phelps dodge Sierrita Inc.
6200 W. Duval Mine Road • P. O. Box 527 • Green Valley, AZ 85622-0527
(520) 648-8500

August 11, 2006

HAND DELIVERED

Mr. Robert Casey
Arizona Department of Environmental Quality
Water Quality Enforcement Unit
1110 West Washington Street
Phoenix, Arizona 85007-2935

Re: Work Plan
Phelps Dodge Sierrita, Inc. – Mitigation Order on Consent, Docket No. P-50-06

Dear Mr. Casey:

In accordance with provisions of the referenced mitigation order on consent ("Consent Order"), enclosed is the Work Plan as required in Section III. A of the Consent Order. The Work Plan describes our proposed approach to completing the characterization of the vertical and horizontal extent of the sulfate plume, completion of an Aquifer Characterization Report (ACR), and development of a Mitigation Plan.

Please do not hesitate to contact Mr. Stuart Brown at (503) 675-5252 or Mr. Ned Hall at (520) 648-8857 if you have any question regarding this work plan.

Sincerely,

John Brack
Phelps Dodge Sierrita, Inc.

JDB:eh
Attachment

cc: Joan Card, ADEQ
Moses Olade, ADEQ
Chad Fretz, Phelps Dodge Sierrita, Inc.
Bill Cobb, Phelps Dodge Corporation
Ray Lazuk, Phelps Dodge Corporation
Stuart Brown, Bridgewater Group, Inc.

WORK PLAN TO CHARACTERIZE AND MITIGATE SULFATE WITH RESPECT TO DRINKING WATER SUPPLIES IN THE VICINITY OF THE PHELPS DODGE SIERRITA TAILING IMPOUNDMENT, PIMA COUNTY, ARIZONA

Prepared for:

Phelps Dodge Sierrita, Inc.
6200 West Duval Mine Road
Green Valley, Arizona

Prepared by:

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

August 11, 2006

WORK PLAN TO CHARACTERIZE AND MITIGATE SULFATE WITH RESPECT TO DRINKING WATER SUPPLIES IN THE VICINITY OF THE PHELPS DODGE SIERRITA TAILING IMPOUNDMENT, PIMA COUNTY, ARIZONA

Prepared for:

Phelps Dodge Sierrita, Inc.
6200 West Duval Mine Road
Green Valley, Arizona

Prepared by:

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

Approved by:

James R. Norris

30842
JAMES R. NORRIS
8/11/06

James R. Norris
Arizona Registered Geologist No. 30842

August 11, 2006

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLES

FIGURES

APPENDICES

LIST OF ACRONYMS

A.A.C.	Arizona Administrative Code
ACP	Aquifer Characterization Plan
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
A.R.S.	Arizona Revised Statutes
ASLD	Arizona State Land Department
AWQS	Aquifer Water Quality Standards
BESST	BESST, Inc.
CWC	Community Water Company
DQO	Data Quality Objective
FS	Feasibility Study
GIS	Geographic Information System
MCL	Maximum Contaminant Level
MO	Mitigation Order
PAG	Pima Association of Governments
PDSI	Phelps Dodge Sierrita, Inc.
PDSTI	Phelps Dodge Sierrita Tailing Impoundment
QAPP	Quality Assurance Project Plan
SDP	Sewage Disposal Ponds
TDS	Total Dissolved Solids
UTM	Universal Transverse Mercator

1. INTRODUCTION

A plume of sulfate-bearing groundwater has been detected downgradient of the Phelps Dodge Sierrita Tailing Impoundment (PDSTI) south of Tucson, Arizona (Figures 1 and 2). In June 2006, Arizona Department of Environmental Quality (ADEQ) and Phelps Dodge Sierrita, Inc. (PDSI) entered into a Mitigation Order on Consent (Docket No. P-50-06) (MO) requiring PDSI to characterize the extent of sulfate in groundwater and to develop a Mitigation Plan for any impacted drinking water supplies attributable to the PDSTI.

PDSI is now mitigating sulfate through groundwater pumping and providing alternative water supplies. The MO provides a structure for conducting additional environmental investigations and evaluating additional potential mitigation alternatives. 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 PDSI.

1.1 Mitigation Order Requirements Pertaining to Work Plan

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

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

- A Quality Assurance Project Plan (QAPP), with a schedule of implementation, that defines the sulfate plume characterization and assessment objectives, and describes the methods, organization, analyses, and Quality Assurance and Quality Control that PDSI will implement and/or perform to ensure that characterization and assessment objectives are met (MO Section III.A.2),

- A plan encompassing one or more phases, to complete characterization of the sulfate plume downgradient of the PDSTI 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 PDSTI as defined by concentrations in excess of 250 milligrams per liter (mg/L), and (2) to evaluate the fate and transport of sulfate downgradient of the PDSTI (MO Section III.A.3), and

- A plan to inventory all existing registered private wells used as a drinking water source or public drinking water system wells located within a (1) mile radius of the sulfate plume's down and cross-gradient 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". In addition to the work identified in Section III.A of the MO, Section III.C.4 requires the Aquifer Characterization Report to address the effectiveness of the existing sulfate control system.

Section III.D 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 an average sulfate concentration in excess of 250 mg/L due to sulfate from the PDSTI. 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 sulfate is due to the PDSTI.

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 generally is modeled 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:

- the formation of a community advisory group which will meet four times yearly,
- a local information repository for the dissemination of information about the MO, and
- 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, and III.D 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 the current efforts to mitigate sulfate, and presents an overview of the geology, groundwater hydrology, and water quality including the known occurrence and extent of sulfate downgradient of the PDSTI.
- **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 cross-gradient 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; an analysis of the effectiveness of the current mitigation control strategy; 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.** Work to identify potential interim actions is described in Section 4. This task which is consistent with FS activities, considers potential interim actions if average 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., well inventory and identification of potential interim actions) are scheduled to be completed 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.

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 PDSTI, 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 PDSI to address sulfate; describes the geology, groundwater hydrology, and water quality downgradient of the PDSTI; and presents a conceptual model of the sulfate plume.

2.1 Background

The PDSTI is approximately 25 miles south of Tucson and from 0.5 to 1.5 miles west of Green Valley in Pima County, Arizona (Figures 1 and 2). The PDSTI covers approximately 3,600 acres located east of the Phelps Dodge Sierrita Mine open pit and mineral processing operations, and west of Green Valley.

The PDSTI is one of several tailing impoundments associated with mines in the Pima mining district. Immediately north of the PDSTI is the inactive Twin Buttes Mine. The Pima mining district had sporadic mining activity starting in the late 1800s, but large-scale development of the copper and molybdenum deposits using modern mining methods did not begin until the 1950s.

In the 1970s, groundwater was found to contain elevated concentrations of sulfate in the vicinity of PDSTI and other mines in the Pima mining district (Pima Association of Governments (PAG), 1983a and 1983b). The origin of the sulfate was identified as seepage from various tailing impoundments into the underlying aquifers.

Tailing impoundments contain the finely milled rock resulting from the liberation of ore minerals at the mines. Tailing are deposited as a slurry containing a high percentage of water. As the solids settle out of the slurry to form the impoundment, tailing water collects in ponds on top of the tailing. Although much of the water contained in tailing evaporates or is reclaimed by pumping it to the mine for reuse, some portion of the water infiltrates the subsurface below the impoundments and mixes with the ambient groundwater flow system. The sulfate concentration of the seepage depends on the original sulfate concentration in the slurry, any concentration by evaporation or dilution by admixture with precipitation or other waters added to the impoundment, and any sulfate produced by oxidation of residual sulfides in the tailing. The sulfate concentration in groundwater flowing in the vicinity of the tailing impoundment depends on the relative volumes and concentrations of sulfate in the tailing seepage and the groundwater into which it mixes.

The MO sets an average sulfate concentration of 250 mg/L for drinking water supplies. As illustrated in Figure 3, groundwater sampling conducted in the Green Valley area has identified a groundwater plume with sulfate concentrations in excess of 250 mg/L based on data available as of April 2006. The zone of elevated sulfate extends from the base of the PDSTI northeast to the western edge of Green Valley and north to approximately Duval Mine Road. As discussed in Section 2.5.1.5, the northern-most extent of the plume is inferred based on apparent historic migration rates. In April 2006, concentrations of sulfate in wells near the eastern edge of the tailing impoundment ranged from 100 to 1,750 mg/L. Based on available data between December 2004 and April 2006, concentrations in wells on the west side of Green Valley ranged from approximately 20 to 570 mg/L.

Because sulfate concentrations exceeding 250 mg/L have been detected in two Community Water Company (CWC) drinking water supply wells, ADEQ determined that a drinking water source is being or is about to be rendered unusable without treatment under A.R.S. § 49-286. In June 2006, PDSI and ADEQ entered into the MO to address the sulfate attributable to the PDSTI.

The MO requires PDSI to mitigate an impacted drinking water supply if the supply can be verified as having an average sulfate concentration greater than 250 mg/L as a result of the sulfate plume originating from the PDSTI. As stated in Section II.B.4 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 prior to ingestion.
- Other mutually agreeable mitigation measures.

2.2 Current Sulfate Mitigation Actions

Current PDSI mitigation actions consist of:

- groundwater pumping to control the migration of sulfate-bearing water in the aquifer,
- alternative water supplies, and
- groundwater monitoring.

PDSI has installed and operates groundwater pumping wells along the eastern and southeastern boundaries of the PDSTI to intercept sulfate-bearing groundwater before it can flow eastward and mix with groundwater in the regional flow system. These wells are called the “interceptor wellfield”. Water from this wellfield is pumped for reuse at the mine.

The first eleven interceptor wells (IW-series wells in Figure 3) were installed between 1978 and 1984. Since 1984 the wellfield has been expanded by the installation of new wells and replacement of damaged wells. In April 2006, the interceptor wellfield pumped approximately 5,550 gallons per minute (gpm) from 23 wells that are designed to be pumped continuously. Since 2002, PDSI has expanded the capacity of the interceptor wellfield through a program of well rehabilitation, well replacement, and infrastructure improvements. The current wellfield pumping rate is approximately 24 percent greater than the 2002 average annual extraction rate of 4,485 gpm.

PDSI is working with CWC to develop both an interim and permanent alternative water supply for the two CWC wells showing elevated sulfate. In June 2005, CWC suspended use of drinking water supply wells CW-7 and CW-8 (Figure 3) due to sulfate concentrations. As an interim alternative drinking water supply, PDSI is providing CWC with water from three PDSI wells known as ESP-1, ESP-2, and ESP-3. PDSI is working with CWC to develop a permanent replacement drinking water supply consisting of two new wells, CW-10 and CW-11 (previously known as AN-1). Because these two new wells contained elevated levels of arsenic attributable to natural background conditions, PDSI has agreed to provide arsenic treatment systems to meet drinking water standards at the wells.

Monitoring well installation, water level monitoring, and groundwater sampling are conducted by PDSI to track the amount and extent of sulfate concentrations in groundwater and to evaluate the performance of the interceptor wellfield. Since December 2003, PDSI has installed 10 monitoring wells (MH-13 A, B, C; MH-25 A, B, C/D; MH-26 A, B, C; and MH-30 on Figure 3) to further characterize the sulfate plume. The environmental monitoring and sampling data provide critical information on the nature and extent of sulfate and the dynamics of the groundwater flow system.

2.3 Geologic Setting

This section provides an overview of the geology in the vicinity of the PDSTI. A more detailed description of the geologic units, with reference to characteristics reported in geologic logs for area borings, is provided in Appendix A. Appendix A also contains geologic cross sections through the area of the plume, illustrating the distribution of subsurface materials and other features such as the depth of bedrock and well construction. Geologic data have been drawn from a variety of sources including U.S. Geological Survey publications; reports on various geologic, water supply, and environmental investigations; and a review of geologic logs for area wells.

The PDSTI is in the southern portion of the Tucson basin (Figure 4). The southern portion of the basin is bounded by the Sierrita Mountains on the west and the Santa Rita Mountains to the east, with the axis of the basin lying approximately along the Santa Cruz River. The mountains are composed of bedrock materials, and the basin consists of clastic sediments with some interbedded volcanic rocks. The basin fill deposits are thickest in the center of the basin and thin towards the basin margins.

The geologic units in the PDSTI area can be divided into three generalized units: Recent alluvium, Quaternary and Tertiary basin fill deposits, and the bedrock complex. As discussed in Section 2.4, Recent alluvium is not a significant aquifer because it is typically unsaturated.

Basin fill materials form the primary water supply aquifer in the area. Bedrock is typically a low permeability material that is not a significant aquifer.

Figure 5 is a generalized geologic map taken from Davidson (1973), who characterized the lithology and formations of the basin fill throughout the Tucson basin. Detailed geologic maps of the Sierrita Mountains and Santa Rita Mountains are provided by Cooper (1973) and Drewes (1971a, 1971b), respectively. General descriptions of the geologic units in the vicinity of the sulfate plume are provided in Sections 2.3.1 through 2.3.3.

2.3.1 Recent Alluvium

Recent alluvium consists of the unconsolidated sediment in stream channels of the Santa Cruz River and the various washes that feed into the Santa Cruz River from the surrounding uplands, alluvial fans, and sheet wash deposits (Anderson, 1987). The alluvium is up to approximately 200 feet thick in the vicinity of the Santa Cruz River and includes coarse grained sediments in the stream channel and clayey to sandy overbank deposits on the flood plain of the river (PAG, 1983a). The alluvium is thin in washes tributary to, but distant from, the Santa Cruz River. Geologic logs for monitoring wells completed in stream channel deposits six or more miles west of the Santa Cruz River indicate the alluvium ranges from zero to several tens of feet thick (Errol L. Montgomery & Associates (ELMA), 2001).

2.3.2 Basin Fill Deposits

The Quaternary-Tertiary basin fill is composed of interbedded sequences of sand, gravel, silt, and clay. The basin fill is an important unit because it is the principal aquifer of the region and because it contains the sulfate plume. Sand and gravel are the primary components of the basin fill and dominate the lower portion of the sequence near the PDSTI. Coarse, cobbly horizons and caliche-cemented zones are sometimes present over large areas. Volcanic flows and tuffs occur in the mid-Tertiary portions of the basin fill.

Davidson (1973) differentiated basin fill deposits into three units: the Pleistocene Fort Lowell Formation, the Miocene Tinaja beds, and the Oligocene Pantano Formation. Although Davidson (1973) and Schmidt (PAG, 1983b) projected these units into the Green Valley area, the basin fill is typically undivided in drill logs and other geologic descriptions of the Green Valley area. An exception is the Pantano Formation which is sometimes identified in geologic logs and area descriptions in the Green Valley area (e.g., Errol L. Montgomery & Associates and Dames and Moore (ELMA & DM), 1994; ELMA, 2001).

2.3.2.1 Fort Lowell Formation

The Fort Lowell Formation is composed of locally-derived sediment and is generally coarser grained than the underlying Tinaja beds. The Fort Lowell Formation is coarser at the basin margins and finer toward the center of the basin. The Fort Lowell Formation typically contains 25 to 60 percent material that is coarser than sand; is loosely consolidated to weakly cemented and light brown, gray brown or reddish brown in color; and commonly contains clasts of volcanic rocks in the vicinity of the Sierrita Mountains (Davidson, 1973). The Fort Lowell Formation is estimated to be 200 feet thick in the vicinity of the Twin Buttes Mine tailing impoundments and over 200 feet thick at the south end of the PDSTI (PAG, 1983b).

2.3.2.2 Tinaja Beds

The Tinaja beds are sandy gravels with interbedded conglomerate and sandstone near the margins of the basin, grading to gypsifeous clayey silt and mudstone in the center of the basin. Felsic to mafic volcanic interbeds are locally present. Interpreted as sedimentary detritus filling the basin during subsidence (Davidson, 1973), the Tinaja beds lie unconformably over the Pantano Formation and are overlain unconformably by Fort Lowell Formation. The lower stratigraphic portion of the Tinaja beds outcrop south of Tinaja Wash in the Sierrita Mountains approximately two miles southwest of the PDSTI. There, the Tinaja beds consist of tuffaceous gravel underlain by felsic flows and tuffs with interbedded conglomerate and gravel. Although shown separately, Davidson (1973) and Anderson (1987) consider the mid-Tertiary volcanics shown on the geologic map (Figure 5) to be part of the Tinaja beds.

In the vicinity of the PDSTI, the Tinaja beds are composed largely of sand and gravel due to the close proximity to the basin margin. Also, the clay and evaporate-rich sequence of the Tinaja is absent in this area. Gravel and sand facies occur near the basin margins with 20 to 50 percent of material being coarser than sand in the gravel facies and 5 to 20 percent of material being coarser than sand in the sand facies. Volcanic clasts compose 50 percent or more of the coarse material.

As interpreted by PAG (1983a), the Tinaja beds west of the Santa Cruz River have a maximum thickness of about 300 feet, whereas the thickness of the beds on the east side of the river is about 1200 feet due to faulting. The Tinaja beds are interpreted to be about 125 feet thick east of the Twin Buttes Mine tailing impoundment and 200 feet thick at the southern end of the PDSTI (PAG, 1983b).

2.3.2.3 Pantano Formation

The Oligocene Pantano Formation is a reddish brown, weakly to moderately consolidated sequence described as silty sandy conglomerate, silty and pebbly sandstones, and moderately well cemented gravel. It is composed of granitic, sedimentary and volcanic clasts in an arkosic to clay-rich, sandy matrix and is weakly to strongly cemented by calcium carbonate. The Pantano Formation averages about 50 percent sand and gravel, but ranges from a low of 30 percent to a high of 70 percent sand and gravel (Davidson, 1973). Interbedded volcanic flows are locally present in the sedimentary sequence.

The Pantano Formation is correlative with the Helmet Fanglomerate, which outcrops northwest of the Twin Buttes Mine (Figure 5). The Pantano Formation is believed to be very thin or nonexistent in the vicinity of the Twin Buttes Mine and PDSTI based on drilling at the interceptor wellfield and elsewhere (Montgomery Watson, and Errol L. Montgomery and Associates, 1998, Barter & Kelly 1982, and ELMA 1986, 1989, 1991, 1995, and 2004a). This interpretation was used to develop the geologic cross sections described in Appendix A.

2.3.3 Bedrock Complex

In the PDSTI area, bedrock comprises upper Cretaceous Demetrie Volcanics, lower Cretaceous Angelica Arkose, and Paleozoic limestones. At the Twin Buttes Mine, subsurface bedrock units include Paleozoic and Mesozoic sediments, early Tertiary intrusives, and Precambrian granite (Cooper, 1973, Barter and Kelly, 1982). The bedrock units are generally low permeability, highly indurated materials. An exception to this general condition is a portion of the Demetrie Volcanics underlying the southeast corner of the PDSTI where many of the wells in the south half of the interceptor wellfield intersect, and produce water from, the upper portion of the Demetrie Volcanics. Appendix A discusses the Demetrie Volcanics and other bedrock units in greater detail.

2.4 Groundwater Hydrology

The hydrology of the PDSTI area and Green Valley is discussed by Davidson (1973), PAG (1983a and 1983b), ELMA & DM (1994), and ELMA (2001).

2.4.1 Hydrostratigraphic Units

Groundwater occurs in three hydrostratigraphic units: Recent alluvium, basin fill, and bedrock complex.

2.4.1.1 Recent Alluvium

The Recent alluvium is typically unsaturated. Alluvium along the Santa Cruz River receives recharge from ephemeral surface water flow. Although there may be local perched zones associated with surface water recharge, zones of extensive saturation in the alluvium have not been reported. Monitoring at wells in alluvium filling ephemeral stream channels west of the PDSTI indicates the alluvium is typically unsaturated, although saturated zones up to five feet thick are observed in some wells (ELMA, 2001). The alluvium is not a significant source of water to area wells.

2.4.1.2 Basin Fill

The principal aquifer in the area is hosted by the basin fill. As used in this work plan, the basin fill is considered to be equivalent to the Fort Lowell Formation, Tinaja beds, and Pantano Formation as defined by Davidson (1973). The basin fill is the primary source of water to large production wells in the area due to its large saturated thickness and relatively high permeability.

The saturated thickness of the basin fill in the vicinity of the PDSTI increases from zero at the basin margins, where the water table is in the underlying bedrock, to 600 to 1,000 feet in the more central part of the basin near Green Valley (see water levels posted on cross sections in Appendices A and D). Greater saturated thicknesses probably occur east of Green Valley as the bedrock elevation continues to decline (ELMA & DM, 1994).

Davidson (1973) reports hydraulic conductivities in the general range of 20 to 93 feet per day (ft/day) for Fort Lowell Formation, 1.3 to 54 ft/day for the Tinaja beds, and 0.7 to 13 ft/day for Pantano Formation. Most hydraulic conductivity estimates in the area of the PDSTI are based on wells with screened intervals extending over the entire basin fill thickness. Thus, the estimates represent an average hydraulic conductivity over the thickness of the various basin fill units penetrated by the wells.

2.4.1.3 Bedrock Complex

The bedrock complex is the informal name given to the highly indurated igneous and sedimentary rocks that underlie the basin fill. The permeability of the bedrock complex is mainly fracture controlled and is generally low, with hydraulic conductivities typically less than 0.1 ft/day. The permeability of bedrock materials may be higher where weathered, highly fractured, or interbedded with more permeable strata. For example, the Demetrie Volcanics in the southern part of the interceptor wellfield contain a thick section of permeable bedrock penetrated by many of the pumping wells (Figure A.4a in Appendix A).

2.4.2 Hydraulic Properties

Numerous hydraulic tests have been conducted at wells and borings that penetrate bedrock and basin fill in the vicinity of the PDSTI and within the basin fill to the east and north of the PDSTI. Tests include pumping and slug tests in wells and constant pressure packer tests in bedrock borings. Table 1 summarizes the available hydraulic conductivity test results. Appendix B lists available hydraulic conductivity data.

Based on the data in Table 1, hydraulic conductivity estimates for different bedrock materials range from approximately 0.000007 ft/day to 2.2 ft/day and have geometric means between 0.0047 and 0.12 ft/day. Hydraulic conductivity estimates of the basin fill range from approximately 6.3 ft/day to 100 ft/day in the vicinity of the interceptor wellfield at the downgradient edge of the PDSTI (Appendix B). Between the PDSTI and the more central portions of the basin, hydraulic conductivity estimates range from approximately 4.8 ft/day to 99 ft/day (Appendix B). Estimates from deep production wells screened over large thicknesses of basin fill may be affected by their penetration of deeper, lower permeability materials such as moderately indurated portions of the Pantano Formation. Spinner logging of some of the existing production wells and hydraulic testing of recently installed well nests indicate that the hydraulic conductivity of the basin fill sometimes varies substantially with depth.

Spinner logging conducted in the vicinity of the interceptor wellfield at IW-4, IW-5, IW-9, and IW-12 (ELMA, 2006) indicates the shallow portion of the basin fill aquifer is more productive than the deeper portions, which include Demetrie Volcanics at IW-4, IW-5, and IW-9 in the southern portion of the wellfield and Pantano Formation at IW-12 (Figures A.4a and A.4b in Appendix A). Spinner logging of ESP-4 (ELMA, 2004b), located near the center of the basin, indicates a highly productive zone in the lower portion of the basin fill, approximately 300 to 480 feet below the water table, that is more than twice as productive as either the 300-foot interval above or the 170-foot interval below.

Figure A.5 in Appendix A is a cross-section showing the distribution of hydraulic conductivities in recently installed well nests MH-13, MH-25, and MH-26 east of the interceptor wellfield (Appendix B). Pumping test results at MH-13 indicate that the hydraulic conductivity of basin fill at shallow and intermediate depths ranges from 13.4 to 17.4 ft/d. These hydraulic conductivities are nearly three orders of magnitude higher than the hydraulic conductivity of 0.023 ft/d measured in the deeper basin fill at MH-13. The deeper basin fill at MH-13 is interpreted to be Pantano Formation equivalent. In contrast to the observations at MH-13, testing at the recently installed MH-25 and MH-26 well nests does not show a significant variation in basin fill hydraulic conductivity with depth (Appendix B). Hydraulic conductivities for the shallow, intermediate, and deep screens in basin fill at MH-25 and MH-26 ranged from 41.4 to 54 ft/d and 41.4 to 65.5 ft/d respectively. The Angelica Arkose bedrock at MH-25 has a hydraulic conductivity of 0.067 ft/d, almost three orders of magnitude lower than the overlying basin fill. Based on these data, there is an apparent increase in hydraulic conductivity from MH-13 in the south to MH-25 and MH-26 in the north. Pumping test results at MH-13, MH-25, and MH-26 also indicate the basin fill is anisotropic with estimates of the ratio of horizontal to vertical hydraulic conductivity ranging from 20 to 435.

2.4.3 Potentiometric Relationships

Regionally, groundwater flow in the southern portion of the Tucson basin is generally to the north, roughly in the direction of flow in the ephemeral Santa Cruz River. Sources of water to the basin include surface water recharge of ephemeral streamflow related to precipitation events, underflow from bedrock bounding the basin on the east and west, and recharge from surface impoundments and irrigation projects. Figure 4 illustrates regional potentiometric relationships in the area using Arizona Department of Water Resources (ADWR) water level data for 1994.

Data presented in ELMA (2001) indicate that the hydraulic gradient within the bedrock complex west of the PDSTI is typically eastward, roughly in the direction of the dip of the topographic surface. The eastward flow in the bedrock complex indicates that it is a source of recharge to the basin fill. ELMA (2001) indicates that the potentiometric surface passes continuously from the bedrock to the basin fill beneath the PDSTI. The hydraulic gradient within the basin fill beneath the PDSTI is also primarily eastward, indicating easterly groundwater flow.

East of the PDSTI, the hydraulic gradient changes from primarily eastward, to northeastward, then to primarily northward near the center of the basin. The northward gradient near the center of the basin is generally in the direction of flow of the ephemeral Santa Cruz River. Consequently, the direction of groundwater flow also changes from eastward beneath the tailing impoundment to northward near the center of the basin. These relationships are illustrated in Figure 6, which is a contour map showing recent water levels in the basin fill aquifer.

Based on the data shown in Figure 6, hydraulic gradients immediately downgradient of the PDSTI range from approximately 0.0063 ft/ft to 0.0240 ft/ft in a northeasterly direction. Near the center of the basin (near Highway I-19), hydraulic gradients range from approximately 0.0068 ft/ft to 0.0180 ft/ft in a northerly direction. Hydraulic gradients in the vicinity of active production wells can be strongly affected by groundwater pumping.

Vertical hydraulic gradients, which can result in a vertical component of groundwater flow, are known to exist within the basin fill aquifer based on water level measurements in well nests and on spinner logging of wells in the basin fill aquifer. Vertical hydraulic gradients within the basin fill can be either upward, downward, or negligible depending on pumping conditions, recharge, and the presence of any low permeability semi-confined horizons that may exist. Both upward and downward hydraulic gradients are indicated by vertical flow measurements at the interceptor wellfield. For example, during spinner logging tests under non-pumping conditions, upward flow, indicating an upward hydraulic gradient, was measured in portions of IW-9 and

IW-12; whereas downward flow, indicating a downward hydraulic gradient, was measured in portions of IW-4 and IW-5 (ELMA, 2006). There were also sections of IW-4, IW-5, IW-9, and IW-12 that had no detectable vertical flow indicated a negligible vertical hydraulic gradient. Measured vertical flows were low, typically less than 10 gpm, and ranged from approximately 0.5 to 15 gpm.

Water levels in the basin vary with time based on the relative strength of recharge sources (such as precipitation and infiltration of surface water runoff) and sinks (such as groundwater pumping). Figure 7 shows water elevation hydrographs of wells MH-11, MH-12, and MH-13 from 1985 through early 2006. Over that period, water levels rose through the late 1980s, declined in the early 1990s, rose again in 1993, and have apparently declined since then. The increases in water levels at the beginning of the record, and after 1993, were most likely related to increased precipitation and recharge during 1983 and 1993. The water levels in MH-11, MH-12, and MH-13 are now approximately 20 feet lower than they were in 1985.

2.4.4 Groundwater Flow

Apparent groundwater flow velocities were estimated using available hydraulic property estimates, an effective porosity of 0.25, and recent water level data (Figure 6). The pore velocity, which is equivalent to the rate of movement of a conservative solute, ranges from approximately 171 ft/yr to 653 ft/yr at the eastern edge of the tailing impoundment, and from approximately 197 ft/yr (between S-1 and GV-1) to 657 ft/yr (between ESP-4 and ESP-3) in the more central portion of the basin. The range of calculated pore velocities is due to the variation of the estimated hydraulic gradient and hydraulic conductivity between different locations.

2.5 Water Quality

This water quality review discusses sulfate concentrations in the vicinity of the PDSTI and reviews the chemistry of sulfate-bearing groundwater in the context of overall groundwater quality in the area. This section begins by examining the spatial and temporal distribution of sulfate in groundwater, using both historical and recent data. Next, the general water quality in the area is discussed, focusing on cation-anion composition. Finally, the data are examined for metals that may be associated with sulfate-bearing groundwater.

The water quality data presented by this review are primarily from the groundwater monitoring conducted by PDSI. The data for wells in the vicinity of the PDSTI were compiled through April 2006 and evaluated to develop maps, graphs, and tables for this section. Water quality data for the CW- and ESP-series wells were provided by CWC. Pima County Wastewater also provided data for monitoring wells north of the sewage disposal ponds (SDP), GV-1 (SDP) and GV-2 (SDP), at the Green Valley Wastewater Treatment Facility. Tables 2 through 5 and Appendix C contain the basic water quality data used for this section. When plotting results for duplicate samples, the highest concentration was used.

PDSI has water quality data for samples collected and analyzed from the late 1970s to the present. To portray current conditions, the most recent (through April 2006) sampling results were used. However, because some wells are not currently monitored, in some instances the data presented are several years old. For this reason, concentrations depicted on maps are accompanied by their sampling date so that the reader is aware that the information may be dated. Because water quality conditions can change over time, observations made using the older data are considered preliminary and require verification by additional sampling. Water quality data presented for well nests MH-13, MH-25, and MH-26, and well MH-30 are considered preliminary because the results are for the initial samples collected from these wells.

2.5.1 Sulfate Distribution

Groundwater containing elevated sulfate concentrations has been documented in the Green Valley area for many years. Early studies (PAG, 1983a and 1983b) identified elevated sulfate concentrations associated with the Sierrita, Twin Buttes, and Mission-Pima mines. Groundwater monitoring activities conducted since that time provide additional information concerning the spatial and temporal distribution of sulfate in the area.

The distribution of sulfate, based on the most recent samples from monitoring and production wells through April 2006 in the area east of the PDSTI, is shown in Figure 8. Table 2 lists the sulfate concentration data used for Figure 8. Numbers posted next to the well identification include the sulfate concentration (in mg/L) and the month and year of sample collection. Sulfate isoconcentration contours (isocons), inferred on the basis of the posted data, are shown and provide an interpretation of the limits of the sulfate plume based on existing data.

The majority of the data in Figure 8 is for samples collected from wells with large screened intervals. Concentration data for wells with short screened intervals, such as the well nests at MH-13, MH-25, and MH-26, are also shown. Data from short-screened interval wells are not necessarily comparable to data from wells with longer screen lengths because they have a dissimilar depth averaging of concentrations. Both data types are depicted in Figure 8 for completeness of areal coverage. The isocons in the vicinity of the nested wells were based on the highest measured concentration at the well nest.

2.5.1.1 Spatial Distribution of Sulfate

The spatial distribution of the sulfate plume is defined by groundwater samples collected from monitoring and production wells in the vicinity of the PDSTI and Green Valley. The spatial distribution can be divided into three components: lateral, longitudinal, and vertical. These relative directions are based on the general direction of groundwater movement in the area (Section 2.4.3). Longitudinal distribution is defined as being the north-northeasterly direction since it is the ultimate direction of groundwater movement from beneath the PDSTI. Lateral distribution is defined in the west-northwest to east-southeast direction representing the “sides” of the plume. Vertical distribution is based on data from co-located wells completed at different depths and depth-specific samples recovered from wells with long screen intervals.

2.5.1.2 Lateral Distribution

Data from 2005 and 2006 indicate that the east-southeast edge of the plume is west of wells GV-1, GV-2, and CW-3 and that the east-northeast edge of the plume is west of wells ESP-2 and ESP-3 and in the vicinity of ESP-1 and ESP-4. Data from 2004 for well CW-8 indicate the plume boundary was east of this location at that time.

The lateral extent of the plume to the west is defined by the IW- and MH-series wells in the interceptor wellfield. West of the interceptor wellfield the basin fill thins and the water table transitions into the bedrock complex. The extent of sulfate in basin fill west of MH-25 and MH-26 is not well defined due to the lack of monitoring wells north of the east edge of the PDSTI.

2.5.1.3 Longitudinal Distribution

The longitudinal distribution of sulfate to the south-southwest and north-northeast is shown in Figure 8. The eastern limit of the plume at its southern extent is defined by IW-2. Sulfate concentrations of samples collected from IW-2 dropped below 250 mg/L in late 2004 and have remained so since then.

The north-northeasterly extent of the plume is defined by wells CW-7 and the MH-26 well nest. CW-7 is the northern-most well with a sulfate concentration greater than 250 mg/L. The sulfate concentration in CW-7 was measured as 371 mg/L and 570 mg/L in samples reported by CWC and PDSI, respectively, for December 13, 2004 (Tables 2 and 3). Sulfate concentrations at the MH-26 well nest ranged from 20 mg/L to 1,570 mg/L in January 2006 (Figure D.5 in Appendix D). East of CW-7, the sulfate concentration in CW-9 was 60 mg/L in 2004. North of CW-7, the M- and ST-series wells had sulfate concentrations less than 100 mg/L when sampled in late 2003 (M wells) and early 2004 (ST wells). The only data available on sulfate northwest of CW-7 and the MH-26 well nest are for the I-series wells installed east of the Twin Buttes Mine pit for dewatering purposes (Terra Matrix, 1998). Sulfate concentrations ranged from 650 mg/L to 780 mg/L in samples collected from the I-series wells between 1999 and 2002. The lack of current information on water quality and water levels for the M- and I-series wells limits their use with respect to defining the northern extent of sulfate.

2.5.1.4 Vertical Distribution

The vertical distribution of sulfate in the basin fill is known from sampling at co-located well nests with screens completed at different elevations and depth-specific sampling from wells with long screened intervals. However, most monitoring and production wells do not provide depth-specific data because they were constructed with long screen intervals, typically penetrating the full extent of the basin fill aquifer. Because sampling from these wells is typically conducted from pump discharge that draws groundwater from the entire screened interval and mixes it in proportion to the proximity to the pump intake and hydraulic conductivity of the formation at any given depth, variations in concentration with depth are indistinguishable using this sampling protocol.

Well nests at MH-13, MH-25, and MH-26 were constructed as multiple wells at a single location or as wells containing separate screened intervals that can be isolated during sampling to allow collection of depth-specific information. Depth-specific samplers have also been used during spinner logging to evaluate changes in sulfate concentration with depth in some production wells.

Appendix D contains cross-sections through the plume showing sulfate concentrations to illustrate depth relationships for sulfate. At well nests MH-13, MH-25, and MH-26 sulfate concentrations greater than 250 mg/L persist to significant depths in the basin fill, although concentrations exhibit some variation with depth. At MH-13 the sulfate concentration decreases with depth, with sulfate concentrations of 1,750 mg/L, 970 mg/L, and 320 mg/L in samples collected from the upper (320-650 feet below land surface (bls)), middle (750-950 feet bls), and lower (1,050-1,350 feet bls) screened intervals in the basin fill, respectively (Figures D.3 and D.7 in Appendix D). At MH-25 and MH-26 sulfate concentrations in recent samples are less than 10 mg/L and 20 mg/L, respectively, at the top (above 538 feet bls) of the basin fill aquifer. Sulfate concentrations in basin fill at MH-25 increase to 1,640 mg/L and 1,410 mg/L at 580 to 680 feet bls in MH-25B and 731 to 901 feet bls in MH-25C, respectively. MH-25D, which is screened in Angelica Arkose from 951 to 1,081 feet bls, had a sulfate concentration of 600 mg/L, or approximately 43 percent of the concentration in overlying basin fill. In basin fill at MH-26, a sulfate concentration of 1,570 mg/L occurs at 620 to 730 feet bls in MH-26B (Figures D.3 and D.5 in Appendix D). MH-26C, which has 90 feet of screen in Angelica Arkose and 30 feet of screen in basin fill, had a sulfate concentration of 730 mg/L, or approximately 50 percent of the concentration in overlying basin fill

Three of the interceptor wells (IW-4, IW-9, and IW-12) were subjected to depth-specific sampling (ELMA, 2006). IW-12 is located in the northern half of the interceptor wellfield, whereas IW-4 and IW-9 are in the southern half. Sulfate concentrations in IW-12 declined from 1,060 mg/L at 510 feet bls to 900 mg/L at 557 feet bls. IW-4 sulfate concentrations increased from 1,460 mg/L at 517 feet bls to 1,560 mg/L at 888 feet bls. Sulfate concentrations in IW-9 ranged from 1,360 to 1,460 mg/L between 445 to 800 feet bls.

Depth-specific sampling was also conducted at ESP-4 (ELMA, 2004b). Samples from the static water level at approximately 336 feet bls to a depth of at least 550 feet bls were below 100 mg/L. At a depth of 785 feet bls the sulfate concentration was approximately 150 mg/L. Sulfate concentrations increased to 230 to 240 mg/L at depths of 880 and 975 feet bls, respectively. These findings suggest that the leading edge of the 250 mg/L concentrations on the east side of plume may be in deep, rather than near-surface groundwater zones.

The sulfate concentration of groundwater in bedrock downgradient of the PDSTI is not well defined. With the exception of MH-25D, no wells in the vicinity of the sulfate plume are screened exclusively in the bedrock and isolated from the basin fill aquifer. Production wells typically do not penetrate the bedrock because of its depth and low permeability. Those wells that are screened across or in very close proximity to the bedrock-basin fill contact may not provide reliable data on sulfate concentrations in the bedrock due to possible leakage from the overlying basin fill during pumping. Even if the bedrock contained elevated sulfate concentrations as suggested by sampling at MH-25D, the potential for significant mass loading from the bedrock to the basin fill can be expected to be low due to the low hydraulic conductivity of bedrock. The potential for exposure to sulfate in bedrock groundwater is probably low because water supply wells are typically not completed in bedrock as its low permeability makes it a poor water supply.

2.5.1.5 Temporal Distribution of Sulfate

Figure 9, from PAG (1983b), shows the distribution of sulfate at the PDSTI in 1982. Well identifiers on Figure 9 have been added to aid review. A comparison of the present distribution of sulfate (Figure 8) with the distribution in 1982 shows that the plume has advanced primarily north-northeastward. Lateral spreading to the east is also suggested by the increased concentrations in wells ESP-1 and ESP-4. The direction of plume migration is consistent with that indicated by water level contours shown on Figure 6.

The apparent rate of northerly plume migration can be estimated by the change in position of the 250 mg/L isocons from 1982 to 2006. The concentrations of sulfate at MH-1 and MH-12 straddle and define the location of the 250 mg/L isocon as being just north of MH-12 in May 1982 (Figure 9). Presently, the 250 mg/L isocon is north of CW-7 (Figure 8). The concentration of sulfate in CW-7 rose above 250 mg/L in January 1999 (Table 3). The travel time from May 1982 to January 1999 was approximately 6,090 days and the distance between the wells is approximately 9,900 feet, yielding an apparent velocity of approximately 590 feet per year. At that rate of northerly movement, the 250 mg/L isocon may have moved approximately 4,400 feet to the north since January 1999. This projection is only approximate, however, because the current migration rate may vary from the historical rate due to changes in aquifer conditions and groundwater pumping. Plume movement to the east is slower than to the north because the direction of groundwater flow is northerly.

The distribution of sulfate concentrations also changed over time. In 1982, concentrations greater than 1,000 mg/L were localized in the central portion of the plume (Figure 9). At present, concentrations exceeding 1,000 mg/L extend throughout most of the plume area, and concentrations exceeding 1,500 mg/L occur as far north as MH-26 (Figure 8).

Hydrographs of sulfate concentrations from the northern half (Figure 10) and southern half (Figure 11) of the interceptor wellfield show that sulfate concentrations in most wells increased steadily between 1980 and 2004 (Table C.3, Appendix C). However, sulfate concentrations, especially in the southern half, have been declining since early 2004, possibly in response to more aggressive pumping in the interceptor wellfield or changes in tailing seepage rates. In contrast to most of the IW wells, IW-1 and IW-2, located along the southern margin of the PDSTI, experienced consistent declines in sulfate concentrations from 1980 to 1990, flat to increasing sulfate concentrations from 1990 to 1998, and flat to declining sulfate concentrations from 1998 to present. The fastest declines in sulfate concentration at IW-1 and IW-2 have occurred since early 2004, again suggesting a response to more aggressive pumping at the interceptor wellfield.

2.5.2 Major Element Chemistry

The composition of groundwater can be characterized in terms of its major cations and anions and their relative concentrations, as well as other general water quality parameters such as total dissolved solids (TDS), hardness, and pH. Proximity to the PDSTI was used to evaluate major element concentration trends in water quality data. Wells within the sulfate plume were differentiated into groups regarded as proximal, medial, or distal to the PSDTI. Wells outside of the plume were identified as upgradient or downgradient from the sulfate plume (Figure 8). This division allows evaluation of changes in water chemistry as groundwater flows away from the tailing impoundment (proximal to distal) and commingles with the groundwater flowing northward beneath Green Valley. Selected wells were identified to characterize these regions. Wells selected for the groupings are:

- **Proximal Wells:** IW-1, IW-2, IW-3, IW-3a, IW-4, IW-5, IW-6a, IW-8, IW-9, IW-10, IW-11, IW-12, IW-13, IW-14, IW-15, IW-16, IW-17, IW-18, IW-19, IW-20, IW-21, IW-22, IW-23, and IW-24;
- **Medial Wells:** MH-11, MH-12, and MH-13;
- **Distal Wells:** ESP-1, ESP-4, CW-7, and CW-8;
- **Upgradient Wells:** GV-1, GV-2, S-1, and S-2; and
- **Downgradient Wells:** ESP-2 and ESP-3.

Table 4 summarizes the most recent analytical results for cations, anions, TDS, hardness, and pH compiled and tabulated with respect to their relationship to the impoundment. Data used to compile this table are presented as Table C.1 in Appendix C.

The summary data in Table 4 indicate that sulfate, chloride, calcium, magnesium, TDS, and hardness show a strong correlation with proximity to the tailing impoundment. In general, major element ion concentrations are greater in groundwater with elevated sulfate concentrations. The maximum and mean concentrations of major element ions decline moving from proximal to distal wells, although the concentration differences between the proximal and medial wells is sometimes slight. Chlorides, TDS, and hardness (a measure of the calcium and magnesium in water) are also correlated with sulfate and their levels are elevated in the sulfate plume.

The pH of the well samples does not show a strong correlation to sulfate. The average pH in the proximal wells is 7.24 and decreases to 7.12 in the medial wells and 7.13 in the distal wells. This indicates that the sulfate-bearing groundwater has neutral pH. The pHs of upgradient and downgradient wells are 7.46 and 7.75, respectively, perhaps reflecting the influence of recharge along the Santa Cruz River.

Concentration data for recent samples from selected wells (Table C.1 in Appendix C) were converted to "milliequivalents" and used to construct trilinear diagrams that plot the combination of cations and anions in a single field (Figure 12). The plotted points demonstrate that waters from the various wells follow a distinctive trend. Proximal and medial wells within the plume contain calcium-sulfate water, whereas the upgradient and downgradient wells outside of the impacted area contain calcium-bicarbonate water. In general, distal wells have cation-anion combinations that fall between the combinations at proximal and medial wells, and unimpacted wells. An exception to the proximal wells is IW-2, a proximal well, which plots in the vicinity of upgradient and downgradient wells due to the effects of dilution by upgradient water from pumping in the interceptor wellfield, as noted in Section 2.5.1.5.

As shown by Figure 12, most well water chemistries fall along a line between wells within and outside of the plume. This suggests that a continuum of mixing exists between the two end-member waters. This is logical considering that (1) the sulfate-impacted water mixes with unimpacted groundwater from upgradient areas, (2) the process water seeping from the tailing impoundment is derived from unimpacted groundwater from the upgradient Canoa wellfield along the Santa Cruz River south of Green Valley, and (3) impacted water from the interceptor wellfield is re-used in the mill.

2.5.3 Metals

Metals analyses for samples from wells in the interceptor wellfield (proximal wells) (Table C.2, Appendix C) were compiled and evaluated to characterize metals from the PDSTI. The data were compared with Arizona numeric Aquifer Water Quality Standards (AWQS)

(A.A.C. R18-11-405) to characterize the relative magnitude of metals concentrations. The metals with AWQS include:

Metal	**AWQS (mg/L)**
Antimony	0.006
Arsenic	0.05
Barium	2
Beryllium	0.004
Cadmium	0.005
Chromium	0.1
Lead	0.05
Mercury	0.002
Nickel	0.1
Selenium	0.05
Thallium	0.002

The U.S. Environmental Protection Agency has established a maximum contaminant level (MCL) for arsenic in public drinking water supplies at 0.010 mg/L effective January 2006 and enforceable in 2007. Therefore, arsenic results will be compared with this standard although the applicable AWQS has not been established at this level.

Table 5 summarizes metals data for the interceptor wells (IW-series) for the past ten years (1997 to April 2006). The metals data were reported as dissolved metals because the samples were filtered in the field prior to preserving the sample for transport to the laboratory. Based on the data in Table 5, metals concentrations in groundwater samples from the interceptor wellfield rarely exceed AWQSs. This indicates that the tailing impoundment is not a source of metals to the groundwater.

Chromium, lead, nickel, and thallium were detected in concentrations exceeding their respective AWQS in 1 percent or fewer of sample analyses. The AWQS for lead (0.05 mg/L) was exceeded in one sample from IW-12 in 1997, but all subsequent samples were below the standard. Nickel and chromium were detected in three samples, and thallium was detected in one sample at concentrations exceeding their respective AWQSs in December 2004, but these results are inconsistent with results from samples collected before and after this sample. Because of the large number of samples (more than 230 samples), low exceedance frequency, and the lack of exceedences in subsequent samples, the few elevated detections of chromium, lead, nickel and thallium are not considered significant and could be the result of laboratory error.

2.6 Preliminary Conceptual Model for the Groundwater Sulfate Plume

The conceptual model describes known and potential sources of sulfate and the movement of sulfate in groundwater at the PDSTI. The conceptual model provides a framework for summarizing what is known about the origin and migration of the sulfate plume and identifying what additional information may be needed to fully characterize it.

2.6.1 Sulfate Sources

Based on groundwater monitoring, a known source of sulfate is seepage from the PDSTI to the underling basin fill aquifer. The seepage results from the gravity drainage of the pore water through the PDSTI. The pore water consists of original slurry water and water that infiltrates into the tailing from the reclaim pond on top of the impoundment.

Sulfate in the tailing water results from the dissolution of sulfate salts and the oxidation of sulfide minerals during the milling and flotation process that produces the tailing, and the use of sulfate-bearing water from the interceptor wellfield in the mill circuit. The tailing slurry water, reclaim pond water, and interceptor wellfield water are chemically similar with respect to sulfate and other major element ion concentrations (ELMA, 1989).

The tailing impoundment represents a finite source of sulfate that will eventually cease following the end of mining and mineral processing, when tailing is no longer deposited and residual moisture drains from the tailing material. The rate of residual seepage will further diminish as the surface of the impoundment is capped and revegetated to minimize infiltration from precipitation.

Groundwater in the bedrock upgradient of the tailing impoundment is a second source of sulfate to the basin fill beneath the impoundment. Groundwater sulfate concentrations in bedrock upgradient of the tailing impoundment are generally in the range of 100 to 3,000 mg/L (ELMA, 2001). However, the contribution of sulfate by bedrock recharge is likely minor compared to the tailing because the low permeability of bedrock (Section 2.4.2) would limit the sulfate mass flux from the upgradient area.

Other potential sources of sulfate may occur outside the PDSTI. As discussed above, PAG studies identified tailing impoundments at other mines as potential sources. Based on historical sampling, groundwater in the vicinity of the Twin Buttes Mine, at the north end of the sulfate plume, may contain sulfate (Section 2.5.1). Another potential source of sulfate is groundwater in the vicinity of the Santa Cruz River. As documented by Laney (1972) and PAG (1983a), groundwater in the vicinity of the Santa Cruz River in this part of the Tucson basin can contain greater than 250 mg/L sulfate (Plate 5 in PAG 1983a). The sulfate is attributed to groundwater derived from gypsiferous sediment east of the Santa Cruz fault, but irrigation return flow may also add TDS.

2.6.2 Movement of Sulfate in Groundwater

Sulfate-containing seepage from the tailing impoundment infiltrates into the basin fill, mixes with groundwater recharge from the upgradient bedrock and flows eastward. Sulfate-impacted groundwater is intercepted through groundwater pumping within the interceptor wellfield. Impacted groundwater that is not intercepted at the wellfield or that has already flowed downgradient of the interceptor wellfield flows north-northeasterly as it enters the northerly flowing regional groundwater system in the basin fill aquifer.

Sulfate is transported at the same rate as the groundwater flow because it is a conservative ion. The direction and velocity of groundwater flow and sulfate transport are determined by the hydraulic properties of the basin fill aquifer and the hydraulic gradients prevailing along the flow path. In addition to regional conditions, groundwater flow and sulfate transport are influenced by local sites of groundwater pumping and recharge. For example, pumping at a well in the vicinity of the plume can induce hydraulic gradients that cause the plume to migrate toward the well. Groundwater pumping in the Green Valley area has increased over time to meet increasing demand for drinking water, as illustrated by the 70% increase in annual groundwater pumping by CWC from 1986 (546.3 million gallons) to 2005 (929.8 million gallons). The collective influence of pumping at drinking water supply wells located near the plume can influence sulfate migration and the location of the plume.

Within the plume, elevated sulfate occurs throughout the thickness of the saturated basin fill aquifer with the exception of the uppermost portions of the aquifer at MH-25, MH-26, and ESP-4 (Section 2.5.1.4). Although existing information indicates some variations in the hydraulic conductivity of the basin fill aquifer with depth (e.g., low permeability Pantano Formation at depth in MH-13 and higher flows at depth in ESP-4), large-scale features that would cause preferential flow paths, such as laterally extensive aquitards or high permeability units within the basin fill, have not been identified. The ACP (Section 3) will further evaluate the vertical variation of hydraulic properties in the basin fill. Based on the results of hydraulic testing of bedrock at MH-25 within the plume and elsewhere in the vicinity of the PDSTI (Section 2.4.2), the bedrock is significantly less permeable than the overlying basin fill aquifer. For this reason, the bedrock aquifer is not considered to have significant groundwater flow or potential to transport sulfate relative to the basin fill aquifer.

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,
- determine the vertical and horizontal extent of the sulfate plume,
- evaluate the fate and transport of the outer edge of the sulfate plume, and
- evaluate the effectiveness of the interceptor wellfield as a groundwater sulfate control system.

3.1.2 Data Needs

Addressing the MO requires the following data:

- locations of drinking water wells within one mile downgradient and cross-gradient 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, and
- information on the operation of the interceptor wellfield, sulfate concentrations in the wellfield, and water levels in the vicinity of the wellfield.

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 assessing 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 consider information on water treatment, current and future water supply and storage infrastructure, and the costs and benefits of mitigation alternatives.

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

- Task 1 – Well Inventory
- Task 2 – Plume Characterization
- Task 3 – Evaluation of PDSI's Sulfate Control System
- Task 4 – Sulfate Fate and Transport Evaluation
- Task 5 – Preparation of the Aquifer Characterization Report

Data needs and the ACP tasks that address them are briefly described below and summarized in Table 6. Sections 3.2 through 3.6 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).

- **Horizontal Extent of Sulfate Plume** – As shown in Figures 3 and 8, the general horizontal extent of the plume is known to within approximately 3,000 to 5,000 feet based on available data. The eastern extent of the plume is bounded by wells GV-1, GV-2, ESP-1, ESP-2, ESP-3, and ESP-4 with concentrations less than 250 mg/L. Additional data is needed along the southeast boundary of the plume where there are no wells or no recent data, such as at CW-3. Few wells are available to define the northern boundary of the plume. Sulfate exceeds 250 mg/L at the MH-26 well nest and CW-7, but was less than 250 mg/L in samples collected from CW-9 in 2004 and the M-series wells in 2003. Recent data are not available for sulfate concentrations in the I-series wells east of the Twin Buttes pit. Task 2 contains groundwater monitoring (Section 3.3.2) and the installation and sampling of additional wells (Section 3.3.4) to further delineate the horizontal extent of the plume.

- **Vertical Distributions of Sulfate** – Ongoing monitoring of nested monitoring wells (MH-13, MH-25, and MH-26) by PDSI will provide information on the vertical distribution of sulfate. Additional monitoring wells will be installed for Task 2 (Section 3.3.4) either as co-located well nests or with multiple screens to characterize the three-dimensional aspects of the plume. Depth-specific water quality sampling in existing wells at the east and north ends of the plume will be conducted for Task 2 (Section 3.3.3) to investigate the vertical distribution of sulfate with depth. Depth-specific sampling will also be conducted at selected monitoring wells where well access is available.

- **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. Routine groundwater monitoring by PDSI will be used to characterize water levels and water quality within the plume. Additional groundwater monitoring will be conducted for Task 2 (Section 3.3.2) to provide water level and water quality information in areas not monitored by PDSI or in areas for which available data are several years old (e.g., wells at the Twin Buttes Mine and some drinking water supply wells). Groundwater monitoring will collect contemporaneous water level and water quality data for a large geographic area outside of the plume. These data are needed to provide information on the regional groundwater flow system for calibration of the groundwater flow model for Task 4 (Section 3.5) 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. Depth-specific flow testing in wells at the east and north ends of the plume will be conducted for Task 2 (Section 3.3.3) to identify any apparent variations in permeability with depth. Aquifer testing to be conducted at monitoring wells installed for Task 2 (Section 3.3.4) will characterize the horizontal and vertical distribution of hydraulic properties.

- **Groundwater Control System Data –** Information regarding water levels in the vicinity of the interceptor wellfield, interceptor wellfield pumping, and sulfate concentrations in extracted groundwater will be compiled and analyzed in Task 3 (Section 3.4) to evaluate flow to the wellfield and wellfield mass capture.

- **Quantification of Groundwater Sources and Sinks –** Groundwater sources (recharge) and sinks (pumping) will be documented for use in the groundwater flow model for Task 4 (Section 3.5). Recharge to the aquifer from the PDSTI, ephemeral flows in the Santa Cruz River, and other sources, such as semi-permanent ponds or the Pima County wastewater treatment facility, 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

A well inventory will be conducted to identify all wells 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 Arizona Department of Water Resources (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, 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 8). The shape file will be used to query the database and identify all wells within one mile of the plume’s downgradient and cross-gradient 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 cross-gradient of the plume, a safety factor will be added to the one-mile search radius to account for the uncertainty in well location due to cadastral coordinates. Because of the safety factor, wells that are farther than one mile from the plume may be identified. 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.

The well inventory records will be sorted by well use and water use to identify wells used to supply drinking water. To augment the well inventory, public and semipublic 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.

The well inventory is an important step in identifying potentially impacted wells. The well inventory will begin shortly after the ACP is finalized and will be conducted initially using the 250 mg/L sulfate contour shown in Figures 8. The well inventory may be revised if the plume defined by the results of characterization work for Task 2 indicate a significantly different shape for the plume.

3.3 Task 2 - Plume Characterization

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 E 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 depth-specific groundwater samples collected from existing production wells and groundwater samples from new and existing monitoring wells.
- Characterize the structure and permeability of the basin fill aquifer through geologic analysis of cuttings from drill holes, aquifer testing, and flow logging of production wells.
- Characterize the groundwater flow system through water level measurements.
- Collect water quality data needed to evaluate water treatment.

The plume characterization includes the following subtasks:

- data compilation and evaluation,
- groundwater monitoring to augment the existing water level and water quality data,
- depth-specific groundwater sampling at existing wells to determine the vertical extent of sulfate and flow logging at existing production wells to evaluate relative well inflows as a function of depth, and
- installation and testing of monitoring wells to define the eastern and northern extents of sulfate.

3.3.1 Task 2.1 - Data Compilation and Evaluation

The data compilation and evaluation will focus on assembling and assessing information on (1) the hydraulic properties of the geologic materials, (2) the subsurface distribution of bedrock, and (3) the water quality of area wells. A secondary objective will be to assemble and evaluate all available geologic logs for wells in the area.

The hydraulic properties of geologic materials are critical information for developing the conceptual and numerical models. The hydraulic conductivity data reported in Table 1 are taken from a variety of reports. As a quality assurance check, the test methods, data, and analysis methods for the tests will be evaluated to assess test reliability. Additional sources of hydraulic data will also be researched.

The depth to bedrock provides important information on the effective thickness of the basin fill aquifer which is needed for construction of the groundwater flow model and estimation of groundwater flow. ELMA & DM (1994) reported bedrock depth in the area of interest using compilations of geologic data. These data will be evaluated and compared to bedrock elevations from borings. Information for any exploration borings in the area will be obtained from the PDSI mine department to further check the bedrock elevation data. Additionally, geophysical data for the area will be reviewed for information on bedrock depth.

Limited water quality data are available for water supply and irrigation wells in the area, and although water quality sampling of these wells is proposed for Task 2.2 (Section 3.3.2), historical water quality data are lacking. The owners of water supply and irrigation 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

PDSI routinely monitors groundwater in its monitoring and production wells. The PDSI monitoring data are used to characterize the PDSTI area and the sulfate plume. The data collected by PDSI's ongoing monitoring will be used for this project. Additionally, a water level and groundwater sampling program is proposed to augment the PDSI monitoring by collecting information on local and regional water levels outside the PDSTI and sulfate plume areas. This information is fundamental to gain a better understanding of regional groundwater flow and its affect on plume migration.

To obtain information for the area outside of the PDSTI and the plume, the monitoring program will attempt to access and sample or obtain current data on wells owned by other parties. The Twin Buttes Mine, CWC, Green Valley Domestic Water Improvement District, Farmers Investment Company, and private individuals are examples of entities that will be approached for well access or sampling data. Thus, the success of this task will depend on cooperation from well owners and local water companies.

The groundwater monitoring task includes collecting static water level measurements and obtaining a groundwater sample for analysis of sulfate and other constituents unless equivalent information is available from the well owner. The collected information will be used to describe current water table conditions and background water quality; both of which are needed for modeling the sulfate plume. Therefore, an objective of this task is to obtain large geographic coverage in the area around the PDSTI.

The groundwater monitoring program will collect data twice; once in winter and once in summer to characterize the annual extremes in water elevation. Access agreements will be obtained from cooperating property owners in order to measure water levels and to collect groundwater samples. The ability to measure water levels will be limited by whether the well has an access port or sounding tube.

Groundwater samples will be collected and submitted to an Arizona-certified laboratory for analysis. The samples will be analyzed for calcium, magnesium, sodium, potassium, chloride, sulfate, alkalinity, fluoride, nitrate, nitrite, and pH to characterize sulfate and the general water chemistry. Water samples from select wells may also be analyzed for the following constituents needed to assess water treatment for the FS: 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. Sampling and analysis will be conducted according to the methods described in the QAPP (Appendix E). 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 included in task reports and will also be provided to the well owner.

3.3.3 Task 2.3 - Depth-Specific Groundwater Sampling at Existing Wells

Many of the wells in, or proximal to, the sulfate plume have screened intervals of 600 feet or more. It is only since 2005 that nested monitoring wells have been installed to collect depth-specific information (e.g., MH-13 A, B, C; MH-25 A, B, C/D; and MH-26 A, B, C). Depth-specific sampling and spinner logging has been used to determine the vertical variation of sulfate and inflow at several interceptor wellfield wells and at ESP-4 (ELMA, 2004b and 2006). The information collected by depth-specific sampling and inflow logging is useful for identifying water quality variations with depth, evaluating changes in relative permeability with depth, and assessing whether a well can be modified to minimize production from a sulfate-bearing horizon.

3.3.3.1 Depth-Specific Sampling of Pumping Wells

Depth specific groundwater sampling for sulfate will be conducted at pumping wells ESP-1, ESP-2, ESP-3, and ESP-4 to evaluate the northeastern extent of sulfate, at CW-7 to evaluate the northern extent of sulfate, and at CW-8 to test the eastern extent of sulfate. Testing at CWC wells is contingent on their permission for access and testing. Because ESP-1, ESP-2, ESP-3, and ESP-4 are pumping wells equipped with pumps and riser pipes, sampling will be conducted using a procedure that does not require removal of the pump string. The sampling procedure, developed and licensed by BESST Inc. (BESST), uses small diameter equipment that can be inserted into wells through a small (less than 1-inch) hole drilled in the surface casing. In conjunction with depth-specific sampling, dynamic inflow profiling will be conducted using BESST's dye tracer injection system, which releases a small amount of dye at a specific depth and monitors its recovery in the discharge stream. The dynamic inflow profiling will be used to characterize the relative permeability with depth in the screened interval of the wells tested.

The status of pumps and piping in CW-7 and CW-8 is uncertain. If the wells are equipped with pumps, the BESST testing method can be used. If the wells are not equipped with pumps, the BESST methods will be employed by installing a temporary pump in the well.

Because the BESST sampling technique has not been used before at the site, the method will be tested at ESP-4 and the results compared to the results of previous spinner logging to evaluate the comparability of results. Groundwater sampling protocols are described in the

QAPP (Appendix E). Groundwater samples collected by depth-specific methods will be analyzed for sulfate only (Appendix E).

3.3.3.2 Depth-Specific Sampling of Monitoring Wells

Depth-specific groundwater samples will be collected at monitoring wells MH-11 and MH-12 to determine any sulfate zoning with depth in the medial part of the plume. Wells MH-11 and MH-12 are monitored by PDSI. Depending on the configuration of the wellhead, depth-specific samples will be collected by using either the BESST system described above, a discrete interval sampler, or a low flow submersible pump lowered to various depths in the screened interval.

3.3.4 Task 2.4 - Offsite Well Installation and Testing

Additional monitoring wells are proposed at six locations off the PDSI property to further define the extent of the sulfate plume, to provide installations for ongoing monitoring, to characterize aquifer materials and hydraulic properties, and to determine bedrock depth. Well installation will be focused in the northern and eastern portions of the plume because these areas have the greatest uncertainty in the distribution of sulfate and are of concern with respect to future plume migration. The scope of this task will be dependent on information gained as the task progresses. If during this task, newly installed offsite 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.

Figure 13 shows the approximate locations of proposed monitoring wells. Table 7 lists the proposed wells, their design objectives, and land ownership. Land access for drilling and well installation is a major issue because the Green Valley area is extensively developed. Offsite well locations are proposed on a combination of private and public lands. Access agreements will have to be negotiated with private land owners prior to drilling. Potential well locations on public property are either along the Pima County roadway right of way or in areas administered by the Arizona State Land Department (ASLD). Land use applications will be submitted for work on public land. Based on prior experience at MH-13, MH-25, and MH-26, obtaining access to ASLD land can take about 12 months. The exact locations of the proposed wells are provisional subject to successful negotiation of site access.

