Final Groundwater Restoration Plan for the Chino, Cobre, and Tyrone Mine Facilities

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Contents

Executive Summary

The New Mexico Office of Natural Resources Trustee (ONRT) has engaged in a cooperative Natural Resource Damage Assessment and Restoration (NRDAR) process for the Freeport-McMoRan Copper & Gold Inc. (FMI) mine sites near Silver City, New Mexico. Groundwater resources have been injured by hazardous substances released from three copper mining facilities owned by FMI. The mines include:

- **Chino Mine:** Located approximately 12 miles east of Silver City, New Mexico, this mine is east of the Continental Divide in the Mimbres watershed. Open-pit mining began in 1910. The mine was temporarily closed in January 2002 but has since reopened. The estimated areal extent of groundwater plumes at the Chino Mine was 13,935 acres.

- **Cobre Mine:** Located approximately 3 miles north of Hanover, New Mexico, this is the smallest of the three mine sites. The mine is east of the Continental Divide in the Mimbres watershed. The mine has a long history of iron ore production. Commercial copper production by underground methods began in 1858; underground copper mining ended in 1971. The mine was closed from 1982 to 1993 due to low copper prices and went on standby in 1999. Although the mine has received approval to resume mining and expand operations, it has not yet resumed mining. The estimated areal extent of groundwater plumes at the Cobre Mine was 528 acres.

- **Tyrone Mine:** Located approximately 10 miles southwest of Silver City, New Mexico, the open-pit mine straddles the Continental Divide and the Mimbres and Gila River basins. Turquoise, copper, and fluorspar were mined in the area from the late 1870s through the early 1900s. Open-pit copper mining began in 1967. Since 1992, the mine has been solely a copper leaching operation. The estimated areal extent of groundwater plumes at the Tyrone Mine was 6,280 acres.

ONRT undertook a groundwater assessment for these three mines. As part of this assessment, ONRT assessed and quantified injuries to groundwater resources and successfully brought claims against FMI for groundwater damages. FMI paid $13 million to settle allegations that the company injured groundwater resources as a result of discharges of hazardous substances from the Chino, Cobre, and Tyrone mines.

In this Groundwater Restoration Plan (RP) for the Chino, Cobre, and Tyrone Mine Facilities, ONRT identifies and evaluates proposed restoration projects and determines which projects would best compensate the public for injuries to groundwater resources that resulted from the release of hazardous substances from the three mines. ONRT solicited a broad range of potential restoration projects from local, state, and federal agencies; nonprofit organizations; and stakeholder groups. ONRT identified 18 potential restoration projects that were described in the

Draft RP. During the public comment period, an additional three projects were identified and included in the evaluation process. All projects were re-evaluated after the public comment period to take into account the additional information obtained during the public comment period. Projects were evaluated using screening and evaluation criteria developed by ONRT that are consistent with federal regulations. To be considered for further evaluation, a project had to meet the following criteria:

- Be technically and administratively feasible
- Affect groundwater resources, either directly or indirectly
- Provide an overall net environmental benefit
- Comply with applicable and relevant federal, state, local, and tribal laws and regulations.

Projects that passed the screening criteria were assessed using a set of evaluation criteria that were designed to evaluate which projects best provided cost-effective, appropriate compensation for injured groundwater resources. Projects were evaluated based on the following set of criteria:

- Potential for long-term success and a low risk of failure
- Feasible and cost-effective operations, maintenance, and monitoring
- Ability to proceed without NRDAR funding
- Proximity to the injury (Gila and/or Mimbres water basins)
- Cost-effectiveness compared to other projects that provide similar benefits
- Consistency with regional planning and federal and state policies
- Likelihood to provide benefits quickly after project implementation.

Based on an evaluation of the proposed restoration projects, ONRT selected a diverse, regional portfolio of groundwater restoration projects that would yield maximum benefits to regional groundwater resources and are consistent with current approaches to regional water planning in the area. Projects that are suitable for funding were grouped into two funding tiers. Tier 1 projects have top priority for funding (Table S.1); Tier 2 projects will be considered for funding if funding is available after Tier 1 projects have received funding.

Projects presented as Tier 1 projects were ranked highest based on application of the screening and evaluation criteria outlined above. Tier 1 projects will be funded in two rounds: a first round of funding is expected to be provided in 2012 and a second round of funding is expected to be made available in the second half of 2012 or 2013. The funding amounts for the second round may be adjusted depending on the availability of funds at that time. Tier 2 projects meet the screening and evaluation, but were ranked lower than the Tier 1 projects. If funding is available after completing the Tier 1 projects, Tier 2 projects will be considered for funding. Given the large number of projects in Tier 1 and Tier 2 (and a cumulative cost for these projects that far exceeds the settlement funding available), ONRT placed Tier 3 projects from the Draft RP into the category of "not recommended for funding" for the Final RP.

Table S.1. Restoration projects selected for funding as Tier 1 projects

Project title (location)	Project description	Proposed funding
Proposed for first round of funding		
San Vicente Creek Mill Option 2 (Silver City)	Full offsite removal of hazardous substances at the San Vicente Creek Mill to avoid ongoing groundwater contamination	$4,800,000
Santa Clara Wellhead Protection (southwest of Village of Santa Clara)	Construct structures to prevent infiltration of contaminants into drinking water wells and groundwater	$109,000
Santa Clara Gravity Sewer Improvements (along Cameron Creek in Village of Santa Clara)	Improve and protect main sewer lines in Santa Clara to prevent re-occurrence of sewage spills into Cameron Creek and associated alluvial groundwater	$316,000
Silver City North/Blackhawk Sewer Line Extension (Silver City)	Extend a sewer line to enable additional household connections and eliminate use of faulty septic systems that contaminate groundwater	$310,000
Proposed for second round of funding		
Bayard Reuse (City of Bayard)	Develop infrastructure to enable groundwater conservation by using treated wastewater for irrigation	$4,000,000[a]
Hurley Sewer Lines Replacement (Town of Hurley)	Replace failing clay sewer pipes with modern impermeable materials to avoid groundwater contamination	$1,375,000[a]
Anticipated total cost for Tier 1 projects		**$10,910,000**

a. Funding amounts may be adjusted depending on availability of funds.

Additional information can be requested by contacting:

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An electronic version of the Final RP is posted on the Natural Resource Damage Assessment website: www.onrt.state.nm.us/ChinoCobreTyrone.html.

1. Introduction

This Final Groundwater Restoration Plan (RP) for the Chino, Cobre,[1] and Tyrone Mine Facilities describes projects that will improve groundwater resources and services in the general vicinity of Silver City, New Mexico. The projects are meant to compensate for the injuries to groundwater resources when hazardous substances,[2] including copper and other heavy metals, were released from three copper mining facilities owned by Freeport-McMoRan Copper & Gold Inc. (FMI)[3] in Grant County, New Mexico. The mines include:

- Chino Mine – located approximately 12 miles east of Silver City
- Tyrone Mine – located approximately 10 miles southwest of Silver City
- Cobre Mine – located approximately 3 miles north of Hanover.

These facilities are referred to as "the Sites" throughout this plan. Their locations are shown in Chapter 2 (Figure 2.1).

The restoration projects described in this plan were identified by the New Mexico Office of Natural Resources Trustee (ONRT) through discussions with local, state, and federal agencies; nonprofit organizations; and stakeholder groups. ONRT is the state agency that implements New Mexico's NRDAR Program. The purpose of this program is to compensate the public through environmental restoration for injuries to natural resources. Restoration projects are paid for with damage settlement funds received from responsible parties.

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1. The Cobre Mine is also known as the Continental Mine.

2. The term "hazardous substance" refers to a hazardous substance as defined in Section 101(14) of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), federal Natural Resource Damage Assessment and Restoration (NRDAR) regulations 43 CFR § 11.14(u). This includes hazardous substances designated or listed by Sections 311(b)(2)(A) and 307(a) of the Federal Water Pollution Control Act (i.e., the Clean Water Act, or CWA), by Section 102 of CERCLA, by Section 3001 of the Solid Waste Disposal Act (i.e., the Resource Conservation and Recovery Act, or RCRA), or Section 112 of the Clean Air Act.

3. FMI is used in this document to collectively refer to any or all of the following entities: the Freeport-McMoRan Corporation, Freeport-McMoRan Chino Mines Company, Freeport-McMoRan Tyrone Inc., Freeport-McMoRan Tyrone Mining LLC, and Freeport-McMoRan Cobre Mining Company.

The purpose of this RP is to inform the public about the groundwater resources that were injured by releases of hazardous substances at the Sites and to present the restoration projects that will compensate the public for these injuries. ONRT released a Draft RP on September 20, 2011, and held a 60-day public comment period. ONRT considered written comments received during the comment period (including comments received during a public meeting held in Silver City) prior to publishing this revised, Final RP. This RP includes a summary of comments received and Trustee responses to those comments (Chapter 7). The restoration actions described in this document are conceptual. Detailed designs and costs will be developed for restoration projects that have been selected for funding prior to implementation.

This introductory chapter explains the responsibility and legal authority of ONRT to develop this plan, summarizes the settlement that occurred between FMI and the State of New Mexico, and describes the role of public involvement in developing this RP.

1.1 Trustee Responsibilities and Authorities

ONRT's authority to pursue NRDAR is identified in the New Mexico Natural Resources Trustee Act [NMSA 1978, §§ 75-7-1 et seq.] and in the following federal statutes:

- CERCLA, as amended [42 U.S.C. § 9601 et seq.]
- CWA [33 U.S.C. §1251 et seq.]
- Oil Pollution Act of 1990 (OPA) [33 U.S.C. 2701–2761 et seq.].

As part of ONRT's NRDAR responsibilities, ONRT assessed and quantified groundwater injuries associated with the Sites and successfully brought claims against FMI for groundwater damages. A copy of the settlement consent decree can be found at http://onrt.state.nm.us/documents/FMI-NMConsentDecreesignedbyJudge021111.pdf.

1.2 Summary of Groundwater Natural Resource Damage Settlement for FMI Mines

ONRT and FMI reached a $13 million settlement for the injuries to groundwater resources resulting from the release of hazardous substances from the Sites. The settlement includes $12,794,000 for the restoration of groundwater resources, plus an additional $206,000 for the reimbursement of outstanding damage assessment costs paid to ONRT. The New Mexico Legislature appropriated $1,500,000 for interstate water litigation. There is currently $11,294,000 available for groundwater restoration planning and implementation.

A settlement for injuries to other natural resources, including birds and wildlife, is in the process of negotiation between FMI, ONRT, and the U.S. Department of the Interior Fish and Wildlife Service. Once settled, a restoration plan for projects to address these other natural resources will be prepared at a later date and made available for public review.

1.3 Summary of Natural Resource Injuries

Groundwater monitoring data reviewed by ONRT showed that hazardous substances from the Sites had contaminated groundwater, resulting in injuries to groundwater, as defined in the federal NRDAR regulations [43 CFR § 11.14(v)].

Specific definitions of injury to groundwater resources include:

- Concentrations of substances in excess of drinking water standards, established by Sections 1411–1416 of the Safe Drinking Water Act (SDWA), or by other federal or state laws or regulations that establish such standards for drinking water, in groundwater that was potable before the discharge or release [43 CFR § 11.62(c)(1)(i)]
- Concentrations of substances sufficient to have caused injury as defined in paragraphs (b), (d), (e), or (f) of this section to surface water, air, geologic, or biological resources, when exposed to groundwater [43 CFR § 11.62(c)(1)(iv)].

1.4 Need for Restoration under CERCLA

The objective of the NRDAR process is to compensate the public, through environmental restoration, for natural resources that have been injured, destroyed, or lost as a result of the release of hazardous substances into the environment. Damage settlements for resource restoration can only be used to restore, rehabilitate, replace, or acquire the equivalent of these natural resources. The amount, or "scale," of restoration required to compensate for these losses depends on the spatial extent and severity of resource injuries, the time period over which resources have been injured, and the time required for resources to return to baseline conditions.

This RP has been developed to evaluate and select restoration projects designed to compensate the public for injuries that have occurred to groundwater resources at the Sites. Selected restoration projects will be implemented over a period of time, depending on the project type.

In a process distinct from the NRDAR activities undertaken by ONRT, remediation actions (termed "response actions") will be conducted under the oversight of the New Mexico Environment Department (NMED) with the objective of controlling exposure to released

hazardous substances in order to protect human health and the environment. Because response actions at the Sites are ongoing, ONRT has chosen to focus on restoration alternatives that will not conflict with or be put at risk from any planned or proposed response actions.

