 to 20 mg/L.

The iron species, ferrous (Fe2+) and ferric (Fe3+), were both included in the model. Observed iron data are not reported by species, so the total iron concentrations were speciated by assigning 95 percent of total iron concentration to the ferrous (Fe2+) ion and 5 percent to the ferric (Fe3+) ion. The ferrous ion is dominant in the simulation results and reaches concentrations of about 300 mg/L, which is higher than most observed concentration values at wells 6-5 and 2-7. Goethite (FeOOH), an equilibrium phase, does not appear to greatly lower iron concentrations when it precipitates out of solution from about years 7 to 10.

Potassium (K) and sodium (Na) are modeled as mobile phase and cation-exchangers, and the model results for both cations match well with the observed data in wells 6-5 and 2-7.

Magnesium is probably derived from the dissolution of chlorite ($Mg_5Al_2Si_3O_{10}(OH)_8$) from rocks in the leach stockpiles and therefore becomes a component in the PLS. Magnesium reaches concentrations predominantly around 250 to 400 mg/L with a maximum of 549 mg/L in well 6-5. The simulation results reach a maximum of about 400 mg/L.

Manganese, zinc, nickel, and copper are typically divalent ions (+2 charge) in solution that will be mobile under acidic conditions such as those that exist beneath and adjacent to leach stockpiles at Tyrone.

- The simulation results tend to under-predict the observed manganese concentrations at well 6-5 by about a factor of 2 (simulated values are about 200 mg/L, while the average of the observed values is about 400 to 500 mg/L [Figure 5-10]).

- Simulated zinc values are about 225 to 250 mg/L, while observed data for well 6-5 average about 400 mg/L. The high end of simulated zinc concentrations (about 250 mg/L) is generally on the low end of observed concentrations at well 6-5, which generally range from about 200 to 750 mg/L (Appendix D).

- Simulated copper concentrations match reasonably well with much of the well 6-5 observed data, which range from about 50 to 100 mg/L, but higher observed values ranging up to about 300 mg/L are not simulated (Figure 5-9).

- Simulated nickel concentrations (about 0.8 mg/L) agree well with observed concentrations for well 6-5, which range from about 0.4 to 1.2 mg/L (Appendix D).

Aluminum, cadmium, lead, arsenic, cobalt, and chromium concentrations simulated by the model match very well with the observed data from well 6-5. With the exception of lead, the model tends to predict concentrations near the maximum values of observed data (Appendix D).

The sulfate results match the observed trend quite well with a slightly increasing trend during the first 12 to 13 years followed by a more rapid increase and then a leveling out (Figure 5-9). The observed data vary significantly between 20 and 30 years (2002 to present), ranging from 3,860 to 10,300 mg/L. The model predicts values within this range, maintaining a near steady-state value of about 7,000 to 8,000 mg/L for the simulated observation points at or just below the water table (observation points 13 and 14 on Figure 5-9).

The simulated pH values in the model and observed data for well 6-5 also agree very well over time (Figure 5-10). The observed data begin near a pH of 6 and exhibit a decreasing trend over the first 10 to 15 years, with observed values varying between 2.6 and 3.7 in recent data. The model simulates pH values of about 2.8 to 3.

The simulated pe tends to be near a value of 4 after about 15 years into the simulation (Appendix D). Observed data do not include measurements of the oxidation-reduction potential, but the simulated value appears reasonable and appropriate. The groundwater environment below the stockpiles would be a slightly oxidizing environment related to low dissolved oxygen concentrations and the oxidation-reduction potential of the iron species. The recharge from the stockpiles likely contains no dissolved oxygen due to oxygen-consuming reactions in the stockpile and would be only slightly oxidizing due to oxidation-reduction reactions of iron species (ferrous and ferric iron).

Variations between the simulated and observed data may be related to multiple characteristics and complexities inherent in the groundwater system that cannot be incorporated in a flow and transport model. Some of these complexities include variable recharge quality over time, particularly from leach stockpiles, different mineralogy along the flow path versus that assumed in the model, variable mixing over time as the water table fluctuates, and the control of fractures on recharge and groundwater flow paths. Selection of initial conditions, inflow components, and mobile and equilibrium phases and concentrations for recharge will also affect the simulation results.

### *5.2.3 Predictive Simulations and Future Groundwater Quality*

Predictive simulations of future regional groundwater quality within the Mine/Stockpile Unit were conducted for seven representative flow paths as illustrated in Figure 5-11. Groundwater within cross sections 1 through 5 will eventually terminate at the Main Pit, although as described in the proposed modeling approach (DBS&A, 2011a), the cross-sectional model domain was not extended all the way to the pit to avoid unnecessary simulation effort. Groundwater within cross section 6 will terminate at the Gettysburg Pit. Groundwater within cross section 7 passes under waste rock and leach stockpiles along the southern side of the Mine/Stockpile Unit and does not terminate at a pit, but rather will flow into the Gila Conglomerate regional aquifer in the vicinity of the mine entrance.

Groundwater flow within each cross section was assumed to be at steady-state conditions, based on the simulated hydraulic heads at year 2060 (Figure 5-6). Simulated flows to the pits are relatively steady by this time (Figure 5-7), and although simulated water levels are changing across much of the mine site, the rate of change is not large. Furthermore, given inherent uncertainties intrinsic in the modeling analysis and the model inputs, 50 years was determined to be a reasonable predictive simulation time period.

The water quality of the prescribed groundwater inflow was determined based on monitor wells near the upgradient end of each cross section. The applied water quality of recharge along the cross section was based on observed data as presented in the proposed modeling approach (DBS&A, 2011a). Initial (starting) conditions for each cross section were set to the assumed inflow groundwater quality. For seepage that reaches the water table below a former leach stockpile, the assumed water quality was the same as PLS used in the comparison cross section discussed in Section 5.2.2. For seepage that emanates from a waste rock stockpile, the observed water quality for seep collection 1C-2 as of November 10, 2010 was used. This approach is consistent with that used in the DP-1341 Condition 89 Feasibility Study (Golder, 2007a), although the constituent concentrations for the 1C-2 seep collection were based on more recent data, because observed concentrations at this collection facility have been rising through time. Table 5-1 summarizes the applied groundwater inflow and seepage water quality for each cross section.

Based on the cross-sectional model inputs described above, each cross-sectional geochemical transport model was run for a period of 50 years. Conceptually, this approach does not simulate the existence of elevated constituent concentrations in the aquifer that already exist due to current operations within the simulated sections. However, when mining stops, facilities are covered, and the current operational recharge rates (assumed to be 1.81 in/yr) transition over time to the long-term average recharge rates expected to occur beneath covered facilities (0.22 in/yr), existing solutes in the cross sections will flow out of the section and the resulting long-term constituents concentrations will be controlled by the future recharge rates. Where facilities are not covered, the current estimated recharge rate of 1.81 in/yr is continued throughout the predictive simulation.

The simulation results are illustrated as a pair of figures for each simulated cross section (Figures 5-12 through 5-25). The top illustration of the first figure (e.g., Figure 5-12 for cross section 1) illustrates the boundary conditions and inputs, such as recharge. The bottom graphic of the same figure illustrates the simulated sulfate concentration at 50 years. The second figure of each pair (e.g., Figure 5-13 for cross section 1) illustrates the simulated sulfate concentration and copper concentration with depth at 50 years for the toe of the stockpile at the downgradient edge of each cross section. The topmost elevation represents the simulated concentration at the model cell that includes the water table, and the lowest elevation concentration is about 400 feet below the water table. As indicated in the figures and as would be expected, the simulated concentrations are greatest at shallow depths in the aquifer. The distribution of constituent concentrations is also affected by the recharge water quality (i.e., leach or waste rock stockpile) and the length of each facility type that contributes seepage to the water table.

Although similar plots could be made for all of the simulated constituents rather than only sulfate and copper, the number of figures would be unwieldy. For the other constituents, therefore, the maximum and minimum simulated concentrations for each cross section within the upper 400 feet of aquifer are summarized in Table 5-2. TDS is not simulated directly by the model, so the TDS values provided in Table 5-2 were calculated by multiplying the sum of the simulated constituent concentrations by a factor of 1.1 for the maximum concentrations. This multiplication factor was determined by evaluation of the observed data at well 6-5, which indicates that the sum of the monitored dissolved constituents is about 90 percent of the observed TDS value. The multiplication factor was therefore calculated as 1.1 (1.0/0.90). The minimum values of TDS reported are taken as the summation of the simulated constituent concentrations, which is consistent with observed data from monitoring wells that do not exhibit high constituent concentrations (e.g., 435-2005-02 and 2-15).

Table 5-2 illustrates a large predicted variation of future constituent concentrations. The simulated maximum future constituent concentrations within the upper 400 feet of aquifer generally exceed Section 3103 standards for all simulated constituents, with the exception of lead and arsenic at several cross sections. As would be expected, the highest simulated concentrations occur in the shallowest portions of the aquifer immediately below leach stockpiles. The minimum simulated values also exceed Section 3103 standards for some constituents within some model cross sections, but for many constituents the minimum simulated constituent concentrations meet Section 3103 standards.

## 5.3 Pit-Water Quality

The results of the predictive simulations were also used to estimate pit water quality for the Main and Gettysburg Pit sumps. Pit water quality was estimated by mixing the predicted inflow from groundwater and surface runoff that will reach each pit. Each source of water was assumed to mix in the pit sump, and the concentration of each constituent was computed using PHREEQC.

The sources and rates of inflow to each pit for the predictive simulation are provided in Table 5-3:

- Groundwater inflow to the Main Pit was determined using selected lateral distances associated with cross sections 1 through 5 as indicated in Figure 5-26. Groundwater inflow to the Gettysburg Pit is associated with cross section 6 (Figure 5-11).

- The average surface water inflow to each pit over a 50-year period was taken from Golder (2012b, provided herein as Appendix E).

- The component of inflow to the Main Pit called near-pit recharge in Table 5-3 represents the rate of simulated inflow to the Main Pit attributable to recharge that occurs between the stockpile toes and the pit. This portion of the Mine/Stockpile APP study area was not simulated explicitly in the cross-sectional models, but the simulated recharge that occurs in this area needs to be accounted for in order to maintain proper mass balance of water that collects at the pits. The near-pit recharge at the Gettysburg Pit is small enough to be neglected.