Well locations and design objectives are based on position in 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 east 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., depth-specific groundwater sampling and groundwater monitoring) and site-specific conditions observed during drilling (e.g., subsurface lithology and water quality).

Co-located nested well installations are recommended at the leading edge of the plume to collect information on vertical zoning and to monitor future plume movement. The primary objective of wells on the east side of plume is to determine the lateral extent of the plume. For this reason, some wells on the east side of the plume incorporate multiple screens in a single well to allow initial and periodic, depth-specific sampling, and routine sampling over the entire screened interval. Sampling these wells from the entire screened interval should be sufficient to monitor for changes in sulfate concentration transverse to the direction of plume movement. Some wells will be installed at the location of an existing well to provide additional vertical characterization.

Monitoring wells will be installed using air and mud rotary methods. Reverse circulation air rotary drilling will be used to install a pilot hole to the bottom of the basin fill and to collect cuttings and water samples with depth. Reconnaissance water samples will be collected from the air rotary return and analyzed in the field using an electrical conductivity meter and a portable spectrophotometer to characterize TDS and sulfate concentrations with depth during drilling. Water samples for laboratory analysis of sulfate may be collected to confirm field measurements if sufficient sample is available. Well designs will be guided by the results of lithologic logging and water quality analyses. Mud rotary drilling will be used to ream out the pilot hole and install any additional wells at the site.

Drilling, well installation, and development methods are described in the QAPP (Appendix E). Each new well will be developed to remove sediment and drilling fluids. After development, short duration (12 to 24 hour) pumping tests will be conducted at each well. At the conclusion of the pumping test, a water quality sample will be collected from each well for analysis of sulfate and other major element ions for characterizing general water chemistry. All new wells will be surveyed by PDSI following completion of their surface casings. Water level measurements and water quality samples will be collected from the new wells 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 E).

3.4 Task 3 - Evaluation of PDSI Groundwater Sulfate Control System

Task 3 analyzes the effectiveness of PDSI's existing sulfate source control system in accordance with the requirement in Section III.C.4 of the MO. Water level, water quality, and wellfield pumping data will be used to evaluate flow to the wellfield and wellfield mass capture.

3.4.1 Review of Source Control Pumping at Interceptor Wellfield

The history of sulfate migration control by the interceptor wellfield will be reviewed including the geology of the wellfield area, the duration of operation, and annual groundwater pumping. The current infrastructure of the system will be described with respect to basic flow routing, design capacities, and water use.

3.4.2 Evaluation of Interceptor Wellfield Effectiveness

The effectiveness of the existing groundwater pumping system will be evaluated based on its operational availability, its mass capture, and hydraulic gradients created by pumping. Operational, water level, pumping rate, and water quality data will be compiled and used to evaluate the effectiveness of the current system. Parameters such as well and wellfield availability, and total and well-by-well pumping will be used to determine operational effectiveness. Water level, pumping, and water quality data will be used to evaluate mass capture.

3.4.2.1 Water Level Data

Water levels in the vicinity of the interceptor wellfield will be used to evaluate the saturated thickness of the aquifer. As discussed in Appendix A, the depth to bedrock is greater in the southern half of the wellfield than the northern half. For this reason, the saturated thickness of the aquifer pumped by the interceptor wells is greater in the south half of the wellfield than in the north half. Other factors held constant, the yield of a pumping well is approximately proportional to its saturated thickness. As water levels in the wellfield area decline due to drawdown caused by pumping and regional water table decline, well yields will also decline. The relationships between water level, saturated thickness, and well yield will be evaluated to assess potential operational constraints on the interceptor wellfield. Additionally, water level data for monitoring wells in the wellfield will be used to examine hydraulic gradients and the local potentiometric surface in the vicinity of the wellfield.

3.4.2.2 Groundwater Pumping

Pumping data will be compiled to document the productivity of individual wells and the wellfield as a whole. The data will be reviewed to identify any significant differences in well yields across the wellfield.

3.4.2.3 Wellfield Mass Capture

Mass capture of individual wells will be estimated as the product of their average pumping rate and average sulfate concentration. The results will be summed to estimate the total wellfield mass capture. Examination of sulfate concentrations in the interceptor wells (Figure 8) indicates that sulfate concentrations do not vary significantly from north to south. Therefore, mass capture across the wellfield is primarily a function of well yield and duration of operation.

3.4.2.4 Estimation of Flow to Wellfield

Groundwater flow to the wellfield will be used to estimate its effectiveness in capturing flow in the basin fill beneath the tailing impoundment. The groundwater flow to the wellfield will be estimated using hydraulic gradient, saturated thickness, and hydraulic conductivity data for the wellfield area. The difference between the calculated flow to the wellfield and the total wellfield pumpage will provide a preliminary estimate of wellfield capture.

3.4.3 Modeling of Wellfield Hydraulics

Analytical or finite difference numerical models may be used to evaluate the hydraulic capture and interference between pumping wells. The objective of the modeling would be to optimize wellfield capture and evaluate the benefits and disadvantages of additional extraction wells. Recommendations for optimizing source control pumping will be developed using the evaluation of wellfield effectiveness and numerical modeling of hydraulic capture.

3.5 Task 4 - 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 PDSTI and, as described below, other sources identified during execution of this work plan. The modeling will include development and use of a regional-scale saturated flow and transport model that will encompass an area that extends in the east-west direction from at least the western edge of the tailing impoundment eastward to the central portion of the basin, and in the north-south direction from several miles upgradient (south) of the tailing impoundment to approximately one mile downgradient (north) of the Twin Buttes Mine. The actual area of the model may be adjusted as deemed necessary based on information gathered as part of the ACP.

The modeling effort will make use of and build upon existing numerical models developed and used for the site (e.g., ELMA & DM, 1994). Boundary conditions and other features of the existing models may be incorporated in whole or in part into the new regional model subject to verification of their adequacy. Existing model inputs such as pumping rate files pertaining to operation of industrial wells and other production wells within the model domain will be updated and incorporated as needed.

The goals of the modeling will be to:

- Calibrate the regional model 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 existing interceptor wellfield pumping only or additional groundwater pumping by the interceptor wellfield, or under long-term conditions such as increased water supply pumping.

3.5.1 Compile 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 regional flow and transport 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 streamflow 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 rate of seepage and sulfate concentration of the seepage over time at the PDSTI will be evaluated and used in the regional groundwater flow and transport model. Seepage will be estimated from a variety of sources including site-specific information on the tailing impoundment water balance and groundwater conditions beneath the impoundment.

Sources of elevated sulfate concentrations within the regional aquifer that are unrelated to PDSTI, such as naturally occurring sources or other mining properties, will be evaluated and incorporated as appropriate into the regional flow and transport model. Naturally occurring sulfate sources, and other background sources, may have resulted in past detections of elevated sulfate in some wells located near the Santa Cruz River (PAG, 1983a). Groundwater quality samples collected in 1981 and 1982 showed elevated sulfate in wells immediately downgradient of the PDSTI, low sulfate concentrations (<100 mg/L) between these wells and wells adjacent to the Santa Cruz River, and concentrations exceeding 100 mg/L in many of the wells along the Santa Cruz River. Groundwater derived from gypsiferous sediment is the suspected origin of the elevated concentrations along the Santa Cruz River, although agricultural sources may also have contributed.

3.5.2 Sulfate Transport Under Current and Future Conditions

The regional-scale 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 regional aquifer. 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, past pumping rate information, and recharge by precipitation and streamflow, as appropriate. It will also expand upon previous modeling efforts by including multiple aquifer layers to enable three-dimensional simulations, and 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 operation of existing sulfate control measures (i.e., the interceptor wellfield).
- Augmentation of existing sulfate control measures with additional sulfate control strategies.

The results of these simulations will be used 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.

3.6 Task 5 - Aquifer Characterization Report

Section III.C of the MO requires PDSI to submit an Aquifer Characterization Report to ADEQ. Pursuant to the MO, the Aquifer Characterization Report will address:

- Current sulfate plume delineation.
- Sulfate fate and transport.
- Identification of all registered private drinking water wells and public drinking water system wells.
- Analysis of the effectiveness of PDSI's current groundwater sulfate control system.

The Aquifer Characterization Report will consist of reports prepared at the conclusion of each task. This reporting process is recommended so that information on individual tasks can be made available to ADEQ expeditiously rather than waiting to assemble all the information into a single final report.

Figure 14 shows a schedule for the ACP tasks. Work for some the ACP tasks is expected to take more than a year to complete. The submittal of periodic task reports will provide the results of the investigation to ADEQ in a sequenced fashion allowing time for ADEQ to evaluate the results and provide comments as the investigation progresses. The schedule is discussed further in Section 6.

The following task reports will be submitted to ADEQ as the Aquifer Characterization Report (Figure 14).

- Well Inventory Report (Task 1)
- Data Compilation and Evaluation Report (Task 2.1)
- Groundwater Monitoring Data Report for First Sampling Event (Task 2.2)
- Results of Depth-Specific Sampling of Existing Wells (Task 2.3)
- Evaluation of PDSI Groundwater Sulfate Control System (Task3)
- Groundwater Monitoring Data Report for Second Sampling Event (Task 2.2)
- Results of Numerical Modeling of Sulfate Fate and Transport (Task 4)
- Results of Offsite Well Installation and Testing (Task 2.4)

These task reports address the Aquifer Characterization Report requirements in Section III.C of the MO. The latest information on the plume delineation will be provided in the reports for Tasks 2.2, 2.3, and 2.4, which will contain maps and cross sections showing the distribution of sulfate.

4. IDENTIFICATION OF POTENTIAL INTERIM ACTIONS

An initial task of this work plan will be to identify potential interim actions that can be employed before the Mitigation Plan is completed if: (1) the average sulfate concentration at the point of use in a drinking water supply exceeds 250 mg/L, or (2) if data demonstrate that the average sulfate concentration at the point of use in a drinking water supply will exceed 250 mg/L before the Mitigation Plan is completed. This task will produce a technical memorandum that: (1) identifies how the "average" sulfate concentration will be determined, (2) discusses potential triggers for an interim action, (3) lists specific responses that could be implemented, and (4) describes site-specific factors to be considered when selecting an interim action. As shown by Figure 14, the development of potential interim actions will begin immediately on approval of the work plan so that a planned response is available and can be implemented if needed.

The possible measures to be considered for an interim action will include water treatment, water system operational changes to increase blending, well modifications, and alternative drinking water supplies. The nature of an interim action will depend on site-specific circumstances and could range from small-scale activities, such as providing bottled water or installation of a household point-of-use water treatment system for affected residences, to large-scale actions, such as temporary wellhead treatment at the point-of-entry to a distribution system. The potential interim actions will be identified to a level of detail sufficient for rapid development, if needed. For example, wellhead treatment options, treatment system vendors, treatment unit model numbers, and lead time requirements will be identified to prepare for rapid mobilization.

5. FEASIBILITY STUDY FOR SULFATE MITIGATION PLAN

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

A 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, and
- 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 and effectiveness, 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 PDSTI.

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 reverse osmosis, electrodialysis, or nanofiltration. Within each technology there may be several process options that can be used to implement the technology.

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

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

The FS will also consider mitigation measures that would control or mitigate sulfate through the application of groundwater/source controls that may include groundwater pumping. Additional mitigation actions to be considered include monitoring of groundwater and drinking water, institutional controls such as restrictions on well drilling, and natural attenuation.

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., reverse osmosis, electrodialysis, and nanofiltration), determination of the most applicable process option will be made based on criteria such as implementability, effectiveness, and cost. PDSI has retained 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. PDSI 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 3.5) 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 objectives. 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 PDSTI. The Mitigation Plan will be submitted to ADEQ for review and approval pursuant to the MO.

6. SCHEDULE

Figure 14 shows a general schedule for implementing the ACP, the identification of interim actions, and the FS for sulfate mitigation. The start of the schedule is the approval of this work plan by ADEQ. Reports identified on Figure 14 will be due on the last day of the month indicated.

The ACP will be implemented immediately on approval of the work plan and a number of tasks can be completed and reported within the first six months. The schedule was developed to complete tasks related to exposure management (e.g., well inventory and identification of potential interim actions) as early as possible and to complete the FS in parallel with the ACP to identify potential mitigation actions as early as possible in the project. However, several tasks will have a long lead time due to the necessity of negotiating access to private and public land to conduct work. For example, the offsite well installation for Task 2.4 could take at least 12 months to permit drill locations on ASLD administered land, although access to some private and public ground may require less lead time. The lead time for Task 2.4 is the critical path item for the ACP. The timing of Task 2.4 impacts the fate and transport modeling for Task 4 which cannot be finalized until the completion of the hydrogeologic characterization.

The identification of potential interim actions will be implemented immediately following approval of the work plan. The objective will be to complete this task within the first four months of the project.

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

Anderson, S.R. 1987. Cenozoic Stratigraphy and Geologic History of the Tucson Basin, Pima County, Arizona, USGS Water-Resources Investigations Report 87-4190.

Barter, C.F., and Kelly, J.L. 1982. Geology of the Twin Buttes Mineral Deposit, in Titley, Spencer, ed. Advances in Geology of the Porphyry Copper Deposits, Southwestern North America. p 407-432.

Cooper, J.R. 1973. Geologic Map of the Twin Buttes Quadrangle, Southwest of Tucson, Pima County, Arizona. U.S.G.S. Miscellaneous Investigation Map I-745.

Davidson, E.S. 1973. Geohydrology and Water Resources of the Tucson Basin, Arizona, USGS Water-Supply Paper 1939-E, 81p.

Drewes, H. 1971a. Geologic Map of the Mt. Wrightson Quadrangle. U.S.G.S. Misc. Inv. Map I-614.

Drewes, H. 1971b. Geologic Map of the Sahuarita Quadrangle. U.S.G.S. Misc. Inv. Map I-613.

Errol L. Montgomery & Associates (ELMA). 1986. Evaluation of Pumping Test Data for Interceptor Wells. June 16, 1986.

ELMA. 1989. Hydrogeologic Report in Support of Groundwater Quality Protection Permit Application, Sierrita Operation, Cyprus Sierrita Corporation, Pima County, Arizona, April 7, 1989.

ELMA. 1991. Supplemental Hydrologic Report in Support of Aquifer Protection Permit Application, Sierrita Operation, Cyprus Sierrita Corporation. July 9, 1991.

ELMA. 1995. Results of Drilling, Construction, Development and Testing, Phase II Interceptor Wells, Sierrita Operation, Cyprus Sierrita Corporation, Pima County, Arizona. June 23, 1995.

ELMA. 2001. Additional Characterization of Hydrogeologic Conditions Aquifer Protection Permit Application 101679 Sierrita Mine, Phelps Dodge Sierrita, Inc. Pima County, Arizona. January 4, 2001.

ELMA. 2004a. Results of Drilling, Construction, and Testing for Interceptor Wells IW-22, IW-23, IW-24, and IW-3A. April 6, 2004

ELMA. 2004b. Results of Spinner Flowmeter Logging and Depth-Specific Water Sampling at Esperanza Well No. 4, May 2004, Phelps Dodge Sierrita, Inc. June 28, 2004.

ELMA. 2006. Interceptor Wells IW-4, IW-5, IW-9, and IW-12: Results of Flow Logging and Depth-Specific Sampling for Identification of Wellbore Fluid Movement and Sulfate Concentrations in Groundwater, Phelps Dodge Sierrita, Inc., Pima County, Arizona. February 6, 2006.

Errol L Montgomery & Associates and Dames & Moore (ELMA & DM). 1994. Aquifer Protection Permit Application, Sierrita Operation, Cyprus Sierrita Corporation, Pima County, Arizona. Volumes I and II. September 7, 1994.

Laney, R.L. 1972. Chemical Quality of Water in the Tucson Basin, Arizona. U.S.G.S. Geological Survey Water Supply Paper 1939-D.

Montgomery Watson and Errol L Montgomery & Associates 1998. APP Permit Application Twin Buttes Mine. Volumes I and II. December 1998.

Pima Association of Governments (PAG). 1983a. Region Wide Groundwater Quality in the Upper Santa Cruz Basin Mines Task Force Area. September 1983.

PAG. 1983b. Ground-Water Monitoring in the Tucson Copper Mining District. September 1983.

Terra Matrix. 1998. Clean Closure Application Twin Buttes Industrial Wells Groundwater Quality Protection Permit NOG-0033-10. March 1998.

TABLES

TABLE 1
Summary of Hydraulic Conductivity Data

AQUIFER MATERIAL	NUMBER OF ESTIMATES	HYDRAULIC CONDUCTIVITY (ft/day)		
		MINIMUM	MAXIMUM	GEOMETRIC MEAN
BASIN FILL				
Basin Fill	51	0.01	118	15.05
Basin Fill and Demetrie Volcanics	7	9.4	15	11.90
Basin Fill and Granodiorite	4	0.011	0.020	0.013
BEDROCK COMPLEX				
Demetrie Volcanics	18	0.0000067	151	0.0047
Cretaceous Sedimentary Rock	1	0.067	0.067	0.067
Brecciated Volcanics	3	0.0019	0.087	0.0122
Intrusive Rocks (Granite, Granodiorite, Quartx Monzonite)	26	0.000067	2.18	0.0312
Meta-Rhyolite and Rhyolite	9	0.03	1.07	0.12

TABLE 2
Sulfate Concentrations in Most Recent (as of April 2006) Groundwater Samples

Well	Sulfate Concentration (mg/L)	Date Sampled	Source
1225	1320	4/12/00	PDSI
1759	340	11/25/03	PDSI
AN-1 (CW-11)	90	12/2/03	PDSI
CW-3	63.6	1/3/05	Community Water Company
CW-5	120	11/5/02	Community Water Company
CW-6	53.7	11/1/04	Community Water Company
CW-7	570	12/13/04	PDSI
CW-8	470	12/13/04	PDSI
CW-9	60	12/13/04	PDSI
ESP-1	220	4/14/06	Community Water Company
ESP-2	35	4/14/06	Community Water Company
ESP-3	36	4/14/06	Community Water Company
ESP-4	210	1/11/05	PDSI
ESP-5	170	4/3/01	PDSI
GV-01 (SDP)	170	4/11/06	Pima County Wastewater Treatment
GV-02 (SDP)	155	4/11/06	Pima County Wastewater Treatment
GV-1	40	12/13/05	PDSI
GV-2	70	12/13/05	PDSI
I-7	650	10/5/99	PDSI
I-9	750	4/3/01	PDSI
I-10	660	9/17/02	PDSI
I-12	780	10/5/99	PDSI
I-13	LAST DATA 1989	LAST DATA 1989	PDSI
IW-1	500	1/30/06	PDSI
IW-2	100	1/30/06	PDSI
IW-3A	1570	1/30/06	PDSI
IW-4	1570	1/30/06	PDSI
IW-5	1720	3/23/06	PDSI
IW-6A	1800	4/24/06	PDSI
IW-7	LAST DATA 1983	LAST DATA 1983	PDSI
IW-8	1810	2/21/06	PDSI
IW-9	1710	1/30/06	PDSI
IW-10	1670	9/14/05	PDSI
IW-11	1700	1/30/06	PDSI
IW-12	1560	4/24/06	PDSI
IW-13	1800	4/24/06	PDSI
IW-14	1800	2/1/06	PDSI
IW-15	1930	9/14/05	PDSI
IW-16	LAST DATA 1998	LAST DATA 1998	PDSI
IW-17	1480	6/7/05	PDSI
IW-18	1600	4/26/06	PDSI
IW-19	1580	4/26/06	PDSI
IW-20	1600	4/26/06	PDSI
IW-21	1560	4/26/06	PDSI
IW-22	1680	1/30/06	PDSI
IW-23	1650	1/24/06	PDSI
IW-24	1670	1/30/06	PDSI

TABLE 2
Sulfate Concentrations in Most Recent (as of April 2006) Groundwater Samples

Well	Sulfate Concentration (mg/L)	Date Sampled	Source
M-1	10	11/25/03	PDSI
M-5	NO DATA	NO DATA	PDSI
M-6	NO DATA	NO DATA	PDSI
M-7	NO DATA	NO DATA	PDSI
M-8	30	11/1/00	PDSI
M-9	40	11/24/03	PDSI
M-10	40	11/24/03	PDSI
M-11	10	11/24/03	PDSI
M-12	50	9/18/02	PDSI
MH-1	1530	12/12/05	PDSI
MH-3	1660	12/6/04	PDSI
MH-4	2090	4/5/01	PDSI
MH-5	1900	12/12/05	PDSI
MH-6	1720	12/9/05	PDSI
MH-7	1810	12/8/05	PDSI
MH-9	420	12/6/05	PDSI
MH-10	1360	12/7/05	PDSI
MH-11	1570	1/24/06	PDSI
MH-12	1090	4/20/06	PDSI
MH-13A	1750	4/29/06	ELMA[1]
MH-13B	970	4/24/06	ELMA
MH-13C	320	4/13/06	ELMA
MH-14	1500	1/30/06	PDSI
MH-15W	1750	1/27/06	PDSI
MH-16W	1180	1/30/06	PDSI
MH-24	NO DATA	NO DATA	PDSI
MH-25A	<10	1/27/06	ELMA
MH-25B	1670	12/17/05	ELMA
MH-25C	1410	2/16/06	ELMA
MH-25D	600	2/20/06	ELMA
MH-26A	20	1/27/06	ELMA
MH-26B	1570	1/4/06	ELMA
MH-26C	730	1/11/06	ELMA
MH-30	1970	3/3/06	ELMA
RT-1	180	9/17/02	PDSI
S-1	70	12/13/05	PDSI
S-2	80	12/13/05	PDSI
ST-5	80	3/19/04	PDSI
ST-6	50	3/19/04	PDSI
ST-7	40	3/19/04	PDSI

[1] *ELMA = Errol L. Montgomery & Associates, unpublished water quality data.*

TABLE 3
Sulfate Concentrations at CW-7

Date Sampled	Sulfate, mg/L
1/14/1992	68
10/5/1995	120
1/27/1999	247
2/10/1999	327
3/18/1999	319
4/12/1999	321
5/17/1999	251
7/15/1999	321
10/26/1999	461
11/15/1999	271
1/11/2000	380
4/19/2000	296
8/14/2000	362
10/18/2000	403
1/30/2001	387
4/4/2001	374
8/14/2001	402
10/15/2001	428
2/6/2002	463
4/8/2002	436
7/10/2002	470
11/5/2002	438
2/4/2003	451
4/21/2003	451
8/4/2003	505
1/20/2004	470
5/20/2004	491
8/3/2004	511
11/1/2004	533
12/13/2004	371

Source: Community Water Company.

TABLE 4
Summary of Major Element Ion Concentrations for Selected Wells

	Proximal Wells	Medial Wells	Distal Wells	Upgradient Wells	Downgradient Wells
Dissolved Calcium					
Sample Number	23	3	4	4	2
Minimum	65.3	368	55.2	50.8	31.6
Maximum	623	505	196	69	32.8
Arithmetic Mean	470.9	454.3	113.9	59.2	32.2
Dissolved Magnesium					
Sample Number	23	3	4	4	2
Minimum	13.9	74.5	5.4	5.9	2.8
Maximum	121	108	21.5	9.5	3.1
Arithmetic Mean	93.7	93.5	11.4	8.1	3
Dissolved Potassium					
Sample Number	23	3	3	4	2
Minimum	5.6	10.5	3	2.9	2.5
Maximum	14.4	14.9	6.1	3.5	2.6
Arithmetic Mean	9.1	12.7	5	3.2	2.6
Dissolved Sodium					
Sample Number	23	3	4	4	2
Minimum	42	77.9	45.4	31.9	35.7
Maximum	221	110	121	50.8	36.2
Arithmetic Mean	147.7	98	70.4	41.5	36
Bicarbonate[1]					
Sample Number	23	3	4	4	2
Minimum	105	71	94	147	130
Maximum	183	99	109	176	137
Arithmetic Mean	136	85.7	102	166	133.5
Chloride					
Sample Number	23	3	4	4	2
Minimum	19	115	20	13	8
Maximum	174	148	53	20	8
Arithmetic Mean	123.2	126.7	38.3	16.3	8
Fluoride					
Sample Number	23	3	4	4	2
Minimum	0.1	0.1	0.2	0.3	0.7
Maximum	0.3	0.2	1.4	0.5	1
Arithmetic Mean	0.2	0.2	0.8	0.4	0.9
Total Sulfate					
Sample Number	23	3	4	4	2
Minimum	100	1100	120	40	30
Maximum	1930	1620	570	80	30
Arithmetic Mean	1514	1430	323	65	30
Total Dissolved Solids[3]					
Sample Number	23	3	3	4	2
Minimum	390	1960	340	300	230
Maximum	3190	2740	1030	400	230
Arithmetic Mean	2625.2	2460	743	350	230
Hardness[4]					
Sample Number	23	3	4	4	2
Minimum	220	1224	160	151	90
Maximum	1965	1666	577	209	95
Arithmetic Mean	1559.8	1518	331	181	93
Field pH (standard units)					
Sample Number	23	3	4	4	2
Minimum	6.58	6.98	6.95	7.25	7.64
Maximum	7.87	7.20	7.51	7.62	7.85
Arithmetic Mean	7.30	7.10	7.17	7.50	7.70

Note:

All Concentrations are in mg/L (except pH)

[1] *as $CaC0_3$*

[2] *as nitrogen*

[3] *filterable, dried at 180° C*

[4] *as $CaCO_3$, computed from dissolved ions*

See Table C.1 (Appendix C) for data.

TABLE 5
Summary of Dissolved Metal Concentrations for Interceptor Wells (IW-series)
1997 through April 2006

	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper
AWQS[1]	**NS**	**0.006**	**0.01**	**2**	**0.004**	**NS**	**0.005**	**0.1**	**NS**	**NS**
Number of Samples	7	252	254	238	237	17	254	254	254	40
Number of Samples with Detections	1	32	207	238	4	17	37	25	4	6
Detection Frequency	14%	13%	81%	100%	2%	100%	15%	10%	2%	15%
Minimum Detected (mg/L)	0.15	0.0002	0.0006	0.024	0.0001	0.07	0.0001	0.01	0.01	0.01
Maximum Detected (mg/L)	0.15	0.0045	0.01	0.095	0.0004	0.30	0.002	1.55	0.03	0.02
Arithmetic Mean[2]	0.15	0.0014	0.0032	0.059	0.0010	0.15	0.0005	0.10	0.020	0.01
Number of AWQS Exceedances	NA	0	0	0	0	NA	0	3	NA	NA
Exceedance Frequency	NA	0.0%	0.0%	0.0%	0.0%	NA	0.0%	1.2%	NA	NA

Notes:
All concentrations are in milligrams per liter (mg/L)
[1] Aquifer Water Quality Standard
[2] Calculated for all samples with detected
NS = No standard
NA = Not applicable
See Table C.2 in Appendix C for data.

TABLE 5
Summary of Dissolved Metal Concentrations for Interceptor Wells (IW-series)
1997 through April 2006

	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Thallium	Zinc
AWQS[1]	**NS**	**0.05**	**NS**	**0.002**	**NS**	**0.1**	**0.05**	**0.002**	**NS**
Number of Samples	232	253	231	231	255	237	255	237	40
Number of Samples with Detections	197	195	52	10	186	20	131	58	27
Detection Frequency	85%	77%	23%	4%	73%	8%	51%	24%	68%
Minimum Detected (mg/L)	0.01	0.0001	0.005	0.0002	0.01	0.01	0.0006	0.00007	0.01
Maximum Detected (mg/L)	19.5	0.08	0.99	0.0005	0.22	0.95	0.005	0.0028	0.15
Arithmetic Mean[2]	0.32	0.0029	0.062	0.0005	0.06	0.11	0.0022	0.00063	0.03
Number of AWQS Exceedances	NA	1	NA	0	NA	3	0	1	NA
Exceedance Frequency	NA	0.4%	NA	0.0%	NA	1.3%	0.0%	0.4%	NA

Notes:
All concentrations are in milligrams per liter (mg/
[1] *Aquifer Water Quality Standard*
[2] *Calculated for all samples with detected*
NS = No standard
NA = Not applicable
See Table C.2 in Appendix C for data.

TABLE 6
Summary of Data Needs and Proposed Work

DATA NEED	PROPOSED AQUIFER CHARACTERIZATION PLAN (ACP)/FEASIBILITY STUDY (FS) WORK
AQUIFER CHARACTERIZATION DATA NEEDS	
Locations of drinking water wells downgradient and cross-gradient of the plume	ACP - Task 1 - Well Inventory: use Arizona Department of Water Resources data to identify the location and water use for individual wells
Groundwater sulfate data to determine the eastern and northern extents of the plume	ACP - Task 2 - Plume Characterization: install and sample proposed new monitoring wells east and north of the plume
Groundwater sulfate data to determine the vertical distribution of sulfate	ACP - Task 2 - Plume Characterization: install and sample proposed new monitoring wells allowing vertical sampling; conduct depth-specific sampling at exiting wells
Local and regional water level measurements to characterize the regional flow system	ACP - Task 2 - Plume Characterization: ongoing monitoring by PDSI, measure regional and local water levels at existing wells, and measure water levels at proposed new monitoring wells
Local and regional water quality data to determine background water quality	ACP - Task 2 - Plume Characterization: ongoing monitoring by PDSI, sample groundwater at existing local and regional wells, and sample groundwater at proposed new monitoring wells
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 proposed new wells; and Task 4 - Sulfate Fate and Transport Evaluation: aquifer data will be incorporated into groundwater flow model
Pumping, sulfate concentrations, and water levels at the interceptor wellfield	ACP - Task 3 - Evaluation of PDSI's Groundwater Sulfate Control System: existing information on pumping, water quality, and water levels will be compiled and evaluated
Quantification of sources and sinks of groundwater for groundwater flow model	ACP - Task 4 - 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
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
Current and projected pumping rates for existing wells	FS - ISMAT and DSMA (see FS Task list below): determine current and projected demands for water users in the Green Valley area
Expected future pumping rates for planned wells	FS - ISMAT and DSMA: determine projected future demands for water users in the Green Valley area
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 Green Valley 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 - Depth-Specific Groundwater Sampling at Existing Wells
  Task 2.4 - Offsite Well Installation and Testing
Task 3 - Evaluation of PDSI Groundwater Sulfate Control System
Task 4 - Sulfate Fate and Transport Evaluation
Task 5 - Aquifer Characterization Report

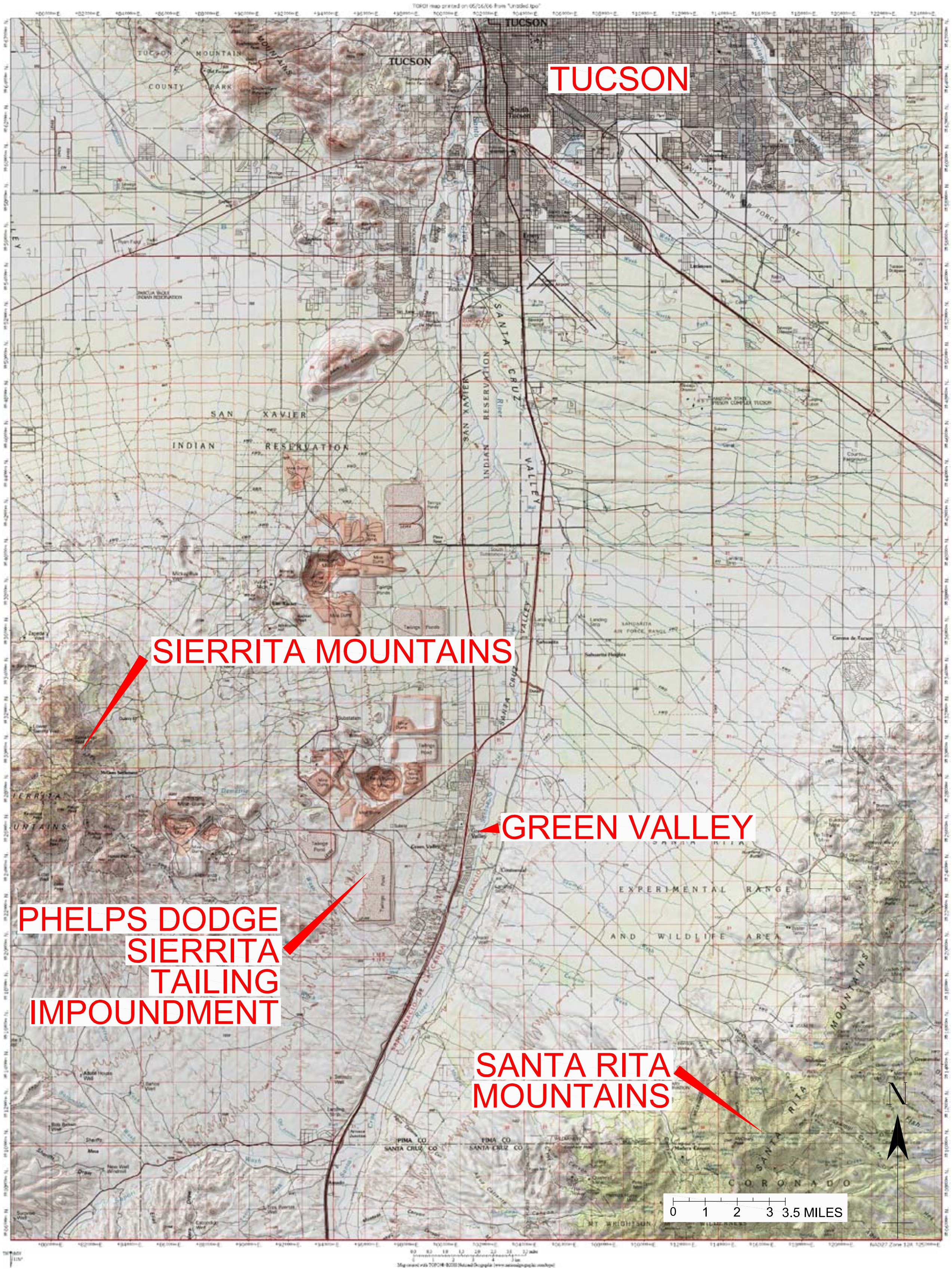
FS Task List
Identification and Screening of Mitigation Actions and Technologies (ISMAT)
Development and Screening of Mitigation Alternatives (DSMA)
Detailed Analysis of Mitigation Alternatives (DAMA)

TABLE 7
Proposed Offsite Well Locations

PROPOSED WELL SITE	PURPOSE	ESTIMATED DEPTH TO BEDROCK (feet)	APPROACH TO WELL INSTALLATION	LAND STATUS
1	Determine northern extent and vertical zoning of sulfate and hydraulic properties; long term water level and water quality monitoring	1,200 - 1,500	Three (3) wells installed to shallow, intermediate, and deep levels	Private
2	Determine northwestern extent and vertical zoning of sulfate and hydraulic properties; long term water level and water quality monitoring	800 - 1,000	Two (2) wells installed to shallow and deep levels	Private or Public
3	Determine eastern extent and vertical zoning of sulfate and hydraulic properties in area between CW-7 and CW-9; long term water level and water quality monitoring	1,500 - 2,000	Three (3) wells installed to shallow, intermediate, and deep levels	Private or Public
4	Determine eastern extent and vertical zoning of sulfate and hydraulic properties in area between CW-8 and CW-6; long term water level and water quality monitoring	1,500 - 2,000	Three (3) wells installed to shallow, intermediate, and deep levels	Private or Public
5	Determine eastern extent and vertical zoning of sulfate and hydraulic properties at CW-3 east of MH-13; long term water level and water quality monitoring	1,200 - 1,500	Single well with two screens installed to intermediate and deep levels to augment depth coverage at CW-3	Private
6	Determine southeastern extent and vertical zoning of sulfate and hydraulic properties east of GV-1 and GV-2; long term water level and water quality monitoring	1,200 - 1,500	Single well with two screens installed at shallow and intermediate levels	Private

Note: See Figure 13 for approximate location of proposed wells. Actual locations may vary depending on negotiation of land access.

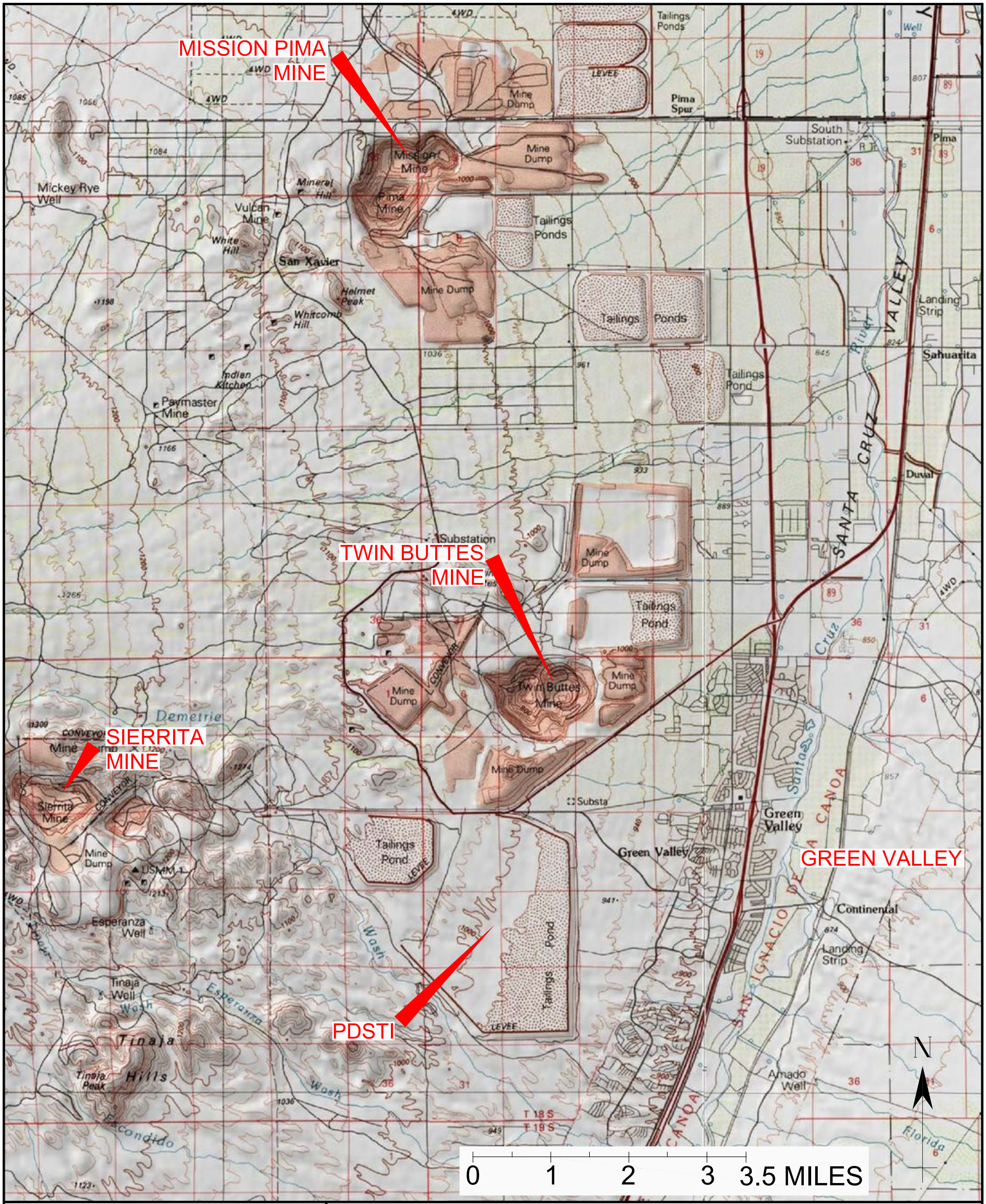
FIGURES



HYDRO
GEO
CHEM, INC.

REGIONAL LOCATION MAP

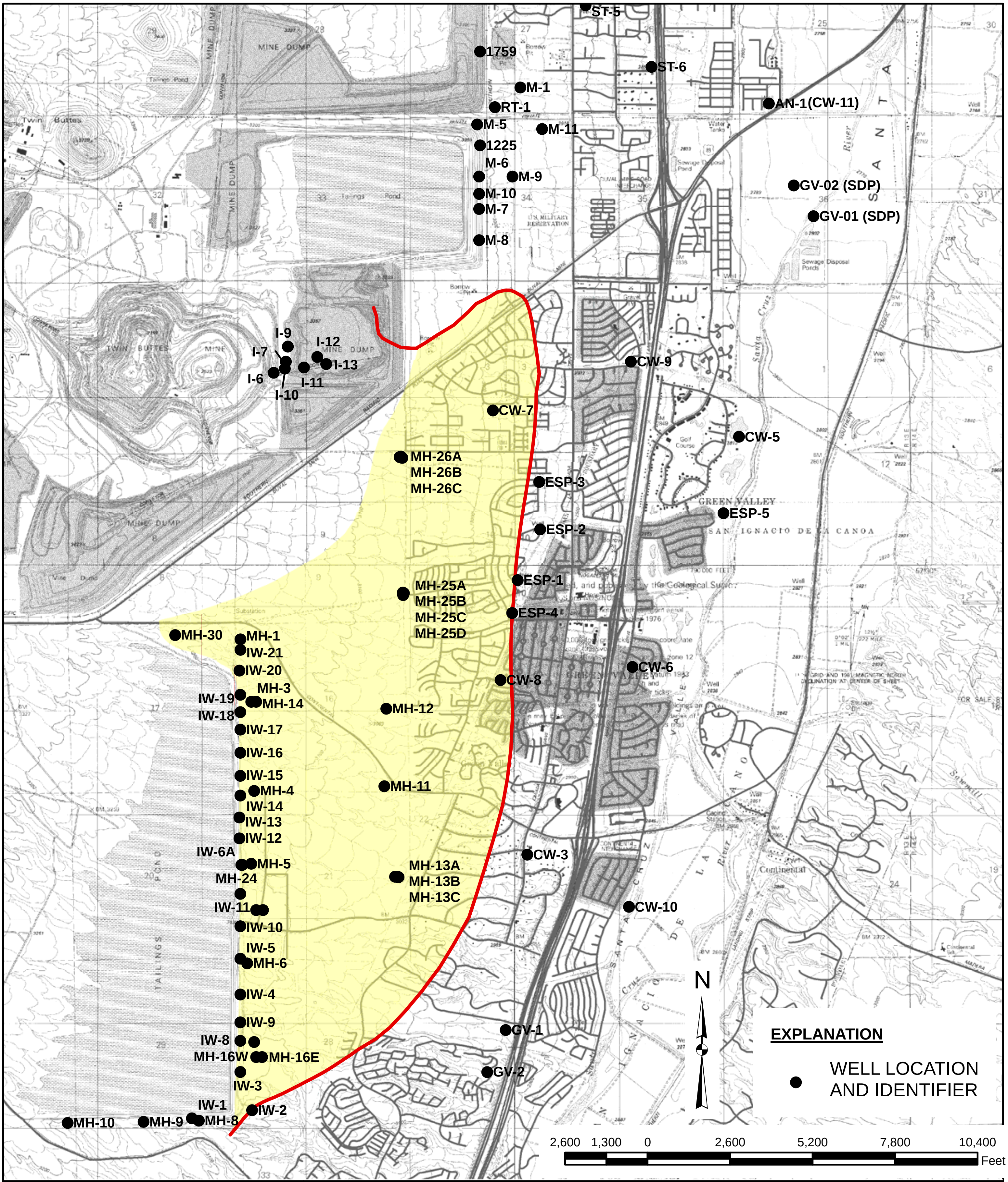
Approved	Date	Revised	Date	Reference:	FIG.
JRN	8/9/06			7830016A	1



HYDRO
GEO
CHEM, INC.

PDSTI AND GREEN VALLEY

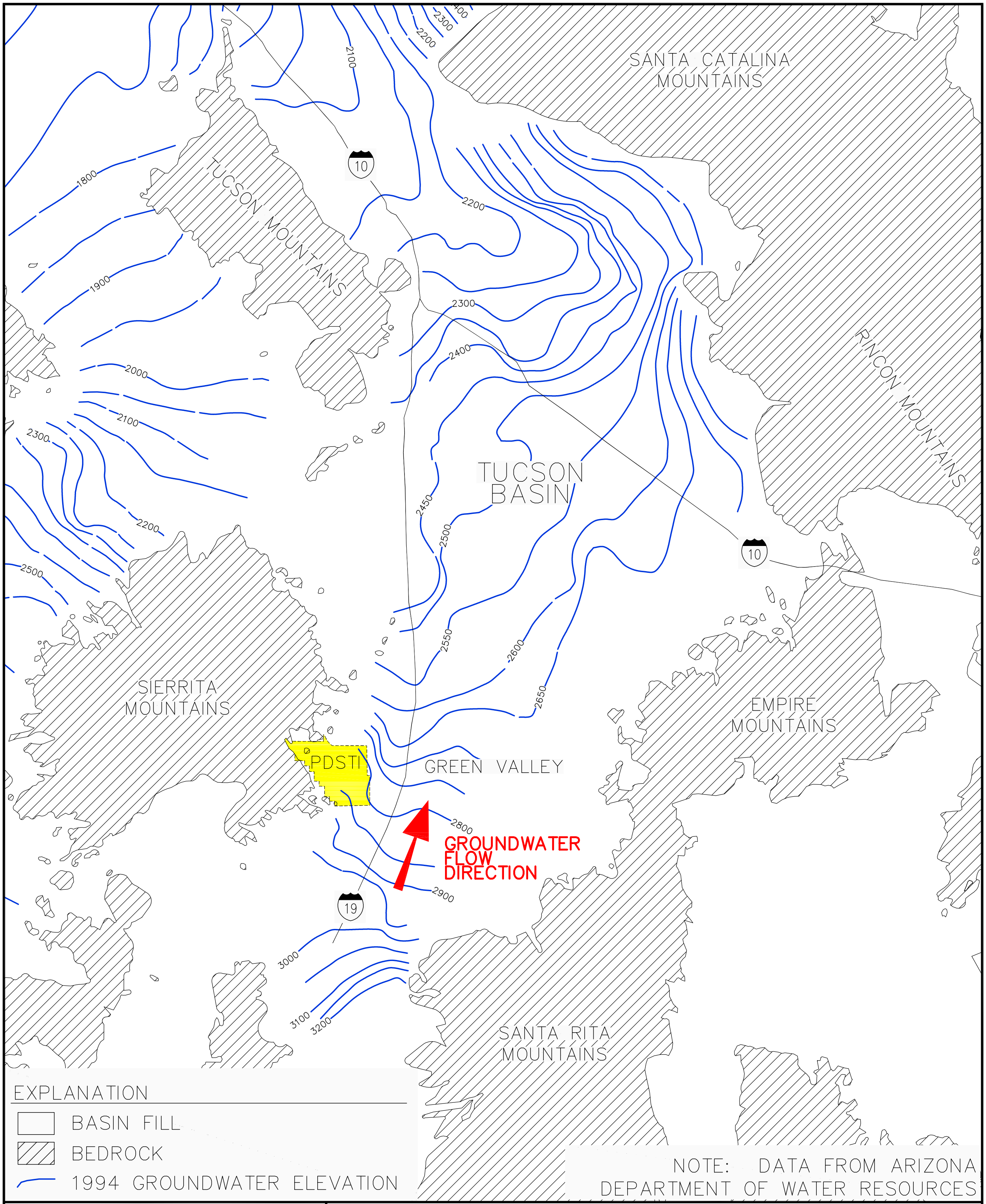
Approved	Date	Revised	Date	Reference:	FIG.
JRN	8/9/06			7830016A	2



HYDRO
GEO
CHEM, INC.

APPROXIMATE EXTENT OF SULFATE CONCENTRATIONS IN EXCESS OF 250 mg/L BASED ON AVAILABLE INFORMATION AS OF APRIL 2006

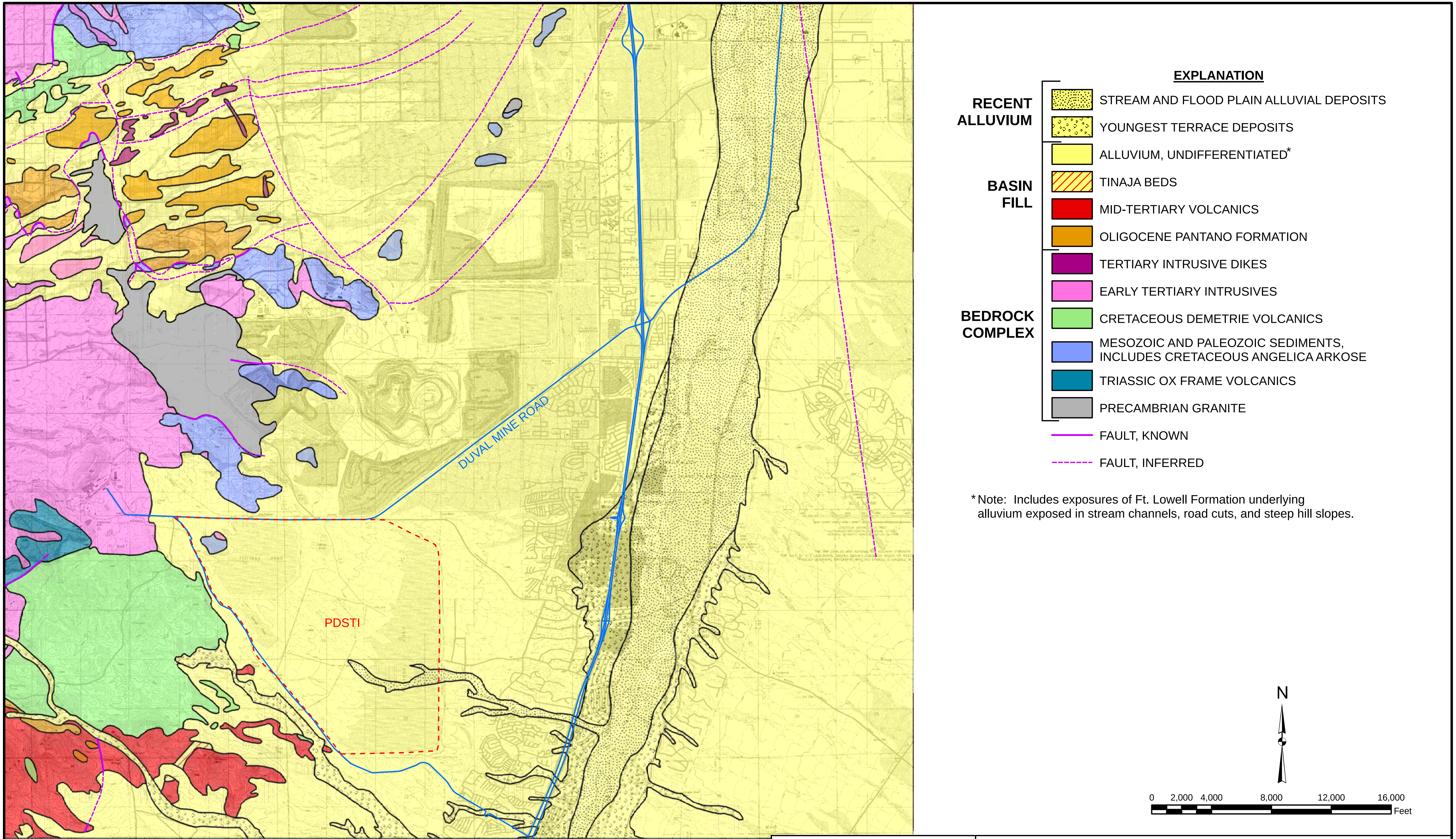
Approved	Date	Revised	Date	Reference:	FIG.
JRN	8/9/06			7830004G	3



HYDRO
GEO
CHEM, INC.

MAP OF TUCSON BASIN

Approved	Date	Revised	Date	Reference:	FIG.
JRN	8/9/06			7830045A	4



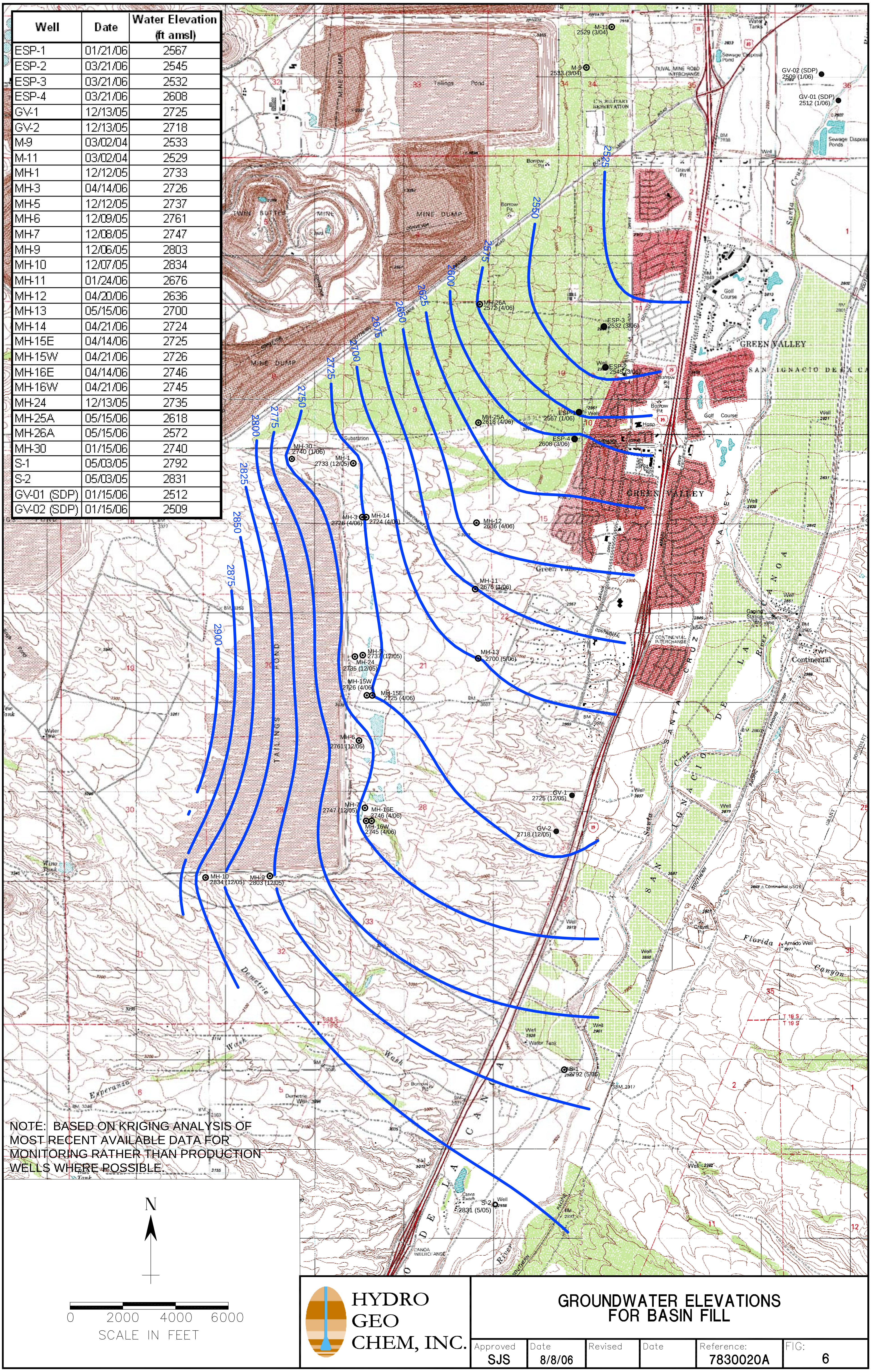
*Note: Includes exposures of Ft. Lowell Formation underlying alluvium exposed in stream channels, road cuts, and steep hill slopes.

SOURCE: DAVIDSON (1973).

HYDRO GEO CHEM, INC.

GEOLOGIC MAP OF PDSTI AND GREEN VALLEY AREA

Approved	Date	Revised	Date	Reference:	FIG.
JRN	6/1/06			7830006G	5



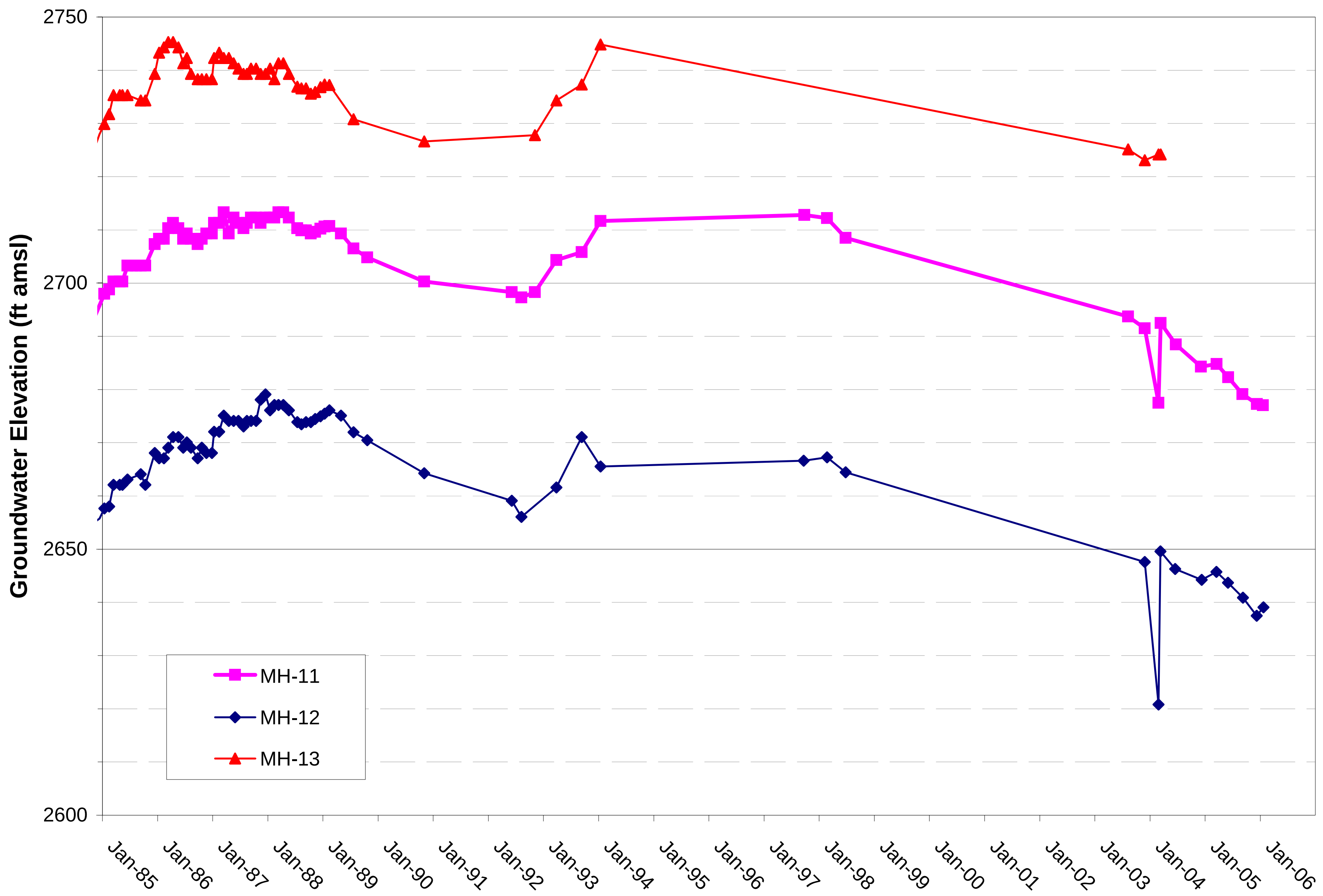
Well	Date	Water Elevation (ft amsl)
ESP-1	01/21/06	2567
ESP-2	03/21/06	2545
ESP-3	03/21/06	2532
ESP-4	03/21/06	2608
GV-1	12/13/05	2725
GV-2	12/13/05	2718
M-9	03/02/04	2533
M-11	03/02/04	2529
MH-1	12/12/05	2733
MH-3	04/14/06	2726
MH-5	12/12/05	2737
MH-6	12/09/05	2761
MH-7	12/08/05	2747
MH-9	12/06/05	2803
MH-10	12/07/05	2834
MH-11	01/24/06	2676
MH-12	04/20/06	2636
MH-13	05/15/06	2700
MH-14	04/21/06	2724
MH-15E	04/14/06	2725
MH-15W	04/21/06	2726
MH-16E	04/14/06	2746
MH-16W	04/21/06	2745
MH-24	12/13/05	2735
MH-25A	05/15/06	2618
MH-26A	05/15/06	2572
MH-30	01/15/06	2740
S-1	05/03/05	2792
S-2	05/03/05	2831
GV-01 (SDP)	01/15/06	2512
GV-02 (SDP)	01/15/06	2509

NOTE: BASED ON KRIGING ANALYSIS OF MOST RECENT AVAILABLE DATA FOR MONITORING RATHER THAN PRODUCTION WELLS WHERE POSSIBLE.

HYDRO
GEO
CHEM, INC.

GROUNDWATER ELEVATIONS FOR BASIN FILL

Approved	Date	Revised	Date	Reference:	FIG:
SJS	8/8/06			7830020A	6

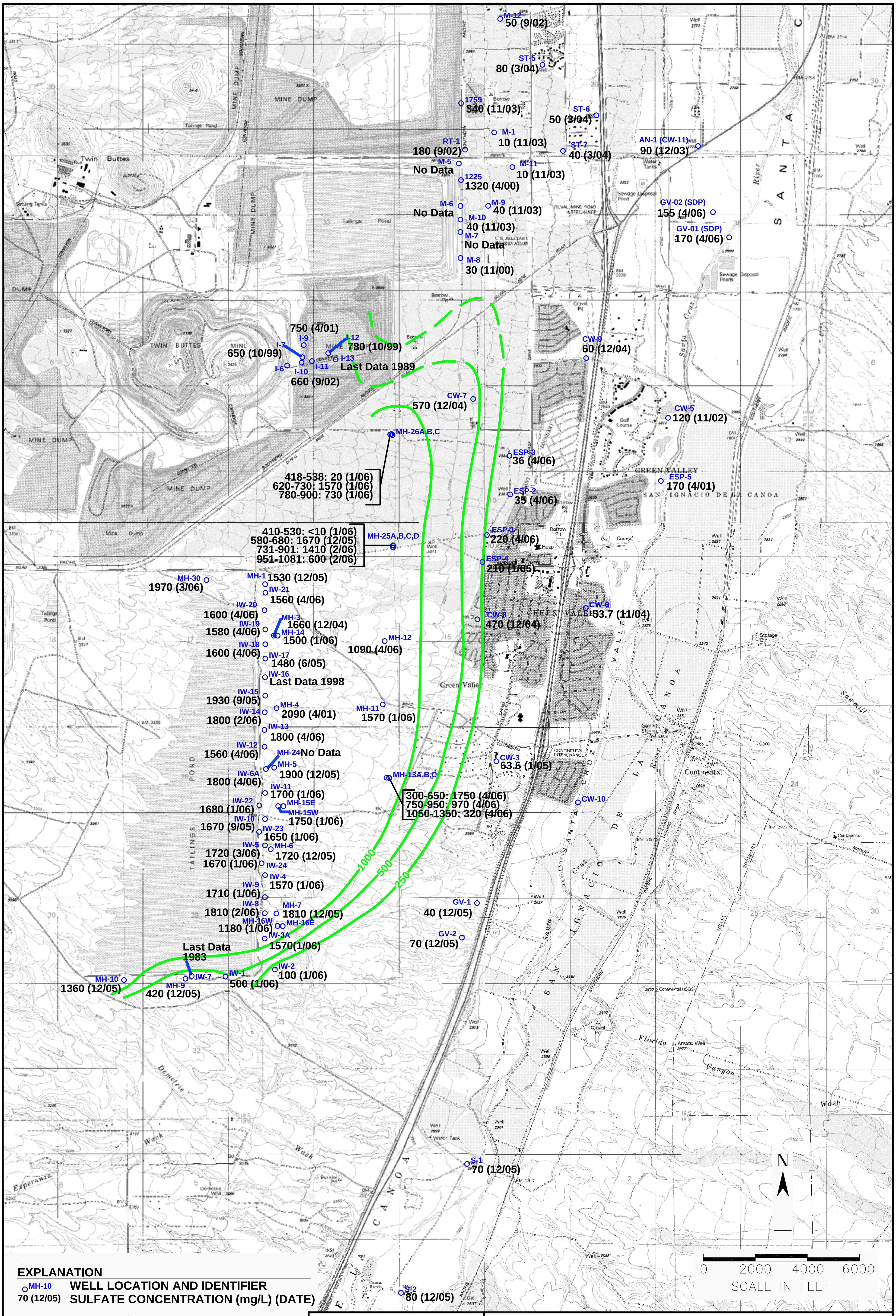


HYDRO
GEO
CHEM, INC.

