REVISION 1
WORK PLAN TO CHARACTERIZE AND MITIGATE SULFATE WITH
RESPECT TO DRINKING WATER SUPPLIES IN THE VICINITY OF THE
CONCENTRATOR TAILING STORAGE AREA
COCHISE COUNTY, ARIZONA
MITIGATION ORDER ON CONSENT DOCKET NO. P-121-07

July 3, 2008

HYDRO
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Prepared for:

FREEPORT-MCMORAN CORPORATION COPPER QUEEN BRANCH
36 West Highway 92
Bisbee, Arizona 85603

Prepared by:

HYDRO GEO CHEM, INC.
51 West Wetmore Road
Tucson, Arizona 85705
(520) 293-1500

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HYDRO GEO CHEM, INC.

Environmental Science & Technology

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51 West Wetmore Road
Tucson, Arizona 85705
(520) 293-1500

Approved by:

REGISTERED GEOLOGIST
CERTIFICATE NO.
30842
JAMES R.
NORRIS
Date Signed 7/3/08
ARIZONA U.S.A.
Expires 12/31/08

James R. Norris
Arizona Registered Geologist No. 30842

July 3, 2008

TABLE OF CONTENTS

1. INTRODUCTION 1
1.1 Mitigation Order Requirements Pertaining to Work Plan 2
1.2 Work Plan Organization 4

2. SUMMARY OF EXISTING INFORMATION 7
2.1 Background 7
2.1.1 Description of the CTSA 7
2.1.2 Historical Land Use of the CTSA and Vicinity 8
2.1.3 Use of Excess Mine Water 9
2.1.4 Location of the Sulfate Plume 10
2.2 Current Sulfate Mitigation Actions 11
2.3 Geologic Setting 12
2.3.1 Recent Alluvium 13
2.3.2 Basin Fill Deposits 14
2.3.3 Bedrock Complex 15
2.3.3.1 Cretaceous Sedimentary Rocks 15
2.3.3.2 Paleozoic Rocks 18
2.3.3.3 Igneous and Metamorphic Rocks 19
2.3.3.4 Structure 19
2.4 Groundwater Hydrology 21
2.4.1 Hydrostratigraphic Units 21
2.4.1.1 Basin Fill 21
2.4.1.2 Bedrock Complex 22
2.4.1.3 Influence of Structure on Groundwater Flow 23
2.4.2 Hydraulic Properties 23
2.4.3 Potentiometric Relationships 25
2.4.4 Groundwater Flow 29
2.4.5 Recharge Sources 30
2.5 Water Quality 32
2.5.1 Sulfate Distribution 34
2.5.1.1 Areal Distribution 34
2.5.1.2 Vertical Distribution 36
2.5.1.3 Comparison of Current Sulfate Distribution to Model Predictions 37
2.5.2 Major Element Chemistry 39
2.5.3 Metals 41
2.6 Preliminary Conceptual Model for the Groundwater Sulfate Plume 43

3. AQUIFER CHARACTERIZATION PLAN 49
3.1 Aquifer Characterization Plan (ACP) Objectives and Data Needs 49
3.1.1 ACP Objectives 49
3.1.2 Data Needs 49
3.2 Task 1 - Well Inventory of Drinking Water Supply Wells 52

TABLE OF CONTENTS (Continued)

3.3 Task 2 - Plume Characterization 54
3.3.1 Task 2.1 - Data Compilation and Evaluation 55
3.3.2 Task 2.2 - Groundwater Monitoring 56
3.3.3 Task 2.3 - New Monitoring Well Installation and Testing 59
3.3.3.1 Drilling Methods and Reconnaissance Sampling 62
3.3.3.2 Well Design Rationale 64
3.3.3.2.1 General Considerations 65
3.3.3.2.2 Wells on the Margin of the Plume 66
3.3.3.2.3 Wells within the Footprint of the Plume 67
3.3.3.2.4 General Construction Guidelines 68
3.3.3.3 Well Installation, Development, and Testing 70
3.3.4 Task 2.4 Additional Hydraulic Testing 71
3.4 Task 3 - Sulfate Fate and Transport Evaluation 71
3.4.1 Compilation of Information on Groundwater Pumping and Recharge 72
3.4.2 Sulfate Transport Under Current and Future Conditions 73
3.5 Task 4 - Reporting 74

4. POTENTIAL INTERIM ACTIONS 77

5. FEASIBILITY STUDY FOR SULFATE MITIGATION PLAN 81
5.1 Identification and Screening of Mitigation Actions and Technologies 81
5.1.1 Mitigation Objectives 82
5.1.2 Mitigation Actions 82
5.2 Development and Screening of Mitigation Alternatives 84
5.3 Detailed Analysis of Mitigation Alternatives 85
5.4 Mitigation Plan 86

6. SCHEDULE 87

7. REFERENCES 89

TABLE OF CONTENTS (Continued)

TABLES

1 Generalized Geologic Column in the Vicinity of the CTSA
2 Summary of Hydraulic Conductivity Data
3 Estimated Groundwater Flow Velocities in the Vicinity of the CTSA
4 Analytical Results for 1996 Groundwater Samples Used for Trilinear Diagrams
5 Summary of Data Needs and Proposed Work
6 Proposed Groundwater Monitoring Wells
7 Proposed New Monitoring Well Locations
8 Schedule for Work Plan Deliverables

FIGURES

1 Location Map Bisbee-Naco Area
2 Facilities in the Vicinity of the Concentrator Tailing Storage Area
3 Well Location Map
4 Sulfate Plume 2005
5 Geological Map of the CTSA and Vicinity
6 A-A' Geological Cross Section
7 B-B' Geological Cross Section
8 Water Level Map 1989
9 Water Level Map 1996
10 Water Level Map 1999
11 Water Level Map September 2005
12 Hydrographs for Wells TM-2, TM-19, BF-2, TM-7, TM-19A, and TM-2A
13 Hydrographs of Monitoring Wells Separated by the Black Gap and the Abrigo Faults
14 Sulfate Concentration Map - July 1989
15 Sulfate Concentration Map - Summer 1996
16 Sulfate Concentration Map - August through November 2005
17 Comparison of 1996 and 2005 Sulfate Plume Boundaries
18 Sulfate Concentrations in Wells BF-1, NWC-3, NWC-4, TM-2, TM-16, and TM-42
19 Measured and Predicted Sulfate Concentrations for Year 2005
20 Trilinear Diagram of Major Ions
21 Schematic Diagram of Conceptual Site Model
22 Proposed Well Locations for Groundwater Monitoring (Task 2.2) at Existing Wells
23 Proposed New Monitoring Well Locations (Task 2.3)
24 Schedule for Aquifer Characterization and Sulfate Mitigation Plans

TABLE OF CONTENTS (Continued)

APPENDICES

A Summary of Wells in the CTSA and Vicinity
B Historic Water Levels for Select Wells
C Historic Sulfate Concentrations, CTSA Wells
D Analytical Results for Groundwater Samples
E Generalized Well Construction Diagrams for Monitoring Wells
F Quality Assurance Project Plan

LIST OF ACRONYMS

A.A.C.	Arizona Administrative Code
ac-ft/yr	acre-feet per year
ACP	Aquifer Characterization Plan
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
ANP	Acid Neutralization Capacity
A.R.S.	Arizona Revised Statutes
AWC	Arizona Water Company
AWQS	Aquifer Water Quality Standards
CQB	Copper Queen Branch
CTSA	Concentrator Tailing Storage Area
DQO	Data Quality Objective
FS	Feasibility Study
GIS	Geographic Information System
gpm	gallons per minute
Sac LOGS	Sacramento Low Ore Grade Storage
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
MO	Mitigation Order
NWC	Naco Water Company
QAPP	Quality Assurance Project Plan
RO	Reverse Osmosis
SDP	Sewage Disposal Ponds
TDS	Total Dissolved Solids
UTM	Universal Transverse Mercator
WWTF	Waste Water Treatment Facility
WWTP	Waste Water Treatment Plant

1. INTRODUCTION

A plume of sulfate has been detected in the groundwater downgradient to the south and southwest from the Freeport-McMoRan Corporation Copper Queen Branch (CQB) Concentrator Tailing Storage Area (CTSA). The CTSA is located in the Naco-Bisbee area in the southeastern upper San Pedro River basin, approximately 85 miles southeast of Tucson, Arizona (Figure 1). The Naco-Bisbee area is bounded by the Mule Mountains to the north and east and by the Sierra San Jose in Sonora, Mexico to the south.

On November 14, 2007, Arizona Department of Environmental Quality (ADEQ) and Phelps Dodge Corporation, Copper Queen Branch entered into a Mitigation Order on Consent Docket No. P-121-07 (MO). In March 2008, Phelps Dodge Corporation changed its name to Freeport-McMoRan Corporation. The MO requires CQB to characterize the extent of sulfate in groundwater and to develop a Mitigation Plan for drinking water supplies impacted due to sulfate from the CTSA. The MO sets a maximum average sulfate concentration of 250 milligrams per liter (mg/L) for drinking water supplies. Because sulfate concentrations approaching and exceeding 250 mg/L have been found in some drinking water supply wells, ADEQ determined that a drinking water source is or is about to be rendered unusable without treatment (MO Section II.A.5). CQB and ADEQ entered into the MO to address the sulfate in groundwater attributable to the CTSA. The Naco-Bisbee aquifer containing the elevated sulfate is designated a Sole Source Aquifer by the U.S. Environmental Protection Agency (http://www.epa.gov/safewater/sourcewater/pubs/qrg-NACOBISBEE.pdf).

CQB is monitoring groundwater levels, has replaced one impacted drinking water supply well, and is providing bottled water to other parties with impacted drinking water supply wells. The MO provides a structure for conducting additional environmental investigations and evaluating additional potential mitigation alternatives for sulfate from the CTSA. As a requirement of the MO, this Work Plan presents the rationale and methods for further investigation and development of a Mitigation Plan. Hydro Geo Chem, Inc. prepared this Work Plan on behalf of CQB. The initial version of this Work Plan was submitted to ADEQ on December 17, 2007. Revision 1 of the Work Plan was developed in response to written comments on the December 17, 2007 Work Plan (ADEQ, 2008a and 2008b) and discussions with ADEQ.

1.1 Mitigation Order Requirements Pertaining to Work Plan

Section III of the MO requires a work plan to complete characterization of the vertical and horizontal extent of the sulfate plume downgradient of the CTSA. Specific work identified in the MO includes:

- A summary of existing information on the characterization of the sulfate plume, including references to known and ongoing characterization and assessment information (MO Section III.A.1).

- A Quality Assurance Project Plan (QAPP) that defines the sulfate plume characterization and assessment objectives, and describes the methods, organization, analyses, and Quality Assurance and Quality Control that CQB will implement to ensure that characterization and assessment objectives are met (MO Section III.A.2).

- A plan to complete characterization of the sulfate plume with an implementation schedule that includes site access and permitting requirements. The plan is to include sampling and testing of additional monitoring wells necessary (1) to identify the horizontal and vertical extent of the sulfate plume downgradient of the CTSA as defined by concentrations in excess of 250 mg/L, and (2) to evaluate the fate and transport of sulfate downgradient of the CTSA (MO Section III.A.3).

- A plan to inventory all existing registered private wells used as a drinking water source or public drinking water system wells located within a one-mile radius of the sulfate plume's downgradient and crossgradient outer edge (MO Section III.A.4).

In accordance with Section III.C of the MO, the findings of this work are to be reported in an "Aquifer Characterization Report".

Section III.E of the MO requires a Mitigation Plan that identifies and evaluates alternatives that practically and cost effectively provide drinking water meeting applicable sulfate levels to the owner or operator of an impacted drinking water supply in accordance with Arizona Revised Statute (A.R.S.) § 49-286. An impacted drinking water supply is one that is determined to have a sulfate concentration in excess of 250 mg/L due to sulfate from the CTSA. The Mitigation Plan is to include sampling and analysis methods for documenting the average sulfate concentration of a drinking water source, and a process for verifying that the CTSA is the sulfate source. If drinking water supply wells are found to be impacted by sulfate prior to implementation of the Mitigation Plan, Section III.D of the MO requires CQB to implement interim mitigation actions for the impacted drinking water supplies.

Although sulfate is a non-hazardous constituent and the applicable legal criteria to address the plume are set forth in the MO and A.R.S. § 49-286, the process approach outlined in the MO and incorporated in this Work Plan is modeled generally after the process for remedial investigations and feasibility studies used in the Arizona Water Quality Assurance Revolving Fund and the Federal Superfund Program. This Work Plan proposes an Aquifer Characterization

Plan (ACP) and a Feasibility Study (FS) for sulfate mitigation to address the requirements of the MO. The ACP will determine the nature, extent, fate, and transport of sulfate and will gather information needed to develop mitigation action alternatives consistent with the MO. The FS will identify and evaluate mitigation action alternatives and recommend a Mitigation Plan in accordance with the objectives in the MO.

Although not addressed by this Work Plan, the MO also requires:

- Formation of a community advisory group, requiring a minimum of eight people, which will meet four times yearly.
- Creation of a local information repository for the dissemination of information about the MO.
- Submittal of quarterly status reports to ADEQ.

1.2 Work Plan Organization

The components of this Work Plan are meant to fulfill the work requirements in Sections III.A, III.C, III.D, and III.E of the MO. The Work Plan is organized as follows:

- **Section 1- Introduction.**
- **Section 2 - Summary of Existing Information**. Section 2 discusses background information, describes CQB's current efforts to mitigate sulfate in drinking water supplies, and presents an overview of the geology, groundwater hydrology, and water quality including the known occurrence and extent of the sulfate plume.
- **Section 3 - Aquifer Characterization Plan**. Section 3 describes work to further characterize the nature and extent of sulfate in groundwater. This work will include: a well inventory to identify private drinking water wells and public water supply systems located downgradient and crossgradient of the sulfate plume; groundwater monitoring; monitoring well installation and testing to determine the aquifer structure, to further delineate the extent of sulfate, and to quantify aquifer hydraulic properties; numerical modeling of groundwater flow to predict the future movement of sulfate and to test potential control strategies; and reporting.

- **Section 4 - Identification of Potential Interim Actions.** Potential interim actions are described in Section 4. This task, which is consistent with FS activities, considers potential interim actions if sulfate concentrations exceed 250 mg/L in a drinking water supply before the Mitigation Plan is completed.

- **Section 5 - Feasibility Study for Sulfate Mitigation Plan**. Section 5 provides the work plan for an FS to develop a sulfate Mitigation Plan. The FS will identify mitigation action objectives, evaluate potentially applicable response actions and technologies, identify mitigation alternatives for meeting the project objectives, evaluate the benefits and costs of the alternatives, and produce a Mitigation Plan.

- **Section 6 - Schedule.** The work and reporting schedule for the ACP and FS for the Mitigation Plan is provided in Section 6. The ACP and FS have been designed to proceed in parallel to identify mitigation options early in the process. Tasks related to identifying and addressing potentially impacted drinking water supplies (e.g., the well inventory and potential implementation of interim actions) are scheduled to begin as soon as possible in the process.

The appendices provide various supporting materials referenced in the text including a QAPP describing the work methods to be used. If during implementation of the Work Plan it is necessary to perform a task at substantive variance with the Work Plan, CQB will submit a written notice of variance and request ADEQ's written permission prior to performing the task. If ADEQ does not respond to a time-critical decision by the date identified in the written notice, CQB will assume that ADEQ approves the variance.

2. SUMMARY OF EXISTING INFORMATION

Section III.A.1 of the MO requires a summary of existing information on the extent of sulfate in groundwater downgradient of the CTSA, including references to known and ongoing characterization and assessment information. To address this requirement, this section: provides an overview of the estimated extent of sulfate in groundwater; reviews the current mitigation actions being taken by CQB to address sulfate in drinking water supplies; describes the geology, groundwater hydrology, and water quality downgradient of the CTSA; and presents a conceptual model of the sulfate plume.

2.1 Background

2.1.1 Description of the CTSA

The CTSA is located approximately 3.5 miles southeast of Bisbee, approximately four miles northeast of Naco, and approximately one mile south of Warren in Cochise County, Arizona (Figure 1). As defined by the MO, the CTSA is comprised of two inactive tailing impoundments (the North Tailing Impoundment and the South Tailing Impoundment), a former evaporation pond, and a storm water containment pond (Horseshoe Pond No. 1). The storm water containment pond is located immediately south of the South Tailing impoundment. Sediments from the former evaporation pond were excavated and placed on the South Tailing Impoundment in 1989 and 1990 (PD, 2004). Horseshoe Pond No. 1, an unlined storm water retention pond, was constructed at the former evaporation pond site in 1990 and currently collects storm water from the North and South Tailing Impoundments and from drainage from areas north of the CTSA (PD, 2004). Collected storm water is periodically pumped from the Horseshoe Pond to the South Tailing Impoundment. The North and South Tailing Impoundments are uncapped and unlined except for certain side slopes of the South Tailing Impoundment. Capping and closure plans for the North and South Tailings Impoundments are in development and will be submitted to ADEQ for approval prior to implementation.

The North and South Tailing Impoundments and former evaporation pond cover an area of approximately 1,000 acres in Sections 27, 33, and 34, Range 24 East, Township 23 South, and Sections 3 and 4 in Range 24 East, Township 24 South. The CTSA was used variably from 1908 through 1987 for the storage and evaporation of excess mine water, the placement of tailing, or containment of stormwater. The CTSA facilities are currently inactive and receive no solids or liquids except for stormwater pumped from Horseshoe Pond No. 1 and rainwater.