As indicated in Table 5-3, total groundwater inflow to the Main Pit at 2060 is predicted to be 568 gpm, including the 66 gpm noted as near-pit recharge. About half of the total groundwater inflow is contributed by cross section 3, which includes a region of high hydraulic conductivity west of the Main Pit relative to other areas of the model. The long-term average surface water runoff predicted to reach the Main Pit is 67 gpm. For the Gettysburg Pit, the groundwater and surface water inflow components are 33 and 8 gpm, respectively.

The predicted water quality associated with each of the pit inflow components is provided in Table 5-4. For each of the simulated cross sections, the average constituent concentration simulated across the depth of the cross section at the toe of the stockpile closest to the pit was applied to the flux of groundwater associated with the section (Figure 5-26). In other words, the simulated constituent concentrations for a given cross section were applied across the entire zone of flow associated with that section. The near-pit recharge for the Main Pit was assigned water quality based on monitor well 2-5A. Quality of the runoff was taken from Golder (2012b [Appendix E]), which followed an approach to determining runoff and associated water quality similar to that applied in the Tyrone Feasibility Study (Golder, 2007a).

The results of mixing the inflow components (Table 5-3) and their associated quality (Table 5-4) at the Main and Gettysburg Pit sumps are presented in Table 5-5. Multiple constituents are predicted to exceed Section 3103 standards at the pit sumps, including sulfate, TDS, aluminum, copper, cadmium, cobalt, fluoride, iron, nickel, and zinc. At the Main Pit, minerals that may become over-saturated and precipitate from solution include alunite, chalcocite, gypsum, and silica (amorphous quartz). The same minerals may become over-saturated at the Gettysburg Pit sump.

## 5.4 Proposal for Alternative Abatement Standards

Consistent with the terms of the Settlement Agreement, Tyrone intends to petition the NMWQCC for alternative abatement standards for groundwater at Tyrone. The specific petition will be developed in consultation with the NMED. Requested alternative standards are expected to be the highest simulated values of each constituent for the Mine/Stockpile area, since monitor wells that will be used to determine compliance with standards are screened across the water table or the first water-producing zone encountered in the fractured rock.

# 6. Mine/Stockpile APP Study Area Peripheral Regions

This section presents the current situation regarding impacted perched and regional groundwater and proposed Stage 2 abatement measures for four areas peripheral to the Mine/Stockpile Unit: Deadman Canyon, the No. 3A leach stockpile, the former concentrator area, and the area bordering Upper Oak Grove Wash on the south side of the mine. Each of these areas has undergone investigation and characterization activities as part of the Stage 1 APP or other studies related to closure or operational DPs.

## 6.1 Deadman Canyon Area

The Deadman Canyon area borders the west side of the Mine/Stockpile Unit (Figure 2-2). Sections 6.1.1 and 6.1.2 describe the current water quality conditions and the proposed abatement approach for perched and regional groundwater in this area.

### *6.1.1 Perched Groundwater*

Deadman Canyon perched groundwater refers to shallow water in the alluvium (about 10 feet deep or less) of Deadman Canyon, which borders the western side of the Mine/Stockpile APP study area. The alluvium overlies quartz monzonite.

#### *6.1.1.1 Current Water Quality Conditions*

Perched groundwater impacts in Deadman Canyon likely originate from tributary drainages entering Deadman Canyon from the mine facility area to the east. These tributary drainages are located adjacent to, and some cases extend under, mine operational areas. The most heavily impacted perched water is observed in the Seep 5E tributary drainage. Impacted water could also be attributable, in part, to a prior operator (United States Natural Resource, Inc [USNR]) that conducted mining operations in the Deadman Canyon area. Previous DBS&A reports (2004, 2006, 2011b) provide more detailed discussion of the groundwater impacts.

Source controls implemented to date in Deadman Canyon include the construction and operation of five active surface seep collection facilities (Seeps 2, 3, 4, and 5E and the DC2-1 lined impoundment) and one collection trench in the Seep 5E tributary canyon (Plate 6-1). In addition, the USNR leach stockpile was removed in 1998, the site was partially reclaimed, and improvements to the seepage collections in this area were installed. Seepage controls implemented in this area have been partially effective in reducing impacts to groundwater, as evidenced by the reduced constituent concentrations at, for example, wells TWS-28 and TWS-29 (Plate 6-1).

The quality of impacted perched water in Deadman Canyon is variable, but the most impacted wells (such as 166-2006-03 at the north end of the Canyon) exceed Section 3103 standards for aluminum, cadmium, cobalt, copper, fluoride, manganese, pH, TDS, and sulfate by substantial amounts (DBS&A, 2011b). Plate 6-1 Illustrates observed TDS and sulfate concentrations and, beginning at well TWS-38, the copper and manganese concentrations for perched zone monitor wells along the Deadman Canyon drainage. The distinct fluctuations in observed water quality in the Deadman Canyon perched zone wells are caused by variation in precipitation (HAI, 2001). Specifically, periods of high precipitation lead to the recharge of good-quality water that dilutes the perched groundwater concentrations. It is common for the alluvium to be dry at some locations and to only become saturated after significant precipitation events (DBS&A, 2011b).

#### *6.1.1.2 Proposed Abatement Approach*

Additional source controls that will be implemented at the outset of closure under DP-1341 consist of regrading and covering the stockpiles in the Deadman Canyon area as described in the Settlement Agreement. In addition, existing seep collection and groundwater extraction from the collector trench in the Seep 5E tributary drainage will continue as long as water that exceeds Section 3103 standards collects there. The reduced infiltration through the stockpiles adjacent to Deadman Canyon is expected to substantially reduce or eliminate the seepage that drains to the current seepage collection points. In addition to these measures, the construction and operation of one to three additional collection trenches is proposed, as described below. The proposed abatement measures are based on the results of the Stage 1 APP investigations summarized above and documented by DBS&A (2004, 2006, 2011b).

*6.1.1.2.1 Seep 5 Area Collection Trench.* A northern Deadman Canyon collection trench is proposed for the north portion of Deadman Canyon at the entrance to the narrows, in the vicinity of wells TWS-28 and 166-2006-03 near Seep 5 (Plate 6-1). The purpose of this collection trench is to capture impacted perched water that reaches the northern extent of the alluvium. Perched water in this portion of the canyon is of poor quality and exceeds Section 3103 standards for multiple constituents. For example, perched water samples collected from well 166-2006-03 generally exceed Section 3103 standards for aluminum, cadmium, cobalt, copper, fluoride, manganese, pH, TDS, and sulfate. Collection of perched groundwater at this location would serve to contain impacted water at a natural collection point, where the alluvium is constricted both vertically and laterally and the water is forced to the surface. All impacted shallow groundwater in Deadman Canyon not captured at other seepage collection trenches can be captured at this location.

Perched groundwater was present at this location over the entire 4-year period (May 2007 through May 2011) during which a transducer was operational in well 166-2006-03 as part of the Stage 1 APP investigation activities (DBS&A, 2011b). Farther to the south at a second monitored location (well 166-2006-01), perched water was documented to be ephemeral and, in fact, was not present over much of the same period of time. The majority of the observed groundwater impacts at the northern Deadman Canyon location are believed to be from the Seep 5E tributary canyon, mixed with impacted perched water that also flows to this point from the south (Plate 6-1).

*6.1.1.2.2 DC2-1 Seep Collection Trench.* A second potential collection trench is proposed immediately downgradient of the DC2-1 lined collection impoundment in what is referred to as the DC2-1 tributary canyon (Plate 6-1). This location is one that was called out for further investigation in the Stage 1 abatement plan final report (DBS&A, 2011b). Perched groundwater impacts are known to have occurred in this canyon because perched groundwater well TWS-31 (destroyed) exhibited the presence of impacted fluids (14,900 mg/L TDS and 11,000 mg/L sulfate) in March of 2000. An additional shallow well will be completed in this canyon adjacent to the DC2-1 collection trench to replace well TWS-31, and if this well indicates the persistent presence of impacted fluids, a collection trench will be constructed to capture the fluids as close to the source as practical. The construction and monitoring of the new well is proposed prior to trench construction to confirm that perched fluids exist because perched zone well TWS-26, along the same tributary canyon about 525 feet downgradient of the DC2-1 collection (Plate 6-1), has been dry for a number of years.

*6.1.1.2.3 Seep 3 Collection Trench.* A third potential collection trench is proposed for the Seep 3 tributary that enters Deadman Canyon from the east near well TWS-37 (Plate 6-1). Well TWS-37 has often (but not always) exceeded the Section 3103 standards for TDS and sulfate, although recently (2010) this well has met standards. Investigation of upgradient (to the south) wells and locations during the Stage 1 APP activities indicated that Section 3103 standards are met in this area, with some sporadic exceedances for manganese, fluoride, and iron that are most likely attributable to sample error or background conditions (Plate 6-1). Consequently, well TWS-37 is the southernmost location in Deadman Canyon where observed groundwater quality has exceeded one or more Section 3103 standards on a relatively consistent basis, and the logical source of impacts to well TWS-37 is seepage from the Seep 3 tributary drainage (Plate 6-1). Note that well TWS-38, about 200 feet downgradient (north) of well TWS-37, meets Section 3103 standards.

Based on the observed water quality at this well as described above, the following approach is proposed. First, well TWS-37 will continue to be monitored as required by DP-166. If the observed water quality continues to meet the Section 3103 standards for TDS and sulfate as has been the case over the past year, no further action will be taken. If any Section 3103 standards are exceeded for two consecutive quarters, an additional monitor well will be installed to the southeast of TWS-37, targeting the Seep 3 tributary drainage. If this monitor well indicates the persistent presence of seepage that exceeds one or more water quality standards, a capture trench will be constructed across the Seep 3 tributary drainage between Seep 3 and well TWS-37.

### *6.1.2 Regional Groundwater*

Regional groundwater exists in quartz monzonite beneath Deadman Canyon. The regional groundwater table is about 20 to 30 feet below the base of the alluvium that contains the perched groundwater.