1.5 Coordination and Public Involvement

1.5.1 Coordination with the responsible party

The assessment process for the Sites was conducted as a cooperative assessment with FMI. Cooperative assessments (like this one) can increase the cost-effectiveness of the process by facilitating the sharing of information and avoiding the duplication of study efforts. Input from FMI was sought and considered throughout the assessment process. However, ONRT had the final authority to make determinations regarding injury and restoration for groundwater resources.

1.5.2 Public participation

The Draft RP was published on September 20, 2011. A press release of the availability of the Draft RP and request for public comments also was released on September 20, 2011. The public was invited to comment on the content of the Draft RP and to propose additional potential projects to restore injured groundwater resources. The public comment period for the Draft RP was September 20, 2011 through November 3, 2011, with an extension to November 18, 2011. A public meeting was held on October 4, 2011, in Silver City, New Mexico. At this meeting, ONRT presented information about the restoration process and the projects described in the Draft RP and answered questions about the Draft RP.

Copies of the Draft RP were made available at the following locations:

The Public Library
515 West College Avenue
Silver City, NM 88061

Bayard Public Library
1120 Central Avenue
Bayard, NM 88023

Gila Valley Library
400 Highway 211
Gila, NM 88038

An electronic version of the Draft RP was posted on the natural resource damage assessment website: www.onrt.state.nm.us/ChinoCobreTyrone.html.

2. Overview of the Sites

This chapter overviews the mine facilities, water resources, and mining history and summarizes remedial actions for the three Sites: Chino, Tyrone, and Cobre mines.

2.1 Mine Facilities and Water Resources

The Sites, located in southwestern New Mexico, are open-pit and underground copper and iron mining, beneficiation, and processing facilities owned and operated by FMI (Figure 2.1).

2.1.1 Chino Mine

The Chino Mine is located approximately 12 miles east of Silver City in Grant County, New Mexico. The site includes the following mine areas and associated facilities (Daniel B. Stephens & Associates, 1999; Golder Associates, 2008) (Figure 2.2):

- North Mine Area
  - Santa Rita Pit and associated stockpiles
  - West of pit area (West, South, and Upper South Stockpile areas; Ivanhoe Concentrator and Former Precipitation Plant; Groundhog Mine Area; Bull Frog Tailing Area)
  - Lampbright Stockpile Area
  - Solvent Extraction/Electrowinning (SX/EW) Plant and mine water/stormwater/process water reservoirs (e.g., Reservoirs 3A, 5, and 8)
- Middle Whitewater Creek Area
- South Mine Area
  - Hurley Smelter
  - Lake One
  - Axiflo Lake
  - Old Tailings Impoundment Area (Impoundments 1, 2, B, C, 6W, 4, and 6E)
  - Tailings Impoundment 7 Area
  - Lower Whitewater Creek Area (south of Tailings Impoundment 7 along creek).

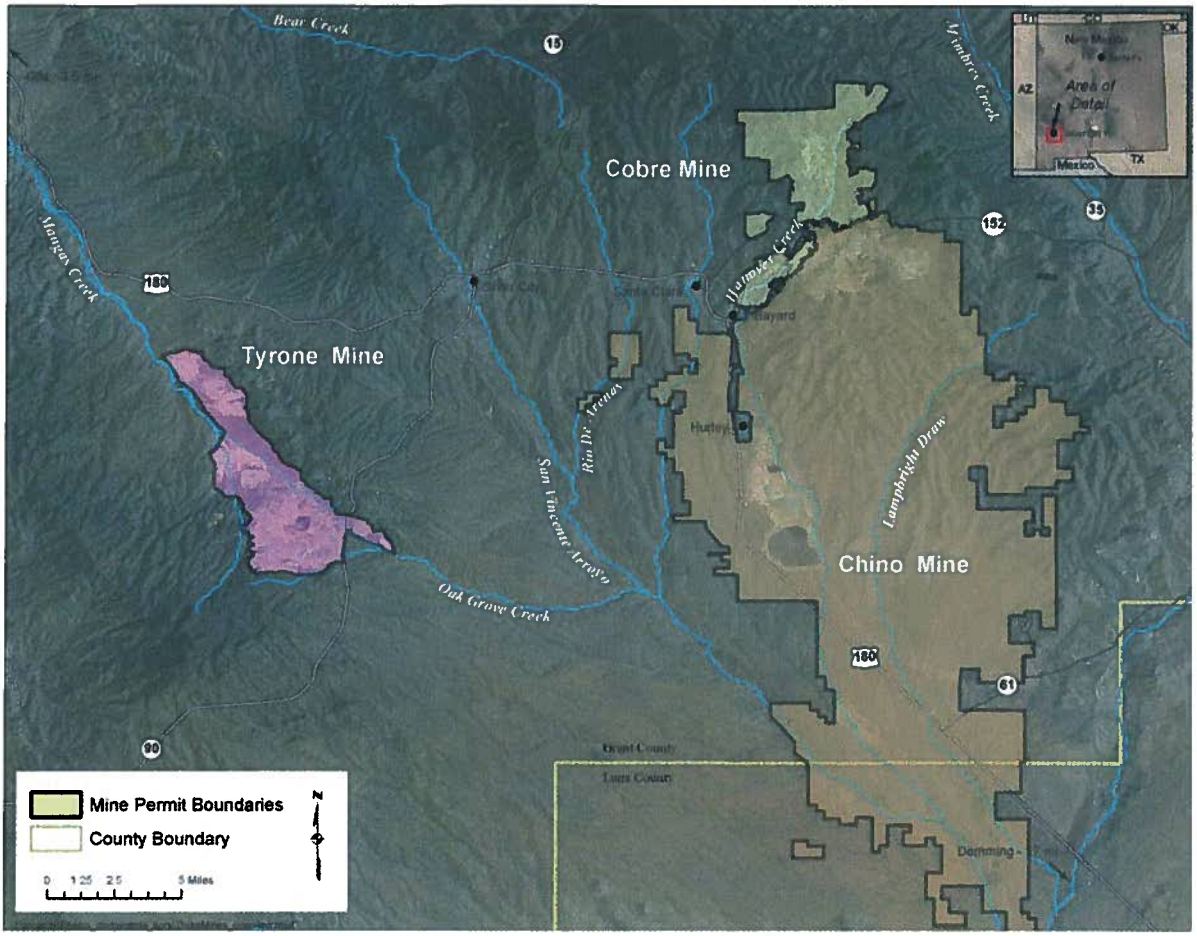

Figure 2.1. Overview of the Chino, Tyrone, and Cobre mines.

Surface water resources

The Chino Mine is east of the Continental Divide in the Mimbres watershed. The Mimbres River is a closed-basin desert stream and a well-defined river channel that terminates approximately 10 miles east of Deming, New Mexico (NMWRRI, 2000). Major drainages at the Chino Mine include Whitewater Creek, Hanover Creek, and Lampbright Draw. Hanover Creek is an ephemeral stream that originates northeast of the Chino Mine and joins Whitewater Creek near the Ivanhoe Concentrator. Whitewater Creek is an ephemeral stream that runs from the North Mine Area to the South Mine Area. Whitewater Creek flows into the San Vicente Arroyo south of the mine. Lampbright Draw is an ephemeral stream draining the eastern portions of the North Mine Area that flows south and eventually joins the San Vicente Arroyo (M3 Engineering & Technology, 2001).

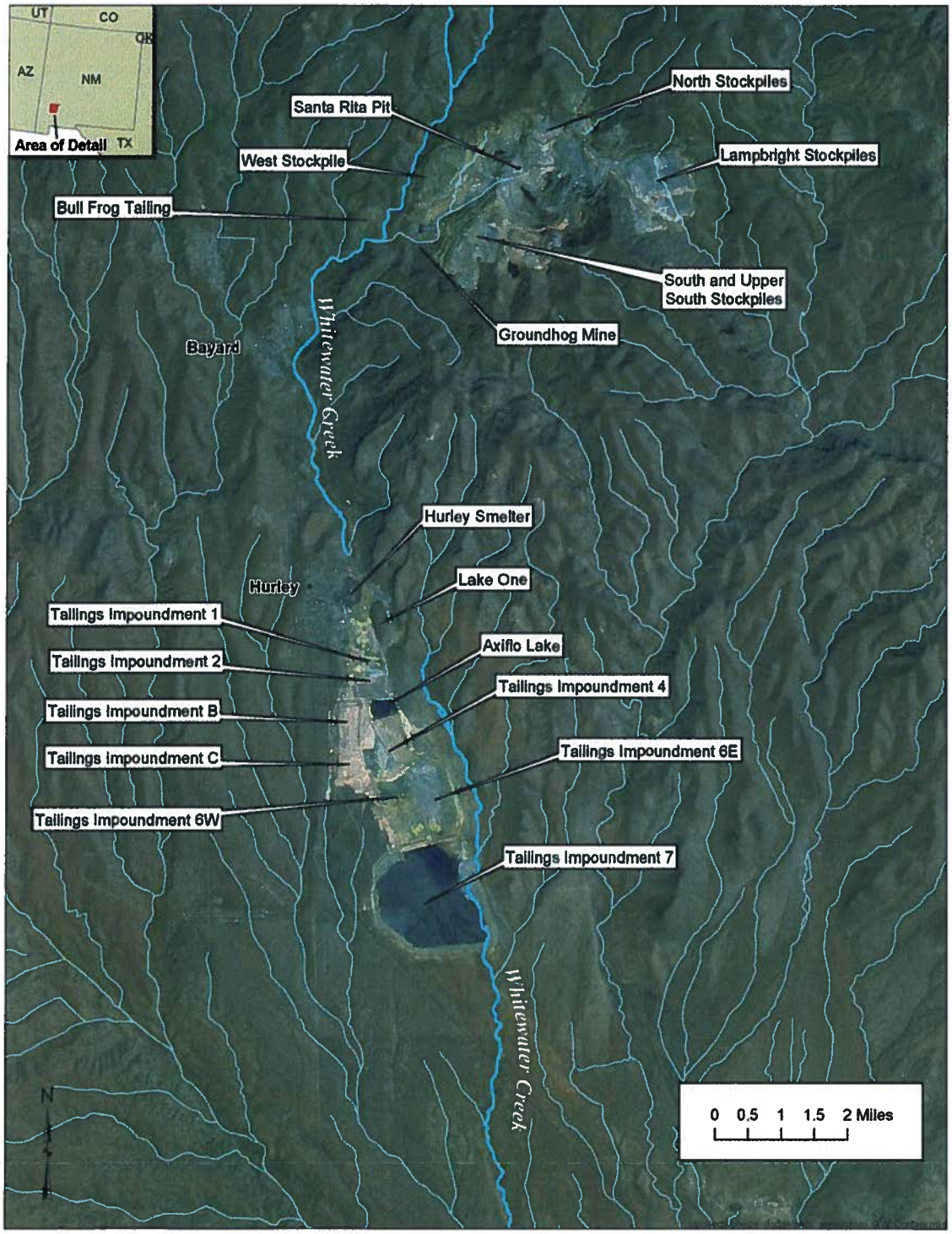

Figure 2.2. Hydrologic features and mine facilities at the Chino Mine.

Geology and groundwater resources

The major aquifers at the Chino Mine include the Gila Conglomerate, igneous and sedimentary rock units, and Quaternary alluvium.

The geology and hydrogeology of the Chino Mine vary widely in the three major geographic areas of the site: the North Mine Area, the Middle Whitewater Creek Area, and the South Mine Area. The ability of rocks to contain and transmit groundwater is a function of the geology of rock (rock type), the amount of open pore spaces or fractures/faults in the rock, the amount of water that infiltrates from the surface, and the groundwater gradient.

The *North Mine Area* contains a complex array of igneous (plutonic and volcanic) and sedimentary rock units and numerous near-vertical, north-to-northeast trending faults (Golder Associates, 2008). The oldest rocks in the area are sedimentary rocks (generally sandstones, limestones, and shales) that were deposited during the Paleozoic (570 to 230 million years ago) and Cretaceous (140 to 65 million years ago) periods. The ore body is largely hosted in the Santa Rita Stock, a plutonic igneous rock that ranges from granodiorite to quartz monzonite in composition (similar to granite). The stock was intruded into the older sedimentary rocks. After the mineralization of the copper deposit, volcanic rocks, including rhyolite tuffs and basaltic-andesitic lava flows, blanketed the igneous intrusion south of what is now the Santa Rita Pit area (see Figure 2.2). The Santa Rita Stock was extensively fractured and cut by intrusive dikes, especially in the areas west of the pit. The composition of the dikes is similar to that of the stock.

The rocks in the North Mine Area generally have low primary porosity and hydraulic conductivity, although higher values can exist in the sedimentary units. Groundwater flow in the plutonic and volcanic units in the North Mine Area is predominantly through the abundant fractures.