WATER LEVEL HYDROGRAPHS FOR MH-11, MH-12, AND MH-13

APPROVED	DATE	FIGURE
JN	8/8/06	7

H:\78300\DATA\HistoricGWElev_M_thru_ST.xls: MH-11_80 (2)



EXPLANATION

MH-10
70 (12/05)

WELL LOCATION AND IDENTIFIER
SULFATE CONCENTRATION (mg/L) (DATE)

ISOCONCENTRATION CONTOUR

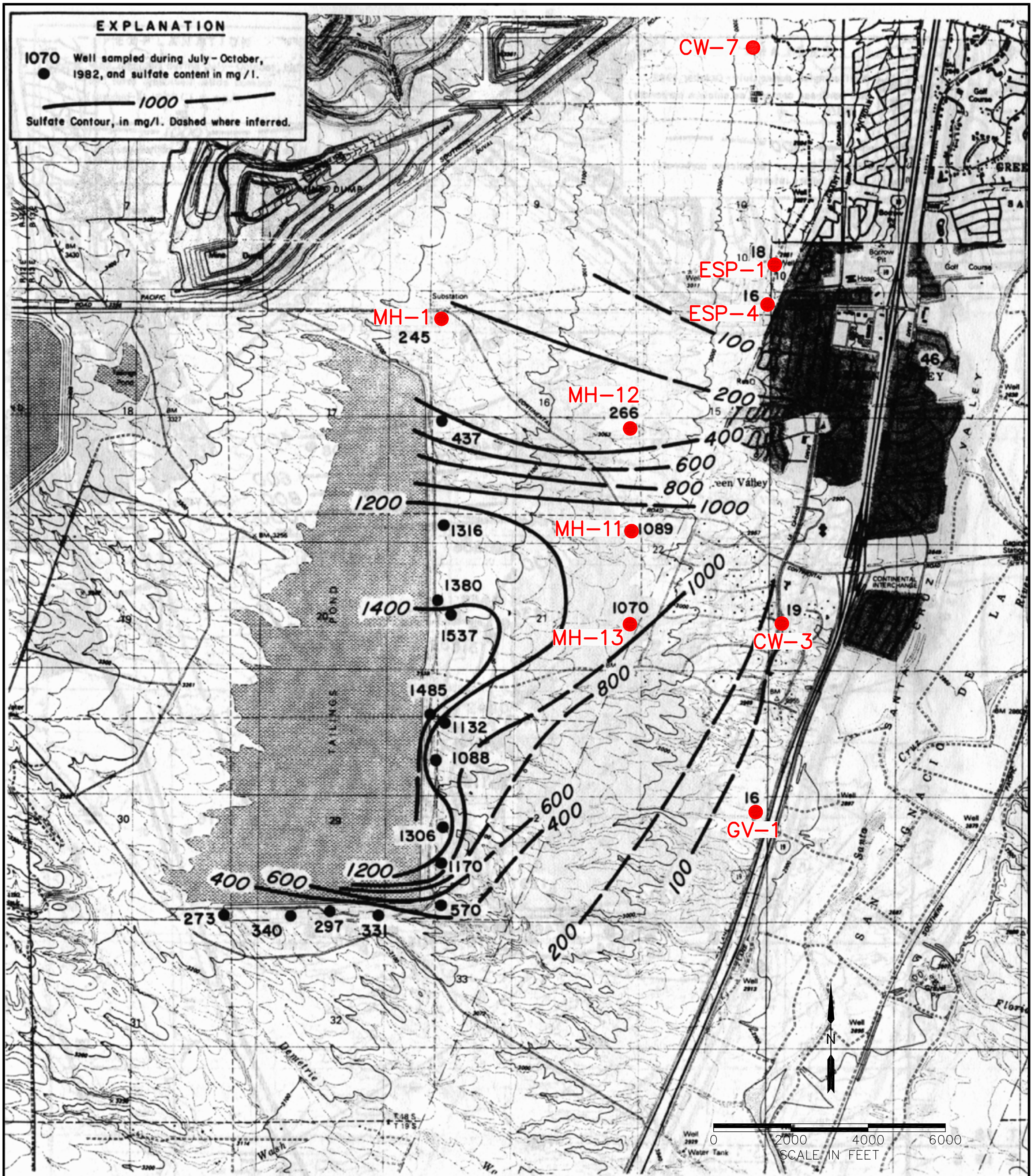
WELL NEST

Screen in ft bgs: Sulfate in mg/L (date) MH-13A,B,C

HYDRO
GEO
CHEM, INC.

SULFATE CONCENTRATIONS IN GROUNDWATER BASED ON DATA AVAILABLE THROUGH APRIL 2006

Approved	Date	Revised	Date	Reference:	FIG:
JRN	8/8/06			7830040A	8

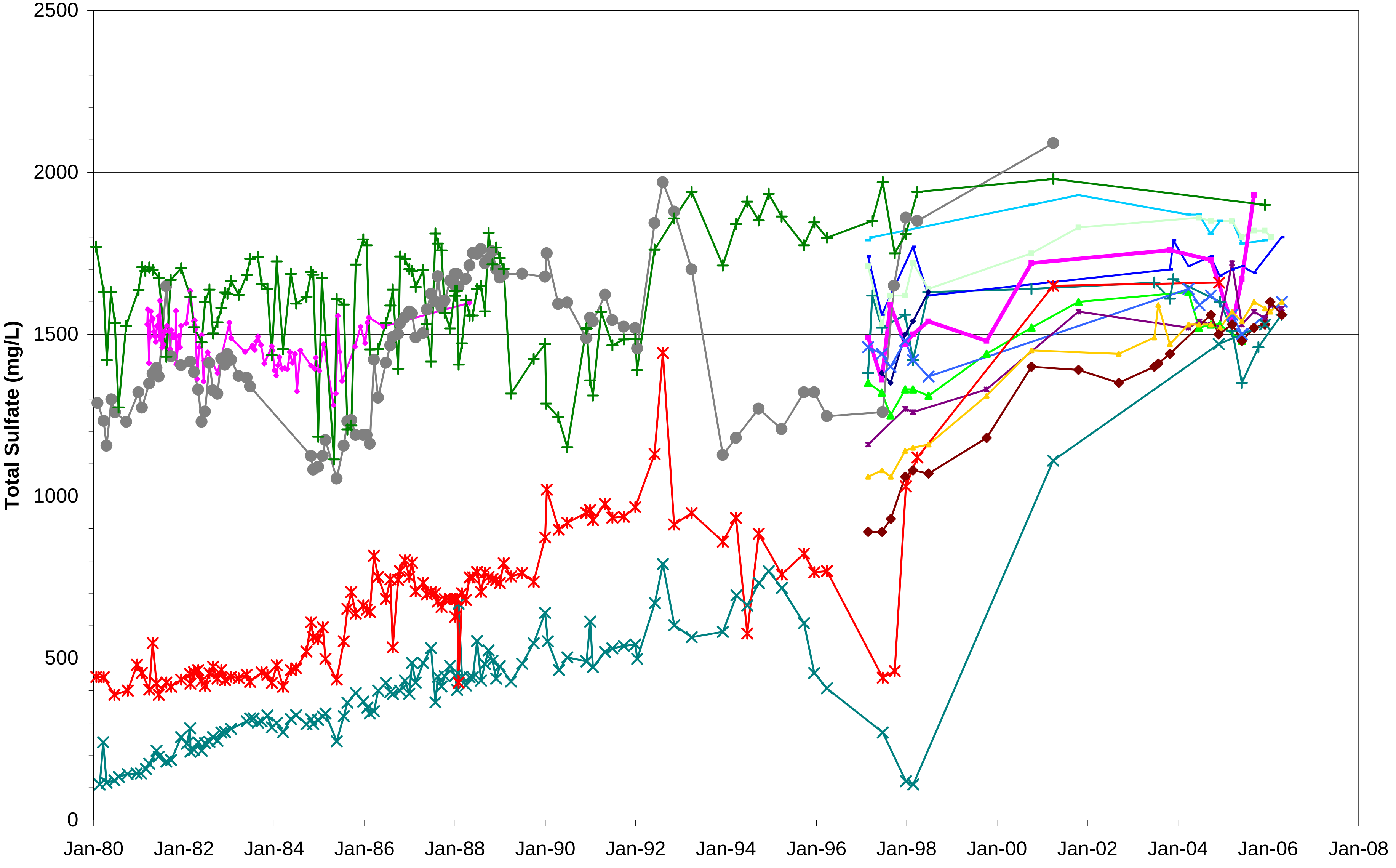


NOTE: MAP FROM PIMA ASSOCIATION OF GOVERNMENTS GROUND-WATER MONITORING IN THE TUCSON COPPERMINING DISTRICT - SEPTEMBER 1983.

HYDRO
GEO
CHEM, INC.

1982 SULFATE CONCENTRATIONS IN GROUNDWATER

Approved	Date	Revised	Date	Reference:	FIG.
JRN	8/8/06			7830048A	9

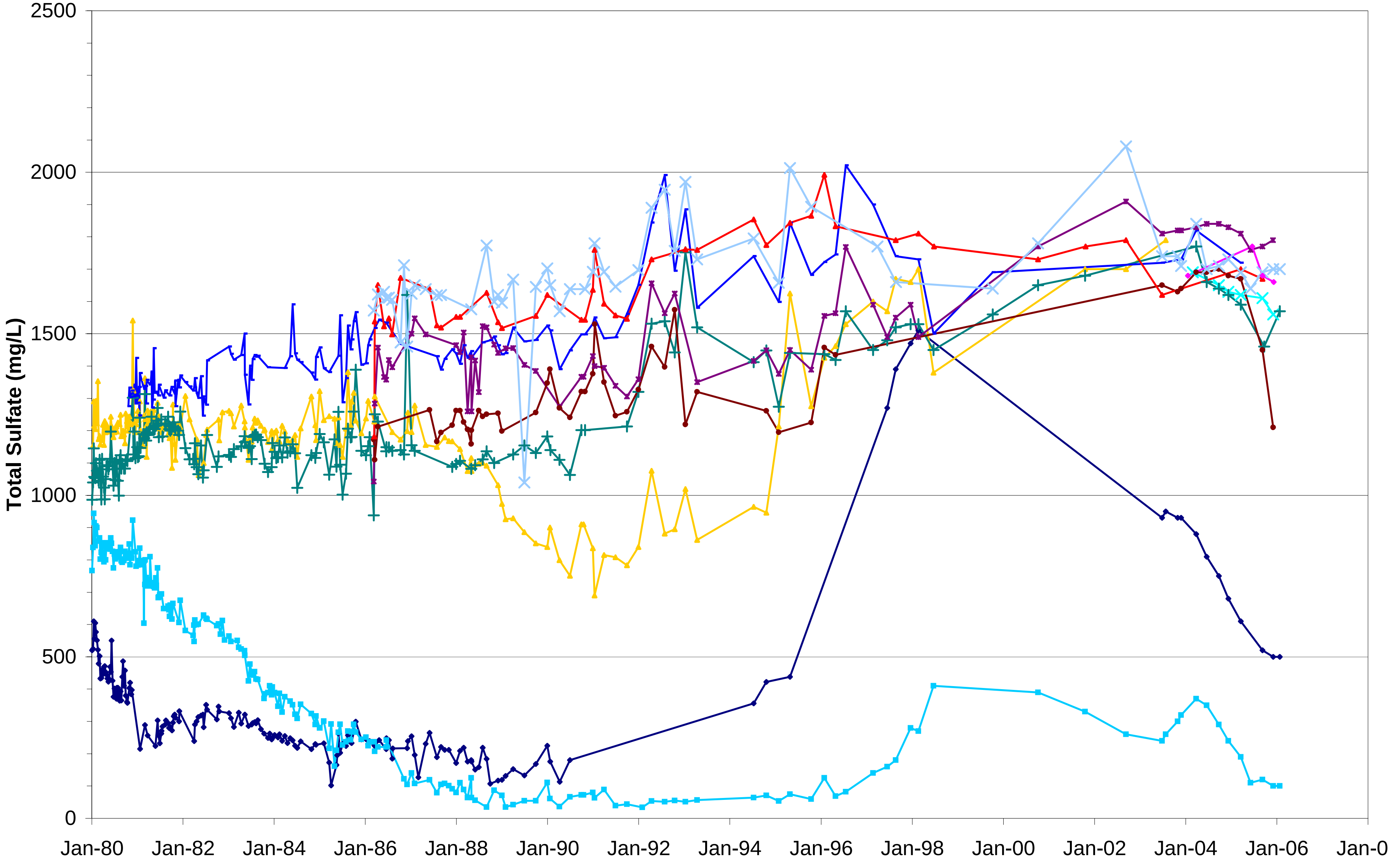


HYDRO
GEO
CHEM, INC.

SULFATE CONCENTRATION IN NORTH HALF OF INTERCEPTOR WELLFIELD

APPROVED	DATE	FIGURE
JRN	8/8/06	10

H:\78300\DATA\Water Quality\Tables_PDSIdbase_April06\PDSI IW Hydrographs.xls: North Half

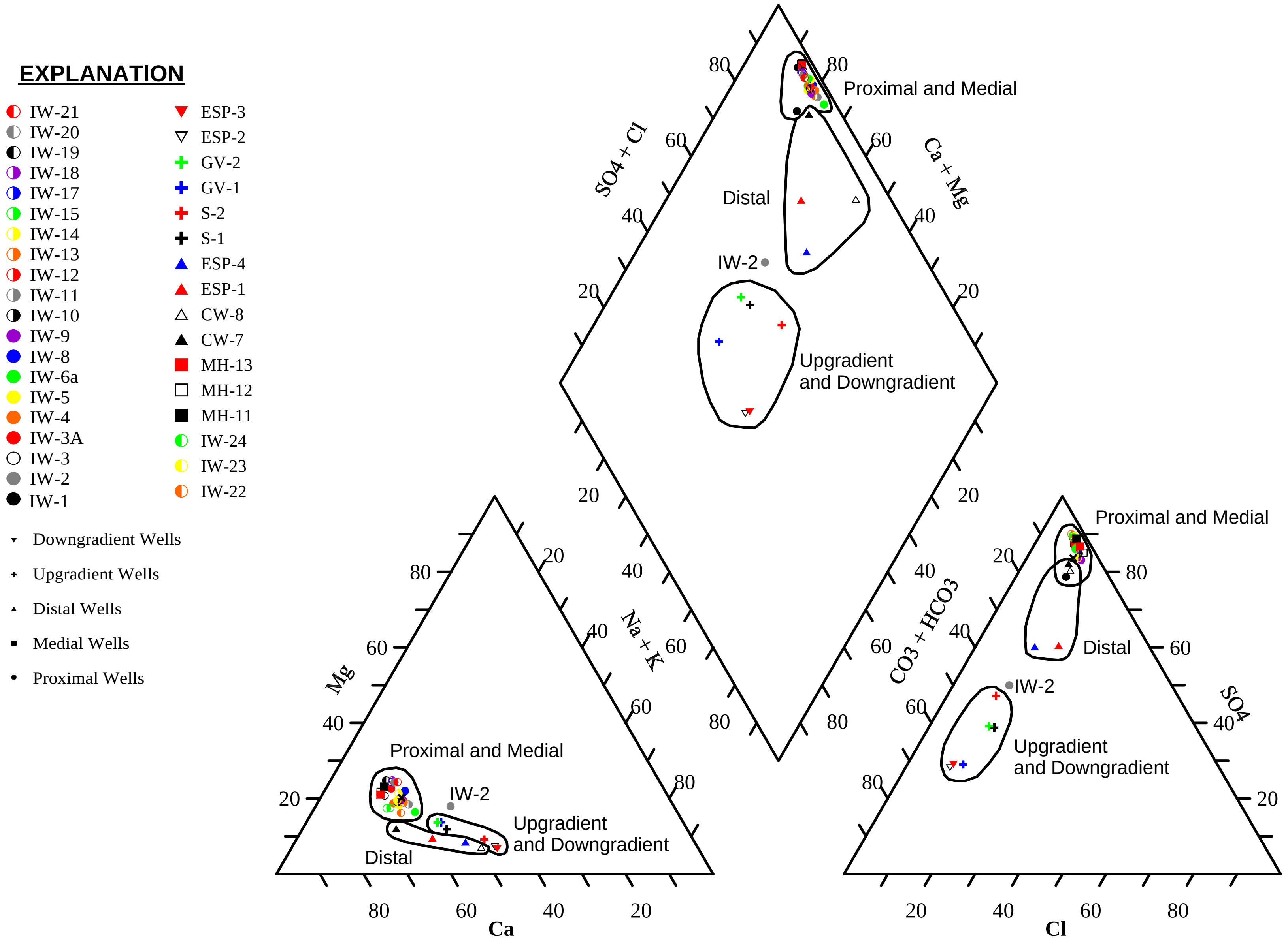


HYDRO
GEO
CHEM, INC.

SULFATE CONCENTRATION IN SOUTH HALF OF INTERCEPTOR WELLFIELD

APPROVED	JRN	DATE	8/8/06	FIGURE	11

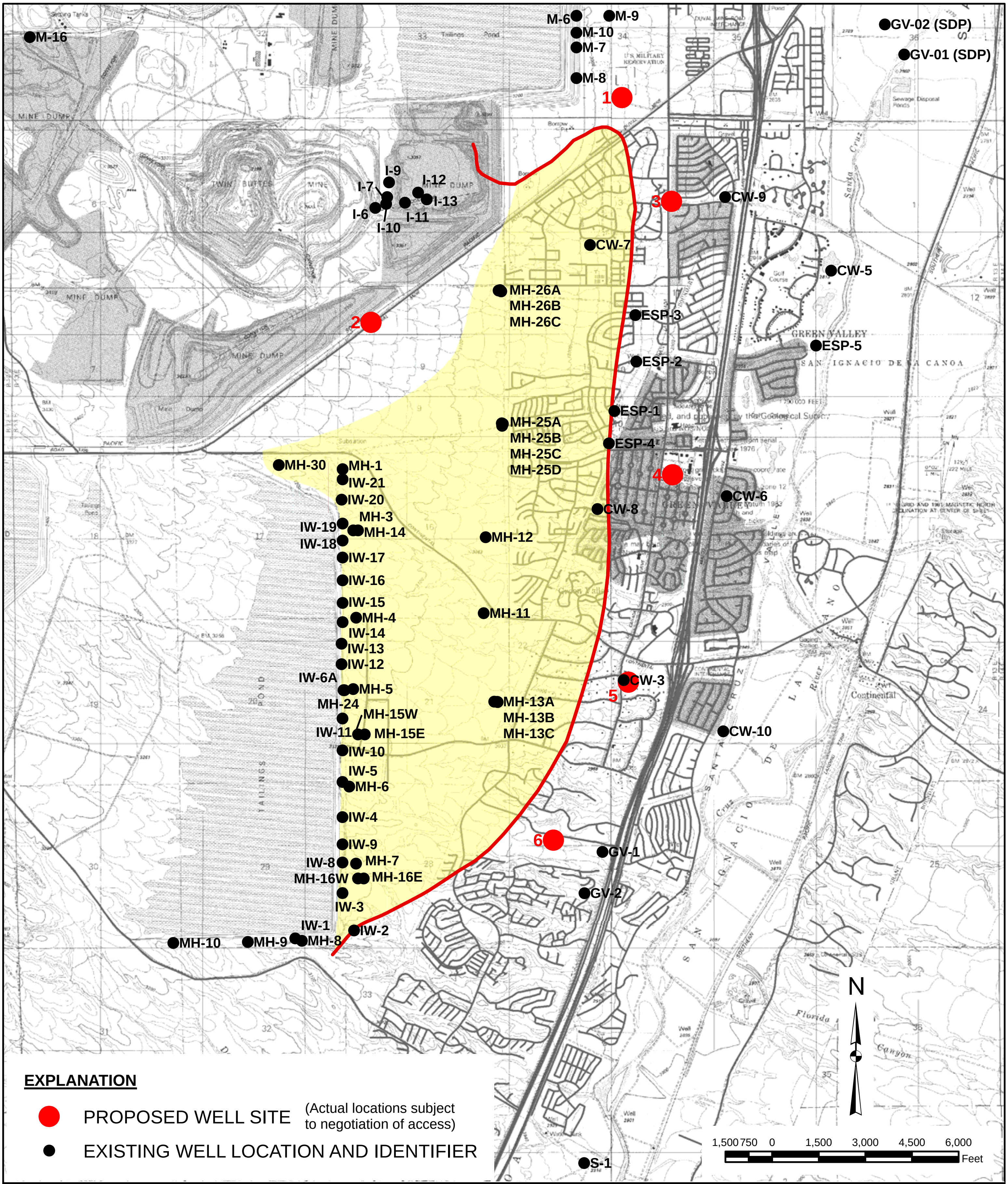
H:\78300\DATA\Water Quality\Tables_PDSIdbase_April06\PDSI IW Hydrographs.xls: South Half



HYDRO GEO CHEM, INC.

TRILINEAR DIAGRAM OF MAJOR IONS IN SIERRITA GROUNDWATER

APPROVED	DATE	REFERENCE	FIGURE
NWH	8/8/06	H:/78300/Sulfate_issues/ TRILIN/sierrita_6-14/sierrita2.srf	12



HYDRO GEO CHEM, INC.

PROPOSED MONITORING WELL LOCATIONS

Approved	Date	Revised	Date	Reference:	FIG.
JRN	8/9/06			7830008G	13

FIGURE 14
Schedule for Aquifer Characterization and Sulfate Mitigation Plans

TASK	MONTHS AFTER ADEQ APPROVAL OF WORK PLAN																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Work Plan Submittal To ADEQ Two Months After Effective Date of Consent Order																								
AQUIFER CHARACTERIZATION PLAN																								
Task 1, Well Inventory	■	■	■																					
Task 2, Plume Characterization																								
Task 2.1 - Data Compilation and Evaluation	■	■	■	■	■																			
Task 2.2 - Groundwater Monitoring (Summer and Winter Events)	■	■	■	■	TBD[1]					TBD[1]	■	TBD[1]												
Task 2.3 - Depth-Specific Sampling in Existing Wells	■	■	■	■	■	■																		
Task 2.4 - Offsite Well Installation and Testing																								
Site Access Agreements and Permitting	■	■	■	■	■	■	■	■	■	■	■	TBD[1]												
Well Installation					TBD[1]	■	■	■	■	■	■	■	■	■	TBD[1]									
Water Sampling and Hydraulic Testing							TBD[1]	■	■	■	■	■	■	■	■	■	TBD[1]							
Task 3, Evaluation of PDSI Groundwater Sulfate Control System						■	■	■	■	■	■													
Task 4, Sulfate Fate and Transport Evaluation								■	■	■	■	■	■	■	■	■	■	■						
Task 5, Aquifer Characterization Reports				1		2		3 [1]	4			5			6 [1]				7		8			
IDENTIFICATION OF POTENTIAL INTERIM ACTIONS																								
Identification of Interim Mitigation Actions	■	■	■	9																				
FEASIBILITY STUDY FOR SULFATE MITIGATION PLAN																								
Identification and Screening of Mitigation Actions and Technologies					■	■	■	■	■															
Development and Screening of Mitigation Alternatives										■	■	■	■	■	■									
Treatability Studies													■	■	■	■	■	■						
Detailed Analysis of Mitigation Alternatives																■	■	■	■	■	■			
Feasibility Study Report with Recommended Mitigation Plan																					■	■	■	10

Notes:

[1] Start and end times to be determined based on ability and timing to access sampling and drill sites through agreements with private parties and public entities.

EXPLANATION OF REPORTS

1. Well Inventory Report (Task 1)
2. Data Compilation and Evaluation Report (Task 2.1)
3. Groundwater Monitoring Data Report for First Sampling Event (Task 2.2)
4. Results of Depth-Specific Sampling of Existing Wells (Task 2.3)
5. Evaluation of PDSI Groundwater Sulfate Control System (Task 3)
6. Groundwater Monitoring Data Report for Second Sampling Event (Task 2.2)
7. Results of Numerical Modeling of Sulfate Fate and Transport (Task 4)
8. Results of Offsite Well Installation and Testing (Task 2.5)
9. Technical Memorandum on Interim Actions
10. Mitigation Plan for Sulfate with Respect to Drinking Water Supplies in the Vicinity of Phelps Dodge Sierrita Tailing Impoundment

APPENDIX A

REVIEW OF GEOLOGIC DATA

TABLE OF CONTENTS

FIGURES

1. GEOLOGY

This appendix reviews the geology in the vicinity of the Phelps Dodge Sierrita Tailing Impoundment (PDSTI). This review includes the Twin Buttes Mine area north of the PDSTI because the basin fill aquifer is continuous between the two properties. Geologic data summarized in this appendix have been drawn from a variety of sources including U.S. Geological Survey publications; reports on various geologic, water supply, and environmental investigations; and a review of geologic logs from area wells.

1.1 Geologic Setting

The PDSTI is in the southern portion of the Tucson basin (Figure A.1). The southern portion of the basin is bounded by the Sierrita Mountains on the west and the Santa Rita Mountains to the east, with the axis of the basin lying approximately along the Santa Cruz River. The mountains are composed of bedrock materials and the basin consists of unconsolidated to indurated clastic sediments, evaporites, and in places interbedded volcanics.

The geologic units in the PDSTI area can be divided into three generalized units: Recent alluvium, Quaternary and Tertiary basin fill deposits, and the bedrock complex. Recent alluvium is not a significant aquifer because it is typically unsaturated. Basin fill materials form the primary water supply aquifer in the area. Bedrock is typically a low permeability material that is not a significant aquifer.

Figure A.2 is a generalized geologic map of the area taken from Davidson (1973) who characterized the lithology and formations of the basin fill throughout the Tucson basin. Detailed geologic maps of the Sierrita Mountains and Santa Rita Mountains are provided by Cooper (1973) and Drewes (1971a, 1971b), respectively.

To illustrate the basin fill character and the bedrock structure, geologic logs for area wells were compiled and reviewed to produce a series of geologic cross sections depicting the distribution of subsurface materials. The cross sections are included as Figures A.3 through A.9.

1.2 Recent Alluvium

Recent alluvium consists of the unconsolidated sediment in stream channels of the Santa Cruz River and the various washes that feed into the Santa Cruz River from the surrounding uplands, alluvial fans, and sheet wash deposits (Anderson, 1987). The stream channel sediments are up to 200 feet thick in the vicinity of the Santa Cruz River and include coarse grained sediments in the stream channel and clayey to sandy overbank deposits on the floodplain of the river (Pima Association of Governments (PAG), 1983a). Recent alluvium is thin in washes tributary to but distant from the Santa Cruz River. Geologic logs for monitoring wells completed in stream channel deposits six or more miles west of the Santa Cruz River, indicate the alluvium ranges from zero feet to several tens of feet thick (Errol L. Montgomery & Associates (ELMA), 2001). Alluvial fan and sheet wash deposits form the upper surface of most non-bedrock areas. The thickness of recent alluvial fan and sheet wash deposits are not well described in geologic logs as they are typically undifferentiated from the underlying basin fill.

1.3 Basin Fill Deposits

The Quaternary-Tertiary basin fill is composed of interbedded sequences of sand, gravel, silt and clay, and is the principal aquifer of the region. Sand and gravel are the primary components of the basin fill and dominate the lower portion of the sequence near the PDSTI. Coarse, cobbly horizons and caliche-cemented zones are sometimes present over large areas. Volcanic flows and tuff interbeds occur in the mid-Tertiary portions of the basin fill.

Davidson (1973) differentiated basin fill deposits into three units: the Pleistocene Fort Lowell Formation, the Miocene to Pliocene Tinaja beds, and the Oligocene Pantano Formation. Although Davidson (1973) and Schmidt (PAG, 1983a) projected these units into the Green Valley area, the basin fill is typically undivided in drill logs and other geologic descriptions of the Green Valley area. An exception is the Pantano Formation which is sometimes identified in geologic logs and area descriptions in Green Valley (e.g., Errol L. Montgomery & Associates and Dames and Moore, 1994; ELMA, 2001).

1.3.1 Fort Lowell Formation

The Fort Lowell Formation is composed of locally-derived sediment and grades from silty gravel at the basin margins to silty sand and clayey silt in the center of the basin. Fort Lowell Formation typically contains 25 to 60 percent material that is coarser than sand; is loosely consolidated to weakly cemented and light brown, gray brown, or reddish brown in color; and commonly contains clasts of volcanic rocks in the vicinity of the Sierrita Mountains (Davidson, 1973). The Fort Lowell is estimated to be 200 feet thick in the vicinity of the Twin Buttes Mine tailing impoundment and over 200 feet thick at the south end of the PDSTI (PAG, 1983a).

1.3.2 Tinaja Beds

The Tinaja beds are mainly sandy gravels with interbedded conglomerate and sandstone near the margins of the basin, grading to gypsifeous clayey silt and mudstone in the center of the basin. Felsic to mafic volcanic interbeds are locally present. Interpreted as sedimentary detritus filling the basin during subsidence (Davidson, 1973), the Tinaja beds lie unconformably over the Pantano Formation and are overlain unconformably by Fort Lowell Formation.

The Tinaja beds are divided into three non-conformable units: the upper Tinaja consisting primarily of gravel and sand near the basin margin and sand and clayey silt in the central portions of the basin; the middle unit represented by gypsiferous and anhydritic clayey silt and mudstone; and the lower unit comprised largely of silty gravel and conglomerate with interbedded volcanics (Anderson, 1987).

Lower Tinaja beds outcrop south of Tinaja Wash in the Sierrita Mountains approximately two miles southwest of the PDSTI. There, they consist of tuffaceous gravel underlain by felsic flows and tuffs with interbedded conglomerate and gravel. Although shown separately on the geologic map (Figure A.2), the mid-Tertiary volcanics are considered to be part of the Tinaja beds by Davidson (1973) and Anderson (1987).

In the vicinity of the PDSTI, the Tinaja beds are composed largely of sand and gravel due to the close proximity to the basin margin. Also, the clay and evaporite-rich middle unit of the Tinaja beds is absent in this area. Sand and gravel facies occur near the basin margins with 20 to 50 percent of material being coarser than sand in the gravel facies and 5 to 20 percent of material being coarser than sand in the sand facies. Volcanic clasts compose 50 percent or more of coarse material.

1.3.3 Pantano Formation

The Oligocene Pantano Formation is a reddish brown, weakly to moderately consolidated sequence described as ranging from silty sandy conglomerate, silty and pebbly sandstones, and moderately well cemented gravel. It is composed of granitic, sedimentary and volcanic clasts in an arkosic to clay-rich, sandy matrix, and weakly to strongly cemented by calcium carbonate. The Pantano Formation averages about 50 percent sand and gravel, but ranges from a low of

30 percent to a high of 70 percent sand and gravel (Davidson, 1973). Interbedded volcanic flows and tuffs are locally present within the sedimentary sequence. The Pantano also contains mudstone, gypsiferous mudstone and local landslide debris, and mega-breccias (Anderson, 1987). The Pantano Formation is correlative with the Helmet Fanglomerate, which outcrops northwest of the Twin Buttes Mine (Figure A.2).

1.3.3.1 Interpretation of Pantano Formation Top and Thickness

There are different interpretations regarding the top and thickness of the Pantano Formation in the vicinity of the PDSTI. The differences are probably due to difficulty in identifying the contact in boreholes, a gradational contact between the Pantano Formation and the overlying Tinaja beds, or a fundamental disagreement as to the attributes of the units as defined by different workers.

As interpreted by PAG (1983b), the Pantano Formation thickens from 200 feet thick at the Twin Buttes Mine tailing impoundment to 500 feet thick at the center of the basin. At the PDSTI, PAG (1983b) interpreted the Pantano Formation to be 125 feet thick near the impoundment and up to 600 feet along the basin axis (PAG, 1983b). Based on drilling in the vicinity of PDSTI and elsewhere, the Pantano Formation is believed to be very thin to nonexistent in the vicinity of the Twin Buttes Mine and PDSTI (Barter & Kelly 1982, ELMA, 1986, 1989, 1991, 1995b, and 2004).

In geologic logs of IW and MH wells in the vicinity of the PDSTI interceptor wellfield (ELMA, 1986, 1989, 1991, 1995b, and 2004), the Pantano Formation is shown as a relatively thin and discontinuous veneer overlying bedrock ranging from zero to 125 feet thick with the thicker intercepts often lying in what may be topographic lows in the bedrock (Figure A.4b). The Pantano Formation is identified only in wells in the northern portion of the IW wellfield drilled in late 1994 through early 1995. Based on summary lithologic logs of wells in the southern portion of the wellfield, the Pantano Formation is either absent or undifferentiated from younger basin fill. Geologic logs for monitoring wells at the interceptor wellfield do not identify the Pantano Formation with the exception of MH-14, which shows a 30 feet thick veneer overlying bedrock. The geologic logs also do not distinguish contacts between the younger basin fill formations, the Tinaja beds and Fort Lowell Formation.

In contrast to the interpretation described above, cross sections developed by Schmidt (PAG, 1983b) depict the Pantano Formation as being consistently present in the vicinity of the PDSTI. PAG (1983b) identifies Pantano Formation as the lower 100 to 200 feet of basin fill overlying bedrock along the entire eastern margin of the tailing impoundment, with a minimum thickness for the Pantano Formation of slightly less than 100 feet at the north end of the IW wellfield, thickening to 200 feet at the south end of the wellfield, and thickening eastward to approximately 500 feet thick at MH-13 which lies approximately 4,700 feet east of the tailing impoundment.

PAG (1983b) suggests the Pantano Formation at the PDSTI area may be equivalent to the caliche conglomerate that overlies bedrock in the vicinity of Twin Buttes Mine. Hargis and

Montgomery (PAG, 1983b, Appendix C.2, Figure 2) present a cross section through wells east of Twin Buttes Mine showing the Pantano Formation as approximately 900 feet thick in the basin four miles east of the Twin Buttes Mine tailing impoundment and thinning to the west, towards the basin margin, such that the Pantano Formation might be absent or of limited thickness under the impoundment. Barter and Kelly (1982) report that the Pantano Formation at Twin Buttes Mine is restricted to paleo-channels cut into bedrock and that the caliche conglomerate is mostly developed in the Tinaja beds rather than in the Pantano Formation.

Davidson (1973) presents a cross section north of the Twin Buttes Mine in the vicinity of the Pima Mine. Davidson (1973) assigns the Pantano Formation to the lower 400 feet of basin fill in a well four miles east of the Pima Mine, and depicts the unit as thinning to the west and becoming absent near the margins of the basin.

Anderson (1987) does not address the depth of the top of the Pantano Formation in the vicinity of the PDSTI. However, Anderson presents cross sections showing wells close to the Santa Cruz River bottoming in Lower Tinaja rather than in Pantano Formation.

Pantano Formation, logged as the correlative Helmet Fanglomerate, was identified at the bottoms of PDSTI wells ESP-1, ESP-3, and ESP-4. These wells were not drilled to bedrock; therefore no estimate of formation thickness can be made at those locations.

In summary, the interpretation by Schmidt (PAG, 1983b) of relatively thick Pantano Formation at the PDSTI is inconsistent with the interpretations of ELMA (1986, 1989, 1991, 1995b, and 2004). The interpretation that the Pantano Formation thins or is absent close to the margins of the basin and may be restricted to paleo-channels as indicated by Davidson (1973), Hargis and Montgomery (PAG, 1983b), and Barter and Kelly (1982) is consistent with extensive drilling data for the PDSTI area. This interpretation was used to develop the cross sections in this appendix.

1.3.4 Characteristics of Basin Fill in the PDSTI Area

Geologic logs for wells in the PDSTI area generally have good descriptions of the basin fill material, although contacts between basin fill formations are generally not identified except for the Pantano Formation in some geologic logs. According to geologic logs of wells in the vicinity of the PDSTI, sand and gravel dominate the lower half of the basin fill immediately overlying bedrock, and are the major components of the overall basin fill sequence there. In general, the occurrence of clay horizons interbedded with sands is more frequent in the upper portions of the basin fill than in the lower portions. Clay beds are thinner and scarcer within a few hundred feet above bedrock compared to intervals closer to the surface. Cobbly horizons, when present, usually occur within sand and gravel horizons, most frequently at stratigraphically lower positions in the basin fill than the clayey horizons. The cobbly horizons may represent paleo-channels in the sedimentary sequence. Rock layers logged in wells IW-8 and IW-9 may be volcanic interbeds in either the Tinaja beds.

The cross section incorporating the interceptor wellfield located along the eastern margin of the PDSTI (Figures A.3, A.4a, and A.4b) shows that the basin fill thickens as bedrock deepens from north to south towards at the southeast corner of the PDSTI. Depth to bedrock is less than 500 feet at IW-20 at the north end of the wellfield, and increases to greater than 1,000 feet in IW-2 at the south end. Wells along the southern margin of the tailing impoundment show a general thickening of basin fill from west to east. Together these two features indicate thickening of basin fill and deepening of bedrock under the southeast corner of the tailing impoundment.

A north-south cross section from MH-13 to MH-26 (Figure A.5) shows the basin fill is thicker at the south end of the section due to an apparent fault that downdrops the bedrock complex between MH-11 and MH-13. East-west cross sections show that the basin fill thickens from west to east as the elevation of the top of the bedrock complex decreases (Figures A.7, A.8, and A.9).

1.3.5 Characteristics of Basin Fill Deposits at the Twin Buttes Mine Area

Basin fill stratigraphic units have not been distinguished in geologic logs for the Twin Buttes Mine area wells. The basin fill is composed largely of multi-lithic gravel and sand, with fine to coarse sand being the most abundant, and lesser amounts of silt and clay. Basin fill deposits thicken from west to east, ranging from zero thickness at the western exposure of bedrock, to about 1,300 feet thick near the Santa Cruz River. The basin fill is 10 to 130 feet thick west of the Twin Buttes pit and approximately 700 to 900 feet thick in the I-wells east of the pit. The most common materials are fine to coarse sand, with gravelly and silty sand layers. Coarser sediments are reportedly more abundant close to the tailing impoundment margin with finer sediment comprising an increasing percentage eastward (ELMA, 1995a).

Most of the basin fill in the Twin Buttes Mine area is probably Tinaja beds and Fort Lowell Formation (ELMA, 1995a; Barter and Kelly, 1982). The Pantano is described in Barter and Kelly (1982) as being primarily confined to paleo-channel filling in bedrock at the Twin Buttes Mine. The Helmet Fanglomerate mapped by Cooper (1973), which outcrops north of the Twin Buttes property (Figure A.2) is considered the stratigraphic equivalent of the Pantano Formation.

Barter and Kelly (1982) describe a caliche conglomerate within what is probably the Tinaja beds at the Twin Buttes Mine pit. The caliche conglomerate is up to 100 feet thick, and lies either directly on bedrock or on older Pantano Formation. The caliche conglomerate occurs at the base of an approximately 700-foot thick sedimentary sequence of Tinaja beds and Fort Lowell Formation. The caliche conglomerate is reported to be up to thirty feet thick in the vicinity of the Twin Buttes oxide plant (ELMA, 1997). Few logs are available for wells along the eastern margin of the Twin Buttes tailing impoundment, so the distribution of the caliche conglomerate is uncertain, but up to 100 feet of caliche conglomerate is reported to have been intercepted in exploration boreholes east of the tailing margin (PAG 1983b, Appendix C.2).

1.4 Bedrock Complex

In the vicinity of the PDSTI, bedrock comprises upper Cretaceous Demetrie Volcanics, lower Cretaceous Angelica Arkose, and Paleozoic limestones. At the Twin Buttes Mine, subsurface bedrock units include Paleozoic and Mesozoic sediments, early Tertiary intrusives, and Precambrian granite (Cooper, 1973, Barter and Kelly, 1982).

1.4.1 Early Tertiary Intrusives

Early Tertiary intrusives include the Ruby Star granodiorite and related dikes, and quartz monzonite. These rocks are associated with the intrusive igneous complex genetically associated with copper mineralization in the district. The Ruby Star granodiorite batholith outcrops extensively to the west of the Twin Buttes Mine and comprises bedrock underlying basin fill in monitoring wells west of the Twin Buttes pit (Montgomery Watson and Errol L. Montgomery & Associates, 1998).

Quartz monzonite dikes cut the Demetrie Volcanics in outcrop west of the PDSTI. Quartz monzonite and granodiorite intervals observed in drill cuttings from the Demetrie Volcanics in the interceptor wellfield may be dikes of the Tertiary intrusives intruding the volcanics.

1.4.2 Upper Cretaceous Demetrie Volcanics

The upper Cretaceous Demetrie Volcanics in the PDSTI area are largely andesite and dacite breccias either overlying a basal conglomerate or lying directly on older rocks. The Demetrie Volcanics lie unconformably on the lower Cretaceous Angelica Arkose and the Triassic Ox Frame Volcanics. Two rhyolite tuffs are interbedded within the andesite-dacite breccias, providing distinct stratigraphic markers. The basal conglomerate, where present, ranges from tens to hundreds of feet thick and is composed of detritus from the underlying rocks. The basal conglomerate thins out laterally, and becoming absent in some areas (Cooper, 1971).

Andesite and dacite breccias comprise the bulk of the Demetrie Volcanics. The breccias are well indurated, consisting of angular to sub-rounded, granule to boulder size fragments in a clastic andesitic matrix. Feldspar and relict mafic phenocrysts in an aphanitic matrix characterize the clasts of the breccia.

The Demetrie Volcanics outcrop immediately west of the PDSTI, with its type section exposed along the northwest trending Demetrie Wash. The surface expression of the volcanics is roughly lensoidal in shape elongate in the east-west direction. Bedding, where recognizable, tilts moderately to the south. The maximum thickness of the Demetrie Volcanics is thought to be 8,000 feet, but it could be less due to unrecognized folds or repetitions in the sequence (Cooper, 1971).

The Demetrie Volcanics form bedrock under the southeast corner of the PDSTI. Logs from wells intercepting the Demetrie Volcanics indicate they are primarily andesitic to dacitic in composition, with interbedded rhyolite tuff. The Demetrie Volcanics at the interceptor wellfield seem to be anomalously soft there because indurated bedrock was not reached until passing through the upper few hundred feet of Demetrie Volcanics (Figure A.4). Therefore, top of the bedrock formation, i.e., the Demetrie Volcanics, in this part of the wellfield does not always correlate with the top of indurated material, as it does elsewhere where the bedrock is comprised of well-indurated Angelica Arkose or Paleozoic limestone.

The apparent softness of the Demetrie Volcanics under the PDSTI seems to be atypical compared to descriptions of the unit elsewhere in the vicinity. The anomalous softness may be related to fracturing due to faulting, sedimentary interbeds, and/or hydrothermal argillic alteration resulting in degradation of the volcanics. The softness of the Demetrie Volcanics in the PDSTI area is important because many wells in the south part of the interceptor wellfield are screened within and produce water from the upper portion of the Demetrie Volcanics.

Intervals of granodiorite and quartz monzonite were logged within the Demetrie Volcanics in wells IW-4 and IW-24 (Figure A.4a). These are interpreted as dikes of Tertiary intrusive rock cutting the volcanics, based on the occurrence of granodiorite and quartz monzonite dikes in outcrops of Demetrie Volcanics west of the PDSTI. Well logs also show occasional sandstone, Arkose, and siltstone layers interbedded within the volcanic sequence. In addition to clay alteration, hydrothermal propyllitic alteration represented by calcite, epidote, chlorite and pyrite as disseminations and veinlets is commonly reported.

1.4.3 Lower Cretaceous Angelica Arkose

The lower Cretaceous Angelica Arkose is an arkose with interbedded quartzite, conglomerate, siltstone and occasional thin limestones. It is approximately 5,000 feet thick, underlying the Demetrie Volcanics with angular unconformity (Cooper, 1971). The Angelica

Arkose outcrops west and north of the PDSTI, in the Twin Buttes pit, and in the Helmet Peak area north of the Twin Buttes Mine (Cooper, 1973). The Angelica Arkose has three members: a basal conglomerate, a middle arkose and siltstone member, and an upper arkosic grit and conglomerate member (Cooper, 1971).

The basal conglomerate is characterized by poorly sorted pebbles and cobbles in a sandstone matrix. Clasts are comprised primarily of silicic and intermediate volcanics, with some quartzite, graywacke, chert, limestone, felsic porphyry, aplite, and vein quartz, derived from older Mesozoic and Paleozoic rock units.

The middle member is comprised of about 2,000 feet of arkosic sandstone and siltstone in well-defined less than two feet thick beds. The sandstone is fine to coarse grained and well sorted. Color varies among olive to medium grey, to locally pale red to grayish red in color. The matrix is variable ranging from argillaceous, siliceous to calcareous and in places hydrothermally altered to epidote, sericite and chlorite (Cooper, 1971).

The upper member consists of a 1,600-foot thickness of light grey to light brown arkosic grit and pebble conglomerate with interbeds of siltstone, feldspathic sandstone, and greywacke. Matrix material is variably calcareous, argillaceous, or quartz. Occasional thin grey limestone beds are also reported in the upper member (Cooper, 1971).

Angelica Arkose comprises bedrock under most of the eastern part of the PDSTI, with the exception of the southeast corner where bedrock is Demetrie Volcanics. The Angelica

Arkose also forms bedrock in monitoring wells MH-13, MH-25 and MH-26 (Figure A.5) approximately 4,700 feet east of the interceptor wellfield. The top of the Angelica Arkose bedrock dips to the east towards the Santa Cruz River (Figures A.8 and A.9). Geologic logs for wells in the PDSTI area describe the arkose as being fine to coarse grained to conglomeritic with some clay layers, weakly to moderately reactive to acid, and red, pink, tan, brown or gray in color. The Angelica Arkose sometimes contains epidote-pyrite alteration in the PDSTI area and is a partial host to mineralization at the Twin Buttes Mine.

1.4.4 Paleozoic Rocks

Paleozoic carbonate bedrock has been intercepted in monitoring wells MH-11 and MH-12 directly below basin-fill east of the interceptor wellfield (Figure A.5). Data is insufficient to determine which formation the carbonates might belong to. Paleozoic sedimentary rock units in the area include Cambrian Bolsa quartzite and Abrigo formations, Devonian Martin Formation, Mississipian Escabrosa limestone and Pennsylvanian Horquilla limestone.

1.4.5 Precambrian Granite

Precambrian granite outcrops north of the PDSTI (Davidson, 1973) and at the Twin Buttes Mine (Barter and Kelly, 1982).

2. REFERENCES

Anderson, S.R. 1987, Cenozoic Stratigraphy and Geologic History of the Tucson Basin, Piima County, Arizona, USGS Water Investigations Report 87-4190.

Barter, C.F., and Kelly, J.L. Geology of the Twin Buttes Mineral Deposit, in Titley, Spencer, ed., 1982, Advances in Geology of the Porphyry Copper Deposits, Southwestern North America, p 407-432

Cooper, J.R. 1971. Mesozoic Stratigraphy of the Sierrita Mountains, Pima County, Arizona, USGS Professional Paper 658-D.

Cooper, J.R., 1973. Geologic Map of the Twin Buttes Quadrangle, southwest of Tucson, Pima County, Arizona, USGS Misc. Inv. Map I-745.

Davidson, E.S. 1973. Geohydrology and Water Resources of the Tucson Basin, Arizona, USGS Water-Supply Paper 1939-E.

Drewes, H. 1971a. Geologic Map of the Mt. Wrightson Quadrangle. USGS Miscellaneous Investigation Map I-614.

Drewes, H. 1971b. Geologic Map of the Sahuarita Quadrangle. USGS Miscellaneous Investigation Map I-613.

Errol L. Montgomery & Associates (ELMA). 1986, Evaluation of Pumping Test Data for Interceptor Wells. June 16, 1986.

ELMA. 1989. Hydrologic Report in Support of Groundwater Quality Protection Permit Application, Sierrita Operation, Cyprus Sierrita Corporation. April 7, 1989.

ELMA. 1991. Supplemental Hydrologic Report in Support of Aquifer Protection Permit Application, Sierrita Operation, Cyprus Sierrita Corporation. July 9, 1991.

ELMA. 1995a. Distribution of Sulfate in Groundwater East from Twin Buttes Tailings Impoundments and Capture Zones for Operation of Reclamation Well RT-1. January 31, 1995.

ELMA. 1995b. Results of Drilling, Construction, Development and Testing, Phase II Interceptor Wells, Sierrita Operation, Cyprus Sierrita Corporation Pima County, Arizona. June 23, 1995.

ELMA. 1997. Characterization of Hydrogeologic Conditions in the Oxide Plant Area, Twin Buttes Mine, Cyprus Sierrita Corporation, Pima County, Arizona. January 30, 1997.

ELMA. 2001. Additional Characterization of Hydrogeologic Conditions Aquifer Protection Permit Application 101679 Sierrita Mine, Phelps Dodge Sierrita, Inc., Pima County, Arizona. January 4, 2001.

ELMA, 2004. Results of Drilling, Construction, and Testing for Interceptor wells IW-22, IW-23, IW-24, and IW-3A. April 6, 2004.

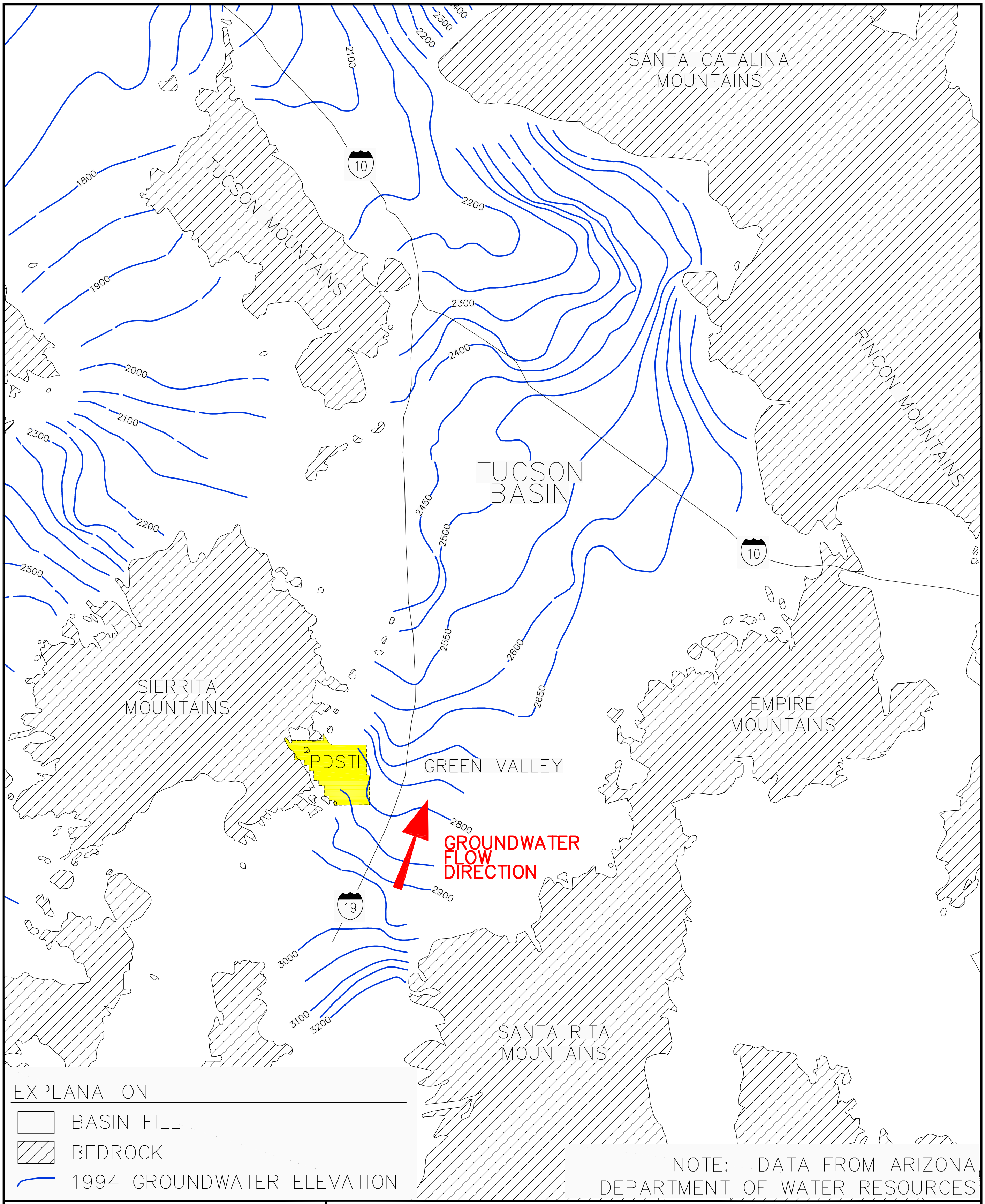
Errol L Montgomery & Associates and Dames & Moore. 1994. Aquifer Protection Permit Application, Sierrita Operation, Cyprus Sierrita Corporation, Pima County, Arizona. Volumes I and II. September 7, 1994.

Montgomery Watson and Errol L Montgomery & Associates. 1998. APP Permit Application Twin Buttes Mine. Volumes I and II. December 1998.

Pima Association of Governments (PAG). 1983a. Region Wide Groundwater Quality in the Upper Santa Cruz Basin Mines Task Force Area. September 1983.

PAG. 1983b. Ground-Water Monitoring in the Tucson Copper Mining District. September 1983.

FIGURES

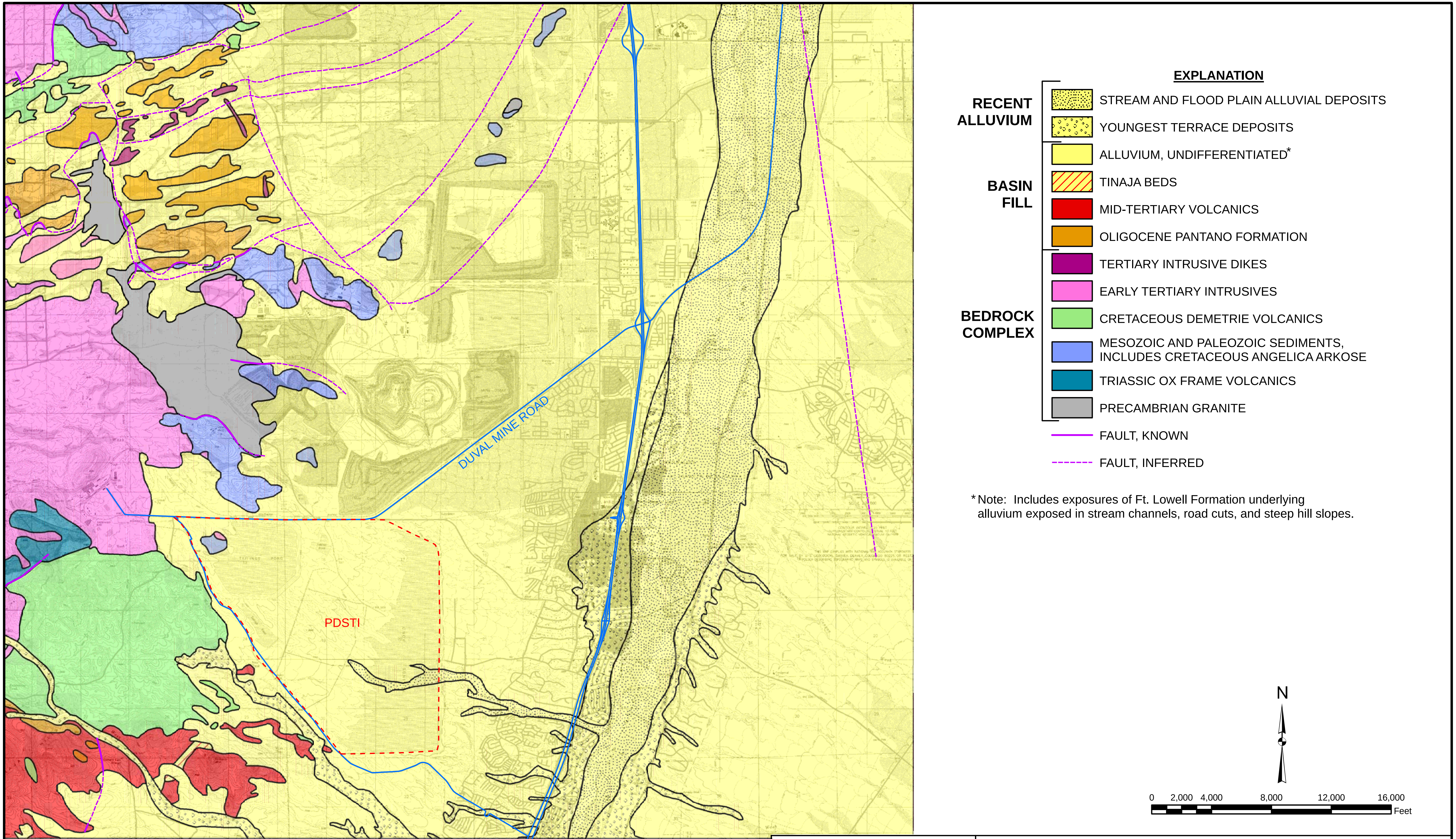


NOTE: DATA FROM ARIZONA DEPARTMENT OF WATER RESOURCES

HYDRO
GEO
CHEM, INC.

MAP OF TUCSON BASIN

Approved	Date	Revised	Date	Reference:	FIG.
JRN	8/9/06			7830045A	A.1



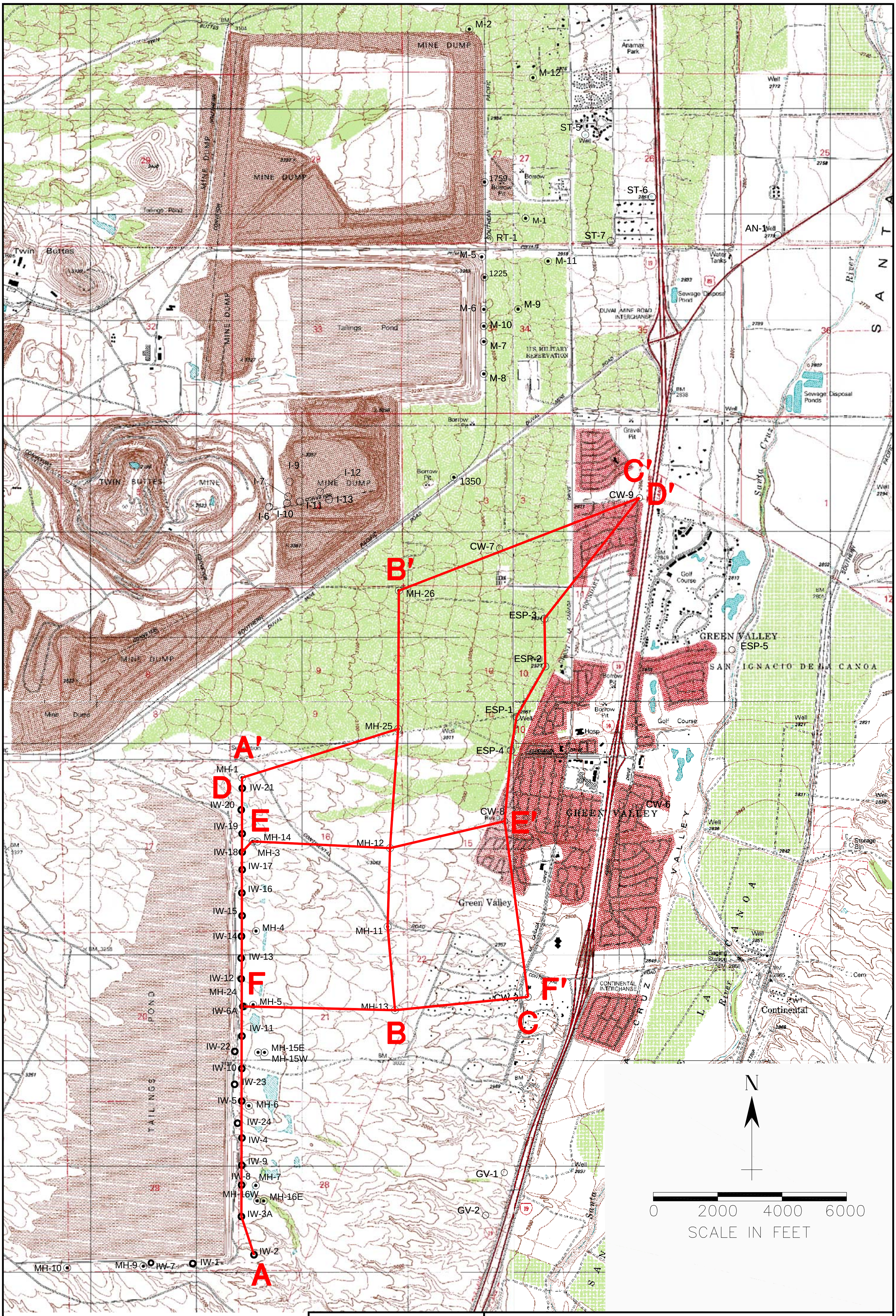
*Note: Includes exposures of Ft. Lowell Formation underlying alluvium exposed in stream channels, road cuts, and steep hill slopes.

SOURCE: DAVIDSON (1973).

HYDRO GEO CHEM, INC.