#### *6.1.2.1 Current Water Quality Conditions*

Regional groundwater in the Deadman Canyon area meets Section 3103 standards at two of the three monitor well locations. At well TWS-8, screened in quartz monzonite below Deadman Canyon, TDS and sulfate concentrations are consistently below standards. Well TWS-9, which is open to the alluvium and the underlying bedrock, also meets Section 3103 standards (Plate 5-1). Water quality at these two wells fluctuates in response to recharge events. Well TWS-9 is influenced because a portion of the screened interval is open to alluvium, and perched alluvial water can enter the well directly if it is present. Well TWS-8 is believed to be completed in a fracture zone in quartz monzonite beneath Deadman Canyon, probably associated with the West Main Fault where it crosses Deadman Canyon just north of the TWS-8 well location. Recharge occurs at this location when the alluvium becomes saturated due to precipitation, resulting in the infiltration of water from the alluvium downward to the regional water table through the fracture zone. The recharge can have a significant effect on water quality. For example, manganese at TWS-8 exceeds the Section 3103 standard of 0.2 mg/L during periods of significant recharge (Appendix A). These sporadic elevated manganese values are considered a natural background condition.

The third regional aquifer monitor well, 166-2006-02, is at the north end of Deadman Canyon at the entrance to what is called the narrows. This location is near the geologic contact between the quartz monzonite and the Precambrian granite. North of this location, where the stream has cut a narrow canyon through the granite, there is no significant alluvium and the canyon bottom is essentially on bedrock. Well 166-2006-02 exceeds Section 3103 standards for cobalt, copper, fluoride, manganese, pH, sulfate, and TDS (Plate 5-1). The source of impacts to this well is believed to be downward seepage of impacted perched water in the alluvium, possibly along the quartz monzonite-granite geologic contact zone.

#### *6.1.2.2 Proposed Abatement Approach*

Existing monitoring indicates that regional groundwater at wells TWS-8 and TWS-9 in the Deadman Canyon area meets Section 3103 standards (except for occasional exceedances of manganese due to natural background conditions) and abatement is thus not necessary. Well 166-2006-02, however, exceeds standards for seven constituents. For this well, the proposed abatement approach is monitored natural attenuation. This approach is appropriate because:

- Additional abatement measures are proposed for the impacted perched water in Deadman Canyon, which is the likely source of impacts to well 166-2006-02 (Section 6.1.1.2). The potential for vertical migration of water may be enhanced in the vicinity of this well because it is near a regional contact between the quartz monzonite and granite. Capture of impacted perched water upgradient (south) of well 166-2006-02 will reduce or eliminate the potential for vertical seepage of impacted water at this location.

- Regional groundwater in the vicinity of well 166-2006-02 flows to the northeast (Plate 5-1) and will ultimately be captured at the Main Pit.

## 6.2 No. 3A Leach Stockpile Area

Perched and regional groundwater in the No.3A leach stockpile area, north of the Main Pit (Figure 2-2), has been impacted by fugitive PLS. Figure 6-1, a hydrogeologic cross section along the northern toe of the No. 3A leach stockpile that is updated from one provided in a previous report (DBS&A, 2006), illustrates the vertical extent of the Quaternary alluvium that has filled drainage channels eroded into the Gila Conglomerate. The channels are referred to as "canyons" at the No. 3A leach stockpile because the stockpile was built on top of the pre-existing drainage pattern and the canyons (drainages) are the mechanism used to channel and collect PLS at the base of the stockpile. Perched fluids exist in the alluvium; the term fluids is used because most of the liquid in the channels appears to be PLS, although there is some limited mixing with meteoric water that may infiltrate into the channels. Regional groundwater occurs about 100 to 200 feet below the base of the alluvial channels, or canyons, near the northern toe of the No. 3A leach stockpile (Figure 6-1).

Sections 6.2.1 and 6.2.2 describe the current water quality conditions and the proposed abatement approach for perched and regional groundwater in this area.

### *6.2.1 Perched Groundwater*

As discussed above, saturated conditions exist within a number of canyons beneath and adjacent to the No. 3A leach stockpile and upgradient of PLS collection facilities. These saturated conditions are an intrinsic component of the mine-for-leach operation conducted at Tyrone, and the saturating fluid is PLS, which exceeds numerous groundwater quality standards. Once leaching ceases and the stockpiles are covered at mine closure, the alluvium channels will no longer be saturated with PLS, but may contain residual PLS in the unsaturated sediments that is a potential source of groundwater contamination when infiltration from precipitation occurs and potentially collects in the alluvial channels.

#### *6.2.1.1 Current Water Quality Conditions*

The perched seepage pathways at the No. 3 leach stockpile area consist of narrow, north- to northeast-oriented, natural drainage channels that contain unconsolidated alluvial sediments and extend outward from the base of the stockpile. Investigations at the stockpile have identified perched seepage in 10 of the 11 existing drainage channels or canyons, with Canyon 9 being the only channel exhibiting no evidence of seepage. The extent of perched zone seepage is illustrated for the first quarter of 2011 in Figure 6-2. The perched zone to the east of Canyon 4 along Mangas Wash exists due to infiltration of precipitation, not due to seepage from the No. 3A leach stockpile. This perched zone is in the former concentrator area and is discussed in Section 6.3.

To reduce the effects of PLS seepage on groundwater quality, a series of interceptor/barrier trenches have been installed in Canyons 4 through 8, 10, and 11 (the Canyon 11 trench has since been abandoned) to capture PLS seepage that is not fully extracted at the primary collection system (Figure 6-2). Although some perched fluid has occurred intermittently in Canyons 1 through 3, in which no interceptor systems are installed, this fluid will move to the north and be intercepted by the Canyon 4/Mangas Wash interceptor/barrier trench system, which extends across the Mangas Wash at its confluence with Niagra Gulch. Small amounts of perched fluid not captured by existing containment systems (e.g., Canyons 6 and 8) eventually mingle with regional groundwater, which is captured by a series of regional groundwater pumping wells (Section 6.2.2). Although water quality samples of perched seepage are not collected at the No. 3A leach stockpile, the perched fluids consist primarily of PLS or PLS mixed with meteoric water and exceed numerous Section 3103 standards.

#### *6.2.1.2 Proposed Abatement Approach*

The proposed abatement approach for perched fluid in the No. 3A leach stockpile area is to continue operating the existing interceptor/barrier trenches during operations and closure. The existing seepage collection facilities have been effective in capturing perched seepage and limiting the downgradient extent of perched fluids. When the No. 3A leach stockpile is reclaimed, push down of the stockpile to the north and west for regrading will bury some of the existing capture systems. The existing trenches that will be buried will be plumbed so that seepage can be collected and routed by gravity flow to the edge of the reclaimed stockpile. In addition, a number of new shallow toe seepage collection facilities and four new seepage collection and cutoff trenches in the distal portions of Canyons 7, 8, 10, and 11 will be constructed (Figure 6-3). The new seepage collection and cutoff trenches will be constructed across the full extent and depth of the alluvial channels so that all perched seepage will be collected and sent to the water treatment plant. As noted in Section 6.2.1, once the leaching operations are stopped at the No. 3A leach stockpile, the volume of seepage in the perched zones will be reduced significantly.

### *6.2.2 Regional Groundwater*

Regional groundwater in the No. 3A leach stockpile area occurs in Gila Conglomerate except on the far eastern and southern sides of the stockpile, where it occurs in granite. Regional water beneath and adjacent to the No. 3A leach stockpile has been impacted by downward seepage of PLS either from the base of the stockpile or from the base of alluvial channels where seepage is collected (DBS&A, 2004, 2006).

#### *6.2.2.1 Current Water Quality Conditions*

Along the toe of the No. 3A leach stockpile, regional groundwater exceeds standards for TDS, sulfate, and pH at many well locations. Other standards commonly exceeded at some locations include those for aluminum, cadmium, cobalt, copper, fluoride, iron, manganese, and zinc (Plate 5-1). Moving away from the stockpile toe to the north by a distance of only several hundred feet, most impacted groundwater that exceeds one or more Section 3103 standards does so for sulfate, TDS, and/or pH, and occasionally fluoride and manganese. As an example, the observed constituent concentrations for wells P-178, P-196 and P-11 near the toe of the No. 3A leach stockpile (Plate 5-1) are provided in Table 6-1. Each well has a similar screened interval. Wells P-178 and P-196 are within about 100 feet of the toe of the leach stockpile and exceed Section 3103 standards for multiple constituents, including aluminum, copper, fluoride, manganese, pH, sulfate, TDS and zinc. Well P-11 is about 250 feet north of the stockpile toe and exceeds standards for fluoride, pH, sulfate and TDS only, and at greatly diminished levels from those observed in wells P-178 and P-196 (Table 6-1). This distribution of observed groundwater concentrations is not surprising, because metals will not remain dissolved in groundwater when the pH is relatively neutral, and the regional groundwater host rock (Gila Conglomerate) will not sustain low pH due to its lithology.

Several regional groundwater collection/capture systems are located downgradient of the No. 3A leach stockpile area (Plate 6-2), including:

- The various canyon collection systems (a total of 36 pumping wells operated at the mouths of seven canyons)
- The L Line collection system (5 wells)
- The Trestle collection system (9 wells)
- The Mangas Flats collection system (3 wells)
- The North Canyon collection system (25 wells).

Although some wells in the canyon, L Line, Trestle, and Mangas Flats collection systems are dry, the combined pumping from the wells that are operational is sufficient to maintain hydraulic capture of impacted water (Plate 6-2).

The North Canyon collection system was installed between 2006 and 2008, and some of the wells became operational in May and June of 2010 to capture impacted water observed in the vicinity of the extraction wells. This system was originally installed as a replacement for the existing canyon collection systems when the No. 3A leach stockpile is reclaimed, which will require a push down of a portion of the stockpile to the north and west (Figure 6-3, Plate 6-2).

Regional aquifer water level elevations based on monitor wells in the No. 3A leach stockpile area are shown in Plate 6-2. This plate illustrates several important characteristics of regional groundwater flow in the area:

- Two major faults occur beneath the leach stockpile: the Southern Star Fault, trending east-west, and the Burro Chief Fault, trending northeast-southwest. Regional groundwater beneath the leach stockpile on the Main Pit side of these faults flows toward the pit, as evidenced by the groundwater divide that exists in the regional aquifer near the western edge of the PLS overflow pond, approximately coincident with the Burro Chief Fault.

- Dewatering due to pumping at the Main Pit controls water level elevations and groundwater flow directions south and east of the divide. Because the hydraulic gradient is primarily to the south in this area, toward the Main Pit, any seepage that might escape capture in the PLS pond or Canyons 1 through 5 and enter the regional aquifer will ultimately be captured at the Main Pit.
- Regional groundwater on the Mangas Valley side of these faults flows north-northwest into the Mangas Valley APP study area unless it is captured by one of the regional groundwater collection systems.