2.1.2 Historical Land Use of the CTSA and Vicinity

Mining activities in the Bisbee area began in 1880. Land in the vicinity of the CTSA has been used variably since 1905 for management of excess water and placement of mined material. Historical facilities in the vicinity of the CTSA include a former irrigation area that used mine water south and southwest of the CTSA and the former Crawford Mill tailing site north of the CTSA. Further to the north were former low-grade ore stockpile areas (Sacramento Low Ore Grade Storage No. 1 (Sac LOGS 1) and Sacramento Low Ore Grade Storage No. 2 (Sac LOGS 2)) (Phelps Dodge Corporation (PD), 1990) (Figure 2).

Mining and smelting of ore from the Sacramento Pit began in 1919 (Stegan, et al, 2005) and operation of the Sacramento Mill began in 1923. Low-grade ore from the Sacramento Pit was stockpiled at Sac LOGS 1 and Sac LOGS 2 from 1923 to 1932 (PD, 2004) and tailing from the mill were piped as slurry to the North Tailing Impoundment through 1932 (PD, 1990). Crawford Mill tailing produced from 1945 through 1954 was sent to the 12.6-acre Crawford Mill Tailing Impoundment (PD, 2004). Lavender Pit ore was mined, milled, and leached from 1954 to 1974 and the Lavender Mill tailing were sent to the North and South Tailing Impoundments.

The former irrigation area, known as the Warren Ranch irrigation area, was in Sections 3, 4, 8, 9, and 10, Range 24 East, Township 24 South. Delivery of excess mine water to the irrigation area began in 1905 and ceased in 1987.

In 1991 and 1992, the relatively small Crawford Mill tailing impoundment was removed from its storage site and placed on the North Tailing Impoundment (PD, 2004). Because the Crawford Mill tailing impoundment was removed, this area is not considered a current or potential future source of sulfate.

2.1.3 Use of Excess Mine Water

The use of excess mine water for irrigation of the former Warren Ranch irrigation area started in 1905 and was followed by discharge of additional excess mine water to the former evaporation pond commencing in 1908 (PD, 2004). Delivery of mine water to both the Warren Ranch irrigation area and the former evaporation pond ceased in 1987. Mine water was pumped to the former Warren Ranch irrigation area at a rate of approximately 2,350 acre-feet per year (ac-ft/yr) or approximately 1,457 gallons per minute (gpm) (PD, 2004). The former evaporation pond received excess water from underground mine and open pit dewatering at a rate of approximately 4,430 ac-ft/yr or approximately 2,746 gpm (PD, 2004).

2.1.4 Location of the Sulfate Plume

In 1987, groundwater in the vicinity of the CTSA was reported to have elevated sulfate and total dissolved solids (TDS) (Littin, 1987). In 1988 and 1989, CQB installed a series of monitoring wells in the CTSA. In addition, several borings were drilled to assess subsurface geology and hydrology, and were either not completed as wells after drilling, or were completed as temporary wells that were abandoned by 1990. Previous hydrogeologic studies have concluded that the primary source of sulfate is seepage from the former evaporation pond and to a lesser degree, water sent to the former irrigation area and not seepage from the North and South Tailing Impoundments (Southwest Groundwater Consultants (SGC), 1994; Savci Environmental Technologies (SET), 1998a).

Figure 3 is a well location map showing sites for which water level and water quality data were available for use in this Work Plan. The sites include current and abandoned monitoring wells, public water supply wells, and private wells. The lithologic unit in which each well is screened is indicated. Well construction data pertaining to wells shown on Figure 3 are summarized in Appendix A (Table A.1).

Based on limited sampling of monitoring and public water supply wells in 2005, the extent of the sulfate plume, defined by the 250 mg/L sulfate concentration contour, is estimated to be approximately 3.5 miles long in a southwesterly direction and 2.5 miles wide, with its northern boundary located at the southern margin of the South Tailing Impoundment and its southern edge south of Naco Water Company (NWC) well 3 (NWC-3) (Figure 4). Where recent data is lacking, the position of the contour is inferred based on historical water quality data for 1996 and consideration of historical hydraulic gradients as described in Section 2.5. As discussed in Section 2.5.2, TDS is associated with the sulfate plume.

The MO requires CQB to mitigate an impacted drinking water supply if the supply can be verified as having a sulfate concentration greater than 250 mg/L as a result of the plume originating from the CTSA. As stated in Section II.B.5 of the MO and A.R.S. § 49-286, mitigation measures may include:

- Providing an alternate drinking water supply
- Mixing or blending if economically practicable
- Economically and technically practicable treatment before ingesting the water
- Such other mutually agreeable mitigation measures as are necessary to achieve the purposes of A.R.S. § 49-286.

2.2 Current Sulfate Mitigation Actions

Current sulfate mitigation activities by CQB consist of supplying bottled water to parties with impacted drinking water wells and replacement of an impacted drinking water well. Bottled water is being provided to thirteen parties in the Naco area that have well water containing greater than 250 mg/L sulfate due to the plume from the CTSA. CQB offered bottled water to a larger number of parties, some of whom have either declined or not responded. One private well was replaced in 2001.

2.3 Geologic Setting

This section provides an overview of the geology in the vicinity of the CTSA. Geologic data have been drawn from a number of sources including U. S. Geologic Survey publications, Arizona Geological Society publications, reports on environmental investigations, and a review of lithologic logs for area wells. The geology of the Mule Mountains and Bisbee-Naco basin has been mapped and described by Hayes (1970) and Hayes and Landis (1964). Stegan, et al (2005) describes the geology and mineralization of the Bisbee-Warren mining district, and references original detailed geologic studies by other workers pertaining to the mining district.

Mining activities in the Bisbee area have been concentrated in the Mule Mountains, which are comprised of Precambrian metamorphic rocks, Paleozoic and Cretaceous sedimentary formations, and Jurassic and Tertiary intrusive rocks. Mining activities have been focused primarily on metal mineralization occurring in the Paleozoic sedimentary units and various Jurassic intrusive rocks.

The Bisbee-Naco area is in a physiographic basin south of the Mule Mountains (Figure 1). The Mule Mountains and the Cerro La Muela in Sonora, Mexico form the northern and eastern margin of the basin. The Sierra San Jose in Sonora, Mexico forms the southern boundary of the physiographic basin, approximately one half of which lies in Mexico (Figure 1). The mountains surrounding the basin are composed of bedrock materials, and the basin is comprised of clastic sediments underlain by bedrock. Surface runoff from the Bisbee-Naco watershed area primarily drains into Greenbush Draw, which flows west and then northwest into the San Pedro River (Figure 1). The CTSA is northeast of Greenbush Draw, in the northeastern portion of the Bisbee-Naco physiographic basin (Figures 1 and 2).

The geologic units present in the Bisbee-Naco area and surrounding mountains can be divided into three generalized units: Recent alluvium, Quaternary and Tertiary basin fill deposits, and the bedrock complex. Recent alluvium is comprised of unconsolidated alluvial material. Basin fill consists of poorly to moderately lithified clastic material (Littin, 1987). The bedrock complex is comprised of older indurated units including the Cretaceous Bisbee Group sedimentary formations, Jurassic to Tertiary age igneous rocks, Paleozoic sedimentary formations, and Precambrian metamorphic rocks. Figure 5 is a generalized geologic map based on mapping by Hayes and Landis (1964). Table 1 is a generalized geologic column for the vicinity of the CTSA. Figures 6 and 7 are geologic cross sections based on borings in the CTSA. The locations of the cross sections are shown in Figures 3 and 5.

2.3.1 Recent Alluvium

Recent alluvium includes stream channel sediments, pediment and terrace gravel, sheet wash deposits and alluvial fans (Hayes and Landis, 1964). Recent alluvium is not a significant aquifer because it typically is unsaturated. In the vicinity of the CTSA, Recent alluvium occurs primarily in Greenbush Draw (Figure 5).

2.3.2 Basin Fill Deposits

The Tertiary to Quaternary basin fill deposits are comprised primarily of poorly to moderately lithified sand and gravel lying unconformably on Cretaceous or older sedimentary bedrock. The basin fill consists of interbedded boulder to pebble conglomerate, gravel, sand, silt and clay (Littin, 1987). Based on logging of cuttings from monitor wells, the estimated average silt and clay content of the basin fill is 15 percent, with a range of 5 to 40 percent. Caliche beds are commonly present within the upper 40 to 100 feet of the basin fill penetrated by monitoring wells in the vicinity of the CTSA (Errol L. Montgomery and Associates (ELMA), 1990) (Figures 6 and 7). Clay beds interbedded with sand and gravel have been logged in portions of the basin fill but no laterally extensive clay units have been defined. For example, clay beds up to 20 feet thick were encountered at various depths in the basin fill at GW-47 (Wright, 2001), TM-2A, and TM-29 (ELMA, 1990).

In the vicinity of the sulfate plume, the basin fill ranges in thickness from zero at its contact with surface outcrop of bedrock along the margins of the Bisbee-Naco physiographic basin to 535 feet thick within the plume area at monitor well TM-19A (ELMA, 1990). Basin fill thickness is shown on cross sections A-A’ and B-B’ (Figures 6 and 7), indicating that the basin fill thickens generally towards the southwest away from the CTSA. In the southern portion of the Bisbee-Naco area in Sonora, Mexico, depth to bedrock data is not currently available. The basin fill deposits south of the international border appear to form thick alluvial fans which slope north and east toward Greenbush Draw from the base of the Sierra San Jose (Figure 1).

2.3.3 Bedrock Complex

For the purposes of this report, bedrock refers to lithified rock units regardless of whether or not they are water-bearing. Bedrock in the vicinity of CTSA is comprised of the lower Cretaceous Bisbee Group formations. Paleozoic sedimentary rocks have been intercepted beneath basin fill only in monitoring wells located north of the CTSA (ELMA, 1990 and Water Management Consultants (WMC), 2006). One of these northern monitoring wells, TM-18 (Figure 3) also intercepted Precambrian Pinal Schist below the Paleozoic units.

2.3.3.1 Cretaceous Sedimentary Rocks

The Bisbee Group consists of four sedimentary formations, which are, in descending order, the Cintura Formation, the Mural Limestone, the Morita Formation and the Glance Conglomerate. These formations have gradational contacts and are conformable with one another where they are exposed in the Mule Mountains north and east of the CTSA (Hayes, 1970). The Morita Formation and the Glance Conglomerate are the principal bedrock units underlying basin fill in the region around the CTSA (Figures 6 and 7). Mural Limestone was intercepted under basin fill in one well, TM-17, south of Purdy Lane (Figures 3 and 7).

The Cintura Formation is comprised of grayish red siltstone and mudstone, feldspathic sandstone, and minor amounts of green-gray calcareous claystone, with a few thin beds of fossiliferous limestone in its basal 100 feet. Maximum preserved thickness in the Mule Mountains is 1850 feet (Hayes and Landis, 1964).

The Mural Limestone is composed of an upper member of dark gray limestone that is up to 275 feet thick with subordinate sandstone in the upper 50 feet, and a lower member up to 453 feet thick consisting of interbedded calcareous sandstone, siltstone and impure fossiliferous limestone (Hayes and Landis, 1964).

The Morita Formation is generally comprised of grayish red siltstone and mudstone, pale red feldspathic sandstone, minor amounts of greenish gray calcareous claystone, a few thin beds of impure limestone in the upper part of the formation, and a very small amount of pebble conglomerate in the lower part of the formation. The upper 300 feet of the Morita Formation is primarily sandstone. Siltstone and mudstone cyclically interbedded with sandstone constitute the remainder of the formation. The Morita Formation probably represents deposition on a slowly subsiding subaerial deltaic plain. Sandstone beds in cut-and-fill relation on underlying siltstone and mudstone are believed to represent channel deposits of meandering streams and intervening siltstone and mudstone units represent inter-fluvial flood deposits (Hayes, 1970). Where it outcrops in the Mule Mountains north and east of the CTSA, the formation is about 2,605 feet thick (Hayes, 1970).

Morita Formation penetrated by monitor wells in the vicinity of the CTSA is described in well logs as variably colored and variably textured clastics with occasional minor limestone. Examples include sandstones varying in texture from fine- to coarse-grained, in composition from arkosic to quartzitic, and in color from grayish red, reddish brown, brown, buff, gray, green-gray to tan. Siltstones and mudstones vary in color from dark reddish brown, blackish red, purplish brown, olive green to yellow. The maximum thickness of Morita Formation penetrated by monitoring wells is 335 feet in TM-2A (ELMA, 1990), where it is observed to overlie Glance Conglomerate and to underlie basin fill. The maximum thickness of Morita Formation in the vicinity of the CTSA is relatively thin compared to the thicknesses outcropping in the Mule Mountains. Description of Morita Formation in geologic logs of area wells report abundant siltstone and mudstone interbedded with sandstone, consistent with penetration of the middle or lower rather than the upper portions of the formation. These two observations suggest that the Morita Formation in the vicinity of the CTSA has probably been faulted, tilted, and/or eroded prior to deposition of the basin fill.

The Glance Conglomerate lies unconformably on a variety of older lithologic units and is the basal Cretaceous unit of the Bisbee Group. The Glance Conglomerate outcrops north of the CTSA in and around the town of Warren, and over several square miles in the Mule Mountains east of the CTSA. Hayes and Landis (1964) estimated that the Glance Conglomerate ranges from zero to over 600 feet in thickness in the Mule Mountains. Beyond the Mule Mountains much greater thicknesses of Glance Conglomerate are reported; for example, over 3,600 feet of Glance Conglomerate has been described in the Huachuca Mountains approximately 22 miles west of Bisbee (Hayes, 1964; Bilodeau, et al, 1987). The thickest interval of Glance

Conglomerate intercepted in area monitoring wells was 740 feet in TM-8 southeast of the former evaporation pond (ELMA, 1990) (Figures 3 and 6).

The Glance Conglomerate is an alluvial fan deposit made up of locally derived material with variable ratios of schist, limestone, and granitic clasts (Hayes, 1970); and consists of poorly sorted, poorly rounded, cobble to pebble sized clasts in a sandy and silty grayish-red mudstone matrix. Boulder-sized clasts are also locally present. Glance Conglomerate intercepted in monitor wells near the CTSA is composed dominantly of schist clasts, with lesser amounts of limestone, quartz, and occasional chert clasts in a dark reddish brown silty matrix (ELMA, 1990).

2.3.3.2 Paleozoic Rocks

Paleozoic sedimentary bedrock formations in the Mule Mountains are represented by, in descending order, the Naco Group, which includes the lower Permian Colina Limestone, upper Pennsylvanian Earp, and middle to upper Pennsylvanian Horquilla Limestone Formations; followed by the Mississippian Escabrosa Limestone, Devonian Martin Limestone, and the Cambrian-age Abrigo Limestone and Bolsa Quartzite (Hayes and Landis, 1964). Paleozoic sedimentary units, particularly the Abrigo, Martin, and Escabrosa Limestones, are important hosts to metal mineralization in the Warren-Bisbee mining district (Stegan, et al, 2005).

North of the CTSA, where monitoring wells intercepted Paleozoic sedimentary rock, the rocks penetrated are not identified in well logs with respect to any formation, but are described as micritic to crystalline limestone, calcareous to non-calcareous siltstone, and dolomitic siltstone and mudstone (ELMA, 1990).

2.3.3.3 Igneous and Metamorphic Rocks

Igneous and metamorphic rocks in the Mule Mountains include Tertiary quartz latite, Jurassic Juniper Flat Granite, a tuff of probable Jurassic age, the Jurassic Sacramento intrusive complex associated with copper mineralization, and the Precambrian Pinal Schist. The Pinal Schist is a light colored quartz-sericite phyllite to quartz-muscovite schist (Stegan, et al, 2005). Eroded Pinal Schist is the source of schist clasts in the Glance Conglomerate (Hayes, 1970). Monitoring well TM-18 drilled approximately one mile north of the North Tailing Impoundment, north of the Bisbee West fault (Figure 3), intercepted Pinal Schist underlying Paleozoic sedimentary rock (ELMA, 1990).

2.3.3.4 Structure

Four major faults influence the hydrogeologic setting of the CTSA: the Bisbee West fault and its eastward extension, the Gold Hill fault, the Abrigo fault, the Black Gap fault, and the Ninety-One Hills fault zone (Figures 4 and 5). The south-dipping Bisbee West and Abrigo faults along the southern margin of the Mule Mountains trend west-northwest and are sub-parallel high-angle range front faults with normal offset. The subsurface projection of the Bisbee West fault passes to the north of the former Sac LOGS 1 and 2. The projected trace of the Abrigo fault as interpreted by SET (1998c) passes under the southwestern corner of the South Tailing Impoundment.

The Black Gap fault trends north-northeast and dips steeply to the west. On the surface it is expressed as a topographic break known as Black Gap, forming a pass between Warren and the CTSA, and vertically offsetting Paleozoic limestone beds (Figure 5). From Black Gap, the fault extends to the north-northeast intersecting the Saginaw fault zone in the subsurface north of Warren (SET, 1998c), and then is exposed again at the surface further north near the Dividend fault in the Mule Mountains (Hays & Landis, 1964) (Figure 5). To the south of Black Gap, the subsurface projection of the Black Gap fault trace passes along the eastern margin of the North Tailing Impoundment and under the South Tailing Impoundment, where it meets the projected subsurface trace of the Abrigo fault (SET, 1998c) (Figure 4).

The Ninety-One Hills fault is a west-northwest and west trending complex of faults paralleling the Abrigo and Bisbee West faults. The fault is located south of the CTSA approximately one mile southeast of Bisbee Junction (Hayes and Landis, 1964) (Figures 4 and 5). The Ninety-one Hills fault has been interpreted to extend under the basin fill towards the west, and offset along it may explain the presence of Mural Limestone underlying basin fill (rather than Morita Formation or Glance Conglomerate) in the vicinity of TM-17 (SET, 1998c) (Figure 3).