GEOLOGIC MAP OF PDSTI AND GREEN VALLEY AREA

Approved	Date	Revised	Date	Reference:	FIG.
JRN	6/1/06			7830006G	A.2



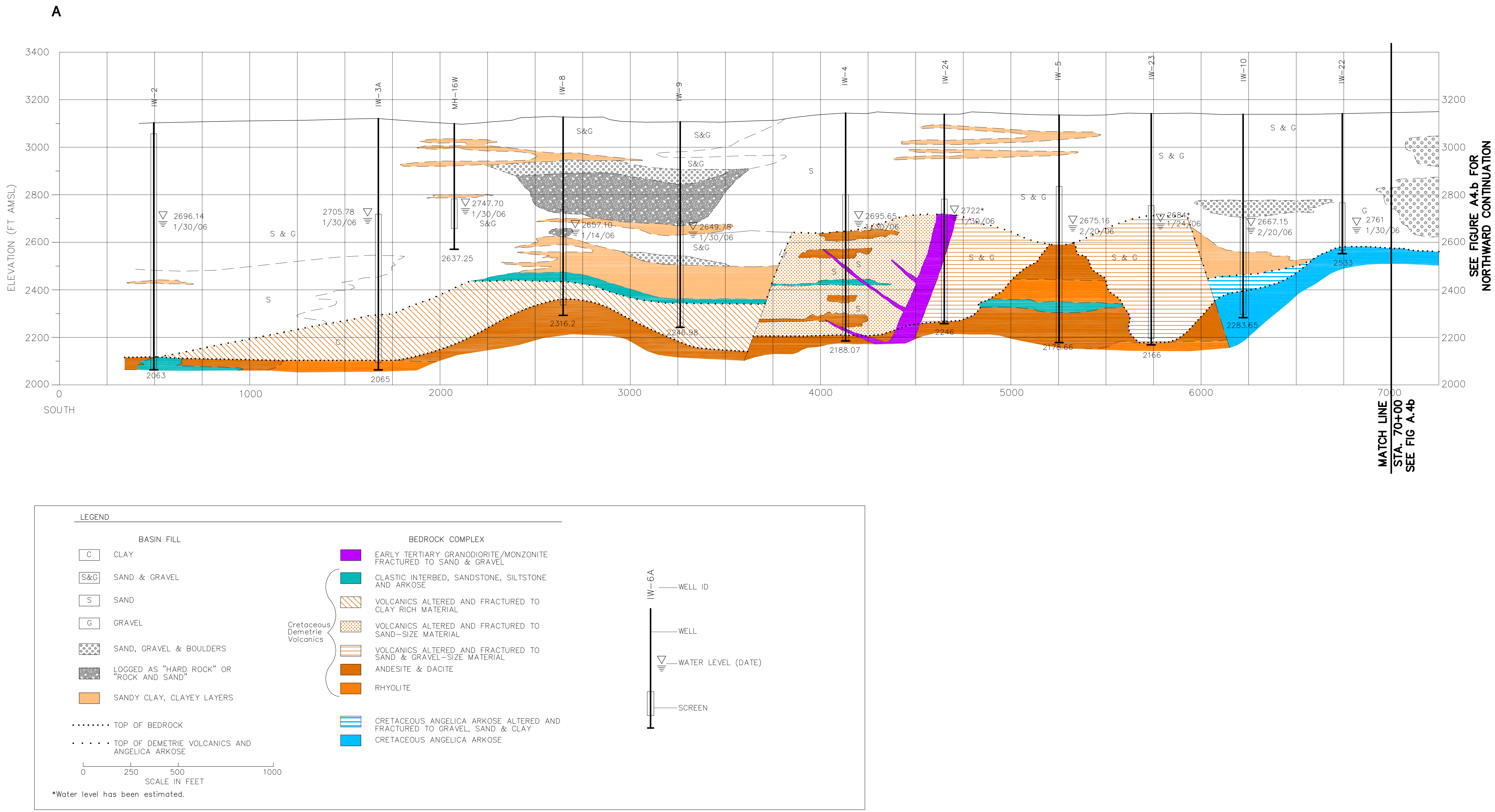
EXPLANATION

●	IW-2	INTERCEPTOR WELL
⊙	MH-16E	MONITOR WELL
○	ESP-4	OTHER WATER WELL

HYDRO
GEO
CHEM, INC.

SIERRITA TAILING IMPOUNDMENT AREA CROSS SECTION LOCATION MAP

Approved	Date	Revised	Date	Reference:	FIG:
KW	8/8/06			7830023A	A.3

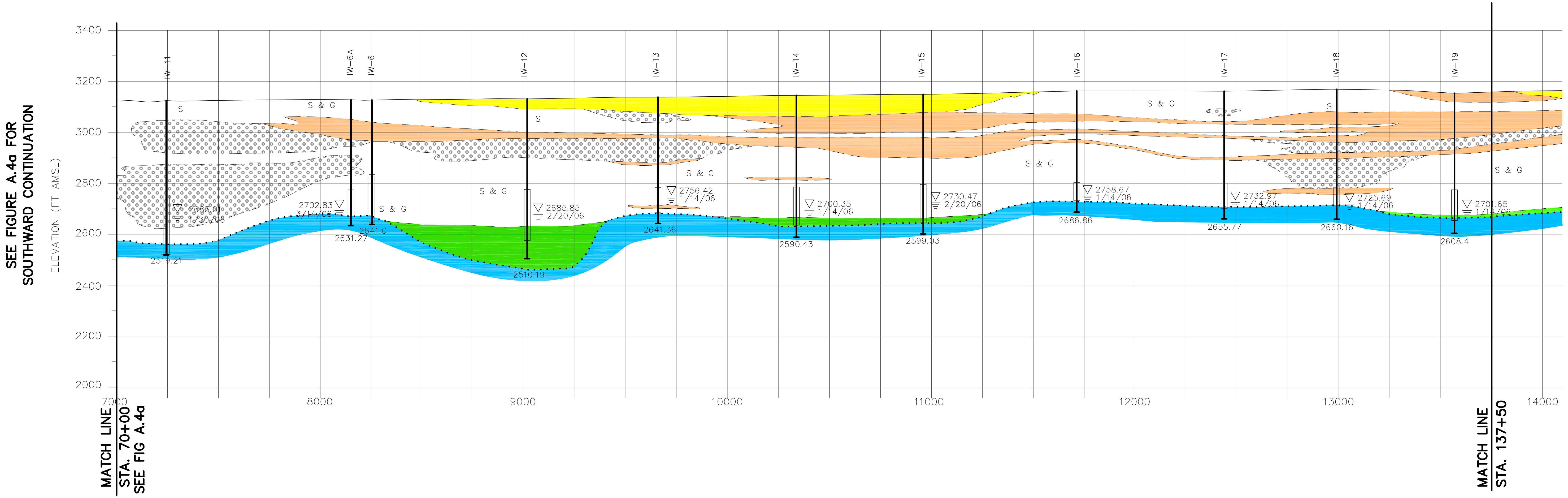


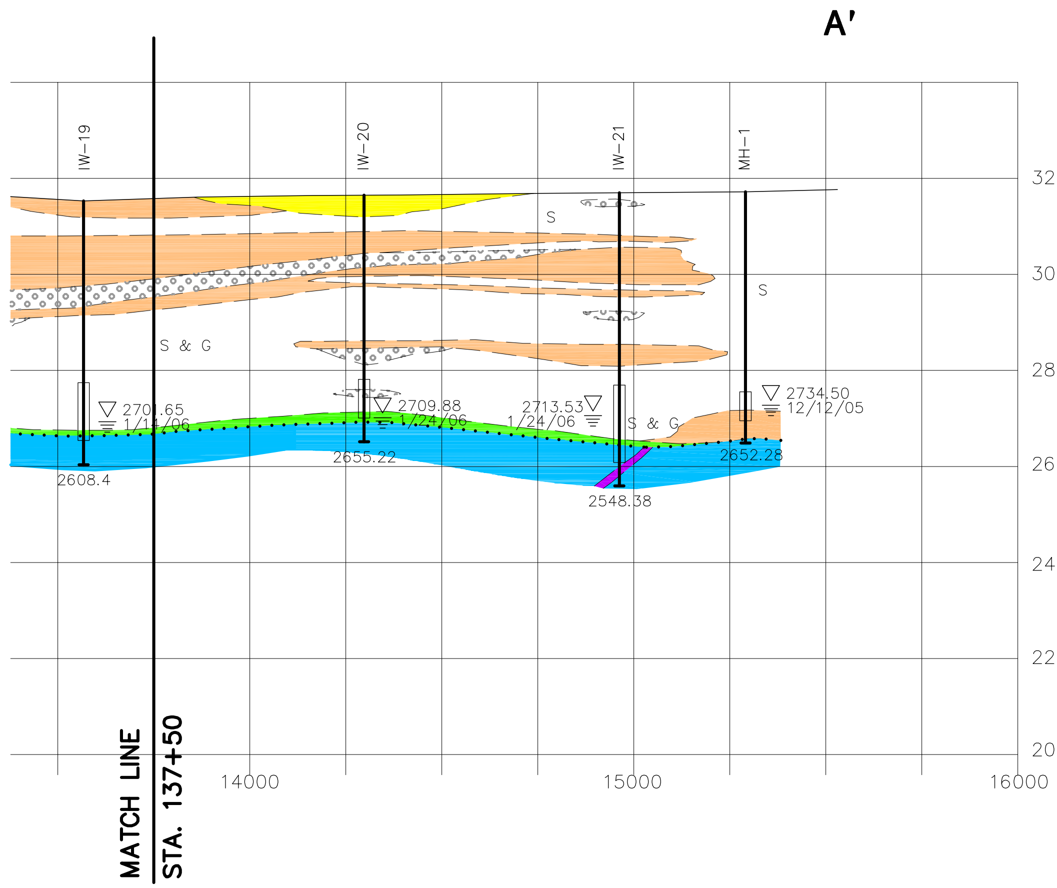
*Water level has been estimated.

HYDRO
GEO
CHEM, INC.

A - A' GEOLOGIC CROSS SECTION
SHEET 1 OF 2
SIERRITA TAILING IMPOUNDMENT AREA

Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830027A	A.4a





LEGEND

BASIN FILL

🟨	CALICHE CEMENTED GRAVEL, SAND, SILT AND CLAY
S	SAND
S&G	SAND & GRAVEL, INCLUDES INTERVALS LOGGED AS SANDY GRAVEL AND GRAVELLY SAND
▨	SAND & GRAVEL WITH COBBLES AND INTERVALS LOGGED AS UNIDENTIFIED ROCK
🟧	SILT AND SANDY CLAY, CLAY
🟩	OLIGOCENE PANTANO FORMATION

BEDROCK COMPLEX

🟪	EARLY TERTIARY QUARTZ MONZONITE
🟦	CRETACEOUS ANGELICA ARKOSE
······	TOP OF BEDROCK

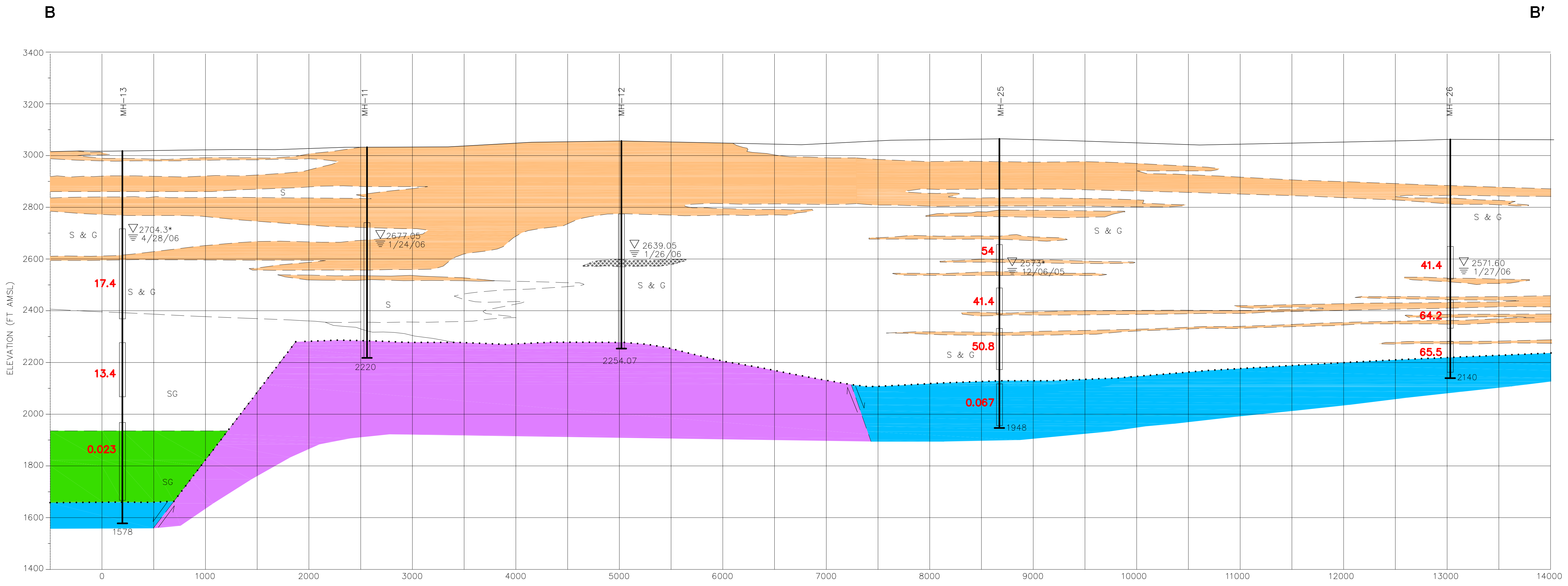
0 250 500 1000
SCALE IN FEET

IW-6A — WELL ID
— WELL
▽ — WATER LEVEL (DATE)
— SCREEN

HYDRO
GEO
CHEM, INC.

A - A' GEOLOGIC CROSS SECTION
SHEET 2 OF 2
SIERRITA TAILING IMPOUNDMENT AREA

Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830026A	A.4b



LEGEND

BASIN FILL

S&G SAND & GRAVEL, INCLUDES GRAVELLY SAND, SANDY GRAVEL AND SILTY SANDY GRAVEL

S SAND

SG GRAVELLY SAND

▨ SAND & GRAVEL WITH COBBLES

🟧 CLAYEY LAYERS, CLAY WITH INTERBEDDED SAND AND SMALL AMOUNTS OF GRAVEL

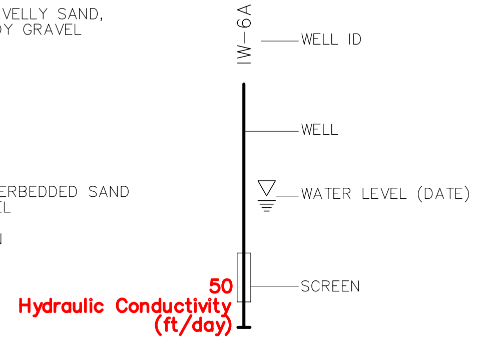
🟩 OLIGOCENE PANTANO FORMATION

BEDROCK COMPLEX

🟦 CRETACEOUS ANGELICA ARKOSE

🟪 PALEOZOIC LIMESTONE

.... TOP OF BEDROCK

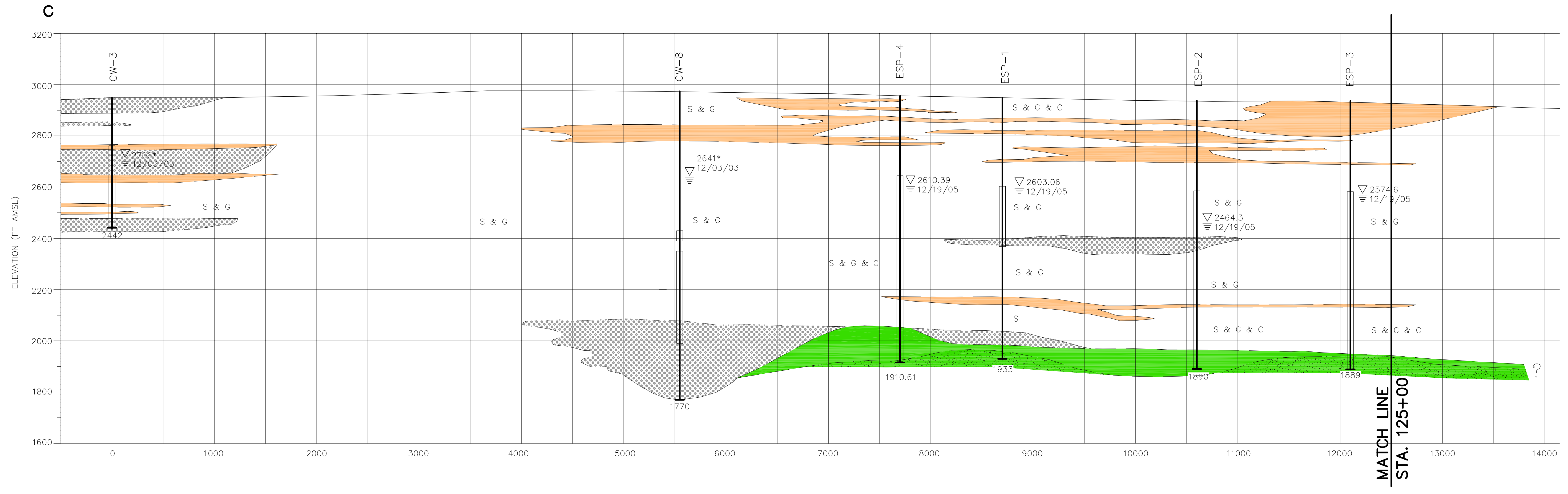


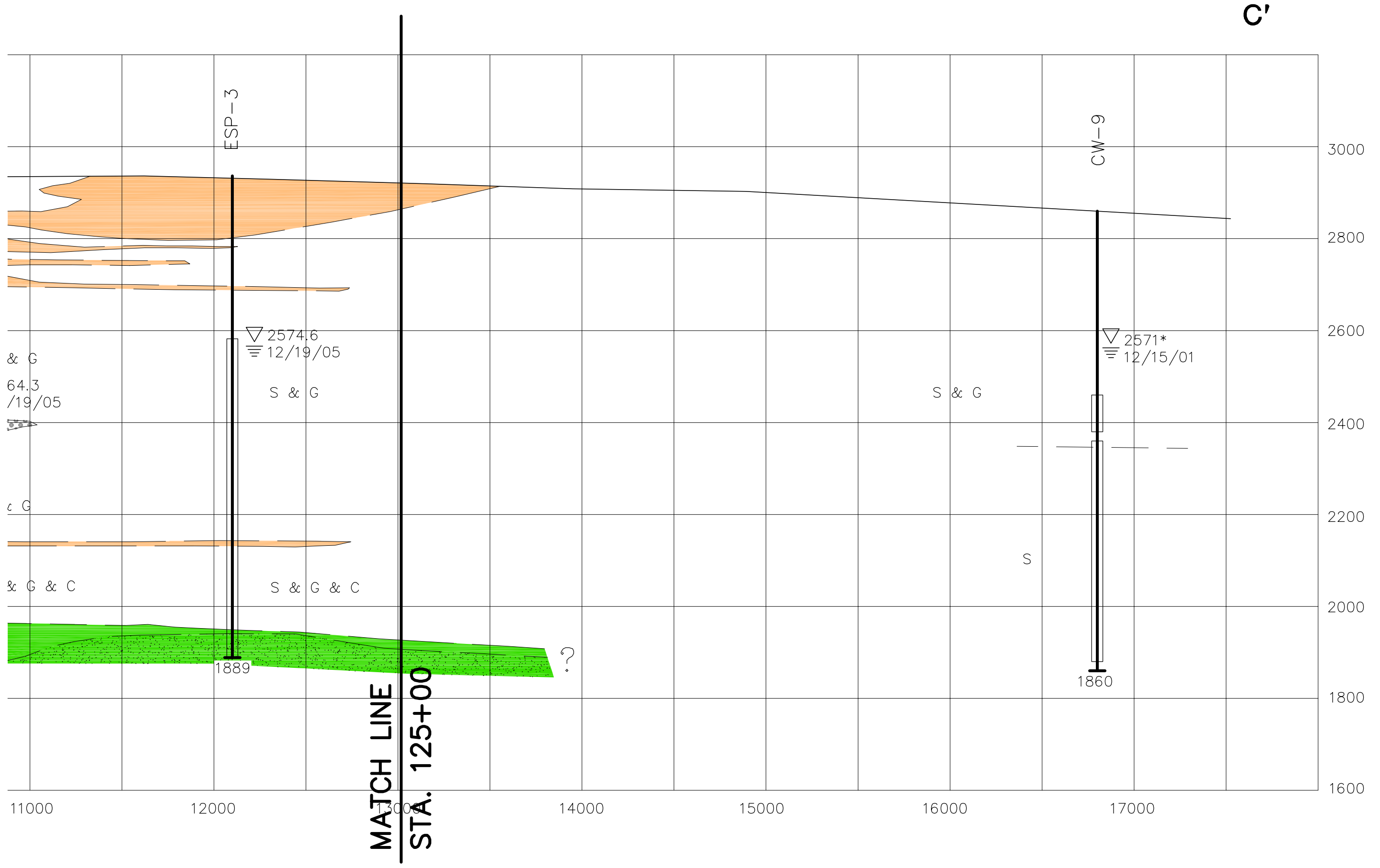
* Water level has been estimated.

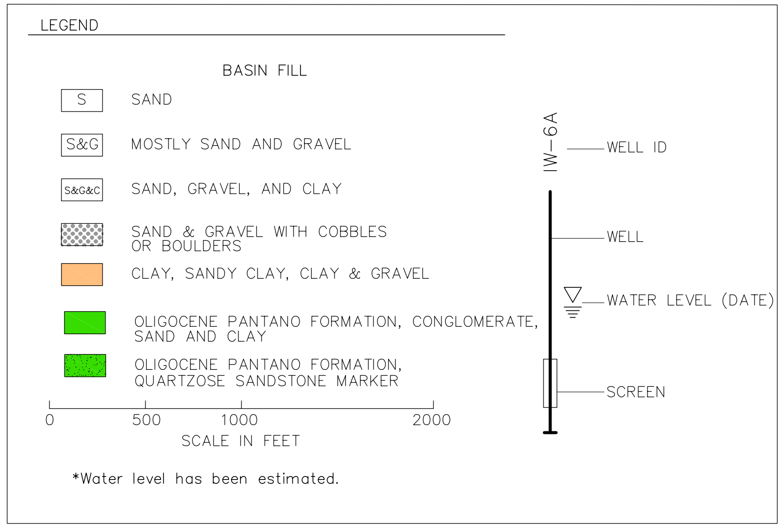
HYDRO
GEO
CHEM, INC.

B - B′ GEOLOGIC CROSS SECTION
SIERRITA TAILING IMPOUNDMENT AREA

Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830025A	A.5







LEGEND

BASIN FILL

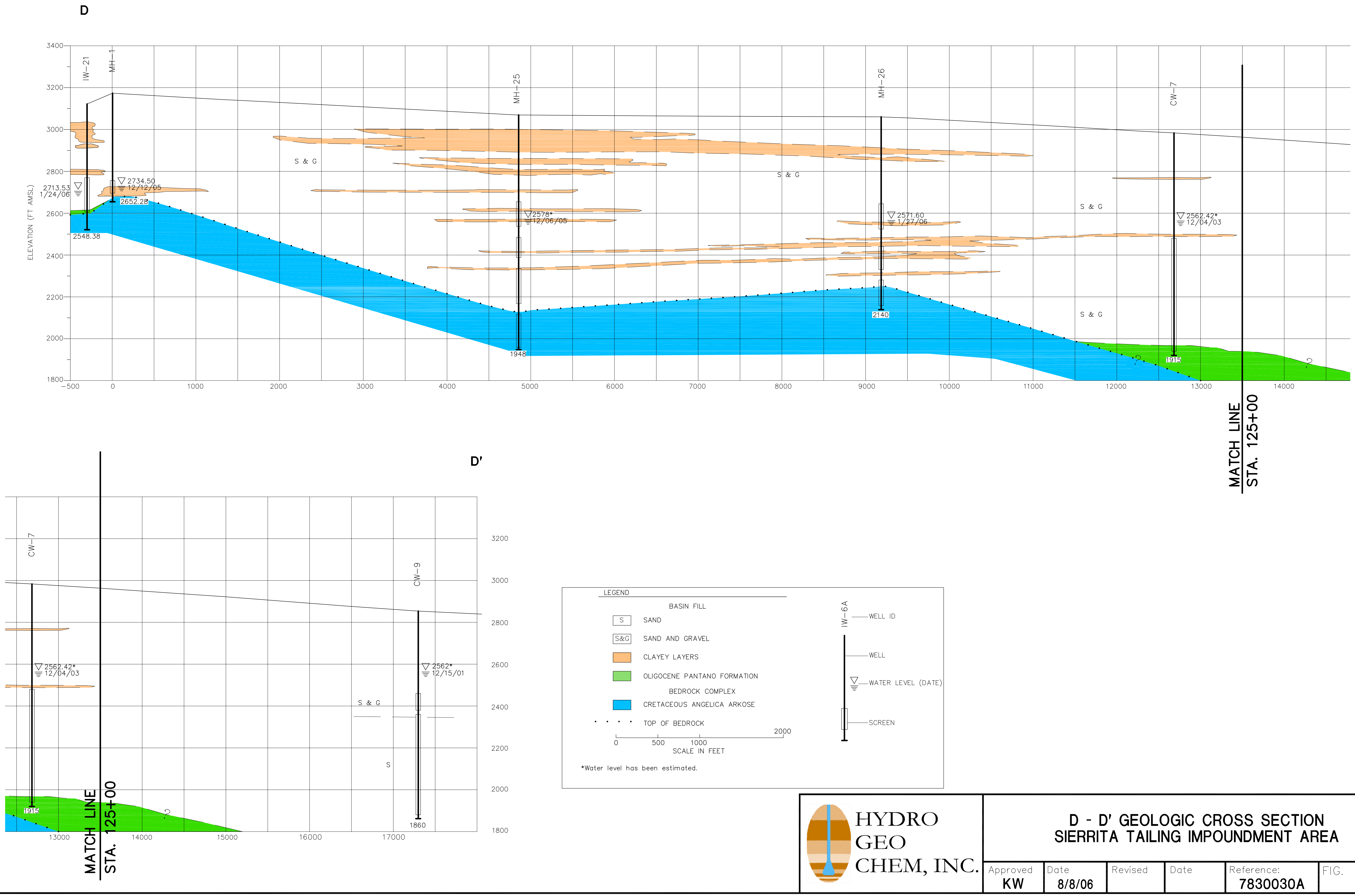
S	SAND
S&G	MOSTLY SAND AND GRAVEL
S&G&C	SAND, GRAVEL, AND CLAY
▨	SAND & GRAVEL WITH COBBLES OR BOULDERS
🟧	CLAY, SANDY CLAY, CLAY & GRAVEL
🟩	OLIGOCENE PANTANO FORMATION, CONGLOMERATE, SAND AND CLAY
▨	OLIGOCENE PANTANO FORMATION, QUARTZOSE SANDSTONE MARKER

*Water level has been estimated.

HYDRO
GEO
CHEM, INC.

C - C' GEOLOGIC CROSS SECTION
SIERRITA TAILING IMPOUNDMENT AREA

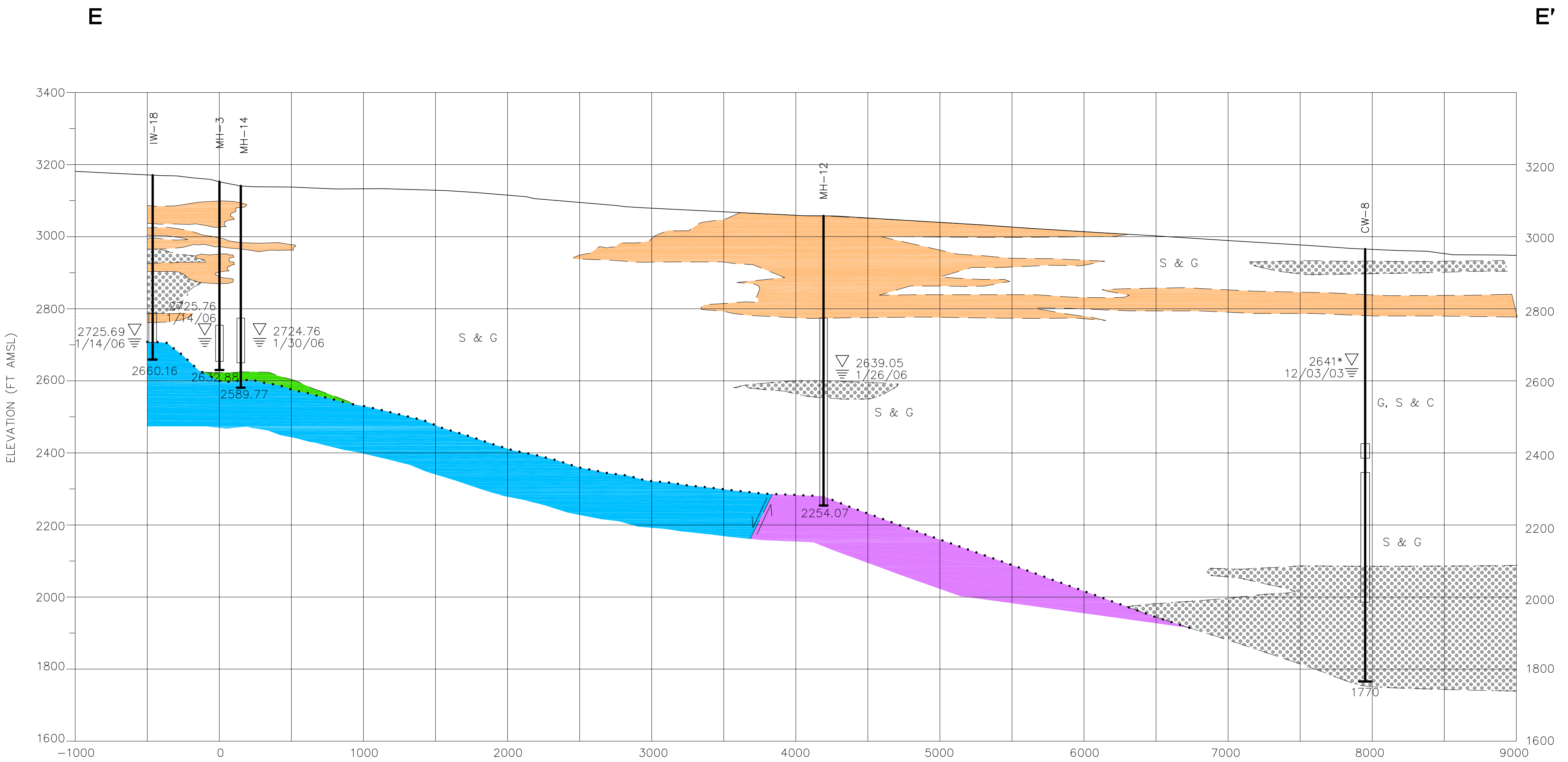
Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830029A	A.6



HYDRO
GEO
CHEM, INC.

D - D' GEOLOGIC CROSS SECTION
SIERRITA TAILING IMPOUNDMENT AREA

Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830030A	A.7



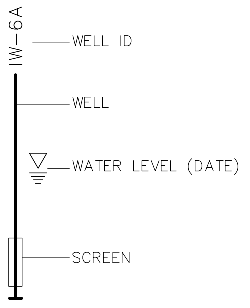
LEGEND

BASIN FILL

S&G	MOSTLY SAND AND GRAVEL
GS&C	GRAVEL, SAND AND CLAY
🟧	CLAY AND SANDY CLAY
▨	SAND AND GRAVEL WITH BOULDERS
🟩	OLIGOCENE PANTANO FORMATION

BEDROCK COMPLEX

🟦	CRETACEOUS ANGELICA ARKOSE
🟪	PALEOZOIC LIMESTONE
. . . . . .	TOP OF BEDROCK

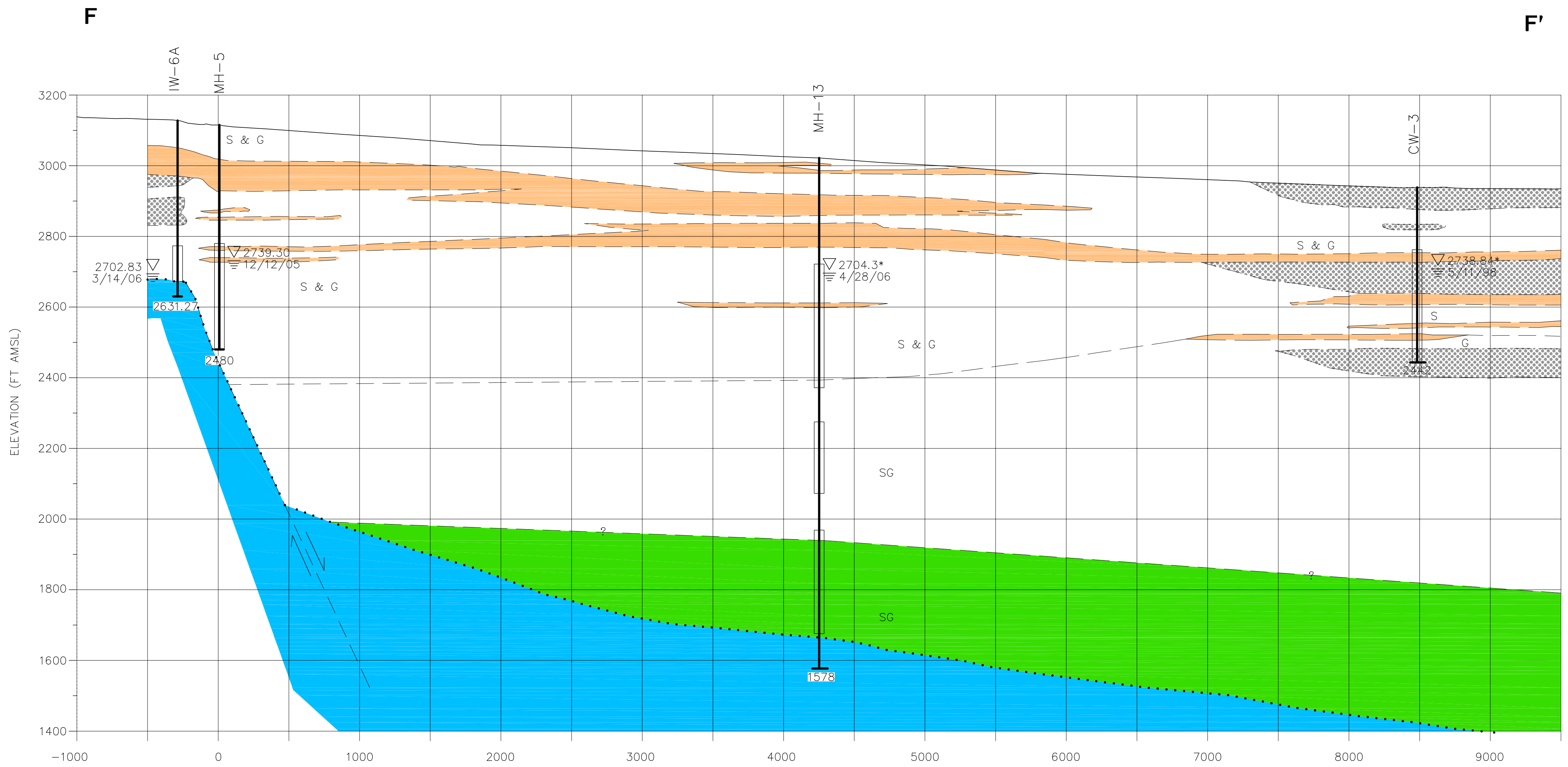


*Water level has been estimated.

HYDRO GEO CHEM, INC.

E - E' GEOLOGIC CROSS SECTION SIERRITA TAILING IMPOUNDMENT AREA

Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830028A	A.8



LEGEND

BASIN FILL

S	SAND
G	GRAVEL
S&G	SAND AND GRAVEL, INCLUDES GRAVELLY SAND, SANDY GRAVEL, AND SILTY SANDY GRAVEL
SG	GRAVELLY SAND
▨	HARD TO SOFT CONGLOMERATE OR SAND AND GRAVEL WITH COBBLES
🟧	CLAY & SILTY LAYERS, SANDY CLAY
🟩	OLIGOCENE PANTANO FORMATION

BEDROCK COMPLEX

🟦	CRETACEOUS ANGELICA ARKOSE
....	TOP OF BEDROCK

IW–6A — WELL ID

WELL

WATER LEVEL (DATE)

SCREEN

0 500 1000
SCALE IN FEET

* Water level has been estimated.

HYDRO
GEO
CHEM, INC.

F - F' GEOLOGIC CROSS SECTION
SIERRITA TAILING IMPOUNDMENT AREA

Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830024A	A.9

APPENDIX B

Hydraulic Conductivity Data

TABLE OF CONTENTS

TABLES

TABLE B.1
Summary of Reported Hydraulic Conductivity Estimates

Well or Boring	Test Date	Type of Test	Aquifer Material	Hydraulic Conductivity *(ft/day)*	References
			BASIN FILL		
Basin Fill					
AN-1 (CW-11)	01/01/68	Pumping	Basin Fill	8.2	ELMA[1] and Dames & Moore, 1994
AN-2	No Date	Pumping	Basin Fill	4.8	ELMA and Dames & Moore, 1994
AN-4	No Date	Pumping	Basin Fill	7.2	ELMA and Dames & Moore, 1994
CW-7	07/06/82	Pumping	Basin Fill	99	ELMA and Dames & Moore, 1994
ESP-5	02/26/70	Pumping	Basin Fill	20	ELMA and Dames & Moore, 1994
I-6	Jan-76	Pumping	Basin Fill	57.5	ELMA and Dames & Moore, 1994
I-7	06/04/76	Pumping	Basin Fill	60	ELMA and Dames & Moore, 1994
IW-2	04/30/86	Pumping	Basin Fill	16	ELMA,1986
IW-6	10/21/93	Pumping	Basin Fill	67	ELMA, 1994
IW-6A	01/30/95	Pumping	Basin Fill	13	ELMA, 1995
IW-10	05/07/86	Pumping	Basin Fill	12	ELMA, 1986
IW-11	05/09/86	Pumping	Basin Fill	24	ELMA, 1986
IW-12	02/03/95	Pumping	Basin Fill	11	ELMA, 1995
IW-13	02/09/95	Pumping	Basin Fill	11	ELMA, 1995
IW-14	02/13/95	Pumping	Basin Fill	9.4	ELMA, 1995
IW-15	02/17/95	Pumping	Basin Fill	6.3	ELMA, 1995
IW-17	02/27/95	Pumping	Basin Fill	22	ELMA, 1995
IW-18	03/03/95	Pumping	Basin Fill	17	ELMA, 1995
IW-19	03/09/95	Pumping	Basin Fill	21	ELMA, 1995
IW-20	03/13/95	Pumping	Basin Fill	21	ELMA, 1995
IW-21	03/17/95	Pumping	Basin Fill	12	ELMA, 1995
IW-23	02/13/04	Pumping	Basin Fill	49	ELMA, 2004b
M-5	07/25/81	Pumping	Basin Fill	1.7	ELMA and Dames & Moore, 1994
M-6	07/22/81	Pumping	Basin Fill	6.7	ELMA and Dames & Moore, 1994
M-7	07/15/81	Pumping	Basin Fill	18.7	ELMA and Dames & Moore, 1994
M-10	04/09/82	Pumping	Basin Fill	16	ELMA and Dames & Moore, 1994
M-11	07/20/82	Pumping	Basin Fill	21	ELMA and Dames & Moore, 1994
MH-13A	04/28/06	Pumping	Basin Fill	17.4	ELMA, 2006a
MH-13B	04/24/06	Pumping	Basin Fill	13.4	ELMA, 2006a
MH-13C	04/12/06	Pumping	Basin Fill	0.023	ELMA, 2006a
MH-14	08/28/90	Pumping	Basin Fill	43	ELMA, 1991
MH-15W	08/22/90	Pumping	Basin Fill	56	ELMA, 1991
MH-16W	08/25/90	Pumping	Basin Fill	100	ELMA, 1991
MH-25	12/30/03	Pumping	Basin Fill	6.3	ELMA, 2004a
MH-25A	01/09/06	Pumping	Basin Fill	53.5	ELMA, 2006a
MH-25B	12/17/05	Pumping	Basin Fill	41.4	ELMA, 2006a
MH-25C	2/16/2006	Pumping	Basin Fill	50.8	ELMA, 2006a
MH-26	12/31/03	Pumping	Basin Fill	118	ELMA, 2004a
MH-26A	01/02/06	Pumping	Basin Fill	41.4	ELMA, 2006a
MH-26B	01/04/06	Pumping	Basin Fill	64.2	ELMA, 2006a
MH-26C	1/11/2006	Pumping	Basin Fill	65.5	ELMA, 2006a
MH-30	3/3/2006	Pumping	Basin Fill	38.8	ELMA, 2006b
RT-1	01/31/81	Pumping	Basin Fill	18.7	ELMA and Dames & Moore, 1994
MH-18	06/19/97	Pumping	Basin Fill	0.01	ELMA, 2001
MH-19	07/15/97	Pumping	Basin Fill	1.71	ELMA, 2001
PZ-1	06/18/97	Pumping	Basin Fill	0.1	ELMA, 2001
GV golf course	02/27/66	Pumping	Basin Fill	59.6	Schmidt, 2005
FICO E-4	03/08/66	Pumping	Basin Fill	33.4	Schmidt, 2005
FICO W-7	03/14/66	Pumping	Basin Fill	93.7	Schmidt, 2005
FICO E-6	03/15/66	Pumping	Basin Fill	19	Schmidt, 2005
Duval Mine #7	09/11/67	Pumping	Basin Fill	35	Schmidt, 2005
			Geometric Mean for Basin Fill	**15.05**	
			Maximum	**118**	
			Minimum	**0.01**	

TABLE B.1
Summary of Reported Hydraulic Conductivity Estimates

Well or Boring	Test Date	Type of Test	Aquifer Material	Hydraulic Conductivity *(ft/day)*	References
Basin Fill and Demetrie Volcanics					
IW-3A	03/04/04	Pumping	Basin Fill and Demetrie Volcanics	13.4	ELMA, 2004b
IW-4	04/29/86	Pumping	Basin Fill and Demetrie Volcanics	13.3	ELMA, 1986
IW-5	05/01/86	Pumping	Basin Fill and Demetrie Volcanics	9.4	ELMA, 1986
IW-8	05/06/86	Pumping	Basin Fill and Demetrie Volcanics	9.4	ELMA, 1986
IW-16	02/23/95	Pumping	Basin Fill and Demetrie Volcanics	13	ELMA, 1995
IW-22	01/14/04	Pumping	Basin Fill and Demetrie Volcanics	15	ELMA, 2004b
IW-24	01/24/04	Pumping	Basin Fill and Demetrie Volcanics	11	ELMA, 2004b
Geometric Mean for Basin Fill and Demetrie Volcanics				**11.9**	
Maximum				**15.0**	
Minimum				**9.4**	
Basin Fill and Granodiorite					
M-16	no date	Slug	Basin Fill and Granodiorite	0.011	MW[2] & ELMA, 1998
M-16	no date	Slug	Basin Fill and Granodiorite	0.011	MW & ELMA, 1998
M-18	no date	Slug	Basin Fill and Granodiorite	0.020	MW & ELMA, 1998
M-18	no date	Slug	Basin Fill and Granodiorite	0.011	MW & ELMA, 1998
Geometric Mean for Granodiorite and Basin Fill				**0.013**	
Maximum				**0.020**	
Minimum				**0.011**	
BEDROCK COMPLEX					
Demetrie Volcanics					
MH-20	12/16/97	Slug	Demetrie Volcanics	0.000013	ELMA, 2001
MH-20	12/16/97	Slug	Demetrie Volcanics	0.000007	ELMA, 2001
MH-22	06/24/97	Pumping	Demetrie Volcanics	151	ELMA, 2001
MH-23	06/24/97	Slug	Demetrie Volcanics	0.0023	ELMA, 2001
MH-23	06/24/97	Slug	Demetrie Volcanics	0.0011	ELMA, 2001
PZ-2	06/18/97	Slug	Demetrie Volcanics	0.0017	ELMA, 2001
PZ-2	06/18/97	Slug	Demetrie Volcanics	0.0012	ELMA, 2001
PZ-13	08/01/97	Slug	Demetrie Volcanics	0.0027	ELMA, 2001
PZ-13	08/01/97	Slug	Demetrie Volcanics	0.0027	ELMA, 2001
PZ-14	08/01/97	Pumping	Demetrie Volcanics	0.081	ELMA, 2001
PZ-15	12/16/97	Slug	Demetrie Volcanics	0.0008	ELMA, 2001
PZ-15	12/16/97	Slug	Demetrie Volcanics	0.00008	ELMA, 2001
PZ-16	06/18/00	Slug	Demetrie Volcanics	0.002	ELMA, 2001
PZ-16	06/18/00	Slug	Demetrie Volcanics	0.002	ELMA, 2001
BW-1	08/16/90	Slug	Demetrie Volcanics	0.04	ELMA, 1991
BW-1	08/16/90	Slug	Demetrie Volcanics	0.08	ELMA, 1991
BW-2	08/17/90	Slug	Demetrie Volcanics	0.16	ELMA, 1991
BW-2	08/17/90	Slug	Demetrie Volcanics	0.21	ELMA, 1991
Geometric Mean for Demetrie Volcanics				**0.00467**	
Maximum				**151**	
Minimum				**0.000007**	

TABLE B.1

Summary of Reported Hydraulic Conductivity Estimates

Well or Boring	Test Date	Type of Test	Aquifer Material	Hydraulic Conductivity *(ft/day)*	References
Cretaceous Sedimentary Rock					
MH-25D	02/20/06	Pumping	Cretaceous Sediments	0.067	ELMA, 2006a
Geometric Mean for Cretaceous Sedimentary Rock				**0.067**	
Maximum				**0.067**	
Minimum				**0.067**	
Brecciated Volcanics					
B3-3 (23'-26')	no date	Packer	Brecciated Andesite	0.0019	ELMA and Dames & Moore, 1994
B3-3 (23'-26')	no date	Packer	Brecciated Andesite	0.011	ELMA and Dames & Moore, 1994
B3-5 (15.5'-21.5')	no date	Packer	Brecciated Andesite	0.087	ELMA and Dames & Moore, 1994
Geometric Mean for Brecciated Andesite				**0.012**	
Maximum				**0.087**	
Minimum				**0.002**	
Intrusive Rocks					
BS-4 (40'-60')	no date	Packer	Granite	0.367	ELMA and Dames & Moore, 1994
BS-4 (50'-60')	no date	Packer	Granite	0.434	ELMA and Dames & Moore, 1994
BS-5 (60'-70')	no date	Packer	Granite	0.445	ELMA and Dames & Moore, 1994
M-14	no date	Slug	Granodiorite	0.00007	MW & ELMA, 1998
M-14	no date	Slug	Granodiorite	0.00007	MW & ELMA, 1998
M-15	no date	Slug	Granodiorite	0.0067	MW & ELMA, 1998
M-15	no date	Slug	Granodiorite	0.0110	MW & ELMA, 1998
M-17	no date	Slug	Granodiorite	0.0011	MW & ELMA, 1998
M-17	no date	Slug	Granodiorite	0.0020	MW & ELMA, 1998
MH-21	06/27/97	Slug	Granodiorite	0.0107	ELMA, 2001
MH-21	06/27/97	Slug	Granodiorite	0.0093	ELMA, 2001
PZ-3	06/25/97	Slug	Granodiorite	0.0094	ELMA, 2001
PZ-3	06/25/97	Slug	Granodiorite	0.006	ELMA, 2001
PZ-4	06/23/97	Pumping	Granodiorite	2.18	ELMA, 2001
PZ-5	08/13/97	Slug	Granodiorite	0.005	ELMA, 2001
PZ-5	08/13/97	Slug	Granodiorite	0.004	ELMA, 2001
PZ-6	07/02/97	Slug	Granodiorite	0.027	ELMA, 2001
PZ-6	07/02/97	Slug	Granodiorite	0.029	ELMA, 2001
PZ-7	07/31/97	Slug	Granodiorite	0.45	ELMA, 2001
PZ-7	07/31/97	Slug	Granodiorite	0.51	ELMA, 2001
PZ-9	08/26/97	Slug	Granodiorite	0.32	ELMA, 2001
PZ-9	08/26/97	Slug	Granodiorite	0.47	ELMA, 2001
BW-3	08/27/90	Packer	Granodiorite	0.08	ELMA, 1991
BW-3	08/27/90	Packer	Tertiary Intrusives	0.11	ELMA, 1991
MH-17	06/18/97	Slug	Quartz Monzonite	0.47	ELMA, 2001
MH-17	06/18/97	Slug	Quartz Monzonite	0.47	ELMA, 2001
Geometric Mean for Intrusive Rocks				**0.031**	
Maximum				**2.18**	
Minimum				**0.000067**	

TABLE B.1

Summary of Reported Hydraulic Conductivity Estimates

Well or Boring	Test Date	Type of Test	Aquifer Material	Hydraulic Conductivity *(ft/day)*	References
Meta-Rhyolite and Rhyolite					
BS-6 A (40'-70')	no date	Packer	Meta-Rhyolite	0.43	ELMA and Dames & Moore, 1994
BS-6 (50'-70')	no date	Packer	Meta-Rhyolite	0.89	ELMA and Dames & Moore, 1994
BS-6 (63'-70')	no date	Packer	Meta-Rhyolite	1.07	ELMA and Dames & Moore, 1994
B5-3 (9'-16')	no date	Packer	Rhyolite	0.03	ELMA and Dames & Moore, 1994
B5-3 (14'-21')	no date	Packer	Rhyolite	0.04	ELMA and Dames & Moore, 1994
B5-5 (5'-12')	no date	Packer	Rhyolite	0.05	ELMA and Dames & Moore, 1994
B5-5 (5'-12')	no date	Packer	Rhyolite	0.09	ELMA and Dames & Moore, 1994
B5-5 (14.5'-20')	no date	Packer	Rhyolite	0.05	ELMA and Dames & Moore, 1994
B5-7 (15'-22')	no date	Packer	Rhyolite	0.03	ELMA and Dames & Moore, 1994
B5-8 (22'-30')	no date	Packer	Rhyolite	Negligible	ELMA and Dames & Moore, 1994
			Geometric Mean for Meta-Rhyolite and Rhyolite	**0.12**	
			Maximum	**1.07**	
			Minimum	**0.03**	

Notes:

[1] ELMA = Errol L. Montgomery and Associates
[2] MW = Montgomery Watson

TABLE B.2

HYDRAULIC CONDUCTIVITY REFERENCES

Errol L. Montgomery and Associates, Inc. (ELMA). 2006a. Unpublished pumping test data for MH-13, MH-25, and MH-26. May 8-9, 2006.

ELMA. 2006b. Results of Drilling, Construction and Testing Monitor Well MH-30, Phelps Dodge Sierrita, Inc., Pima County, Arizona, unpublished technical memorandum. June 5, 2006.

ELMA. 2001. Additional Characterization of Hydrologic Conditions: Aquifer Protection Permit Application no. 101679, Sierrita Mine, Phelps Dodge Sierrita Inc., Pima County, Arizona. January 4, 2001.

ELMA. 2004a. Results of Construction, Development, Testing, and Sampling of Groundwater Monitor Wells MH-25 and MH-26, Sierrita Mine, Phelps Dodge Sierrita Inc., Pima County, Arizona. March, 10, 2004.

ELMA. 2004b. Results of Drilling, Construction, and Testing for Wells IW-22, IW-23, IW-24, IW-3A. April 6, 2004.

ELMA. 1995. Results of Drilling, Construction, Development, and Testing Phase II Interceptor Wells, Sierrita Operation, CSC, Pima County, AZ, prepared for Cyprus Sierrita Corporation, Green Valley, Arizona. June 23, 1995.

ELMA. 1994. Results of Rehabilitation, Redevelopment, and Pumping Test Operations for Interceptor Well IW-6, Sierrita Operation, Cyprus Sierrita Corporation, Pima County, Arizona, prepared for Cyprus Sierrita Corporation, Green Valley, Arizona. January, 1994.

Errol L. Montgomery and Associates and Dames and Moore, 1994. Aquifer Protection Permit Application, Sierrita Operation, Cyprus Sierrita Corporation, Pima County, Arizona. September 7, 1994.

ELMA. 1991. Supplemental Hydrogeologic Report in Support of Aquifer Protection Permit Application, Sierrita Operation, Cyprus Sierrita Corporation Pima County, Arizona: prepared for Cyprus Sierrita Corporation, Green Valley, Arizona. July, 1991.

ELMA. 1986a. Evaluation of Pumping Test Data for Interceptor Wells, Cyprus Sierrita Corporation, Pima County, Arizona: prepared for Cyprus Sierrita Corporation, Green Valley, Arizona. June, 1986.

ELMA. 1986b. Supplemental Proposal for Groundwater Quality Protection Permit Application, Sierrita Operation, Cyprus Sierrita Corporation, Pima County, Arizona: Prepared for Cyprus Sierrita Corporation, Green Valley, Arizona. June, 1986.

Schmidt, Buck. 2005. Well Spacing/Well Impact Investigation – Community Water Company of Green Valley's Well # 10, D-18-13 23cac: Memorandum to Arizona Department of Water Resources Groundwater Management Support Section. May 6, 2005.

Montgomery Watson Mining Group and Errol L. Montgomery and Associates, Inc. 1988. Aquifer Protection Permit Application, Twin Buttes Mine: prepared for Arizona Department of Environmental Quality. December 1998.

APPENDIX C

Water Quality Data

TABLE OF CONTENTS

TABLES

TABLE C.1
General Chemistry and Major Element Concentrations for Selected Wells

Well Name	Sample Date	Calcium	Magnesium	Potassium	Sodium	Bicarbonate Alkalinity	Chloride	Fluoride	Sulfate	TDS	Calculated Hardness	pH
Proximal Wells												
IW-1	09/14/2005	193.0	41.4	9.6	61.3	135	56	0.3	520	1,010	652	6.85
IW-2	12/08/2005	65.3	13.9	5.6	42.0	155	19	0.3	100	390	220	7.75
IW-3	09/16/2002	396.0	77.0	10.4	94.9	120	109	0.3	1,700	2,790	1,304	7.78
IW-3A	12/08/2005	477.0	105.0	14.4	123.0	125	119	0.2	1,560	2,580	1,622	7.50
IW-4	03/23/2005	527.0	93.7	10.5	159.0	147	144	0.3	1,590	2,780	1,700	7.38
IW-5	03/23/2005	557.0	98.5	8.1	187.0	177	174	0.2	1,720	2,950	1,795	7.29
IW-6a	12/09/2005	501.0	83.1	7.2	221.0	114	112	0.3	1,790	2,970	1,592	7.51
IW-8	12/07/2005	521.0	117.0	13.6	177.0	113	128	0.2	1,790	3,070	1,781	7.51
IW-9	12/08/2005	506.0	97.8	12.4	175.0	126	137	0.3	1,210	2,860	1,664	7.61
IW-10	03/23/2005	479.0	116.0	8.3	130.0	139	126	0.2	1,600	2,650	1,672	6.94
IW-11	12/09/2005	490.0	90.6	8.7	191.0	131	131	0.2	1,700	2,890	1,595	7.33
IW-12	06/07/2005	427.0	82.5	7.6	139.0	109	100	0.3	1,350	2,320	1,404	7.25
IW-13	09/14/2005	510.0	95.3	7.5	183.0	114	98	0.2	1,690	2,760	1,664	7.26
IW-14	12/09/2005	524.0	111.0	7.2	165.0	105	121	0.2	1,820	3,030	1,764	6.96
IW-15	09/14/2005	623.0	100.0	7.5	175.0	128	128	0.2	1,930	3,190	1,965	7.32
IW-17	06/07/2005	466.0	112.0	7.0	120.0	124	135	0.3	1,480	2,620	1,623	7.17
IW-18	06/07/2005	491.0	121.0	8.8	125.0	134	133	0.3	1,500	2,660	1,722	6.79
IW-19	12/12/2005	486.0	117.0	7.2	109.0	144	124	0.2	1,590	2,640	1,693	6.58
IW-20	12/12/2005	542.0	99.9	10.9	175.0	160	168	0.2	1,700	2,940	1,763	7.87
IW-21	12/12/2005	460.0	113.0	9.8	131.0	134	121	0.2	1,530	2,660	1,612	6.97
IW-22	12/12/2005	521.0	80.9	10.3	186.0	149	142	0.1	1,680	2,910	1,632	7.29
IW-23	12/08/2005	522.0	98.6	9.2	166.0	183	167	0.2	1,610	2,870	1,708	7.07
IW-24	12/12/2005	546.0	89.2	8.2	162.0	161	142	0.1	1,660	2,840	1,729	7.43
Medial Wells												
MH-11	12/14/2005	490.0	108.0	14.9	106.0	87	115	0.1	1,570	2,680	1,666	7.17
MH-12	12/13/2005	368.0	74.5	10.5	77.9	71	117	0.2	1,100	1,960	1,224	6.98
MH-13	03/16/2004	505.0	98.1	12.7	110.0	99	148	0.2	1,620	2,740	1,663	7.20
Distal Wells												
CW-7	12/13/2004	196.0	21.5	5.8	68.9	108	53	0.4	570	1,030	577	6.97
CW-8	12/13/2004	124.0	10.8	6.1	121.0	97	50	1.0	470	860	354	7.23
ESP-1	11/29/2005	80.5	7.8	3.4	46.1	94	30	0.2	130	430	233	7.51
ESP-4	05/20/2004	55.2	5.4	3.0	45.4	109	20	1.4	120	340	160	6.95
Upgradient Wells												
S-1	12/13/2005	69.0	9.0	3.2	45.7	174	20	0.4	70	400	209	7.25
S-2	12/13/2005	50.8	5.9	2.9	50.8	147	14	0.5	80	340	151	7.50
GV-1	12/13/2005	52.7	7.9	3.1	31.9	167	13	0.3	40	300	164	7.62
GV-2	12/13/2005	64.4	9.5	3.5	37.4	176	18	0.3	70	360	200	7.48
Downgradient Wells												
ESP-2	12/19/2005	32.8	3.1	2.6	36.2	137	8	1.0	30	230	95	7.85
ESP-3	12/19/2005	31.6	2.8	2.5	35.7	130	8	0.7	30	230	90	7.64

Note:
All concentrations in milligrams per liter (mg/L) except pH
pH in standard units
TDS = Total Dissolved Solid Residue (Dried at 180C)

Source: PDSI Database.