As illustrated by the groundwater flow directions and water quality information provided in Plate 6-2, the existing regional groundwater capture/collection systems are effectively capturing impacted groundwater that exceeds Section 3103 standards.

Water quality is either stable or improving throughout much of the Mangas Valley adjacent to the No. 3 stockpile (DBS&A, 2011b), indicating that the source control and regional water capture systems operated in this region are effective. For example, monitor wells that form the E.L. line (wells P-60 through P-68 and P-73), located downgradient of the L line pumping center, contain declining or stable TDS and sulfate concentrations that are below Section 3103 standards. Monitor wells P-100 and P-101 (now dry), which lie between the L line and E.L. line, show declining TDS and sulfate concentrations, to levels that also meet Section 3103 standards. The L line wells all contain declining or stable TDS and sulfate concentrations (e.g., P-49, P-54, P-56, P-57 and P-70), as do the Trestle line area wells (e.g., P-162, P-164, and P-14A). Water quality at wells near the toe of the No. 3A stockpile is highly variable, but many wells in this area have relatively stable, although elevated, constituent concentrations.

Well 24 is due north of the No. 3A leach stockpile and northeast of Mangas Wash, at the boundary of the Mangas Valley and Mine/Stockpile Unit APP study areas (Plate 4-1). This well exceeds the Section 3103 standard for TDS, at about 1,450 mg/L, and exhibits sulfate concentrations that while elevated, at about 350 mg/L, meet the Section 3103 standard. Observed TDS values for well 24 indicate no discernible upward or downward trend. The source of the elevated TDS at this well is not clear, but it will continue to be monitored.

#### *6.2.2.2 Proposed Abatement Approach*

The proposed abatement approach for regional groundwater at the No. 3A leach stockpile area is continued operation of the groundwater capture systems as needed. This approach is appropriate because:

- Existing regional groundwater capture systems have proven effective at the containment and reduction of groundwater impacts. Construction of the Northern Canyon collection system took into account the planned push-down of the No. 3A leach stockpile at closure, and this system will capture impacted water along the toe of the reclaimed stockpile as needed. Other capture/collection systems not affected by the reclamation (e.g., L Line wells and Canyons 4 and 6 extraction wells) will also remain operational to the extent required.

- Regional groundwater not captured at the existing collection systems east and south of the Burro Chief Fault will eventually flow to the Main Pit. Water extracted at the Main Pit will be treated to meet Section 3103 water quality standards prior to discharge.

- Source controls will be implemented through the regrading and covering of the stockpile as required by the Settlement Agreement and DP-1341. Source controls for perched seepage will also be continued or constructed (Section 6.2.1). At this location, the cessation of leaching alone (regardless of the cover construction) is expected to lead to a significant reduction in fluids in the alluvial channels and less seepage to regional groundwater.

- Multiple monitor wells exist downgradient of the zone of impacted water adjacent to the No. 3A leach stockpile. Sampling of these wells will confirm the effectiveness of the abatement measures.

## 6.3 Former Concentrator Area

Soil and groundwater contamination by diesel fuel was discovered in the former concentrator area and adjacent to the Tyrone power plant (Figure 2-2) in 1997. The source of the diesel contamination was determined to be several cracks and small holes along the welded seams of two lengths of an underground pipeline that runs from a storage tank on the eastern side of Mangas Wash to the pump house near the power plant; the two pipeline segments were replaced in July 1998 (DBS&A, 1999c). Diesel fuel released at the leaking pipeline migrated through the Mangas Wash alluvium, impacting soil and perched groundwater approximately 30 to 50 feet below the surface. An investigation of the area conducted in 1998 indicated that diesel contamination reached Mangas Wash at its confluence with Niagra Gulch (DBS&A, 1999c).

Regional groundwater was also impacted by downward migration of diesel fuel along the annulus of two regional monitor wells (wells 32 and 33) located in Mangas Wash within the area of impact. These wells were deep exploration borings that had been converted to monitor wells in 1988 by filling the borings with pea gravel and installing PVC well casing in the top 300 feet of the boreholes. These wells, therefore, had no low-permeability seal to stop the vertical migration of fluids. Both of these wells were drilled out in 1998 and recompleted with proper well seals (DBS&A, 1999c).

Remediation activities performed since the 1998 investigation consisted of light nonaqueous-phase liquid (LNAPL) removal from monitor wells by bailing, pumping, or using absorbent socks.

### *6.3.1 Perched Groundwater*

Perched groundwater exists in the shallow alluvium of the Mangas Wash in the former concentrator area due to infiltration of precipitation and runoff. The alluvium is about 10 to 55 feet deep, depending on location within the Mangas Wash, and sits on top of Gila Conglomerate. Perched water may not be present at all times and at all locations, but rather is likely variable based on climatic conditions.

### *6.3.1.1 Current Water Quality Conditions*

A subsurface investigation was conducted at the former concentrator area as part of the Stage 1 APP to confirm and re-evaluate the nature and extent of the diesel impacts to alluvial sediments and perched groundwater (DBS&A, 2011b). Borings were installed in six transects across the area of known or suspected diesel impacts, approximately coincident with the course of the Mangas Wash alluvial channel (Figure 6-4). Drilling locations were refined during the field investigation to account for the presence of underground or overhead utilities and reclaimed areas and to allow for equipment access.

The presence of impacted groundwater in shallow monitor wells MV-1 and MV-2 indicates the presence of perched groundwater in the vicinity of Transect 1. Groundwater in the alluvial channel may be discontinuous or limited in areal extent in the vicinity of Transects 1 and 2. Perched groundwater appears to be captured by the Canyon 4/Mangas Wash interceptor/barrier trench (C4TU-1 and C4TU-2) in the vicinity of Transect 5 (Figure 6-4).

Groundwater samples from three of the shallow borings were collected and analyzed. Total naphthalene concentrations exceeded the Section 3103 standard of 0.03 mg/L in borings 286-2011-02 and 286-2011-03, with concentrations of 0.21 mg/L and 0.79 mg/L, respectively (Figure 6-4). The benzene standard for groundwater of 0.01 mg/L was exceeded in boring 286-2011-03 with a concentration of 0.07 mg/L. Diesel phase-separated hydrocarbon (PSH) was observed or measured in boring 286-2011-04 and in perched zone monitoring wells 286-2010-02, MV-1, and MV-2.

Based on these findings, shallow perched groundwater is impacted by diesel where it occurs in the alluvial channel, and the downgradient extent of perched alluvial groundwater is limited to the vicinity of Transect 5, adjacent to the Canyon 4/Mangas Wash interceptor/barrier trench. The presence and extent of perched groundwater likely changes with climatic conditions. When perched water is present, it becomes impacted by infiltrating or flowing though diesel-impacted alluvium. When perched water is not present, the diesel-impacted alluvium is unsaturated and part of the vadose zone. The total mass of hydrocarbons impacting both the unsaturated and saturated portions of the alluvial aquifer was estimated at approximately 700,000 pounds, which is about 100,000 gallons of diesel equivalent mass.

#### 6.3.1.2 Description of Abatement Options

Several remedial technologies were identified for initial consideration to address impacted groundwater and sediments associated with the historical release of diesel fuel along Mangas Wash. As explained below, none of these technologies are believed to be highly effective to achieve remediation of the diesel-contaminated groundwater and sediments in the former concentrator area. The primary reasons for this are the physical characteristics of the contaminant (diesel fuel is not as volatile as other petroleum products, such as gasoline), the limited saturated thickness and ephemeral nature of the perched groundwater zone, and the observation that much of the diesel contamination exists within impacted sediments above the water table. The technologies considered for an initial screen are:

- Monitored natural attenuation
- Soil excavation and off-site disposal
- Soil vapor extraction (SVE)
- Pumping and treatment of perched groundwater
- In-situ bioremediation with monitored natural attenuation

Each of these technologies is discussed below.

*Natural attenuation* is degradation due to naturally occurring physical, chemical, and biological processes. These processes may include one or more of the following: biodegradation, dispersion, dilution, adsorption, and volatilization. Under monitored natural attenuation, the degradation of the diesel would be allowed to occur at natural rates, with limiting factors, including the redox potential of the aquifer, remaining uninfluenced by anthropogenic processes. The rate of degradation would be evaluated through the collection of water quality data from existing monitor wells. Any residual contaminated perched groundwater would be captured at the downgradient Canyon 4/Mangas Wash interceptor/barrier trench (Figure 6-4).

Under the *soil excavation and off-site disposal* technology, contaminated soils would be excavated and disposed of at a landfill licensed for the disposal of hydrocarbon-impacted soil. In this approach, clean soils would be stockpiled on-site and diesel-impacted soils would be excavated and disposed of off-site. Contaminated soil excavation would be accomplished using traditional excavation equipment (excavators, loaders, etc.). Hauling of contaminated soils would be performed in lined trucks by entities permitted for this type of waste hauling. It is estimated that as many as 1.3 million cubic yards ($yd^3$) of soil would need to be handled under this remedial alternative, with approximately 325,000 $yd^3$ of soil requiring off-site disposal.

*SVE* is a common technology used for remediation of volatile contaminants in the vadose zone. SVE systems generally consist of a number of wells plumbed to a central vacuum blower and treatment system. The vacuum blower draws air from the soil pore space and volatilizes contaminants. The contaminated air is then treated, typically using granular activated carbon or thermal/catalytic oxidation, prior to discharge to the atmosphere.

*Pumping and treating of impacted groundwater* is a widely applied technology. While several treatment alternatives exist, treatment of hydrocarbon-impacted groundwater typically uses some combination of air stripping and granular activated carbon filtration.

*In-situ bioremediation with monitored natural attenuation* would be undertaken using a slurry amendment that introduces oxygen into the subsurface. The slurry has a flushing effect in the capillary fringe and provides oxygen over an extended period of time to enhance bioremediation. Introduced oxygen is generally distributed through the subsurface initially by injection and subsequently by groundwater movement. A number of commercially available amendments are available to accomplish enhancement of in-situ bioremediation.

#### *6.3.1.3 Assessment of Abatement Options*

Soil excavation is an immediate and effective response to soil impacts and requires no treatment equipment operation and maintenance. However, it requires a very substantial cost relative to the limited amount of vadose zone contamination that exists at the site. In addition, a portion of the diesel contamination lies below the former concentrator area, which has already been reclaimed, and some lies below or adjacent to aboveground storage tanks and other infrastructure related to the Tyrone Power Plant, which prevent the excavation of impacted soil in these areas.