2.4 Groundwater Hydrology

The hydrology of the Bisbee-Naco area is discussed by Littin (1987), and the hydrologic conditions in the vicinity of the CTSA and the sulfate plume by Canonie (1990), ELMA (1990), and SET (1998a, 1998b, and 1998c). The Bisbee-Naco area watershed and aquifers are separate from those of the mining area in the Mule Mountains to the north. The hydrology of the mine area is discussed in WMC, 2006.

2.4.1 Hydrostratigraphic Units

Groundwater occurs in two hydrostratigraphic units in the vicinity of the CTSA: the basin fill and the bedrock complex. Recent alluvium is typically unsaturated and not a significant source of water to area wells. Within the bedrock complex, the Cretaceous Morita Formation and Glance Conglomerate are the most important water-bearing units.

2.4.1.1 Basin Fill

Basin fill is the principal aquifer in the Bisbee-Naco area south of the Abrigo fault and west of the Black Gap fault due to its relatively high permeability and large saturated thickness. In this area, the basin fill provided about 95 percent of all water for domestic purposes in the Bisbee area in the 1980s (Littin, 1987). The thickness of the basin fill increases from zero at the margins to at least 535 feet in the central portion of the basin north of Naco, based on the well log of monitor well TM-19A. North of the Abrigo fault and east of the Black Gap fault, the basin fill is unsaturated.

Clay beds are interbedded with sand and gravel within the basin fill (ELMA, 1990; Wright, 2001). Although well logs indicate that there is interbedded clay and silt in the basin fill in some TM wells and GW-47, clay and silt beds within the basin fill cannot be correlated from well to well. The role of these clay and silt beds in controlling groundwater flow, particularly vertical mixing in the aquifer, is uncertain.

2.4.1.2 Bedrock Complex

The bedrock complex generally has low permeability unless the intrinsic permeability is enhanced by secondary structures such as faults, fractures, and/or dissolution in the case of limestone. For this reason, the bedrock units typically do not yield as much water to wells as the basin fill (Litten, 1987), although the Bisbee Group is a source of water in the vicinity of the CTSA. The Cretaceous Morita Formation and Glance Conglomerate are the primary aquifers east of the Black Gap fault where the basin fill is unsaturated and thin.

Paleozoic sedimentary, igneous, and metamorphic rock units have not been intercepted in wells in the vicinity of the CTSA south of the Bisbee West-Gold Hill fault except at Arizona Water Company (AWC) well 5, which reportedly intercepted volcanic rock at a depth of 1,140 feet (Arizona Department of Water Resources (ADWR), 2006). Paleozoic and igneous rocks are not a source of water to CTSA wells. However, outside the CTSA in the Bisbee-Warren Mining District, highly fractured zones associated with faults in the Paleozoic units are capable of producing large volumes of water in localized areas (Littin, 1987; WMC, 2006).

2.4.1.3 Influence of Structure on Groundwater Flow

Faults play a significant role in controlling groundwater flow in the vicinity of the CTSA. The Abrigo and Black Gap faults have been regarded as hydraulic barriers or aquitards in previous hydrologic modeling of the Bisbee-Naco area (SET, 1998b and 1998c).

Although the fault zones themselves may have low permeability and restrict groundwater flow across them, adjacent fracturing in the wall rocks may increase permeability and water yield substantially in zones along or parallel to the faults. For example, the Black Gap fault forms the eastern boundary of the underground mine workings in the Warren Mining district because mine dewatering became difficult once this fault zone was crossed (Litten, 1987; WMC, 2006). North of the CTSA area, the highest flows encountered during underground mining in the district are reportedly from the fracture system developed at the intersection of the Black Gap and Saginaw faults (WMC, 2006). Enhanced permeability along the Black Gap fault may be due to subsidiary fracturing parallel to the Black Gap fault enlarging over time through dissolution (WMC, 2006). The influence of structure on groundwater elevation and flow in the vicinity of the CTSA is discussed further in Section 2.4.3.

2.4.2 Hydraulic Properties

Hydraulic conductivity data are available from pumping tests conducted at monitoring wells in the basin fill and bedrock aquifers (Steffen, Robertson, and Kirsten (SRK), 1997). Hydraulic conductivity data summarized in Table 2 include estimates for basin fill, basin fill plus Morita Formation, and Morita Formation. Table 2 contains three sets of data. The two data sets reported by SRK (1997) consist of previously unpublished data for the original aquifer tests conducted by ELMA in 1990 and SRK's reinterpretation of the results. The third data set contains hydraulic conductivity estimates from the calibrated groundwater flow model of the Bisbee-Naco area by SET (1998c). Although not the result of field tests, the model-derived estimates are included for comparison because they represent volume-averaged hydraulic properties for the area.

Based on the original pumping test interpretations by ELMA (SRK, 1997), estimates of the hydraulic conductivity in basin fill wells TM-11 and TM-13 range from 39.0 to 59.0 feet per day (ft/day) and average 49.0 ft/day. Average hydraulic conductivities in co-located wells open to both basin fill and Morita Formation were estimated at 24.1 ft/day at TM-1and TM-1A, and 4.9 ft/day at TM-29, TM-29A, and TM-29B. Estimates of hydraulic conductivities for the Morita Formation west of the Black Gap fault average 9.3 ft/day based on pumping tests at TM-30, TM-30A, TM-19A and TM-38. East of the Black Gap fault, the hydraulic conductivity of the Morita Formation was estimated to be 1.3 ft/day at TM-16. Hydraulic conductivities reported by WMC (2006) for the Morita Formation in the mining area range from 5.8×10^{-4} to 14.4 ft/day and generally appear to be lower than Morita Formation hydraulic conductivities in the vicinity of the CTSA.

Other hydraulic data reported for the basin fill include an average porosity of 0.35, average effective porosity of 0.25, and for the Morita Formation, an average porosity of 0.25 and an average effective porosity of 0.15 (ELMA, 1990).

2.4.3 Potentiometric Relationships

Figures 8, 9, 10, and 11 illustrate water level data compiled from CQB files, ADWR (2005), and previous hydrological investigations of the area for the years 1989, 1996, 1999, and 2005, respectively. Fewer water level data are available for 1996, 1999, and 2005 than for 1989 because some of the monitoring points available in 1989 were not completed as wells and also because some of the wells were abandoned by 1990. Figures 8, 9, 10, and 11 only show wells with water level data for that period. The water level data shown on these figures is reported in Appendix B.

The potentiometric contour lines in Figures 8 through 11 are interpretive based on the conceptual model discussed in Section 2.6. Water level contours are not shown crossing the Abrigo and Black Gap faults in the vicinity of the tailing impoundments since differing water levels on either side of the faults indicate poor hydraulic communication across the faults in this area. Possible refraction of water level contours across fault zone heterogeneities is not depicted.

In general, the depth to water varies from approximately 60 feet east of the Black Gap fault to greater than 800 feet north of the Abrigo fault under the South Tailings Impoundment. The water level data indicate that in the vicinity of the CTSA, the groundwater flows southwest and west on the west side of the Black Gap fault and south and southwest on the east side of the fault. South of the CTSA, the groundwater flow direction shifts to westerly in the vicinity of Naco and Greenbush Draw.

Figure 8 illustrates water levels in the CTSA for the year 1989. To provide sufficient coverage, 1988 and 1990 water levels are included for NWC and AWC wells, respectively, because 1989 data were not available for these wells. The water level at TM-35 was not used in contouring the 1989 data due to its anomalously low water level relative to neighboring wells to the west. The 1989 water elevations east of the Black Gap fault are interpreted to reflect mounding in the vicinity of the CTSA. Figures 9, 10, and 11 illustrate water levels for the years 1996, 1999, and 2005, respectively. Water level data for these years are sparser than 1989 due to the abandonment of many temporary monitoring wells by 1990.

Since 1988, when systematic water level measurements began, water levels in monitoring wells have generally declined. Wells in the vicinity of the former evaporation pond show the greatest decline. Hydrographs of wells BF-2, TM-2, TM-2A, TM-7, TM-19, and TM-19A, located near and downgradient of the former evaporation pond (Figure 3), are shown in Figure 12. These wells show a steady decline in water levels from 1988 through 1997, probably reflecting the dissipation of a ground water mound formed in response to water discharged between 1908 and 1987 to the former evaporation pond. The rate of dissipation of the mound appears to have slowed after 1997.

In contrast to the drop in water levels over time at the former evaporation pond area wells (Figure 12), the hydrograph of well GL-3, located north of the Abrigo fault and west of the Black Gap fault, shows a nearly constant rise in water levels from the time the well was installed in 1993 through 2006 (Figure 13). The hydrograph of GL-3, compared to those of wells lying on opposite sides of the Black Gap and Abrigo faults, indicate that there is poor hydraulic communication across the faults. As discussed by SET (1998b) and WMC (2006), the water level recovery at GL-3 matches that observed in the mining area to the north. On this basis, WMC (2006) concluded that the portion of the CTSA north of the Abrigo fault and west of the Black Gap fault lies in a structural block within the cone of depression resulting from mine dewatering. In this interpretation, the area north of the Abrigo fault is separated from the area south of the Abrigo fault by a groundwater divide, with groundwater flowing to the north in bedrock north of the Abrigo fault and to the south and west in basin fill and bedrock south of the Abrigo fault. The water level data shown on Figure 7 further illustrate potentiometric relationships in the vicinity of the Abrigo and Black Gap faults.

The influence of faults on permeability and groundwater flow in the area is largely inferred from potentiometric data. A combination of the Black Gap fault plane acting as a barrier to groundwater flow across the fault and a sub-parallel zone of fracture-enhanced permeability allowing flow along the fault plane may in part explain the unusual water level patterns north and west (GL-3) of the CTSA (Figures 7, 8, 9, 10, and 11). The exact nature of potentiometric relations across the projection of the Black Gap fault south of the tailing impoundment is uncertain and can only be inferred. South of the tailing impoundments water level elevations on either side of the Black Gap fault do not differ as dramatically as in the vicinity of the tailing impoundments, although monitoring data are sparse. It is possible that whatever process causes the discontinuity in water levels in the vicinity of the impoundments did not occur to the same degree south of the impoundments and so the fault may not represent as significant a heterogeneity south of the impoundment. Possible scenarios include that the fault feathers out south of the impoundments or that the degree of fractures, offset, or mineralization along the fault is less.

The degree of hydraulic connection between the Glance Conglomerate and the overlying Morita Formation and basin fill is uncertain due to the lack of co-located wells in each hydrostratigraphic unit and limited time series water level data. This is true east of the Black Gap fault (Figures 8, 9, 10, and 11) and south of the Abrigo fault in the vicinity of TM-19 and TM-19A (Figure 12). At issue is whether potentiometric conditions in the Glance Conglomerate differ significantly from those in the Morita Formation and basin fill such that the Glance Conglomerate should be treated as a separate potentiometric system. Despite this complication, potentiometric conditions south of the Abrigo fault and east of the Black Gap fault were assumed to be continuous between basin fill, Morita Formation, and Glance Conglomerate for the purpose of contouring water elevation maps.

2.4.4 Groundwater Flow

Apparent groundwater flow velocities for the years 1989 and 2005 were estimated for the basin fill and Morita aquifers using available hydraulic property estimates (Table 2), water level data for 1989 and 2005 (Figures 8 and 11), and effective porosities of 0.25 and 0.15 for the basin fill and Morita formations, respectively. Table 3 summarizes the calculation of groundwater flow velocities. To evaluate a potential range for groundwater flow velocities, the average hydraulic conductivities from field tests (ELMA results in SRK, 1997) and the estimated hydraulic conductivities from numerical modeling by SET (1998c) were used.

The groundwater pore velocity in basin fill between TM-2 and TM-11 in 1989 was estimated to range between 0.23 and 0.48 ft/day in the southwest direction using the model-derived and field test hydraulic conductivities respectively. The groundwater pore velocity in the basin fill between TM-2 and well 641802 in 2005 was estimated likewise to be between 0.09 and 0.19 ft/day in the southwest direction. Well 641802 was used for the 2005 calculation rather than TM-11 because no 2005 water level data are available for TM-11, and 641802 is the well closest to TM-11 with a 2005 water level measurement (Figure 11). The hydraulic conductivity from the calibrated model of 23 ft/day for silty sand was used to estimate flow velocity because it is the material type used in modeling flow between these wells.

The groundwater pore velocity in the north-south direction on the east side of the Black Gap fault between Glance Conglomerate well TM-28 and Morita Formation well TM-16 was estimated to be between 0.29 and 0.9 ft/day in 1989 using the model-derived and field test hydraulic conductivities, respectively. The pore velocity in the Morita Formation in the east-west direction between TM-16 and TM-19A was estimated likewise to be between 0.29 and 0.91 ft/day in 1989 and between 0.36 and 1.12 ft/day in 2005. Pore velocity in the Morita Formation in the north-south direction east of the Black Gap fault in 2005 was not calculated due to insufficient water level data.

In summary, pore velocities based on the ELMA (SRK, 1997) hydraulic conductivity estimates are greater than those based on the SET (1998c) model estimates by a factor of approximately three in the Morita Formation and a factor of two in the basin fill. Groundwater west of the Black Gap fault and south of the Abrigo fault is flowing to the southwest and west towards Naco. Groundwater flow east of the Black Gap fault is southerly, towards Bisbee Junction. Rates of groundwater movement in the basin fill west of the Black Gap fault have diminished since 1989 due to a reduction in hydraulic gradients. Rates of groundwater movement in the Morita Formation and the Glance Conglomerate east of the Black Gap fault have changed little between 1989 and 2005 because little change in hydraulic gradient had occurred. Calculated rates of movement are currently higher for the Morita Formation and Glance Conglomerate aquifers compared to basin fill because of higher hydraulic gradients and lower effective porosities in the former.

2.4.5 Recharge Sources

Range front recharge to the Bisbee-Naco area comes from the Sierra San Jose and the Mule Mountains. Littin (1987) suggested that a significant amount of recharge north of the Greenbush Draw may occur away from the Mule Mountain range front through fractured and faulted rocks in the subsurface. Surface water runoff and recharge from mountain areas is from the Mule Mountains to the north and east and from the Sierra San Jose in Mexico to the south into the center of the physiographic basin.

Historically, mine water discharged to the former evaporation pond and the former irrigation area were a source of recharge. Other recharge sources in the Naco-Bisbee area include urban runoff, municipal wastewater treatment plant (WWTP) discharge, and irrigation water. In 2006, an expanded San Jose Wastewater Treatment Facility (WWTF) began operation, replacing three smaller WWTPs: the Warren WWTP and the San Jose WWTP located within the vicinity of the CTSA (Figure 3), and the Mule Gulch WWTP outside the vicinity of the CTSA. Each treatment plant had its own on-site discharge ponds. The Warren WWTP provided recharge east of the South Tailing Impoundment in Section 35, Range 24 East, Township 23 South. SET (1998c) estimated the maximum recharge rates at the Warren WWTP as 100 gpm. The San Jose WWTP provided recharge to the former irrigation area in Section 9, Range 24 East, Township 24 South (Figure 2).

As of 2006, effluent from the new San Jose WWTF is conveyed approximately 1.5 miles southwest and either discharged into Greenbush Draw at its intersection with the Bisbee-Naco Highway approximately one half mile northeast of Naco (Figure 3) or used for golf course irrigation. Effluent-dependent surface flow in Greenbrush Draw occurs for at least one mile downstream from the discharge point. The San Jose WWTF is permitted to collect a maximum average monthly flow of approximately 850 gpm (ADEQ, 2006). The Naco Sanitary District WWTF is located in the northwest portion of Section 13, Range 23 East, Township 24 South.

Additional recharge sources in the area are the Naco Sonora Sewage pond and El Oasis Irrigation area in Sonora, Mexico. SET (1998c) estimated maximum recharge from the Naco Sonora Sewage pond and El Oasis Irrigation area as approximately 100 gpm and 500 gpm, respectively.

2.5 Water Quality

CQB has monitored groundwater quality in the vicinity of the CTSA since the late 1980s. Water quality data has been generated primarily for groundwater monitoring wells installed in the area, but has also been generated for some municipal and private water supply wells. Appendix C contains sulfate concentration data for groundwater samples for 1987 through 2005 compiled from Canonie Environmental, 1990; SGC, 1994; SET, 1998b, 1998c, 1999; ADEQ, 2006; Weiskopf, 2006; the Arizona Water Company; and the Naco Water Company. Additional groundwater quality data for 1987 through 1997 were compiled from SET (1999) and are provided in Appendix D.

Most groundwater monitoring wells in the vicinity of the CTSA were installed between October 1988 and November 1989 for the Aquifer Protection Permit investigation (ELMA, 1990), although several additional wells were installed in 1993 (SGC, 1994) and 1997 (SRK, 1997) to further characterize the site. Water quality samples have been collected from wells completed in the three principal water-bearing units in the area; the basin fill, the Morita Formation, and the Glance Conglomerate. Many of the groundwater monitoring wells sampled in 1989 are no longer available for sampling because they were abandoned by 1990.

Water samples collected from monitoring wells in the vicinity of the CTSA have been analyzed for metals, organic compounds, and inorganic parameters such as sulfate. Based on the historical sampling, metals and organic compounds are not of concern because detections have been infrequent and at low concentrations (Appendix D). Major element chemistry and metal concentrations in groundwater are discussed in more detail in Sections 2.5.2 and 2.5.3, respectively.