TABLE C.2
Dissolved Metal Concentrations for Interceptor Wells (IW-series)
1997 through April 2006

Well Name	Sample Date	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Thallium	Zinc
AWQS		*NS*	*0.006*	*0.01*	*2*	*0.004*	*NS*	*0.005*	*0.1*	*NS*	*NS*	*NS*	*0.05*	*NS*	*0.002*	*NS*	*0.1*	*0.05*	*0.002*	*NS*
IW-1	12/23/1997	NM	<0.01	0.001	NM	NM	0.07	<0.003	0.01	<0.05	<0.05	0.02	0.002	0.006	<0.001	<0.05	NM	<0.005	NM	0.01
IW-1	07/01/2003	NM	<0.0004	0.004	0.051	<0.0002	NM	<0.0002	<0.01	<0.01	NM	0.03	0.0005	<0.005	<0.0002	<0.02	<0.02	<0.001	0.0002	NM
IW-1	08/01/2003	<0.03	<0.0002	0.00351	0.051	<0.0001	NM	0.0002	<0.01	<0.01	NM	0.07	0.0002	<0.005	0.0002	<0.01	<0.01	<0.001	<0.00005	NM
IW-1	11/03/2003	NM	<0.0002	0.0037	0.052	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.03	0.0005	<0.005	<0.0002	<0.01	0.01	<0.001	<0.00005	NM
IW-1	12/01/2003	NM	<0.0002	0.0031	0.038	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.02	0.0003	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.00005	NM
IW-1	03/31/2004	NM	<0.0004	0.004	0.045	<0.0002	NM	0.0015	<0.01	<0.01	NM	<0.01	0.0003	<0.005	<0.0002	<0.01	<0.01	<0.001	0.0001	NM
IW-1	06/24/2004	NM	<0.0004	0.004	0.042	<0.0002	NM	<0.0002	<0.01	<0.01	NM	0.06	0.0003	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0001	NM
IW-1	09/29/2004	NM	<0.0004	0.004	0.041	<0.0002	NM	<0.0002	<0.01	<0.01	NM	0.02	0.0009	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0002	NM
IW-1	12/15/2004	NM	<0.0002	0.0044	0.038	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.04	0.0003	<0.005	<0.0002	<0.01	<0.01	0.001	<0.0001	NM
IW-1	12/15/2004	NM	<0.0002	0.0042	0.038	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.04	0.0002	<0.005	<0.0002	<0.01	<0.01	0.001	<0.0001	NM
IW-1	03/23/2005	NM	<0.0002	0.0028	0.037	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.03	0.0002	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0001	NM
IW-1	06/10/2005	NM	<0.0004	0.0041	0.034	<0.0001	NM	<0.0001	<0.02	<0.01	NM	0.16	0.0022	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0001	NM
IW-1	09/14/2005	NM	<0.0004	0.0022	0.037	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.25	0.0009	<0.005	<0.0002	<0.01	<0.01	<0.001	0.0001	NM
IW-1	12/08/2005	NM	<0.0004	0.0035	0.033	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.16	0.0013	<0.005	<0.0002	0.01	<0.01	<0.001	<0.0001	NM
IW-1	01/30/2006	NM	<0.0004	0.0041	0.035	<0.0001	NM	<0.0001	<0.01	<0.01	<0.01	NM	0.0013	NM	NM	<0.01	<0.01	0.0015	<0.0001	<0.01
IW-2	12/23/1997	NM	<0.01	0.006	NM	NM	0.07	<0.003	<0.05	<0.05	<0.05	0.01	<0.005	<0.03	<0.001	<0.05	NM	<0.005	NM	<0.05
IW-2	06/25/1998	NM	<0.002	0.005	0.06	<0.001	NM	<0.002	<0.05	<0.05	NM	0.03	0.0006	<0.03	<0.001	<0.05	<0.05	0.001	<0.001	NM
IW-2	10/10/2000	NM	0.0002	0.005	0.043	<0.0001	NM	0.0009	<0.01	<0.01	NM	0.27	0.005	0.008	<0.0002	<0.01	<0.01	0.002	<0.00005	NM
IW-2	10/22/2001	NM	<0.0002	0.0049	0.038	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.02	0.001	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0001	NM
IW-2	09/16/2002	NM	<0.0002	0.005	0.035	<0.0001	NM	<0.0002	<0.01	<0.01	NM	0.03	0.0008	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.00005	NM
IW-2	07/01/2003	NM	<0.0004	0.005	0.035	<0.0002	NM	<0.0002	<0.01	<0.01	NM	<0.02	0.0002	<0.005	<0.0002	<0.02	<0.02	<0.001	0.0003	NM
IW-2	08/01/2003	<0.03	<0.0002	0.00531	0.034	<0.0001	NM	<0.0001	<0.01	<0.01	NM	<0.02	0.0033	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.00005	NM
IW-2	11/03/2003	NM	0.0003	0.0063	0.038	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.04	0.0002	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.00005	NM
IW-2	12/01/2003	NM	<0.0002	0.0053	0.026	<0.0001	NM	<0.0001	<0.01	<0.01	NM	<0.01	0.0002	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.00005	NM
IW-2	03/31/2004	NM	<0.0004	0.0058	0.039	<0.0002	NM	<0.0002	<0.01	<0.01	NM	<0.01	<0.0002	<0.005	<0.0002	<0.01	<0.01	<0.001	0.0001	NM
IW-2	06/24/2004	NM	<0.0002	0.0056	0.036	<0.0002	NM	<0.0001	<0.01	<0.01	NM	0.04	<0.0001	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0001	NM
IW-2	09/29/2004	NM	<0.0002	0.006	0.03	<0.0001	NM	<0.0001	<0.01	<0.01	NM	<0.01	<0.0001	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0001	NM
IW-2	12/15/2004	NM	<0.0002	0.0066	0.026	<0.0001	NM	<0.0001	<0.01	<0.01	NM	<0.01	0.0001	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0001	NM
IW-2	03/23/2005	NM	<0.0002	0.0051	0.026	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.07	<0.0001	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0001	NM
IW-2	06/10/2005	NM	<0.0004	0.0075	0.024	<0.0001	NM	<0.0001	<0.01	<0.01	NM	<0.01	0.0034	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0001	NM
IW-2	09/14/2005	NM	<0.0004	0.003	0.027	<0.0001	NM	<0.0001	<0.01	<0.02	NM	<0.04	0.0004	<0.005	<0.0002	<0.01	<0.02	<0.001	0.0001	NM
IW-2	12/08/2005	NM	<0.0004	0.0054	0.025	<0.0001	NM	<0.0001	<0.01	<0.01	NM	<0.02	0.0003	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0001	NM
IW-2	01/30/2006	NM	<0.0004	0.0065	0.024	<0.0001	NM	<0.0001	<0.01	<0.01	<0.01	NM	0.0009	NM	NM	<0.01	<0.01	0.0007	0.0001	<0.01
IW-3	12/23/1997	NM	<0.01	0.002	NM	NM	0.11	<0.003	<0.05	<0.05	<0.05	<0.05	<0.005	<0.03	<0.001	0.01	NM	<0.005	NM	<0.05
IW-3	06/25/1998	NM	<0.005	<0.03	0.05	<0.003	NM	<0.005	<0.1	<0.1	NM	0.08	<0.005	<0.05	<0.001	<0.1	<0.1	<0.005	<0.003	NM
IW-3	10/22/2001	NM	<0.0004	0.003	0.043	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.11	<0.0002	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0001	NM
IW-3	09/16/2002	NM	<0.0004	0.004	0.034	<0.0002	NM	<0.0005	<0.02	<0.02	NM	0.14	0.0025	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0001	NM
IW-3	08/01/2003	0.15	<0.0004	0.0035	0.041	<0.0002	NM	0.0002	<0.01	<0.01	NM	<0.02	0.0005	<0.005	<0.0002	0.02	<0.01	<0.001	<0.0001	NM
IW-3A	03/04/2004	<0.03	<0.0004	0.0035	0.053	<0.0005	NM	<0.0005	<0.01	<0.01	NM	0.06	0.0005	0.014	0.0005	0.01	<0.01	<0.001	<0.0003	NM
IW-3A	09/29/2004	NM	<0.001	<0.003	0.049	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.07	<0.0005	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0005	NM
IW-3A	12/14/2004	NM	<0.0004	0.004	0.049	<0.0002	NM	<0.0002	0.03	<0.02	NM	0.21	0.0012	<0.01	<0.0002	<0.02	0.02	<0.001	<0.0002	NM
IW-3A	03/23/2005	NM	<0.0002	0.0026	0.048	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.05	0.0006	<0.005	<0.0002	0.01	<0.01	<0.001	<0.0001	NM
IW-3A	09/14/2005	NM	<0.0008	0.004	0.049	<0.0002	NM	<0.0002	<0.02	<0.02	NM	<0.04	0.0007	<0.01	<0.0002	<0.02	<0.02	<0.001	0.0002	NM
IW-3A	12/08/2005	NM	<0.0004	0.0027	0.045	<0.0002	NM	<0.0001	<0.02	<0.02	NM	<0.04	0.0009	<0.01	<0.0002	0.03	<0.02	<0.001	<0.0001	NM
IW-3A	01/30/2006	NM	<0.0008	0.0029	0.044	<0.0002	NM	<0.0002	<0.01	<0.01	<0.01	NM	0.0009	NM	NM	<0.02	<0.01	0.0006	0.0005	0.01
IW-4	12/23/1997	NM	0.004	0.001	NM	NM	0.13	<0.003	<0.05	<0.05	<0.05	<0.05	<0.005	0.014	<0.001	0.01	NM	0.002	NM	<0.05
IW-4	06/25/1998	NM	<0.005	0.006	0.049	<0.003	NM	<0.005	<0.1	<0.1	NM	0.03	<0.005	0.01	<0.001	<0.1	<0.1	0.002	<0.003	NM
IW-4	10/13/1999	NM	<0.0003	0.007	0.05	<0.0005	NM	<0.0005	<0.01	<0.01	NM	0.02	0.0015	0.01	<0.0002	0.01	<0.01	0.002	<0.0003	NM
IW-4	10/10/2000	NM	<0.0005	<0.001	0.044	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.02	0.001	0.03	<0.0002	0.04	<0.02	0.001	<0.0001	NM
IW-4	10/22/2001	NM	<0.0004	0.002	0.045	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.02	0.0009	0.02	<0.0002	<0.02	<0.02	0.002	<0.0001	NM
IW-4	04/01/2004	NM	<0.0004	0.0019	0.039	<0.0002	NM	0.0006	<0.02	<0.02	NM	0.11	0.0002	0.02	<0.0002	<0.02	<0.02	<0.001	0.0001	NM
IW-4	06/24/2004	NM	<0.001	<0.003	0.039	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.14	<0.0005	0.02	<0.0002	<0.02	<0.02	<0.001	<0.0003	NM
IW-4	09/29/2004	NM	<0.001	<0.003	0.046	<0.0005	NM	<0.0005	0.02	<0.02	NM	0.08	<0.0005	0.02	<0.0002	0.02	<0.02	0.001	<0.0005	NM
IW-4	12/14/2004	NM	<0.0004	0.003	0.042	<0.0002	NM	<0.0002	0.03	<0.02	NM	0.19	0.0003	0.02	<0.0002	0.03	0.03	0.002	<0.0002	NM
IW-4	03/23/2005	NM	<0.0002	0.0016	0.04	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.08	0.0003	0.01	<0.0002	0.02	<0.01	<0.001	<0.0001	NM
IW-4	01/30/2006	NM	<0.0008	0.0015	0.038	<0.0002	NM	<0.0002	<0.01	<0.01	<0.01	NM	0.0013	NM	NM	0.03	<0.01	0.0015	0.0004	0.03
IW-5	06/25/1998	NM	<0.005	0.006	0.036	<0.003	NM	<0.005	<0.1	<0.1	NM	<0.1	<0.005	<0.05	<0.001	0.08	<0.1	0.003	<0.003	NM
IW-5	10/13/1999	NM	<0.0003	NM	0.03	<0.0005	NM	<0.0005	<0.02	<0.02	NM	<0.02	NM	<0.01	<0.0002	0.06	<0.02	0.002	<0.0003	NM
IW-5	07/01/2003	NM	<0.001	<0.003	0.034	<0.0005	NM	<0.0005	<0.02	<0.02	NM	<0.02	0.0007	<0.01	<0.0002	0.05	<0.02	0.001	0.0007	NM
IW-5	12/01/2003	NM	<0.0002	0.0012	0.026	<0.0001	NM	0.0002	<0.02	<0.02	NM	<0.02	0.0002	<0.01	<0.0002	0.05	<0.02	<0.001	<0.00005	NM
IW-5	04/01/2004	NM	<0.001	0.0019	0.035	<0.0005	NM	0.002	<0.02	<0.02	NM	0.05	<0.0005	<0.01	<0.0002	0.06	<0.02	<0.001	0.001	NM
IW-5	03/23/2005	NM	<0.0002	0.0009	0.038	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.17	<0.0001	0.017	<0.0002	0.06	<0.01	0.002	<0.0001	NM
IW-6	06/25/1998	NM	<0.002	0.005	0.039	<0.001	NM	<0.002	<0.05	<0.05	NM	<0.05	0.0021	<0.03	<0.001	<0.05	<0.05	<0.005	<0.001	NM
IW-6a	04/01/1997	NM	NN	<0.05	NM	NM	0.3	<0.2	0.03	<0.1	<0.1	0.04	<0.4	<0.05	<0.001	0.09	NM	0.003	NM	0.02
IW-6a	10/10/2000	NM	0.0014	<0.003	0.039	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.05	0.0009	<0.01	<0.0002	0.1	<0.02	0.001	<0.0003	NM
IW-6a	10/26/2001	NM	0.002	0.003	0.037	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.05	0.0007	<0.01	<0.0002	0.11	<0.02	<0.001	<0.0003	NM
IW-6a	04/01/2004	NM	<0.001	0.0018	0.034	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.1	<0.0005	0.01	<0.0002	0.15	<0.02	<0.001	0.0012	NM
IW-6a	06/25/2004	NM	<0.001	0.0015	0.035	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.07	0.0007	<0.01	<0.0002	0.19	<0.02	<0.001	0.0012	NM
IW-6a	09/29/2004	NM	<0.001	<0.003	0.035	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.09	0.0014	<0.01	<0.0002	0.18	<0.02	0.001	<0.0005	NM
IW-6a	12/14/2004	NM	<0.0004	0.004	0.036	<0.0002	NM	<0.0002	0.03	<0.02	NM	0.19	0.0018	0.01	<0.0002	0.19	0.03	0.002	<0.0002	NM
IW-6a	03/23/2005	NM	0.0004	0.001	0.036	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.15	<0.0001	0.014	<0.0002	0.19	<0.01	0.001	<0.0001	NM
IW-6a	06/07/2005	NM	<0.0004	<0.0005	0.035	<0.0001	NM	0.0002	<0.01	<0.01	NM	0.01	0.0047	<0.005	<0.0002	0.16	<0.01	<0.001	<0.0001	NM
IW-6a	12/09/2005	NM	<0.0008	0.001	0.035	<0.0002	NM	0.0002	<0.02	<0.02	NM	<0.04	0.001	<0.01	<0.0002	0.16	<0.02	<0.001	<0.0002	NM
IW-6a	01/30/2006	NM	<0.0008	0.0015	0.033	<0.0002	NM	0.0003	<0.01	<0.01	<0.01	NM	0.0009	NM	NM	0.18	<0.01	0.0015	0.0004	<0.01
IW-6a	04/24/2006	NM	<0.0008	0.001	0.037	<0.0002	NM	<0.0002	<0.02	<0.02	<0.02	NM	0.0002	NM	NM	0.17	<0.02	0.0012	<0.0002	0.03
IW-8	12/23/1997	NM	0.003	0.001	NM	NM	0.09	<0.003	<0.05	<0.05	<0.05	<0.05	<0.005	<0.03	<0.001	0.03	NM	0.002	NM	0.01
IW-8	10/10/2000	NM	0.0045	0.003	0.045	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.04	<0.0002	<0.01	<0.0002	0.04	<0.02	<0.001	<0.0001	NM
IW-8	09/16/2002	NM	<0.0004	0.003	0.037	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.19	<0.0002	<0.01	<0.0002	0.03	<0.02	<0.001	<0.0001	NM
IW-8	07/01/2003	NM	<0.001	<0.003	0.048	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.06	<0.0005	<0.01	<0.0002	0.04	<0.02	<0.001	0.0007	NM
IW-8	11/03/2003	NM	<0.0002	0.0021	0.048	<0.0001	NM	<0.0001	0.01	<0.01	NM	0.05	0.0003	<0.005	<0.0002	0.04	0.02	<0.001	<0.0001	NM
IW-8	12/01/2003	NM	<0.0002	0.0019	0.036	<0.0001	NM	0.0002	<0.02	<0.02	NM	<0.02	0.0004	<0.01	<0.0002	0.03	<0.02	<0.001	<0.00005	NM
IW-8	03/31/2004	NM	<0.001	0.0022	0.045	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.03	<0.0005	<0.01	<0.0002	0.03	<0.02	<0.001	0.0012	NM
IW-8	06/24/2004	NM	<0.001	<0.003	0.044	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.11	<0.0005	<0.01	<0.0002	0.02	<0.02	<0.001	<0.0003	NM
IW-8	09/29/2004	NM	<0.001	<0.003	0.046	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.04	<0.0005	<0.01	<0.0002	0.04	<0.02	<0.001	<0.0005	NM
IW-8	12/14/2004	NM	<0.0004	0.003	0.046	<0.0002	NM	<0.0002	0.02	<0.02	NM	0.93	0.0004	<0.01	<0.0002	0.05	<0.02	<0.001	<0.0002	NM
IW-8	03/23/2005	NM	<0.0002	0.0019	0.047	<0.0001	NM	0.0002	<0.02	<0.02	NM	0.1	0.0004	<0.01	<0.0002	0.04	<0.02	<0.001	<0.0001	NM
IW-8	06/10/2005	NM	<0.0004	0.003	0.042	<0.0001	NM	0.0002	<0.02	<0.02	NM	0.09	<0.0001	<0.01	<0.0002	0.04	<0.02	<0.001	<0.0001	NM
IW-8	09/14/2005	NM	<0.0008	0.003	0.049	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.1	0.0021	<0.01	<0.0002	0.04	<0.02	<0.001	<0.0002	NM
IW-8	12/07/2005	NM	<0.0008	0.002	0.047	<0.0004	NM	0.0003	<0.02	<0.02	NM	0.13	0.0058	<0.01	<0.0002	0.05	<0.02	<0.001	0.0003	NM
IW-8	02/02/2006	NM	<0.0008	0.0017	0.045	<0.0002	NM	<0.0002	<0.01	<0.01	<0.01	NM	0.0012	NM	NM	0.04	<0.01	0.0007	<0.0002	0.04
IW-9	07/01/2003	NM	<0.001	<0.003	0.039	<0.0005	NM	0.0008	<0.02	<0.02	NM	0.15	<0.0005	0.99	<0.0002	0.02	<0.02	<0.001	0.0009	NM
IW-9	11/03/2003	NM	0.0005	0.0021	0.042	<0.0001	NM	0.0003	0.01	<0.01	NM	0.09	<0.0001	0.019	<0.0002	0.03	0.02	<0.001	0.0002	NM
IW-9	12/01/2003	NM	0.0002	0.0018	0.035	<0.0001	NM	0.0002	<0.02	<0.02	NM	0.04	<0.0001	<0.01	<0.0002	0.03	<0.02	<0.001	0.00007	NM
IW-9	03/31/2004	NM	<0.001	0.0026	0.041	<0.0005	NM	0.0011	<0.02	<0.02	NM	0.04	<0.0005	<0.01	<0.0002	0.02	<0.02	<0.001	0.0012	NM
IW-9	06/24/2004	NM	<0.001	0.003	0.039	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.17	<0.0005	0.01	<0.0002	<0.02	<0.02	<0.001	<0.0003	NM
IW-9	09/29/2004	NM	<0.001	<0.003	0.046	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.08	<0.0005	<0.01	<0.0002	0.04	<0.02	0.001	<0.0005	NM
IW-9	12/14/2004	NM	<0.0004	0.003	0.044	<0.0002	NM	<0.0002	1.55	0.03	NM	2.26	0.0004	0.35	<0.0002	0.05	0.95	0.001	0.0028	NM
IW-9	03/23/2005	NM	<0.0002	0.0021	0.042	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.05	0.0005	<0.005	<0.0002	0.03	<0.01	0.001	<0.0001	NM
IW-9	12/08/2005	NM	<0.0008	0.002	0.043	<0.0004	NM	<0.0002	<0.02	<0.02	NM	0.11	0.0021	<0.01	<0.0002	0.03	<0.02	<0.001	<0.0002	NM
IW-9	01/30/2006	NM	<0.0008	0.0023	0.04	<0.0002	NM	<0.0002	0.02	<0.01	<0.01	NM	0.001	NM	NM	0.03	<0.01	0.0013	0.0004	0.01
IW-10	06/29/1998	NM	<0.005	0.005	0.045	<0.003	NM	<0.005	<0.05	<0.05	NM	0.02	<0.005	<0.03	<0.001	0.09	<0.05	0.004	<0.003	NM
IW-10	10/10/2000	NM	<0.0005	<0.001	0.037	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.05	0.0021	<0.01	<0.0002	0.1	<0.02	0.003	<0.0001	NM
IW-10	10/26/2001	NM	<0.001	<0.003	0.041	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.03	0.0036	<0.01	<0.0002	0.08	0.04	0.002	<0.0003	NM
IW-10	09/16/2002	NM	<0.0004	<0.003	0.033	<0.0002	NM	<0.0005	<0.02	<0.02	NM	0.13	<0.0005	<0.01	<0.0002	0.06	<0.02	0.002	<0.0003	NM
IW-10	07/01/2003	NM	<0.001	<0.003	0.053	<0.0005	NM	<0.0005	<0.01	<0.01	NM	0.03	0.0011	0.008	<0.0002	0.09	<0.01	0.002	0.0008	NM
IW-10	03/23/2005	NM	<0.0004	0.0017	0.044	<0.0001	NM	<0.0002	<0.01	<0.01	NM	0.06	0.0004	<0.005	<0.0002	0.07	<0.01	0.002	<0.0002	NM
IW-10	09/14/2005	NM	<0.0008	0.003	0.049	<0.0002	NM	0.0004	<0.02	<0.02	NM	1.23	0.0298	0.05	<0.0002	0.06	0.04	<0.001	<0.0002	NM
IW-11	04/01/1997	NM	NM	<0.05	NM	NM	0.3	<0.2	0.02	<0.1	<0.1	0.03	<0.4	<0.05	<0.001	0.12	NM	0.005	NM	0.04
IW-11	10/13/1999	NM	0.0003	<0.003	0.03	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.02	<0.0005	<0.01	<0.0002	0.1	<0.02	0.003	<0.0003	NM
IW-11	10/10/2000	NM	<0.0005	<0.003	0.039	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.02	<0.0005	<0.01	<0.0002	0.12	<0.02	0.003	<0.0003	NM
IW-11	09/16/2002	NM	<0.0004	<0.003	0.028	<0.0002	NM	<0.0005	<0.02	<0.02	NM	0.14	<0.0005	<0.01	<0.0002	0.09	<0.02	0.002	<0.0003	NM
IW-11	07/01/2003	NM	<0.001	<0.003	0.036	<0.0005	NM	<0.0005	<0.02	<0.01	NM	0.33	0.001	<0.005	<0.0002	0.12	<0.02	0.002	0.0007	NM
IW-11	11/03/2003	NM	0.0004	0.0017	0.041	<0.0001	NM	0.0004	<0.01	0.02	NM	<0.01	0.0003	<0.005	<0.0002	0.14	0.01	0.001	<0.0001	NM
IW-11	12/01/2003	NM	<0.0002	0.0013	0.032	<0.0001	NM	0.0002	<0.02	<0.02	NM	<0.02	0.0001	<0.01	<0.0002	0.13	<0.02	<0.001	<0.00005	NM
IW-11	04/01/2004	NM	<0.001	0.0018	0.039	<0.0005	NM	<0.0005	<0.02	<0.02	NM	1.05	0.0022	0.01	<0.0002	0.13	<0.02	0.001	0.001	NM
IW-11	06/24/2004	NM	<0.001	<0.005	0.039	<0.001	NM	<0.0005	<0.02	<0.02	NM	0.1	<0.0005	<0.01	<0.0002	0.11	<0.02	0.002	0.0007	NM
IW-11	09/29/2004	NM	<0.001	<0.003	0.051	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.03	0.0006	<0.01	<0.0002	0.16	<0.02	0.002	<0.0005	NM
IW-11	12/14/2004	NM	<0.0004	0.004	0.039	<0.0002	NM	<0.0002	0.07	<0.02	NM	0.3	<0.0002	0.01	<0.0002	0.13	0.03	0.003	0.0003	NM
IW-11	03/23/2005	NM	<0.0002	0.0016	0.041	<0.0001	NM	0.0003	<0.02	<0.02	NM	0.06	<0.0001	<0.01	<0.0002	0.12	<0.02	0.002	<0.0001	NM
IW-11	06/10/2005	NM	<0.0004	0.0022	0.039	<0.0001	NM	<0.0001	<0.02	<0.02	NM	0.06	0.0012	<0.01	<0.0002	0.12	<0.02	0.002	<0.0001	NM
IW-11	06/10/2005	NM	<0.0004	0.0024	0.041	<0.0001	NM	<0.0001	<0.02	<0.02	NM	0.06	0.0013	<0.01	<0.0002	0.11	<0.02	0.002	<0.0001	NM
IW-11	09/14/2005	NM	<0.0008	0.002	0.045	<0.0002	NM	<0.0002	<0.02	<0.02	NM	<0.04	0.0005	<0.01	<0.0002	0.13	<0.02	<0.001	<0.0002	NM
IW-11	12/09/2005	NM	<0.0004	0.0015	0.039	<0.0001	NM	0.0002	<0.02	<0.02	NM	<0.04	0.0006	<0.01	<0.0002	0.12	<0.02	<0.001	<0.0001	NM
IW-11	01/30/2006	NM	<0.0008	0.0015	0.039	<0.0002	NM	0.0003	0.01	<0.01	<0.01	NM	0.0011	NM	NM	0.12	<0.01	0.0028	0.0004	0.01
IW-12	04/01/1997	NM	NM	<0.05	NM	NM	0.2	<0.2	0.03	<0.1	<0.1	0.02	0.08	<0.05	<0.001	0.06	NM	0.003	NM	0.02
IW-12	12/23/1997	NM	<0.01	0.003	NM	NM	0.11	<0.003	<0.05	<0.05	<0.05	0.01	<0.005	<0.03	<0.001	0.08	NM	0.003	NM	<0.05
IW-12	06/29/1998	NM	<0.005	0.008	0.058	<0.003	NM	<0.005	<0.05	<0.05	NM	0.04	0.001	<0.03	<0.001	0.09	<0.05	0.002	<0.003	NM
IW-12	12/09/1998	NM	0.0004	0.004	0.08	NM	NM	NM	NM	NM	NM	0.05	NM	NM	NM	0.01	NM	0.002	NM	NM
IW-12	10/10/2000	NM	<0.0005	0.004	0.052	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.08	0.006	<0.01	<0.0002	0.1	<0.02	<0.001	<0.0001	NM
IW-12	07/01/2003	NM	<0.001	<0.003	0.048	<0.0005	NM	<0.0005	<0.02	<0.01	NM	0.05	0.0126	<0.005	<0.0002	0.1	<0.02	0.002	0.0008	NM
IW-12	08/01/2003	<0.06	0.0002	0.00553	0.05	<0.0001	NM	<0.0001	<0.01	<0.01	NM	<0.02	0.0008	<0.005	<0.0002	0.02	<0.01	0.004	<0.00005	NM
IW-12	11/03/2003	NM	0.0002	0.0038	0.052	<0.0001	NM	<0.0001	<0.01	0.02	NM	0.04	0.0026	<0.005	<0.0002	0.1	<0.01	<0.001	0.0001	NM
IW-12	12/01/2003	NM	<0.0002	0.0031	0.048	<0.0001	NM	<0.0001	<0.02	<0.02	NM	0.06	0.0016	0.02	<0.0002	0.11	<0.02	<0.001	<0.00005	NM
IW-12	12/14/2004	NM	<0.0004	0.005	0.051	<0.0002	NM	<0.0002	0.03	<0.02	NM	0.14	0.0005	<0.01	<0.0002	0.11	<0.02	0.002	<0.0002	NM
IW-12	03/23/2005	NM	0.0003	0.0038	0.052	0.0001	NM	0.0003	0.04	<0.02	NM	19.5	0.0003	0.74	<0.0002	0.22	0.03	0.002	0.0001	NM
IW-12	06/07/2005	NM	<0.0004	<0.0005	0.047	<0.0001	NM	0.0001	<0.01	<0.01	NM	4.65	0.0009	0.083	<0.0002	0.09	<0.01	0.002	<0.0001	NM
IW-12	04/24/2006	NM	<0.0008	0.004	0.054	<0.0002	NM	<0.0002	<0.02	<0.02	<0.02	NM	0.0063	NM	NM	0.1	<0.02	0.002	<0.0002	<0.02
IW-13	06/29/1998	NM	<0.005	0.007	0.057	<0.003	NM	<0.005	<0.05	<0.05	NM	0.03	0.001	0.007	<0.001	0.09	<0.05	0.002	<0.003	NM
IW-13	11/03/2003	NM	<0.0002	0.0024	0.051	<0.0001	NM	0.0001	<0.01	<0.01	NM	0.08	0.0006	<0.005	<0.0002	0.09	0.02	0.001	0.0001	NM
IW-13	12/01/2003	NM	<0.0002	0.0017	0.045	<0.0001	NM	<0.0001	<0.02	<0.02	NM	0.14	0.0004	0.02	<0.0002	0.11	<0.02	0.004	<0.00005	NM
IW-13	04/01/2004	NM	<0.001	0.0025	0.049	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.05	0.0009	<0.01	<0.0002	0.08	<0.02	<0.001	0.0012	NM
IW-13	09/29/2004	NM	<0.001	<0.003	0.047	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.07	0.0009	<0.01	<0.0002	0.1	<0.02	0.002	<0.0005	NM
IW-13	12/10/2004	NM	<0.0004	0.002	0.06	<0.0002	NM	0.0002	0.19	<0.02	NM	0.74	0.0007	0.03	<0.0002	0.11	0.1	<0.001	0.0002	NM
IW-13	03/23/2005	NM	<0.0002	0.0026	0.057	<0.0001	NM	0.0002	<0.01	<0.01	NM	0.06	0.0002	<0.005	<0.0002	0.09	<0.01	0.002	<0.0001	NM
IW-13	03/23/2005	NM	<0.0002	0.0022	0.056	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.06	0.0002	<0.005	<0.0002	0.09	<0.01	0.001	<0.0001	NM
IW-13	06/07/2005	NM	<0.0004	0.0008	0.051	0.0001	NM	0.0001	<0.01	<0.01	NM	4.7	0.0057	0.05	<0.0002	0.1	<0.01	<0.001	<0.0001	NM
IW-13	09/14/2005	NM	<0.0008	0.003	0.058	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.04	0.0018	<0.01	<0.0002	0.1	<0.02	<0.001	<0.0002	NM
IW-13	04/24/2006	NM	<0.0008	0.003	0.046	<0.0002	NM	<0.0002	<0.02	<0.02	<0.02	NM	0.0181	NM	NM	0.11	<0.02	0.0011	<0.0002	0.15
IW-14	12/23/1997	NM	<0.01	0.001	NM	NM	0.15	<0.003	<0.05	<0.05	0.01	<0.05	<0.005	<0.03	<0.001	0.05	NM	0.002	NM	0.01
IW-14	06/29/1998	NM	<0.005	0.008	0.056	<0.003	NM	<0.005	<0.1	<0.1	NM	0.06	0.002	<0.05	<0.001	0.05	<0.1	0.002	<0.003	NM
IW-14	10/10/2000	NM	0.0004	0.004	0.057	<0.0002	NM	<0.0002	0.02	<0.02	NM	0.08	0.0034	<0.01	<0.0002	0.06	<0.02	<0.001	<0.0001	NM
IW-14	10/25/2001	NM	<0.0004	0.003	0.053	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.04	0.0014	<0.01	<0.0002	0.04	<0.02	0.002	<0.0003	NM
IW-14	04/01/2004	NM	<0.001	0.0023	0.047	<0.0005	NM	<0.0005	<0.02	<0.02	NM	<0.02	<0.0005	<0.01	<0.0002	0.04	<0.02	<0.001	0.0012	NM
IW-14	06/25/2004	NM	<0.001	0.0023	0.046	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.04	<0.0005	<0.01	<0.0002	0.04	<0.02	<0.001	0.0009	NM
IW-14	09/30/2004	NM	<0.001	<0.003	0.047	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.03	<0.0005	<0.01	<0.0002	0.05	<0.02	<0.001	<0.0005	NM
IW-14	03/21/2005	NM	<0.0002	0.0018	0.05	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.01	0.0003	<0.005	<0.0002	0.04	<0.01	<0.001	<0.0001	NM
IW-14	06/07/2005	NM	<0.0004	0.0011	0.05	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.02	0.0057	<0.005	<0.0002	0.03	<0.01	<0.001	<0.0001	NM
IW-14	09/14/2005	NM	<0.0008	0.003	0.054	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.07	0.0015	<0.01	<0.0002	0.04	<0.02	<0.001	0.0002	NM
IW-14	12/09/2005	NM	<0.0008	0.002	0.046	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.07	0.0019	<0.01	<0.0002	0.04	<0.02	<0.001	<0.0002	NM
IW-14	02/01/2006	NM	<0.0008	0.002	0.046	<0.0002	NM	<0.0002	<0.02	<0.02	<0.02	NM	0.0011	NM	NM	0.04	<0.02	0.0014	<0.0002	0.02
IW-15	12/23/1997	NM	0.002	0.002	NM	NM	0.15	<0.003	<0.05	<0.05	<0.05	0.01	<0.005	<0.03	<0.001	0.04	NM	0.002	NM	0.01
IW-15	06/29/1998	NM	<0.005	0.008	0.064	<0.003	NM	<0.005	<0.1	<0.1	NM	0.03	0.002	<0.05	<0.001	0.04	<0.1	0.002	<0.003	NM
IW-15	10/13/1999	NM	<0.0003	0.004	0.06	<0.0005	NM	<0.0005	<0.01	<0.01	NM	0.02	0.0065	<0.005	<0.0002	0.04	<0.01	0.002	<0.0003	NM
IW-15	10/10/2000	NM	<0.0005	0.004	0.059	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.03	0.0062	<0.01	<0.0002	0.04	<0.02	0.002	<0.0003	NM

AWQS = Arizona Aquifer Water Quality Standard
NS = No standard
NM = Not measured

TABLE C.2
Dissolved Metal Concentrations for Interceptor Wells (IW-series)
1997 through April 2006

Well Name	Sample Date	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Thallium	Zinc
AWQS		*NS*	*0.006*	*0.01*	*2*	*0.004*	*NS*	*0.005*	*0.1*	*NS*	*NS*	*NS*	*0.05*	*NS*	*0.002*	*NS*	*0.1*	*0.05*	*0.002*	*NS*
IW-15	11/03/2003	NM	0.0002	0.0021	0.042	<0.0001	NM	<0.0001	0.02	<0.01	NM	0.17	0.0004	<0.005	<0.0002	0.05	0.02	<0.001	<0.0001	NM
IW-15	09/30/2004	NM	<0.001	<0.003	0.049	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.09	<0.0005	<0.01	<0.0002	0.04	<0.02	0.001	<0.0005	NM
IW-15	03/23/2005	NM	<0.0002	0.001	0.074	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.04	<0.0001	0.01	<0.0002	0.02	<0.01	0.002	<0.0001	NM
IW-15	06/07/2005	NM	<0.0004	0.0009	0.055	<0.0001	NM	<0.0001	0.02	<0.01	NM	0.01	0.0021	<0.005	<0.0002	0.04	<0.01	<0.001	<0.0001	NM
IW-15	09/14/2005	NM	<0.0008	<0.001	0.055	<0.0002	NM	<0.0002	<0.02	<0.02	NM	6.85	0.0003	0.14	<0.0002	0.02	<0.02	<0.001	<0.0002	NM
IW-16	12/23/1997	NM	0.002	0.003	NM	NM	0.14	<0.003	<0.05	<0.05	<0.05	<0.05	<0.005	<0.03	<0.001	0.02	NM	0.003	NM	0.01
IW-16	06/29/1998	NM	<0.005	0.007	0.058	<0.003	NM	<0.005	<0.1	<0.1	NM	0.14	0.002	<0.05	<0.001	<0.1	<0.1	0.002	<0.003	NM
IW-17	12/23/1997	NM	0.002	0.004	NM	NM	0.15	<0.003	<0.05	<0.05	<0.05	<0.05	0.001	<0.03	0.0003	0.03	NM	0.003	NM	<0.05
IW-17	06/30/1998	NM	<0.005	0.01	0.059	<0.003	NM	<0.005	<0.1	<0.1	NM	0.04	0.001	<0.05	0.0004	0.03	<0.1	0.002	<0.003	NM
IW-17	10/13/1999	NM	<0.0003	0.006	0.06	<0.0005	NM	<0.0005	<0.01	<0.01	NM	0.03	0.0077	<0.005	0.0005	0.03	<0.01	0.002	<0.0003	NM
IW-17	10/10/2000	NM	0.0007	0.005	0.058	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.04	0.0069	<0.01	<0.0002	0.03	<0.02	0.002	<0.0001	NM
IW-17	10/25/2001	NM	0.0004	0.005	0.058	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.12	0.0056	<0.01	<0.0002	0.02	<0.02	0.001	<0.0001	NM
IW-17	04/01/2004	NM	<0.001	0.0038	0.054	<0.0005	NM	<0.0005	<0.02	<0.02	NM	<0.02	0.0042	<0.01	<0.0002	<0.02	<0.02	<0.001	0.0011	NM
IW-17	06/25/2004	NM	<0.001	0.0039	0.055	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.06	0.0008	<0.005	<0.0002	0.04	<0.02	<0.001	0.0013	NM
IW-17	09/30/2004	NM	<0.001	0.004	0.055	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.08	0.0039	<0.01	<0.0002	0.02	<0.02	0.001	<0.0005	NM
IW-17	12/10/2004	NM	<0.0004	0.004	0.06	<0.0002	NM	<0.0002	0.24	<0.02	NM	0.95	0.0006	0.03	<0.0002	0.02	0.14	<0.001	<0.0002	NM
IW-17	06/07/2005	NM	<0.0004	0.002	0.058	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.06	0.0123	<0.005	<0.0002	0.02	<0.01	<0.001	<0.0001	NM
IW-18	12/23/1997	NM	0.002	<0.005	NM	NM	0.12	<0.003	<0.05	<0.05	<0.05	0.1	<0.005	0.008	<0.001	0.05	NM	0.003	NM	0.01
IW-18	06/30/1998	NM	<0.005	0.008	0.061	<0.003	NM	<0.005	<0.1	<0.1	NM	0.04	0.003	<0.05	<0.001	0.05	<0.1	0.003	<0.003	NM
IW-18	04/01/2004	NM	<0.001	0.0029	0.058	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.08	0.0086	<0.01	<0.0002	0.04	<0.02	<0.001	0.0013	NM
IW-18	06/29/2004	NM	<0.001	<0.003	0.058	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.11	0.0067	<0.01	<0.0002	0.04	<0.02	<0.001	0.0007	NM
IW-18	09/30/2004	NM	<0.001	<0.003	0.058	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.07	0.0064	<0.01	<0.0002	0.04	<0.02	0.001	<0.0005	NM
IW-18	03/23/2005	NM	0.0003	<0.0005	0.08	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.69	0.0009	0.03	<0.0002	0.02	<0.01	0.001	<0.0001	NM
IW-18	06/07/2005	NM	<0.0004	0.0006	0.073	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.25	0.0036	0.041	<0.0002	0.01	<0.01	<0.001	0.0002	NM
IW-18	04/26/2006	NM	<0.0008	0.003	0.067	<0.0002	NM	<0.0002	<0.02	<0.02	<0.02	NM	0.0047	NM	NM	0.04	<0.02	0.0015	<0.0002	<0.02
IW-19	12/23/1997	NM	0.003	0.002	NM	NM	0.13	<0.003	<0.05	<0.05	0.01	<0.05	<0.005	0.006	<0.001	0.01	NM	0.003	NM	<0.05
IW-19	10/13/1999	NM	<0.0003	0.005	0.07	<0.0005	NM	<0.0005	<0.01	<0.01	NM	0.02	0.0112	<0.005	<0.0002	0.02	<0.01	0.002	<0.0003	NM
IW-19	10/25/2001	NM	0.0007	0.004	0.078	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.05	0.0071	<0.01	<0.0002	<0.02	<0.02	0.001	<0.0001	NM
IW-19	04/01/2004	NM	<0.001	0.0032	0.065	<0.0005	NM	<0.0005	<0.02	<0.02	NM	<0.02	0.0031	<0.01	<0.0002	<0.02	<0.02	<0.001	0.0011	NM
IW-19	06/29/2004	NM	<0.001	<0.003	0.071	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.06	0.0018	<0.01	<0.0002	<0.02	<0.02	<0.001	0.0008	NM
IW-19	09/30/2004	NM	<0.001	0.003	0.069	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.02	0.0022	<0.01	<0.0002	0.02	<0.02	<0.001	<0.0005	NM
IW-19	12/06/2004	NM	<0.0004	0.003	0.069	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.08	0.0019	<0.01	<0.0002	<0.02	0.03	0.001	<0.0002	NM
IW-19	03/21/2005	NM	<0.0002	0.0032	0.071	<0.0001	NM	<0.0001	<0.02	<0.02	NM	0.03	0.0039	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0001	NM
IW-19	06/07/2005	NM	<0.0004	0.0038	0.074	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.09	0.0043	<0.005	<0.0002	0.02	<0.01	<0.001	0.0002	NM
IW-19	09/14/2005	NM	<0.0008	0.004	0.077	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.26	0.0036	<0.01	<0.0002	<0.02	<0.02	<0.001	0.0002	NM
IW-19	12/12/2005	NM	<0.0004	0.003	0.073	<0.0002	NM	<0.0001	<0.02	<0.02	NM	0.06	0.0042	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0001	NM
IW-19	12/12/2005	NM	<0.0004	0.0029	0.067	<0.0002	NM	<0.0001	<0.02	<0.02	NM	0.17	0.0029	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0001	NM
IW-19	01/24/2006	NM	<0.0008	0.0033	0.075	<0.0002	NM	<0.0002	<0.01	<0.01	<0.01	NM	0.0037	NM	NM	0.01	<0.01	0.0013	<0.0002	0.01
IW-19	04/26/2006	NM	<0.0008	0.003	0.069	<0.0002	NM	<0.0002	<0.02	<0.02	<0.02	NM	0.0045	NM	NM	0.03	<0.02	0.0013	<0.0002	0.03
IW-20	12/23/1997	NM	0.003	0.001	NM	NM	0.13	<0.003	<0.05	<0.05	0.01	0.03	0.001	0.007	<0.001	0.01	NM	0.003	NM	0.01
IW-20	06/30/1998	NM	<0.005	0.009	0.075	<0.003	NM	<0.005	<0.1	<0.1	NM	0.04	<0.005	<0.05	0.0003	0.02	<0.1	0.003	<0.003	NM
IW-20	10/13/1999	NM	<0.0003	0.005	0.07	<0.0005	NM	<0.0005	<0.01	<0.01	NM	0.03	0.0023	<0.005	0.0002	0.02	<0.01	0.003	<0.0003	NM
IW-20	10/10/2000	NM	0.0011	0.003	0.077	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.06	0.0012	<0.01	0.0003	<0.02	<0.02	0.002	<0.0001	NM
IW-20	09/16/2002	NM	<0.0004	0.003	0.061	<0.0002	NM	<0.0005	<0.02	<0.02	NM	0.12	<0.0005	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0003	NM
IW-20	07/01/2003	NM	0.001	<0.003	0.067	<0.0005	NM	<0.0005	<0.02	<0.01	NM	0.13	0.0007	<0.005	<0.0002	0.02	<0.02	0.002	0.0007	NM
IW-20	08/01/2003	<0.06	<0.0004	0.0024	0.067	<0.0002	NM	<0.0002	<0.01	<0.01	NM	0.03	0.0005	<0.005	<0.0002	0.02	<0.01	<0.001	<0.0001	NM
IW-20	11/03/2003	NM	<0.0002	0.0024	0.061	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.11	0.0003	<0.005	<0.0002	0.02	0.01	<0.001	<0.0001	NM
IW-20	04/01/2004	NM	<0.001	0.0023	0.069	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.06	<0.0005	<0.01	<0.0002	<0.02	<0.02	<0.001	0.0011	NM
IW-20	06/25/2004	NM	<0.001	0.0025	0.073	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.06	0.0006	<0.005	<0.0002	0.03	<0.02	<0.001	0.0009	NM
IW-20	09/30/2004	NM	<0.001	<0.003	0.072	<0.0005	NM	<0.0005	<0.02	<0.02	NM	0.05	0.0006	<0.01	<0.0002	0.02	<0.02	0.001	<0.0005	NM
IW-20	12/14/2004	NM	<0.0004	0.002	0.059	<0.0002	NM	<0.0002	0.03	<0.02	NM	2.39	<0.0002	0.07	<0.0002	0.03	<0.02	0.002	<0.0002	NM
IW-20	03/21/2005	NM	<0.0002	0.002	0.073	<0.0001	NM	<0.0001	<0.02	<0.02	NM	0.3	0.0008	<0.01	<0.0002	<0.02	<0.02	0.001	<0.0001	NM
IW-20	06/07/2005	NM	<0.0004	0.0026	0.083	0.0003	NM	<0.0001	<0.01	<0.01	NM	0.22	0.0064	<0.005	<0.0002	<0.01	<0.01	<0.001	<0.0001	NM
IW-20	09/14/2005	NM	<0.0008	0.003	0.078	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.12	0.0029	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0002	NM
IW-20	12/12/2005	NM	<0.0008	0.002	0.068	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.08	0.0036	<0.01	<0.0002	0.02	<0.02	<0.001	<0.0002	NM
IW-20	01/24/2006	NM	<0.0008	0.0023	0.075	<0.0002	NM	<0.0002	<0.01	<0.01	<0.01	NM	0.0045	NM	NM	<0.01	<0.01	0.0013	<0.0002	0.01
IW-20	04/26/2006	NM	<0.0008	0.002	0.071	<0.0002	NM	<0.0002	<0.02	<0.02	<0.02	NM	0.0023	NM	NM	0.03	<0.02	0.0013	<0.0002	<0.02
IW-21	12/23/1997	NM	0.002	0.001	NM	NM	0.12	<0.003	<0.05	<0.05	0.01	0.04	<0.005	0.005	<0.001	0.01	NM	0.004	NM	0.01
IW-21	06/30/1998	NM	<0.005	0.007	0.086	<0.003	NM	<0.005	<0.1	<0.1	NM	0.04	0.002	<0.05	<0.001	0.02	<0.1	0.003	<0.003	NM
IW-21	10/12/1999	NM	<0.0003	0.003	0.09	<0.0005	NM	<0.0005	<0.01	<0.01	NM	0.08	0.0065	<0.005	<0.0002	0.03	<0.01	0.004	<0.0003	NM
IW-21	10/10/2000	NM	<0.0005	0.002	0.085	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.05	0.0023	<0.01	<0.0002	0.02	<0.02	0.002	<0.0001	NM
IW-21	10/25/2001	NM	<0.0004	0.002	0.083	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.11	0.0041	<0.01	<0.0002	0.02	<0.02	0.003	<0.0001	NM
IW-21	09/16/2002	NM	<0.0004	<0.003	0.064	<0.0002	NM	<0.0005	<0.02	<0.02	NM	0.12	0.0009	<0.01	<0.0002	<0.02	<0.02	0.001	<0.0001	NM
IW-21	07/01/2003	NM	<0.001	<0.003	0.078	<0.0005	NM	0.0006	<0.02	<0.01	NM	0.05	0.015	<0.005	<0.0002	0.02	<0.02	0.002	0.0007	NM
IW-21	08/01/2003	<0.06	<0.0004	0.0017	0.073	<0.0002	NM	<0.0002	<0.01	<0.01	NM	0.02	0.0023	<0.005	<0.0002	0.02	<0.01	0.001	<0.0001	NM
IW-21	11/03/2003	NM	0.0002	0.0017	0.08	<0.0001	NM	0.0001	0.03	<0.01	NM	0.1	0.0015	<0.005	<0.0002	0.04	<0.01	0.001	0.0001	NM
IW-21	10/01/2004	NM	<0.0004	0.002	0.095	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.03	0.0007	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0002	NM
IW-21	12/03/2004	NM	<0.0004	0.002	0.079	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.07	0.0002	<0.01	<0.0002	<0.02	0.67	0.002	<0.0002	NM
IW-21	03/21/2005	NM	<0.0002	0.0015	0.079	<0.0001	NM	<0.0001	<0.02	<0.02	NM	0.05	0.0026	<0.01	<0.0002	<0.02	<0.02	0.001	<0.0001	NM
IW-21	06/07/2005	NM	<0.0004	0.0024	0.079	0.0004	NM	<0.0001	<0.01	<0.01	NM	0.08	0.0075	0.006	<0.0002	0.02	<0.01	<0.001	<0.0001	NM
IW-21	06/07/2005	NM	<0.0004	<0.0005	0.078	<0.0001	NM	<0.0001	<0.01	<0.01	NM	0.09	0.0066	0.007	<0.0002	0.02	<0.01	<0.001	<0.0001	NM
IW-21	09/14/2005	NM	<0.0008	0.002	0.08	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.09	0.0046	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0002	NM
IW-21	12/12/2005	NM	<0.0004	0.0013	0.073	<0.0002	NM	<0.0001	<0.02	<0.02	NM	0.25	0.0039	<0.01	<0.0002	<0.02	<0.02	<0.001	<0.0001	NM
IW-21	01/24/2006	NM	<0.0008	0.0015	0.081	<0.0002	NM	<0.0002	<0.01	<0.01	<0.01	NM	0.0043	NM	NM	0.02	<0.01	0.0015	<0.0002	0.01
IW-21	04/26/2006	NM	<0.0008	0.001	0.073	<0.0002	NM	<0.0002	<0.02	<0.02	<0.02	NM	0.0029	NM	NM	0.03	<0.02	0.0014	<0.0002	<0.02
IW-22	01/15/2004	NM	<0.001	0.0018	0.043	<0.0002	NM	<0.0005	<0.01	<0.01	NM	0.11	0.0032	0.03	<0.0002	0.12	<0.01	0.001	<0.0001	NM
IW-22	06/24/2005	NM	<0.0008	<0.001	0.034	<0.0002	NM	0.0002	<0.02	<0.02	NM	0.39	0.0021	<0.01	0.0002	0.13	<0.02	0.001	<0.0002	NM
IW-22	09/14/2005	NM	<0.0008	0.002	0.048	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.31	0.0019	<0.01	<0.0002	0.09	<0.02	<0.001	<0.0002	NM
IW-22	12/12/2005	NM	<0.0008	0.001	0.042	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.36	0.0019	<0.01	<0.0002	0.08	<0.02	<0.001	<0.0002	NM
IW-22	01/30/2006	NM	<0.0008	0.0012	0.043	<0.0002	NM	0.0003	0.01	<0.01	<0.01	NM	0.0034	NM	NM	0.1	<0.01	0.0025	0.0004	0.03
IW-23	02/14/2004	NM	<0.0004	0.001	0.033	<0.0001	NM	0.0003	<0.01	<0.02	NM	0.09	0.001	0.028	<0.0002	0.08	<0.01	0.001	<0.00005	NM
IW-23	06/24/2005	NM	<0.0008	<0.001	0.035	<0.0002	NM	0.0002	<0.02	<0.02	NM	0.79	0.003	0.01	0.0002	0.07	<0.02	0.001	<0.0002	NM
IW-23	09/16/2005	NM	<0.0008	0.002	0.036	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.16	0.0012	<0.01	<0.0002	0.08	<0.02	0.001	<0.0002	NM
IW-23	12/08/2005	NM	<0.0008	0.002	0.043	<0.0004	NM	<0.0002	<0.02	<0.02	NM	0.16	0.0005	0.01	<0.0002	0.08	<0.02	<0.001	<0.0002	NM
IW-23	01/24/2006	NM	<0.0008	0.0018	0.044	<0.0002	NM	<0.0002	<0.01	<0.01	<0.01	NM	0.0008	NM	NM	0.06	<0.01	0.002	<0.0002	0.01
IW-24	01/25/2004	NM	<0.0004	0.0014	0.05	<0.0002	NM	<0.0002	<0.01	0.01	NM	0.27	0.0043	0.041	<0.0002	0.03	0.01	0.001	0.0001	NM
IW-24	06/24/2005	NM	<0.0008	<0.001	0.042	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.66	0.0016	0.05	<0.0002	<0.02	<0.02	0.001	<0.0002	NM
IW-24	09/14/2005	NM	<0.0008	0.002	0.045	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.25	0.002	0.01	<0.0002	0.03	<0.02	<0.001	<0.0002	NM
IW-24	12/12/2005	NM	<0.0008	0.001	0.042	<0.0002	NM	<0.0002	<0.02	<0.02	NM	0.17	0.0014	0.01	<0.0002	0.04	<0.02	<0.001	<0.0002	NM
IW-24	01/30/2006	NM	<0.0008	0.001	0.043	<0.0002	NM	0.0003	<0.02	<0.01	0.02	NM	0.0045	NM	NM	0.03	<0.01	0.0013	0.0004	0.08
IW-24	01/30/2006	NM	<0.0008	<0.0002	0.04	<0.0002	NM	<0.0002	<0.02	<0.01	0.02	NM	0.0011	NM	NM	0.03	<0.01	<0.0002	0.0006	0.07

AWQS = Arizona Aquifer Water Quality Standard
NS = No standard
NM = Not measured

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
IW-1	1/3/80	520	IW-1	6/17/81	257	IW-1	3/27/84	255
IW-1	1/11/80	525	IW-1	6/30/81	232	IW-1	4/18/84	233
IW-1	1/16/80	610	IW-1	7/10/81	262	IW-1	5/9/84	248
IW-1	1/21/80	556	IW-1	7/13/81	271	IW-1	5/29/84	241
IW-1	1/28/80	605	IW-1	7/20/81	284	IW-1	6/18/84	225
IW-1	2/4/80	577	IW-1	8/11/81	290	IW-1	7/5/84	218
IW-1	2/11/80	551	IW-1	8/18/81	303	IW-1	8/1/84	238
IW-1	2/19/80	522	IW-1	9/4/81	295	IW-1	10/26/84	214
IW-1	2/25/80	479	IW-1	9/11/81	280	IW-1	11/26/84	230
IW-1	3/3/80	502	IW-1	9/16/81	281	IW-1	12/3/84	228
IW-1	3/10/80	433	IW-1	9/21/81	283	IW-1	2/4/85	232
IW-1	3/17/80	434	IW-1	10/5/81	272	IW-1	3/18/85	173
IW-1	3/23/80	459	IW-1	10/13/81	296	IW-1	4/3/85	102
IW-1	3/31/80	446	IW-1	10/19/81	316	IW-1	5/16/85	165
IW-1	4/8/80	469	IW-1	10/26/81	321	IW-1	5/21/85	195
IW-1	4/14/80	471	IW-1	11/1/81	311	IW-1	6/1/85	262
IW-1	4/21/80	452	IW-1	12/1/81	300	IW-1	6/15/85	203
IW-1	4/28/80	445	IW-1	12/2/81	332	IW-1	7/4/85	230
IW-1	5/5/80	433	IW-1	3/31/82	239	IW-1	8/1/85	224
IW-1	5/12/80	423	IW-1	4/7/82	290	IW-1	8/15/85	257
IW-1	5/19/80	431	IW-1	4/20/82	300	IW-1	9/6/85	235
IW-1	5/27/80	469	IW-1	5/4/82	314	IW-1	9/15/85	233
IW-1	6/1/80	453	IW-1	5/25/82	318	IW-1	10/17/85	299
IW-1	6/8/80	550	IW-1	6/11/82	321	IW-1	12/2/85	244
IW-1	6/16/80	426	IW-1	6/16/82	282	IW-1	1/8/86	245
IW-1	6/23/80	376	IW-1	7/6/82	351	IW-1	1/25/86	230
IW-1	6/30/80	402	IW-1	7/14/82	336	IW-1	2/6/86	239
IW-1	7/8/80	382	IW-1	9/30/82	306	IW-1	3/14/86	227
IW-1	7/17/80	370	IW-1	10/14/82	346	IW-1	3/19/86	224
IW-1	7/21/80	404	IW-1	10/20/82	331	IW-1	4/23/86	242
IW-1	7/28/80	404	IW-1	1/6/83	326	IW-1	6/18/86	214
IW-1	8/4/80	374	IW-1	1/20/83	310	IW-1	6/21/86	248
IW-1	8/11/80	364	IW-1	2/13/83	283	IW-1	7/10/86	242
IW-1	8/18/80	393	IW-1	3/25/83	327	IW-1	8/7/86	185
IW-1	8/25/80	365	IW-1	4/13/83	293	IW-1	8/11/86	216
IW-1	9/2/80	438	IW-1	5/12/83	321	IW-1	12/3/86	217
IW-1	9/8/80	486	IW-1	6/10/83	286	IW-1	12/10/86	239
IW-1	9/15/80	410	IW-1	7/5/83	290	IW-1	1/7/87	254
IW-1	9/22/80	458	IW-1	7/14/83	295	IW-1	2/3/87	196
IW-1	9/29/80	380	IW-1	7/30/83	298	IW-1	3/4/87	127
IW-1	10/8/80	360	IW-1	8/11/83	294	IW-1	5/1/87	231
IW-1	10/13/80	357	IW-1	8/24/83	304	IW-1	6/1/87	265
IW-1	10/27/80	403	IW-1	9/19/83	276	IW-1	7/31/87	189
IW-1	11/3/80	420	IW-1	10/14/83	262	IW-1	9/1/87	221
IW-1	11/13/80	384	IW-1	11/14/83	249	IW-1	10/1/87	212
IW-1	11/17/80	397	IW-1	11/28/83	262	IW-1	11/3/87	212
IW-1	1/21/81	215	IW-1	12/14/83	244	IW-1	1/1/88	171
IW-1	3/2/81	289	IW-1	12/30/83	253	IW-1	2/1/88	209
IW-1	3/23/81	256	IW-1	2/2/84	250	IW-1	3/1/88	219
IW-1	5/25/81	224	IW-1	2/14/84	260	IW-1	4/1/88	176
IW-1	6/11/81	303	IW-1	3/7/84	240	IW-1	5/1/88	180

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
			IW-2	3/31/80	815	IW-2	5/11/81	718
IW-1	5/2/88	176	IW-2	4/28/80	853	IW-2	5/19/81	713
IW-1	6/1/88	151	IW-2	5/5/80	841	IW-2	5/28/81	744
IW-1	7/1/88	158	IW-2	5/12/80	835	IW-2	6/2/81	721
IW-1	8/1/88	219	IW-2	5/19/80	841	IW-2	6/11/81	775
IW-1	9/1/88	184	IW-2	5/27/80	833	IW-2	6/17/81	683
IW-1	10/1/88	107	IW-2	6/1/80	868	IW-2	6/22/81	685
IW-1	12/1/88	117	IW-2	6/8/80	851	IW-2	6/30/81	691
IW-1	1/1/89	119	IW-2	6/16/80	826	IW-2	7/13/81	694
IW-1	2/1/89	131	IW-2	6/23/80	775	IW-2	7/31/81	649
IW-1	4/1/89	152	IW-2	6/30/80	818	IW-2	9/4/81	657
IW-1	7/1/89	133	IW-2	7/8/80	803	IW-2	9/11/81	645
IW-1	10/1/89	168	IW-2	7/17/80	825	IW-2	9/16/81	625
IW-1	1/1/90	225	IW-2	7/21/80	815	IW-2	9/21/81	660
IW-1	1/23/90	176	IW-2	7/28/80	808	IW-2	10/5/81	617
IW-1	4/10/90	113	IW-2	8/4/80	821	IW-2	10/13/81	665
IW-1	7/1/90	180	IW-2	8/11/80	825	IW-2	12/1/81	606
IW-1	7/14/94	356	IW-2	8/18/80	838	IW-2	12/10/81	675
IW-1	10/24/94	422	IW-2	8/25/80	797	IW-2	1/21/82	581
IW-1	5/1/95	438	IW-2	9/2/80	792	IW-2	3/23/82	566
IW-1	6/18/97	1,270	IW-2	9/8/80	802	IW-2	3/29/82	598
IW-1	8/26/97	1,390	IW-2	9/15/80	798	IW-2	3/31/82	547
IW-1	12/23/97	1,470	IW-2	9/22/80	826	IW-2	4/7/82	614
IW-1	2/24/98	1,510	IW-2	9/29/80	818	IW-2	4/20/82	599
IW-1	7/1/03	930	IW-2	10/8/80	805	IW-2	5/4/82	601
IW-1	8/1/03	950	IW-2	10/13/80	807	IW-2	6/16/82	629
IW-1	11/3/03	930	IW-2	10/20/80	820	IW-2	7/6/82	619
IW-1	12/1/03	930	IW-2	10/27/80	849	IW-2	7/14/82	616
IW-1	3/31/04	880	IW-2	11/3/80	785	IW-2	9/30/82	596
IW-1	6/24/04	810	IW-2	11/13/80	816	IW-2	10/14/82	602
IW-1	9/29/04	750	IW-2	11/17/80	805	IW-2	10/29/82	570
IW-1	12/15/04	680	IW-2	11/24/80	923	IW-2	11/14/82	612
IW-1	3/23/05	610	IW-2	12/15/80	825	IW-2	12/2/82	552
IW-1	9/14/05	520	IW-2	12/22/80	780	IW-2	1/6/83	564
IW-1	12/8/05	500	IW-2	1/5/81	784	IW-2	1/20/83	547
IW-1	1/30/06	500	IW-2	1/12/81	798	IW-2	3/13/83	550
IW-2	1/3/80	767	IW-2	1/19/81	836	IW-2	3/25/83	529
IW-2	1/11/80	838	IW-2	1/26/81	785	IW-2	4/13/83	524
IW-2	1/16/80	944	IW-2	2/17/81	798	IW-2	5/11/83	519
IW-2	1/21/80	915	IW-2	2/22/81	604	IW-2	5/12/83	504
IW-2	1/28/80	844	IW-2	2/24/81	797	IW-2	6/10/83	425
IW-2	2/4/80	905	IW-2	3/2/81	724	IW-2	6/23/83	477
IW-2	2/11/80	900	IW-2	3/3/81	800	IW-2	7/5/83	449
IW-2	2/19/80	858	IW-2	3/11/81	745	IW-2	7/14/83	443
IW-2	3/3/80	868	IW-2	3/25/81	719	IW-2	7/30/83	454
IW-2	3/10/80	802	IW-2	3/31/81	738	IW-2	8/11/83	431
IW-2	3/17/80	823	IW-2	4/11/81	719	IW-2	8/24/83	430
IW-2	3/23/80	853	IW-2	4/13/81	810	IW-2	10/14/83	371
IW-2	4/8/80	794	IW-2	4/24/81	723	IW-2	10/18/83	385
IW-2	4/14/80	841	IW-2	4/28/81	729	IW-2	11/14/83	389
IW-2	4/21/80	800	IW-2	5/5/81	729	IW-2	11/28/83	410

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
IW-2	12/14/83	382	IW-2	2/1/88	110	IW-2	3/31/04	370
IW-2	12/20/83	406	IW-2	3/1/88	89	IW-2	6/24/04	350
IW-2	1/6/84	389	IW-2	4/1/88	64	IW-2	9/29/04	290
IW-2	2/2/84	347	IW-2	5/1/88	125	IW-2	12/15/04	240
IW-2	2/14/84	387	IW-2	5/2/88	64	IW-2	3/23/05	190
IW-2	3/7/84	329	IW-2	6/1/88	56	IW-2	6/10/05	110
IW-2	3/27/84	376	IW-2	9/1/88	35	IW-2	9/14/05	120
IW-2	5/9/84	363	IW-2	11/1/88	87	IW-2	12/8/05	100
IW-2	5/29/84	351	IW-2	1/1/89	71	IW-2	1/30/06	100
IW-2	6/18/84	322	IW-2	2/1/89	35	IW-3	1/11/80	1,153
IW-2	7/5/84	309	IW-2	4/1/89	42	IW-3	1/16/80	1,291
IW-2	8/1/84	353	IW-2	7/1/89	54	IW-3	1/21/80	1,215
IW-2	10/26/84	324	IW-2	10/1/89	54	IW-3	1/28/80	1,205
IW-2	11/26/84	290	IW-2	1/1/90	111	IW-3	2/4/80	1,292
IW-2	12/3/84	317	IW-2	1/22/90	61	IW-3	2/11/80	1,222
IW-2	1/2/85	280	IW-2	4/9/90	36	IW-3	2/19/80	1,353
IW-2	1/4/85	280	IW-2	7/1/90	66	IW-3	2/25/80	1,174
IW-2	2/4/85	301	IW-2	10/1/90	72	IW-3	3/3/80	1,184
IW-2	3/18/85	216	IW-2	10/18/90	72	IW-3	3/10/80	1,157
IW-2	4/3/85	292	IW-2	1/1/91	80	IW-3	3/23/80	1,171
IW-2	5/1/85	161	IW-2	1/14/91	63	IW-3	3/31/80	1,218
IW-2	5/16/85	210	IW-2	4/1/91	89	IW-3	4/8/80	1,156
IW-2	6/1/85	266	IW-2	7/1/91	39	IW-3	4/14/80	1,230
IW-2	6/15/85	291	IW-2	10/1/91	44	IW-3	4/21/80	1,195
IW-2	7/4/85	227	IW-2	2/1/92	34	IW-3	4/28/80	1,220
IW-2	8/1/85	237	IW-2	4/15/92	54	IW-3	5/5/80	1,212
IW-2	8/15/85	270	IW-2	7/30/92	52	IW-3	5/12/80	1,205
IW-2	9/6/85	243	IW-2	10/19/92	55	IW-3	5/19/80	1,197
IW-2	9/15/85	268	IW-2	1/13/93	51	IW-3	5/27/80	1,208
IW-2	10/1/85	291	IW-2	4/16/93	57	IW-3	6/1/80	1,243
IW-2	10/17/85	267	IW-2	7/14/94	64	IW-3	6/8/80	1,214
IW-2	12/2/85	244	IW-2	10/24/94	71	IW-3	6/16/80	1,198
IW-2	1/8/86	251	IW-2	1/31/95	54	IW-3	6/23/80	1,180
IW-2	1/25/86	225	IW-2	5/1/95	75	IW-3	6/30/80	1,195
IW-2	2/6/86	237	IW-2	10/17/95	59	IW-3	7/8/80	1,211
IW-2	3/14/86	237	IW-2	1/31/96	125	IW-3	7/17/80	1,213
IW-2	3/19/86	207	IW-2	4/30/96	68	IW-3	7/21/80	1,197
IW-2	4/14/86	221	IW-2	7/22/96	82	IW-3	7/28/80	1,225
IW-2	6/18/86	221	IW-2	2/26/97	140	IW-3	8/4/80	1,221
IW-2	6/21/86	242	IW-2	6/18/97	160	IW-3	8/11/80	1,220
IW-2	11/9/86	122	IW-2	8/26/97	180	IW-3	8/18/80	1,249
IW-2	12/3/86	105	IW-2	12/23/97	280	IW-3	8/25/80	1,183
IW-2	1/7/87	140	IW-2	2/24/98	270	IW-3	9/2/80	1,192
IW-2	2/3/87	108	IW-2	6/25/98	410	IW-3	9/8/80	1,200
IW-2	6/1/87	119	IW-2	10/10/00	390	IW-3	9/15/80	1,188
IW-2	7/31/87	79	IW-2	10/22/01	330	IW-3	9/22/80	1,161
IW-2	9/1/87	105	IW-2	9/16/02	260	IW-3	9/29/80	1,253
IW-2	10/1/87	108	IW-2	7/1/03	240	IW-3	10/8/80	1,230
IW-2	11/3/87	101	IW-2	8/1/03	260	IW-3	10/13/80	1,213
IW-2	11/30/87	91	IW-2	11/3/03	300	IW-3	10/20/80	1,200
IW-2	1/1/88	80	IW-2	12/1/03	320	IW-3	10/27/80	1,244