Pump and treat can be effective for impacted groundwater, but would rely on natural infiltration to mobilize contaminants in the capillary fringe. Due to the seasonality and limited extent and thickness of perched groundwater in the alluvial sediments, the remedial time frame under this alternative is likely very long, and groundwater extraction rates (and therefore overall effectiveness) would be limited. As already noted, diesel-impacted perched groundwater is already captured and removed at the Canyon 4/Mangas Wash interceptor/barrier trench.

SVE is a proven technology for hydrocarbon remediation in the vadose zone. However, because the primary hydrocarbon at the site is diesel fuel, the volatilization rate would be very slow and this approach would be much less effective than it would be at non-diesel petroleum-contaminated sites. In addition, the relatively thin, extended nature of the impacted sediments would make physical access (i.e., through wells) to conduct SVE of impacted soils difficult.

In-situ bioremediation requires periodic injections of costly amendments over a number of years, with a similar level of effort each time. Because the technology relies on enhancement of natural degradation processes, remedial time frames may be long. A significant impediment to this approach is that in order for it to be effective throughout the diesel-impacted soil and groundwater, the natural occurrence and flow of perched groundwater would have to be relied on as the mechanism to distribute the amendment away from injection points and throughout the impacted alluvium. This approach has a great deal of uncertainty and is likely to lead to significant improvements to water quality being realized in only limited zones.

#### *6.3.1.4 Proposed Abatement Approach*

Based on the above analysis and conclusions, Tyrone proposes that monitored natural attenuation and plume-front containment be conducted for impacted perched zone groundwater in the former concentrator area. Monitored natural attenuation for the impacted groundwater is an appropriate abatement approach because the downgradient extent of diesel-impacted perched groundwater is contained by the Canyon 4/Mangas Wash interceptor/barrier trench (Figure 6-4), and the effectiveness of the containment is monitored. Furthermore, diesel contamination will remain in the vadose zone if it is not flushed and will degrade naturally over long time periods (e.g., decades).

### 6.3.2 Regional Groundwater

Regional groundwater in the former concentrator area occurs in the Gila Conglomerate roughly 200 feet below the perched alluvial groundwater. Diesel-impacted regional groundwater has been confirmed at wells 32, 33, and 48 (Plate 6-2). The direction of regional groundwater flow is generally toward the southwest, where it is ultimately captured at the hydraulic sink formed by pumping at the Main Pit. Regional monitor wells P-232 and P-233, northwest of wells 32, 33, and 48, have exhibited no indications of diesel contamination and confirm that groundwater flow is toward the pit, rather than north toward the Mangas Valley (Plates 5-1 and 6-2).

#### *6.3.2.1 Current Water Quality Conditions*

Groundwater in four regional aquifer monitor wells, P-232, 32, 33, and 48, was monitored in March 2011 (DBS&A, 2011b). Well 33 contained 0.52 foot of free-phase diesel fuel, and product sheen was observed at well 48; therefore, these wells were not sampled. The thickness of free-phase diesel measured in a well is greater than the equivalent thickness in the adjacent formation by about a factor of 2 to 10; thus the observed diesel thickness of 0.52 foot in well 33 would be equivalent to about 0.26 to 0.05 foot of diesel in the Gila Conglomerate adjacent to the well bore. A water quality sample was collected from well 32 and analyzed for benzene, toluene, ethylbenzene, and total xylenes (BTEX) and total petroleum hydrocarbons (TPH). Except for benzene, concentrations of these compounds were below laboratory detection limits. The detected benzene concentration was 0.0006 mg/L, well below the Section 3103 standard of 0.01 mg/L. Another water quality sample was collected from well 32 in August 2011 and BTEX and TPH were not detected above the laboratory detection limits in this sample.

This information is consistent with field observations made in August 2006, when approximately 5.7 feet of free-phase diesel was measured at well 33, a slight organic odor was noted at well 48, and wells 32, P-232 and P-233 exhibited no organic odor or other indication that they were impacted by diesel (DBS&A, 2006). Comparison of the observations for free-phase diesel thickness indicates a reduction in about 5 feet between 2006 and 2011. Some portion of the free-phase diesel may have migrated downgradient from well 33 over the 5-year time span, but a more likely explanation is that a significant portion of the free-phase product became residual fluid in the unsaturated zone above the regional water table, as the water table at well 33 has declined about 15 feet over the equivalent time period.

During the Stage 1 APP investigation, a product recovery test was attempted in regional aquifer monitor well 33, which has historically contained some measurable thickness of free-phase diesel fuel since discovery of the diesel pipeline leak in 1997. A measurement taken on April 7, 2011 indicated 0.39 foot of free product in a 1-inch sounding tube installed adjacent to the well casing (or about 0.2 to 0.04 feet of free product in the adjacent formation). The well was found to be obstructed and not suitable for bailing. Due to the small thickness of free-phase product, a recovery test was not feasible.

Impacts to regional groundwater are limited to existing wells 33, 48, and 32 and have been interpreted to be the result of an improper well construction at wells 32 and 33 that allowed fuel product to flow into the deeper regional aquifer. Given that diesel fuel is a light nonaqueous-phase liquid that will float on water, this seepage of product down the well bore would be possible only if there were no perched groundwater at these wells for some period of time. Wells 32 and 33 were drilled out, the bottoms were plugged with grout, and new, properly sealed well casings were installed in 1998 (DBS&A, 1999c).

#### *6.3.2.2 Proposed Abatement Approach*

Tyrone proposes monitored natural attenuation for abatement of the regional diesel contamination in the former concentrator area. Groundwater monitoring results indicate that the extent of diesel contamination in regional groundwater is limited and, more importantly, is contained by the existing (and future) configuration of the groundwater flow field. Degradation of the diesel would be allowed to occur at natural rates, with limiting factors such as redox potential of the aquifer remaining uninfluenced by anthropogenic processes. The rate of degradation would be evaluated through the collection of water quality data from existing monitor wells. Any residual contaminated regional groundwater will ultimately be captured by the Main Pit (Plate 6-2).

## 6.4 South Side and Upper East Side Areas

Perched and regional groundwater is present in the South Side and Upper East Side Mine/Stockpile Unit peripheral zones (Figure 2-2). Since these peripheral areas are contiguous, they are discussed together in this section. The perched and regional groundwater zones are discussed in Sections 6.4.1 and 6.4.2, respectively.

### *6.4.1 Perched Groundwater*

Perched groundwater exists in the shallow alluvium of Upper Oak Grove Wash due to infiltration of precipitation and runoff and, at some locations, seepage from waste rock stockpiles (Nos. 7A and 1C) along the south side of the mine (Plate 6-3). The alluvium is about 30 to 40 feet deep and overlies quartz monzonite or granite. Perched fluid (predominantly PLS) also occurs in alluvium at the toes of the Nos. 1A and 1B leach stockpiles, where it is collected at interceptor/barrier trenches. The alluvium in these areas occurs in drainages that are tributary to either Brick Kiln Gulch or Upper Oak Grove Wash. The effectiveness of these capture systems is monitored.

#### *6.4.1.1 Current Water Quality Conditions*

Plate 6-3 illustrates the approximate current extent of perched groundwater in the South Side area based on shallow monitor wells in Upper Oak Grove Wash. Where perched water occurs, it is generally impacted and exceeds Section 3103 standards for multiple constituents. However, the perched zone groundwater on the South Side is, for the most part, less impacted than perched groundwater in Brick Kiln Gulch and Oak Grove Wash farther to the east, as discussed in Section 7. This is probably because the perched zone on the South Side is impacted primarily by waste rock pile seepage, whereas the perched groundwater farther to the east is impacted primarily by poorer-quality leach stockpile seepage.

A significant amount of reclamation activity has been ongoing on the South Side over the past several years. The No. 1C waste rock pile is partially reclaimed and is expected to be completely reclaimed in 2012, and the same is true of the No. 7A waste rock pile (Plate 6-3). A portion of the No. 1C waste rock pile formerly covered Oak Grove Wash, but the pile was pulled back and the original course of Upper Oak Grove Wash is being restored. As part of these reclamation activities, toe drains and seepage collection trenches have been and are being installed to collect impacted water before it reaches the perched groundwater zone beneath Upper Oak Grove Wash.

The perched fluid that occurs in the alluvium immediately adjacent to the Nos. 1A and 1B leach stockpiles is predominately PLS, and it exceeds numerous Section 3103 water quality standards. The extent of this fluid is not illustrated on Plate 6-3 because it occurs in a limited area between the trenches and the stockpile toes.

#### *6.4.1.2 Proposed Abatement Approach*

The proposed abatement approach for the South Side perched groundwater is monitored natural attenuation. This approach is selected because source controls are partially in place and will be fully in place by the end of 2012, and implementation of these controls should lead to significant improvement of water quality through time. In addition, impacted water will eventually flow down the Upper Oak Grove Wash perched zone and be extracted at the Upper Oak Grove interceptor/barrier trench (Plate 6-3); therefore, the downgradient extent of impacted water is contained, and the effectiveness of the containment is monitored.

The proposed abatement approach for perched fluid in the Upper East Side area immediately adjacent to the Nos. 1A and 1B leach stockpiles is to continue operating the existing interceptor/barrier trenches during operations and closure. The existing seepage collection facilities have been effective in capturing perched seepage and limiting the downgradient extent of perched fluids, and the performance of the systems will continue to be monitored. Once the leaching operations are stopped at the Nos. 1A and 1B leach stockpiles and the stockpiles are reclaimed, the volume of seepage in the perched zones adjacent to the stockpiles will be reduced significantly or eliminated altogether.

### *6.4.2 Regional Groundwater*

Regional groundwater beneath the South Side and Upper East Side exists in quartz monzonite and granite.

#### *6.4.2.1 Current Water Quality Conditions*

Recent water quality measured in regional groundwater monitor wells is illustrated in Plate 6-3. In the far southwest corner of the mine, water quality generally meets all Section 3103 standards or exceeds only a single standard, such as that for fluoride or manganese due to background conditions (e.g., wells 2-11, 2-13, 2-15, 166-2008-01, and 166-2008-02 on Plates 5-1 and 6-3). Moving downgradient (east) from these locations, however, regional groundwater is impacted at several monitoring locations immediately adjacent to waste rock piles. For example:

- Wells 2-12, 455-2005-02, and MB-32 exceed the Section 3103 standards for TDS and sulfate.
- Well 396-2006-02 exceeds the standards for these constituents as well as those for aluminum, cadmium, cobalt, copper, fluoride, manganese, pH, and zinc.
- Well 396-2006-02 is typical of the level of groundwater impacts observed at some other wells formerly adjacent to the eastern toe of the No. 1C waste rock pile that had to be abandoned due to reclamation activities (i.e., wells MB-18D and MB-15).