Canonie Environmental (1990) evaluated groundwater for organic compounds. Out of a total of 59 organic compounds analyzed, only 5 were detected, and detected concentrations were below Arizona Aquifer Water Quality Standards (AWQS). Samples collected by Canonie were analyzed for 59 organic compounds using EPA Method 601/602 (phenol analyzed using EPA 420.2). The organic compounds detected in the 1989 sampling event conducted by Canonie were the following:

- Benzene (1 detection in 39 samples at a concentration of 1.7 µg/L)
- Chloroform (3 detections in 40 samples at concentrations from 2.9 to 10.6 µg/L)
- Toluene (4 detections in 39 samples at concentrations from 14.3 to 69.5 µg/L)
- Dithiocarbmates as Ziram (2 detections in 40 samples at concentrations of 0.020 and 0.039 µg/L)
- Phenols (22 detections in 62 samples at concentrations of 0.003 to 0.124 mg/L)

Because AWQS were not exceeded, and because detections were limited to one or two sampling events out of multiple sampling events at each well, the detections are believed to be the result of analytical error.

2.5.1 Sulfate Distribution

The sulfate plume (as defined by sulfate levels greater than 250 mg/L) extends over an area of approximately 2.5 miles by 3.5 miles and is confined primarily to the basin fill and Morita Formation aquifers. Within areas where the basin fill aquifer is the principal aquifer and is impacted by the sulfate plume, the underlying Morita Formation is typically unimpacted. Vertical stratification of sulfate within the basin fill aquifer is known to occur in at least one downgradient location based on depth-specific sampling during drilling of GW-47 (Section 2.5.1.2). Here, only the upper portion of the basin fill aquifer is impacted by sulfate.

2.5.1.1 Areal Distribution

Figures 14, 15, and 16 are contour maps showing the areal distribution of sulfate in August 1989, summer 1996, and August through November 2005, respectively. Figures 14 through 16 only show wells that have sulfate measurements for the period. The 1996 map shows 1997 data from wells for which 1996 data were unavailable. The map for August through November 2005 plots the most recent data available for the period and includes one data point from 2006. As indicated, sulfate extends downgradient of the area of the former evaporation pond and former irrigation area. West of the Black Gap Fault, the sulfate plume is contained primarily within the basin fill. East of the fault, where the basin fill is largely unsaturated, the sulfate plume has been identified in the underlying Morita Formation.

Contour lines are uncertain (and therefore dashed) over the plume area due to sparse data. The sparse data and, in many cases, the lack of measurements from the same wells over time prevent precise positioning of contours and accurate determination of changes in contour positions over time. This is particularly true of the 250 mg/L contours, which are inferred over most of their extent. The rate of plume migration, based on the movement of the 250 mg/L contour over time, was likely higher between 1989 and 1996 than between 1996 and 2005 due to reduced hydraulic gradients in the latter period (Section 2.4.4). Because of dispersion and the reduction in hydraulic gradients over time, the plume may be relatively stagnant in some areas, but migrating in others, especially in marginal areas near production wells where groundwater gradients can be locally higher due to pumping. Additionally, the data are insufficient to contour sulfate concentrations in each individual hydrostratigraphic unit.

Figure 17 compares the extent of the sulfate plumes (defined by the 250 mg/L contour) in 1996 and 2005. As indicated, there are no significant differences in the apparent shape of the plume, although the southwestern margin of the plume migrated to the southwest between 1996 and 2005 and impacted well NWC-3. This well was predicted to remain outside the sulfate plume by previous numerical modeling (SET, 1998c). Concentrations at NWC-3 were 119 mg/L in August 1996 and 460 and 390 mg/L in October and November 2005, respectively. Figure 18 shows sulfate concentrations over time at NWC-3 and other wells in the vicinity of the plume.

Elsewhere, changes in sulfate concentrations within downgradient portions and at the margins of the plume indicate that the plume has expanded slightly, or, in places, has contracted slightly since 1996. Concentrations at downgradient well TM-16 (in the southeastern portion of the plume near Bisbee Junction) increased from 500 mg/L in June 1996, to 528 and 619 mg/L in August and October 2005, respectively, indicating possible expansion of the plume. However, decreasing concentrations at NWC-4, located approximately 2500 feet south (and downgradient) of TM-16, indicate that the sulfate plume has contracted slightly. NWC-4 was within the plume with a concentration of 255 mg/L in August 1996, and is now outside the plume with October and November 2005 concentrations of 220 mg/L and 200 mg/L, respectively. Changes in sulfate concentrations over time at TM-16 and at NWC-4 are shown in Figure 18. A reduction in concentrations within the plume and possible contraction are also indicated by data from downgradient well TM-42 (in the southern portion of the sulfate plume near Purdy Lane) (Figure 18). Sulfate concentrations at TM-42 decreased from 985 mg/L in July 1997 to 656 mg/L in October 2005.

Sulfate concentrations in the upgradient portion of the plume (wells TM-2 and BF-1) have not changed significantly between 1996 and 2005 (Figure 18), although concentrations at TM-2 decreased substantially between 1989 and 1996 (from greater than 2,500 mg/L to less than 1,300 mg/L). Specifically, concentrations at well TM-2 were 1,200 mg/L in June 1996 and 1,280 mg/L in October 2005. Sulfate concentrations in BF-1 were 1,400 mg/L in June 1996 and 1410 mg/L in October 2005. The post-1989 drop in sulfate concentrations in TM-2 probably reflects a lack of further sulfate source loading when mine water discharge to the former evaporation pond stopped in 1987.

2.5.1.2 Vertical Distribution

Historical sampling indicates that west of the Black Gap fault, where the basin fill is the principal aquifer, the sulfate plume is confined primarily to the basin fill. Wells completed only in the underlying Morita Formation or Glance Conglomerate west of the Black Gap fault are not impacted. For example, at paired wells TM-2/2A and TM 19/19A, in which one of the pair is screened in basin fill and the other in bedrock, the bedrock aquifer is unimpacted. East of the Black Gap fault, where the basin fill is unsaturated, the sulfate plume has been detected within the Morita Formation, and the extent of sulfate in Glance Conglomerate is undetermined.

Sulfate is vertically stratified within the basin fill at the location of GW-47. Depth-specific sampling during drilling indicated that sulfate concentrations in the basin fill decreased from 632 mg/L to 25.8 mg/L between the depths of 280 feet and 345 feet below land surface (Wright, 2001). The total depth of basin fill at GW-47 is 540 feet and the static water level was measured at a depth of 184 feet in October 2001. Water quality samples collected at depths of 250 to 280, 345 to 375, 455 to 485, 545 to 575, and 630 to 670 feet below ground surface had sulfate concentrations of 632, 25.8, 16.7, 39.8, and 54.2 mg/L, respectively. These data indicate that the sulfate plume is localized in the upper portion of the total 360-foot thickness of saturated basin fill. The underlying Morita Formation in which the well was completed had sulfate concentrations less than 55 mg/L, indicating the Morita Formation is unimpacted by the sulfate plume.

2.5.1.3 Comparison of Current Sulfate Distribution to Model Predictions

SET (1998c) developed a groundwater flow and sulfate transport model as a tool to predict the future movement of the sulfate plume. The model was calibrated to historical water levels in the basin fill, Morita Formation, and Glance Conglomerate, and to sulfate concentrations measured up to year 1997. The model was then run forward in time to predict post-1997 sulfate concentrations based on assumed future pumping and recharge conditions. Predicted year 2005 sulfate concentrations at many of the wells, such as TM-2 and TM-16 (approximately 1,250 mg/L and 700 mg/L, respectively) are similar to measured values (1,280 mg/L and 610 mg/L, respectively). Measured sulfate concentrations at other locations, however, such as TM-42, are lower than predicted in 2005 (approximately 656 mg/L measured and 1,125 mg/L predicted). Figure 19 shows measured and predicted concentrations for the above wells.

As noted in Section 2.5.1.1, the SET model under predicted sulfate concentrations measured at NWC-3 in year 2005. Model predicted concentrations of approximately 100 mg/L for year 2005 are about one quarter the concentrations of 390 mg/L and 460 mg/L measured in October and November 2005, respectively (Figure 18). NWC-3 is of concern because it is a water supply well located at the downgradient edge of the sulfate plume. Differences between simulated and measured concentrations are likely due, in part, to unforeseen changes in groundwater flow resulting from changes in pumping rates and other factors that must be projected into the future at the time the predictive simulations are made. However, the model was under predicting sulfate concentrations at NWC-3 as early as 1997 (Figure 5-6B in SET, 1998c), suggesting that the model calibration needs improvement in this area.

2.5.2 Major Element Chemistry

The composition of groundwater within and outside the sulfate plume was examined with regard to major ions, TDS, and pH. Data collected as close to June 1996 as possible from selected wells completed within both the basin fill and Morita Formation aquifers were considered. Table 4 summarizes the data and Figure 20 displays the data in a trilinear plot after converting the concentrations to “milliequivalents per liter”.

There are two generally well-defined populations evident in Figure 20 that distinguish groundwater collected from inside the sulfate plume from groundwater collected from outside the plume. This distribution indicates that the chemistry of groundwater outside the plume is generally similar in both the Morita Formation and basin fill aquifers, and that the chemistry of groundwater inside the plume is generally similar in both the Morita Formation and basin fill. Otherwise, four distinct populations would be evident. An obvious outlier is the sample from NWC-5, which has a relatively high chloride concentration and has been impacted by nitrate. This is likely the result of local infiltration of septage.

Groundwater inside the plume is a calcium sulfate type whereas groundwater outside the plume is bicarbonate type with either calcium or potassium. The groundwater chemistries of the basin fill and Morita Formation aquifers do have slight differences. Outside the sulfate plume, groundwater in the Morita Formation tends to have sodium concentrations that are higher than their respective concentrations in the basin fill. Inside the plume, potassium concentrations within the Morita Formation are generally higher than in the basin fill.

Concentrations of calcium, magnesium, carbonate, and TDS strongly correlate with sulfate concentrations. In general, this correlation is similar for groundwater samples collected from both the basin fill and Morita Formation aquifers. The concentration of TDS in a groundwater sample is a measure of the material dissolved in solution, whether it is ionized or not. Typically, the most abundant dissolved solids in groundwater are the major element cations of calcium, magnesium, sodium, and potassium, and the major anions of chloride, sulfate, and bicarbonate. Groundwater samples from the plume are a calcium sulfate type water, indicating the predominance of calcium and sulfate in solution. Table D.1 in Appendix D provides TDS, calcium, sulfate, and bicarbonate concentrations for groundwater samples. Inspection of Table D.1 indicates that the TDS concentration at TM-2 in the source area near the former evaporation pond ranged from a high of 5,520 mg/L to a low of 2,500 mg/L between January 1989 and November 1997. Sulfate, calcium, and bicarbonate can be seen to vary in rough proportion to TDS and each other. Because there are elevated concentrations of calcium, sulfate, and bicarbonate associated with the sulfate plume, the TDS within the plume is elevated. Mitigation actions that address sulfate would also address TDS because sulfate is a major component of the TDS.

Strongly acidic conditions (pH<5) have not been detected in groundwater near the former evaporation pond or tailing impoundments. The pH of groundwater in both the basin fill and Morita is neutral to slightly alkaline (generally between 7 and 8) outside the sulfate plume and neutral to slightly acidic (generally between 6 and 7) inside the plume. Thus, on average, groundwater impacted by the sulfate plume has a slightly lower pH than groundwater unimpacted by the plume.

2.5.3 Metals

Appendix D (Table D.1) contains the results of analysis of metals in groundwater samples from the CTSA and vicinity. Based on historical groundwater sampling, detections of metals have been infrequent enough and at low enough concentrations when detected that they are not of concern in the vicinity of the CTSA south of the Abrigo Fault. Furthermore, when detected, metals do not generally correlate well with the presence of elevated sulfate in the groundwater.

Metals for which AWQS have been established have been detected sporadically at low concentrations, including antimony, arsenic, barium, cadmium, chromium, lead, mercury, nickel, selenium, and thallium (Table D.1). The highest detected metals concentrations compared with their respective AWQS are as follows:

Metal	Location	Highest Detected Concentration (mg/L)	AWQS (mg/L)
Antimony	BF-2 (within plume)	0.06	0.006
Arsenic	TM-7 (within plume)	0.006	0.01
	TM-15 (outside plume)	0.006	0.01
	NWC-5 (outside plume)	0.006	0.01
Barium	AWC-3 (outside plume)	0.39	2.0
Cadmium	TM-2A (within plume)	0.0013	0.005
Chromium	GL-3 (outside plume)	0.045	0.1
Lead	GL 3 (outside plume)	0.034	0.05
Mercury	TM-2 (within plume)	0.00245	0.002
Nickel	GL-3 (outside plume)	0.036	0.1
Selenium	TM-2 (within plume)	0.011	0.05
Thallium	TM-16 (within plume)	0.002	0.002

GL-3 is located north of the Abrigo Fault and outside the sulfate plume. Disregarding GL-3, nickel was not detected, and the highest detected chromium and lead concentrations within the plume were as follows:

Metal	Location	Highest Detected Concentration (mg/L)	AWQS (mg/L)
Chromium	ELKS well (within plume)	0.036	0.1
	BF 01 (within plume)	0.036	0.1
Lead	TM-2A (within plume)	0.022	0.05

Table D.2 (Appendix D) summarizes the analytical results for metals for the wells listed in Table D.1. The summary in Table D.2 provides several insights regarding metals in groundwater:

- Most metals with AWQS were infrequently detected (a detection frequency of less than 15 percent), if detected at all. Arsenic, cadmium, chromium, mercury, nickel, lead, and selenium all had detection frequencies less than 15 percent.

- Antimony, mercury, and thallium were the only metals with one or more detections at or in excess of their respective AWQS.

- The constituent most frequently detected at concentrations above AWQS, antimony, was detected above AWQS in 9 of the 25 samples with MDLs less than the AWQS (detection frequency of 36 percent). The majority of antimony exceedances (8 of the 9 exceedances) were in samples collected and analyzed by ADEQ in 1996; including exceedances at two wells outside of the sulfate plume (AWC-2 and AWC-3). Samples from wells TM-2 and TM-16 which had exceedances in 1996 were collected again in two separate sampling events in 1997 and found to have no detectable antimony at an MDL of 5 ug/L.

- Mercury was detected in 1 of 97 samples (detection frequency of 1 percent). The lone detection was in a sample from TM-2 collected in 1989. The MDLs for all 97 analyses of mercury were less than the MDL.

- Thallium was detected in 1 of 18 samples with MDLs at or below the AWQS (detection frequency of 6 percent). The detection was at the MDL and the AWQS.

The above observations illustrate that (1) elevated concentrations of metals are not characteristic of the sulfate plume, (2) metal occurrences in excess of AWQS are neither widespread in space, nor persistent over time, and (3) the antimony exceedances are anomalous in that they were associated with a single sampling event and were not duplicated in subsequent sample events. Furthermore, the elevated concentrations of antimony cannot be associated with the sulfate plume because the antimony concentrations in excess of AWQS occurred both inside and outside of the plume extents. Given the infrequent detection of metals and the lack of association of elevated metal concentrations with the sulfate plume, metals are not constituents of concern with respect to sulfate mitigation.

2.6 Preliminary Conceptual Model for the Groundwater Sulfate Plume

The groundwater sulfate plume resulted from seepage of sulfate bearing waters from the tailing impoundment, the former evaporation pond, and the former irrigation area. All three of these areas received water containing elevated sulfate concentrations. The primary source of seepage was likely the former evaporation pond because of the relatively high hydraulic conductivity of the basin fill on which the water was applied (Section 2.4.2), and due to the maintenance of ponded conditions. Seepage from the tailing was relatively low due to the relatively low hydraulic conductivity of the tailing material, and is likely negligible at the present time based on the results of investigations by SET, 1998a. Also, the North Tailing Impoundment and most of the South Tailing Impoundment are north of the Abrigo fault and east of the Black Gap fault in the hydraulic domain isolated from the plume. Relative to the evaporation pond, seepage from the former irrigation area was presumably low because of lower water application rates, less ponding, and higher evapotranspiration rates due to the crops grown.

Sulfate-bearing seepage mixed with groundwater in the basin fill to the west of the Black Gap fault, and with groundwater in the Morita Formation to the east of the fault. West of the fault, the basin fill is the principal aquifer, and east of the fault, the Morita Formation is the principal aquifer. The sulfate then moved downgradient with the direction of groundwater movement in each aquifer, to the west, southwest, and south in basin fill on the west side of the fault, and to the south and southwest in the Morita Formation on the east side of the fault. The rate of movement of sulfate is expected to be about the same as the rate of groundwater movement in each aquifer because sulfate behaves conservatively and does not significantly sorb onto, or react chemically with the aquifer materials.

The majority of the sulfate that entered groundwater was dissolved in seepage from the former evaporation pond. Seepage rates were high enough to create a groundwater mound in both the basin fill and Morita Formation aquifers. This mound has dissipated since the cessation of water delivery to the former evaporation pond in 1987 (Figure 12). This dissipation has occurred more quickly in the basin fill than the Morita Formation due to the lower average hydraulic conductivity of the Morita Formation (SET, 1998c). Although the primary source of the plume (the former evaporation pond) has been inactive since 1987, and sulfate concentrations in the upgradient portion of the plume have diminished since that time, residual sulfate concentrations in the upgradient portion of the plume were in excess of 1,400 mg/L as of year

2005. The CTSA facilities are inactive and do not receive discharges except for stormwater and rainfall (Section 2.1.1).

Movement of the sulfate plume has been primarily laterally within the basin fill, Morita Formation, and Glance Conglomerate. West of the Black Gap fault, where the basin fill is impacted, sulfate does not appear to have migrated vertically into the underlying Morita or Glance Formations. An exception may be monitoring well BF-1 near the former evaporation pond. BF-1, completed in basin fill, Morita Formation, and Glance Conglomerate, had a 2005 sulfate concentration of 1,410 mg/L. Although the source of sulfate in this well is likely the basin fill aquifer, it is unknown how much, if any, of the sulfate may be contributed by bedrock. East of the Black Gap fault, where the Morita Formation aquifer is impacted, it is unclear whether sulfate has migrated vertically into the underlying Glance Conglomerate aquifer. Flow from the Glance Conglomerate to the Morita Formation and from the Morita Formation to the basin fill across the dipping contacts, possibly in conjunction with higher horizontal hydraulic conductivity compared to vertical hydraulic conductivity, would act to maintain the sulfate plume at shallow depths, and may also partly explain the confinement of the sulfate plume to the upper portion of the basin fill at the location of GW-47 (Wright, 2001). Upward hydraulic gradients would enhance this behavior. Slight upward hydraulic gradients over much of the area of the plume were present in the site numerical model prepared by SET, (1998c). However, sustained upward hydraulic gradients have not been detected based on water level measurements in paired monitoring wells (Figure 12) and the vertical distribution of the plume is yet to be characterized.