The *Middle Whitewater Creek Area* is located geographically between the North and South Mine areas and extends from Gold Gulch in the north (near the Town of Bayard) to the Town of Hurley in the south (see Figure 2.2). The most important aquifer in the Middle Whitewater Creek Area is the alluvium along Whitewater Creek (Golder Associates, 2008). In the north end of the area, the underlying bedrock is principally igneous (quartz diorite sill), and south of Bayard the bedrock consists largely of volcanic tuffs. The thickest alluvium (> 100 feet) is located around Bayard. South of Bayard the alluvium varies from approximately 5 to 20 feet thick and from 500 to 3,000 feet wide.

The *South Mine Area* geology and hydrogeology are dominated by the Gila Conglomerate. Alluvium of varying thickness lines and underlies Whitewater Creek in this area. Volcanic rocks outcrop to the east of the tailings impoundments, and limestones outcrop on the western side of the impoundments. The Gila Conglomerate was formed essentially as an alluvial fan, filled

streambeds and lakes, and is composed of gravel on the large end to clays on the small end (Golder Associates, 2008). The Gila Conglomerate in Grant County is divided into upper and lower units. The upper part of the upper unit has the highest porosity and ability to transmit water and is the most important aquifer in the area (Trauger, 1972). The Gila Conglomerate pinches out on the north end, near Lake One, and thickens to the south, where it is approximately 500-feet thick south of Tailings Impoundment 7 and up to 1,000-feet thick farther to the south (Figure 2.2).

2.1.2 Tyrone Mine

The Tyrone Mine is located approximately 10 miles southwest of Silver City, New Mexico, in southwest Grant County. The site includes the following mine areas and associated facilities (Daniel B. Stephens & Associates, 2004) (Figure 2.3):

- Mine/Stockpile Area
  - Main Pit, Gettysburg Pit, Copper Mountain Pit (and several smaller pit areas)
  - SX/EW Plant
  - Pregnant Leach Solution (PLS) Collection Impoundments
  - Mill and Concentrator Facilities
  - Former Precipitation Plant Area and Acid Unloading Area
  - Leach Stockpiles (Nos. 1, 1A, 1B, 2, 2A, 3, East Main, Gettysburg Out Pit, and Gettysburg In Pit stockpiles)
  - Waste Stockpiles (Nos. 1C, 1D, 3B, a portion of the 2B, Savanna, and Upper Main stockpiles)
- Oak Grove Wash/Brick Kiln Gulch Area
  - No. 1 Leach Stockpile
  - Burro Mountain Tailings Impoundment
- Mangas Valley
  - Nos. 1, 1A, 1X, 2, 3X, and 3 Tailings Impoundments.

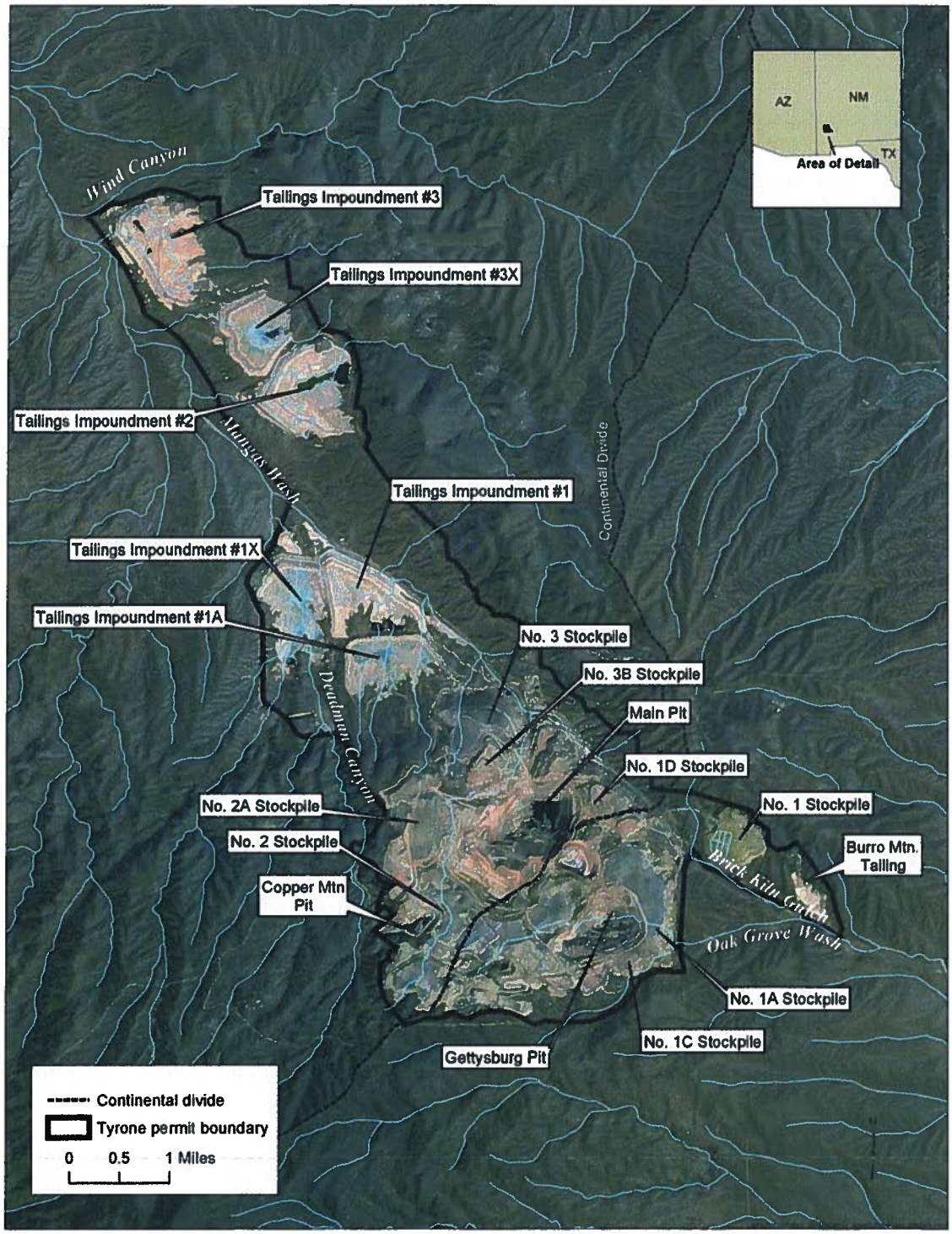

Figure 2.3. Hydrologic features and mine facilities at the Tyrone Mine.

Surface water resources

The open pit straddles the Continental Divide (Figure 2.3). Before open-pit mining, the pit area drained toward the northwest into Mangas Creek, an ephemeral stream that flows north into the Gila River, and toward the southwest into Brick Kiln Gulch and Oak Grove Wash, which flow into the Mimbres River. Because open-pit mining and associated dewatering operations have altered the hydrologic regime, some groundwater that would have flowed into the Gila and Mimbres basins is now captured by pit dewatering operations (M3 Engineering & Technology, 2001).

Geology and groundwater resources

The most important hydrogeologic units at the Tyrone Mine are the Gila Conglomerate, alluvium along the creeks and washes, and the igneous rocks in and around the open pit and stockpiles. The copper ore body is contained in a granite-like igneous rock and is bounded by several major faults on the western, eastern, and southern sides (Daniel B. Stephens & Associates, 1999). This igneous rock (quartz monzonite) is located under and around the open pit and stockpiles, along the eastern flanks of Deadman Canyon, and near the 1A leach stockpile in Oak Grove Wash.

As noted for the Chino Mine, the Gila Conglomerate is a sedimentary rock with a range of porosities and is derived from the physical weathering of local mountains. The most permeable portion of the Gila Conglomerate, the upper Gila, is located under the northern end of the No. 3 leach stockpile in uppermost Mangas Wash just downgradient of the stockpile, and downgradient of the No. 1 and 1A stockpiles in Oak Grove Wash (see Figure 2.3).

The younger alluvial material is the most porous material on the site and was deposited directly on the Gila Conglomerate. Alluvium lines Deadman Canyon, Oak Grove Wash/Brick Kiln Gulch, small tributaries of the upper Mangas Wash under and downgradient of the No. 3 leach stockpile, and Mangas Wash under and downgradient of all the tailings impoundments (see Figure 2.3 for locations). Groundwater is present in the alluvium but is not necessarily continuous in underlying, lower-permeability, igneous rocks or the Gila Conglomerate (i.e., the upper portions of the regional aquifers are not saturated with groundwater). Shallow groundwater that is not directly connected to underlying regional groundwater is called "perched." Perched water in the Tyrone Mine area may feed groundwater to deeper regional groundwater (Daniel B. Stephens & Associates, 1997c, 2004).

Igneous rocks on the western side of the site have been upthrown hundreds of feet along the Sprouse-Copeland Fault, a regional, nearly vertical, north-trending fault in the upper/middle portion of Oak Grove Wash, and moved directly against the Gila Conglomerate (Daniel B. Stephens & Associates, 1999). The regional Mangas Fault runs in a northwesterly direction on the eastern side of the Mangas Wash and Brick Kiln Gulch. The Gila Conglomerate is thickest

on the northeastern side of the Mangas Fault and is only a few feet thick on the southwestern side. Faulting can increase the porosity of adjacent rocks due to the increased fracturing associated with the fault. The large differences in groundwater levels across faults at the Tyrone Mine suggest that they inhibit groundwater flow between different rock types across the faults (Daniel B. Stephens & Associates, 1997c).

2.1.3 Cobre Mine

The Cobre Mine is located approximately 3 miles north of Hanover, New Mexico, in Grant County. The site includes the following main mine facilities (Shepherd Miller, 1999; M3 Engineering & Technology, 2001; Telesto Solutions, 2005) (Figure 2.4):

- Continental Pit
- Continental underground mine and workings
- West, East, South, Buckhorn, and Union Hill Waste Rock Disposal Facilities (WRDFs)
- Low-grade and high-grade ore stockpiles
- Main tailings impoundment
- Magnetite tailings impoundment.

Surface water resources

The site drains into Hanover Creek and the Mimbres River watershed. Hanover Creek headwaters are in the Pinos Altos Range to the north of the site. The creek is perennial only for a short distance adjacent to the Towns of Hanover and Fierro, possibly due to contributions from local septic system outfalls, and downstream of Fierro Spring (Shepherd Miller, 1999; M3 Engineering & Technology, 2001). Hanover Creek flows into Whitewater Creek, which flows southward to the Chino Mine. Ephemeral drainages on the mine site include Grape Gulch, Poison Spring Drainage, and Buckhorn Gulch. These drainages usually flow only after summer thunderstorms (M3 Engineering & Technology, 2001). Perennial springs and seeps exist on the site, including Fierro Spring; seeps in Grape Gulch, Gap Canyon, and Poison Spring, which are located upstream of the mine; and Buckhorn Gulch Spring and seeps along Hanover Creek, which are downstream of mining activity.

Geology and groundwater resources

Even though the Cobre Mine is the smallest of the three sites, it has the most complex geology. More than 30 types of igneous rock exist at the site, including sills, dikes, stocks and plugs, older sedimentary rocks, younger volcanic rocks, and more recent alluvium (M3 Engineering & Technology, 2001). The alluvium is limited to an approximately 0.75-mile stretch of Hanover