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
IW-3	11/3/80	1,226	IW-3	11/2/81	1,110	IW-3	5/1/85	1,237
IW-3	11/13/80	1,221	IW-3	11/23/81	1,222	IW-3	5/16/85	1,162
IW-3	11/17/80	1,220	IW-3	12/1/81	1,199	IW-3	6/1/85	1,241
IW-3	11/24/80	1,541	IW-3	12/10/81	1,210	IW-3	6/15/85	1,156
IW-3	12/1/80	1,324	IW-3	1/21/82	1,307	IW-3	7/4/85	1,119
IW-3	12/8/80	1,223	IW-3	2/22/82	1,235	IW-3	8/1/85	1,206
IW-3	12/15/80	1,195	IW-3	4/22/82	1,173	IW-3	8/15/85	1,381
IW-3	12/22/80	1,220	IW-3	5/6/82	1,062	IW-3	9/6/85	1,216
IW-3	12/29/80	1,241	IW-3	6/16/82	1,100	IW-3	9/15/85	1,290
IW-3	1/5/81	1,261	IW-3	7/6/82	1,187	IW-3	10/1/85	1,317
IW-3	1/12/81	1,233	IW-3	7/14/82	1,203	IW-3	10/17/85	1,231
IW-3	1/19/81	1,291	IW-3	10/14/82	1,234	IW-3	12/2/85	1,192
IW-3	1/26/81	1,200	IW-3	10/20/82	1,170	IW-3	1/8/86	1,238
IW-3	2/17/81	1,152	IW-3	11/14/82	1,257	IW-3	1/25/86	1,292
IW-3	2/24/81	1,247	IW-3	1/6/83	1,261	IW-3	3/14/86	1,228
IW-3	3/2/81	1,362	IW-3	1/20/83	1,254	IW-3	3/19/86	1,306
IW-3	3/3/81	1,236	IW-3	2/13/83	1,213	IW-3	8/7/86	1,196
IW-3	3/11/81	1,214	IW-3	4/13/83	1,278	IW-3	10/11/86	1,172
IW-3	3/16/81	1,119	IW-3	5/11/83	1,229	IW-3	12/3/86	1,199
IW-3	3/23/81	1,262	IW-3	5/12/83	1,210	IW-3	12/10/86	1,256
IW-3	3/25/81	1,206	IW-3	6/10/83	1,110	IW-3	1/7/87	1,196
IW-3	3/31/81	1,218	IW-3	6/23/83	1,176	IW-3	2/3/87	1,278
IW-3	4/11/81	1,250	IW-3	7/5/83	1,166	IW-3	5/1/87	1,156
IW-3	4/17/81	1,259	IW-3	7/14/83	1,210	IW-3	7/31/87	1,150
IW-3	4/24/81	1,235	IW-3	7/30/83	1,237	IW-3	10/1/87	1,179
IW-3	4/28/81	1,254	IW-3	8/11/83	1,224	IW-3	11/3/87	1,168
IW-3	5/5/81	1,235	IW-3	8/24/83	1,232	IW-3	11/30/87	1,167
IW-3	5/11/81	1,264	IW-3	9/19/83	1,215	IW-3	2/1/88	1,143
IW-3	5/19/81	1,227	IW-3	10/14/83	1,200	IW-3	4/1/88	1,075
IW-3	5/28/81	1,233	IW-3	10/18/83	1,203	IW-3	5/1/88	1,115
IW-3	6/2/81	1,240	IW-3	11/14/83	1,165	IW-3	5/2/88	1,075
IW-3	6/11/81	1,286	IW-3	12/14/83	1,199	IW-3	6/1/88	1,096
IW-3	6/17/81	1,207	IW-3	12/20/83	1,146	IW-3	7/1/88	1,098
IW-3	6/22/81	1,245	IW-3	1/6/84	1,194	IW-3	8/1/88	1,100
IW-3	6/30/81	1,196	IW-3	1/19/84	1,200	IW-3	9/1/88	1,092
IW-3	7/10/81	1,220	IW-3	2/2/84	1,171	IW-3	12/1/88	1,031
IW-3	7/13/81	1,218	IW-3	2/14/84	1,166	IW-3	1/1/89	973
IW-3	7/20/81	1,206	IW-3	3/7/84	1,215	IW-3	2/1/89	926
IW-3	7/31/81	1,215	IW-3	3/27/84	1,197	IW-3	4/1/89	929
IW-3	8/11/81	1,225	IW-3	4/18/84	1,171	IW-3	7/1/89	886
IW-3	8/18/81	1,213	IW-3	5/9/84	1,161	IW-3	10/1/89	851
IW-3	9/4/81	1,189	IW-3	5/29/84	1,173	IW-3	1/1/90	840
IW-3	9/11/81	1,187	IW-3	6/18/84	1,187	IW-3	1/22/90	900
IW-3	9/16/81	1,177	IW-3	7/5/84	1,119	IW-3	4/9/90	799
IW-3	9/21/81	1,200	IW-3	8/1/84	1,207	IW-3	7/1/90	751
IW-3	10/5/81	1,085	IW-3	10/26/84	1,306	IW-3	10/1/90	910
IW-3	10/13/81	1,281	IW-3	11/26/84	1,217	IW-3	10/18/90	910
IW-3	10/14/81	1,203	IW-3	12/3/84	1,171	IW-3	1/1/91	836
IW-3	10/19/81	1,216	IW-3	1/2/85	1,322	IW-3	1/14/91	690
IW-3	10/26/81	1,159	IW-3	2/4/85	1,233	IW-3	4/1/91	815
IW-3	11/1/81	1,110	IW-3	3/18/85	1,245	IW-3	7/1/91	808

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
IW-3	10/1/91	783	IW-4	6/1/80	1,197	IW-4	10/1/81	1,205
IW-3	1/1/92	840	IW-4	6/23/80	1,030	IW-4	5/19/81	1,205
IW-3	4/15/92	1,076	IW-4	6/30/80	1,100	IW-4	10/13/81	1,213
IW-3	7/30/92	881	IW-4	7/8/80	1,047	IW-4	10/19/81	1,226
IW-3	10/19/92	895	IW-4	7/17/80	1,106	IW-4	10/26/81	1,211
IW-3	1/13/93	1,019	IW-4	7/21/80	1,082	IW-4	11/2/81	1,206
IW-3	4/16/93	862	IW-4	7/28/80	1,045	IW-4	11/23/81	1,200
IW-3	7/14/94	964	IW-4	8/4/80	999	IW-4	12/1/81	1,187
IW-3	10/24/94	946	IW-4	8/11/80	1,110	IW-4	12/10/81	1,259
IW-3	1/31/95	1,213	IW-4	8/18/80	1,124	IW-4	1/21/82	1,146
IW-3	5/1/95	1,625	IW-4	8/25/80	1,083	IW-4	2/22/82	1,111
IW-3	10/17/95	1,276	IW-4	9/2/80	1,098	IW-4	3/23/82	1,113
IW-3	1/31/96	1,426	IW-4	9/15/80	1,083	IW-4	3/31/82	1,096
IW-3	4/30/96	1,462	IW-4	9/22/80	1,083	IW-4	4/7/82	1,161
IW-3	7/22/96	1,530	IW-4	9/29/80	1,108	IW-4	4/20/82	1,087
IW-3	2/26/97	1,600	IW-4	10/8/80	1,111	IW-4	5/4/82	1,065
IW-3	6/18/97	1,570	IW-4	10/13/80	1,106	IW-4	5/25/82	1,154
IW-3	8/26/97	1,670	IW-4	11/24/80	1,302	IW-4	6/11/82	1,055
IW-3	12/23/97	1,660	IW-4	12/1/80	1,126	IW-4	6/16/82	1,077
IW-3	2/24/98	1,700	IW-4	12/8/80	1,197	IW-4	7/14/82	1,187
IW-3	6/25/98	1,380	IW-4	12/15/80	1,115	IW-4	9/30/82	1,088
IW-3	10/22/01	1,700	IW-4	12/29/80	1,149	IW-4	10/14/82	1,120
IW-3	9/16/02	1,700	IW-4	1/5/81	1,118	IW-4	1/6/83	1,125
IW-3	8/1/03	1,790	IW-4	1/12/81	1,121	IW-4	1/20/83	1,119
IW-3A	3/4/04	1,690	IW-4	1/19/81	1,240	IW-4	2/13/83	1,143
IW-3A	9/29/04	1,650	IW-4	1/26/81	1,147	IW-4	4/13/83	1,152
IW-3A	12/14/04	1,630	IW-4	2/17/81	1,190	IW-4	5/11/83	1,183
IW-3A	3/23/05	1,620	IW-4	2/24/81	1,177	IW-4	5/12/83	1,165
IW-3A	9/14/05	1,610	IW-4	3/2/81	1,313	IW-4	6/10/83	1,147
IW-3A	12/8/05	1,560	IW-4	3/3/81	1,187	IW-4	6/23/83	1,152
IW-4	1/3/80	986	IW-4	3/11/81	1,169	IW-4	7/5/83	1,112
IW-4	1/11/80	1,040	IW-4	3/16/81	1,195	IW-4	7/14/83	1,181
IW-4	1/16/80	1,145	IW-4	3/25/81	1,190	IW-4	7/30/83	1,186
IW-4	1/21/80	1,057	IW-4	3/31/81	1,187	IW-4	8/11/83	1,188
IW-4	1/28/80	1,053	IW-4	4/11/81	1,205	IW-4	8/24/83	1,180
IW-4	2/4/80	1,099	IW-4	4/24/81	1,243	IW-4	9/19/83	1,171
IW-4	2/11/80	1,076	IW-4	5/5/81	1,208	IW-4	10/18/83	1,098
IW-4	2/19/80	1,068	IW-4	5/11/81	1,213	IW-4	11/14/83	1,072
IW-4	2/25/80	1,045	IW-4	5/28/81	1,215	IW-4	12/14/83	1,087
IW-4	3/3/80	1,110	IW-4	6/2/81	1,231	IW-4	12/20/83	1,162
IW-4	3/17/80	987	IW-4	6/11/81	1,270	IW-4	1/6/84	1,135
IW-4	3/23/80	1,113	IW-4	6/17/81	1,222	IW-4	1/19/84	1,115
IW-4	3/31/80	1,058	IW-4	6/22/81	1,180	IW-4	2/2/84	1,118
IW-4	4/8/80	1,024	IW-4	7/10/81	1,235	IW-4	2/14/84	1,154
IW-4	4/14/80	988	IW-4	7/20/81	1,182	IW-4	3/7/84	1,117
IW-4	4/21/80	1,050	IW-4	8/11/81	1,222	IW-4	3/27/84	1,179
IW-4	4/28/80	1,090	IW-4	8/18/81	1,218	IW-4	4/18/84	1,132
IW-4	5/5/80	1,093	IW-4	9/4/81	1,243	IW-4	5/9/84	1,136
IW-4	5/12/80	1,080	IW-4	9/11/81	1,205	IW-4	5/29/84	1,158
IW-4	5/19/80	1,090	IW-4	9/16/81	1,213	IW-4	6/18/84	1,130
IW-4	5/27/80	1,113	IW-4	9/21/81	1,200	IW-4	7/5/84	1,023

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
IW-4	10/26/84	1,124	IW-4	1/1/92	1,320	IW-5	4/28/81	1,272
IW-4	11/26/84	1,116	IW-4	4/15/92	1,531	IW-5	5/5/81	1,296
IW-4	12/3/84	1,131	IW-4	7/30/92	1,539	IW-5	5/11/81	1,455
IW-4	1/2/85	1,190	IW-4	10/19/92	1,442	IW-5	5/19/81	1,317
IW-4	2/4/85	1,164	IW-4	1/12/93	1,752	IW-5	5/28/81	1,320
IW-4	3/18/85	1,064	IW-4	4/16/93	1,520	IW-5	6/2/81	1,320
IW-4	5/1/85	1,173	IW-4	7/14/94	1,412	IW-5	6/17/81	1,309
IW-4	5/16/85	1,089	IW-4	10/24/94	1,448	IW-5	6/22/81	1,342
IW-4	6/1/85	1,258	IW-4	1/31/95	1,274	IW-5	7/31/81	1,302
IW-4	6/15/85	1,095	IW-4	5/1/95	1,441	IW-5	8/11/81	1,325
IW-4	7/4/85	1,002	IW-4	1/31/96	1,437	IW-5	9/16/81	1,309
IW-4	8/1/85	1,067	IW-4	4/30/96	1,419	IW-5	10/1/81	1,335
IW-4	8/15/85	1,206	IW-4	7/22/96	1,570	IW-5	10/26/81	1,315
IW-4	9/6/85	1,179	IW-4	2/26/97	1,450	IW-5	10/31/81	1,355
IW-4	9/15/85	1,181	IW-4	6/18/97	1,480	IW-5	11/1/81	1,276
IW-4	10/1/85	1,259	IW-4	8/26/97	1,520	IW-5	11/23/81	1,357
IW-4	10/17/85	1,389	IW-4	12/23/97	1,530	IW-5	12/1/81	1,334
IW-4	12/2/85	1,138	IW-4	2/24/98	1,530	IW-5	12/10/81	1,371
IW-4	1/8/86	1,124	IW-4	6/25/98	1,450	IW-5	1/21/82	1,350
IW-4	1/25/86	1,152	IW-4	10/13/99	1,560	IW-5	2/22/82	1,337
IW-4	2/6/86	1,180	IW-4	10/10/00	1,650	IW-5	3/23/82	1,324
IW-4	3/11/86	938	IW-4	10/22/01	1,680	IW-5	3/31/82	1,334
IW-4	3/19/86	1,251	IW-4	4/1/04	1,770	IW-5	4/7/82	1,362
IW-4	4/14/86	1,228	IW-4	6/24/04	1,660	IW-5	4/20/82	1,317
IW-4	6/18/86	1,136	IW-4	9/29/04	1,640	IW-5	5/4/82	1,301
IW-4	6/21/86	1,149	IW-4	12/14/04	1,620	IW-5	5/25/82	1,368
IW-4	7/10/86	1,148	IW-4	3/23/05	1,590	IW-5	6/11/82	1,246
IW-4	8/7/86	1,138	IW-4	9/27/05	1,460	IW-5	6/16/82	1,306
IW-4	10/11/86	1,140	IW-4	1/30/06	1,570	IW-5	7/6/82	1,280
IW-4	11/9/86	1,126	IW-5	10/20/80	1,276	IW-5	7/14/82	1,417
IW-4	12/3/86	1,620	IW-5	10/27/80	1,333	IW-5	1/6/83	1,460
IW-4	1/7/87	1,155	IW-5	11/3/80	1,304	IW-5	1/20/83	1,438
IW-4	2/3/87	1,138	IW-5	11/13/80	1,315	IW-5	2/13/83	1,420
IW-4	11/30/87	1,088	IW-5	11/17/80	1,324	IW-5	4/13/83	1,434
IW-4	1/1/88	1,097	IW-5	12/1/80	1,306	IW-5	6/23/83	1,401
IW-4	2/1/88	1,107	IW-5	12/8/80	1,342	IW-5	7/6/83	1,357
IW-4	5/1/88	1,082	IW-5	12/15/80	1,284	IW-5	7/14/83	1,421
IW-4	6/1/88	1,093	IW-5	12/22/80	1,425	IW-5	7/30/83	1,434
IW-4	8/1/88	1,111	IW-5	12/29/80	1,286	IW-5	8/11/83	1,429
IW-4	9/1/88	1,136	IW-5	1/5/81	1,286	IW-5	8/24/83	1,432
IW-4	11/1/88	1,100	IW-5	1/12/81	1,335	IW-5	11/14/83	1,396
IW-4	4/1/89	1,126	IW-5	1/16/81	1,247	IW-5	3/27/84	1,394
IW-4	7/1/89	1,154	IW-5	1/19/81	1,378	IW-5	5/9/84	1,430
IW-4	10/1/89	1,131	IW-5	2/17/81	1,338	IW-5	5/29/84	1,591
IW-4	1/1/90	1,182	IW-5	2/24/81	1,329	IW-5	6/18/84	1,439
IW-4	1/25/90	1,140	IW-5	3/3/81	1,338	IW-5	7/5/84	1,420
IW-4	4/9/90	1,110	IW-5	3/11/81	1,284	IW-5	8/1/84	1,412
IW-4	7/1/90	1,063	IW-5	3/16/81	1,357	IW-5	10/26/84	1,380
IW-4	10/1/90	1,202	IW-5	4/11/81	1,343	IW-5	5/11/83	1,500
IW-4	10/31/90	1,202	IW-5	4/17/81	1,350	IW-5	5/12/83	1,373
IW-4	10/1/91	1,213	IW-5	4/24/81	1,383	IW-5	6/10/83	1,281

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
IW-5	11/26/84	1,358	IW-5	10/1/91	1,561	IW-6	10/19/81	1,498
IW-5	12/3/84	1,428	IW-5	1/1/92	1,651	IW-6	10/26/81	1,491
IW-5	1/2/85	1,457	IW-5	4/15/92	1,844	IW-6	10/31/81	1,572
IW-5	2/4/85	1,393	IW-5	7/30/92	1,991	IW-6	11/2/81	1,408
IW-5	3/18/85	1,381	IW-5	10/19/92	1,695	IW-6	11/23/81	1,495
IW-5	6/1/85	1,432	IW-5	1/12/93	1,885	IW-6	12/1/81	1,460
IW-5	6/15/85	1,557	IW-5	4/16/93	1,580	IW-6	12/10/81	1,526
IW-5	7/4/85	1,288	IW-5	7/14/94	1,740	IW-6	1/21/82	1,534
IW-5	8/1/85	1,362	IW-5	1/31/95	1,598	IW-6	2/22/82	1,634
IW-5	8/15/85	1,525	IW-5	5/1/95	1,843	IW-6	3/23/82	1,540
IW-5	9/6/85	1,451	IW-5	10/17/95	1,682	IW-6	3/29/82	1,528
IW-5	9/15/85	1,482	IW-5	1/31/96	1,722	IW-6	3/31/82	1,543
IW-5	10/1/85	1,539	IW-5	4/30/96	1,745	IW-6	4/7/82	1,516
IW-5	10/17/85	1,567	IW-5	7/22/96	2,021	IW-6	4/20/82	1,362
IW-5	12/2/85	1,404	IW-5	2/26/97	1,900	IW-6	5/4/82	1,459
IW-5	1/8/86	1,408	IW-5	8/26/97	1,740	IW-6	5/25/82	1,498
IW-5	1/25/86	1,464	IW-5	2/24/98	1,730	IW-6	6/11/82	1,355
IW-5	2/6/86	1,482	IW-5	6/25/98	1,500	IW-6	6/16/82	1,419
IW-5	3/19/86	1,518	IW-5	10/13/99	1,690	IW-6	7/14/82	1,444
IW-5	4/23/86	1,543	IW-5	7/1/03	1,720	IW-6	9/30/82	1,380
IW-5	6/18/86	1,534	IW-5	12/1/03	1,730	IW-6	1/6/83	1,536
IW-5	10/11/86	1,469	IW-5	4/1/04	1,820	IW-6	1/20/83	1,489
IW-5	7/31/87	1,430	IW-5	3/23/05	1,720	IW-6	5/11/83	1,446
IW-5	9/1/87	1,389	IW-6	3/11/81	1,531	IW-6	7/5/83	1,461
IW-5	10/1/87	1,422	IW-6	3/16/81	1,577	IW-6	7/14/83	1,466
IW-5	11/30/87	1,452	IW-6	3/25/81	1,411	IW-6	7/30/83	1,452
IW-5	1/1/88	1,439	IW-6	3/31/81	1,492	IW-6	8/11/83	1,478
IW-5	2/1/88	1,407	IW-6	4/11/81	1,571	IW-6	8/24/83	1,493
IW-5	3/1/88	1,464	IW-6	4/17/81	1,542	IW-6	9/19/83	1,467
IW-5	4/1/88	1,426	IW-6	4/24/81	1,549	IW-6	10/14/83	1,410
IW-5	5/1/88	1,446	IW-6	5/5/81	1,508	IW-6	12/14/83	1,463
IW-5	5/2/88	1,426	IW-6	5/11/81	1,495	IW-6	12/20/83	1,450
IW-5	8/1/88	1,473	IW-6	5/19/81	1,477	IW-6	1/6/84	1,389
IW-5	10/1/88	1,480	IW-6	5/28/81	1,525	IW-6	1/19/84	1,373
IW-5	11/1/88	1,491	IW-6	6/2/81	1,523	IW-6	2/2/84	1,404
IW-5	12/1/88	1,464	IW-6	6/11/81	1,556	IW-6	2/14/84	1,429
IW-5	1/1/89	1,436	IW-6	6/17/81	1,495	IW-6	3/7/84	1,394
IW-5	2/1/89	1,440	IW-6	6/22/81	1,604	IW-6	3/27/84	1,395
IW-5	4/1/89	1,519	IW-6	6/30/81	1,483	IW-6	4/18/84	1,393
IW-5	7/1/89	1,476	IW-6	7/10/81	1,459	IW-6	5/9/84	1,445
IW-5	10/1/89	1,481	IW-6	7/13/81	1,493	IW-6	5/29/84	1,412
IW-5	1/1/90	1,525	IW-6	7/15/81	1,497	IW-6	6/18/84	1,439
IW-5	1/25/90	1,510	IW-6	7/20/81	1,468	IW-6	7/5/84	1,324
IW-5	4/10/90	1,390	IW-6	7/31/81	1,510	IW-6	8/1/84	1,450
IW-5	7/1/90	1,448	IW-6	8/18/81	1,526	IW-6	10/26/84	1,403
IW-5	10/1/90	1,498	IW-6	9/4/81	1,510	IW-6	11/26/84	1,394
IW-5	10/31/90	1,498	IW-6	9/11/81	1,454	IW-6	12/3/84	1,428
IW-5	1/1/91	1,531	IW-6	9/16/81	1,454	IW-6	1/2/85	1,388
IW-5	1/14/91	1,550	IW-6	9/21/81	1,513	IW-6	2/4/85	1,469
IW-5	4/1/91	1,486	IW-6	10/5/81	1,490	IW-6	4/26/85	1,282
IW-5	7/1/91	1,489	IW-6	10/14/81	1,498	IW-6	5/16/85	1,317

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
IW-6	6/1/85	1,557	IW-8	3/19/86	1,284	IW-8	10/10/00	1,770
IW-6	6/15/85	1,446	IW-8	4/14/86	1,457	IW-8	9/16/02	1,910
IW-6	7/4/85	1,356	IW-8	6/2/86	1,366	IW-8	7/1/03	1,810
IW-6	10/17/85	1,462	IW-8	6/18/86	1,358	IW-8	11/3/03	1,820
IW-6	12/2/85	1,523	IW-8	7/10/86	1,419	IW-8	12/1/03	1,820
IW-6	1/8/86	1,473	IW-8	8/7/86	1,396	IW-8	3/31/04	1,830
IW-6	1/25/86	1,536	IW-8	1/7/87	1,500	IW-8	6/24/04	1,840
IW-6	2/6/86	1,552	IW-8	2/3/87	1,548	IW-8	9/29/04	1,840
IW-6	6/2/86	1,524	IW-8	5/1/87	1,498	IW-8	12/14/04	1,830
IW-6	5/1/88	1,597	IW-8	1/1/88	1,465	IW-8	3/23/05	1,810
IW-6a	2/26/97	1,790	IW-8	2/1/88	1,443	IW-8	6/10/05	1,760
IW-6a	4/1/97	1,800	IW-8	3/1/88	1,504	IW-8	9/14/05	1,770
IW-6a	10/10/00	1,900	IW-8	4/1/88	1,260	IW-8	12/7/05	1,790
IW-6a	10/26/01	1,930	IW-8	5/1/88	1,427	IW-9	3/11/86	1,172
IW-6a	4/1/04	1,870	IW-8	5/2/88	1,260	IW-9	3/19/86	1,110
IW-6a	6/25/04	1,870	IW-8	6/1/88	1,417	IW-9	4/14/86	1,212
IW-6a	9/29/04	1,810	IW-8	7/1/88	1,319	IW-9	6/1/87	1,264
IW-6a	12/14/04	1,850	IW-8	8/1/88	1,524	IW-9	7/31/87	1,166
IW-6a	3/23/05	1,850	IW-8	9/1/88	1,520	IW-9	9/1/87	1,194
IW-6a	6/7/05	1,780	IW-8	11/1/88	1,466	IW-9	11/30/87	1,217
IW-6a	12/9/05	1,790	IW-8	12/1/88	1,441	IW-9	1/1/88	1,262
IW-7	1/16/80	253	IW-8	2/1/89	1,455	IW-9	2/1/88	1,262
IW-7	3/19/81	218	IW-8	4/1/89	1,456	IW-9	3/1/88	1,227
IW-7	3/25/81	234	IW-8	7/1/89	1,404	IW-9	4/1/88	1,204
IW-7	3/31/81	202	IW-8	10/1/89	1,385	IW-9	5/1/88	1,159
IW-7	4/11/81	356	IW-8	4/10/90	1,274	IW-9	5/2/88	1,201
IW-7	4/14/81	247	IW-8	10/1/90	1,367	IW-9	7/1/88	1,262
IW-7	5/28/81	263	IW-8	10/18/90	1,367	IW-9	8/1/88	1,244
IW-7	6/2/81	260	IW-8	1/1/91	1,431	IW-9	9/1/88	1,251
IW-7	6/11/81	285	IW-8	1/14/91	1,400	IW-9	12/1/88	1,254
IW-7	6/17/81	262	IW-8	4/1/91	1,395	IW-9	1/1/89	1,199
IW-7	7/10/81	267	IW-8	7/1/91	1,339	IW-9	10/1/89	1,256
IW-7	7/13/81	258	IW-8	10/1/91	1,306	IW-9	1/1/90	1,347
IW-7	7/15/81	260	IW-8	1/1/92	1,359	IW-9	1/22/90	1,390
IW-7	7/20/81	272	IW-8	4/15/92	1,656	IW-9	4/9/90	1,270
IW-7	9/11/81	249	IW-8	7/30/92	1,564	IW-9	7/1/90	1,241
IW-7	9/16/81	240	IW-8	10/19/92	1,625	IW-9	10/1/90	1,321
IW-7	9/21/81	229	IW-8	4/16/93	1,350	IW-9	10/31/90	1,321
IW-7	1/21/82	268	IW-8	7/14/94	1,416	IW-9	1/1/91	1,376
IW-7	2/22/82	281	IW-8	10/24/94	1,449	IW-9	1/16/91	1,530
IW-7	3/31/82	251	IW-8	1/31/95	1,376	IW-9	4/1/91	1,350
IW-7	4/20/82	297	IW-8	5/1/95	1,450	IW-9	7/1/91	1,246
IW-7	1/6/83	372	IW-8	10/17/95	1,389	IW-9	10/1/91	1,258
IW-7	1/20/83	370	IW-8	1/31/96	1,555	IW-9	1/1/92	1,327
IW-7	2/13/83	382	IW-8	4/30/96	1,564	IW-9	4/15/92	1,460
IW-7	3/25/83	351	IW-8	7/22/96	1,769	IW-9	7/30/92	1,397
IW-7	4/13/83	333	IW-8	2/26/97	1,590	IW-9	10/19/92	1,574
IW-7	5/11/83	340	IW-8	6/18/97	1,490	IW-9	1/12/93	1,219
IW-7	5/12/83	356	IW-8	8/26/97	1,550	IW-9	4/16/93	1,320
IW-7	6/23/83	364	IW-8	12/23/97	1,590	IW-9	10/24/94	1,261
IW-8	3/11/86	1,043	IW-8	2/24/98	1,490	IW-9	1/31/95	1,195

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
IW-9	10/17/95	1,225	IW-10	9/16/02	1,790	IW-11	11/3/03	1,740
IW-9	1/31/96	1,457	IW-10	7/1/03	1,620	IW-11	12/1/03	1,710
IW-9	4/30/96	1,435	IW-10	3/23/05	1,700	IW-11	4/1/04	1,840
IW-9	7/1/03	1,650	IW-10	9/14/05	1,670	IW-11	6/24/04	1,700
IW-9	11/3/03	1,630	IW-11	3/11/86	1,572	IW-11	9/29/04	1,710
IW-9	12/1/03	1,640	IW-11	4/14/86	1,622	IW-11	12/14/04	1,730
IW-9	3/31/04	1,690	IW-11	6/2/86	1,630	IW-11	3/23/05	1,690
IW-9	6/24/04	1,690	IW-11	6/18/86	1,610	IW-11	6/10/05	1,640
IW-9	9/29/04	1,700	IW-11	7/10/86	1,612	IW-11	9/14/05	1,690
IW-9	12/14/04	1,680	IW-11	8/4/86	1,605	IW-11	12/9/05	1,700
IW-9	3/23/05	1,670	IW-11	10/11/86	1,473	IW-11	1/30/06	1,700
IW-9	9/14/05	1,450	IW-11	11/9/86	1,712	IW-12	2/26/97	1,380
IW-9	12/8/05	1,210	IW-11	12/3/86	1,460	IW-12	4/1/97	1,620
IW-10	3/14/86	1,182	IW-11	1/7/87	1,624	IW-12	6/18/97	1,520
IW-10	3/19/86	1,538	IW-11	2/3/87	1,650	IW-12	12/23/97	1,560
IW-10	4/14/86	1,651	IW-11	5/1/87	1,638	IW-12	2/24/98	1,420
IW-10	6/2/86	1,523	IW-11	7/31/87	1,619	IW-12	6/29/98	1,630
IW-10	7/10/86	1,548	IW-11	9/1/87	1,620	IW-12	10/10/00	1,640
IW-10	8/4/86	1,498	IW-11	5/1/88	1,576	IW-12	7/1/03	1,660
IW-10	10/11/86	1,673	IW-11	9/1/88	1,773	IW-12	11/3/03	1,610
IW-10	6/1/87	1,638	IW-11	11/1/88	1,599	IW-12	12/1/03	1,670
IW-10	7/31/87	1,526	IW-11	12/1/88	1,620	IW-12	12/14/04	1,600
IW-10	9/1/87	1,519	IW-11	1/1/89	1,596	IW-12	3/23/05	1,510
IW-10	1/1/88	1,552	IW-11	4/1/89	1,668	IW-12	6/7/05	1,350
IW-10	2/1/88	1,552	IW-11	7/1/89	1,040	IW-12	10/20/05	1,460
IW-10	9/1/88	1,627	IW-11	10/1/89	1,645	IW-12	4/24/06	1,560
IW-10	12/1/88	1,536	IW-11	1/1/90	1,702	IW-13	2/26/97	1,740
IW-10	1/1/89	1,518	IW-11	1/23/90	1,650	IW-13	6/18/97	1,560
IW-10	10/1/89	1,555	IW-11	4/10/90	1,570	IW-13	2/24/98	1,770
IW-10	1/1/90	1,620	IW-11	7/1/90	1,638	IW-13	6/29/98	1,620
IW-10	10/1/90	1,543	IW-11	10/31/90	1,638	IW-13	11/3/03	1,700
IW-10	10/31/90	1,543	IW-11	1/1/91	1,692	IW-13	12/1/03	1,790
IW-10	1/1/91	1,636	IW-11	1/14/91	1,780	IW-13	4/1/04	1,710
IW-10	1/14/91	1,760	IW-11	4/1/91	1,692	IW-13	9/29/04	1,740
IW-10	4/1/91	1,593	IW-11	7/1/91	1,646	IW-13	12/10/04	1,680
IW-10	7/1/91	1,557	IW-11	1/1/92	1,697	IW-13	3/23/05	1,700
IW-10	10/1/91	1,546	IW-11	4/15/92	1,890	IW-13	6/7/05	1,710
IW-10	4/15/92	1,730	IW-11	7/30/92	1,946	IW-13	9/14/05	1,690
IW-10	1/12/93	1,761	IW-11	10/19/92	1,757	IW-13	4/24/06	1,800
IW-10	4/16/93	1,760	IW-11	1/12/93	1,970	IW-14	2/26/97	1,710
IW-10	7/14/94	1,854	IW-11	4/16/93	1,730	IW-14	6/18/97	1,530
IW-10	10/24/94	1,775	IW-11	7/14/94	1,795	IW-14	8/26/97	1,620
IW-10	5/1/95	1,843	IW-11	1/31/95	1,658	IW-14	12/23/97	1,620
IW-10	10/17/95	1,865	IW-11	5/1/95	2,013	IW-14	2/24/98	1,720
IW-10	1/31/96	1,992	IW-11	10/17/95	1,893	IW-14	6/29/98	1,640
IW-10	4/30/96	1,833	IW-11	4/1/97	1,770	IW-14	10/10/00	1,750
IW-10	8/26/97	1,790	IW-11	8/27/97	1,660	IW-14	10/25/01	1,830
IW-10	2/24/98	1,810	IW-11	10/13/99	1,640	IW-14	6/25/04	1,860
IW-10	6/29/98	1,770	IW-11	10/10/00	1,780	IW-14	9/30/04	1,850
IW-10	10/10/00	1,730	IW-11	9/16/02	2,080	IW-14	3/21/05	1,850
IW-10	10/26/01	1,770	IW-11	7/1/03	1,740	IW-14	6/7/05	1,800

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
IW-14	9/14/05	1,820	IW-19	10/25/01	1,570	IW-21	12/12/05	1,530
IW-14	12/9/05	1,820	IW-19	4/1/04	1,520	IW-21	1/24/06	1,600
IW-14	2/1/06	1,800	IW-19	6/29/04	1,540	IW-21	4/26/06	1,560
IW-15	2/26/97	1,490	IW-19	9/30/04	1,530	IW-22	1/15/04	1,720
IW-15	6/18/97	1,360	IW-19	12/6/04	1,520	IW-22	6/24/05	1,830
IW-15	8/26/97	1,590	IW-19	3/21/05	1,720	IW-22	9/14/05	1,650
IW-15	12/23/97	1,470	IW-19	6/7/05	1,530	IW-22	12/12/05	1,680
IW-15	2/24/98	1,500	IW-19	9/14/05	1,570	IW-22	1/30/06	1,680
IW-15	6/29/98	1,540	IW-19	12/12/05	1,550	IW-23	2/14/04	1,820
IW-15	10/13/99	1,480	IW-19	1/24/06	1,590	IW-23	6/24/05	1,550
IW-15	10/10/00	1,720	IW-19	4/26/06	1,580	IW-23	9/16/05	1,600
IW-15	11/3/03	1,760	IW-20	2/26/97	1,060	IW-23	12/8/05	1,610
IW-15	9/30/04	1,730	IW-20	6/19/97	1,080	IW-23	1/24/06	1,650
IW-15	3/23/05	1,530	IW-20	8/28/97	1,060	IW-24	1/25/04	1,680
IW-15	6/7/05	1,670	IW-20	12/23/97	1,140	IW-24	6/24/05	1,770
IW-15	9/14/05	1,930	IW-20	2/24/98	1,150	IW-24	9/14/05	1,680
IW-16	6/18/97	1,380	IW-20	6/30/98	1,160	IW-24	12/12/05	1,660
IW-16	8/27/97	1,350	IW-20	10/13/99	1,310	MH-1	2/22/80	110
IW-16	12/23/97	1,500	IW-20	10/10/00	1,450	MH-1	3/20/80	240
IW-16	2/24/98	1,540	IW-20	9/16/02	1,440	MH-1	4/16/80	115
IW-16	6/29/98	1,630	IW-20	7/1/03	1,490	MH-1	6/19/80	123
IW-17	2/26/97	1,350	IW-20	8/1/03	1,590	MH-1	7/24/80	133
IW-17	6/18/97	1,320	IW-20	11/3/03	1,470	MH-1	10/3/80	142
IW-17	8/27/97	1,250	IW-20	4/1/04	1,530	MH-1	12/15/80	144
IW-17	12/23/97	1,330	IW-20	6/25/04	1,530	MH-1	1/19/81	144
IW-17	2/24/98	1,330	IW-20	9/30/04	1,530	MH-1	2/27/81	158
IW-17	6/30/98	1,310	IW-20	12/14/04	1,520	MH-1	3/27/81	174
IW-17	10/13/99	1,440	IW-20	3/21/05	1,570	MH-1	5/26/81	214
IW-17	10/10/00	1,520	IW-20	6/7/05	1,540	MH-1	6/12/81	196
IW-17	10/25/01	1,600	IW-20	9/14/05	1,600	MH-1	8/13/81	181
IW-17	4/1/04	1,630	IW-20	12/12/05	1,580	MH-1	9/21/81	185
IW-17	6/25/04	1,520	IW-20	1/24/06	1,570	MH-1	12/10/81	256
IW-17	9/30/04	1,530	IW-20	4/26/06	1,600	MH-1	1/26/82	236
IW-17	12/10/04	1,530	IW-21	2/26/97	890	MH-1	2/21/82	283
IW-17	6/7/05	1,480	IW-21	6/19/97	890	MH-1	2/23/82	211
IW-18	2/26/97	1,460	IW-21	8/28/97	930	MH-1	3/25/82	217
IW-18	6/18/97	1,440	IW-21	12/23/97	1,060	MH-1	4/27/82	240
IW-18	8/27/97	1,400	IW-21	2/24/98	1,080	MH-1	5/26/82	214
IW-18	12/23/97	1,480	IW-21	6/30/98	1,070	MH-1	6/23/82	237
IW-18	2/24/98	1,420	IW-21	10/12/99	1,180	MH-1	7/27/82	242
IW-18	6/30/98	1,370	IW-21	10/10/00	1,400	MH-1	8/26/82	256
IW-18	4/1/04	1,640	IW-21	10/25/01	1,390	MH-1	9/30/82	245
IW-18	6/29/04	1,590	IW-21	9/16/02	1,350	MH-1	11/2/82	270
IW-18	9/30/04	1,620	IW-21	7/1/03	1,400	MH-1	11/30/82	272
IW-18	3/23/05	1,560	IW-21	8/1/03	1,410	MH-1	1/19/83	282
IW-18	6/7/05	1,500	IW-21	11/3/03	1,440	MH-1	5/25/83	305
IW-18	4/26/06	1,600	IW-21	10/1/04	1,560	MH-1	6/22/83	314
IW-19	2/26/97	1,160	IW-21	12/3/04	1,500	MH-1	7/20/83	314
IW-19	12/23/97	1,270	IW-21	3/21/05	1,530	MH-1	8/24/83	301
IW-19	2/24/98	1,260	IW-21	6/7/05	1,480	MH-1	9/22/83	305
IW-19	10/13/99	1,330	IW-21	9/14/05	1,520	MH-1	11/8/83	323

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
MH-1	12/14/83	286	MH-1	10/1/89	546	MH-3	6/23/82	415
MH-1	1/23/84	300	MH-1	1/1/90	640	MH-3	7/27/82	453
MH-1	3/14/84	271	MH-1	1/24/90	552	MH-3	8/26/82	474
MH-1	5/17/84	312	MH-1	4/24/90	463	MH-3	9/30/82	437
MH-1	6/28/84	324	MH-1	7/1/90	502	MH-3	11/2/82	464
MH-1	9/19/84	296	MH-1	12/1/90	490	MH-3	11/30/82	432
MH-1	10/26/84	311	MH-1	12/4/90	490	MH-3	1/19/83	443
MH-1	11/14/84	297	MH-1	1/1/91	613	MH-3	3/21/83	438
MH-1	12/24/84	309	MH-1	1/24/91	472	MH-3	5/25/83	449
MH-1	1/29/85	320	MH-1	5/1/91	519	MH-3	6/22/83	427
MH-1	2/20/85	329	MH-1	7/1/91	530	MH-3	9/22/83	456
MH-1	5/21/85	243	MH-1	10/1/91	538	MH-3	11/8/83	449
MH-1	7/19/85	321	MH-1	1/1/92	542	MH-3	12/14/83	424
MH-1	8/17/85	362	MH-1	1/17/92	498	MH-3	1/23/84	478
MH-1	10/22/85	392	MH-1	6/8/92	670	MH-3	3/14/84	412
MH-1	12/23/85	366	MH-1	8/12/92	791	MH-3	5/17/84	463
MH-1	1/25/86	347	MH-1	11/11/92	602	MH-3	6/28/84	468
MH-1	2/14/86	329	MH-1	4/1/93	565	MH-3	9/19/84	520
MH-1	3/20/86	336	MH-1	12/9/93	581	MH-3	10/26/84	611
MH-1	4/23/86	400	MH-1	3/29/94	694	MH-3	11/14/84	565
MH-1	6/24/86	424	MH-1	6/24/94	663	MH-3	12/24/84	558
MH-1	7/29/86	395	MH-1	9/27/94	732	MH-3	1/29/85	595
MH-1	8/19/86	389	MH-1	12/15/94	769	MH-3	2/20/85	498
MH-1	10/17/86	400	MH-1	3/31/95	717	MH-3	5/21/85	434
MH-1	11/25/86	431	MH-1	9/27/95	608	MH-3	7/19/85	552
MH-1	12/30/86	390	MH-1	12/19/95	454	MH-3	8/17/85	652
MH-1	1/22/87	486	MH-1	3/31/96	407	MH-3	9/17/85	704
MH-1	2/19/87	425	MH-1	6/24/97	270	MH-3	10/22/85	638
MH-1	4/21/87	485	MH-1	12/30/97	120	MH-3	12/23/85	663
MH-1	6/25/87	531	MH-1	2/26/98	110	MH-3	1/20/86	649
MH-1	7/29/87	364	MH-1	4/4/01	1,110	MH-3	2/14/86	643
MH-1	8/19/87	443	MH-1	12/3/04	1,470	MH-3	3/20/86	816
MH-1	9/16/87	413	MH-1	12/12/05	1,530	MH-3	4/23/86	751
MH-1	10/13/87	444	MH-3	1/25/80	442	MH-3	6/24/86	683
MH-1	11/25/87	477	MH-3	3/24/80	441	MH-3	7/29/86	743
MH-1	1/6/88	446	MH-3	6/19/80	387	MH-3	8/19/86	533
MH-1	1/21/88	402	MH-3	10/6/80	400	MH-3	9/30/86	742
MH-1	2/1/88	668	MH-3	12/18/80	480	MH-3	10/17/86	769
MH-1	3/1/88	442	MH-3	1/28/81	455	MH-3	11/25/86	802
MH-1	4/1/88	416	MH-3	3/27/81	403	MH-3	12/30/86	751
MH-1	5/1/88	441	MH-3	4/24/81	547	MH-3	1/22/87	795
MH-1	5/26/88	441	MH-3	5/26/81	422	MH-3	2/19/87	706
MH-1	7/1/88	553	MH-3	6/12/81	387	MH-3	4/21/87	733
MH-1	8/1/88	431	MH-3	8/13/81	425	MH-3	5/21/87	697
MH-1	9/1/88	482	MH-3	9/21/81	412	MH-3	6/25/87	704
MH-1	10/1/88	524	MH-3	12/10/81	434	MH-3	7/29/87	701
MH-1	11/1/88	492	MH-3	2/21/82	451	MH-3	8/19/87	675
MH-1	12/1/88	437	MH-3	2/23/82	421	MH-3	9/16/87	658
MH-1	1/1/89	475	MH-3	3/25/82	456	MH-3	10/13/87	682
MH-1	4/1/89	428	MH-3	4/27/82	463	MH-3	11/25/87	683
MH-1	7/1/89	483	MH-3	5/26/82	430	MH-3	1/1/88	682

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
MH-3	1/6/88	628	MH-4	5/26/80	1,299	MH-4	4/21/87	1,504
MH-3	1/21/88	682	MH-4	6/24/80	1,259	MH-4	5/21/87	1,576
MH-3	2/1/88	425	MH-4	9/23/80	1,230	MH-4	6/25/87	1,625
MH-3	3/1/88	700	MH-4	12/30/80	1,321	MH-4	7/29/87	1,601
MH-3	4/1/88	680	MH-4	1/28/81	1,273	MH-4	8/19/87	1,679
MH-3	5/1/88	749	MH-4	3/27/81	1,348	MH-4	9/16/87	1,583
MH-3	5/26/88	749	MH-4	4/24/81	1,378	MH-4	10/13/87	1,604
MH-3	7/1/88	766	MH-4	5/26/81	1,396	MH-4	11/25/87	1,666
MH-3	8/1/88	705	MH-4	6/12/81	1,370	MH-4	1/1/88	1,686
MH-3	9/1/88	764	MH-4	8/13/81	1,648	MH-4	1/6/88	1,650
MH-3	10/1/88	751	MH-4	9/21/81	1,432	MH-4	1/21/88	1,686
MH-3	11/1/88	744	MH-4	12/10/81	1,404	MH-4	2/1/88	1,647
MH-3	12/1/88	742	MH-4	2/23/82	1,416	MH-4	4/1/88	1,671
MH-3	1/1/89	732	MH-4	3/25/82	1,383	MH-4	5/1/88	1,712
MH-3	2/1/89	793	MH-4	4/27/82	1,329	MH-4	5/26/88	1,751
MH-3	4/1/89	752	MH-4	5/26/82	1,230	MH-4	7/1/88	1,748
MH-3	7/1/89	763	MH-4	6/23/82	1,261	MH-4	8/1/88	1,763
MH-3	10/1/89	736	MH-4	7/27/82	1,411	MH-4	9/1/88	1,719
MH-3	1/1/90	873	MH-4	8/26/82	1,327	MH-4	10/1/88	1,733
MH-3	1/16/90	1,020	MH-4	9/30/82	1,316	MH-4	11/1/88	1,756
MH-3	4/23/90	897	MH-4	11/2/82	1,425	MH-4	12/1/88	1,701
MH-3	7/1/90	918	MH-4	11/30/82	1,406	MH-4	1/1/89	1,675
MH-3	12/1/90	949	MH-4	12/21/82	1,439	MH-4	2/1/89	1,685
MH-3	12/4/90	949	MH-4	1/19/83	1,421	MH-4	7/1/89	1,687
MH-3	1/1/91	957	MH-4	3/21/83	1,371	MH-4	1/1/90	1,678
MH-3	1/23/91	926	MH-4	5/25/83	1,366	MH-4	1/16/90	1,750
MH-3	5/1/91	976	MH-4	6/22/83	1,339	MH-4	4/19/90	1,593
MH-3	7/1/91	934	MH-4	10/26/84	1,124	MH-4	7/1/90	1,598
MH-3	10/1/91	937	MH-4	11/14/84	1,082	MH-4	12/1/90	1,488
MH-3	1/1/92	966	MH-4	12/24/84	1,090	MH-4	12/4/90	1,488
MH-3	6/5/92	1,130	MH-4	1/29/85	1,124	MH-4	1/1/91	1,551
MH-3	8/12/92	1,443	MH-4	2/20/85	1,173	MH-4	1/23/91	1,540
MH-3	11/10/92	913	MH-4	5/21/85	1,054	MH-4	5/1/91	1,622
MH-3	4/1/93	948	MH-4	7/19/85	1,156	MH-4	7/1/91	1,544
MH-3	12/9/93	860	MH-4	8/17/85	1,231	MH-4	10/1/91	1,523
MH-3	3/25/94	933	MH-4	9/17/85	1,235	MH-4	1/1/92	1,519
MH-3	6/24/94	576	MH-4	10/22/85	1,189	MH-4	1/17/92	1,456
MH-3	9/26/94	884	MH-4	12/23/85	1,189	MH-4	6/5/92	1,843
MH-3	3/31/95	758	MH-4	1/20/86	1,189	MH-4	8/12/92	1,969
MH-3	9/27/95	823	MH-4	2/14/86	1,162	MH-4	11/11/92	1,879
MH-3	12/19/95	765	MH-4	3/20/86	1,422	MH-4	4/1/93	1,700
MH-3	3/31/96	769	MH-4	4/23/86	1,304	MH-4	12/9/93	1,127
MH-3	6/25/97	440	MH-4	6/24/86	1,412	MH-4	3/25/94	1,180
MH-3	9/30/97	460	MH-4	7/29/86	1,465	MH-4	9/26/94	1,270
MH-3	12/30/97	1,030	MH-4	8/19/86	1,492	MH-4	3/30/95	1,207
MH-3	3/31/98	1,120	MH-4	9/30/86	1,501	MH-4	9/27/95	1,321
MH-3	4/4/01	1,650	MH-4	10/17/86	1,533	MH-4	12/19/95	1,321
MH-3	12/6/04	1,660	MH-4	11/25/86	1,552	MH-4	3/31/96	1,247
MH-4	2/4/80	1,288	MH-4	12/30/86	1,570	MH-4	6/25/97	1,260
MH-4	3/24/80	1,233	MH-4	1/22/87	1,564	MH-4	9/23/97	1,650
MH-4	4/17/80	1,156	MH-4	2/19/87	1,490	MH-4	12/30/97	1,860

TABLE C.3
Interceptor Wellfield Sulfate Concentrations

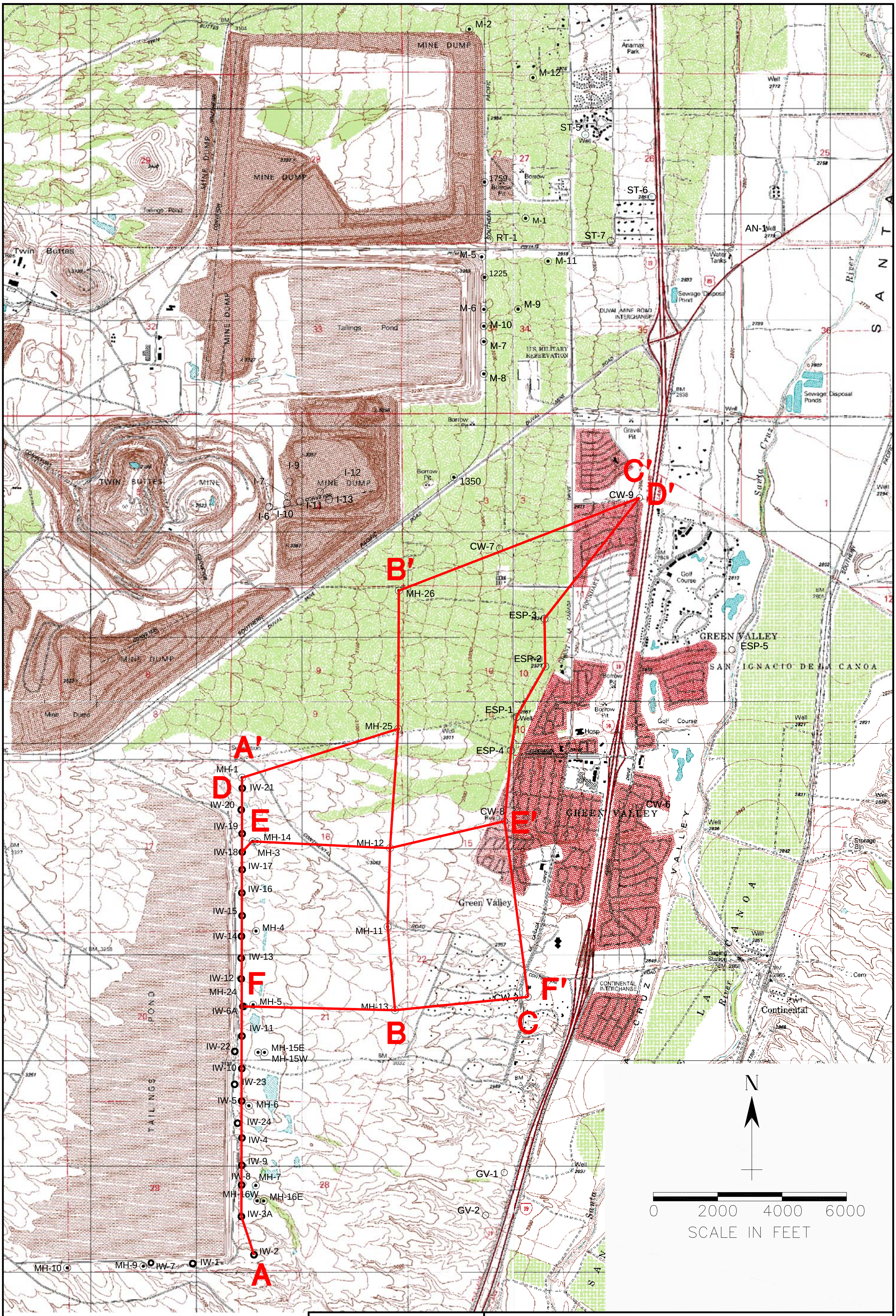
Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)	Well Name	Sample Date	Sulfate (mg/L)
MH-4	3/31/98	1,850	MH-5	10/22/85	1,715	MH-5	1/1/92	1,486
MH-4	4/5/01	2,090	MH-5	12/23/85	1,793	MH-5	1/15/92	1,389
MH-5	1/22/80	1,770	MH-5	1/20/86	1,775	MH-5	6/5/92	1,761
MH-5	3/24/80	1,630	MH-5	2/14/86	1,453	MH-5	11/10/92	1,858
MH-5	4/18/80	1,420	MH-5	4/23/86	1,454	MH-5	4/1/93	1,940
MH-5	5/22/80	1,630	MH-5	6/24/86	1,535	MH-5	12/9/93	1,712
MH-5	6/23/80	1,535	MH-5	7/29/86	1,589	MH-5	3/25/94	1,840
MH-5	7/22/80	1,274	MH-5	8/19/86	1,638	MH-5	6/24/94	1,910
MH-5	9/22/80	1,526	MH-5	9/30/86	1,394	MH-5	9/26/94	1,852
MH-5	12/30/80	1,637	MH-5	10/17/86	1,740	MH-5	12/15/94	1,934
MH-5	1/29/81	1,707	MH-5	11/25/86	1,732	MH-5	3/30/95	1,864
MH-5	2/24/81	1,696	MH-5	12/30/86	1,701	MH-5	9/27/95	1,775
MH-5	3/27/81	1,706	MH-5	1/22/87	1,696	MH-5	12/19/95	1,846
MH-5	4/24/81	1,699	MH-5	2/19/87	1,646	MH-5	3/31/96	1,798
MH-5	6/12/81	1,675	MH-5	4/21/87	1,699	MH-5	4/1/97	1,850
MH-5	8/13/81	1,431	MH-5	5/21/87	1,531	MH-5	6/25/97	1,970
MH-5	9/18/81	1,668	MH-5	6/25/87	1,416	MH-5	9/30/97	1,750
MH-5	12/10/81	1,704	MH-5	7/29/87	1,811	MH-5	12/29/97	1,810
MH-5	2/23/82	1,615	MH-5	8/19/87	1,780	MH-5	3/31/98	1,940
MH-5	3/25/82	1,522	MH-5	9/16/87	1,759	MH-5	4/5/01	1,980
MH-5	5/26/82	1,475	MH-5	10/13/87	1,566	MH-5	12/12/05	1,900
MH-5	6/23/82	1,600	MH-5	11/25/87	1,518			
MH-5	7/27/82	1,638	MH-5	1/1/88	1,634			
MH-5	8/26/82	1,503	MH-5	1/6/88	1,619			
MH-5	9/30/82	1,537	MH-5	1/21/88	1,634			
MH-5	11/2/82	1,581	MH-5	2/1/88	1,407			
MH-5	11/30/82	1,629	MH-5	3/1/88	1,472			
MH-5	12/21/82	1,625	MH-5	4/1/88	1,605			
MH-5	1/19/83	1,664	MH-5	5/1/88	1,558			
MH-5	3/21/83	1,622	MH-5	5/26/88	1,558			
MH-5	5/25/83	1,683	MH-5	7/1/88	1,640			
MH-5	6/22/83	1,733	MH-5	8/1/88	1,650			
MH-5	8/24/83	1,739	MH-5	9/1/88	1,571			
MH-5	9/22/83	1,654	MH-5	10/1/88	1,813			
MH-5	11/8/83	1,641	MH-5	11/1/88	1,716			
MH-5	12/14/83	1,435	MH-5	12/1/88	1,768			
MH-5	1/23/84	1,725	MH-5	1/1/89	1,736			
MH-5	3/14/84	1,454	MH-5	2/1/89	1,702			
MH-5	5/17/84	1,687	MH-5	4/1/89	1,317			
MH-5	6/28/84	1,595	MH-5	10/1/89	1,424			
MH-5	9/19/84	1,615	MH-5	1/1/90	1,470			
MH-5	10/26/84	1,692	MH-5	1/10/90	1,286			
MH-5	11/14/84	1,684	MH-5	4/19/90	1,245			
MH-5	12/24/84	1,184	MH-5	7/1/90	1,151			
MH-5	1/21/85	1,674	MH-5	12/1/90	1,518			
MH-5	2/20/85	1,498	MH-5	12/4/90	1,518			
MH-5	5/1/85	1,114	MH-5	1/1/91	1,358			
MH-5	5/21/85	1,609	MH-5	1/23/91	1,311			
MH-5	7/19/85	1,592	MH-5	4/1/91	1,569			
MH-5	8/17/85	1,206	MH-5	7/1/91	1,466			
MH-5	9/17/85	1,218	MH-5	10/1/91	1,484			

APPENDIX D

Water Quality Cross Sections

TABLE OF CONTENTS

FIGURES



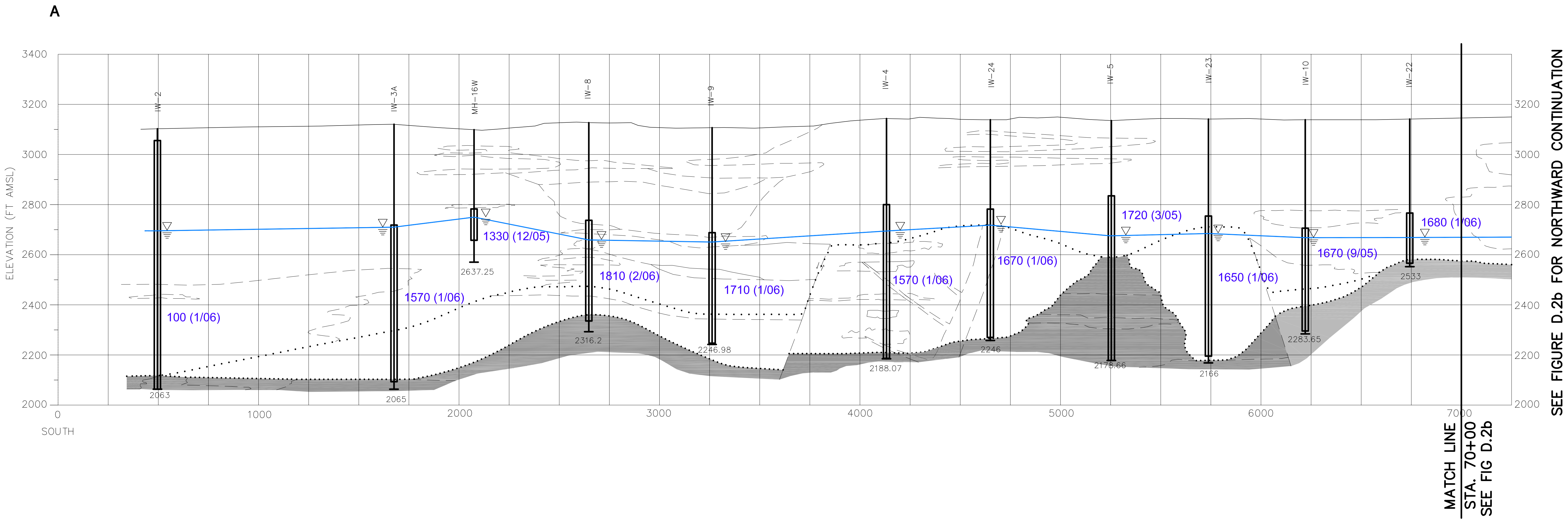
EXPLANATION

- ● IW–2 INTERCEPTOR WELL
- ⊙ MH–16E MONITOR WELL
- ○ ESP–4 OTHER WATER WELL

HYDRO GEO CHEM, INC.

SIERRITA TAILING IMPOUNDMENT AREA CROSS SECTION LOCATION MAP

Approved	Date	Revised	Date	Reference:	FIG:
KW	8/8/06			7830023A	D.1



LEGEND

BASIN FILL

☐ BASIN FILL, UNDIFFERENTIATED

BEDROCK COMPLEX

▨ CRETACEOUS ANGELICA ARKOSE

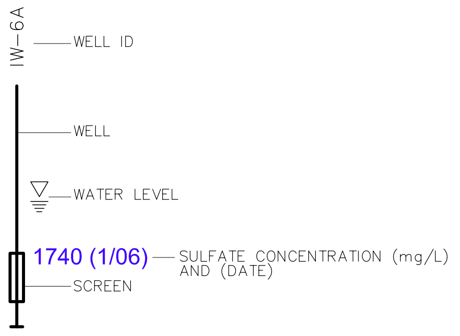
▨ CRETACEOUS DEMETRIE VOLANICS

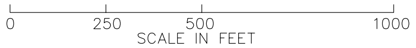
·········· TOP OF BEDROCK

· · · · · TOP OF DECOMPOSED BEDROCK

—— WATER TABLE

SEE GEOLOGICAL CROSS SECTIONS FOR LITHOLOGIC DETAIL

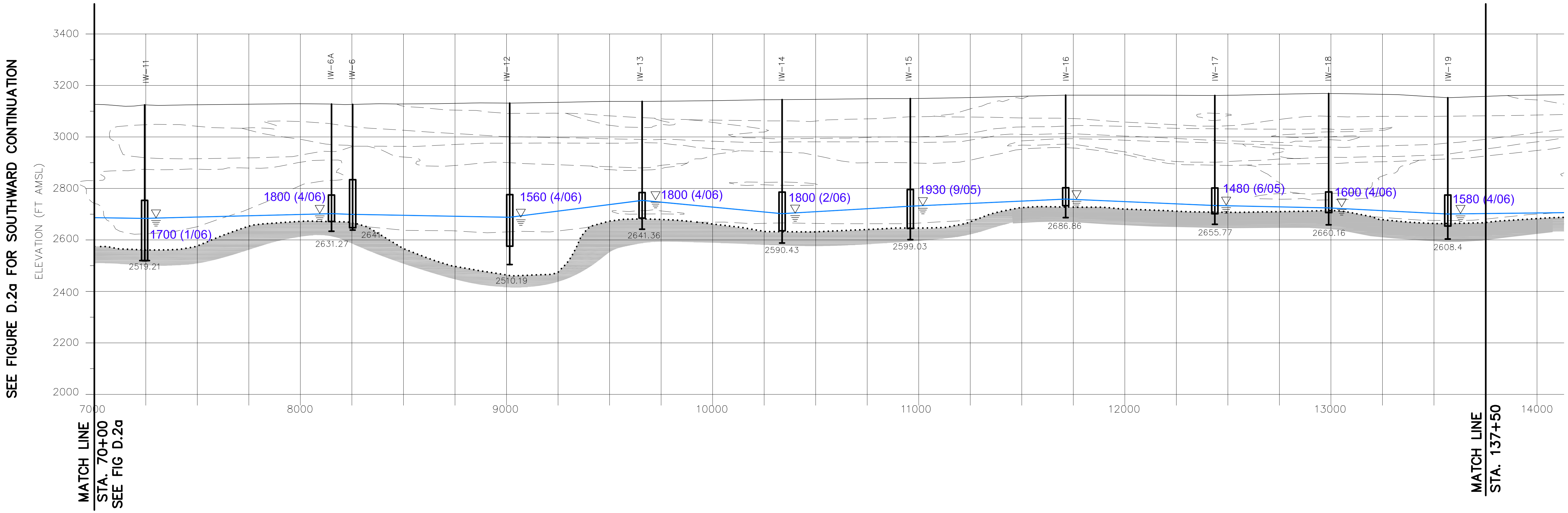




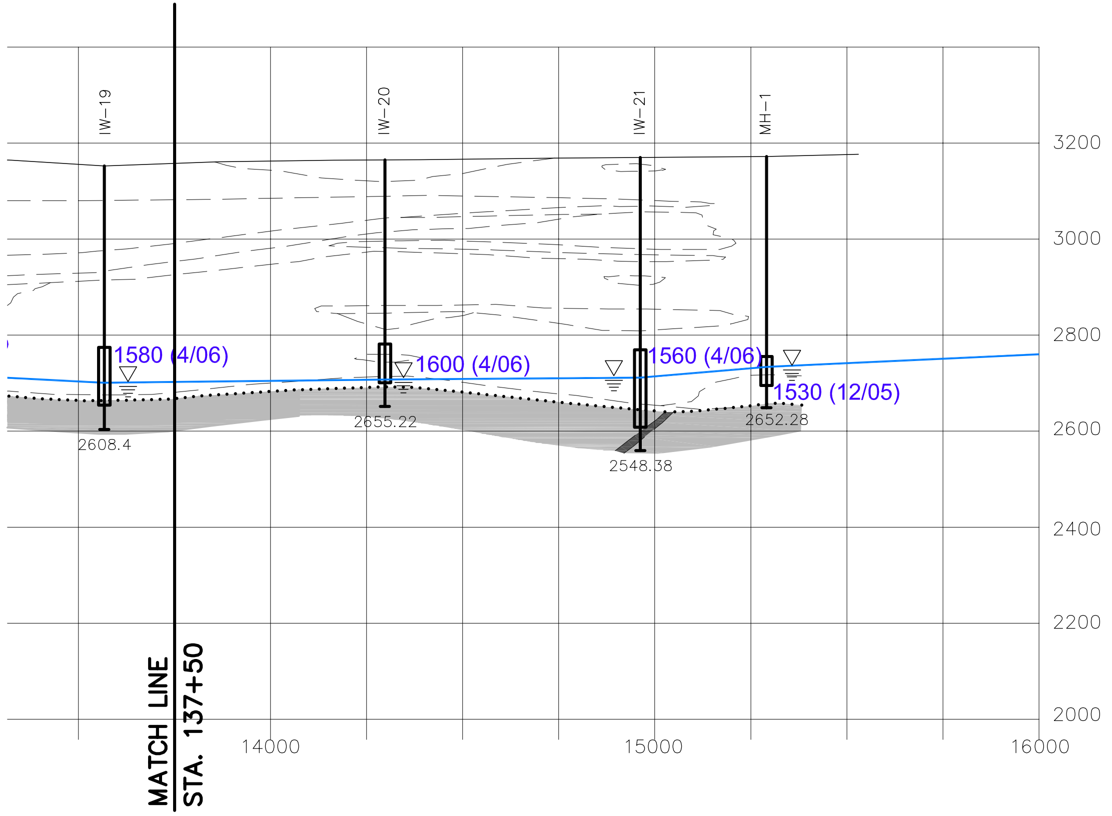
HYDRO
GEO
CHEM, INC.