With respect to lateral movement, the sulfate plume changes from a more southerly to a more westerly direction as it moves south towards Greenbush Draw, where the direction of groundwater flow changes from more southerly to westerly. Ultimately, the groundwater exits the basin flowing westerly, approximately parallel to the direction of surface water flow in Greenbush Draw.

The direction and rate of movement of the sulfate plume are locally influenced by areally non-uniform recharge rates, and groundwater pumping. As sulfate continues to move downgradient, hydrodynamic mixing and dilution by low-sulfate recharge act to reduce the average sulfate concentrations within the plume. These processes, and the absence of a continuing source, are important in reducing concentrations within both upgradient and downgradient portions of the plume. Furthermore, the reduction in hydraulic gradients between the upgradient and downgradient portions of the plume, that has resulted from dissipation of the groundwater mound associated with the former evaporation pond, will act to reduce the rate of downgradient migration of the sulfate plume.

In summary, the source of the sulfate plume was the seepage of sulfate–bearing water released to the former evaporation pond. The sulfate-bearing seepage migrated vertically to the groundwater table, likely forming a recharge mound in the subsurface beneath the former evaporation pond. Sulfate-bearing seepage mixed with groundwater in the basin fill and Morita Formation, and flowed primarily to the south and west under the prevailing hydraulic gradients. The sulfate plume formed because the discharge of sulfate-bearing water to the former evaporation pond persisted for decades. The source of sulfate-bearing seepage was eliminated when discharges to the former evaporation pond were eliminated in 1987. Although the source is eliminated, the previously impacted groundwater composing the plume is still migrating under the current hydraulic gradients in the basin fill and Morita Formation aquifers. The migration pathway for sulfate-bearing water is as groundwater flow which is southerly and westerly from the area of the former evaporation pond. Potential receptors of sulfate-impacted groundwater are municipal or private drinking water supply wells in the downgradient reaches of the plume near Bisbee Junction and Naco. Potential exposure to sulfate-bearing groundwater would be through the ingestion of water from a well with a well screen in the plume. Figure 21 is a schematic diagram illustrating the hydrogeology, the source of sulfate, the migration pathway, and potential receptors.

3. AQUIFER CHARACTERIZATION PLAN

3.1 Aquifer Characterization Plan (ACP) Objectives and Data Needs

3.1.1 ACP Objectives

The objectives of the ACP are to address the MO requirements to characterize the sulfate plume and to collect data sufficient to complete the FS. Based on Sections III.A and III.C of the MO, the ACP will:

- Complete a well inventory to identify drinking water wells within one mile downgradient and cross gradient of the outer edge of the sulfate plume within the state of Arizona.
- Determine the vertical and horizontal extent of the sulfate plume.
- Evaluate the fate and transport of the sulfate plume.

3.1.2 Data Needs

Addressing the ACP requires collection of the following data:

- Locations of drinking water wells within one mile downgradient and crossgradient of the plume.
- Sulfate concentration data collected at different locations and depths.
- Water level measurements to document potentiometric conditions.
- Information on the structure and hydraulic properties of the aquifer.
- Water level and water quality conditions in the potential source area.

A numerical model for groundwater flow and solute transport will be developed to evaluate the fate and transport of sulfate. In addition to the data identified above, information quantifying existing and future sources and sinks of groundwater will be needed to construct the model.

Data needs for the FS include: water quality data pertinent to assess potential treatment technologies, the current and future pumping rates for existing wells, expected future pumping rates for planned wells, and design specifications for existing and future water distribution and storage systems. Water quality data for assessing treatability will be developed under the ACP; whereas the FS (Section 5) will develop information on water treatment, current and future water supply needs and storage infrastructure, and the costs and benefits of mitigation alternatives.

The ACP consists of the following four tasks that will collect the data needed to address the MO requirements.

- Task 1 – Well Inventory.
- Task 2 – Plume Characterization.
- Task 3 – Sulfate Fate and Transport Evaluation.
- Task 4 – Preparation of the Aquifer Characterization Report.

Data needs and the ACP tasks that address them are briefly described below and summarized in Table 5. Sections 3.2 through 3.5 describe the individual ACP tasks.

- **Well Inventory** – The locations of drinking water supply wells will be identified by the well inventory for Task 1 (Section 3.2). Water quality samples will be collected from drinking water supply wells identified by the well inventory, provided access is granted by the owner.

- **Horizontal Extent of Sulfate Plume –** As shown in Figure 4, the current horizontal extent of the plume can only be inferred because there are few water quality data from outside the plume. The eastern extent of the plume is poorly constrained due to a lack of any water quality data in the vicinity of the Bisbee airport. The southeastern extent of the plume is defined by well NWC-4 with a sulfate concentration of 220 mg/L, which is less than the 250 mg/L mitigation level set by the MO for drinking water supplies. The western edge of the plume is not well defined due to a lack of recent data, but lies no further west than TM-15 with a 2005 sulfate concentration of 22.6 mg/L. The plume extends to the southwest to at least NWC-3 which has a 2005 sulfate concentration of 390 mg/L. Additional data is needed on all sides of the plume in order to more precisely define its extent. Task 2 specifies groundwater monitoring (Section 3.3.2) and the installation and sampling of additional wells (Section 3.3.3) to further delineate the horizontal extent of the plume.

- **Vertical Distribution of Sulfate –** Ongoing monitoring of existing co-located wells screened in different materials, i.e., the basin fill, Morita Formation and Glance Conglomerate, will provide information on the vertical distribution of sulfate. Additional monitoring wells will be installed for Task 2 (Section 3.3.3) as co-located well nests to characterize the vertical dimension of the plume.

- **Water Level and Water Quality Information –** Water level and water quality data will be updated in areas lacking current information and the spatial coverage of water level and water quality data will be expanded. Groundwater monitoring will be conducted for Task 2 (Section 3.3.2) to provide water level and water quality information inside and outside of the plume area. Groundwater monitoring will provide contemporaneous water level and water quality data for areas outside the plume. These data are needed to provide information on the regional groundwater flow system for calibration of the groundwater flow model for Task 3 (Section 3.4) and for characterizing background water quality conditions.

- **Aquifer Structure and Hydraulic Properties –** Existing data on the aquifer structure and hydraulic properties will be compiled for Task 2. Aquifer testing to be conducted at monitoring wells installed for Task 2 (Section 3.3.3) will characterize the horizontal and vertical distribution of hydraulic properties. Additional aquifer testing will be conducted at existing wells pending a review of well construction and successful negotiation of site access (Section 3.3.4).

- **Conditions in the Potential Source Area –** Groundwater monitoring wells will be installed at the former evaporation pond and South Tailing Impoundment for Task 2.3. These installations will allow ongoing monitoring of water levels and water quality in the former source area.

- **Quantification of Groundwater Sources and Sinks –** Groundwater sources (recharge) and sinks (pumping) will be documented for use in the groundwater flow model for Task 3 (Section 3.4). Recharge to the aquifer from ephemeral flows into the basin, and other sources, such as surface discharge from the San Jose WWTF, will be documented or estimated for the groundwater flow model. Current and future expected groundwater pumping from water supply, irrigation, and industrial wells will be obtained from well owners or estimated using available information.

3.2 Task 1 - Well Inventory of Drinking Water Supply Wells

A well inventory will be conducted to identify all wells in Arizona within one mile of the sulfate plume. Wells within one mile downgradient and cross gradient of the outer edge of the plume will be categorized on the basis of water use to identify wells that may supply drinking water.

The well inventory will be based on the ADWR Well Registry Database, which contains records for all registered wells in Arizona. Records in the well registry pertain to a variety of types of installations including water supply wells (private, domestic, and municipal), environmental monitoring wells, remediation pumping wells, piezometers, geotechnical borings, mineral exploration borings, and abandoned wells. Information potentially available for individual wells includes the well registry identification number, cadastral and Universal Transverse Mercator (UTM) coordinates, well use, water use, installation data, geological data, well construction information, pumping information, and well owner.

The ADWR Well Registry Database is provided in a Geographic Information System (GIS) format, which allows the use of spatial queries to identify and extract well information based on the location of the well. A spatial query will be constructed using a geo-referenced shape file defining the outer edge of the sulfate plume defined by the 250 mg/L contour (Figure 4). The shape file will be used to query the database and identify all wells in the plume and within one mile of the plume's downgradient and crossgradient edge.

Well locations in the ADWR database are described by cadastral coordinates based on township, range, and section. Most well locations are described to the "quarter, quarter, quarter section", an area of 10 acres or 660 feet by 660 feet. The database assigns UTM coordinates for the well to the midpoint of the area, although the well can be anywhere in the 10-acre area. To ensure the well inventory is comprehensive and identifies all wells potentially within one mile downgradient and crossgradient of the plume in Arizona, a safety factor will be added to the one-mile search radius to account for the uncertainty in well location due to cadastral coordinates. Wells will be removed from the set of wells identified using the safety factor only if they can be verified as being farther than one mile from the plume based on survey information or more detailed cadastral coordinates.

To augment the well inventory, public and semi-public water systems on file with ADEQ will be checked against the well inventory to identify water systems. Also, the ADWR Water Providers database will be used to identify the service areas of municipal water providers in the area. Cochise County, local water providers (AWC and NWC), the ADEQ public water system inspector, and local residents will be checked for information on potential water supply wells.

The well inventory is an important step in identifying potentially impacted drinking water supply wells. The owners of drinking water supply wells identified by the well inventory will be contacted to determine if they have current water quality data for the well, and if not, to determine if the owner would allow CQB to access the well for sampling. CQB will offer to collect samples from drinking water supply wells and analyze for sulfate at no cost to the well owner. The results of the analysis will be provided to the well owner. Water level information will also be recorded if the well is equipped with a sounding tube. Drinking water supply wells will be field checked and their locations identified with a hand-held Global Positioning System unit. All well information will be entered into a well inventory database.

The well inventory will begin shortly after the Work Plan is finalized and will be conducted initially using the 250 mg/L sulfate contour shown in Figure 4. The well inventory may be revised if the plume defined by the results of characterization work for Task 2 indicates a significantly different shape for the plume.

3.3 Task 2 - Plume Characterization

The main objectives of the ACP are to investigate the hydrogeology of the plume area and to characterize the lateral and vertical extent of the sulfate plume. Plume characterization for Task 2 consists of data compilation and evaluation activities as well as field investigations. The data compilation and evaluation activities will ensure that the existing data used to characterize the plume are complete and verified. The field investigations focus on characterizing water level and water quality conditions in the regional aquifer, determining the vertical and lateral distribution of sulfate in the plume, and estimating aquifer hydraulic properties. The QAPP in Appendix F presents the data quality objectives (DQOs) for plume characterization. In summary, the DQOs are to:

- Define the extent of groundwater with sulfate in excess of 250 mg/L based on groundwater samples from new and existing monitoring wells and water supply wells.

- Characterize the materials, structure, and permeability of water-bearing units in the CTSA through geologic analysis of cuttings from drill holes and aquifer testing to support groundwater modeling of plume migration.

- Characterize potentiometric conditions and the groundwater flow system through water level measurements to support groundwater modeling of plume migration.

- Characterize sulfate concentrations in the source area.

- Collect water quality data needed to evaluate potential water treatment technologies.

The plume characterization includes the following subtasks:

- Data compilation and evaluation.

- Groundwater monitoring to augment the existing water level and water quality data.

- Installation and testing of monitoring wells as needed to define the southern, western, and eastern extents of sulfate, and source conditions.

Results of the well inventory (Task 1) and sampling of existing monitoring wells (Task 2) will help define the number and location of new monitoring wells needed.

3.3.1 Task 2.1 - Data Compilation and Evaluation

The data compilation and evaluation will focus on assembling and assessing information on the subsurface distribution of bedrock and the water quality of area wells. A secondary objective will be to assemble and evaluate available geologic logs for wells in the area.

The effective thicknesses of the basin fill and Morita Formation aquifers are needed for construction of the groundwater flow model and estimation of groundwater flow. Outcrop elevations and geologic contact elevations from drilling logs will be used to define the surfaces representing the bases of the basin fill and Morita Formations. Additionally, any geophysical data for the area will be reviewed for relevant information.

Limited water quality data are available for water supply wells in the area, and water quality sampling of these wells is proposed for Task 2.2 (Section 3.3.2). The owners of water supply wells will be contacted to obtain any water quality information they are willing to share. This data will then be compiled and evaluated to document existing conditions and to identify any water quality changes over time. Well owners will also be asked for access to geologic logs for wells, if that information is not available elsewhere.

3.3.2 Task 2.2 - Groundwater Monitoring

The groundwater monitoring program involves collecting data from CQB monitoring wells, as well as private wells within and outside the plume. CQB routinely monitors groundwater elevation in monitoring wells in the vicinity of the CTSA. Pursuant to the MO, groundwater sampling of CQB wells will also be conducted to evaluate water quality within the CTSA and sulfate plume areas. Additionally, a water level and groundwater sampling program at private and public supply wells is proposed to augment the CQB monitoring by collecting information on local and regional groundwater elevation and water quality at the margins of the sulfate plume and outside the CTSA. The collected information will be used to describe current water table conditions, the extent of the sulfate plume, and background water quality; all of which are needed for modeling the sulfate plume.

Groundwater monitoring will be conducted for two purposes, namely, plume monitoring and regional monitoring. Plume monitoring will be conducted at wells proximal to the sulfate plume to track its position and concentration. Regional monitoring will be conducted over a larger geographic area than the plume in order to document regional water level and water quality conditions for fate and transport modeling.

Plume monitoring will be conducted quarterly to document groundwater elevations and sulfate concentrations only at CQB monitoring wells in the vicinity of the CTSA and at private and public supply wells within and on the margins of the plume. The monitoring program will be reviewed and modified as necessary after the third quarter of plume monitoring. Plume monitoring will continue until the monitoring requirements under the Mitigation Plan become effective.

Regional monitoring will be conducted twice, once in winter and once in summer, to characterize any seasonality in water elevations. Samples for regional monitoring will be analyzed for a suite of major element constituents to characterize general water quality conditions in addition to sulfate.

Both the plume monitoring and regional monitoring efforts will seek to access private wells that are not controlled by CQB for monitoring water elevation and water quality. The AWC, NWC, Naco and San Jose Sanitation Districts, and private individuals are examples of entities that will be approached for well access or sampling data. Thus, the success of the groundwater monitoring task will partly be dependent on cooperation from private well owners and water companies. Wells provisionally identified for plume and regional monitoring are listed in Table 6 and shown by Figure 22. Should a well owner refuse access or should a well be inappropriate for monitoring based on well construction or other considerations, CQB will attempt to identify a suitable substitute well.

Groundwater monitoring will include collection of static water level measurements and groundwater samples for chemical analysis unless equivalent information is available from the well owner. Water level measurements will be collected over a 30-day period, if possible, for the purpose of gathering contemporaneous data. Groundwater samples will be collected and submitted to an Arizona-certified laboratory for analysis. Samples for plume monitoring will be analyzed for sulfate only. Samples for regional monitoring will be analyzed for calcium, magnesium, sodium, potassium, chloride, sulfate, alkalinity, fluoride, nitrate, nitrite, and pH to characterize sulfate and the general water chemistry. If required by the FS, samples from select wells may also be analyzed for the following constituents useful for assessing water treatment by membrane processes: aluminum, ammonia, barium, chemical oxygen demand, ferrous and total iron, manganese, phosphate, selenium, soluble and colloidal silica, strontium, sulfide, total organic carbon, silt density index, turbidity, and bacteria.

Groundwater sampling and analysis will be conducted according to the methods and protocols in accordance with ADEQ approved procedures described in the QAPP (Appendix F). The ability to measure water levels at wells may be limited by whether the well has an access port or sounding tube, a determination that will be made in the field. Water level measurements will only be attempted if the well construction permits unobstructed access for the water level sounder. Specific conductance, pH, and temperature will be measured in the field during groundwater sample collection. Groundwater samples will be collected as close to the wellhead as is feasible, upstream of any filtration, sand cyclones, chlorine or other chemical additions to the well water. The results of analyses will be provided to the well owner and included in groundwater monitoring reports to ADEQ. Groundwater data will be electronically submitted to ADEQ for inclusion in the ADEQ water quality database.

3.3.3 Task 2.3 - New Monitoring Well Installation and Testing

Additional monitoring wells are proposed at 12 locations to further define the extent of the sulfate plume, to characterize aquifer materials and hydraulic properties, to determine bedrock depth, to further evaluate conditions in the former source area, and to provide installations for ongoing groundwater monitoring. Monitoring wells will be installed for the following purposes:

- Determination of the lateral plume margin.
- Characterization of the vertical extent of sulfate in various aquifers.
- Evaluation of fault control of potentiometric and water quality conditions.
- Determination of aquifer hydraulic properties.
- Source area monitoring.