Well MB-44 on the south side of the Sprouse-Copeland Fault, about 2,200 feet south of well 396-2006-02, meets all Section 3103 standards, with no increasing or decreasing trends in observed TDS and sulfate concentrations, which are about 550 and 170 mg/L, respectively. Although some impacted regional water may seep across the Sprouse-Copeland Fault (Section 7), the major groundwater flow pathway from well 396-2006-02 appears to be due north, parallel to the Sprouse-Copeland Fault, until the vicinity of wells MB-12 and MB-35, where it turns to the east-southeast when it enters the more permeable Gila Conglomerate.

#### *6.4.2.2 Proposed Abatement Approach*

The proposed abatement approach for regional groundwater in the South Side and Upper East Side areas is monitored natural attenuation, supplemented by regional groundwater extraction. Continued monitoring is appropriate because significant reclamation and other source control measures have recently been implemented on the south side of the mine and will be completed in 2012. In addition, multiple monitor wells that meet Section 3103 standards are downgradient of the wells that exceed standards, including wells 363-2006-01, 363-2005-01, and MB-12. Former well MB-17 met Section 3103 standards until it was plugged and abandoned in December of 2007.

In addition to monitored natural attenuation, a regional groundwater extraction system (marked as regional extraction system 1 on Plate 6-3) is proposed for the general vicinity of monitor wells 396-2006-02 and MB-32. As noted above, this area has been characterized by significant historical groundwater impact, and there may also be some seepage of regional groundwater across the Sprouse-Copeland Fault. The actual extraction system still needs to be designed, but an approximate zone of groundwater capture estimated using the Tyrone groundwater model for a combined extraction rate of 50 to 60 gpm from three extraction wells is illustrated on Plate 6-3. Tyrone proposes to operate this system so long as the extracted groundwater exceeds Section 3103 standards. Operation of this system may be stopped (regardless of the extracted water quality) if the second system described below is constructed in the future. This approach is appropriate because groundwater flow at this location is predominantly north, and impacted groundwater would ultimately be captured at the second system if it is built.

In addition to the regional extraction system described above, a second extraction system will be implemented if conditions warrant. This second system could be operated in conjunction with, or in lieu of, the first system depending on the results of future groundwater monitoring. If a second regional groundwater extraction system is implemented, it would likely be placed on the west (upgradient) side of the Sprouse-Copeland Fault to capture impacted water before it seeps across the fault or flows north into the Gila Conglomerate and turns east-southeast (see system No. 2 on Plate 6-3). Details of a second extraction system will be designed when and if one is needed. Preliminary simulations conducted using the updated Tyrone groundwater flow model indicated that three to four pumping wells with a combined total extraction rate of about 30 to 50 gpm would create a zone of capture large enough to capture the potential region of impacted water (Plate 6-3).

The need for the second extraction system will be based on observed constituent concentrations at wells MB-12 and MB-35 and the MB-36 replacement well. If these wells, or potentially other monitor wells constructed in the future, indicate that a plume of regional groundwater that exceeds Section 3103 standards is migrating unabated to the east-southeast beneath Brick Kiln Gulch/Oak Grove Wash, then the second regional groundwater extraction system will be considered. Design and implementation of the system will be based on the observed data.

# 7. Oak Grove Wash/Brick Kiln Gulch APP Study Area

This section discusses the current situation regarding impacted perched and regional groundwater and proposes Stage 2 abatement measures for the Oak Grove Wash/Brick Kiln Gulch APP study area (Figure 2-2), which consists of what is referred to as the East Side of the Tyrone Mine. This area is separated from the adjacent Mine/Stockpile APP study area by the Sprouse-Copeland Fault, which is approximately coincident with Highway 90 as it runs north-south past the mine. Known or potential sources of groundwater impacts in this area include the No. 1 leach stockpile (approximately 200 acres reclaimed in 2009) (Figure 7-1), the Burro Mountain tailing impoundment (approximately 70 acres reclaimed in 2004), and seepage from the Nos. 1A and 1B leach stockpiles and the No. 1C waste rock pile (partially reclaimed during 2011) that migrated from the west into this area, primarily within perched zones in the alluvium that fills the channels of the washes. Perched water occurs in this area in the wash alluvium within about 30 to 90 feet of land surface; the alluvium gets thicker moving downstream. Regional groundwater occurs in the Gila Conglomerate, and the regional aquifer water table is about 400 to more than 500 feet below the base of the perched water.

## 7.1 Perched Groundwater

East Side perched groundwater refers to shallow water in the alluvium (about 100 feet deep or less) of Upper and Lower Oak Grove Wash and Brick Kiln Gulch. Section 7.1.1 and 7.1.2 discuss current perched water quality and the abatement technologies considered, respectively. Perched groundwater conditions immediately adjacent to the Nos. 1A and 1B leach stockpiles (called the Upper East Side in this report) and the No. 1C waste rock pile are addressed in Section 6.4.1.

### *7.1.1 Current Water Quality Conditions*

Results of a 1996 East Side perched seepage investigation indicated that PLS was escaping the collection systems of the Nos. 1, 1A, and 1B stockpiles and was migrating in alluvium-filled channels eroded into the Gila Conglomerate (DBS&A, 1996a, 1996b). Seepage of a quality consistent with acid mine drainage was also migrating through the No. 1C stockpile into a similar alluvium-filled channel. The seepage-containing alluvial channels are referred to as perched seepage zones, as groundwater in this alluvial zone is several hundred feet higher in elevation than regional groundwater, which occurs in the Gila Conglomerate below the alluvium. Impacted perched groundwater exists within Brick Kiln Gulch and Lower Oak Grove Wash from the vicinity of the No. 1 leach stockpile down to the series of monitor wells referred to as Oak Grove Transect 6, a distance of approximately 2 miles (Plate 7-1). When it was discovered in 1996, the extent of perched PLS seepage was approximately 3.4 miles from the No. 1A leach stockpile.

Ongoing East Side activities are a continuation of remedial investigations and seepage assessments that began at the No. 1A leach stockpile in 1996 (DBS&A, 1996a). These activities include:

- Operation and monitoring of the collection systems at the Nos. 1A and 1B stockpiles and at the Oak Grove trench to capture and remove fugitive PLS seepage issuing from these stockpiles

- Remedial pumping from the residual perched seepage zones downgradient of the PLS collection trenches (pumping currently occurs at four well transects if saturation exists)

- Monitoring of remedial pumping rates, water levels, and field chemical parameters in the perched seepage zones, as well as water sampling for laboratory analysis

- Monitoring of water levels and field chemical parameters in the regional aquifer, as well as water sampling for laboratory analysis

In order to evaluate whether transient pulses of saturation occur within the Oak Grove Wash perched zone, in May 2007 transducers were installed in perched zone monitor wells OG-3 of Oak Grove Transect 1 and OG-61 of Oak Grove Transect 6 (Plate 7-1) (DBS&A, 2011b). Data collected at both locations indicated variability in the amount of perched water present:

- Data collected at OG-3 indicated that pulses of water move through the alluvium following significant precipitation events or a cumulative series of smaller events. The primary source of perched groundwater at this location is believed to be the infiltration of surface water that enters the wash from tributary drainages, since perched water upgradient of this location is captured by the Upper Oak Grove interceptor/barrier trench (Plate 7-1).

- Observed water levels at OG-61 did not appear to correlate as well to discrete periods of precipitation, although some correlation was evident (DBS&A, 2011b). Because this well is farther downgradient in Oak Grove Wash and no collection trench is capturing perched water beneath the main stem of Brick Kiln Gulch, the sources of perched water at this location appear to be more diffuse and persistent.

Monitoring data indicate that the perched groundwater generally exceeds Section 3103 standards for TDS, sulfate, pH, fluoride, and multiple metals. However, the pH of the perched water increases with distance down Oak Grove Wash (Plate 7-1), and at downgradient well OG-20, the perched water meets standards for all constituents except TDS and sulfate.

Figures 7-2 through 7-4 illustrate the observed concentrations of copper, fluoride, manganese, pH, sulfate, and TDS for perched zone wells OG-25, OG-23, OG-40, OG-46, OG-21 and OG-20 (as with Plate 7-1, where a value is not plotted, the well was dry during that sampling event). As shown in Figures 7-2 through 7-4, constituent concentrations generally improve moving downgradient along Oak Grove Wash.

In summary, impacted water migrates through alluvium within Upper Oak Grove Wash, Brick Kiln Gulch, and Lower Oak Grove Wash subsequent to recharge events. At some locations, this impacted water is likely in addition to residual seepage within the alluvium from previous recharge events or residual seepage from adjacent mine facilities. It appears that a significant source of impacts to the perched water is remobilization of residual salts and metals within the alluvium from former PLS seepage. Because the residual mass of salts and metals adsorbed to the soil is unknown, the duration of the selected remedy within the washes is indeterminate. Low pH (which makes the metals more mobile) has persisted in the perched water for more than a decade after remedial measures were first implemented. Since all of the considered remedies (Section 7.1.2) rely on flushing of the impacted sediments, each remedy is expected to be required for at least several decades.

### 7.1.2 Assessment of Abatement Options

Based on the results of previous investigations, a variety of best available treatment technologies for remediation of the contaminants of concern were evaluated:

- Monitored natural attenuation (MNA)
- Continued operation, and possibly enhancement, of the existing extraction system
- In-situ treatment through permeable reactive barriers
- Containment using low-permeability barriers
- Enhanced groundwater extraction through horizontal well and interceptor trenches

Selected combinations of these technologies were also considered. Each remedial alternative was evaluated based on treatment effectiveness and implementability of the solution at the site, as discussed in the following subsections and Table 7-1.

#### *7.1.2.1 Monitored Natural Attenuation*

Under this technology, metal and soluble salt concentrations would decrease as a result of infiltration of waters through the impacted native materials. Decreases in concentrations would be evaluated through the collection of water quality samples from existing wells.