A - A' WATER QUALITY CROSS SECTION
SHEET 1 OF 2
SIERRITA TAILING IMPOUNDMENT AREA

Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830034A	D.2a



A'



LEGEND

BASIN FILL

☐ BASIN FILL, UNDIFFERENTIATED

BEDROCK COMPLEX

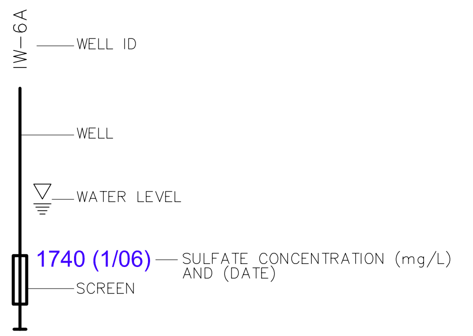
▨ CRETACEOUS ANGELICA ARKOSE

■ EARLY TERTIARY GRANODIORITE

········· TOP OF BEDROCK

— WATER TABLE

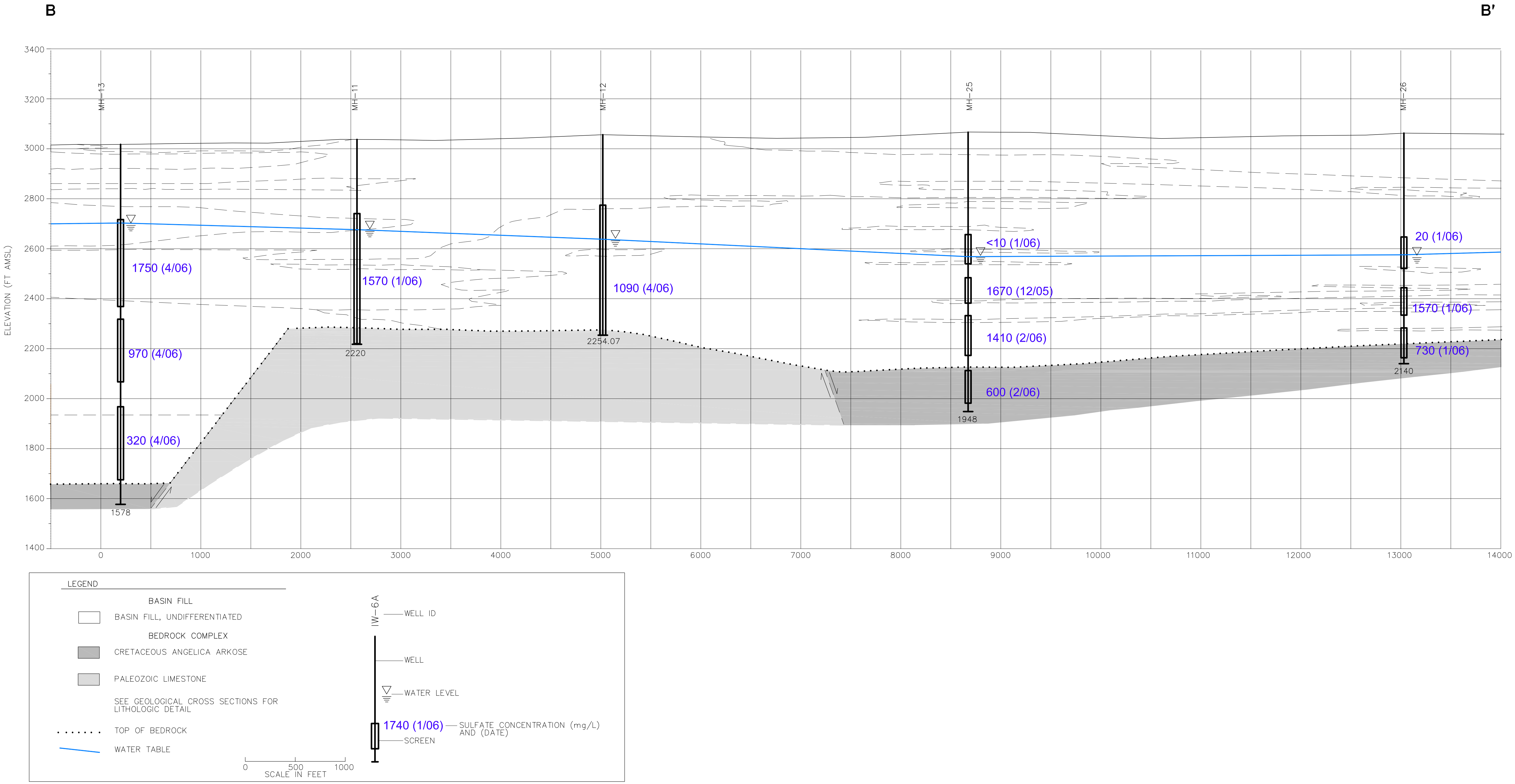
0 250 500 1000
SCALE IN FEET



HYDRO
GEO
CHEM, INC.

A - A' WATER QUALITY CROSS SECTION
SHEET 2 OF 2
SIERRITA TAILING IMPOUNDMENT AREA

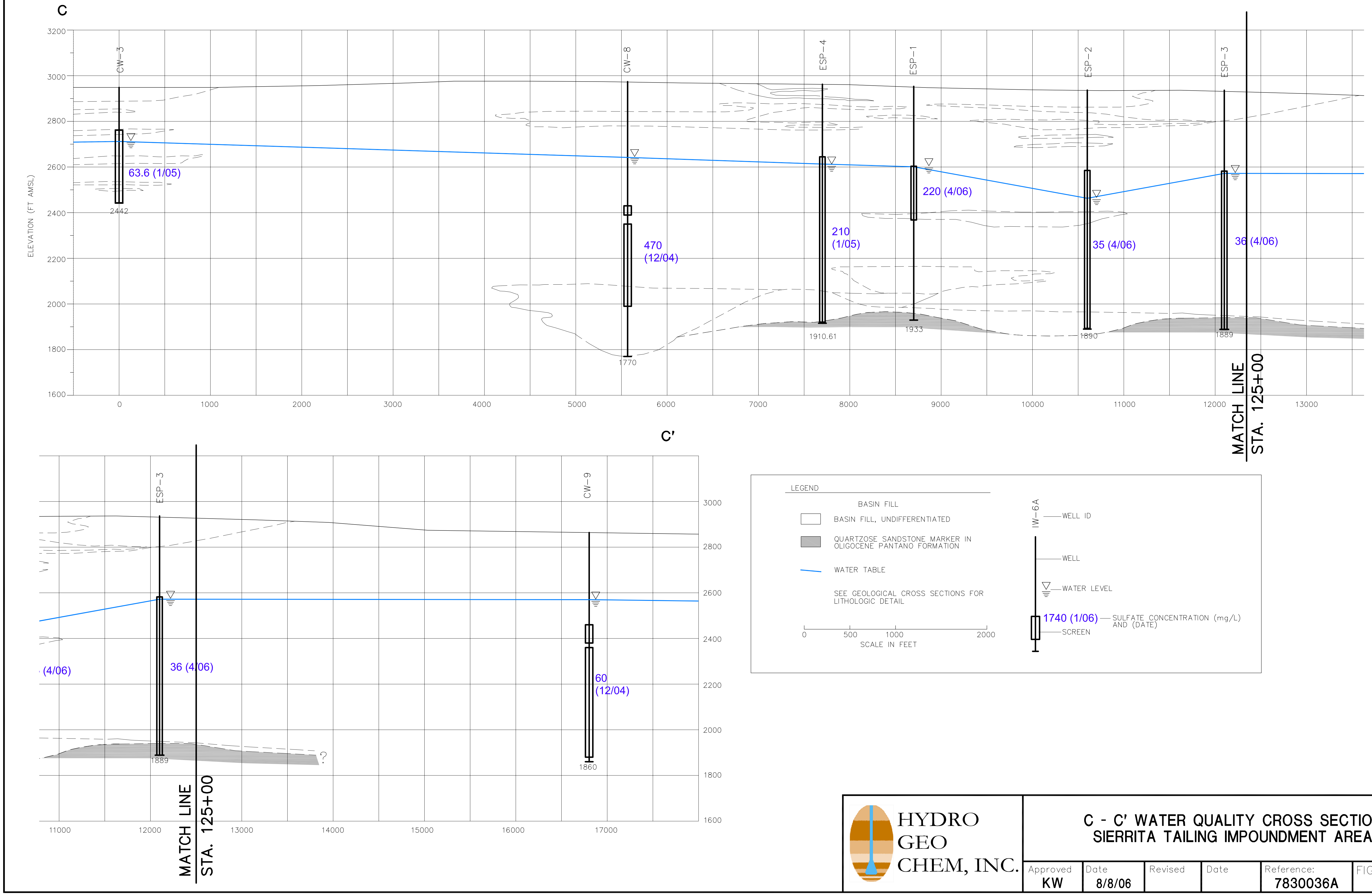
Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830033A	D.2b



HYDRO
GEO
CHEM, INC.

B - B' WATER QUALITY CROSS SECTION
SIERRITA TAILING IMPOUNDMENT AREA

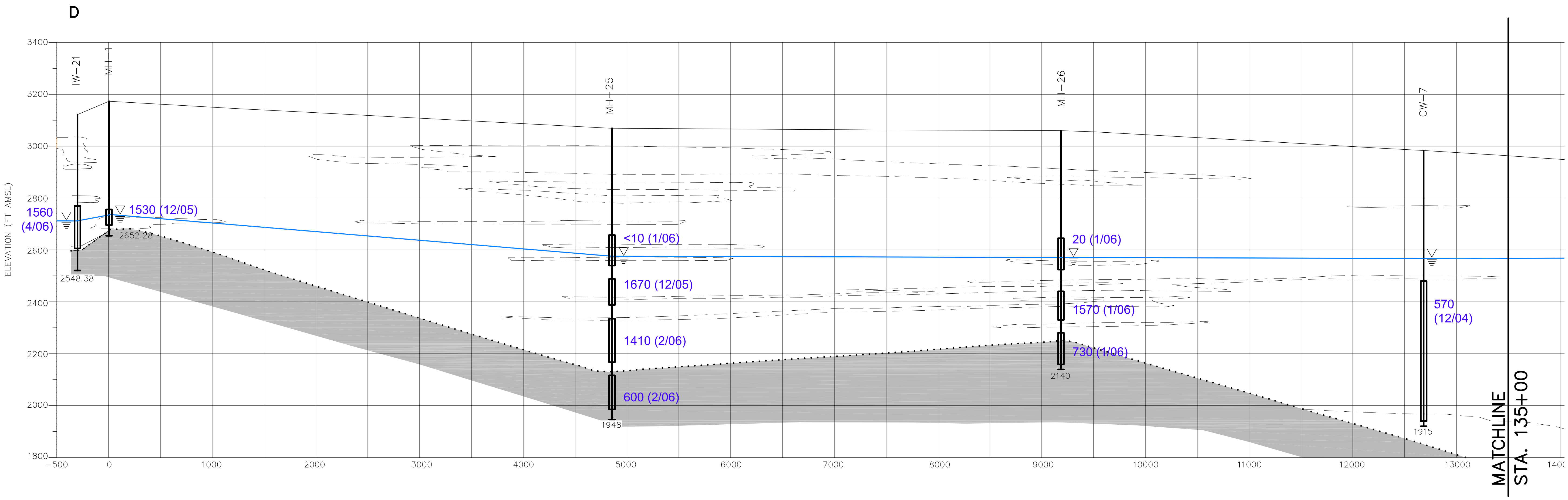
Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830032A	D.3

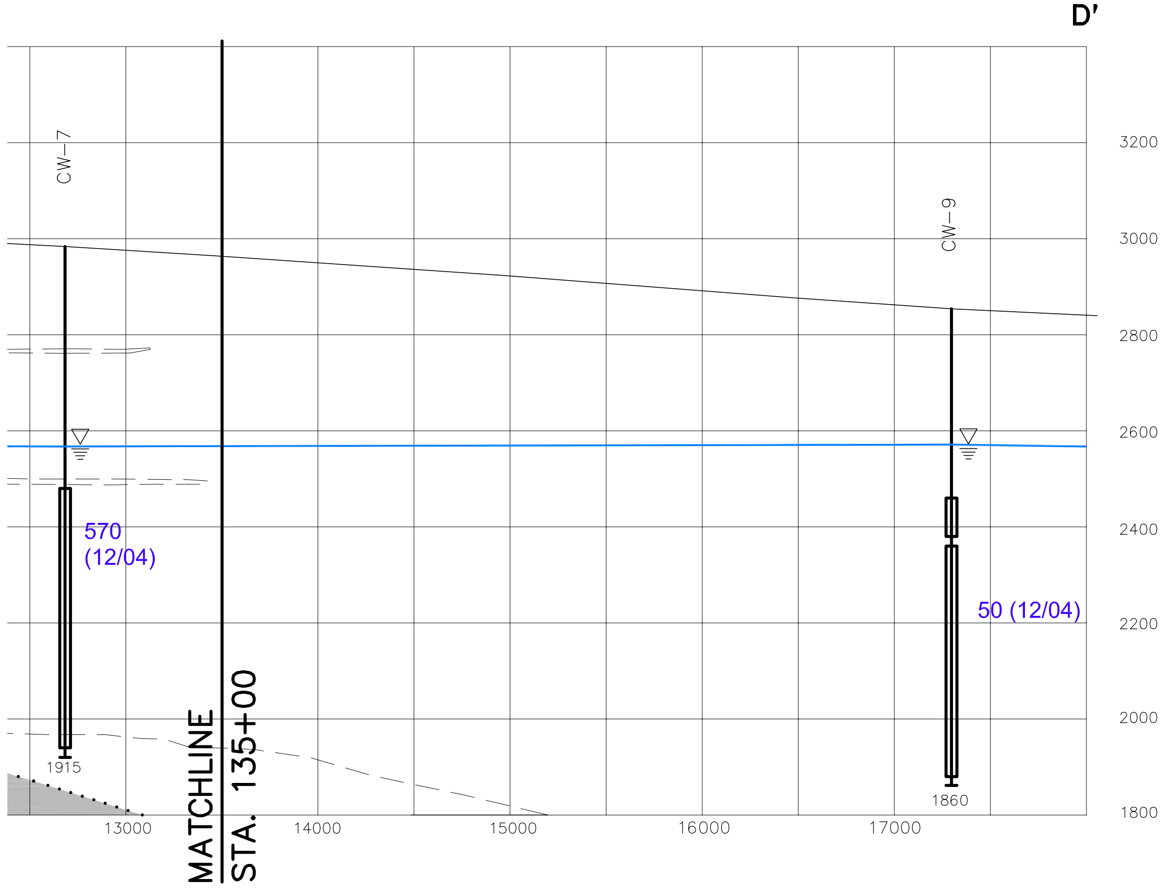


HYDRO
GEO
CHEM, INC.

C - C' WATER QUALITY CROSS SECTION
SIERRITA TAILING IMPOUNDMENT AREA

Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830036A	D.4





LEGEND

BASIN FILL

☐ BASIN FILL, UNDIFFERENTIATED

BEDROCK COMPLEX

▨ CRETACEOUS ANGELICA ARKOSE

· · · · · · · TOP OF BEDROCK

— WATER TABLE

SEE GEOLOGICAL CROSS SECTIONS FOR LITHOLOGIC DETAIL

0 500 1000
SCALE IN FEET

IW-6A — WELL ID

WELL

▽ WATER LEVEL

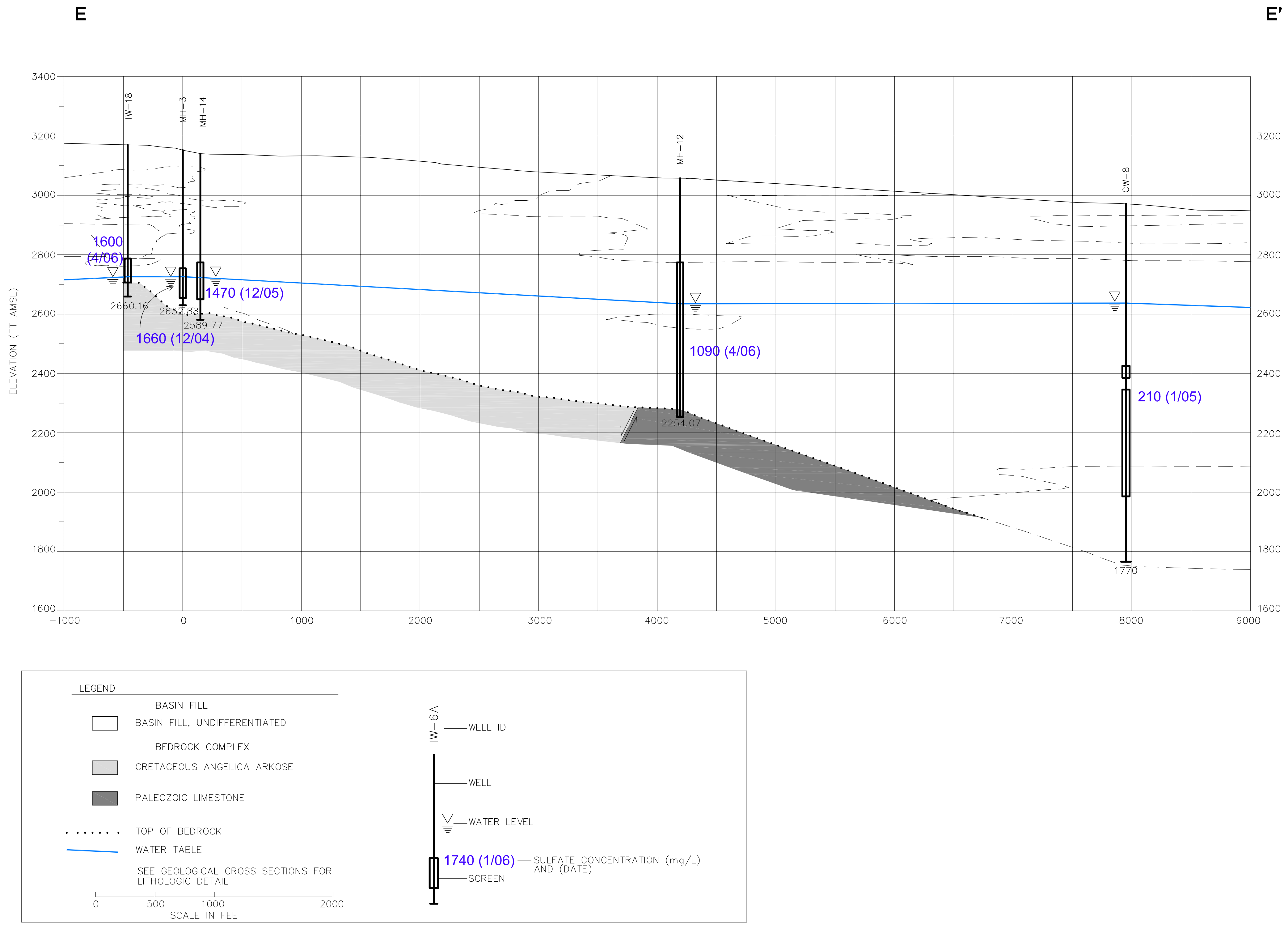
1740 (1/06) — SULFATE CONCENTRATION (mg/L) AND (DATE)

SCREEN

HYDRO
GEO
CHEM, INC.

D - D' WATER QUALITY CROSS SECTION
SIERRITA TAILING IMPOUNDMENT AREA

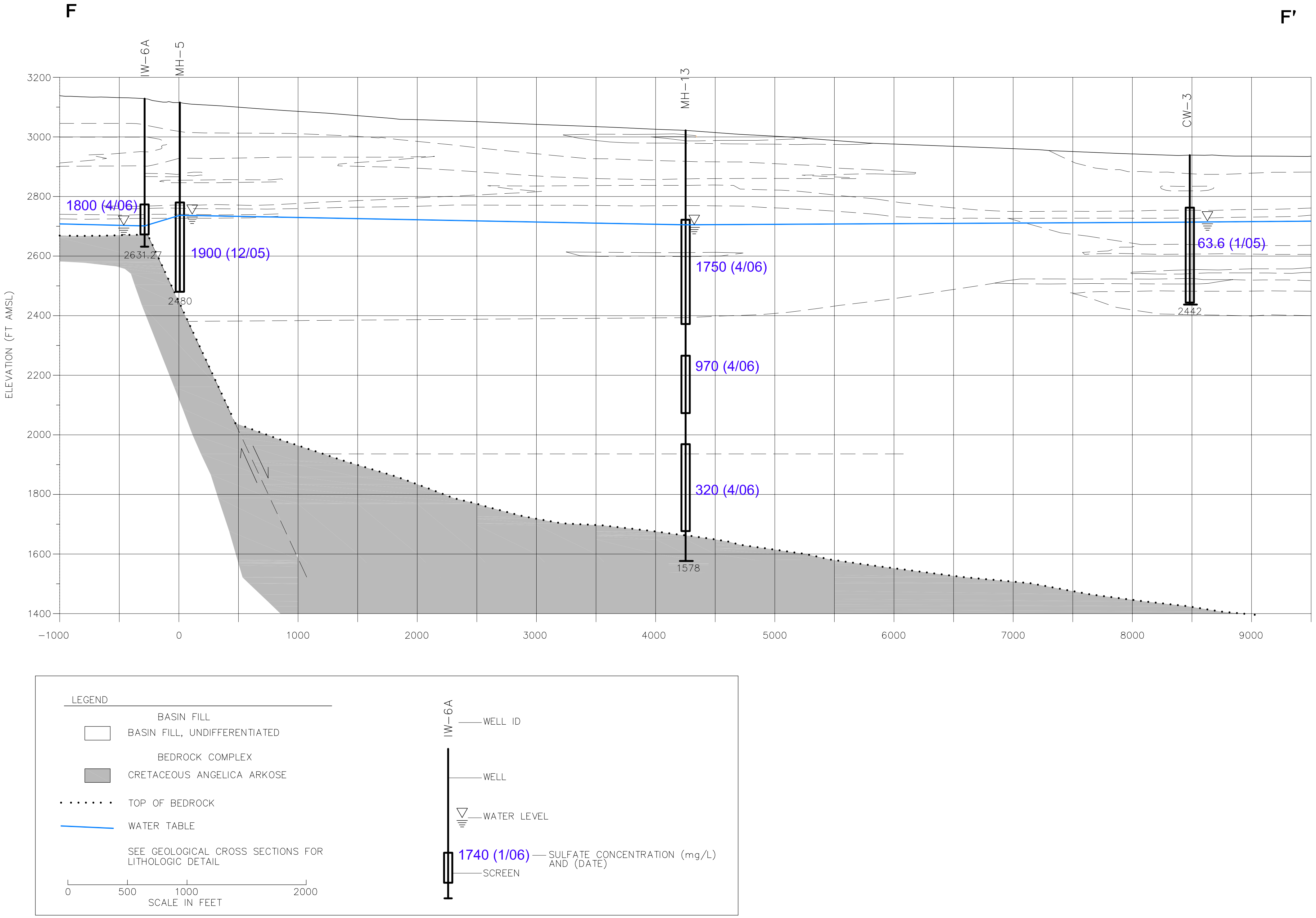
Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830037A	D.5



HYDRO
GEO
CHEM, INC.

E - E' WATER QUALITY CROSS SECTION
SIERRITA TAILING IMPOUNDMENT AREA

Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830035A	D.6



HYDRO
GEO
CHEM, INC.

F - F' WATER QUALITY CROSS SECTION
SIERRITA TAILING IMPOUNDMENT AREA

Approved	Date	Revised	Date	Reference:	FIG.
KW	8/8/06			7830031A	D.7

APPENDIX E

Quality Assurance Project Plan

QUALITY ASSURANCE PROJECT PLAN FOR AQUIFER CHARACTERIZATION PLAN

Prepared for:

Phelps Dodge Sierrita, Inc.
6200 West Duval Road
Green Valley, Arizona 85614

Prepared by:

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

August 11, 2006

APPROVAL & DISTRIBUTION SHEET
QUALITY ASSURANCE PROJECT PLAN
FOR AQUIFER CHARACTERIZATION PLAN
PHELPS DODGE SEIRRITA MINE, PIMA COUNTY, ARIZONA

______________________________ Stuart Brown Bridgewater Group, Inc. Project Director (503) 675-5252 date: ____________________	______________________________ E.L. (Ned) Hall Phelps Dodge Sierrita, Inc. Project Manager (520) 648-8700 date: ____________________
______________________________ Bill Dorris Phelps Dodge Sierrita, Inc. Quality Assurance Manager (520) 648-8873 date: ____________________	______________________________ James R. Norris Hydro Geo Chem, Inc. Project Manager (520) 293-1500 ext. 112 date: ____________________
______________________________ Kimberly Garcia Hydro Geo Chem, Inc. Quality Assurance Manager (520) 293-1500 ext. 123 date: ____________________	______________________________ Field Technician date: ____________________
______________________________ Scott Habermehl ACZ Laboratories Analytical Laboratory Project Manager (800) 334-5493 date: ____________________	______________________________ Kirsten Russell ACZ Laboratories Analytical Laboratory QA Manager (800) 334-5493 date: ____________________
______________________________ Subcontractor date: ____________________	______________________________ Subcontractor date: ____________________

ACRONYM AND ABBREVIATION LIST

°C	degrees Celsius
μmhos/cm	micro mhos per centimeter
ACP	Aquifer Characterization Plan
ACZ	ACZ Laboratories, Inc.
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
AZPDES	Arizona Pollutant Discharge Elimination System
ARS	Arizona Revised Statutes
bgs	below ground surface
CLP	Contract Laboratory Program
COC	chain-of-custody
DGP	De Minimus General Permit
DQI	data quality indicator
DQO	data quality objective
DTW	depth to water
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
ft	feet
HGC	Hydro Geo Chem, Inc.
ID	identification
in	inch
LCS	laboratory control sample
MDL	method detection limit
mg/L	milligrams per liter
MO	Mitigation Order on Consent Docket No. P-50-06, dated June 8, 2006
MHSA	Mine Health and Safety Administration
MS/MSD	matrix spike/matrix spike duplicate
nm	nanometer
OHSA	Occupational Health and Safety Administration
PDSI	Phelps Dodge Sierrita, Inc.
PDSTI	Phelps Dodge Sierrita Tailing Impoundment
PQL	practical quantitation limit
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RPD	relative percent difference
SOP	standard operating procedure
TDS	total dissolved solids
USCS	Unified Soil Classification System

CROSS-REFERENCE OF QUALITY ASSURANCE ELEMENTS

The following table contains a cross reference between this document and the elements specified by the Arizona Department of Environmental Quality (ADEQ) in its *Quality Assurance Project Plan Review*, based on the U.S. Environmental Protection Agency (EPA) *Requirements for Quality Assurance Plans for Environmental Data Operations*, EPA QA/R-5 (EPA, 2001a).

QUALITY ASSURANCE /R-5 ELEMENTS	COMMENT ADDRESSED
A1, Title and Approval Sheet	**Cover, Pg. i**
A2, Table of Contents	**Pg. vii**
A3, Distribution List	**Pg. i**
A4, Project Organization	**Section 2, Figure 1**
A5, Problem Definition/Background	**Section 1.1**
A6, Project/Task Description	**Section 1.1**
A7, Quality Objectives and Criteria for Measurement Data	**Section 3**
A8, Special Training/Certification	**Sections 4.1, 5.1**
A9, Documentation and Records	**Sections 4.6, 5.7**
B1, Sampling Process Design	**Sections 4.2, 4.3**
B2, Sampling Methods Requirements	**Sections 4.2, 4.3**
B3, Sample Handling and Custody Requirements	**Sections 4.2.3, 5.2**
B4, Analytical Methods Requirements	**Section 5.3**
B5, Quality Control Requirements	**Sections 4.2.1.5, 5.4**
B6, Instrument/Equipment Testing, Inspection, and Maintenance	**Sections 4.5., 5.5**
B7, Instrument/Equipment Calibration and Frequency	**Sections 4.5, 5.5**
B8, Inspection/Acceptance of Supplies and Consumables	**Sections 4.5**
B9, Data Acquisition for Non-Direct Measurements	**N/A**
B10, Data Management	**Section 6**
C1, Assessments and Response Actions	**Sections 4.7, 5.7, 6.4**
C2, Reports to Management	**Sections 5.6, 6.4**
D1, Data Review, Verification, and Validation	**Section 6.2**
D2, Verifications and Validation Methods	**Section 6.2**
D3, Reconciliation with User Requirements	**Section 6.2**

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLES

FIGURES

APPENDICES

1. INTRODUCTION

This Quality Assurance Project Plan (QAPP) describes the quality assurance levels and procedures for field operations and the associated laboratory and data management activities that will be conducted for the Aquifer Characterization Plan (ACP) contained in the *Work Plan to Characterize and Mitigate Sulfate with Respect to Drinking Water Supplies in the Vicinity of the Phelps Dodge Sierrita Tailing Impoundment, Pima County, Arizona* (Work Plan). The Work Plan was developed pursuant to Mitigation Order on Consent Docket No. P-50-06 (MO) between Phelps Dodge Sierrita, Inc. (PDSI) and the Arizona Department of Environmental Quality (ADEQ). Section III.A.2 of the MO states that a QAPP, with a schedule for implementation, will be provided with the Work Plan. Components of the QAPP are to define, "the sulfate plume characterization and assessment objectives," and describe "the methods, organization, analyses, and quality assurance and quality control" needed to meet the objectives of the Work Plan. Hydro Geo Chem, Inc. (HGC) prepared this QAPP on behalf of PDSI.

1.1 Background and Project Description

The Phelps Dodge Sierrita Tailing Impoundment (PDSTI) is one of several tailing impoundments in the Pima mining district. It is located approximately 25 miles south of Tucson and 2 miles east of Green Valley in Pima County, Arizona. In the 1970s, groundwater in the vicinity of PDSTI and other tailing impoundments in the Pima mining district was found to contain elevated concentrations of sulfate. The origin of the sulfate was identified as the seepage from various tailing impoundments into the underlying aquifer.

Groundwater sampling in the Green Valley area has identified a groundwater plume with sulfate concentrations exceeding 250 milligrams per liter (mg/L). The zone of elevated sulfate extends from the base of the PDSTI northeastward to the western edge of Green Valley and northward to approximately Duval Mine Road.

In June 2006, PDSI and ADEQ entered into the MO to address sulfate attributable to the PDSTI. To meet the MO requirements, the Work Plan proposes an ACP and a Feasibility Study (FS) for the sulfate mitigation. The ACP will determine the nature, extent, fate, and transport of sulfate in groundwater and will gather information needed to develop mitigation action alternatives for drinking water supplies consistent with the MO. This QAPP pertains to data collection activities for the ACP for use in characterizing the sulfate plume and conducting the FS.

1.2 Quality Assurance Project Plan Overview

Quality assurance (QA) is a planned, systematic set of activities designed to ensure that a product or service meets defined standards of quality within a stated level of confidence. Quality control (QC) is the routine application of procedures for obtaining prescribed performance standards for monitoring and measuring. This QAPP provides the QA/QC procedures needed to provide confidence that the data generated during ACP activities are appropriate for their intended use, are legally defensible, and are of sufficient quality to support decisions concerning characterization of sulfate in groundwater and development of the Mitigation Plan. The QA/QC program described in this QAPP covers procedures to be followed for field activities, sample handling, chain-of-custody (COC) documentation, laboratory analyses, and data management.

Portions of the groundwater sampling described in the ACP will be conducted by PDSI as part of their routine monitoring activities. The sampling protocols and QA/QC procedures for data collected by PDSI will be governed by the *Quality Assurance/Quality Control Plan for Water Monitoring, Phelps Dodge Sierrita, Inc.* (PDSI, 2005a) and *Standard Operating Procedures - Water and Environmental Sample Collection, Phelps Dodge Sierrita* (PDSI, 2005b) which are provided in Appendix A. QA of data collected under the direction of HGC will be governed by this QAPP. This QAPP is designed to be generally consistent with PDSI (2005a) and PDSI (2005b) and the following documents:

- *EPA Guidance for Quality Assurance Project Plans*, EPA/240/R-02/009. (EPA, 2002a),
- *Guidance on Systematic Planning Using the Data Quality Objective Processes*, EPA/540/B-06/001. (EPA, 2006).
- *EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review, Final* (EPA, 2004).
- *ADEQ Quality Management Plan*, EQR00-01. (ADEQ, 1999).

1.3 Quality Assurance Project Plan Distribution

The HGC QA Manager is responsible for ensuring that each project member has access to the most current version of the QAPP, including all subsequent addenda or revisions. The project members include, but may not be limited to, all individuals named on the signature page of this QAPP and all subcontractors performing field operations and laboratory analyses. The QAPP will be reviewed yearly by the HGC Project Manager to address any changes in data collection requirements. If revisions are made to the QAPP, they will be made under the direction of the HGC Project Manager and a revised document will be issued a sequential revision number and a new signature page.

1.4 Quality Assurance Project Plan Organization

This QAPP begins by describing the project organization and QA responsibilities for ACP activities (Section 2). It then defines the data quality objectives for data generated by activities conducted for the ACP (Section 3). Finally, it gives the QA/QC procedures, for field, analytical laboratory, and data management activities (Sections 4, 5, and 6).

2. PROJECT ORGANIZATION AND RESPONSIBILITIES

An organizational chart indicating the relationships and lines of communication among project participants is provided in Figure 1. As depicted in Figure 1, there are parallel project management and QA responsibilities between PDSI and HGC. PDSI is responsible for implementing and reporting environmental monitoring activities for its routine groundwater monitoring and additional sampling to be identified by and conducted for the ACP. For Task 2.2 of the ACP, PDSI will conduct groundwater monitoring at selected monitoring wells already sampled under the PDSI monitoring plan. PDSI will conduct these monitoring activities independent from field activities conducted by HGC. Data collected by PDSI will be used by HGC for groundwater monitoring under the ACP. HGC will coordinate and oversee ACP tasks, such as groundwater sampling of wells not routinely monitored by PDSI and the installation, testing, and sampling of new wells. The roles and responsibilities of the individuals given in Figure 1 are described below.

2.1 ADEQ Project Manager

The ADEQ Project Manager conducts regulatory oversight of the Work Plan activities and provides regulatory review and approval of documents, reports, plans, schedules, and other communications submitted pursuant to the MO.

2.2 Phelps Dodge Corporation Project Director

The Phelps Dodge Corporation Project Director has the overall responsibly for implementing the Work Plan. The Project Director will direct the schedule and scope of operations and provide fiscal oversight for resources needed for Work Plan activities.

2.3 PDSI Project Manager

The PDSI Project Manager directs PDSI sampling activities. The PDSI Project Manager has the responsibility to ensure that PDSI personnel are properly trained, and, in cooperation with the PDSI QA Manager, to ensure the quality of data collected by PDSI. The PDSI Project Manager will work with the HGC Project Manager to provide resources for implementation of ACP tasks.

2.4 PDSI QA Manager

The PDSI QA Manager provides QA documentation, review, and verification of field and laboratory data collected by PDSI, identifies data quality deficiencies, and initiates corrective action. The PDSI QA Manager also ensures that records are properly stored in PDSI files and electronic databases and coordinates transfer of data with HGC QA Manager.

2.5 HGC Project Manager

The HGC Project Manager directs field activities for the ACP, ensures that all personnel are properly trained, and ensures adequate resources for the completion of ACP tasks. The HGC Project Manager also works with the HGC QA Manager to provide QA checks of data quality and to implement corrective actions. The HGC Project Manager is responsible for providing final review and approval of documents, reports, plans, schedules, and other communications submitted to ADEQ pursuant to the MO. The HGC Project Manager will periodically review and provide any needed updates to the QAPP.

2.6 HGC QA Manager

The HGC QA Manager reviews data and documentation from ACP activities to ensure compliance with the provisions of this QAPP, initiates corrective actions, and ensures that records are properly stored in HGC files and electronic databases. The HGC QA Manager will also coordinate data transfer with the PDSI QA Manager and be responsible for entry of data collected by PDSI into the HGC database.

2.7 Field Technicians

Field technicians are all personnel (geologists, hydrologists, or environmental technicians) performing field activities described in the ACP, including groundwater sampling, lithologic and borehole logging, well construction oversight, and aquifer testing. All field technicians should be adequately trained for the activities that they will perform, and they are responsible for ensuring the quality of their own work, including complete and accurate documentation.

2.8 Laboratory Project Manager

The Laboratory Project Manager ensures that laboratory resources are available, reviews final analytical reports produced by the laboratory, reviews and directs compliance with the QAPP, coordinates scheduling of laboratory analyses, and supervises in-house COC procedures. The Laboratory Project Manager also has the responsibility of submitting analytical reports to HGC.

2.9 Laboratory QA Manager

The Laboratory QA Manager maintains laboratory QA procedures and QA/QC documentation, conducts periodic internal laboratory audits, and recommends corrective actions when necessary. The Laboratory QA Manager is responsible to ensure that laboratory procedures are in compliance with this QAPP.

2.10 Drilling Subcontractors

Drilling subcontractors are responsible for the specific drilling, well construction, and well sampling activities for which they are contracted. They are also responsible for being properly licensed and trained to perform these activities.

3. DATA QUALITY OBJECTIVES

The primary data collection activities for the ACP are water level measurement, collection and analysis of water quality samples, lithologic logging of boreholes, and aquifer testing. Data collected by these activities will be used by PDSI and ADEQ to characterize the extent of sulfate in groundwater and to develop and evaluate mitigation alternatives for drinking water supplies. The overall QA objective is to implement field procedures, laboratory analyses, and reporting that will provide results that are scientifically valid and legally defensible. Data Quality Objectives (DQOs) are qualitative and quantitative objectives that specify the quality of data needed from a sampling program. Data Quality Indicators (DQIs) aid in this goal by specifying criteria for data types, quality, quantity, and applications that are needed to minimize decision errors due to data uncertainties. This section discusses DQOs, QA deliverables, and the DQIs used to evaluate if the DQOs have been met for field operations and laboratory analyses.

3.1 Data Quality Objectives

The DQOs for this project are:

- Collection of water level data of sufficient quantity and representativeness to evaluate potentiometric conditions during seasonal high (summer) and low (winter) pumping conditions.
- Collection and laboratory analysis of water samples of sufficient quality to define the lateral and vertical distribution of sulfate and to characterize water quality parameters pertinent to the identification and evaluation of potential water treatment technologies for the FS.

- Collection of lithologic information of sufficient accuracy to develop a reliable understanding of subsurface materials.

- Collection of aquifer test data of sufficient quality to estimate hydraulic properties of subsurface materials.

- Water flow rate and volume measurements of sufficient accuracy to support estimation of hydraulic properties and major components of the water budget.

3.2 Quality Assurance of Deliverables

The QA program should ensure the quality of all deliverables from field activities, laboratory analyses, and data processing. The U.S. Environmental Protection Agency (EPA) has identified five levels of QA/QC. The QA/QC level required for a project depends on the purpose of that project and the data deliverables requested. Levels I through IV are defined in Table 1. Level V refers to non-conventional parameters and is not applicable to this QAPP. The relevance of levels I through IV to this QAPP is discussed below.

$ Level I analytical methods are required for field data collection. Field data will be generated using portable instruments that are regularly calibrated. Level I methods will be implemented in the field and include the use of pH, temperature, and electrical conductivity meters, as well as other instruments.

$ Level II may be used for screening-level measurements such as in-field sulfate detection. In general, however, Level II is not pertinent to this QAPP because it does not provide adequate accuracy or sensitivity.

$ Level III analytical methods are required for the majority of project data collected per this QAPP. For most groundwater samples, the quality of laboratory data must be sufficient to monitor current groundwater conditions. Additionally, the data must be of sufficient quality to meet all objectives identified for this project.

$ Level IV consists of a highly accurate and rigorous QA/QC review that would only be undertaken in this project if there was a persistent problem identified with analytical results. HGC may request a Level IV "Contract Laboratory Program (CLP)-

equivalent" QC package from the laboratory and independent validation of the data. PDSI may request a Level IV "CLP-equivalent" QC package for all or some percentage of the data. Data validation documentation will be consistent with *Laboratory Documentation Required for Data Evaluation* as established by EPA Region IX QA Office (2001b).

3.3 Data Quality Indicators

Field and laboratory data will be evaluated using the following DQIs: precision, bias, accuracy, representativeness, comparability, completeness, and sensitivity. If laboratory data DQIs do not meet the data acceptance criteria, the reason will be noted in the case narrative submitted to HGC. If DQI acceptance criteria are not met, corrective actions to be taken may include additional sampling and/or re-analysis.

3.3.1 Precision

Precision is “the measure of agreement among repeated measurements of the same property under identical, or substantially similar, conditions” (EPA, 2002a). For this QAPP, data precision is measured by calculating the relative percent difference (RPD) of the analytical results for field and laboratory duplicates. RPD is calculated using the following formula:

$$RPD = \frac{x_1 - x_2}{x_m} \times 100 \qquad (1)$$

where x_1 is the analytical result from the original sample
x_2 is the analytical result from the duplicate sample
x_m is the mean of the two samples

Acceptance criteria for precision of laboratory duplicates will be set by method guidance or in-house laboratory limits, whichever is more stringent. The default acceptance criteria for field duplicates from groundwater samples will be an RPD of less than 20%, which is the criteria listed in EPA functional guidelines (EPA, 2004).

3.3.2 Bias

Bias is "the systematic or persistent distortion of measurements that causes consistent errors in one direction" (EPA, 2002a). Bias can be caused by matrix interferences that either enhance or suppress the response of an instrument to the presence of a constituent. Bias is addressed both in the field and in the laboratory by calibration of instruments and consistent application of standardized procedures (Sections 4.5 and 5.4).

3.3.3 Accuracy

Accuracy is "a measure of the overall agreement of a measurement to a known value" (EPA, 2002a). Accuracy can be decreased by errors related to both precision and bias. A measured value is of acceptable accuracy when it does not differ beyond acceptable limits from the true value or the known concentration of a spike or standard. Accuracy of analytical results is measured by calculating the percent recoveries of surrogates, matrix spikes, and blank spikes. Laboratory accuracy is expressed as the percent recovery (%R), calculated as follows:

$$\%R = \frac{x_s - x}{T} \times 100 \qquad (2)$$

where x_s is the measured value of the spiked sample
x is the measured value of the unspiked sample
T is the true value of the spike solution added

Acceptance criteria for laboratory accuracy are set by the stricter of in-house limits or method guidance (Section 5.4).

3.3.4 Representativeness

Representativeness is a qualitative measure that conveys “the degree to which sample data accurately and precisely represents a characteristic of the environmental condition being measured” (EPA, 2002a). Representativeness is best satisfied by ensuring that sampling procedures, locations, and quantities are selected properly. Field data will be considered representative when obtained by adherence to sample identification and collection techniques and decontamination procedures (Section 4.2). In addition, proper laboratory analytical procedures and methods are mandatory to ensure representativeness of field data (Section 5).

3.3.5 Comparability

Comparability is a qualitative expression of the confidence with which one data set is comparable to and/or compatible with previous and subsequent data. Comparability is achieved by adhering to standardized methods and QA procedures established in this QAPP during sample collection, handling, and analysis. The comparability of laboratory data is achieved through compliance with analytical method protocols. Comparability is enhanced when the same laboratory is used to analyze samples from successive sampling events and when data is reported in consistent and standard units of measurement.

3.3.6 Completeness

Completeness is a measure of the amount of valid data needed to be obtained from a sampling campaign or measurement program. Completeness will be expressed as the percentage of the total number of each type of sample or measurement that satisfies the QA/QC criteria for this project. Percent completeness will be calculated as follows:

$$\left(\frac{number\ of\ \ valid\ data\ obtained}{number\ of\ \ valid\ data\ \ possible}\right)\times 100 \qquad (3)$$

Completeness will be calculated and reported by the HGC QA Manager. Adherence to this QAPP is expected to yield data sets that will be at least 90% complete. Common factors that reduce data completeness include the following:

- The laboratory did not analyze the sample for the requested parameter.
- The laboratory did not analyze the sample following the correct method.
- The laboratory did not provide the correct sensitivity.
- The laboratory rejected data due to QC failure.
- The data reviewer rejected data due to QC failure.

3.3.7 Sensitivity

Sensitivity is a measure of "the capability of the method or instrument to discriminate between measurement responses representing different levels of a variable of interest" (EPA, 2002a). Sensitivity requirements for field measurement instruments are as follows:

- Water levels probes = 0.01 foot (ft).
- Temperature meters = 1 degree Celsius (ºC).
- pH meters = 0.1 standard units.
- Electrical conductivity meters = 10 micromhos per centimeter (µmhos/cm).
- Pressure transducers = 0.01 ft water head or as appropriate for pressure rating.
- Flow meters = 5 percent of measured flow rate.
- Togopgraphic survey instruments = 0.01 ft horizontal and vertical.
- Borehole depth measurement devices = 0.1 ft.

Sensitivity requirements for analytical laboratories are generally described by the analytical method detection limits (MDLs). A MDL is the minimum amount of an analyte that can be consistently measured and reported with a high degree of confidence that the analyte concentration is above a background response. A practical quantitation limit (PQL) is that amount that can be consistently quantified with acceptable precision and accuracy. Target PQLs for each analyte will be set by method guidance or laboratory specifications, whichever is stricter (Section 5.3).

4. FIELD ACTIVITIES

This section gives the QA procedures that will be used for field activities, including groundwater sampling (water level measurement and water quality sampling), drilling and well construction, and aquifer testing. It also describes the procedures for equipment care, investigation derived waste management, and field documentation. Field activities will be documented in a dedicated field logbook or on field forms as described in Section 4.6. Sampling conducted by PDSI should conform to PDSI's quality assurance/quality control plan and standard operating procedures for environmental sampling which are included in Appendix A of this QAPP. HGC has reviewed PDSI's plans and procedures and has determined that the data generated in accordance with them will be acceptable for use.

4.1 Certification and Preliminary Activities

All field staff shall have Occupational Safety and Health Administration (OSHA) 40-hour training and certification as described in the Code of Federal Regulations (CFR), Title 29, Section 1910.120. Staff working within the PDSI property boundaries shall also have site-specific hazard awareness training and Mining Safety and Health Administration (MSHA) training as prescribed in 30 CFR Subchapter H. All certified field operations personnel must annually complete OSHA and MSHA refresher courses to maintain their certifications. All personnel and subcontractors will have appropriate licensure and certification as required by law to perform their specific field operation. In particular, drillers will have a current well driller's license issued by the Arizona Department of Water Resources (ADWR).

Prior to starting field activities, the HGC Project Manager will obtain necessary permits, notify property owners of scheduled field activities, and locate all subsurface utilities near areas where drilling will occur. Required permits may include an ADEQ Arizona Pollutant Discharge Elimination System (AZPDES), De Minimus General Permit (DGP), an ADWR drilling permit, and an ADWR groundwater withdrawal permit. The HGC Project Manager will complete and submit Notice of Intent to Drill a Well forms to ADWR for all proposed wells. The HGC Project Manager will locate subsurface utilities by requesting a Blue Stake Survey at least 72 hours, but not more than 2 weeks, prior to drilling.

4.2 Groundwater Sampling Activities

The ACP specifies groundwater sampling from existing PDSI wells and from existing privately-owned wells. Most samples taken from existing wells will be taken from the screened interval of the well without regard to collection depth within the screen (Section 4.2.1). Depth-specific sampling that will collect water samples at discrete depths within the well screen will also be conducted (Section 4.2.2). All groundwater sampling activities will be consistent with the procedures outlined in EPA-approved methodologies, ADEQ sampling guidance documents, and this section so that data obtained from the sampling activities is of sufficient quality to meet the DQOs (Section 3). QA procedures for sampling activities are described below. Following the description of QA procedures, protocols for sample handling from the collection site to the analytical laboratory are provided. Sample receipt and handling by the analytical laboratory are discussed in Section 5.2.

4.2.1 Groundwater Sampling from Existing Wells

Groundwater sampling will be conducted in a variety of well types including monitoring wells, active production wells, and possibly, private wells. For wells with a dedicated pump, that pump will be used for purging and sampling. If a well does not have a dedicated pump, a decontaminated, portable, submersible pump will be used to purge the well and collect groundwater samples. Prior to sampling, well construction specifications will be obtained from the well owner or ADWR records. Upon arrival at the sampling location, the sampling personnel will document the condition of the well in the field notebook or on a sampling form. Groundwater sampling then will be conducted using the following steps:

1. Depth-to-water (DTW) measurement.
2. Well purging and collection of groundwater indicator parameters.
3. Sample collection and labeling.
4. Equipment decontamination.

QA procedures for these steps are described below.

4.2.1.1 Depth to Water Measurements

Water level measurements will be taken in both pumping and non-pumping wells, if possible. For wells that are not being continuously pumped, the static DTW in wells will be measured prior to purging and sampling and will be recorded as a static pumping level. For wells that are being pumped, the pumping water level will be measured and the DTW will be recorded as a dynamic water level. The following QA procedures will be followed when making the DTW measurements:

- Use a decontaminated electronic well sounder probe capable of measuring water levels with an accuracy of 0.01 ft (Section 3.3.7).
- Verify the well identification (ID) and check to ensure that measurement equipment is operating properly.
- Record the well ID, top of casing elevation, and surface elevation, if known.
- Measure DTW from the surveyed measuring point on the top of well casing or from the north side of the top of the inner well casing if the casing has no surveyed measuring point.
- Record the DTW to the nearest 0.01 foot.
- Take DTW measurement a second time to verify that a correct measurement has been made. The two measurements should agree to within 0.03 ft.

4.2.1.2 Well Purging and Collection of Indicator Parameters

After taking DTW measurements and prior to taking groundwater samples, the wells will be purged of resident water so that groundwater samples will be representative of water from the formation. The HGC Project Manager will determine the needs for a DGP for purge water once sample locations are selected. While purging the well, groundwater indicator parameters (pH, electrical conductivity, and temperature) will be measured. Groundwater purging and indicator parameter measurements will adhere to the following QA practices:

- Calculate the wetted casing volume based on the DTW measurement and well construction.
- Collect the indicator parameters readings at regular time or pumped volume intervals, and record the readings on a groundwater sampling form.
- If possible, purge the well of three wetted casing volumes and allow indicator parameters to stabilize so that consecutive parameter measurements (collected at approximately one-half casing volumes apart) are within the following: pH - 0.3 standard units, temperature - 2 °C, and electrical conductivity - 100 µmhos/cm.
- Permit any well that goes dry during pumping to recover at least 50% of its starting water elevation prior to groundwater sampling.

No more than five wetted casing volumes need to be pumped regardless of parameter stabilization; however, parameter instability may indicate a problem with the measurement instrument(s). If stabilized parameters cannot be obtained, field instruments will be re-calibrated (Section 4.5.2). For wells that are being pumped when sampling personnel arrive (e.g., production wells), the sampling personnel do not need to purge the well if it has been pumping continuously for a period sufficient to remove three wetted casing volumes. DTW and field parameters should still be measured and recorded.

4.2.1.3 Groundwater Sample Collection

Two types of groundwater samples will be collected at each sampling location: filtered (0.45 micron) samples will be collected for analysis of dissolved constituent concentrations and unfiltered samples will be collected for analysis of total constituent concentrations.

All groundwater samples will be analyzed for major element ions (calcium, magnesium, sodium, potassium, chloride, sulfate, nitrate, nitrite, and fluoride) and wet chemistry (alkalinity, total dissolved solids, and pH) for characterizing the general water chemistry and sulfate. Groundwater samples from select wells will also be analyzed for the following constituents needed to evaluate water treatment for the FS: 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 (total plate count). Table 2 lists the analytical suites for characterization of general chemistry and for characterization of water treatment constituents. Table 2 lists analytical methods; target method detection limits; and filtration, preservation, and holding time requirements.

The HGC QA manager will be responsible for ensuring that the analytical laboratory provides pre-preserved sample containers for all samples. Duplicate samples, equipment blank samples, and field duplicate samples will be collected as described in Section 4.2.1.5. QA practices for collecting groundwater samples are as follows:

- Verify that sample containers have been properly prepared, including addition of any preservative required (Table 2).

- Minimize the lag time between filtered and unfiltered samples by setting up the sample containers near the sampling location and by first taking the filtered sample.

- Install a new (unused) 0.45 filter in-line to the pump discharge and collect a filtered sample from the filtered discharge. If the in-line filter cannot be connected to the pump discharge from the well, collect a sample aliquot, then filter the aliquot using a portable pump and the in-line filter.

- Take the unfiltered samples directly from the pump discharge.

Sample containers do not need to have zero headspace since volatilization of analytes is not a concern.

4.2.1.4 Sample Labeling

Each sample will be uniquely labeled with permanent indelible ink either directly on the container or on a water-proof label that is affixed to the container. For consistency between samples collected by PDSI and samples collected by HGC, the samples will be labeled following the identification instructions given in Procedure DH-B and DH-D of PDSI (2005b) (Appendix A). This labeling system provides an alphanumeric identifier for each well. Samples from wells not given an area/type designator in PDSI (2005b) will be labeled according to the identification used in the ACP or by the well owner. Each sample will also be labeled with the date and time of sample collection, the analysis requested, and the preservative used.

4.2.1.5 Field Quality Control Samples

Field QC samples will be collected to verify sampling and analytical precision, accuracy, and representativeness. Two types of field QC samples will be used as QC check samples: field duplicates and field blanks. Field duplicates will be collected to assess analytical precision (Section 3.3.1). Field blanks will be collected to check for the introduction of contamination in sample handling, shipment, storage, or analysis. These field QC samples will be assigned a unique ID so that the laboratory does not know they are QC samples; however, the QC sample IDs will be clearly noted in the field logbook and on the groundwater sampling form. The collection of field duplicates, and field blanks is described below.

- <u>Field Duplicate Samples</u> are samples that are collected at the same time and location as another groundwater sample. The field duplicate and its partner sample will be split samples collected from the same aliquot of water. The field duplicate will be collected by first obtaining a groundwater sample in a large sampling container, and then distributing the water into sample bottles for analysis of like analytes (e.g. fill bottles for anion analysis from the same sample draw). Field duplicates of filtered and unfiltered water will be collected at a frequency of at least one per 20 samples and will be numbered and packaged following the procedures given in Procedure QC-A of PDSI (2005b) (Appendix A).

- <u>Field Blank Samples</u> will be collected from laboratory-grade de-ionized water that is poured directly into a sample container while in the field. Field blank samples will be subject to the same sampling procedures as samples being collected from a designated sampling location, including container type and preparation, storage, and handling. Field blanks will be collected following the procedure given in Procedure QC-B of PDSI (2005) (Appendix A). One field blank will be collected for every 20 samples. The HGC QA Manager will be responsible for having the analytical laboratory supply laboratory grade de-ionized water along with the pre-preserved sample containers.

4.2.1.6 Equipment Decontamination

Properly decontaminated sampling equipment will help prevent errors due to cross-contamination. Prior to the start of sampling, all reusable equipment will be decontaminated according to Procedure DM-A of PDSI (2005b) (Appendix A). This includes non-dedicated groundwater pumps, reusable bailers, DTW probes, and any other equipment brought onsite. Cleaned equipment should not lie on the ground or any unclean surfaces. Disposable, single-use equipment such as filters, bailers, sampling spigots, and nylon string will be used at a single sample collection location and then discarded.

4.2.2 Depth-Specific Sampling from Existing Wells

The ACP calls for depth-specific groundwater samples to be collected at discrete depths within the well's screened interval. The depth-specific sampling will consist of logging the groundwater inflow velocity along the wells screened interval and collecting groundwater samples at discrete depths. The depth-specific sampling will be a one-time sampling event to provide unique information on the vertical distribution of sulfate. Depth-specific samples will be collected at intervals of approximately 50 ft or as appropriate depending on site-specific well and sampling conditions. Groundwater sampling and inflow logging are explained below.

4.2.2.1 Groundwater Inflow Logging

Groundwater inflow logging will be conducted for wells specified in the ACP. The inflow logging will map the vertical profile of groundwater influx along the wells' screened interval for the purpose of identifying potential preferential zones of groundwater movement and sulfate transport. The logging will be accomplished using the BESST, Inc. Dye Tracer Velocity Profiling technique. A description and brief SOP of this technique is provided in Appendix B. Prior to flow logging, the field technician will perform checks of sampling equipment, including tubing, dye-tracer, and monitoring apparatus. During logging, the field technician will follow the SOP for the BESST, Inc. Dye Tracer Velocity Profiling Technique and note any deviations from the technique in the field logbook. Electronic data will be downloaded daily, as discussed in Section 4.6.

4.2.2.2 Depth-Specific Groundwater Sampling

The DTW procedures in Section 4.2.1.1 will be followed for depth specific samples, although purging will not be conducted. For wells with a dedicated pump, depth-specific sampling will be accomplished using BESST Inc. HydroBooster^{TM} groundwater sampling technique (BESST technique). The BESST technique provides depth-specific groundwater sampling from a well without first having to remove the pump. A brief SOP for the BESST technique is provided in Appendix B. For wells that do not have a dedicated pump, depth-specific samples may be collected using the BESST technique or devices such as a discrete interval sampler (e.g., Solinst Model 425; www.groundwatersoftware.com) or a low-flow submersible pump lowered to the appropriate depths. Selection of the sampling device will depend on well depth and access. QA practices for depth-specific sampling include the following:

- Perform checks of sampling equipment and document site conditions in the field logbook.

- Obtain permission and necessary permits to sample. Permission should be obtained from the well owner. A DGP will be obtained to discharge any purge water if it is determined necessary by the HGC Project Manager.

- Follow the SOPs given for the depth-specific sampling method (Appendix B).

- For wells where inflow logging was conducted, attempt to collect groundwater samples from the same vertical locations as used for inflow logging.

- Label the sample with the depth at which the sample was collected in addition to the other labeling requirements discussed in Section 4.2.1.4.

Groundwater samples collected by depth-specific methods will be unfiltered and analyzed for sulfate only. The sulfate analytical method is listed in Table 2.

4.2.3 Sample Custody and Handling

Groundwater samples will be stored in coolers with ice (4 ºC ± 2º) from the time they are collected until they arrive at the laboratory. COC documentation will be maintained from the time of collection until the samples are analyzed to ensure the defensibility of the results. Further instructions on sample custody and shipping are specified below.

4.2.3.1 Sample Custody and COC Documentation

Samples are in the sampler's custody upon collection. The custody of the samples will be the responsibility of the sampler until the samples are delivered or shipped to the laboratory. A sample is considered to be under a person’s custody if one or more of the following conditions are met:

- The sample is in the person’s physical possession.
- The sample is in the view of the person after that person has taken possession.
- The sample is secured by that person so that no one can tamper with the sample.
- The sample is secured by that person in an area that is restricted from unauthorized personnel.

Custody of samples will be documented from the time of sample collection to completion of the analyses using COC forms. An example COC is provided in Figure DH-A of PDSI (2005b) (Appendix A). COC forms will be filled out and will accompany the samples when shipped to the laboratory. The COC form will identify the contents of each shipment. The COC form will remain in the sampler’s possession until the samples have been hand delivered or shipped to the laboratory. The sampling team leader or designee will sign the COC form in the "relinquished by" box and note the date and time the samples were relinquished. A properly completed COC form will specify:

$ The project name, all required signatures, dates, and times that samples were relinquished and accepted.

$ Analyses requested, time and date of sampling, and sample matrix.

$ Unique field identification of each sample.

$ Number of containers submitted.

$ Temperatures upon receipt by the analytical laboratory.

4.2.3.2 Sample Shipping

Procedures for packing and transporting samples to the laboratory may vary depending on whether samples are hand delivered to the laboratory by field personnel or delivered via a commercial shipping service such as Federal Express or United Parcel Service. The method of sample shipment will be noted on the COC form. Table 3 provides a checklist for shipping requirements.

If samples are shipped by a delivery service, all U.S. Department of Transportation (DOT) regulations for packaging and shipment must be followed. Each sample will be packaged and transported according to the procedures outlined below, which meet DOT requirements.