Figure 23 shows the approximate locations of proposed monitoring wells. Table 7 lists the proposed wells, their design objectives, and land ownership. Some of the proposed well locations are on land not owned by CQB; therefore, access agreements will have to be negotiated with landowners prior to drilling. The exact locations of the proposed wells are provisional subject to successful negotiation of site access and the results of data collection in Tasks 1 and 2.2. Additionally, the scope of this task will be dependent on information gained as the task progresses. For example, some of the proposed wells may not be installed if the well inventory and groundwater monitoring programs identify suitable existing wells in the vicinity of the proposed locations.

Well locations and design objectives are based on position in relation to the plume, the level of information available in the area of the proposed well, and the potential long-term use of the monitoring well. Some well sites on the west and south side of the plume are expected to be between the plume and existing drinking water supply wells, allowing them to be useful as sentinel wells and for plume definition. Well designs in Table 7 are subject to modification based on the results of other plume characterization tasks that will provide information on the subsurface distribution of sulfate (e.g., water supply sampling for the well inventory (Task 1), groundwater monitoring of existing wells (Task 2.2), and the results from installation of new monitoring wells) and site-specific conditions observed during drilling (e.g., subsurface lithology and water quality).

Proposed well Sites 1, 2, 3, 5, and 6 will be installed to determine the horizontal and vertical extents of sulfate south, southwest, and west of the inferred plume because these areas have the greatest uncertainty in the extent of sulfate and are of interest with respect to future plume migration. Proposed Sites 2 and 5 will provide information on the vertical extent of sulfate in the vicinity of well NWC-4 and the AWC supply wells, respectively. If during this task, newly installed wells are determined to be within the plume, a determination will be made as to whether additional wells need to be installed to meet the data quality objective of defining the extent of the plume.

Proposed well Sites 4, 7, and 10 will be installed to determine the vertical extent of sulfate in the plume area. Wells at Sites 4 and 7, near existing wells NWC-3 and MW-1, respectively, will be installed to allow collection of data at depth.

Proposed well Sites 8 and 9 will be installed on either side of the inferred Black Gap fault to investigate fault control on water levels and water quality. These wells will also provide information on vertical water quality in the plume.

Proposed well Sites 10, 11, and 12 will be installed at the former evaporation pond and peripheral to the South Tailing Impoundment to document water level and water quality conditions in the area of former sources. These proposed well sites will allow ongoing monitoring of groundwater elevation and sulfate concentration to characterize the area in the vicinity of the upgradient portion of the plume. A new well nest will be installed at proposed well Site 10 to characterize the vertical extent of sulfate in the plume at the former evaporation pond source area.

The vertical distribution of sulfate will be evaluated by water sampling during drilling and prior to well installation. The vertical extent of sulfate will be established by installing wells beneath the impacted zone (sulfate concentrations greater than 250 mg/L) that yield water samples with sulfate concentrations below 250 mg/L. Co-located well installations are recommended to collect information on vertical zoning and for long-term monitoring of the vertical movement of the plume. Co-located wells are individual wells located in close proximity to one another but in separate borings. A generalized well construction diagram for monitoring wells is provided in Appendix E. Appendix F describes methods for well drilling, reconnaissance groundwater sampling during drilling, well construction techniques and materials, well development, and well testing.

3.3.3.1 Drilling Methods and Reconnaissance Sampling

Drilling of new monitoring wells will be accomplished using a variety of drilling methods including air-rotary casing hammer (ARCH), under-reaming casing advance using Stratex® tools, reverse circulation air-rotary, open-hole air rotary, or mud rotary methods. Selection of the drilling method is determined by the site conditions and the need for lithologic and formation water sampling for the particular borehole.

One of the primary objectives of the drilling is to obtain grab samples of groundwater at the drilling face at regular depth intervals during drilling (Section 4.3.4 of Appendix F). The preferred method to accomplish this sampling is a casing advance method (i.e., either ARCH or Stratex) that provides temporary casing of the borehole as it is being advanced into the formation. Alternatively, reverse circulation air-rotary may be used depending on drilling conditions. Reconnaissance water samples will be collected from the air return and analyzed in the field using an electrical conductivity meter to characterize TDS as described in Section 4.3 of Appendix F. Water samples for laboratory analysis of sulfate will also be collected.

In the event that reconnaissance sampling from the air rotary return is infeasible, reconnaissance water samples may be collected through a temporary well screen or using a straddle packer system. A temporary well screen would consist of 20-foot length of slotted casing which would be placed at the target sampling depth, surrounded by gravel pack, and sealed from the underlying and overlying formation and borehole using bentonite pellets or packers. The temporary well screen would be developed by air lifting, pumping, or bailing to remove at least three wetted borehole volumes in the event of installation by air drilling techniques or until the water is clear in the event of installation in by mud rotary. A straddle packer system may be used in bedrock boreholes where competent conditions exist. The use of temporary well screens or straddle packers for reconnaissance sampling may not be suitable for all sites, but should be capable of providing high quality water samples. Sampling through temporary well screens would be conducted by drilling to a pre-determined depth and setting and sampling temporary well screens at various depths.

Borehole conditions may make infeasible the collection of reconnaissance water samples from the air rotary return or from temporary well screens. If temporary water samples cannot be collected, the vertical extent of sulfate would need to be determined by sampling monitoring wells after they are installed.

Mud-rotary methods may be substituted for casing advance or reverse circulation if water sampling is unsuccessful, unstable hole conditions occur, or on the advice of the driller that doing so is necessary to maintain the borehole. Open-hole conventional circulation air-rotary methods may be used in bedrock formations if water sampling is unsuccessful or not required for the specific borehole (e.g., if an adjacent borehole has already been drilled and satisfactorily sampled). If additional wells are installed at a borehole location that has been characterized by reconnaissance sampling, they would likely be installed using mud-rotary methods in basin fill and open-hole air-rotary methods in bedrock.

3.3.3.2 Well Design Rationale

Drilling, well construction, and hydraulic testing for Task 2.3 will be conducted to gather information to address the following data needs (Section 3.1 of this text) and DQOs (Section 3.1 of Appendix F):

- water level data to evaluate potentiometric conditions
- water samples to define the lateral and vertical distribution of sulfate
- lithologic information to understand subsurface material
- aquifer test data to estimate the hydraulic properties of subsurface materials

The proposed wells fall into two groups; namely, wells on the margins of the plume and wells within the footprint of the plume. Wells on the margin of the plume are intended primarily to define the lateral extent of the plume. Wells in the footprint of the plume are intended primarily to determine the vertical extent of sulfate. All the wells will be used for hydraulic testing to estimate hydraulic properties, and for long-term water quality and water level monitoring.

3.3.3.2.1 General Considerations

There are several considerations that go into the design of monitoring wells under this work plan.

- Wells must be screened over a significant portion of the aquifer such that the interval is long enough to represent the water quality of a portion of the aquifer that might be reasonably tapped by a drinking water supply well but short enough so as not to overly generalize water quality in areas where vertical stratification of sulfate concentrations may exist.

- Wells must be isolated in one hydrostratigraphic or water quality unit such that the water drawn from the well represents the unit in which the well is completed and does not draw water from overlying or underlying units.

- Wells screens must be long enough to provide representative data on the hydraulic properties of the hydrostratigraphic unit so that the data can be used to evaluate flow and transport in the vicinity of monitor well.

- Where multiple wells are necessary to characterize a hydrostratigraphic unit in one location, well screens must be spaced widely enough so that they tap different portions of the hydrostratigraphic unit and closely enough to provide water quality and hydraulic property coverage of the aquifer interval spanned by the screens.

To accomplish the DQOs, a design objective for wells installed for Task 2.3 is that they have screen lengths sufficient to provide water quality and hydraulic response data representative of a significant section of the aquifer. Short screen lengths have the risk of providing concentration and hydraulic response data that are of localized extent and unrepresentative of average conditions. Conversely, long screen lengths have the risk of underestimating the hydraulic conductivity of a high permeability zone significantly thinner than the length of the screen. However, at this stage in the aquifer characterization study, large-scale average properties are desired to characterize the extent and average concentration of the plume for making decisions regarding vertical and lateral extents of the plume, potential mitigation actions that can be undertaken for drinking water supply wells, and to determine hydraulic properties of a representative elementary volume of the aquifer as needed for numerical modeling. Another consideration for wells on the margin of the plume is that they extend across portions of the aquifer in a manner similar to drinking water supply wells that are the focus of the Mitigation Order. In that way, the monitoring wells can serve as sentinel wells for supply wells. Drilling conditions, such as hard drilling, borehole stability, or flowing sand, if encountered, may also influence well design.

3.3.3.2.2 Wells on the Margin of the Plume

Wells on the margin of the plume are proposed in locations where sulfate concentrations are expected to be less than 250 mg/L, although they may be elevated with respect to background. These wells will provide sites for ongoing monitoring to document groundwater elevation and sulfate concentration, and will be tested to estimate representative hydraulic properties for aquifer materials.

Wells on the margins of the plume (Sites 1, 3, 5, 6, 11, and 12) will typically be constructed with screens ranging from 100 to 200 feet in length. Longer screens will be used for basin fill wells to get volume-averaged properties because the basin fill may be up to 1,000 feet thick and composed of interbedded sediments with variable hydraulic conductivity. Shorter screen lengths would tend to be used for wells in bedrock which are expected to have a low vertical hydraulic conductivity that would limit the potential depth of sulfate penetration and make monitoring over a longer screen length less important than in basin fill.

Wells on the margin of the plume will be installed with screened intervals extending from approximately the water table to depths of approximately 100 to 200 feet below the water table because most drinking water supply wells at the margins of the plume are within 200 feet of the water table and because limited data indicate that sulfate is in the upper portion of the basin fill aquifer and not the lower on the southwest margin of the plume. At locations where nested wells are to be installed on the margin of the plume (Sites 5 and 6) the top of the lower screen will be within 100 to 200 feet of the bottom of the overlying well. The actual depth placement of the wells and screen will depend on field decisions based on actual subsurface materials as determined from inspection of cuttings, water quality as indicated by reconnaissance grab samples of formation water, and on the well construction of nearby drinking water supply wells. Information determined during installation of wells within the plume may also be used in determining the design of wells on the margin of the plume.

3.3.3.2.3 Wells within the Footprint of the Plume

Wells within the footprint of the plume (Sites 2, 4, 7, 8, 9, and 10) will be installed to characterize conditions in the impacted zone or determine the vertical extent of sulfate. These monitoring wells will allow estimation of hydraulic properties of aquifer materials and establish sites for ongoing groundwater monitoring. Groundwater is assumed to be impacted at these sites, some of which have impacts in the basin fill aquifer (Sites 4, 7, and, possibly, 8 and 9) and some of which are impacted in the bedrock aquifer (Sites 2 and 10).

At sites with impacted basin fill, reconnaissance water sampling will continue until at least 200 feet below the impacted zone or until bedrock is encountered and a screen would be placed within 100 feet of the impacted zone to monitor the unimpacted aquifer below it. At sites in impacted bedrock (Sites 2, 10, and, possibly, 8 and 9) drilling will proceed to at least 200 feet below the impacted zone as determined by reconnaissance sampling and a well screen will be installed no farther than 100 feet from the base of the impacted zone to monitor the unimpacted aquifer below it. Borings in impacted bedrock will be advanced until unimpacted conditions are observed to determine the vertical extent of sulfate.

Wells in the footprint of the plume will typically be constructed with screens ranging from 100 to 200 feet in length to provide data on the large scale characteristics of the aquifer. When setting a well in unimpacted bedrock below impacted basin fill, the top of the gravel pack of the well will be no closer than 50 feet to the impacted aquifer and 50 feet to the top of the overlying geologic unit. The actual depth placement of a well and screen will depend on field decisions based on actual subsurface materials as determined from inspection of cuttings, water quality as indicated by reconnaissance grab samples of formation water, and on the well construction of nearby drinking water supply wells.

3.3.3.2.4 General Construction Guidelines

The approaches to well design are discussed below. Because of the uncertainties in geology, water quality, and drilling conditions at each site it would be highly speculative to stipulate presumptive well depths and screen lengths in advance. However, the general guidelines described below will be used to guide the well design process. Additionally, well designs and objectives may change as new information is developed by drilling and sampling for Task 2.3 and by groundwater monitoring for Tasks 1 and 2.2.

The placement and length of well screen will be based on the results of reconnaissance water sampling during drilling. The following are general guidelines for placement and length of well screen. These guidelines provide the decision process for well design and may be modified at any given location based on lithologic, water quality, or drilling conditions that may be encountered in the borehole.

- Wells constructed in unimpacted (concentration of sulfate is below 250 mg/L) basin fill will be screened starting at approximately the water table down to approximately 100 to 200 feet below the water table.

- The deep well at paired shallow and deep wells constructed in unimpacted basin fill will be screened starting at approximately 100 to 200 feet below the shallow well screen and will have a screen length of 100 to 200 feet.

- Wells constructed in impacted (concentration of sulfate is above 250 mg/L) basin fill to monitor the impacted zone will have screened intervals up to 200 feet long, centered on the impacted zone to sample all, or as much of the zone as possible.

- Wells constructed in unimpacted basin fill beneath an impacted zone to monitor the unimpacted zone will be screened starting no farther than 100 feet below the impacted zone to approximately 200 to 300 feet below the impacted zone.

- Wells constructed in unimpacted bedrock below impacted basin fill to monitor the unimpacted bedrock will be screened starting at 50 feet below the bedrock contact to approximately 150 feet below the contact.

- Wells constructed in unimpacted bedrock where the water table is in bedrock will be screened starting at approximately the water table down to approximately 100 to 200 feet below the water table.

- Wells constructed in impacted bedrock to monitor the impacted zone will have screened intervals up to 200 feet long, centered on the impacted zone to sample all, or as much of the zone as possible.

- Wells constructed in unimpacted bedrock beneath an impacted bedrock zone to monitor the unimpacted zone will be screened starting no farther than 100 feet below the impacted zone to approximately 200 to 300 feet below the impacted zone.

As noted in Section 3.3.2.1, it may not be feasible to obtain reconnaissance water samples for definition of the sulfate distribution prior to constructing monitoring wells if reconnaissance water sampling efforts are unsuccessful. The decision process described above would be used for well installation when there are no reconnaissance water quality data. In such cases, the selection of screen lengths and depths would be based on best professional judgment given the general construction guidelines and recognizing that well installation would be the primary means of exploring the extent of the plume.

3.3.3.3 Well Installation, Development, and Testing

Drilling, well installation, and development methods are described in the QAPP (Appendix F). Each new well will be developed to remove sediment and drilling fluids. After development, a short duration (10 to 24 hour) step rate pumping test will be conducted. During or at the conclusion of the pumping test, a water quality sample will be collected for analysis of sulfate and other major element ions for characterizing general water chemistry (i.e., the analyte suite for regional monitoring wells (Section 3.3.2)). Following completion of their surface casings, CQB will survey all new wells. After the initial sampling, monitoring wells will be sampled as plume monitoring wells (Section 3.3.2) on a quarterly basis until a long-term monitoring plan is developed pursuant to the Mitigation Plan (Section 5). Water level measurement, water quality sampling, and pumping test methods are described in the QAPP (Appendix F).

3.3.4 Task 2.4 Additional Hydraulic Testing

In addition to hydraulic testing of all new monitoring wells, efforts will be made to conduct additional pumping tests in existing monitoring, public supply, and private wells in portions of the plume where hydraulic properties are critical for modeling such as at the leading edge of the plume near Naco and Bisbee Junction. Wells at the leading edge of the plume that are accessible and appropriately constructed for conducting step or constant rate pump test as long as feasible within a 24-hour period, will be identified and tested, depending on the well owners' permission and based on service commitments.

3.4 Task 3 - Sulfate Fate and Transport Evaluation

The information collected to meet the data needs described in Section 3.1.2 will be used to refine the preliminary conceptual model in Section 2.6. Numerical groundwater flow and transport models will then be developed based on the refined conceptual model to further evaluate the fate and transport of sulfate originating from the CTSA and, as described below, any other sources identified during execution of this Work Plan. The modeling will include development and use of a saturated flow and transport model that will encompass an area that extends from approximately one mile west of AWC-2 to Gold Gulch in the east-west direction and from the North Tailing Impoundment to at least the Arizona border. The actual area of the model will be adjusted as deemed necessary based on information gathered as part of the ACP. At a minimum, the model will focus on flow and transport within the basin fill and Morita Formation aquifers.

The modeling effort will make use of and build upon existing numerical models developed and used for the site (e.g., SET, 1998c). Boundary conditions and other features of the existing models may be incorporated in whole or in part into the new flow and transport model subject to verification of their adequacy. Existing model inputs, such as pumping rate files pertaining to production wells within the model domain, will be updated and incorporated as needed.

The goals of the modeling will be to:

- Calibrate to reproduce with acceptable accuracy past measured hydraulic head and sulfate distributions within the model domain.
- Examine the groundwater flow dynamics under existing conditions to understand how groundwater pumping at different locations in the basin influences the current distribution of sulfate.
- Predict future hydraulic head and sulfate distributions under various possible mitigation scenarios, such as installation of extraction wells to pump sulfate-bearing water, or under long-term conditions such as increased water supply pumping.

3.4.1 Compilation of Information on Groundwater Pumping and Recharge

Available pumping information for production wells within the model domain will be compiled and analyzed for input to the flow and transport sulfate model. It is anticipated that this effort will entail updating existing files of pumping rate information used in previous site models. Any recently installed production wells will be included, as will any existing wells that may be brought into a potentially expanded model domain. Water supply plans for local water companies will be used to estimate future groundwater pumping.

Areal recharge estimates resulting from infiltration by precipitation or as a result of stream flow will be developed for input to the model. This process will also build, to the extent appropriate, on recharge data incorporated into existing site numerical models. The sulfate concentration of the seepage over time at the CTSA and other recharge sources will be evaluated and used in the groundwater flow and transport model.