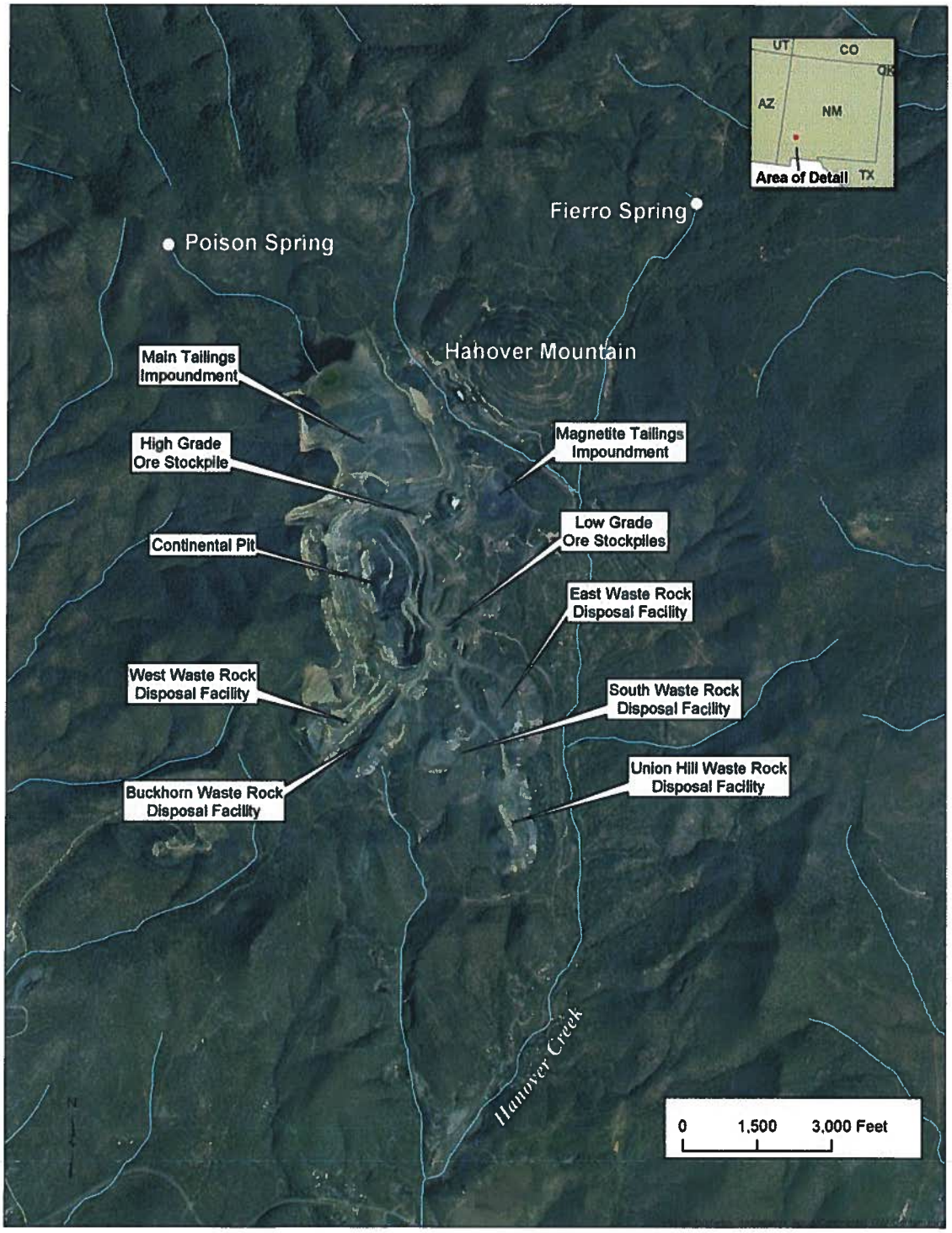

Figure 2.4. Hydrologic features and mine facilities at the Cobre Mine.

Creek downstream of Fierro Spring (Figure 2.4). Shallow perched groundwater exists in alluvium, terrace gravels, and weathered rock in Grape Gulch, Poison Spring, and upper Buckhorn Gulch and generally flows to the south or southeast. Two of the main springs in the area, Fierro and Poison springs, discharge perched groundwater (M3 Engineering & Technology, 2001).

Regional groundwater exists in the upper bedrock units (Colorado Formation and Beartooth Quartzite) and in the lower bedrock unit (older Paleozoic sedimentary rocks and the Hanover-Fierro intrusive stock) (Shepherd Miller, 1999; M3 Engineering & Technology, 2001). Groundwater in the upper bedrock unit flows to the south and southwest from the Pinos Altos Range and does not appear to be affected by mining-related groundwater dewatering. Groundwater in the lower bedrock unit on the site generally flows radially toward the underground workings (M3 Engineering & Technology, 2001) north of the Barringer Fault, where most of the upper bedrock unit has been eroded. On the southern side of the fault, groundwater flows to the south, and both the upper and lower bedrock units exist (Shepherd Miller, 1999).

2.2 Overview of Site Histories

The following sections provide an overview of the site histories for the Chino, Tyrone, and Cobre mines.

2.2.1 Chino Mine

Open-pit mining at Chino began in 1910. As of 1998, the Santa Rita Pit was approximately 1,500 feet deep, 1.8 miles in diameter, and covered more than 1,500 acres (M3 Engineering & Technology, 2001). The pit is actively dewatered by pumping groundwater wells to allow access to the ore. The pumping creates a cone of depression in the groundwater table, with the lowest groundwater elevations below the open pit. As a result, surrounding groundwater flows toward the pit (M3 Engineering & Technology, 2001). Mine dewatering water from the underground mine was historically discharged directly to Whitewater Creek (Golder Associates, 2008).

In 1911, a mill and concentrator were built near the current Hurley smelter site. The ore was extracted from the open pit and ground at the mill. In the flotation process, the ground ore is suspended in water and flotation chemicals (including a substance similar to pine sap), and air is bubbled through the mixture. The flotation chemicals attach to the copper sulfide minerals in the ground ore, air bubbles attach to the flotation chemicals, and the copper sulfide concentrate floats to the top of the flotation cells. The concentrate is skimmed from the top and sent to a smelter for sulfur removal. The material that does not float to the top (more than 99% of the ore) becomes

waste, which is referred to as tailings. The Hurley smelter was completed in 1939. Lake One was created in 1910 by damming Whitewater Creek to store water for the mill (Integrated Analytical Laboratories, 2009). Waste from the smelter (slag) was deposited on the northwestern side of Lake One. In 1982, a new mill and concentrator (the Ivanhoe Concentrator) near the open pit replaced the original Hurley mill and concentrator. Tailings from the flotation operation have been deposited east of Hurley in piles and impoundments along and near the former Whitewater Creek drainage.

In 1936, leaching operations of low-grade ore stockpiles were initiated near the open pit. Copper was extracted from leach solutions at precipitation plants. In 1988, the SX/EW plant was constructed east of the open pit, and additional leaching activities began (M3 Engineering & Technology, 2001). In the leaching process a sulfuric acid solution (pH 1.7 to 2.5) is applied to the top of the stockpiles. This solution percolates through the piles to form a high-copper PLS, which is collected at the bottom of the stockpiles. The PLS is then transferred to uncovered solution ponds and pumped to the SX/EW plant. An organic solvent is added to the PLS (SX), and the copper-bearing organic solvent solution is stripped of copper in the EW process, where the copper is precipitated onto a 99.9% pure metallic copper cathode. The stripped but still acidic PLS, known as raffinate, is recycled for further stockpile leaching (Dresher, 2001).

In 1997, 99,900 tons of copper were produced by flotation, and an additional 69,100 tons of copper were produced by the SX/EW process. In 2001, production rates dropped to 18,300 tons of copper by flotation and 59,900 tons of copper by SX/EW (U.S. Securities and Exchange Commission, 2002). The copper mill and flotation operation were shut down temporarily in March 2001. In January 2002, the Chino Mine was temporarily closed (U.S. Securities and Exchange Commission, 2002) but has since reopened. Primary extraction of ore from the pit by flotation continues, and the tailings are deposited in the active Tailings Impoundment 7. Flotation concentrate is currently sent to a smelter in Arizona (Golder Associates, 2008). Leaching of stockpiles and operation of the SX/EW plant are also ongoing. FMI is required by NMED to continue actively dewatering the open pit to prevent formation of a contaminated pit lake.

Located within the permit boundary of the Chino Mine, the Groundhog Mine is a historical underground polymetallic (zinc, lead, copper, silver) mine (see Figure 2.2). Lead carbonate was first mined along the Groundhog Fault in the late 1860s. Controlling interest in the three claims that make up the mine was sold to ASARCO in 1928, and mining continued into the 1970s. In 1994, ASARCO sold the property to Phelps Dodge. As a condition of the sale, ASARCO moved the stockpiles from Bayard Canyon to the San Jose shaft area and covered them with a thin layer of soil. One uncovered stockpile (Groundhog No. 5) remains (M3 Engineering & Technology, 2001).

2.2.2 Tyrone Mine

In the late 1870s through the early 1900s, a number of companies mined turquoise, copper, and fluorspar in the Tyrone Mine area. Phelps Dodge consolidated the mining claims in the area by 1913 and developed a large-scale underground operation that shut down in 1921, with sporadic operations from 1921 to 1929 and from 1941 to 1950.

Open-pit copper mining began in 1967 when excavations were made to expose and mine the ore. By September 1969, 95 million tons of overburden had been removed from the Tyrone pit to allow the mining of copper ore to begin (SARB, 1999). In February 1999, the Tyrone open pit was approximately 1,400 feet deep and covered an area of about 1,400 acres. Parts of the pit have been partially or completely backfilled. The pit is actively dewatered, which induces groundwater flow toward the pit (M3 Engineering & Technology, 2001).

Initially, copper was recovered from the ore using flotation methods, with an initial mill and concentrator capacity in 1969 of 29,000 tons of ore per day. In 1972, the concentrator capacity was expanded to 50,000 tons per day (SARB, 1999). The copper concentrator operated from 1969 to 1992, and the concentrate was shipped offsite for smelting (M3 Engineering & Technology, 2001). The flotation process produced tailings as a by-product, which was then piped to one of six tailings impoundments in the Mangas Valley (SARB, 1999).

Stockpile leaching operations began in 1972 on the No. 1 stockpile, with copper extracted from the leach solution in a precipitation plant. Additional leaching operations began in 1984, with the opening of the SX/EW plant (SARB, 1999). In 2003, Discharge Permit 166 allowed the discharge of up to 35 million gallons per day of leach solution to the No. 2 leach stockpile and up to 49 million gallons per day of PLS to the SX/EW plant (NMED, 2003).

Since 1992, Tyrone has been solely a copper leach operation. From 1997 to 2001, annual production of copper through the SX/EW process at the Tyrone Mine ranged from 76,400 to 82,600 tons. An additional 2,600 tons of copper were produced by the precipitate process in 1997, but no precipitate copper has been produced since (U.S. Securities and Exchange Commission, 2002). In 2010, 202 million tons of ore were produced using SX/EW methods at an average ore grade of 0.28% (Freeport-McMoRan Copper & Gold, 2010).

2.2.3 Cobre Mine

The Cobre Mine has a long history of copper and iron ore production. Commercial copper production by underground methods at the site began in 1858, and approximately 1 million pounds of copper were produced over a three-year period (M3 Engineering & Technology, 2001). The Modoc and Republic mines, located near the present-day Continental Pit and owned by the United States Smelting, Refining, and Mining Company (USSR&M), produced iron ore

(magnetite) from the early 1900s through 1974. Magnetite production peaked at 200,000 tons per year from 1916 to 1931. The magnetite tailings impoundment stored magnetite ore from 1967 to 1982. Underground mining of copper ore from a skarn deposit under what is now the Continental Pit began in 1947. The copper ore was extracted by USSR&M and processed using flotation methods at their Bullfrog Mill, located approximately 6 six miles south of the mine. Underground copper mining ended in 1971, shortly after open-pit extraction began at the Continental Pit in 1967.

The current phase of copper mining at the site began in 1964 with underground extraction and flotation operations at the Nos. 1 and 2 flotation mills (started in 1967 and 1973, respectively). The mine was closed from 1982 to 1993 due to low copper prices and went on standby in 1999 (Telesto Solutions, 2005). Although the mine has received approval to resume mining and expand operations (including excavation of Hanover Mountain, and expansion of the South WRDF and the Continental Pit), it has not yet resumed mining (as of 2011) (Telesto Solutions, 2005).

2.3 Summary of Remedial Actions

FMI has conducted a number of remedial actions at the Sites, as listed in Table 2.1. Table 2.1 includes remedial measures completed by late 2009/early 2010 and some planned future remedial actions. The general types of remedial actions include groundwater pumping to maintain open-pit capture zones; regrading, covering, and revegetating tailings impoundments; installing groundwater and seep capture systems; limited removals of waste rock piles; restoration of Oak Grove Wash; and improvements in PLS collection systems. These remedial measures generally do not eliminate currently injured groundwater but could limit the future expansion of injured groundwater.