#### *7.1.2.2 Continued Operation and Enhancement of the Existing Extraction System*

The existing impacted groundwater containment system consists of the Upper Oak Grove interceptor/barrier trench and pumping wells at Transects 1, 6, 7, and 9 (Plate 7-1). Multiple collection trenches with monitor wells have also been installed along the toes of the Nos. 1, 1A, 1B, and 1C stockpiles. The continuation of the existing system option continues pumping and collection at these existing locations and operation and maintenance as needed.

Enhancement of the existing system includes the installation of up to four new extraction wells and telemetry systems that would be required to ensure that pumping rates are adjusted to extract the maximum amount of water in response to precipitation events.

#### 7.1.2.3 In-Situ Treatment through Permeable Reactive Barriers

In-situ treatment includes the installation of permeable reactive barriers (PRBs) within the washes. For the impacted water in Upper Oak Grove Wash and Brick Kiln Gulch, the PRBs would be designed to reduce the concentrations of metals in the groundwater, but they would likely have little effect on TDS and sulfate concentrations. Conceptually, PRBs transform the metals from soluble to insoluble precipitates as groundwater passes through the reactive media. The composition of the reactive media is dependent upon the water quality and target contaminants. The thickness of the barrier is determined by taking into account both the chemical precipitation reaction time and groundwater velocity. PRBs would be located in transverse alignments in both Upper Oak Grove Wash and Brick Kiln Gulch and would be installed to a depth of approximately 40 ft bgs. PRB(s) were not considered for Lower Oak Grove Wash due to the greater depth of alluvium (about 100 feet) and because they are not effective for TDS and sulfate.

#### 7.1.2.4 Containment Using Low-Permeability Barriers

Containment would be achieved with the installation of low-permeability slurry walls. These can be installed in a number of ways, including as overlapping jet-grouted members or as a semi-solid cement/bentonite barrier installed with traditional excavation equipment including clam shells. The containment structures could be installed either in conjunction with or in lieu of the PRBs, again in transverse alignments to Upper Oak Grove Wash and Brick Kiln Gulch (Plate 7-1).

If installed with the PRBs, the slurry walls would serve as funneling structures that would direct groundwater through the PRBs. If installed with a groundwater extraction system, the slurry wall would act as a physical barrier (subsurface dam) that would pond impacted water behind it. This approach would allow a more predictable pumping rate since the impacted water can be extracted from behind the wall over time periods longer than the precipitation events that generate recharge to the perched zone. Slurry walls in Upper Oak Grove Wash and Brick Kiln Gulch would be installed to depths of approximately 40 ft bgs. Due to thicker alluvium, a slurry wall in Lower Oak Grove Wash would be installed from 50 to 100 ft bgs, depending on the selected location.

#### 7.1.2.5 Enhanced Groundwater Extraction

Groundwater extraction can occur using either a single well located immediately upgradient of a slurry wall, a horizontal well installed parallel to groundwater flow in the main channel, or interceptor trenches. Extraction would occur using submersible pumps controlled by transducers, which would allow pumping of water during the sporadic recharge events that characterize the perched groundwater flow regime. Submersible pumps would be sized to pump to either a storage and treatment system dedicated to the site or a centralized treatment system elsewhere on the mine property. Based on historical water level data, it is anticipated that extraction pumping rates from the entire site would be on the order of 20 to 30 gallons per minute (gpm). Pumping of individual areas would result in commensurately lower pumping rates. As with the PRBs, the interceptor trenches are considered only for the upper reaches of the perched groundwater system (Plate 7-1) due to the depth of alluvium.

#### 7.1.2.6 Summary of Abatement Technology Evaluation

Table 7-1 summarizes the evaluation of the remedial technologies and addresses issues including short-term and long-term effectiveness and implementability. All of the remedies that were evaluated can be implemented, although additional data collection would be useful or necessary prior to the implementation of some technologies.

### 7.1.3 Proposed Abatement Approach

Several abatement options, described in Section 7.1.2 and summarized in Table 7-1, were considered in the context of site hydrogeologic conditions and other factors listed in the table. Ultimately, PRBs were rejected because they probably could not be constructed to effectively treat all constituents of concern for the observed water quality in the washes. Likewise, continuation of the existing system without modification was also rejected because it is not known how effective the systems are in extracting the majority of impacted water that may move through the washes after storm events. Enhancement of the existing system with additional wells, transducers, and telemetry would allow for more rapid and efficient extraction of impacted water when storm surges occur, but peak pumping would be required at the same time that other mine facilities are dealing with large influxes of surface water. In addition, it is difficult to capture all impacted water using vertical wells, since the pumps need some amount of saturation adjacent to the well to operate (i.e., the pump cannot extract water until the adjacent perched zone is entirely dry). A horizontal well would alleviate this limitation to a large degree and would provide for the more effective extraction of impacted water, but construction of such a well at the base of the alluvium for a substantial distance along the wash, although possible, would be challenging.

The most practical and effective abatement approach is believed to be as follows:

1. Construct a low-permeability barrier (commonly called a slurry wall) within the alluvium below the confluence of Upper Oak Grove Wash and Brick Kiln Gulch. Impacted water that collects behind (upgradient of) the barrier would be extracted using a dedicated pumping well and added to the mine operational circuit or (at closure) sent to the water treatment plant. The final location of the barrier would be selected based on additional analysis, but it would likely be placed at or close to Oak Grove Transect 9 (Plate 7-1).

2. Continue the existing abatement pumping at downstream locations (Oak Grove Transects 6 and 7). With implementation of the low-permeability barrier, pumping Transects 1 and 9 would be eliminated.

3. Monitor changes in the perched zone system using a series of transducers along Oak Grove Wash, primarily below the low-permeability barrier, to determine if additional abatement may be necessary in the future.

This proposed approach was selected for the following reasons:

- The low-permeability barrier below the confluence of the washes will capture storm surges of perched water from Upper Oak Grove Wash (as described in DBS&A, 2011b) and residual seepage and/or storm surges from Brick Kiln Gulch. In addition, the proposed location is downgradient of the reclaimed No. 1 leach stockpile and the majority of the reclaimed Burro Mountain tailing impoundment and is therefore positioned to capture potential subsurface seepage from either of these facilities that may enter Oak Grove Wash or Brick Kiln Gulch.

- The low-permeability barrier will pond water behind it in the subsurface, thereby creating storage capacity. Surges in perched water can thus be stored and extracted over a period of time, which is a more tractable and efficient approach than trying to extract surges of perched water as they occur after precipitation events.

- The selected location for the low-permeability barrier is upgradient of the location where the Mangas Fault crosses Oak Grove Wash (Plate 7-1), and therefore impacted water will not be ponded at the fault location. Ponding water on top of the fault is not desirable because the downward seepage of impacted water could be enhanced if in fact the fault is a pathway for vertical seepage.

- The selected location for the low-permeability barrier is one where the alluvial sediments are not too deep (about 50 to 60 feet), the width of the alluvial channel is relatively narrow, and the geometry of the channel as determined from Oak Grove Transect 9 drilling is simple and well-defined (Plate 7-1). These conditions will aide ease of design and construction and the ultimate effectiveness of the proposed abatement.

- Implementation of the low-permeability barrier will effectively capture perched zone flows, and the resulting effects on perched zone water levels downstream in Oak Grove Wash will be readily apparent. Continued monitoring will provide the basis to make informed decisions concerning additional abatement measures required in the future, if any.

## 7.2 Regional Groundwater

Regional groundwater in the East Side area east of the Sprouse-Copeland Fault occurs primarily in Gila Conglomerate. The Sprouse-Copeland Fault acts as an impediment (barrier) to groundwater flow, as evidenced by the fact that regional groundwater elevations on the east (downthrown) side of the fault are approximately 200 feet lower than observed water levels on the west (upthrown) side of the fault (Plate 7-2). West of the fault, the direction of regional groundwater flow is primarily north until it reaches the general vicinity of wells MB-12 and MB-35, where it turns and flows southeast. East of the fault, the direction of groundwater flow is primarily to the east-southeast (Plate 7-2). Comparison of the observed water levels for the perched groundwater in Oak Grove Wash and Brick Kiln Gulch (Plate 7-1) with the regional water levels (Plate 7-2) illustrates that the regional water table is from about 350 to more than 500 feet below the base of the perched alluvial water.

### *7.2.1 Current Water Quality Conditions*

The current water quality for East Side regional wells is illustrated in Plate 7-2. Most of the wells in this area meet Section 3103 standards. Wells MB-41, MB-35, MB-12, MB-28, MB-31 and 363-2005-01 appear unaffected by mining activities based on the low sulfate and TDS concentrations. At well MB-28 the observed manganese value of 0.3 mg/L exceeds the Section 3103 standard of 0.2 mg/L, but given the observed concentrations of the other constituents, the exceedance is believed to be attributable to background conditions. In addition to the wells illustrated on Plate 7-2, two additional monitor wells farther down Oak Grove Wash (wells MB-4 and MB-8) meet all Section 3103 standards (Plate 5-1).

Several other wells that meet standards, including MB-42, 363-2005-03, 363-2005-02, MB-43 and 363-2006-01 (Plate 7-2), have probably been impacted by seepage of mine fluids. These wells exhibit elevated TDS and sulfate above that which would be expected for background conditions, although at some of these wells (i.e., MB-42, MB-43 and 363-2006-01), these constituents are trending downward. Some of the water quality impacts may be due to limited seepage of impacted water vertically downward or across faults. For example, the portion of the Sprouse-Copeland Fault between wells MB-32 (west side of the fault) and well 363-2006-01 (east side of the fault) was previously identified by DBS&A (2007) as a zone of possible seepage based on the observed water level at well MB-32. Seepage of impacted water across this portion of the Sprouse-Copeland Fault could be the source of apparent impacts to well 363-2006-01. Well MB-17 in this same area was plugged and abandoned due to reclamation activities at the No. 1C waste rock pile. However, from 1987 through 2008, this well met Section 3103 standards, although it probably had some impacts due to mining as indicated by 2008 TDS and sulfate concentrations of about 410 and 190 mg/L, respectively.

Wells MB-42, 363-2005-03, 363-2005-02, and MB-43 have likely been impacted by seepage of impacted perched water down the Mangas Fault where it crosses Oak Grove Wash or through some other pathway. Two wells with the longest period of record, wells MB-42 and MB-43, exhibit declining trends in sulfate and TDS, likely attributable to perched zone remediation efforts (Plate 7-2).