3.4.2 Sulfate Transport Under Current and Future Conditions

The numerical model developed to evaluate the fate and transport of sulfate in the regional aquifer will be calibrated to past and present measured hydraulic heads and sulfate concentrations. The calibrated model will be used to predict future conditions of hydraulic head and sulfate distribution in the relevant aquifers. Simulations of future conditions will include the effects of pumping from future wells and water supply development described by water system plans.

The regional model will incorporate elements of existing site models such as boundary conditions, and recharge by precipitation and stream flow, as appropriate. It will be three-dimensional, and will include, at a minimum, two layers representing basin fill and one representing the Morita Formation. Compared to previous models, the model will use different hydrogeological properties, sources and sinks, and boundary conditions based on most current information.

At a minimum, it is anticipated that the model will be used to simulate future conditions assuming:

- Continued inactivity of the CTSA.
- Addition of sulfate control strategies, such as ground water pumping to control plume migration.

The results of these simulations will be used by the FS (Section 5) to evaluate the potential future migration of sulfate and the effectiveness of different groundwater pumping schemes and/or the use of institutional controls and natural attenuation as potential mitigation actions. The groundwater flow and transport simulations will be used to provide conceptual design bases for potential mitigation actions.

3.5 Task 4 - Reporting

The following task reports will be submitted to ADEQ pursuant to the ACP:

- Well Inventory Report (Task 1).
- Quarterly Groundwater Monitoring Data Reports (Task 2.2).
- Aquifer Characterization Report (Tasks 1, 2, and 3).

Figure 24 shows a schedule for the ACP reports assuming ADEQ approves the revised Work Plan.

The well inventory report will be submitted to ADEQ shortly after approval of the revised Work Plan (Section 6). A preliminary review of ADWR well records indicates there may be as many as 100 water supply wells within one mile of the plume. The schedule for the well inventory report is based on the time needed to conduct the well inventory to identify potential drinking water wells, contact well owners to verify well use, field check wells to verify their location and condition, obtain access agreements for sampling, conduct sampling, analyzes samples, and compile and report results.

Quarterly groundwater monitoring reports will be submitted to ADEQ in the month following the end of the quarter. This schedule will allow for laboratory turn around of samples collected during the quarter and for data review and reporting. Section 6 discusses the schedule for groundwater monitoring reports.

Section III.C of the MO requires CQB to submit an Aquifer Characterization Report to ADEQ. Pursuant to the MO, the Aquifer Characterization Report will provide the findings of work conducted pursuant to the ACP, including:

- Current sulfate plume delineation.
- Sulfate fate and transport.
- Identification of all registered private drinking water wells and public drinking water system wells.

The Aquifer Characterization Report will summarize previously submitted information from the well inventory and quarterly groundwater monitoring reports, and will provide reports for Tasks 2.1, 2.3, and 3. New information presented in the Aquifer Characterization Report will consist of the data compilation for Task 2.1, the results of drilling, well installation, hydraulic testing, and initial sampling of monitoring wells for Task 2.3, and the results of construction and calibration of the groundwater flow and sulfate transport model for Task 3. Section 6 discusses the schedule for the Aquifer Characterization Report.

The well inventory and quarterly groundwater monitoring reports will provide current water quality information to ADEQ through the course of the ACP. The latest information on the plume delineation will be provided in the Aquifer Characterization Report, which will contain maps and cross sections showing the distribution of sulfate.

Figure 24 shows a schedule for the ACP tasks. Work for some the ACP task is expected to take more than a year to complete. Although CQB proposes this schedule, the groundwater monitoring and well installation tasks have scheduling uncertainties due to the need to negotiate access to private property. The schedule is discussed further in Section 6.

4. POTENTIAL INTERIM ACTIONS

Pursuant to Section III.D of the MO, CQB will identify and implement interim mitigation actions for a drinking water supply found to have a sulfate concentration in excess of 250 mg/L sulfate due to the CTSA prior to implementation of the Mitigation Plan. Potential interim actions will be implemented before the Mitigation Plan is completed if: (1) the sulfate concentration at the point of use in a drinking water supply exceeds 250 mg/L, or (2) if data demonstrate that the sulfate concentration at the point of use in a drinking water supply will exceed 250 mg/L before the Mitigation Plan is completed.

As part of the well inventory (Section 3.2), CQB will sample and analyze drinking water supplies for sulfate free of charge or will work with water providers to collect and share water quality data sufficient to determine the sulfate concentration of the water supply. The sulfate concentration will be determined based on discrete samples collected at the point of use or the point of entry to the supply system unless there is downstream blending. The discrete sulfate concentration of a drinking water supply will be the result of the most recent single sample at the point of use or the point of entry.

If the discrete sulfate concentration of a drinking water supply is found to exceed 250 mg/L sulfate, interim action selection and implementation will begin immediately. On receipt of sampling results, CQB may resample the drinking water supply to confirm that the sulfate concentration exceeds 250 mg/L.

A water supply having a discrete sulfate concentration between 135 mg/L and 250 mg/L will be monitored monthly for four months to determine whether concentrations are increasing and to identify any trend in sulfate concentrations over time. Based on the apparent trend in sulfate concentrations, a monitoring schedule will be developed for the supply. If the trend indicates increasing concentrations, an interim action will be selected for the water supply and an implementation plan will be developed to implement the selected action, if possible, before the sulfate concentration at the point of use or point of entry exceeds 250 mg/L.

Water supplies with discrete sulfate concentrations less than 135 mg/L will receive water sampling quarterly as follow-up monitoring to track the discrete sulfate concentration.

The nature of an interim action will depend on site-specific circumstances. For private wells, possible interim actions would include provision of bottled water or other measures to be developed pursuant to A.R.S. § 49-286. For a public supply well, possible interim actions could consist of providing bottled water to each customer served by the public supply well, installation of a temporary reverse osmosis (RO) treatment system at the wellhead, or, if applicable, blending. Should an interim action be undertaken, sampling would be conducted at points appropriate for the situation, including well head and point of entry, if applicable. If changes to water system infrastructure are required, ADEQ approvals would be obtained as necessary to perform the action in compliance with applicable existing regulations.

Pursuant to the MO, CQB shall submit an interim action report to ADEQ within 30 days of implementing an interim action, which shall state the name of the owner(s)/operator(s) of the affected well, the location and type of well (public or private) affected, and the interim action selected. There are thirteen parties currently receiving bottled water as an interim action. A report for these previously implemented interim actions was submitted to ADEQ on May 22, 2008 (CQB, 2008).

Once an interim action is implemented, follow-up monitoring of the water supply will be at a frequency recommended in the interim action report submitted to ADEQ. Follow-up sampling will be used to calculate an average sulfate concentration for a water supply. The average sulfate concentration will be calculated as the arithmetic mean of the three most recent discrete water quality samples for the water supply. Any interim action implemented would continue until follow-up monitoring determines that the average sulfate concentration of the drinking water supply is less than the sulfate mitigation level of 250 mg/L based on at least three quarters of follow-up monitoring. The interim action and follow-up water supply monitoring will continue until superseded by the mitigation and monitoring recommendations of the Mitigation Plan developed pursuant to the FS (Section 5).

5. FEASIBILITY STUDY FOR SULFATE MITIGATION PLAN

Pursuant to Section III.E of the MO, CQB will develop a Mitigation Plan for submittal to ADEQ. The scope of the Mitigation Plan is to practically and cost effectively provides drinking water to owners or operators of a drinking water supply affected by sulfate in excess of 250 mg/L due to the CTSA.

An FS will be conducted to identify and evaluate mitigation alternatives for the Mitigation Plan. The purpose of the FS is to provide a structured approach for identifying and evaluating the various ways in which mitigation can be accomplished.

The main components of the FS will be:

- Identification and Screening of Mitigation Technologies.
- Development and Screening of Mitigation Alternatives.
- Detailed Analysis of Mitigation Alternatives.
- Preparation of a Mitigation Plan.

5.1 Identification and Screening of Mitigation Actions and Technologies

The identification and screening of mitigation actions and technologies is a multi-step process, identifying mitigation objectives, mitigation actions, mitigation technologies, and process options. Mitigation actions are broad categories of possible actions consisting of one or more mitigation technologies and the process options used by the technologies. A series of screening steps is applied, consisting of criteria such as implementability, effectiveness, and cost to reduce the range of potentially applicable mitigation technologies and process options by eliminating inappropriate or unworkable options. Information developed for the identification of interim actions (Section 4) will be incorporated into the screening as appropriate. Mitigation actions, mitigation technologies, and process options retained by the screening will be assembled into mitigation alternatives for subsequent analysis. Mitigation alternatives are plans that may consist of a single mitigation action or a combination of actions for meeting mitigation objectives.

5.1.1 Mitigation Objectives

Mitigation objectives are qualitative and quantitative goals that meet the requirements of the MO. The constituent of concern is sulfate, an inorganic substance contained in affected groundwater. The MO sets a sulfate level of 250 mg/L for drinking water. Based on the factors identified in the MO, the objective for mitigation is to provide drinking water meeting applicable water quality standards to the owner of a drinking water supply containing sulfate in excess of 250 mg/L due to the CTSA.

5.1.2 Mitigation Actions

Mitigation actions are generic approaches to mitigation that can be employed singly or in combination to accomplish the mitigation action objectives. A mitigation action can consist of several different technologies and process options. For example, water treatment is a mitigation action that can be used to remove sulfate from drinking water. Water treatment can employ different technologies for removing sulfate such as chemical precipitation, ion exchange, or semi-permeable membranes. Within each technology there may be several process options that can be used to implement the technology. In the case of semi-permeable membrane technology, RO, electrodialysis, or nanofiltrations are examples of different process options.

For the mitigation of non-hazardous substances such as sulfate, A.R.S. § 49-286 identifies alternative mitigation actions as follows:

- Providing an alternative water supply.
- Mixing or blending if economically practicable.
- Economically and technically practicable treatment before ingesting the water.
- Other mutually agreeable mitigation measures.

The FS also will consider mitigation measures that would control or mitigate sulfate through the application of groundwater controls that may include groundwater pumping to reduce sulfate concentrations to meet the numeric mitigation objective. Additional mitigation actions to be considered include monitoring of groundwater and drinking water, institutional controls, such as restrictions on well drilling, natural attenuation, and if needed, alternatives that could reduce sulfate loading to groundwater from the CTSA.

Each mitigation action can employ various technologies depending on site-specific conditions. Alternative water supply can be accomplished by various means including replacement wells, use of an unimpacted supply well, well modification, connection to an existing public water supply, or bottled water. Mixing and blending refers to commingling waters with different sulfate concentrations to meet the numeric mitigation objective. Water treatment would use a physical, chemical, or biological process to remove sulfate and other constituents from drinking water. Depending on the situation, water treatment can be conducted before the point-of-entry to a distribution system using a centralized plant or wellhead treatment system or at the point-of-use with home-based treatment systems.

5.2 Development and Screening of Mitigation Alternatives

Mitigation alternatives will be formulated using mitigation actions, mitigation technologies, and process options retained by the previous screening evaluation. Mitigation alternatives can consist of either a single mitigation action or a combination of mitigation actions that address the mitigation objectives.

For cases in which multiple mitigation technologies or process options are retained by the screening (e.g., RO, electrodialysis, and nanofiltration), determination of the most applicable process option will be made based on criteria such as implementability, effectiveness, and cost. CQB will retain a specialist in water treatment as part of the FS team. Treatability studies will be undertaken at bench and field scale, if needed, to test the effectiveness of potentially applicable treatment process options and to estimate operational costs.

Mitigation alternatives will be developed in consultation with, and considering the requirements of local water providers and well owners. Factors to be considered in developing alternatives include projected water needs, infrastructure constraints on water supplies, and water rights. CQB will retain a water systems engineering firm to evaluate the water needs and delivery infrastructure in the area of the sulfate plume and to provide guidance in the development of mitigation alternatives.

The groundwater fate and transport model (Section 3.4) will be used to develop and evaluate potential plume control response actions. The migration and concentration of sulfate over time will be key factors in evaluating the effectiveness of plume control response actions.

5.3 Detailed Analysis of Mitigation Alternatives

The detailed analysis of mitigation alternatives will evaluate each alternative with respect to its benefits and cost. A.R.S. § 49-286.B indicates that the mitigation selection process shall balance the short-term and long-term public benefits of mitigation with the cost of each alternative, and that only the least costly alternative may be required if more than one alternative satisfies the mitigation objective. The analysis of alternatives will include consideration of residuals. The estimated quantity and type of residuals created by each alternative will be determined. Means for managing these residuals will be evaluated and included in the feasibility determination and cost estimate.

The mitigation alternatives will then be compared with respect to their benefits and cost. Quantitative estimates of benefits and cost will be developed. The cost analysis will consider direct and indirect capital and the long-term operating costs of each alternative. Costs will be compared based on their 30-year net present value or a similar long-term estimate.

A recommended mitigation alternative or combination of alternatives will be selected using the detailed analysis of alternatives. The recommended mitigation alternative(s) will describe the work to be implemented for the Mitigation Plan.

5.4 Mitigation Plan

The Mitigation Plan will report the results of the alternatives analysis for the FS and will identify the recommended mitigation alternative(s). A schedule for implementation of the recommended alternative(s) will be included in the Mitigation Plan. The plan will also contain a methodology for verification sampling and analysis of drinking water sources to determine (1) when the average sulfate concentration of a drinking water source exceeds the numeric mitigation objective and (2) whether the sulfate is attributable to the CTSA. The Mitigation Plan will be submitted to ADEQ for review and approval pursuant to the MO.

6. SCHEDULE

Figure 24 charts the schedule for the ACP and FS for sulfate mitigation. The start of the schedule is assumed to be February 2008 because CQB initiated water sampling for Tasks 1 and 2.2 prior to work plan approval while ADEQ was commenting on the Work Plan and CQB was responding to the comments. Table 8 lists deliverable dates for key reports based on the February start of work. Although work was started in February, reporting was suspended pending completion of discussions with ADEQ and revision of the Work Plan. For this reason, deliverables for the well inventory and the first two quarters of groundwater monitoring will be provided on an expedited basis as listed in Table 8, the schedule for Work Plan deliverables.

The schedule provides for completion of tasks related to exposure management (e.g., well inventory, interim actions, and first quarterly groundwater monitoring) as early as possible and completion of the FS to identify potential mitigation actions in parallel with the ACP. However, several tasks may have a long lead-time due to the necessity of negotiating access to private land to conduct work. The lead-time for Task 2.3 is the critical path item for the ACP. The timing of Task 2.3 impacts the fate and transport modeling for Task 3, which cannot be finalized until the completion of the hydrogeologic characterization.

As described in Section 4, interim actions will be implemented immediately on identification of a drinking water supply exceeding 250 mg/L sulfate due to sulfate from the CTSA. Interim action monitoring will commence with monitoring for the well inventory.

The FS will be conducted in parallel with the ACP. The identification and screening of mitigation technologies, identification and screening of mitigation alternatives, treatability studies, and certain aspects of the detailed analysis of mitigation alternatives will be implemented during the ACP. Completion of the detailed analysis of alternatives requires completion of the sulfate fate and transport evaluation in order to evaluate alternatives using groundwater pumping and completion of treatability studies for evaluating treatment technologies. The Mitigation Plan will be prepared following completion of the detailed analysis of mitigation alternatives.