Table 2.1. List of general remedial actions taken as of January 2010 at the Chino, Tyrone, and Cobre mines

Mine site	Area	Current or completed remedial actions	Potential effect on groundwater injury
Chino Mine	Open Pit	Groundwater pumping (in perpetuity, with future treatment); upgraded PLS collection with steel raffinate tank.	Limits future expansion of injured groundwater around pit
	North Mine Area	*Lampbright Area/Reservoir 8:* drained PLS from Reservoir 8 (formerly unlined), cleaned out sediment, made lined concrete collection system with concrete and high-density polyethylene pipes and liners and stainless steel tank for PLS; pumpback systems using converted monitoring wells; after PLS spill (booster tank) on north slope of Lampbright, cleaned contaminated sediment, power-washed outcrops, installed warning system to shut down booster; installed French drain and pump north of Lampbright; lengthened trench near Sump 3. *SX/EW Area:* upgraded PLS collection with steel raffinate tank. *West/South Stockpiles*: built dams in paleochannels on west side; upgraded dams with new pumps and backup pumps. *South Stockpile:* upgraded PLS collection system, installed French drains. *Lucky Bill:* Reclaimed waste rock pile.	Size of spill area is diminishing; could decrease concentrations in injured groundwater near Lampbright and prevent formation of injured groundwater mound in future
	Middle Whitewater Creek Area	None.	NA
	South Mine Area	*Lake One, Axiflow Lake, smelter, old tailings impoundments, Impoundment 7:* Lake One regraded; smelter reclamation completed; conducted cleanup of house yards in Hurley; reclaiming Impoundments B, C, and 6 West (3-foot cover, revegetation); pumping injured groundwater from south toe of Impoundment 7 to top of Impoundment 7. *South of Impoundment 7/Distributary Area:* no plans for reclamation.	Limits future expansion of injured groundwater near old tailings areas
Tyrone Mine	Open Pit	Groundwater pumping (in perpetuity, with future treatment).	Limits future expansion of injured groundwater around pit
	Deadman Canyon	Water from pumpback well at seep 5E sent to No. 2A stockpile; removed the *United States Natural Resources, Inc. (USNR) Stockpile* and put on 2B waste pile; capture of contaminated seeps.	Could improve groundwater quality under former USNR stockpile area; limits future expansion of plumes associated with stockpiles

Table 2.1. List of general remedial actions taken as of January 2010 at the Chino, Tyrone, and Cobre mines (cont.)

Mine site	Area	Current or completed remedial actions	Potential effect on groundwater injury
Tyrone Mine (cont.)	East Side/Oak Grove	Capped *7A and 1C waste piles:* regrading and covering slopes; installed pumpback capture systems for 7A, 7A west, and other piles and some alluvial groundwater; removed southeast side of *1C waste stockpile. Oak Grove Wash*: rebuilt to create free-flowing stream (now water of the United States under CWA); installed capture systems across wash, smaller systems along Brick Kiln. *1A/1B leach stockpiles*: covered, regraded, and revegetated No. 1 and pumpback systems; covered Burro Mountain; moved some material from 1A to 1B; surface PLS collection structures upgraded.	Lessened extent of PLS plume in Oak Grove Wash, but alluvial groundwater becomes recontaminated after rain events; could limit future extent of injured groundwater from stockpiles; improves quality of stream
	No. 3 Stockpile	Installed two pump-back lines (L and EL) across upper Mangas Wash and many pumping wells – pumps to PLS pond; hydrocarbon remediation – pumping free product on perched water table.	Limits future expansion of injured alluvial and regional groundwater
	Mangas Valley	Installed line of pumpback wells north of 1X tailings; capped Nos. 1, 2, 3X, 3 impoundments (capped tops and sides, side slopes 3:1, stormwater channels around impoundments). Extracting diesel fuel oil (leak in distribution pipeline at diesel tank farm) with skimmer pump – migrated to regional aquifer (poor well casings).	Limits future expansion of injured alluvial groundwater; limits increase in diesel fuel contaminant concentrations in groundwater
Cobre Mine	Continental open pit and underground workings	Closure of shafts and adits, including Hanover Empire Zinc area (only covered if less than threshold acid-generating values); collecting seeps and stormwater; reclaimed Pearson Barnes area (revegetation unsuccessful); reclaimed Slate, Bullfrog, Copper Flat, Kearny; removed hydrocarbon-contaminated soils on east side of pit.	Limits future expansion of injured regional groundwater
	Tailings impoundments	Removed reclaim pond on *main tailings impoundment* (send water to Chino); removing (selling) *magnetite tailings*; installed dust cover on main tailings area (only 6 inches thick).	Could decrease injured groundwater under tailings impoundment and in underground workings
	Waste rock facilities	Collecting seeps on south side of West waste rock facility, sending to Chino; covered much of West WRDF; collecting seeps on east side of East WRDF and Union Hill; upgraded seep collection systems in Poison Hill drainage (collects mine and natural seeps).	Reduces infiltration through piles, which could reduce future extent of injured groundwater

Sources: Daniel B. Stephens & Associates, 1997a, Table 2-2; Kurt Vollbrecht and Clint Marshall, NMED, personal communication, December 17, 2009 and January 20, 2010.

3. Injury Evaluation and Estimation of Groundwater Damages

ONRT evaluated injuries to groundwater resulting from releases of hazardous substances at the Sites. ONRT also quantified the extent of groundwater injury over time in order to determine the amount of restoration that would be required to compensate for the injury. This chapter describes the injury quantification approach for groundwater resources.

3.1 Injury Assessment Strategy

The injury assessment strategy followed the general approach described in the NRDAR regulations developed for CERCLA [43 CFR § 11]. The categories of injury include the concepts of "injury," "destruction," and "loss," as described in 43 CFR § 11.14(v).

To assess injury, ONRT used a three-part approach that included (1) evaluating the area where injury had occurred and the time periods over which injury had occurred; (2) developing an appropriate "metric" to quantify resource debits; and (3) quantifying the amount of injury using the selected metric.

3.2 Groundwater Injury Determination

This section describes injuries to groundwater resources and explains how the injuries were assessed and quantified. The evaluation focused on injured groundwater resources at the Sites that resulted from the release of hazardous substances from mining-related sources. The amount of injured groundwater is based on quantification of groundwater with concentrations of hazardous or related substances in excess of federal or New Mexico water quality standards.

The relevant definitions of groundwater injury for the Sites are:

- Concentrations of substances in excess of drinking water standards, established by sections 1411-1416 of the SDWA, or by other federal or state laws or regulations that establish such standards for drinking water, in ground water that was potable before the discharge or release [43 CFR § 11.62(c)(1)(i)].

- Concentrations of substances sufficient to have caused injury as defined in paragraphs (b), (d), (e), or (f) of this section to surface water, air, geologic, or biological resources, when exposed to ground water [43 CFR § 11.62(c)(1)(iv)].

3.2.1 Hazardous substance sources

Mining differs from other industrial processes in that one of the principal sources of hazardous substances is the material itself (ore, waste rock, tailings). The other general source of hazardous substances is the chemicals added as part of the mining process, such as the low pH, sulfuric acid solution ("raffinate") that is applied to the top of the stockpiles to leach copper. The primary sources of hazardous substances at the Sites include:

- Walls of the underground workings and open pits
- Mine wastes, including tailings, waste rock, and spent ore leach piles
- Ore and leach stockpiles
- Mine waters (PLS, raffinate, tailings supernatant water, seepage from wastes and mined materials, stormwater that contacts mine wastes).

The primary sources of hazardous substances can cause injury to groundwater and surface water, which in turn can become secondary sources of hazardous substances to downgradient groundwater.

3.2.2 Identity of hazardous substances

The potential for mining sources to leach hazardous substances is estimated by laboratory leach tests. Concentrations of hazardous substances in seepage or groundwater samples taken downgradient of known hazardous substance sources confirm that releases have occurred. Hazardous substances have been identified in laboratory leach tests, mine waste seepage, and groundwater at all three mine sites.

Hazardous substances in laboratory leach test samples

At the Chino Mine, waste rock samples were subjected to humidity cell tests, which simulate the leaching of substances from mine wastes to groundwater. These tests demonstrated that the hazardous substances cadmium, cobalt, copper, manganese, and selenium had leached from the source material to groundwater at concentrations in excess of the State of New Mexico groundwater standards for human health and domestic water supply (State of New Mexico, 2011, 20.6.2.3103 NMAC, Subparts A and B). Detectable concentrations of the hazardous substances antimony, barium, beryllium, chromium, lead, mercury, silver, and thallium were also observed in the leachate from the same tests (Golder Associates, 1998).

At the Tyrone Mine, samples representative of the pit wall, stockpiles, and tailings were subjected to the short-term synthetic precipitation leaching procedure (SPLP) and longer-term (humidity cell) leach testing (Daniel B. Stephens & Associates, 1997b, 1997d). The leach test results showed that the hazardous substances arsenic, cadmium, copper, iron, lead, manganese,

and zinc had leached into groundwater from the source material at concentrations in excess of State of New Mexico groundwater standards for human health and domestic water supply. In addition, the SPLP leachate included detectable concentrations of the hazardous substances cobalt and zinc (Daniel B. Stephens & Associates, 1997d, 1999).

At the Cobre Mine, tailings samples were subjected to the SPLP test. These tests showed that the hazardous substances arsenic, cadmium, copper, lead, and manganese had leached into the groundwater from the source material at concentrations in excess of State of New Mexico standards for human health and domestic water supply. The SPLP leachate also contained detectable concentrations of the hazardous substances cobalt and zinc (Daniel B. Stephens & Associates, 1997b).

Hazardous substances in mine leachate and groundwater samples

Using water quality databases supplied by FMI and NMED for groundwater wells, seeps, and springs at the Chino, Tyrone, and Cobre mines, the following hazardous and related substances were detected at elevated concentrations and were, in most cases, above relevant human-health-based water quality standards[1]:

- Antimony
- Arsenic
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Copper
- Ferrous and ferric sulfate
- Lead
- Manganese
- Nickel
- Selenium
- Sulfate
- Sulfuric acid
- Thallium

1. There are no federal or New Mexico water quality standards for sulfuric acid, ferrous sulfate, or ferric sulfate. Cobalt was detected at levels above the New Mexico irrigation standard of 0.05 milligrams per liter. Nickel was detected at levels above the federal lifetime health advisory of 0.1 milligrams per liter (U.S. EPA, 2009). Measured concentrations for the remainder of the hazardous substances on the list were compared to health-based New Mexico or federal standards. Toluene concentrations did not exceed standards but reached as high as 0.26 milligrams per liter in groundwater at the Chino Mine. Data ranged from 1980 to 2006.

- Toluene
- Zinc.

Use of sulfate concentrations to determine groundwater injury

As described in this section, exceedence of the sulfate standard is considered an injury because sulfate is a product of reactions resulting from the release of hazardous substances:

> Injury means a measurable adverse change, either long- or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a discharge of oil or release of a hazardous substance, or exposure to a product of reactions resulting from the discharge of oil or release of a hazardous substance [43 C.F.R. § 11.14(v)].

There are three ways in which sulfate is a product of reactions resulting from the release of hazardous substances at the Sites:

1. Sulfate derives from the release of hazardous substances at the Sites through the formation of acidic leachate from stockpiles, waste rock, and pit walls. The acidic, metal- and sulfate-rich solution that forms is referred to as acid mine or acid rock drainage ("acid drainage"), and it is one of the most serious environmental issues at mine sites (U.S. EPA, 1994). Acid drainage occurs at all three Sites, especially at the open pits and stockpiles. The exposure of mined materials (e.g., wall rock, waste rock, tailings, stockpiles, ore) to air and water starts the leaching process. At the Chino Mine, the main sulfide mineral in the ore and surrounding rocks is an iron sulfide mineral called pyrite (Golder Associates, 2008). When pyrite is exposed to oxygen and water, it generates sulfuric acid, a listed hazardous substance. The sulfuric acid, which contains sulfate, leaches hazardous substances from other metal sulfides that contain copper, lead, cadmium, zinc, and other metals and metalloids. The metal sulfides in waste rock and tailings are themselves listed hazardous substances (e.g., cadmium and compounds, lead sulfide, copper and compounds, zinc and compounds). When these sulfide minerals are exposed to air and water, they produce leachate that contains elevated concentrations of sulfate and metals (Plumlee, 1999).

2. Raffinate, the leaching solution for the stockpiles, contains sulfuric acid and ferrous and ferric sulfate (Dames & Moore, 1983). After the raffinate has percolated through the piles, it contains sulfuric acid, ferrous and ferric sulfate, and copper, and is known as PLS. Sulfuric acid, ferrous sulfate, and ferric sulfate are listed hazardous substances and all contain sulfate. Leakage of PLS has contaminated groundwater in Oak Grove Wash at the Chino Mine and in the upper Mangas Wash and Deadman Canyon at the Tyrone Mine (Daniel B. Stephens & Associates, 1997a; Golder Associates, 2008).

3. Acidic and non-acidic leachate derived from mined materials can evaporate and form highly soluble metal sulfate salts (Nordstrom and Alpers, 1999), which are also listed hazardous substances (e.g., cupric sulfate, ferric sulfate, ferrous sulfate, zinc sulfate). Such salts often form on the walls of open pits and underground workings and on the surfaces of waste rock and tailings impoundments. When they dissolve, for example, after a summer thunderstorm or snowmelt, they rapidly produce leachate with elevated concentrations of sulfate and metals.

In summary, sulfate forms from leaching of primary mined materials, from dissolution of metal sulfate salts, and from the addition of raffinate to the leach piles. Because sulfate is ubiquitous at the Sites and a product of reactions resulting from the release of hazardous substances, exceedence of the sulfate standard was used as the overall measure of injury at the Sites.