Well MB-33 currently exceeds the Section 3103 TDS standard and is close to the standard for sulfate. This well is most likely affected by seepage that originated from the No. 1 leach stockpile or its associated facilities such as the No. 1 PLS pond. Seepage may have migrated vertically downward along the Mangas Fault, which passes underneath the stockpile or beneath portions of Brick Kiln Gulch. Reclamation of the No. 1 leach stockpile and its associated collection ponds and facilities was completed in 2009. For about the past 5 years the TDS and sulfate trends observed at well MB-33 have been relatively flat, with some variation up and down from year to year (Plate 7-2).

Well MB-27 is immediately adjacent to the Sprouse-Copeland Fault and consistently exceeds Section 3103 standards for TDS and sulfate, although these constituent concentrations appear relatively flat over the past several years (Plate 7-2). Observed TDS and sulfate at this well are about 3,300 and 1,700 mg/L, respectively. The most likely source of impacts to this well is deep seepage of PLS from the No. 1A leach stockpile down, or across, the Sprouse-Copeland Fault. Wells MB-29 and its replacement (in 2005), 363-2005-04, exhibit increasing TDS and sulfate concentrations for most of their period of record, although the observed sulfate trend at well 363-2005-04 appears to be stabilizing at about 1,000 mg/L (Plate 7-2). The groundwater sampled by these wells has been impacted through downward migration of PLS from the overlying perched zone or by horizontal migration of impacted water from the west through some unknown preferential zone of groundwater flow. The former explanation is believed to be more likely. Perched zone remediation efforts have extracted the impacted perched water that overlies this location, although precipitation events can lead to periods of revived saturation.

### *7.2.2 Proposed Abatement Approach*

The proposed abatement approach for impacted regional water in the Oak Grove Wash/Brick Kiln Gulch APP study area is monitored natural attenuation. With source controls recently completed in the area (i.e., reclamation of the No. 1 leach stockpile and the Burro Mountain tailing impoundment and partial reclamation of the No. 1C waste rock pile), abatement of impacted perched water through pumping and capture trenches, and the proposed additional perched and regional groundwater abatement actions proposed in Sections 7.1.3 and 6.4.2.2, respectively, the observed TDS and sulfate concentrations should decrease through time, although the decline may not be immediate and the time-frame to reach Section 3103 standards is unknown. Tyrone will continue monitoring all East Side wells as required by the operational DPs and DP-1341.

This approach is appropriate because:

- The extent of impacted water that exceeds one or more Section 3103 standards is limited.
- Significant source controls are in place, and additional source controls (additional perched zone abatement) will be implemented as part of this Stage 2 APP.
- Observed TDS and sulfate concentrations that exceed standards have leveled out at wells MB-27 and MB-33, and sulfate has leveled out at well 363-2005-04 (TDS is still increasing).
- Multiple observation wells that meet Section 3103 standards exist downgradient of all wells that exceed standards, and the downgradient wells do not exhibit increasing concentrations of TDS or sulfate.

# 8. Monitoring Program

Item 20.6.2.4106 E(4) NMAC lists the following requirement relative to a monitoring program for Stage 2 abatement activities:

> *Modification, if necessary, of the monitoring program approved pursuant to Stage 1 of the Abatement Plan, including the designation of pre and post abatement-completion sampling stations and sampling frequencies to be used to demonstrate compliance with the standards and requirements set forth in 20.6.2.4103 NMAC*

The monitoring program proposed and approved as part of the Stage 1 APP was to continue monitoring in accordance with all existing DP requirements or, as the DPs are renewed, updated requirements (DBS&A, 2004). Additional monitoring conducted as part of Stage 1 APP investigation activities was to be reported under the applicable operational DP that includes the location where the monitoring occurred. In some cases the results of unique Stage 1 APP investigation and monitoring activities, such as high-frequency water level monitoring using transducers in selected monitoring wells, were reported in addenda to the Stage 1 APP (DBS&A, 2006, 2011b) or in DP-1341 conditional study reports (e.g., DBS&A, 2007).

Tyrone proposes to continue with the same approach, where monitoring will comply with the requirements of the existing operational DP that encompasses the geographic location of a given groundwater abatement activity. If a monitoring activity falls outside an operational DP area, monitoring requirements and reporting will be the same as those required for that area. For example, within the former DP-27 area (Mangas Valley Tailing Area) monitoring data are reported quarterly under the DP-27 Settlement Agreement. This proposed approach to the monitoring program is currently followed and is therefore readily implementable. Furthermore it is flexible because DPs are renewed and updated every 5 years, and the DP renewal and updating process is a logical mechanism for dealing with changes or updates to abatement measures and associated monitoring that may be required in the future.

# 9. Site Maintenance Activities to be Performed After Termination of Abatement Activities

Item 20.6.2.4106 E(5) NMAC stipulates that, if needed, site maintenance activities proposed to be performed after termination of Stage 2 abatement activities should be included as part of the Stage 2 APP. Site maintenance activities required to be performed after the termination of abatement activities at Tyrone are primarily related to source control provisions, such as inspection and maintenance of the vegetated covers. Tyrone proposes, therefore, that all post-abatement maintenance activities be conducted in accordance with the latest version of the CCP in place at the termination of Stage 2 abatement activities. Tyrone believes that there is no need to propose a separate set of post-abatement activities as part of the Stage 2 APP.

# 10. Schedule and Duration of Abatement Activities

A schedule and duration for abatement activities is provided in Table 10-1. As summarized in the table, many abatement activities, including source control, have already been accomplished or are in process. Examples include reclamation of the Mangas Valley tailing impoundments (Figures 3-2 and 3-3) and the No. 1 leach stockpile (Figure 7-1). Most other proposed Stage 2 abatement actions will be initiated within 2 to 3 years of Stage 2 APP approval, which is anticipated to occur in the second quarter of 2012. The schedule for some major closure activities, such as the covering and regrading of stockpiles within the interior region of the Mine/Stockpile APP study area, is not currently known because the mine is active.

# 11. Public Notification and Participation Proposal

In accordance with NMAC 20.6.2.4108 B and C, Tyrone will provide the NMED Secretary proof of public notice within 30 days of filing this Stage 2 APP. The public will be notified, in both English and Spanish, through publication of a notice in newspapers of general circulation in New Mexico and in Grant County. The notice will also be provided by certified mail to the following:

- Any persons who have specifically requested notification from the NMED Secretary
- The New Mexico Trustee for Natural Resources and other local, state and federal governmental agency affected by this plan
- Owners and residents of surface property located inside and within 1 mile from the perimeter of the geographic area where the standards are exceeded at the site
- The Governor or President of each Indian tribe, Pueblo, or Nation within the state of New Mexico.

An example of the general form of the notice is provided as follows:

**NOTICE OF SUBMITTAL OF**
**STAGE 2 ABATEMENT PLAN PROPOSAL**
**Date of Notice: To Be Determined, 2012**

Notice is hereby given by Freeport-McMoRan Tyrone, Inc. (Tyrone) of the submittal to the New Mexico Environment Department (NMED) of a Stage 2 Abatement Plan Proposal for the Tyrone Mine site near Silver City, New Mexico, as follows:

1. The responsible party is:

   Freeport-McMoRan Tyrone, Inc.
   P.O. Box 571
   Tyrone, NM  88065

2. The site is located approximately 10 miles south of Silver City, New Mexico.

3. Tyrone holds multiple ground water discharge permits for Tyrone, including Closure Permit DP-1341, which requires Tyrone to implement specified closure actions following the conclusion of mining operations and requires abatement of ground water contamination related to discharges from mining operations in accordance with the

regulations adopted by the Water Quality Control Commission. NMED has approved Tyrone's Stage 1 Final Site Investigation Report for investigation of the impacted groundwater, and has authorized Tyrone to develop a Stage 2 Abatement Plan Proposal. The Stage 2 Abatement Plan Proposal provides an overview of current site conditions and proposes abatement measures for different areas with impacted groundwater at the site to be implemented in addition to the closure activities required by DP-1341. The closure activities already specified under DP-1341, and not changed by the Stage 2 Abatement Plan Proposal, include regrading and installation of covers on mine stockpiles and tailing piles. These closure measures already have been implemented on all tailing impoundments at the Tyrone Mine and some stockpile areas. The additional proposed abatement activities include installation of new structures to control water contaminants in some areas, enhanced pumping of impacted groundwater in some areas, and groundwater monitoring to assess the results.

4. The Secretary of the NMED will review the Stage 2 Abatement Plan Proposal following an opportunity for public comment, including a possible public meeting or a hearing as described below, and will either approve the proposal or notify the responsible person of any deficiencies. If no public meeting or hearing is held, the Secretary shall notify the responsible person of approval or any deficiency within ninety (90) days of receiving the proposal. If a public meeting or hearing is held, then the Secretary shall notify the responsible person of approval of the proposal or of any deficiencies, based on the information contained in the proposal and information submitted at the meeting or hearing, within sixty (60) days of receiving all required information. If the Secretary notifies the responsible person of deficiencies in the proposal, the responsible person is required to modify the proposal to cure the specified deficiencies within thirty (30) days of receipt of notice of the deficiency. If the requirements of the abatement regulations are met, the Stage 2 Abatement Plan Proposal will result in the standards and requirements of section 20.6.2.4103 NMAC being met within a schedule that is reasonable, given the particular circumstances of the site, and the Secretary shall approve the Stage 2 Abatement Plan Proposal.

5. This notice is intended to notify the public that the Stage 2 Abatement Plan Proposal is being made available for public comments and requests for a public meeting or hearing. Written comments or requests for a public meeting or hearing will be accepted and considered if provided by the deadline set forth below.

6. A copy of the Stage 2 Abatement Plan Proposal can be viewed by interested parties at the following NMED offices:

   NMED Ground Water Quality Bureau
   3082 E. 32nd Street Bypass, Suite D
   Silver City, NM 88061

   NMED Ground Water Quality Bureau
   Harold Runnels Building Room N2250
   1190 Saint Francis Drive
   Santa Fe, NM 87502

7. Written comments on the Stage 2 Abatement Plan Proposal and requests for a public meeting or hearing that include a statement of the reasons why a public meeting or hearing should be held, will be accepted for consideration if sent to the Secretary, at the address below, within sixty (60) days after the Secretary determines that the Stage 2 Abatement Plan Proposal is administratively complete.

8. Interested persons may obtain further information by contacting:

   Mr. Kurt Vollbrecht
   Mining Environmental Compliance Section
   Ground Water Quality Bureau
   New Mexico Environmental Department
   P.O. Box 5469
   Santa Fe, New Mexico 87502
   505-827-0195

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