7. REFERENCES

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TABLES

TABLE 1
Generalized Geologic Column in the Vicinity of the CTSA

Age		Hydro-geologic Unit	GEOLOGIC UNIT
QUATERNARY	RECENT	ALLUVIUM	**Recent Alluvium** Unconsolidated stream channel sediments
	Pliocene - Pleistocene	BASIN FILL	**Basin Fill** Valley fill, pediment, terrace and fan deposits; weakly to moderately consolidated interbedded gravel, sand, silt, and clay
TERTIARY		BEDROCK COMPLEX	**Intrusive Porphyry** Quartz latite porphyry
CRETACEOUS	*BISBEE GROUP*		**Cintura Formation** Grayish-red siltstone and mudstone, pale-red feldspathic sandstone, and minor greenish- gray calcareous claystone, few thin beds of limestone in basal 100 feet
			Mural Limestone Upper member: medium dark-gray limestone with subordinate sandstone in upper 50 feet Lower member: interbedded light-gray calcareous sandstone and siltstone and impure fossiliferous limestone
			Morita Formation Grayish-red siltstone and mudstone, pinkish-gray to pale-red feldspathic sandstone, minor greenish-gray calcareous claystone; few thin beds of impure limestone in the upper part and very subordinate pebble conglomerate in the lower part
			Glance Conglomerate Locally derived boulder to pebble conglomerate with grayish-red matrix
JURASSIC			**Jurassic Intrusive Complex** Stocks and dikes of porphyritic leucratic alkali granite
PALEOZOIC	*NACO GROUP*		**Colina Limestone** Medium-gray thick bedded limestone, locally slightly cherty
			Earp Formation Pale-red calcareous siltstone and mudstone with subordinate medium-gray thin bedded limestone and marl.
			Horquilla Limestone Light-gray, medium-bedded limestone with subordinate pale-red calcareous siltstone and silty limestone
	MISSISSIPPIAN		**Escabrosa Limestone** Medium- to light-gray thick-bedded to massive crinoidal limestone and medium- to dark-gray thin-bedded limestone
	DEVONIAN		**Martin Limestone** Medium- to dark-gray limestone, marl, dolomite and sandy dolomite, and calcareous siltstone
	CAMBRIAN		**Abrigo Limestone** Laminated hornfels with subordinate limestone, silty and argillaceous limestone with chert; overlain by interlaminated silty limestone and chert; glauconitic sandy dolomite, dolomitic sandstone, with minor interbedded marl, medium-gray locally dolomitized laminitic limestone
			Bolsa Quartzite Resistant yellowish- to reddish-brown-weathering siliceous sandstone
PRE-CAMBRIAN	*LOWER PRE-CAMBRIAN*		**Pinal Schist** Muscovite, sericite, chlorite and quartz schist

Source: Hayes and Landis 1964; Stegan et al, 2005

TABLE 2
Summary of Hydraulic Conductivity Data

Well or Boring	Aquifer Material	Hydraulic Conductivity (ft/day)		
		ELMA, 1990; published by SRK, 1997	SRK,1997; re-interpretation of ELMA, 1990 data	SET, 1998c
TM-11	basin fill	39.0	1.2	
TM-13	basin fill	59.0	19.1	
	average, basin fill	**49.0**	**10.1**	
TM-1	basin fill-Morita Formation	21.4	11	
TM-1A	basin fill-Morita Formation	26.8	not calculated	
	average, TM-1, TM-1A	**24.1**		
TM-29	basin fill-Morita Formation	6.7	not calculated	
TM-29A	basin fill-Morita Formation	4.0	1.3	
TM-29B	basin fill-Morita Formation	4.0	1.8	
	average, TM-29, TM-29B	**4.0**	1.6	
	average, all basin fill-Morita Formation	**12.6**	**4.7**	
TM-30	Morita Formation, west of Black Gap fault	12.0	not calculated	
TM-30A	Morita Formation, west of Black Gap fault	1.3	not calculated	
	average, TM-30, TM-30A	**6.7**		
TM-19A	Morita Formation, west of Black Gap fault	12.0	5.8	
TM-38	Morita Formation, west of Black Gap fault	12.0	not calculated	
	average, all Morita Formation, west of Black Gap fault	**9.3**	**5.8**	
TM-16	Morita Formation, east of Black Gap fault	1.3	2.2	
Flow and Transport Model (SET,1998c)	basin fill, gravel			72
	basin fill, gravelly sand			65
	basin fill, sand			30
	basin fill, silty sand			23
	average, basin fill			**48**
	Morita Formation, sandstone			20
	Morita Formation, siltstone			3
	Morita/Mural Formations, siltstone limestone			2
	Morita Formation, siltstone/mudstone			1
	Morita Formation, mudstone			2
	average, Morita Formation			**6**
	Glance Conglomerate, silty matrix			2
	Glance Conglomerate, clayey matrix			1
	average, Glance Conglomerate			**1**

Notes:
ft/day = feet per day

TABLE 3
Estimated Groundwater Flow Velocities in the Vicinity of the CTSA

Description		K (ft/d)	n	h1 (ft)	h2 (ft)	dH (ft)	dX (ft)	v (ft/d)
1989 Basin Fill	**TM-2 to TM-11**							
Avg ELMA (1990)		49	0.25	4460.8	4497.72	-36.92	15000	**0.48**
Avg SET (1998c)		22.96	0.25	4460.8	4497.72	-36.92	15000	**0.23**
2005 Basin Fill	**TM-2 to 641802**							
Avg ELMA (1990)		49	0.25	4443	4457.9	-14.9	15000	**0.19**
Avg SET (1998c)		22.96	0.25	4443	4457.9	-14.9	15000	**0.09**
1989 Glance-Morita (North-South)	**TM-28 to TM-16**							
Avg ELMA (1990)		9.3	0.15	4623.64	4750.59	-126.95	8750	**0.90**
Avg SET (1998c)		2.952	0.15	4623.64	4750.59	-126.95	8750	**0.29**
2005 Morita-Glance (North-South)								
Avg ELMA (1990)		9.3	0.15	na	na	na	8750	**na**
Avg SET (1998c)		2.952	0.15	na	na	na	8750	**na**
1989 Morita (East-West)	**TM-16 to TM19A**							
Avg ELMA (1990)		9.3	0.15	4470.07	4623.64	-153.57	10500	**0.91**
Avg SET (1998c)		2.952	0.15	4470.07	4623.64	-153.57	10500	**0.29**
2005 Morita (East-West)	**TM-16 to TM-19A**							
Avg ELMA (1990)		9.3	0.15	4435.5	4625.8	-190.3	10500	**1.12**
Avg SET (1998c)		2.952	0.15	4435.5	4625.8	-190.3	10500	**0.36**

Assumptions:

1. *Unidimensional (horizontal) groundwater flow in direction of measurement locations.*
2. *Linear water table with distance (confined flow equations good approximate).*
3. *Homogeneous, isotropic properties between well locations.*

Note:

ft/d = feet per day.

$$v = (-K/n)[dH/dx]$$

where:
v = groundwater flow velocity
K = hydraulic conductivity
n = porosity
dH = change in water elevation between locations
dX = distance between locations

TABLE 4
Analytical Results for 1996 Groundwater Samples Used for Trilinear Diagrams [1]

Well No.	Formation	Sample Date	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	HCO3 (mg/L)	CO3 (mg/L)	pH (standard units)	TDS (mg/L)
TM-41	Morita	07/30/97	620	250	47	28	22	1940	488	0.3	6.2	3600
TM-16	Morita	06/27/96	200	44.1	28.2	11.1	28	500	126	0.3	7.4	1100
TM-2	Basin Fill	06/20/96	628	147	35.6	4.9	28	1200	457	0.3	6.4	2700
BF-2	Basin Fill	06/25/96	958	206	30.1	4.1	33	2000	602	0.3	6.3	3800
TM-19	Basin Fill	06/20/96	427	55.6	41.3	4.3	19	1100	126	0.3	7.2	2100
NWC 5	Morita	08/07/96	158	33.0	25.8	4.56	180	78.9	77	0.3	7.4	888
TM-6	Morita	06/26/96	36.1	18.2	54	1.5	18	29	137	0.3	7.9	320
TM-19A	Morita	06/25/96	43.8	10.2	58.6	2.5	14	56	119	0.3	7.8	320
TM-12	Basin Fill	06/26/96	57.7	7.5	23.3	1.8	25	7	110	0.3	7.7	270
TM-15	Basin Fill	06/27/96	26	16.4	30.3	1.9	7.2	14	114	0.3	7.8	230
AWC 3	Basin Fill	08/06/96	60.4	7.6	15.7	2.27	8.0	5.0	109	0.3	7.6	248
TM-5	Basin Fill	06/26/96	50.5	5.6	19.8	1.6	24	10	90	0.3	7.8	240

Notes:

[1] *select data from SET, 1999 used for trilinear diagram (Figure 18)*

mg/L = milligrams per liter.

TABLE 5
Summary of Data Needs and Proposed Work

DATA NEEDS	PROPOSED AQUIFER CHARACTERIZATION PLAN (ACP)/FEASIBILITY STUDY (FS) WORK
AQUIFER CHARACTERIZATION DATA NEEDS	
Locations of drinking water wells downgradient and crossgradient of the plume	**ACP - Task 1 - Well Inventory: use Arizona Department of Water Resources and Arizona Department of Environmental Quality data to identify the location and water use for individual wells.**
Groundwater sulfate data to determine the eastern, southern, and western horizontal extents of the plume	**ACP - Task 2 - Plume Characterization: conduct plume and regional groundwater monitoring to characterize lateral extent of sulfate, install and sample proposed new monitoring wells east, south, and west of the plume; and Task 1 - Well Inventory: samples from drinking water supplies will provide data on extent of sulfate.**
Groundwater sulfate data to determine the vertical distribution of sulfate	**ACP - Task 2 - Plume Characterization: conduct plume monitoring at existing well nests, and install and sample proposed new monitoring well nests to evaluate the vertical distribution of sulfate.**
Local and regional water level measurements to characterize the regional flow system	**ACP - Task 2 - Plume Characterization: conduct plume and regional monitoring to measure local and regional water levels at existing wells, and measure water levels at new monitoring wells.**
Local and regional water quality data to determine background water quality	**ACP - Task 2 - Plume Characterization: conduct plume and regional groundwater monitoring to characterize background water quality, install and sample proposed new monitoring wells east, south, and west of the plume.**
Aquifer structure and hydraulic properties	**ACP - Task 2 - Plume Characterization: compile and evaluate data on the depths and hydraulic properties of aquifer units, conduct pumping tests at new wells; and Task 3 - Sulfate Fate and Transport Evaluation: aquifer data will be incorporated into a calibrated groundwater flow model.**
Conditions in the potential source area	**ACP - Task 2 - Plume Characterization: install and sample proposed new monitoring wells at the former evaporation pond area site and on the east and west sides of the South Tailing Impoundment.**
Quantification of sources and sinks of groundwater for groundwater flow model	**ACP - Task 3 - Sulfate Fate and Transport Evaluation: the flow rates and sulfate concentrations of historical and current sources and sinks of groundwater will be compiled or estimated for incorporation into the groundwater flow model; project concentrations and flows of future sources and sinks for predictive simulations.**
FEASIBILITY STUDY DATA NEEDS	
Water quality data for assessing treatability	**ACP - Task 2 - Plume Characterization: identify and collect information on water quality parameters that may influence treatment effectiveness, if needed.**
Current and projected pumping rates for existing wells	**FS - ISMAT and DSMA (see FS Task list below): determine current and projected demands for water use in the Bisbee-Naco area; and ACP - Task 3 - Sulfate Fate and Transport Evaluation: future sources and sinks will be projected for predictive simulations.**
Expected future pumping rates for planned wells	**FS - ISMAT and DSMA: determine projected future demands for water use in the Bisbee-Naco area; and ACP - Task 3 - Sulfate Fate and Transport Evaluation: future sources and sinks will be projected for predictive simulations.**
Specifications for existing and planned water supply distribution and storage systems	**FS - ISMAT and DSMA: obtain existing and projected future infrastructure specification from water users in the Bisbee-Naco area.**

ACP Task List

Task 1 - Well Inventory

Task 2 - Plume Characterization

- *Task 2.1 - Data Compilation and Evaluation*
- *Task 2.2 - Groundwater Monitoring*
- *Task 2.3 - New Monitoring Well Installation and Testing*

Task 3 - Sulfate Fate and Transport Evaluation

Task 4 - Aquifer Characterization Report

FS Task List

Identification and Screening of Mitigation Actions and Technologies (ISMAT)

Development and Screening of Mitigation Alternatives (DSMA)

Detailed Analysis of Mitigation Alternatives (DAMA)

TABLE 6
Proposed Groundwater Monitoring Wells

ADWR 55 Well Registry Number	Well ID	Monitoring Purpose	Sampling Frequency
200393	Walker	Regional	Semi Annual
203321	NWC3relp	Plume	Quarterly
212268	Burke	Plume	Quarterly
502527	Gallant	Regional	Semi Annual
510298	Yates	Plume	Quarterly
516399	Conner	Regional	Semi Annual
522573	TM-2	Plume	Quarterly
522574	TM-2A	Plume	Quarterly
522575	TM-3	Plume	Quarterly
522576	TM-7	Plume	Quarterly
522578	TM-16	Plume	Quarterly
522580	TM-19	Plume	Quarterly
522581	TM-19A	Plume	Quarterly
522694	TM-5	Regional	Semi Annual
522695	TM-6	Plume	Quarterly
522696	TM-10	Plume	Quarterly
522697	TM-12	Regional	Semi Annual
522698	TM-13	Plume	Quarterly
522699	TM-15	Regional	Semi Annual
522700	TM-17	Plume	Quarterly
522815	TM-11	Plume	Quarterly
522816	TM-14	Regional	Semi Annual
522817	TM-8	Regional	Semi Annual
527586	NSD-3	Regional	Semi Annual
527587	NSD-2	Regional	Semi Annual
539782	GL-3	Plume	Quarterly
539783	BF-1	Plume	Quarterly
544535	Rozzano	Plume	Quarterly
558557	Garner	Plume	Quarterly
562554	TM-42	Plume	Quarterly
562555	TM-41	Plume	Quarterly
562944	NWC-2repl	Plume	Quarterly
564726	TM-43A	Regional	Semi Annual
564728	TM-45	Regional	Semi Annual
564729	TM-43	Regional	Semi Annual

TABLE 6
Proposed Groundwater Monitoring Wells

ADWR 55 Well Registry Number	Well ID	Monitoring Purpose	Sampling Frequency
565004	TM-43B	Regional	Semi Annual
568875	Naco Golf Course (Lawson)	Plume	Quarterly
570012	City of Bisbee	Regional	Semi Annual
575700	NWC-6	Regional	Semi Annual
576415	Parra	Plume	Quarterly
577927	Bima LLC	Plume	Quarterly
587635	GW-47	Plume	Quarterly
590620	AWC-5	Plume	Quarterly
593116	City of Bisbee	Plume	Quarterly
599796	East	Regional	Semi Annual
602134	SJ-9	Plume	Quarterly
606854	Hull	Plume	Quarterly
616585	AWC-3	Plume	Quarterly
623564	Laeding	Plume	Quarterly
624535	Power	Regional	Semi Annual
627682	NWC-1	Regional	Semi Annual
627685	NWC-4	Plume	Quarterly
627696	NWC-5	Plume	Quarterly
628546	Galloping Goose Properties	Plume	Quarterly
628547	ELKS	Plume	Quarterly
637069	Hutson	Plume	Quarterly
641340	Miller	Plume	Quarterly
641341	Miller	Plume	Quarterly
641342	Miller	Regional	Semi Annual
641802	Grout	Plume	Quarterly
641803	Rogers	Plume	Quarterly
642937	Helga	Regional	Semi Annual
903984	City of Bisbee	Plume	Quarterly
903992	MW-1	Plume	Quarterly
no number	BJ-1	Plume	Quarterly
no number	BJ-2	Plume	Quarterly
no number	BJ-4	Plume	Quarterly
no number	BJ-5	Plume	Quarterly

ADWR = Arizona Department of Water Resources

TABLE 7
Proposed New Monitoring Well Locations

PROPOSED WELL SITE	PURPOSE	ESTIMATED WELL DEPTH	ESTIMATED DEPTH TO BEDROCK	BEDROCK FORMATION	APPROACH TO WELL INSTALLATION	LAND STATUS
1	Determine eastern extent and of sulfate and hydraulic properties; long term water level and water quality monitoring in the vicinity of abandoned assessment well TM-4 (Figure 3)	400	75	Glance Conglomerate	Single well in Glance Conglomerate	Private
2	Determine southeastern extent and vertical zoning of sulfate and hydraulic properties in Morita Formation or Glance Conglomerate; long term water quality monitoring in the vicinity of Bisbee Junction basin watershed margin is impacted by the CTSA	600	5-15	Morita Formation and Glance Conglomerate	Single well in Morita Formation or Glance Conglomerate, depending on construction details of NWC 4 and thickness of Morita Formation; existing private well may substitute if suitable	Private
3	Determine southern extent and of sulfate and hydraulic properties; long term water level and water quality monitoring	550-700	550-700	Morita Formation and Glance Conglomerate	Single well in basin fill	Private
4	Determine vertical zoning of sulfate and hydraulic properties in the vicinity of NWC-3, specifically whether or not sulfate is present in deep basin fill below screened depths of area wells; long term water level and water quality monitoring	600-1000	600-1000	Morita Formation and Glance Conglomerate	Single well in deep basin fill	Private
5	Determine southwestern extent and vertical zoning of sulfate and hydraulic properties; serve as sentinel well between plume margin and AWC public supply wells; long term water level and water quality monitoring	600	600-1000	Morita Formation and Glance Conglomerate	Two wells in shallow and deep basin fill; existing private well(s) may substitute for shallow basin fill well if suitable	Private
6	Determine western extent and vertical zoning of sulfate and hydraulic properties between TM-14 and TM-13; long term water level and water quality monitoring	550	450-550	Morita Formation and Glance Conglomerate	Two wells in shallow and deep basin fill; existing private well(s) may substitute if suitable	Private
7	Determine vertical zoning of sulfate and hydraulic properties inside the plume in the vicinity of MW-1; specifically, monitor sulfate concentrations in bedrock; long term water quality monitoring	600	450-500	Morita Formation	Single well in Morita Formation	PDCQB
8	Determine vertical zoning of sulfate and hydraulic properties on the west side of the Black Gap fault; determine the hydrologic influence of the fault; test for presence of and monitor sulfate in the bedrock aquifer; long term water level and water quality monitoring	550-650	350-450	Morita Formation	Two wells, one in basin fill and one in Morita Formation	PDCQB
9	Determine vertical zoning and hydraulic properties within the Morita Formation +/- Glance Conglomerate below the depth of TM-41; long term monitoring of water quality east of the Black Gap fault	500	150	Morita Formation and Glance Conglomerate	Single well in deep bedrock	PDCQB
10	Source area monitoring; determine vertical sulfate zoning within bedrock aquifer and hydraulic properties on the east side of the Black Gap fault	500	140	Morita Formation and Glance Conglomerate	Two wells in shallow and deep bedrock	PDCQB
11	Source area monitoring; long term water level and water quality monitoring	400	240	Morita Formation	Single well in bedrock	PDCQB
12	Source area monitoring; long term water level and water quality monitoring	200	60	Glance Conglomerate	Single well in bedrock; existing private well may substitute if suitable	Private

Note:
PDCQB = Phelps Dodge Copper Queen Branch
Location of proposed wells may be subject to change depending on land access and results of data collection in Task 2.2.
Some wells may not be drilled if suitable existing wells are available for groundwater monitoring.

TABLE 8
Schedule for Work Plan Deliverables

DELIVERABLE	DATE
Well Inventory Report	July 31, 2008
Groundwater Monitoring Reports	
First Quarter 2008	July 31, 2008
Second Quarter 2008	July 31, 2008
Third Quarter 2008	October 31, 2008
Fourth Quarter 2008	January 31, 2008
First Quarter 2009	April 30, 2009
Second Quarter 2009	July 31, 2009
Third Quarter 2009	October 31, 2009
Aquifer Characterization Report	April 30, 2009
Feasibility Study	July 31, 2009
Mitigation Plan	September 30, 2009