3.2.3 Relevant standards

The relevant water quality standards for evaluation of groundwater injury are the SDWA maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCLs), and the State of New Mexico human health groundwater standards. Table 3.1 summarizes the relevant standards for hazardous or related substances identified at the Sites. The New Mexico standards are applied to dissolved concentrations (State of New Mexico, 2011).

3.2.4 Identification of injured groundwater plumes

ONRT considered all groundwater affected by mining activities with sulfate concentrations exceeding 250 milligrams per liter to be injured because sulfate levels in this water exceeded federal SDWA standards. For the injury quantification phase, areas were classified as either having no injury (if sulfate concentrations were below 250 milligrams per liter) or being completely injured (if sulfate concentrations were above 250 milligrams per liter).

Injury to groundwater was evaluated using water quality data supplied by FMI and NMED. The groundwater plumes were determined by identifying the areas where groundwater exceeded the federal sulfate standard. The areal extent was determined by mapping the projection of plumes on the land surface. Areas with sulfate concentrations above 250 milligrams per liter were considered to be in the plume, whereas areas with concentrations below 250 milligrams per liter were considered to be outside the plume. Using sulfate concentrations resulted in delineation of the largest plumes of any other individual hazardous substance. However, there were some limited areas where concentrations for other hazardous substances outside of the sulfate plumes exceeded standards.

Table 3.1. Water quality standards used to determine groundwater injury for the Sites (mg/L)

Analyte	State of New Mexico standard[a]	Federal SDWA standard[b]
Antimony	–	0.006
Arsenic	0.1	0.01
Beryllium	–	0.004
Cadmium	0.01	0.005
Chromium	0.05	0.1
Copper	1.0	1.3[c]
Lead	0.05	0.015[c]
Selenium	0.05	0.05
Sulfate	600	250
Thallium	–	0.002
Toluene	0.75	1
Zinc	10.0	5.0

a. 20.6.2.3103 NMAC, Subparts A and B (human health and domestic water supply only).
b. Federal MCL for all but sulfate and zinc (SMCL).
c. Action level (the concentration of a contaminant that, if exceeded, triggers treatment or other requirements that a water system must follow; U.S. EPA, 2009).

Sources: State of New Mexico, 2011; U.S. EPA, 2009.

The plumes were mapped separately in alluvial and regional aquifers. Rock types in the regional aquifers included the Gila Conglomerate, granite, volcanics, sedimentary rocks, and igneous sills and dikes. Table 3.2 lists the identified contaminant plumes in groundwater at the Sites.

3.2.5 Examples of water quality standard exceedences

Table 3.3 contains examples of exceedences of New Mexico and federal human health-based water quality standards for the Chino, Tyrone, and Cobre mines. Wells listed in Table 3.3 were selected based on the longest period of record for a given area at each mine site. Examples were selected from both regional and alluvial plumes. The most common analyte that exceeded water quality standards was sulfate. Some of the highest measured sulfate concentrations were in the Chino open-pit area, with values more than 300 times the federal drinking water standard and almost 140 times the New Mexico groundwater standard.

Table 3.2. Identified groundwater plumes in alluvial and regional aquifers at the Sites

Mine site	General area	Plume name and aquifer type	Geologic unit
Chino	Open Pit	Open Pit Regional	Volcanics, Santa Rita Stock, metasedimentary, sills and dikes
	North Mine Area	Lampbright Regional	Mix of sedimentary, sills and dikes, volcanics
		West and South Stockpiles Regional	Mostly sills and dikes (West Stockpile); volcanics (South Stockpile)
	Groundhog Mine Area	Groundhog Alluvial	Alluvium
	Middle Whitewater Creek Area	Middle Whitewater Alluvial	Alluvium
		Middle Whitewater Regional	Volcanics
	South Mine Area	Lake One Area Regional	Upper Gila Conglomerate
			Volcanics
		Old Tailings Impoundment Area – Regional	Upper Gila Conglomerate
		Bolton Wellfield – Regional	Volcanics
		Eastern edge of Old Tailings and Tailings Impoundment 7 – Regional	Volcanics
		Old Tailings Impoundment Area – Regional	Upper Gila Conglomerate
		Tailings Impoundment 7 Area – Regional	Upper Gila Conglomerate
		South of Tailings Impoundment 7 Area – Regional	Upper Gila Conglomerate
		South Whitewater Area – Regional	Upper Gila Conglomerate
Tyrone	Open Pit	Open Pit Regional	Granite
	Deadman Canyon	Deadman Canyon Alluvial	Alluvium
	East Side	East Side Alluvial	Alluvium
		East Side Regional	Gila Conglomerate
	Mangas Valley	Mangas Valley Alluvial	Alluvium
		Mangas Valley Regional	Gila Conglomerate
	No. 3 Stockpile	No. 3 Stockpile Alluvial	Alluvium
		No. 3 Stockpile Regional	Gila Conglomerate

Table 3.2. Identified groundwater plumes in alluvial and regional aquifers at the Sites (cont.)

Mine site	General area	Plume name and aquifer type	Geologic unit
Cobre	Continental Pit	Continental Pit Regional	Limestone, granite, shale, siltstones
	WRDFs	West Waste Rock Regional	Limestone, shale
		Buckhorn Waste Rock Regional	Limestone, shale
		East Waste Rock Regional	Hanover-Fierro Stock (granite)
		South Waste Rock Regional	Dolomite, granite
		Union Hill Waste Rock Regional	Dolomite, granite
	Hanover Creek	Hanover Creek Alluvial	Alluvium

Table 3.3. Examples of water quality exceedences in groundwater from the Chino, Tyrone, and Cobre mines

Mine site	General area	Plume name and aquifer type	Example wells	Period of record	Selected concentration ranges (mean value), (mg/L)
Chino	North Mine Area	Open Pit Regional	459-98-05	1999–2006	Sulfate = 13,600–83,400 (31,800); cadmium = 0.523–1.39 (0.817); copper = 359–1,100 (684); lead = 0.086–17 (3.52)
		West and South Stockpiles Regional	WD-6S (West Stockpile)	1989–2003	Sulfate = 1,869–12,100 (4,470); cadmium = 0.09–4.86 (0.787); copper = 0.004–7.02 (0.376); lead = 0.005–1.51 (0.456)
	Middle Whitewater Creek Area	Middle Whitewater Alluvial	B-40 (southern end)	1982–2005	Sulfate = 290–1,200 (857); copper = 0.004–2.2 (0.20); lead = 0.006–0.42 (0.07)
	South Mine Area	Old Tailings Impoundment Area – Regional	DM-14D (near Bolton wellfield)	1982–2001	Sulfate = 1,280–1,979 (1,620); copper = 0.001–1.3 (0.13); lead = 0.003–0.049 (0.015)
Tyrone	Deadman Canyon	Deadman Canyon Alluvial	TWS-28 (most downstream end)	2003–2004	Sulfate = 649–945 (785); cadmium = 0.005–0.012 (0.008); copper = 33.2–50.6 (39.6)
	East Side	East Side Regional	MB-18D (Upper Oak Grove Wash)	1995–2004	Sulfate = 1,050–7,350 (2,720); cadmium = 0.02–1.0 (0.24); copper = 2.2–276 (140)
	No. 3 Stockpile	No. 3 Stockpile Regional	6-2R (Upper Mangas Wash)	1991–2005	Sulfate = 340–1,280 (707); cadmium = 0.032–0.29 (0.08); copper = 0.01–4.56 (1.31)

Table 3.3. Examples of water quality exceedences in groundwater from the Chino, Tyrone, and Cobre mines (cont.)

Mine site	General area	Plume name and aquifer type	Example wells	Period of record	Selected concentration ranges (mean value), (mg/L)
Cobre	Continental Pit	Continental Pit Regional	MW-2 (ore stockpile)	2007–2009	Sulfate = 1,100–1,430 (1,200)
	WRDFs	West Waste Rock Regional	MW-20	2006–2009	Sulfate = 1,700–2,500 (1,960)
	Hanover Creek	Hanover Creek Alluvial	MW-12 (Hanover Creek area)	2007–2009	Sulfate = 2,250–2,550 (2,390); manganese = 0.664–0.755 (0.710)

Data sources: Electronic databases provided to Stratus Consulting by FMI and NMED, 2006–2008.

Cadmium concentrations also exceeded health-based water quality standards in groundwater at the Chino Mine (North Mine Area) and the Tyrone Mine (Deadman Canyon, the East Side, and the No. 3 Stockpile area). Copper and lead concentrations exceeded New Mexico and/or federal water quality standards in regional groundwater at the Chino Mine and in alluvial and regional groundwater at the Tyrone Mine. Sulfate concentrations in groundwater samples at the Cobre Mine regularly exceeded both federal and New Mexico water quality standards, and some of the samples also had manganese exceedences.

3.3 Pathway Determination

Federal regulations at 43 CFR Part 11 define pathway as:

> Pathway means the route or medium through which oil or a hazardous substance is or was transported from the source of the discharge or release to the injured resource [43 CFR § 11.14(dd)].

Hazardous substances from sources at the Sites (see Section 3.2.1) are transported to groundwater from infiltration of contaminated surface runoff; seepage from the walls of open pits and underground workings, waste rock, stockpiles, tailings, and leach piles; and leaks from mine water, stormwater, or process water reservoirs. Injured groundwater can then expose downgradient biologic, geologic, and surface water resources.

3.3.1 Primary pathways for groundwater contamination

Hazardous substances move from mining-related sources through natural resources, such as groundwater, to receptors, such as surface water. Two site-specific examples of ways in which groundwater can become injured and then injure other resources are provided in this section [see also a similar discussion for the Chino Mine in Golder Associates (2008), Section 5.1].

Stockpiles or waste rock to alluvial and regional groundwater

At the Chino and Tyrone mines, ore stockpiles are leached by infiltrating raffinate, natural precipitation (rain and snow), and stormwater runoff. At the Cobre Mine, no ore stockpiles exist, but the same pathway process functions at the WRDFs via infiltration of rain and snow and leaching of hazardous substances. The resulting liquid leachate has elevated concentrations of hazardous and related substances, including sulfate, cadmium, copper, lead, and zinc. The majority of the leachate from the ore stockpiles at the Chino and Tyrone mines is captured as PLS and processed at the SX/EW facility. However, some of the leachate leaks to groundwater under the unlined facilities (no stockpiles or waste rock facilities are lined at any of the Sites). Escaped leachate and PLS have injured alluvial groundwater in Deadman Canyon and alluvial and regional groundwater in Oak Grove Wash at the Tyrone Mine. Escaped PLS and leachate from the No. 3 stockpile at the Chino Mine have injured alluvial "fingers" under and downgradient of the stockpile, and this groundwater has further injured alluvial groundwater in Mangas Wash. Contaminants in alluvial groundwater can enter surface water in zones where surface water and alluvial groundwater mix, thereby exposing surface water and biological resources.

Tailings areas to alluvial and regional groundwater

All three mine sites have tailings in unlined impoundments. Hazardous and related substances in the tailings are leached by tailings supernatant (water sitting on top of tailings impoundments), which can include water pumped with the tailings and natural precipitation. In addition, before the tailings impoundments at the Tyrone Mine were remediated, the concentrations of hazardous substances increased during the summer dry season in small ponds on top of the impoundments. Metal-sulfate salts are formed by evaporation and dissolve rapidly during a thunderstorm event, resulting in high concentrations of metals in the ponds. Water associated with the tailings impoundments has infiltrated to underlying alluvial and regional groundwater. The injuries identified in regional groundwater at the Chino South Mine Area and in alluvial groundwater in Mangas Wash at the Tyrone Mine are due, at least in part, to infiltration through tailings.

As discussed above, contaminants in alluvial groundwater can enter surface water in zones where surface water and alluvial groundwater mix, thereby exposing surface water and biological resources.

3.4 Groundwater Injury Quantification

3.4.1 Baseline conditions

Baseline conditions are those that existed at the Sites absent the release of hazardous and related substances:

> Baseline means the condition or conditions that would have existed at the assessment area had the discharge of oil or release of the hazardous substance under investigation not occurred. [43 CFR § 11.14(e)].

According to Trauger (1972), regional groundwater in Grant County is a calcium-bicarbonate-type water with low sulfate concentrations (7–56 milligrams per liter), and alluvial groundwater is a calcium-bicarbonate-sulfate-type water with elevated nitrate and moderate sulfate concentrations (119 milligrams per liter). Studies of baseline groundwater quality have been conducted by consultants for FMI, including Daniel B. Stevens & Associates (1997a) for the Tyrone Mine, Golder Associates (1999, 2004) for the Chino Mine, and Shepherd Miller (1999) for the Cobre Mine. The results show that water quality is potable outside the influence of the mining areas. Manganese concentrations were naturally elevated in the Chino North Mine Area (Golder Associates, 1999) and the Cobre Mine (Shepard Miller, 1999). A study of 165 domestic wells in the vicinity of the Sites showed that trace metal concentrations in all sampled wells away from mining influence were below primary drinking water standards and therefore potable, although elevated concentrations of sulfate and total dissolved solids (TDS) were present in some areas (Golder Associates, 2004). Baseline groundwater quality in the Chino South Mine Area had low sulfate concentrations in all regional geologic units, including 46 milligrams per liter in the Gila Conglomerate, 55 milligrams per liter in volcanic rocks, and 65 milligrams per liter in limestone units (Golder Associates, 1999).

Plots of constituent concentrations over time can be used to estimate baseline groundwater quality in locations not affected by mining activity or wells affected only after mining activities began. There are many wells in regional aquifers outside of identified plumes with sulfate concentrations below federal and New Mexico standards. For example:

- Chino Mine well SX-6 (located on the northeastern side of the open pit and SX/EW areas, inside but topographically below the cone of depression; depth = 300 feet)
    - Sulfate concentrations ranged from 9.4 to 136 milligrams per liter throughout the period of record (1990–2003)

- Chino Mine well 459-96-03 (located north of the open pit outside the cone of depression; depth = 220 feet)
  - Sulfate concentrations ranged from 123 to 154 milligrams per liter throughout the period of record (1999–2005)
- Tyrone Mine well C111.1 (located in channel on northwestern toe of the No. 3 stockpile; depth = 210 feet)
  - The average sulfate concentration was 113 milligrams per liter from December 1990 through September 1996; concentrations increased after this time and peaked at 1,590 milligrams per liter in February 2003.

Figure 3.1 shows sulfate concentrations in another regional well (7AS) in the South Mine Area at the Chino Mine. Concentrations were low through January 1990 (the mean sulfate value was 42.7 milligrams per liter between 1986 and early 1990). Deposition of tailings into Tailings Impoundment 7 began in mid-1988 (Golder Associates, 2008). Concentrations in well 7AS peaked at 1,500 milligrams per liter in mid-1999 and remained above 1,200 milligrams per liter through at least 2005.

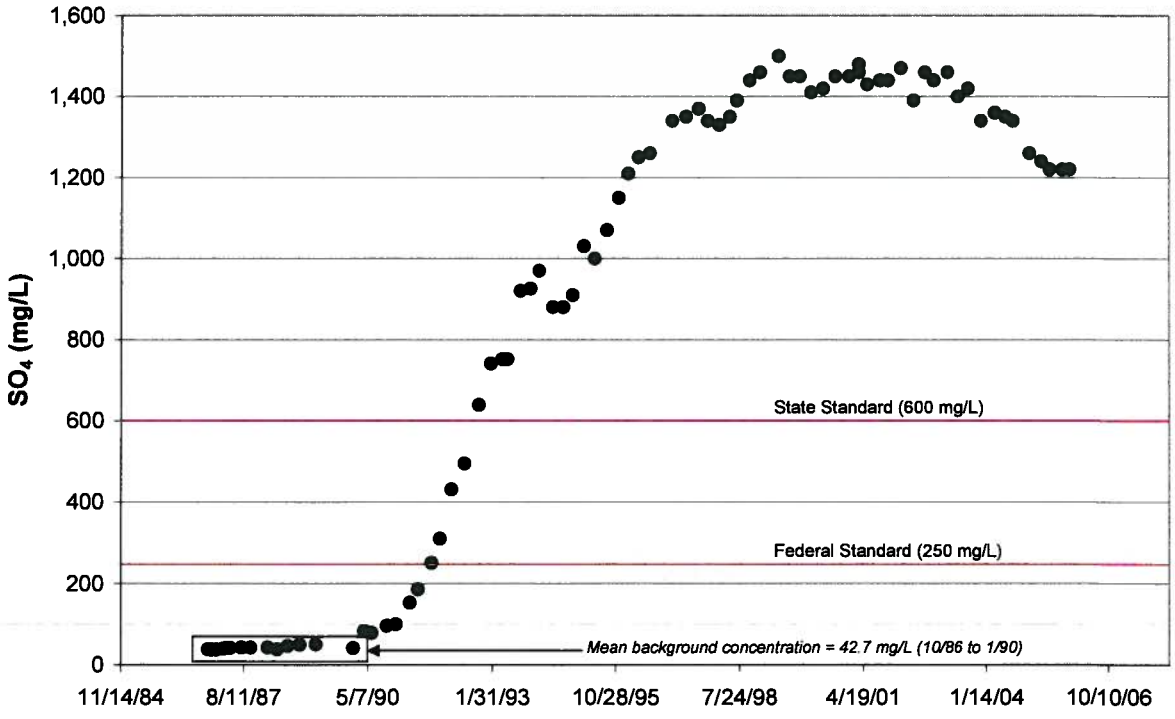

Figure 3.1. Concentrations of sulfate in well 7AS at the Chino Mine, located on the west side of Tailings Impoundment 7. The well is 222 feet deep and in the Gila Conglomerate.

Data source: Golder Associates, 2006.

Most or all the alluvial aquifers at all three mine sites have been injured from mining activity. Baseline water quality for the alluvial aquifer relies largely on studies in nearby areas that have not been affected by mining, as noted above. There are a limited number of upgradient alluvial aquifer wells at the Sites, and sulfate concentrations are generally low. For example:

- Tyrone Mine alluvial well TWS-35 in upper Deadman Canyon (11.3 feet deep) had sulfate concentrations ranging from approximately 30 to 115 milligrams per liter, with all but one value below 100 milligrams per liter.

- Chino Mine alluvial well 526-2000-4D, located on the far east side of the Middle Whitewater Area (200 feet deep). Sulfate concentrations in 2001–2006 ranged from 18.8 to 40.9 milligrams per liter. The shallower associated well, 526-2000-4S, is in the injured portion of the alluvial aquifer and has sulfate concentrations ranging from 1,340 to 1,930 milligrams per liter.

In summary, baseline concentrations of sulfate, the parameter used to measure groundwater injury at the Sites, and metals were lower than relevant water quality standards. This groundwater was potable prior to the release of hazardous substances at the Sites. Therefore, the groundwater injury definition has been met at the Sites, and no areas were excluded from injury because of baseline exceedences.

3.4.2 Extent of injured groundwater

The calculation of groundwater injury focused on sulfate and took into account baseline groundwater quality. Groundwater that was pumped and used in mine processes was not counted as injured groundwater because it avoided the use of clean surface water or groundwater. Examples of pumped water include dewatering water pumped from the Tyrone and Chino open-pit areas and PLS pumped from recovery wells in Oak Grove Wash at the Tyrone Mine. However, water that was pumped from the active tailings area at the Chino Mine (Tailings Impoundment 7) was counted as injured because it was released to the Mangas Valley rather than used in mine processes.

For the Chino and Tyrone mines, average groundwater sulfate concentrations in alluvial and regional wells were used to delineate the extent of groundwater injury at the Sites. Wells with sulfate concentrations exceeding the federal SDWA standard of 250 milligrams per liter were identified on geographic information system (GIS) maps of each mine site. The maps delineated regional and alluvial injury separately. Plumes were hand-drawn using the maps showing sulfate exceedences. Areas under mine installations, including open pits, waste rock, stockpiles, and tailings impoundments, were included in the plumes.

For the Cobre Mine, a different approach was used to delineate groundwater injury because only limited groundwater monitoring data were available (groundwater monitoring began in 1995; Telesto Solutions, 2007). ONRT and FMI agreed during the settlement process that it was reasonable to assume that all alluvial groundwater on the site downgradient of mining sources exceeded the sulfate water quality standard after 1981. For the regional aquifer, Telesto Solutions (2007) assumed that water derived from precipitation infiltrating the waste rock piles would injure regional groundwater a certain distance downgradient of the piles. The distance was determined using an assumed infiltration rate for the piles (5% of total precipitation), maximum leachate concentrations measured in longer-term humidity cell tests, and a specific yield in the regional aquifer of 2% (Telesto Solutions, 2007). The East, Union Hill, South, West, and Buckhorn Waste Rock facilities were included in the analysis.

In some cases, injured alluvial groundwater overlies injured regional groundwater (e.g., downgradient of the No. 3 Stockpile at the Tyrone Mine). In these instances, both injuries were counted because two layers of injured groundwater existed at those locations. Figures 3.2–3.4 depict the areal extent of injured groundwater in alluvial and regional aquifers at the Chino, Tyrone, and Cobre mines, respectively.

Table 3.4 summarizes the areal extent of injured groundwater at the Sites. The Chino Mine had the largest areal extent of injured alluvial and regional groundwater, at 13,935 acres. The Tyrone Mine had an injured areal extent of 6,280 acres, and the Cobre Mine had an areal extent of 528 acres of injured groundwater. The extent of regional groundwater was larger than that of alluvial groundwater at all three sites. The total areal extent of injured regional groundwater was 19,299 acres, while the total areal extent of injured alluvial groundwater was 1,444 acres.

In addition to injured groundwater, ONRT accounted for water that was pumped from Tailings Impoundment 7 at the Tyrone Mine and not used in the flotation operations. The concentrator at the Tyrone Mine was closed from March 2001 to June 2004. During this time, water was pumped from the impoundment at a rate of 3,222 acre-feet per year and released to the Mangas Valley tailings impoundments. The total volume pumped while the concentrator was closed was 10,600 acre-feet. Information on the pumped volumes and duration of pumping was provided by FMI during the settlement process.

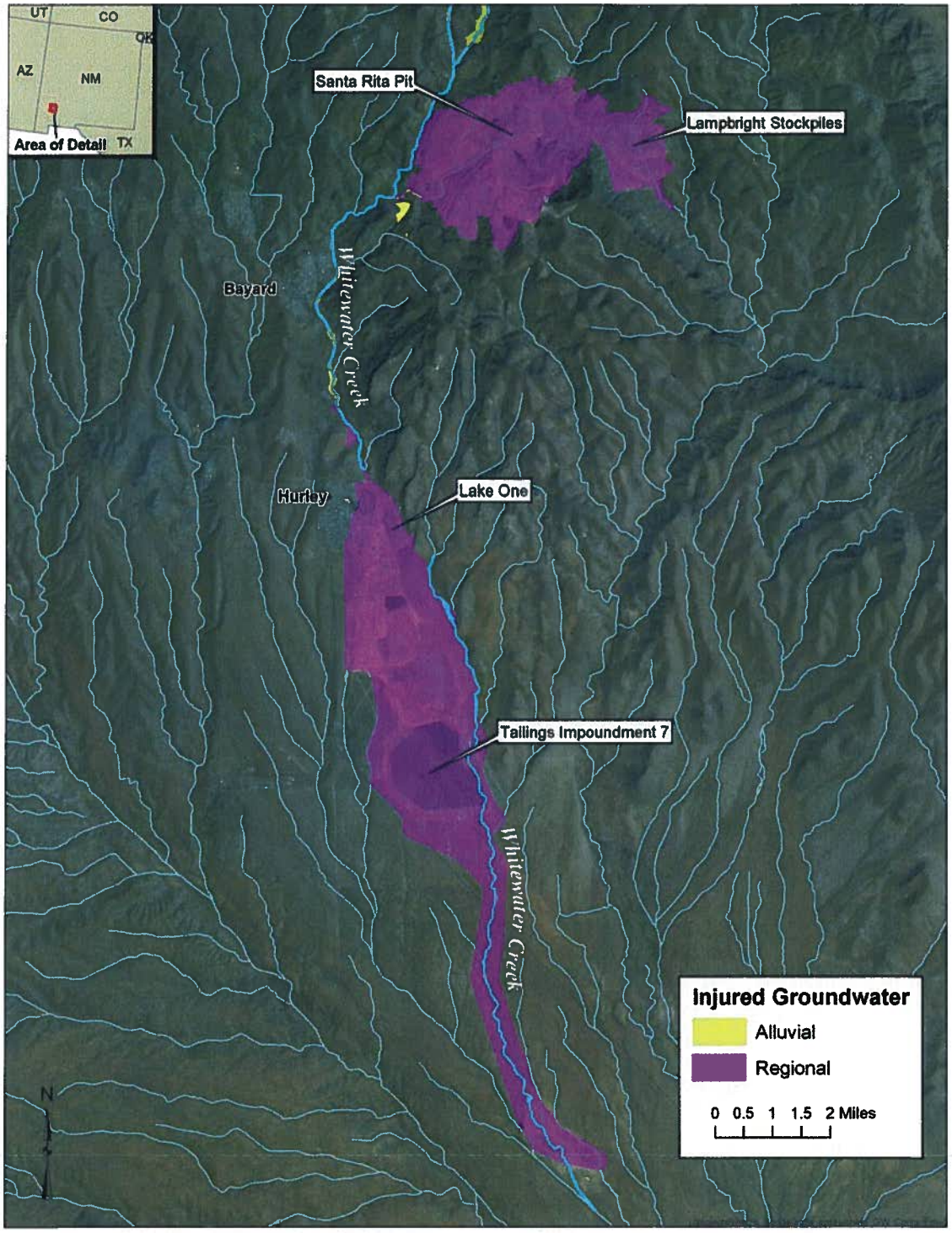

Figure 3.2. Areal extent of injured alluvial and regional groundwater at the Chino Mine.

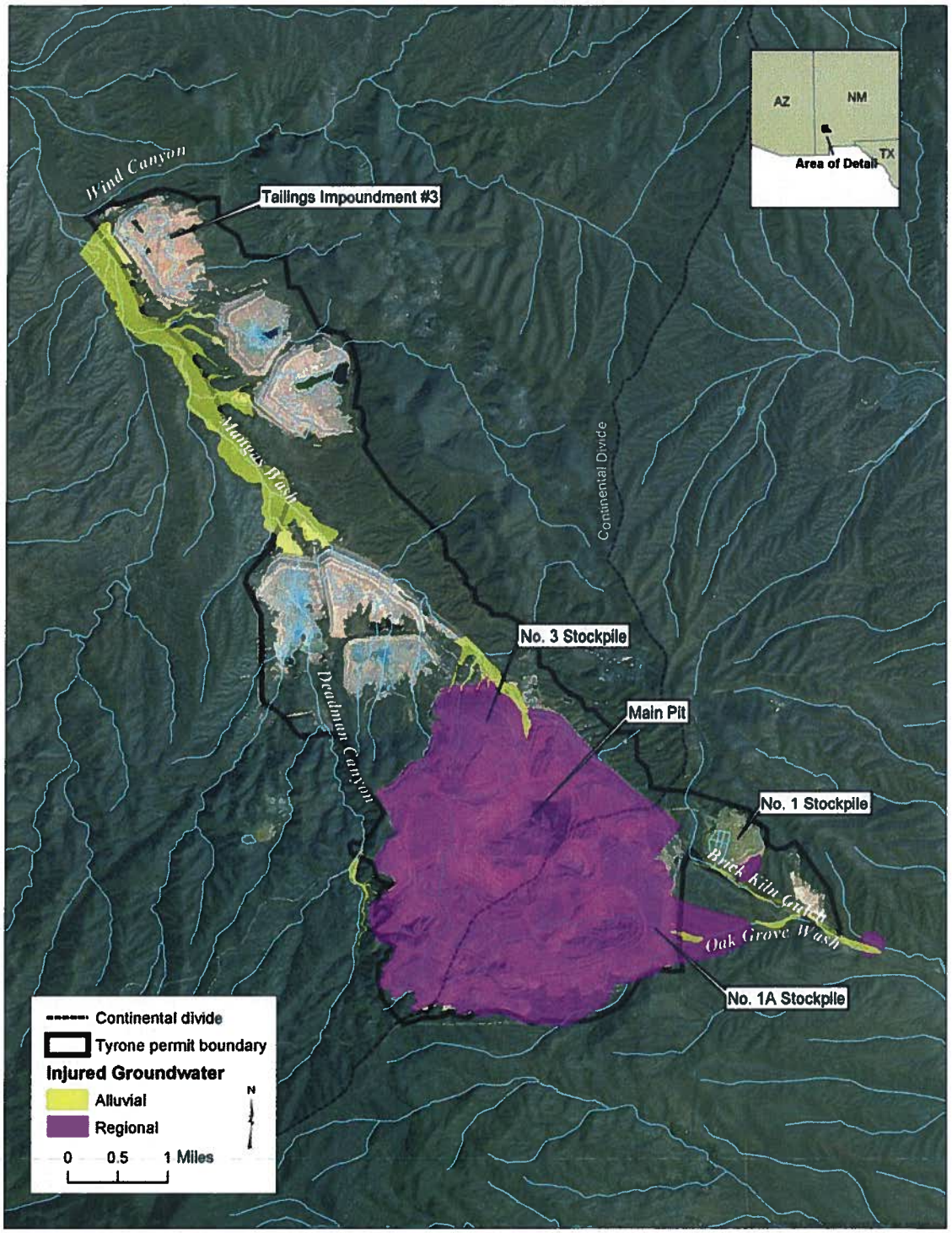

Figure 3.3. Areal extent of injured alluvial and regional groundwater at the Tyrone Mine.

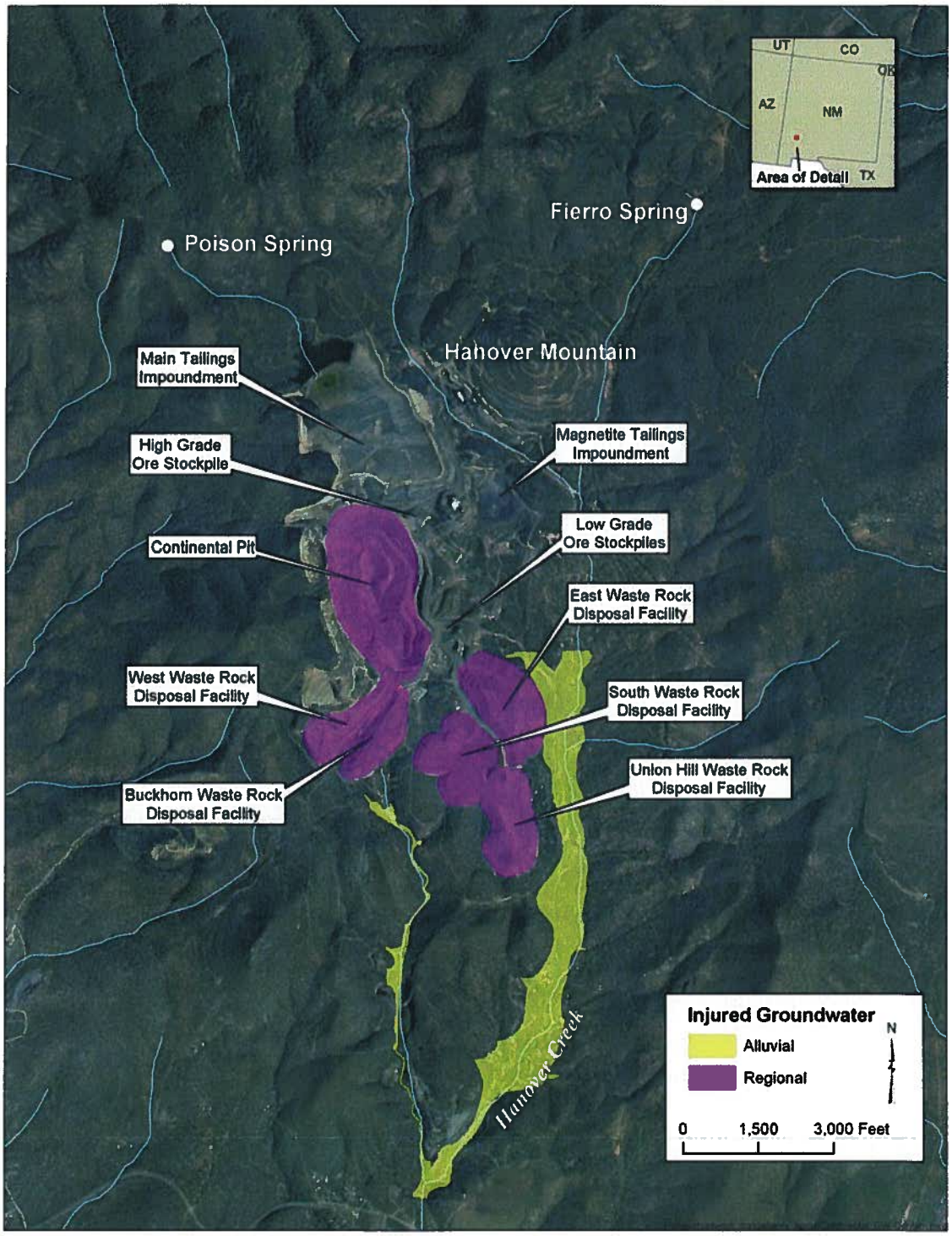

Figure 3.4. Areal extent of injured alluvial and regional groundwater at the Cobre Mine.

Table 3.4. Areal extent of injured groundwater at the Chino, Tyrone, and Cobre mines

Mine site	Aquifer type	Injured areal extent (acres)
Chino	Regional groundwater	13,718
	Alluvial	217
	Sum	13,935
Tyrone	Regional groundwater	5,253
	Alluvial	1,027
	Sum	6,280
Cobre	Regional groundwater	328
	Alluvial	200
	Sum	528
Total injured areal extent:		**20,743**

3.4.3 Duration of release

For the assessment, groundwater injury was quantified starting in 1981. Although groundwater injury likely existed before 1981 at all Sites, especially in areas around the pits and older tailings impoundments, ONRT limited their quantification of injury to the time period following the enactment of CERCLA legislation in December 1980. Groundwater quality samples at the Sites were collected as early as the late 1970s/early 1980s in some locations. Many of these samples revealed mining-related exceedences from the first sampling efforts. Some samples near the edges of plumes and away from primary sources initially had low concentrations of hazardous and related substances and later had exceedences of water quality standards (see discussion of baseline water quality in Section 3.4.1). In these instances, shorter durations of injury were incorporated into the injury quantification.

As part of the settlement process, ONRT and FMI agreed in 2008 that groundwater injuries were expected to continue for a significant period into the future. Although future implementation of remedial actions at the Site may shorten the time period of groundwater injury in limited locations, ONRT assumed a "reasonable worst case scenario" of continued injury for 100 years, through 2108, for the purpose of evaluating and quantifying injury.

3.4.4 Likelihood of future recovery

The injured groundwater consists of plumes of sulfate and metals in alluvial and regional aquifers. Unlike organic compounds, inorganic compounds such as metals do not degrade thermally or bacterially in groundwater. Although sulfate can be converted to other sulfur compounds, such as sulfide, under highly reducing conditions, there are many wells at the Sites with more than 20 years of relatively constant and elevated sulfate concentrations. Concentrations of some inorganic compounds at mine sites, such as nitrate, which derives from blasting agents used to excavate open pits and underground workings, can decrease over time if blasting operations cease. However, the sources of sulfate and metals at the Sites still remain and are still leaching contaminants to groundwater. It is highly unlikely that concentrations of these constituents will decrease markedly over time. These characteristics of the groundwater injury plumes support an assumption that injury will last for at least 100 years at the Sites.

3.4.5 Quantifying compensatory restoration

To develop an estimate of monetary damages necessary to offset the quantified groundwater injury and compensate the citizens of the State of New Mexico, ONRT used the "cost of replacement and/or acquisition of equivalent natural resources" approach described in the CERCLA natural resource damage assessment regulations at 43 C.F.R. 11.80 (b). ONRT chose the cost of acquiring water rights in two watersheds in New Mexico as the measure of "acquiring equivalent natural resources." To develop an estimate of the cost to acquire the equivalent water resources, ONRT utilized the following information:

- The estimated volume of injured groundwater. This estimate was developed using a set of assumptions about factors such as aquifer porosity and saturated thickness of injured groundwater that allowed ONRT to translate estimates of the areal extent of injured groundwater to a volume of injured groundwater in different locations.
- Estimates of when groundwater injury began for each plume (start date), and when groundwater may be considered not injured based on remedial actions and natural attenuation (recovery path).
- The cost to acquire equivalent groundwater resources.
- An economic discount rate that accounts for the duration of injury. ONRT applied a 3% discount rate, which is standard practice in economic analysis and natural resource damage assessment applications (NOAA, 1999).

To develop the cost to acquire equivalent water resources, ONRT used recent estimates of the cost to acquire water rights in the Silver City region of New Mexico. A water right allows the holder to use a certain amount of water, typically measured in acre-feet,[2] each year into the future. To estimate the amount of water rights necessary to provide an amount of water equivalent to what was injured, ONRT developed an estimate of how much water is provided over time by a 1 acre-foot water right. This estimate applied the 3% annual discount factor, which accounts for the fact that a water right provides a certain volume of water over time to the owner of the right. The resulting volume measure is described as "discounted" acre-feet. Using information on the amount of groundwater injured and the discounted acre-feet of water provided by a 1 acre-foot water right, ONRT estimated the number of acre-feet of water rights necessary to compensate for the injured groundwater and the associated cost of acquiring these water rights. In this manner, the cost to acquire equivalent water resources was the measure of damages used to help develop the final restoration settlement amount of $12,794,000.

2. An acre-foot of water is the amount of water necessary to cover 1 acre of land to a depth of 1 foot. This is equivalent to 325,851 gallons of water.