- Ice will be placed in a sturdy plastic bag to prevent leaking. Samples will be protected by bubble wrap, foam, or some other packing material. Sufficient packing material will be used to prevent sample containers from making contact during shipment. Enough ice will be added to maintain the cooler temperature at 4°C ± 2°, until receipt by the laboratory. The plastic bag will be twisted and secured with a twist tie or cable tie.

- The COC records will be signed by the person relinquishing possession of the samples and will be placed inside a plastic bag. The bag will be sealed and taped to the inside of the cooler lid. The shipping address will be verified before the samples are relinquished to the courier.

- The cooler will be closed and taped shut with packing tape around both ends.

- One or more signed custody seals consisting of tape imprinted with the date and initials of the sampler(s) will be placed on the cooler so that the cooler cannot be opened without the seal(s) being broken. Additional seals may be used if the sampler or shipper determines more seals are necessary. Wide, clear tape will be placed over the seal(s) to help ensure against accidental breakage.

- The cooler will be transferred to the courier along with a completed shipping bill.

4.3 Drilling and Well Construction Activities

As described in the ACP, drilling and well construction activities will be conducted to install monitoring wells at offsite locations. These activities involve the following:

- Licensure and Permits
- Drilling of boreholes
- Lithologic logging of boreholes
- Reconnaissance water quality sampling of drilling return water
- Well construction
- Well completion
- Well development
- Hydraulic testing and water sampling of new wells

QA procedures for these activities are discussed below.

4.3.1 Licensure and Permits

All drilling, well construction, and well development activities will be performed by a drilling contractor who is licensed by ADWR. Prior to drilling, well development, and hydraulic testing of wells, applicable forms and permits will be filed and obtained from ADWR and ADEQ. These forms and permits may include a Notice of Intent to Drill, a well permit, a Groundwater Withdrawal Permit, and a DGP to discharge groundwater to the ground surface.

Drilling activities, including drilling progress, setbacks, and milestones will be noted in the field logbook or appropriate forms.

4.3.2 Borehole Drilling

Proposed approximate drilling locations are given in the ACP. Drilling for offsite monitoring wells will be accomplished using a reverse circulation, air-rotary method to drill a small diameter pilot hole for collection of cuttings and water samples for determination of subsurface lithology and water quality. Mud-rotary methods may be needed for parts of the pilot hole depending on hole conditions and the advice of the driller. If additional wells are installed at the pilot hole location, they will be installed using mud rotary methods. Well design will be based on the results of lithologic sampling and water quality data collected during drilling. The drilling methods outlined here may be modified based on the judgement of the site geologist or recommendations from the drilling contractor.

The site geologist has responsibility of logging the borehole drilling and making sure that boreholes are satisfactorily drilled according to the requirements of the ACP. The site geologist will follow the QA practices given below when logging boreholes.

- Prior to drilling, measure (to ± 0.01 ft) and record the size and length of the drill, sub-assembles, and drill rods. Know and document the relationship between the number of drill rods in the ground and the depth of the borehole.
- Give constant attention to drilling progress, including the number of drill rods in the ground and verify that the driller is in agreement with the depth estimates.

- Immediately discuss any suspected deviations in drilling progress with the driller. Record deviations in the field logbook and immediately report them to the HGC Project Manager.

- Record the following in the field notebook or on the borehole log along with the corresponding depths and times: groundwater depth, observed changes in drilling conditions, and any materials added to the borehole.

4.3.3 Lithologic Logging

Lithologic logging of boreholes for offsite wells will be conducted by the site geologist. The lithology will be logged at 10-ft intervals or more frequently if needed to note significant changes in material properties. Materials used for lithologic logging will be collected from the air-rotary cyclone or mud return. To ensure comparability between lithologic descriptions between different locations logging will be conducted according to the specifications of American Society for Testing and Materials (ASTM) D2488-00. A copy of this ASTM standard is provided in Appendix C. Logging will, as a minimum, note the following:

- Soil type or rock lithology
- Color (using a Munsell color chart)
- Unified Soil Classification System (USCS) classification symbol or lithologic name
- Grading (for coarse grained soils)
- Moisture
- Structure
- Local or geologic name, if applicable
- Visual estimates for percent gravel, sand, silt, and clay
- Reaction with hydrochloric acid

4.3.4 Reconnaissance Groundwater Sampling from Boreholes

Grab samples of groundwater will be collected from the air rotary return for reconnaissance estimation of sulfate concentrations with depth. Grab sampling will commence when the borehole reaches the groundwater table and will continue at approximately 40-ft intervals to the bottom of the borehole if there is sufficient water in the return. The sulfate concentration in samples will be estimated using an electrical conductivity meter and a portable spectrophotometer.

Procedures for borehole water sampling are below.

- Collect return water in a decontaminated container.
- Measure indicator parameters (temperature, pH, and electrical conductivity) as soon as possible so that temperature does not significantly increase.
- Collect sample for spectrophotometer measurement. When water is turbid, the sample for spectrophotometer measurement can be set aside to allow solids to settle. The groundwater sample for spectrophotometer measurement will be collected from the clearest portion of the settled water.
- If the sample concentration is greater than the spectrophotometer range, the sample will be diluted with laboratory grade de-ionized water until the sulfate concentration is in the measurable range. Record the dilution factor in the field notebook.
- Record the indicator parameter measurements and field-measured sulfate concentrations in the field notebook along with the name of the boring, the depth of the casing at the time of sample collection, and the date and time of the measurements.

Unfiltered water samples for laboratory confirmation field analyses will be collected periodically if sufficient water is available. The labeling and handling of confirmatory samples will follow those for unfiltered samples of existing wells (Sections 4.2.1.3 and 4.2.3) except that sample depth will be identified in the sample ID.

4.3.5 Well Construction

Well construction materials will be determined by the the site geologist in consultation with the HGC Project Manager and the driller. Materials will be determined according to the purpose of the well, site geologic conditions, and the quality of water samples collected during drilling. As a general rule, well casings for wells deeper than 500 feet will be 4-in or 5-in diameter, and will be constructed of low-carbon (= 0.3%) steel. Casing may be 4-in or 5-in in diameter, schedule 80 PVC for wells less than 500 feet deep. Annular materials including filter pack, bentonite pellet seals, and bentonite grout will be applied through a tremie pipe. From 0 to 20 feet below ground surface (bgs), grout will be a bentonite/cement mixture. To ensure that wells are properly constructed, the field technician will observe the following:

- Prior to well construction, estimate the amount of materials (e.g., well casing, packing material, and grout) needed to construct the well. During well construction, immediately notify the driller of a potential problem if the materials needed for well construction are significantly more or less than estimated.

- Prepare and use a well-construction diagram to monitor the progress of the well construction. Record the progress in the field notebook or on a well construction form.

- Periodically have the driller measure the depth of the filter pack and check to make sure that “bridging” of the packing material does not occur. A tightly fitting rubber surge block may be used in wetted portions of the well screen to compact the filter pack.

4.3.6 Well Completion

Surface completion of all wells include a watertight well plug or cap fitted to the well casing. The north side of the top of the casing will be notched to establish a permanent measurement datum. This datum will be surveyed to ± 0.01 ft by a licensed surveyor contracted by PDSI. A surface vault will be installed around the well casing and cemented in place. The well name and the ADWR well registry number will be stamped into the vault lid. The well registry number will also be written near the top of the well casing near the top with permanent black marker. After the well is completed, the DTW with be measured and recorded.

4.3.7 Well Development

Following well completion, the well will be developed using the following procedure:

1. The base of the well will be measured to determine whether any sediment has accumulated in the well.
2. The wetted portion of the well screen will be surged with a tightly fitting rubber surge block to dislodge any material finer than the screen slot size.
3. Air lifting or bailing will be used to remove sediments from the well.
4. The well will be pumped for at least three purge volumes to complete development.

4.3.8 Hydraulic Testing and Water Sampling

A 10- to 24-hour pumping test will be conducted at each new well to estimate the hydraulic conductivity of the formation. Prior to the pumping test, the HGC Project Manager will contact ADWR to determine the need for a groundwater withdrawal permit. The pumping test will be conducted using the guidelines provided below:

1. Obtain a DGP from ADEQ prior to conducting a pump test.

2. Prior to beginning the test, measure the static water level using a well sounder. Install a pressure transducer connected to a data logger. Be certain to install the transducer below the anticipated draw-down level. Measure the static water level with the pressure transducer and verify the transducer DTW measurement by using a sounder probe.

3. Select the pumping rate for the test so that it is similar to the well development pumping rate. Use a constant pumping rate throughout the test.

4. Measure DTW levels during the test with a pressure transducer/data logger assembly and periodically verify it with a sounder probe. At a minimum, take measurements according to the following schedule:

Time of Pump Test	Measurement Interval
0 to 15 minutes	1 minute
15 to 50 minutes	5 minutes
50 to 100 minutes	10 minutes
100 to 500 minutes	30 minutes
500 to 1000 minutes	60 minutes
> 1000 minutes	4 hours

5. Ensure that water discharged during the pumping test is directed down gradient of the well so that re-infiltration of the discharge water does not affect the test results.

6. Continue pumping long enough to collect sufficient draw-down data. Ideally, pumping will be continued for 1000 minutes or longer; although, the work location or other constraints may dictate a shorter pumping period.

7. After pumping is discontinued, measure the recovery of water levels in the well at frequency intervals similar to those used for the active pumping period. Continue measurements until the water level in the well has recovered to within 90 percent of its pre-pumping level.

After the end of each pumping test, a groundwater sample from the test well will be collected just prior to pump shutdown following the sample collection and handling procedures given in Sections 4.2. Pumping test results will be interpreted using analytical software such as the Well Hydraulics Interpretation Program (HGC, 1987) or AQTESOLV (Hydro Solve, Inc., 2000).

4.4 Investigation-Derived Waste Management

Investigation-derived wastes are expected to be purge water, drill cuttings, any drilling fluids, and development water. Prior to initiation of field activities, the HGC Project Manager will contact ADEQ to determine the need for a DGP for the release of purge water. DGP is expected to be needed for the release of development water. Cuttings and drilling fluids will be collected in tanks or rolloff containers and transported to PDSM for disposal according to methods approved by the PDSI Project Manger. This may include spreading cuttings in a thin layer over the ground.

4.5 Field Equipment and Consumables

4.5.1 Field Equipment Maintenance and Calibration

The field technician will be responsible for properly maintaining and calibrating all field equipment. Operation, calibration, and maintenance procedures for all equipment will be kept accessible when equipment is being used, calibrated, or serviced. Measurement equipment will be calibrated when it is first used and recalibrated periodically based on the recommendations in the instrument's operations manual. Maintenance practices also will follow the manufacturers' recommendations. All calibration and maintenance will be recorded on a maintenance record that is readily available for reference in the field.

Precautionary measures will be taken to avoid equipment problems. Some precautionary measures are listed below.

- Keep spare parts such as batteries and probes on hand.
- Store equipment in a cool, clean, dry place when not in use.
- Clean equipment after each use.
- Keep sensitive parts covered and protected from potential hazards.
- Inspect equipment for potential problems prior to use.
- Keep battery packs charged.

Should a piece of equipment become inoperable, it will be removed from service and tagged to indicate that repair, recalibration, or replacement is needed. The HGC QA Manager will be notified when equipment needs to be repaired or replaced so that prompt service can be performed or substitute equipment can be obtained. Instrument problems encountered during the field program will be recorded and, if possible, resolved in the field.

4.5.2 Electrical Conductivity, Temperature, and pH Measuring Equipment

A multi-probe meter with automatic temperature correction of electrical conductivity measurements will be used to measure indicator parameters. The instrument will be properly stored and calibrated each day that it is in use. The instrument probes will be triple-rinsed with deionized water and stored according to the manufacturer's specifications after use. The electrical conductivity probe will be calibrated before each sampling event using a commercial standard. Because electrical conductivity measurements may be correlated with, and used for, sulfate ion estimation, electrical conductivity measurements must be accurate and temperature corrected. The pH probe will be calibrated with two buffers that have pH values that bracket the anticipated pH values for the samples to be tested. Because the groundwater is neutral to alkaline, pH 7 and pH 10 buffers will be used. The calibration will be checked at least once every 4 hours thereafter, and the probe will be recalibrated, if necessary.

4.5.3 Water Level Measuring Equipment

Each electric sounder probe should be checked for accuracy at least once every 3 months. The accuracy will be checked by comparing the depth markings on the probe tape with the markings on a graduated steel tape. The sounder will also be checked after any incident that may alter the instrument's accuracy. If the difference between markings on the steel tape and on the sounder probe tape exceeds 0.05 ft per 100 ft, a correction factor will be determined and applied to DTW measurements. The sounder probe will be kept clean and functional. Portions of the cable that are submerged below fluid levels in wells will be properly cleaned, as described in the decontamination procedures outlined in Section 4.2.1.6.

4.5.4 Pressure Transducers and Data Loggers

The pressure transducer should be capable of measuring water levels with a sensitivity of 0.01 ft although the transducer accuracy may differ depending on pressure rating. The data logger may be internal to the pressure transducer or a separate instrument, but it must be programmable to collect pressure data at a minimum frequency consistent with the schedule given in Section 4.3.7. The accuracy of the pressure transducer will be periodically verified using the sounder probe. Data collected by the data logger will be downloaded daily. Maintenance for the pressure transducer/data logger assembly will follow the guidelines of the operations manual. The assembly will be stored in a clean, secure location when not in use.

4.5.5 Flow Meters

Flow meters will be capable of measuring flow rates in the range needed for well development and hydraulic testing. The flow meters will have a sensitivity of approximately 5 percent of the measured flow rate. Maintenance and calibration of flow meters will follow the guidelines of the operations manual.

4.5.6 Spectrophotometer

The spectrophotometer used to measure sulfate concentrations in the field will be a multi-wavelength unit designed for field analysis. A Hach DR-2500 spectrophotometer, or equivalent, will be used. Depending on reagents, the DR-2500 has a range of 2 to 900 mg/L sulfate. Maintenance and calibration of the spectrophotometer will follow the guidelines noted in the operations manual. The unit will be stored in a clean, secure location when not in use.

4.5.7 Consumables

The field technician, under the direction of the HGC QA Manager, has the responsibility for performing daily checks of consumables and for ensuring that there is adequate supply. Consumables include the following:

- Groundwater sampling containers prepared with preservatives.
- Sample identification labels and packing supplies.
- Coolers and ice for sample storage and transport.
- Disposable gloves for groundwater sampling.
- Markers and/or ink pens for sample labeling and for recording field activities.
- Detergent and water for decontamination.
- Laboratory grade de-ioned water for QC samples.

4.6 Field Documentation and Reporting

Field notes will be maintained for all sampling, drilling, well construction, well development, and pump test activities. The field logbook will be a bound, water resistant notebook with consecutively numbered pages. Documentation in the field logbook will be sufficient to reconstruct a field activity, including any corrective actions taken, without relying on memories from field team members. At a minimum, the information specified in Procedure DH-A of PDSI (2006) will be recorded in the field logbook (Appendix A). Deviations from the ACP or this QAPP also will be noted in the logbook. Field logbooks will be clearly identified on the cover with the project name and each page of the logbook should note the date that the entry was made. Entries will be made in blue or black ink. Incorrect entries will be crossed out with a single stroke and the change will be initialed and dated by the person making it. Manually recorded data will be transferred to an electronic format after field activities are concluded. Specialized information for some tasks may be recorded on field forms developed for that data type (e.g., groundwater sampling forms, geologic logs, well construction logs). When combined with the field logbook, these comprise the field record for the ACP.

At the end of each day, the carbon copy of the pages of the day's entries in the field logbook will be removed, or the pages will be photocopied, and stored in a secure area. Field forms and any other field checklists also will be photocopied and stored at the end of each day. This practice will protect against lost data should the logbook or forms be lost or destroyed. Data measured by field instruments and recorded in digital storage devices will be downloaded daily for processing. At least once a week, all data that was collected in the field, including field notes, field forms, checklists, and electronic data, will be presented to the HGC QA Manager for review and verification.

4.7 Field Corrective Action Procedures

Corrective action procedures will be taken for all field nonconformances. Nonconformances are defined as events or measurements that are either unexpected or do not meet established acceptance criteria and that might affect data quality if uncorrected. Examples of nonconformances include:

- Incorrect use of field equipment.
- Field instrument failure.
- Improper sample collection, preservation, and shipment procedures.
- Incomplete field documentation, including COC records.
- Incorrect decontamination procedures.
- Incorrect collection of QC samples.

The appropriate corrective action will depend on the nonconformance. In cases where immediate and complete corrective action can be implemented by field personnel, corrective actions should be completely described in the field logbook. If a nonconformance can not be completely and immediately corrected in the field, the individual involved with the field activity will immediately notify the HGC QA Manager and corrective actions will be taken as described in Section 6.5.

5. ANALYTICAL LABORATORY PROCEDURES

Upon receipt of samples from HGC field activities, the analytical laboratory will be responsible for sample handling, analysis, and reporting. Analytical laboratory procedures must be conducted in a consistent, accurate, and quality controlled manner so that the data generated from field activities is useful for achieving the purposes of the Work Plan. This section discusses the following items related to QA of analytical laboratory procedures:

- Licensure
- Sample receipt and handling
- Analytical methods
- Laboratory QC samples
- Laboratory equipment
- Reporting
- Corrective action

PDSI currently uses ACZ Laboratories, Inc. of Steamboat Springs, Colorado (ACZ) for analysis of samples. For consistency, samples collected by HGC will be analyzed by ACZ; however, alternative laboratories may be used at the discretion of the HGC Project Manager. Therefore, the analytical laboratory requirements are discussed generically.

5.1 Licensure

The designated analytical laboratory and any laboratories to which sample analyses will be subcontracted shall be licensed by Arizona Department of Health Services (ADHS) to perform each analysis requested, unless ADHS licensure is not provided or required for that particular method. If the status of the laboratory's license changes, or if laboratory performance is unsatisfactory, an alternate licensed analytical laboratory may be selected to perform the analyses. A laboratory performing analyses will notify the HGC Project Manager for approval prior to subcontracting analyses to another licensed laboratory. Documentation verifying the subcontracted laboratory’s ADHS license must be received by the HGC Project Manager prior to performance of the analytical services.

5.2 Sample Receipt and Handling

When the samples arrive at the laboratory, the laboratory will check samples for label identifications and complete, accurate COC documentation. The sample condition will be checked and recorded on the COC. Any discrepancies between the COC documentation and sample labels, any inaccurate or incomplete sample preservation, or any problem encountered that may compromise the sample integrity must be noted and communicated to the person submitting the samples and to the PDSI or HGC QA Managers.

A unique laboratory ID number will be assigned to each sample. This number will be cross-referenced to the sample field ID to avoid the possibility of mislabeling. Analytical reports will contain both laboratory ID numbers and field IDs for sample results. Access to the sample control area will be restricted to prevent unauthorized contact with samples, extracts, or documentation. All samples and extracts will be maintained by the laboratory until at least 30 days following the release of the final report. A detailed description of the laboratory sample receiving, custody, login, and tracking procedures will be contained in the laboratory's QA plan and/or SOP.

Samples may be shipped from one laboratory to another for analysis. Laboratories will package and transport samples as described in Section 4.2.3. The temperature inside the cooler will be checked and documented on the COC by the receiving laboratory upon receipt of the samples. Samples shall then be placed immediately on ice or in a refrigerator at 4 °C ± 2° at the receiving laboratory.

5.3 Analytical Methods

Samples collected as part of the ACP will be analyzed for the following major element ions and parameters: calcium, magnesium, sodium, potassium, sulfate, chloride, fluoride, nitrate-nitrite, silica, hardness, total dissolved solids, alkalinity, and pH. Water samples will be analyzed using the methods specified in Table 2. If analyses by alternative methods are deemed necessary or more appropriate by the Laboratory Project Manager, they will first be approved by the HGC QA Manager and by ADEQ. The following documents can serve as a guide in selecting alternative methods.

- *Analytical Methodologies Designed for Testing Conducted Under the Clean Water Act*, CFR, Title 40, Part 136.

- *National Primary Drinking Water Regulations Analytical Methodologies*, cited in the Federal Register under the National Primary Drinking Water Regulations. These may be used to evaluate groundwater concentrations as they pertain to human receptors of drinking water.

- *Standard Methods for the Examination of Water and Wastewater* American Public Health Association, 1995). These are EPA-approved methods for analysis of inorganic compounds and can be used to evaluate surface water or groundwater samples.

The laboratory performing sample analysis should use the most efficient and cost-effective approach to achieve the accuracy and precision requirements of this QAPP. Target method detection limits (MDLs) are given in Table 2 of PDSI (2005a) (Appendix A). If sample dilution is necessary due to a relatively high concentration of an individual compound or if there is interference, the MDLs and other DQIs may not be achieved for every analyte. Similarly, matrix interferences may cause surrogate and analyte recoveries to fall outside of the required percent recoveries listed in the laboratory's SOPs. The laboratory will document all analyte and matrix interferences in all laboratory reports and evaluate the possible matrix effects using ADEQ policy 0154.000 *Addressing Spike and Surrogate Recovery as They Relate to Matrix Effects in Water, Air, Sludge and Soil Matrices* (ADEQ, 1998a). Analytical data will be qualified by the ADEQ Data Qualifiers (Appendix D).

If laboratory results are outside any of the method acceptance criteria or the acceptance criteria listed in the laboratory's SOPs, the laboratory will document the deviations in the case narrative. If deviations are the result of laboratory procedures, the laboratory will take the appropriate corrective action, such as re-analysis of samples or a detailed review of instrument output.

5.4 Laboratory Quality Control

QC of laboratory operations consists of documentation of all actions taken by personnel regarding issues such as equipment maintenance, reagent purity, standards traceability, waste disposal, and corrective action systems. These policies should be specified in each laboratory's QA manual.

The designated laboratory should be familiar with and follow ADEQ Policies related to QA/QC of laboratory results such as Policy 0154.000, *Addressing Spike and Surrogate Recovery as They Relate to Matrix Effects* (ADEQ, 1998a), and Policy 0155.000, *Analytical Methods Having Provisions for a One-point Calibration and Continuing Calibration Verification Constraints* (ADEQ, 1998b). Laboratory QA/QC procedures will be in accordance with method requirements and as described in each laboratory's QA plan and/or SOP. The laboratories' QA plan and SOP will be provided by the laboratory if requested.

Laboratory QC also includes the routine measurements taken within the laboratory to verify the integrity of analysis, data processing, and record maintenance. The laboratory will analyze internal QC samples as required by the analytical methods to ensure analytical precision, accuracy, and representativeness. Field samples and laboratory QC samples will be analyzed to a minimum reporting limit as specified by the method, or in-house requirements, whichever is stricter. The precision acceptance criteria for those analytes (RPD; Section 3.3.1) and accuracy (percent recovery; Section 3.3.3) also will be based on the stricter of in-house laboratory established limits or method requirements.

Typical laboratory QC samples include blank spikes, laboratory control samples (LCSs), method blanks, surrogates, matrix spike/matrix spike duplicate (MS/MSD) analysis, internal (reference) standards, and duplicate samples. These samples are described below:

$ The blank spike is a sample of water demonstrated to be free of matrix interference and has non-detectable concentrations of the target analyte to which a known amount of the analyte is added. ADEQ Policy 0154.000 (ADEQ, 1998a) requires a blank spike and a blank spike duplicate to be analyzed to demonstrate both precision and accuracy when the MSs are unacceptable because of matrix interference. The percent recovery of the blank spike and blank spike duplicate pair is used to evaluate the accuracy and recovery of each preparation and analytical batch, and may be used to establish statistical control of the analysis.

$ The LCS is a standard or sample that is derived from a different source (i.e., different vendor or lot number) than the standards that are used to calibrate the instrument. It is used as a cross-check to verify the accuracy of the calibration and typically must be analyzed once for every instrumental calibration (ADEQ Policy 0154.000 (ADEQ, 1998a)).

$ A method blank is a sample of water that has non-detectable concentrations of the target analytes. For most methods, at least one method blank is prepared for every batch of 20 samples. The method blank is taken through the entire analytical process as part of the sample batch to demonstrate that contamination did not occur during the testing.

$ A surrogate is a compound that is expected to perform similarly to the compounds being analyzed in the laboratory method. The surrogate is not normally found in the environment and can therefore be used to monitor the recovery efficiency of the analytical process.

$ The MS/MSD is used to demonstrate both the precision and accuracy of the test and the presence or absence of matrix interferences. The MS/MSD is prepared by spiking a sample with a known concentration of the target compounds and taking it through the entire analytical process as part of the sample batch.

$ Internal standards are reference samples that contain a known concentration of the analyte. The internal standards are used to test the accuracy of the instruments and analytical methods.

$ Duplicate samples are taken from the same aliquot as the environmental sample being tested. The duplicate sample is analyzed within the same batch and in exactly the same manner as the original aliquot. Duplicate samples evaluate the analytical precision at the concentration of the environmental sample.

5.5 Laboratory Equipment

All laboratory equipment will be maintained and calibrated as described in the laboratory's QA plan and SOPs. Any equipment problems that may affect data quality will be documented in the case narrative. Regular calibration of laboratory instruments is essential to ensure that the analytical system is operating correctly and functioning at the proper sensitivity to meet established detection limits. Each instrument will be calibrated with standard solutions appropriate for the type of instrument and the linear range established for the analytical method. Each analytical method contains requirements for the number and concentration of calibration standards, which are described in the laboratory's QA plan.

ADHS has established criteria for instrument calibration and the quantification of analytes as part of the Laboratory Licensure program. All analyses must be consistent with these requirements, and quantification of analytes must be consistent with the reporting requirements of ADHS (the lowest calibration concentration will be at or below the reporting level). Each calibration will then be verified through the use of statistical tests (e.g., a Pearson's Correlation Coefficient or relative standard deviation calculations), initial and continuing calibration verification standards and blanks, and LCSs prior to the sample results being approved.

5.6 Laboratory Data and Reporting

Laboratories will be expected to provide preliminary analytical data reports within 15 working days of receiving the samples and final reports shortly thereafter. Laboratory data reports will be sent to the HGC QA Manager in hard and electronic formats from the designated laboratory. Analytical laboratories will be expected to store the original hard copy and electronic reports for 5 years. The laboratories will be expected to notify HGC prior to destruction of records. The requirements for the content and the handling of hard and electronic reports are given below.

5.6.1 Hardcopy Data

Analytical data will contain the necessary sample results and QC data to evaluate the DQOs defined for this project (Section 3). Omissions or insufficient levels of detail will be corrected at the laboratory's expense. The laboratory reports will be consistent with EPA Level III documentation (Section 3.2) and include, at a minimum, the following:

- Case narrative (including a complete description of any analytical difficulties or QA/QC deficiencies encountered during sample analysis), sample number cross-reference, COC documentation, and method references.
- Analytical results with cross-reference to analytical batch.
- Surrogate recoveries (as applicable).
- Blank results.

- LCS recoveries.
- Sample spike recoveries.
- Duplicate sample results or duplicate spike recoveries.
- Outliers qualified according to ADEQ Data Qualifiers (Appendix D).

The laboratory report, as defined above, will be submitted to the QA Manager for use in the data verification/validation process. If requested, the laboratory will make supporting documentation consistent with EPA Level IV (Section 3.2.). The following QC issues may trigger the need for the submission of Level IV documentation:

- Continued quality issues detected through the data verification/validation process
- Unexpected or unexplained sample results

5.6.2 Electronic Data

An electronic data report will be submitted by the laboratory in a format that is compatible with HGC's database. HGC's QA Manager will verify that the report is in an acceptable format and that all elements needed are present. HGC's QA Manager will enter the analytical data into a temporary database for verification before it is uploaded to the permanent database or used in any reports or calculations.

5.7 Laboratory Corrective Action Procedures

The internal laboratory corrective action procedures and a description of out-of-control situations requiring corrective action will be contained in the laboratory QA plan. At a minimum, corrective action will be implemented when control chart warnings, control limits, sample holding times are exceeded, or if the method QC requirements are not met. Out-of-control situations that cannot be resolved within 2 days of identification will be reported to HGC. In addition, a corrective action report, signed by the Laboratory Project Manager and the Laboratory QA Manager, will be provided for the project files. HGC's Project Manager can request the re-analysis of any or all of the data acquired since the system was last in control.

6. DATA MANAGEMENT

Reports and documentation from activities conducted under the direction of HGC will be submitted to the HGC QA Manager. The QA Manager has the responsibility of processing these data and evaluating and maintaining the data quality. The sequence for processing field and analytical data is shown in Figure 2. This process consists of the following items:

- Data compilation
- Data entry into temporary database
- Data review and verification
- Data entry into permanent database
- Reporting
- Corrective Action

6.1 Data Compilation and Entry to Temporary Database

6.1.1 Field Data

The field logbook and other field forms generated from field activities directed by HGC will be submitted to the HGC QA Manager at least once per week for review. The HGC QA Manager will review the field logbook and field forms using the checklist provided in Table 4. This review will consist of checking for incomplete documentation and anomalous data entries.

The HGC QA Manager will immediately contact the person submitting the field forms to verify or correct missing or anomalous entries. When the problems are resolved or if no problems are found, the information will be entered into a temporary data base for the sampling event.

6.1.2 Laboratory Data

Hardcopy and electronic laboratory reports will be reviewed for completeness (Table 4). Electronic data deliverables will be entered into a temporary database for review by the QA Manager. Hardcopy laboratory reports will be stored in HGC's files.

6.2 Data Review, Verification, and Validation

Data verification is "the process of evaluating the completeness, correctness, and conformance/compliance of a specific data set against the method, procedural, or contractual requirements" (EPA 2002b). Data validation is "an analyte- and sample-specific process that extends the evaluation of data beyond method, procedural, or contractual compliance (i.e., data verification) to determine the analytical quality of a specific data set" (EPA 2002b).

Data validation is not expected for this project. Data validation would require a thorough review of all the field data and/or the analytical laboratory results to provide data documentation consistent with EPA Level IV requirements. This level of review will not be performed unless there are persistent concerns regarding the quality of field or laboratory data. If persistent concerns do arise and an EPA Level IV package is deemed necessary, 100% of the affected data will undergo data validation (Section 6.4).

During review and verification, project data will be stored in a temporary database accessible only by personnel authorized by the HGC Project Manager. Results of the data verification will be documented and summarized in a data verification report that is sent to the HGC Project Manager and placed in the HGC project files (Section 6.4). The HGC QA Manager also will prepare a draft report of the new data that have been entered and reviewed against original input data. Any comments or required revisions will be noted on the draft report. Once all data verification issues have been resolved, the verified data will be entered into the permanent database. Data collected under the direction of PDSI will be reviewed and verified according to the provisions of its quality assurance plan (PDSI, 2005a) (Appendix A). Once data has been verified by the PDSI QA Manager and entered into the PDSI database, the data can be transferred to HGC without re-verification by the HGC QA Manager.

6.2.1 Field Data

The HGC QA Manager will review and verify all field data to evaluate their completeness and check for data anomalies prior to entry into the permanent project database. Where appropriate, DQI's will be evaluated as described in Section 3.3. The data quality assessment checklist, provided in Table 4, will be completed as part of this review.

6.2.2 Laboratory Data

The HGC QA Manager will verify analytical data by reviewing it for compliance with the QA/QC specifications outlined in the analytical methods and Table 4 of this QAPP. After the data have been verified, the HGC QA Manager will determine whether the DQOs have been met. Data verification flags will be applied to those sample results that fall outside acceptance criteria specified in the analytical methods, the laboratory SOPs, and this QAPP and therefore did not meet the DQOs. Data verification flags to be used for this project are defined by the ADEQ Data Qualifiers (Appendix D). Data verification flags will indicate whether results are considered anomalous, estimated, or rejected. Only rejected data are considered unusable for decision-making purposes, however, other qualified data may require further verification. All corrective action to be taken by the laboratory should be completed as described in Section 5.7 and 6.5 prior to the final review of the data.

6.2.3 Final Data Assessment

All field and laboratory data will undergo a final data assessment (Table 4). This assessment involves checking data entered into the temporary database with the original data source and, where appropriate, comparing data against time series plots to check for data anomalies. The final assessment also will verify that all QA issues have been resolved and proper corrective actions have been taken.

6.3 Data Storage and Data Transfer

Data generated by PDSI will be shared with HGC so that a comprehensive database of all ACP activities can be maintained. Data will be exchanged only after being verified. To the degree possible, data transfer should be performed electronically to eliminate human transcription errors. When electronic data transfer is not possible, a staff member will manually input data to the database, and another staff member will proof these manually entered data to ensure that they are correct before they are uploaded and reported. Key data that cannot be verified will be brought to the attention of the appropriate QA Manager. All reported results are ultimately stored in the permanent project database along with original copies of field notes, monitoring forms, and laboratory reports being stored in PDSI or HGC project files.

6.4 Reporting

A data verification report will be prepared by the HGC QA Manager for each sampling event, or on another routine basis, as specified by the HGC Project Manager. The report will summarize data flags, document corrective actions, and evaluate the data quality against the DQO's. Each report also will include a summary of any significant QA/QC problems. If data quality problems necessitate data validation and reporting, the content and frequency of such reports will be identified in the verification report.

The HGC QA Manager will assemble a data package for each sampling event or field activity. Where applicable, the data package is to include the following:

- Field documentation of monitoring, sample collection, and handling records (Sections 4.2.3 and 4.6)
- Field equipment calibration and decontamination records (Sections 4.5.2 and 4.2.1.5)
- QC sample collection records (Section 4.2.1.4)
- COC forms (Section 4.2.3)
- Sample receipt records and shipping bills (Section 4.2.3)
- Laboratory analytical reports including laboratory QC summaries (Sections 5.6)
- Data Quality Assessment Checklist (Table 4)

6.5 Corrective Action

The QA Manager and Project Manager will promptly and thoroughly act to correct any nonconformance that is expected to compromise the quality of the project data. Rapid and effective corrective action minimizes the possibility of questionable data or documentation. All QA problems and corrective actions will be documented by the HGC QA Manager and explained to the HGC Project Manager in a brief memorandum. This documentation will provide a complete record of QA activities and also will help to identify long-term corrective actions that may be necessary. After the source of the error is determined and remedied, the HGC QA Manager will ensure that all suspect data are either deleted from the permanent database or re-collected.

Corrective action procedures will depend on the nonconformance. For a nonconformance that can be easily corrected, immediate corrective actions can be taken in the field or laboratory.

Often, the source of the problem is obvious and can be corrected at the time of observation. Nonconformances that have substantial impact on data quality will require the completion of a Corrective Action Request Form (Figure 3). This form may be filled out by any project individual who suspects that any aspect of data integrity is being compromised by a nonconformance. Each form is limited to a single nonconformance. Copies of the corrective action request form will be given to the HGC Project Manager and be placed in the project file. The HGC Project Manager and QA Manager will meet along with other staff as necessary to discuss the appropriate steps to resolve the problem. Issues that may be discussed include the following:

- Determination of when and how the problem developed
- Assignment of responsibility for problem investigation and documentation
- Determination of the corrective action to be implemented to eliminate the problem
- Development of a schedule for completion of the corrective action
- Assignment of responsibility for implementing the corrective action
- Documentation and verification that the corrective action has eliminated the problem

The HGC Project Manager can require field and/or laboratory activities to be limited, discontinued, or repeated until the corrective action is complete and the nonconformance eliminated. The HGC Project Manager should continue to monitor the status of corrective actions and periodically (as determined in the corrective action report) complete a corrective action status report. This report should briefly describe the problem, the individual who identified it, and list the personnel who are responsible for the determination and implementation of the corrective action. Completion dates for each phase of the corrective action procedure will also be listed in the status report, along with the date for the designated personnel to review and check the effectiveness of the solution. A follow-up date will also be listed to check that the problem has not reappeared. This follow-up will be conducted to ensure that the solution has adequately and permanently corrected the problem.

7. REFERENCES

ADEQ. 1998a. 0154.000. Addressing Spike and Surrogate Recovery as they relate to water, air, soil, and sludge matrices policy. October 23, 1998.

ADEQ. 1998b. 0155.000. Analytical Methods Having Provisions for a One-Point Calibration and Continuing Calibration Verification Constraints Policy. October 23, 1998.

ADEQ. 1999. Quality Management Plan. EQR00-01. October 1, 1999.

American Public Health Association. 1995. Standard Methods for the Examination of Water and Wastewater. 19th Edition.

EPA. 2001a. Requirements for Quality Assurance Plans for Environmental Data Operations. EPA QA/R-5. March, 2001.

EPA. 2001b. Laboratory Documentation Required for Data Evaluation. EPA R9QA/004.2. August 2001. (Appendix B).

EPA. Region IX QA Office, 2001. Laboratory Documentation Required for Data Evaluation. R9QA/004.2. August 2001.

EPA. 2002a. EPA Guidance for Quality Assurance Project Plans. EPA/240/R-02/009. December 2002.

EPA. 2002b. Guidance on Environmental Data Verification and Data Evaluation. EPA/240/R-02/004. November 2002.

EPA, 2004. EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review, Final. EPA 540-R-04-004. October 2004.

EPA. 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process. EPA QA/G-4. February 2006.

Hydro Geo Chem (HGC). 1987. WHIP Well Hydraulics Interpretation Program Version 3.2. Users Manual. February 1987.

Hydro Solve, Inc. 2000. AQTESOLVE for Windows User’s Guide. Reston, Virginia: Hydro Solve, Inc.

PDSI, 2005a. Quality Assurance/Quality Control Plan for Water Monitoring, Phelps Dodge Sierrita, Inc. June 2005.

PDSI, 2005b. Standard Operating Procedures – Water and Environmental Sample Collection Procedures. March 2005.

TABLES

TABLE E.1
Summary of EPA Analytical Levels

EPA Analytical Level	Type of Analysis	Accuracy	Sensitivity	Level of Documentation
Field Check Level 1	Temperature, pH, and specific conductivity measurement using portable instruments.	**Low;** provides general indication of contamination.	**Low to moderate;** at least sufficient to screen for general levels of ions. Instruments may not be sensitive to some chemicals.	**Low;** often digital readout of final result only or visual indication of concentration range (e.g., by change in color.)
Routine Screening Level II	Preliminary analyses of sulfate using in-field method.	**Moderate;** provides data typically as concentration ranges	**Moderate to high;** sufficient to document presence or absence of selected chemicals.	**Low;** often only the final quantitative results without supporting quality assurance data.
Level III	Analysis of major element ions using standard EPA procedures.	**High;** provides data of known bias and precision for an overall accuracy level that is useful for most applications.	**Moderate to high;** sufficient to document presence or absence of a wide range of chemicals.	**Low to moderate;** summary of quality assurance results is provided but is usually not adequate for an independent verification of results.
Program Specific Level IV	Standard analyses of major element ions using EPA procedures.	**High;** similar accuracy as Level III with a focus on confirmation of results.	**Moderate to high;** similar sensitivity as Level III but most standardized protocols focus on characterization of waste materials.	**Rigorous;** standardized data package of sample and quality assurance results is sufficient for independent verification of results.

The QC requirements may be specially defined for each level. For example:

-- Level I requirements may include running only a standard and a blank.
-- Level II requirements may include a blank and running multiple standards to determine the range.
-- Level III requirements would include the QA/QC required by the method.
-- Level IV requirements would include Level III requirements, plus any additional steps you would like the laboratory to take, such as CLP protocols.

TABLE E.2
Groundwater Sampling and Analysis Requirements

Analyte	Method	MDL (mg/L)	Container	Preservation	Holding Time	Filtered (F), Unfiltered (U)
Constituents for General Chemistry						
pH	EPA 150	N/A	500 mL plastic or glass	N/A	analyze immediately	U
Temperature (C^o)	Thermometric	N/A	500 mL plastic or glass	N/A	analyze immediately	U
Conductivity	Conductance	N/A	500 mL plastic or glass	N/A	analyze immediately	U
TDS	SM 2540C/160.1	10	250 mL HDPE	4º C	7 days	F
Total Alkalinity (as $CaCO_3$)	SM 2320B	2	500 mL HDPE	4º C	14 days	U
Chloride	EPA 300.0	1	250 mL HDPE	4º C	28 days	F
Fluoride	EPA 300.0	0.1	250 mL HDPE	4º C	28 days	F
Nitrate	EPA 300.0	0.02	250 mL HDPE	4º C	48 hours	F
Nitrite	EPA 300.0	0.02	250 mL HDPE	4º C	48 hours	F
Sulfate	EPA 300.0	10	250 mL HDPE	4º C	28 days	U, F
Calcium	EPA 200.7	0.2	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Magnesium	EPA 200.7	0.2	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Potassium	EPA 200.7	0.3	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Sodium	EPA 200.7	0.3	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Constituents for Water Treatment Evaluation						
Ammonia	EPA 350.1	0.05	500 mL HDPE	4º C; H_2SO_4 to pH < 2	28 days	F
Barium	EPA 200.8	0.0001	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Strontium	EPA 200.7	0.01	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Ferrous Iron	EPA 3500	0.01	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Iron (total)	EPA 200.7	0.02	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	U
Manganese	EPA 200.7	0.005	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Boron	EPA 2007	0.01	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Aluminum	EPA 200.7	0.03	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Phosphate	EPA 365.1	0.01	250 mL HDPE	4º C	48 days	F
Sulfide	EPA 376.2	0.02	125 mL HDPE	4º C; Zn acetate; pH>9 NaOH	7 days	F
Silica (total)	EPA 200.7	0.2	125 mL HDPE	4º C	28 days	U
Silica (soluble)	EPA 200.7	0.2	125 mL HDPE	4º C	28 days	F
Selenium	EPA 200.7	0.004	250 mL HDPE	4º C; HNO_3 to pH < 2	6 months	F
Total organic carbon	EPA 415.1	1	250 mL HDPE	4º C; HCl or H_2SO_4 to pH < 2	28 days	U
Chemical Oxygen Demand	EPA 410.4	10	250 mL HDPE	4º C; H_2SO_4 to pH < 2	28 days	F
Total hardness	SM 2340B	Calculation	N/A	N/A	N/A	F
Silt density index (SDI)	ASTM D4189-82	N/A	500 mL HDPE	N/A	N/A	U
Bacteria (count/ml)	EPA 9222D	1 cfu / 100mL	100 mL HDPE (Sterile)	4º C; H_2SO_4 to pH < 2	24 hrs.	U
Turbidity	EPA 180	N/A	500 mL HDPE	N/A	48 hrs.	U

TABLE E.3
Sample Shipment Checklist

Sample Handling Checklist	**Yes**	**No**	**Not Applicable**
Sample bottles are free of defects and in their original packaging:			
Field Duplicate samples named with unrecognizable IDs and actual locations recorded in field logbook			
Samples labeled with:			
Sample Name/Date (e.g., LE-1-041604)			
Analyses Required			
Sample Matrix			
Filtered or Unfiltered			
Sampler's Initials			
Preservative			
COC filled out with:			
Project Name, required signatures, dates, and times			
Analytical Suite required			
Date and time of sampling, sample IDs, sample matrix			
Number of containers submitted			
QA Sample IDs, matrices, date and time of sampling			
Samples stored on sufficient ice to remain at 4ºC until arrival at lab			
Sample package will not leak during shipment			
Sign COC to relinquish sample custody, remove pink slip, and enclose original in sample shipment			
Samples shipped withing 48 hours of collection			

Notes:
COC = Chain of Custody
QA = Quality Assurance
ID = Identification

TABLE E.4
Data Quality Assessment Checklist

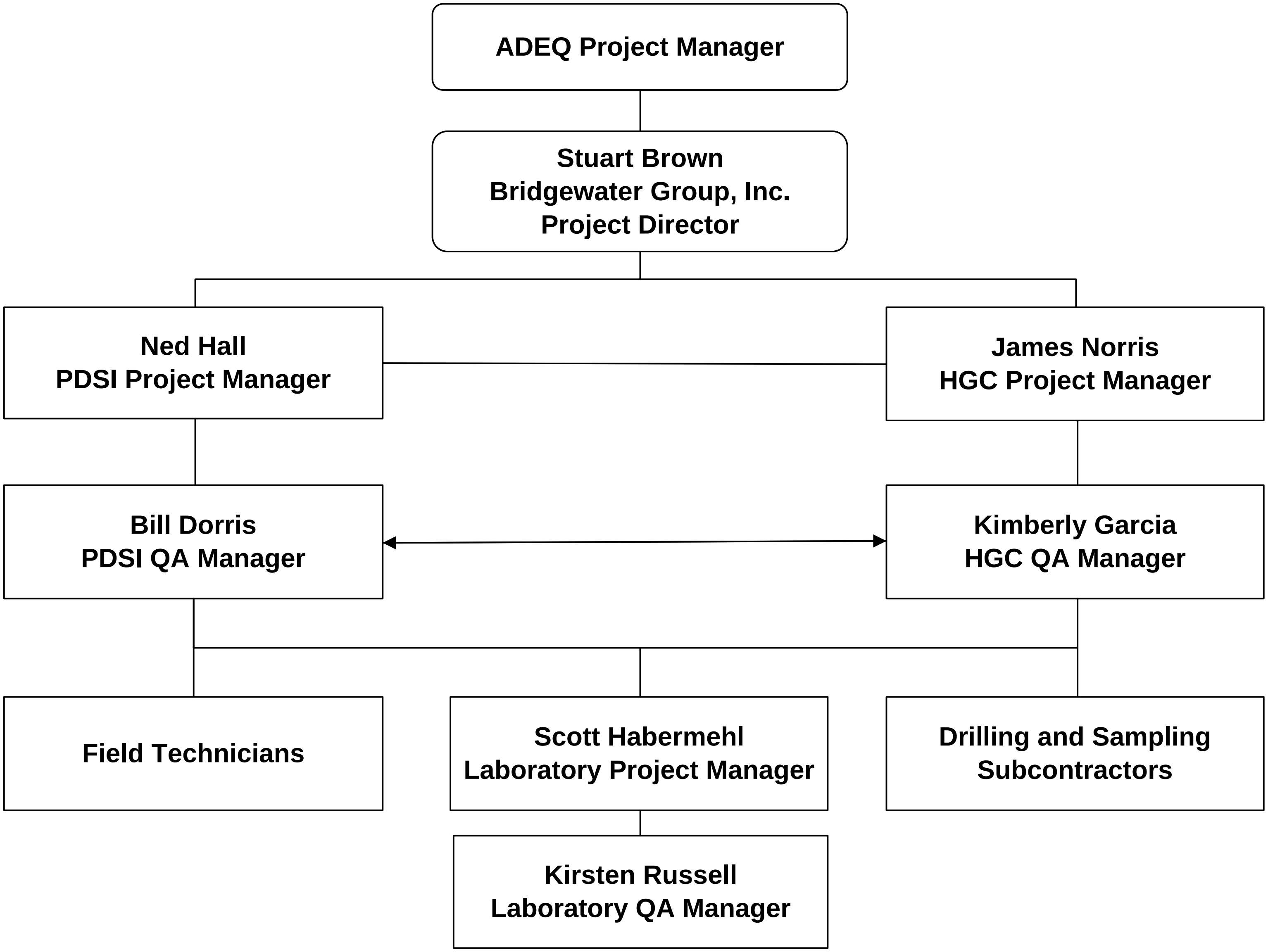
	Yes	No	Not Applicable
Data Compilation			
Field Data			
Field Logbook Entries Current			
Field Sampling Forms Completed			
Borehole and Lithologic Logging Forms Completed			
Well Construction Diagrams Completed			
Hydraulic Testing Forms Completed			
Anomalous Data Entries Resolved			
Chain of Custody Forms Completed			
Correct Analyses Requested			
Laboratory Data			
Hard Copy Reports Received			
Electronic Reports Received			
Case Narrative and QC Summaries Included in Report			

Data Review and Verification			
Field Data **Groundwater Sampling**			
Monitoring Conducted at Correct Locations			
Measuring Point for Water Levels is Consistent			
Field Equipment Calibration Requirements Met			
Field Equipment Decontaminated Before Uses			
Purge Parameters Stabilized Prior to Sample Collection			
QC Samples Taken at Appropriate Frequency			
Drilling and Well Construction			
Lithologic Logging per ASTM Standards			
Reconnaisance Borehole Sampling Completed			
Portable Spectrophotometer Samples			
Laboratory Samples			
Wells Properly Constructed			
Hydrualic Testing Properly Conducted			
Laboratory data			
All Required Analyses Performed			
Holding Times and Temperatures Met			
Laboratory QC Samples Within Acceptable Limits			
Field QC Samples Within Acceptable Limits			
MDLs < Target MDLs			

Final Data Quality Assessment Checklist:	Yes	No	Not Applicable
Data Entry Checked Against Original			
Time-Series of Analytical and Field Data Checked for Anomalies			
QA Issues Resolved and Documented			
Corrective Action Taken and Documented			

Notes:
QC = Quality Control
QA = Quality Assurance
MDLs = Method Detection Limits
PQLs = Practical Quantification Limits
RAOs = Mitigation Order Objectives

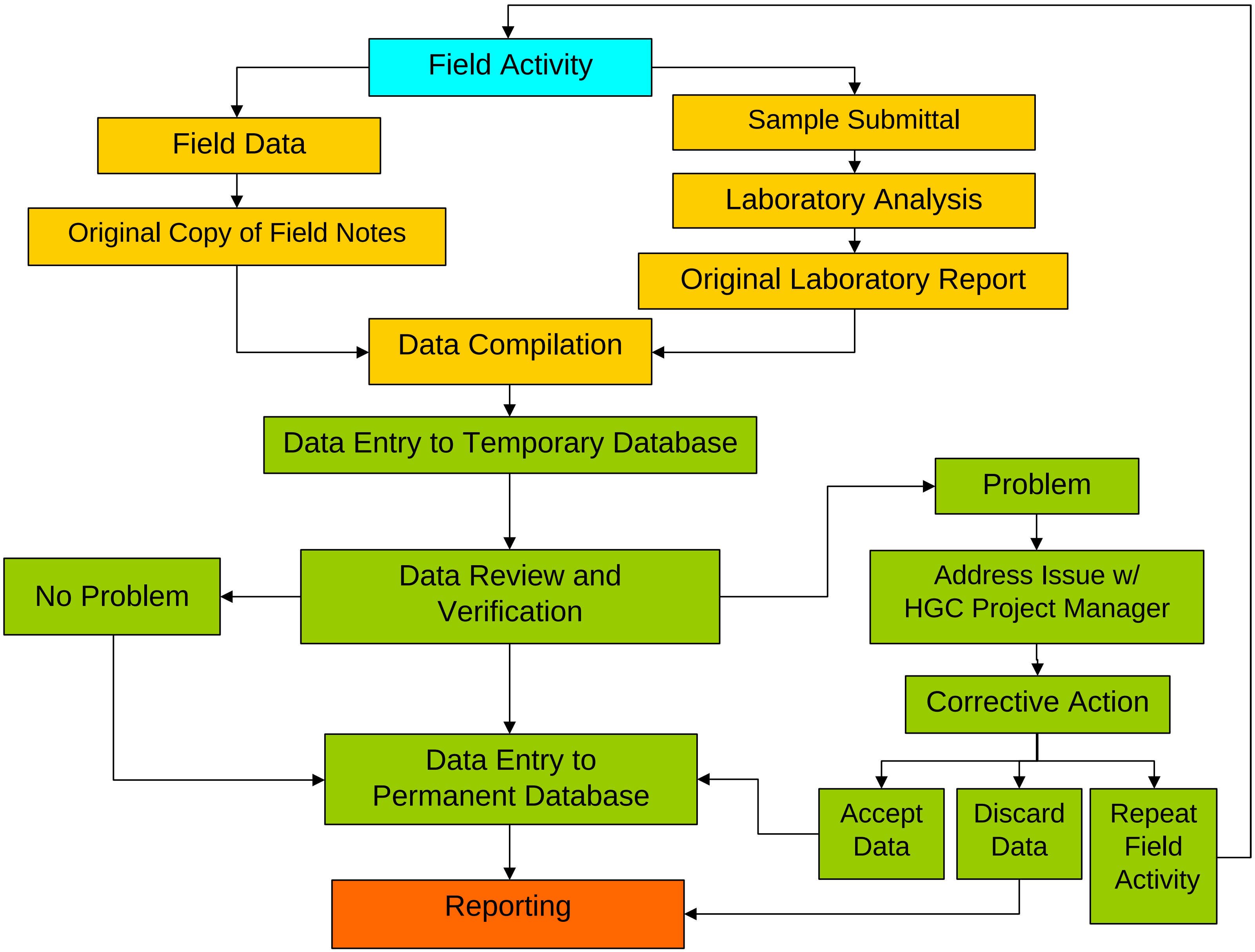
FIGURES



HYDRO
GEO
CHEM, INC.

ORGANIZATIONAL CHART

APPROVED	DATE	FIGURE
NWH	8/1/06	**E.1**



HYDRO
GEO
CHEM, INC.

FIELD AND ANALYTICAL DATA PROCESSING SEQUENCE

APPROVED	DATE	FIGURE
NWH	7/6/06	**E.2**

FIGURE E.3
CORRECTIVE ACTION FORM

Service or Activity:____Date:___________
____

Contractor or Support Organization:____
Date Discovered:__________ Location:______________
Notation in Logbook Vol. No. _____ Page_____ Date_______

Nature of Alteration: Description of Alteration and Apparent Cause:
( )Procedural Deficiency ____
( )Data Deficiency ____
( )Instrumentation Def. ____
( )Other ____

Recommended Disposition: Justification for Recommended Disposition:
( )Accept Deviation ____
( )Modify Plan/Procedure ____
( )Repeat Service/Activity ____
( )Terminate, Recommended Corrective Action:__________________________________
( )Conditional Acceptance*____
*State Conditions____
____
Originator:____________ Organization:______________ Phone: ______________
Corrective Action Verification:
( ) Verified (note any appropriate conditions):_________________________________
____
____
( ) Cannot verify (note reasons for lack of verification):___________________________
____
____
Project QA:_________________ Date:_____________
(Use space below for comments or extensions to the above topics.)

APPENDIX A

PHELPS DODGE SEIRRITA
QUALITY ASSURANCE/QUALITY CONTROL PLAN
AND FIELD SAMPLING PLAN

QUALITY ASSURANCE/ QUALITY CONTROL PLAN

FOR

WATER MONITORING

phelps dodge
Sierrita Inc.
Green Valley, Arizona

June, 2005 (Original)

TABLES

CHECKLISTS

SECTION 1

INTRODUCTION

This Quality Assurance Quality Control Plan (QAQCP) for Water Monitoring establishes the protocols necessary to achieve data quality objectives (DQOs) defined to insure the highest quality of data is obtained through recorded field and laboratory measurements. Different monitoring programs will identify criteria and frequency for monitoring Sierrita's mine and surrounding properties groundwater and surface water systems. The data collected will be used to establish background data for current and historical local conditions.

This document includes discussions of: 1) project management and responsibilities, purpose of sample collection, matrix to be sampled, analytes or compounds to be measured, applicable technical, regulatory, or program action criteria, personnel qualification requirements for collecting samples 2) sampling and analytical procedures holding times, number and type of quality assurance quality control samples to be taken 3) Identification of ADHS/EPA certified laboratories to analyze collected samples, provisions for proficiency demonstration by laboratory for contract awarding, required laboratory quality control (QC) results to be reported 4) guidelines for data verification and reporting, data acceptance criteria, quality control checks, performance and systems audits, corrective actions, and quality assurance reporting.

SECTION 2
PROJECT MANAGEMENT AND RESPONSIBILITIES

All personnel involved in the investigation and in the generation of data are implicitly a part of the overall project and quality assurance program. Certain individuals have specifically delegated responsibilities, as described below. Personnel assigned to each position will be identified in each specific project plan.

2.1 PROJECT MANAGER

The Project Manager is responsible for fiscal oversight, direction and scheduling of the project work plan, and ensuring that all work is conducted in accordance with established standard operating procedures. In cooperation with the Quality Assurance Manager, the Project Manager will evaluate project objectives and based on audit findings, QC checks, and data review, determine the necessary corrective actions if needed

2.2 QUALITY ASSURANCE MANAGER

The Quality Assurance Manager is responsible for the evaluation and update of this Quality Assurance Quality Control Plan. The Quality Assurance Manager will evaluate the need for corrective actions and make recommendations to the Project Manager. The Quality Assurance Manager will be responsible for the review and update of the Quality Assurance Quality Control Plan annually. The Quality Assurance Manager is responsible for the collection of water samples according to established schedules and will ensure that work is done according to specified procedures.

2.3 SAMPLING CREW

Sampling Crew personnel are responsible for following procedures for sample collection, including complete and accurate documentation. These personnel, as well as all staff members involved with the project, are responsible for ensuring the quality of their own work. Personal qualification requirements for these individuals include but not limited to, a thorough understanding of standard operating procedures for water sampling, decontamination, and field documentation.

SECTION 3

QUALITY ASSURANCE QUALITY CONTROL OBJECTIVES FOR MEASUREMENT

Quality assurance (QA) is defined as the process used to ensure that data, which provides the basis for decision making, are technically sound, statistically valid, and properly documented. Quality control (QC) procedures are the tools utilized to assure the monitoring processes are adequate and up to specified standards. This section discusses the objectives for the measurement of data in terms of precision, accuracy, representativeness, comparability, and completeness (PARCC). These objectives are based on the intended use of the data, available laboratory procedures, and available resources. Procedures on collecting quality control samples to evaluate field activities are described in greater detail in Section 6.

3.1 OVERALL QUALITY ASSURANCE OBJECTIVE

The overall quality assurance objective is to validate the integrity of the data for its future use. Specific data quality requirements such as; target detection limits, criteria for accuracy and precision, sample representativeness, data comparability and data completeness are identified in this document.

Data Quality Objectives (DQOs) are quantitative and qualitative measures that specify the required standards for the collected data. The DQOs purpose is to define an acceptable level of uncertainty in the evaluation of collected data.

The data collected during the course of each specific project will be used to determine; constituents that are present (qualitative), the types or classes of constituents that are present, the quantities or concentrations of constituents that are present (quantitative), the distribution of constituents with respect to potential sources, the trends in concentrations and plume movements, and the hydrologic and geochemical conditions, which control water movement.

3.2 PROJECT INVESTIGATION QUALITY OBJECTIVE

The project investigation quality objective is to maximize confidence in the data in terms of PARCC.

If there are only two analytical points used for comparison (such as; original sample point vs. blind duplicates), precision will be calculated as relative percent difference (RPD). Precision will be calculated as a computed outlier statistic (T_n) if there are more than two analytical points. The RPD is calculated as the difference between two results, relative to their arithmetic mean, and expressed as a percent:

$$\text{RPD} = 100\% * \left[\frac{\text{X1 - X2}}{\left(\frac{\text{X1+X2}}{2}\right)}\right]$$

The outlier statistic (T_n) is calculated by completing the following steps:

A. Order data from highest to lowest.

B. If the data resembles a lognormal distribution, compute logarithm values of the data points.

C. Calculate the mean and standard deviation.

The standard deviation of a series of data is calculated as follows;

$where: \bar{x}$ = The Arithmetic Mean of the Measurements(x);

$where: n$ = The Number of Measurements;

$where:$ s = Standard Deviation;

$$s = \sqrt{\Sigma(x - \bar{x})^2 / n - 1}$$

The T_n is then calculated as the largest value minus the mean, divided by the standard deviation (USEPA 1989):

$where: \bar{x}$ = The Arithmetic Mean of the Measurements(x);

$where: X_n$ = The Largest or Smallest Value of all Measurements;

$where:$ s = Standard Deviation;

$$T_n = \frac{(X_n - \bar{x})}{s}$$

T_n is then compared to the tabulated values in table 3, based on the sample size n. If T_n is greater or less than the tabulated value, then the measurement is identified as an outlier (USEPA 1989). The Environmental Data Management Systems (EDMS) database conducts an automatic outlier statistical analysis using this method.

Submission of field blanks will provide a check with respect to data accuracy. Evaluating the results of blanks to monitor contaminants, which may be introduced, can assess accuracy during sampling, preservation, handling, shipping, and analysis. The DQO for field blanks is to have no quantifiable amounts of analytes above target quantitation limits.

Section 6 identifies the frequency for which blank and duplicate samples will be collected and analyzed such that a specific degree of precision and accuracy may be calculated. Quantitative objectives are summarized in Table 1.

Accuracy may be measured and expressed as % Recovery and is calculated as followed;

$$\%\text{Recovery} = 100\% * \frac{\text{Analytical Value}}{\text{True Value}}$$

$$\%\text{Recovery on a spike } (\%R_{sp}) = 100\% * \left[\frac{(\text{Spiked sample - Sample value})}{\text{Spiked sample}}\right]$$

To assure sample representativeness, all sample collection and measurements will be performed in accordance with both the protocol outlined in this QAQCP and procedures outlined in the *Standard Operating Procedures – Water and Environmental Sample Collection* manual.

In order to evaluate comparability, such that observations and conclusions can be directly compared with previous data, standardized methods of field analysis, sample collection, and preservation will be consistently used. These methods are also documented in the *Standard Operating Procedures – Water and Environmental Sample Collection* manual.

3.3 LABORATORY QUALITY OBJECTIVE

The laboratory quality objective is to ensure PARCC with respect to analytical results. The designated laboratory will demonstrate analytical precision and accuracy through the analyses of blind standards, duplicates, matrix spike duplicates, spike recoveries, and TDS and ion balances. Laboratory data quality objectives require that the QA guidelines specified in the EPA analytical methodology are followed.

ADHS/EPA certified laboratories approved to analyze samples collected are identified in the contact information below. All laboratories have demonstrated proficiency by achieving PARCC objectives.

ACZ Laboratories
2773 Downhill Drive
Steamboat Springs, Colorado 80487
ADHS#:*AZ0102*
Contact: Scott Habermechl
(800) 334-5493
Approved for: Ground Water, Surface Water, & Waste Water

Aerotech Environmental Laboratories
4455 South Park Avenue Suite #110
Tucson, Arizona 85714
ADHS#: *AZ0609, AZ0610, AZ0611*
Contact: Lorena Leal
(520) 807-3801
Approved for: Drinking, Surface, and Waste Water

Energy Laboratories
2393 Salt Creek Highway
Casper, Wyoming 82601-9654
ADHS#: *AZ0647*
Contact: Cheryl Garling
(888) 235-0515
Approved for: Radiochemical Analysis

3.4 DATA MANAGEMENT OBJECTIVE

The data management objective is to accurately and completely document field and laboratory activities and results. All aspects of sample collection, shipment, and analysis will be performed in conjunction with sufficient QA/QC documentation. The procedures for documentation of field activities and measurements are contained within the *Standard Operating Procedures – Water and Environmental Sample Collection* manual. This includes the use of Field Log Books, Field Data entry computers, sample container labeling and chain-of-custody forms. Field data are entered into the Environmental Data

Management Systems (EDMS) database. For laboratory data, the designated Laboratory Manager will verify results and submit a signed certificate of analysis to the Project Manager. In coordination with the designated Laboratory and Project Managers, the Quality Assurance Manager will also verify that the completed data are properly submitted on the electronic reporting system for downloading to the EDMS database. Field documents will be downloaded and/or filed (with actual file locations noted) in the Environmental Department Filing System.

SECTION 4

SAMPLING AND ANALYTICAL PROCEDURES

This section summarizes sampling and analytical procedures used in water monitoring activities.

4.1 SAMPLING PROCEDURES

The purpose of water sampling is to obtain specimens that accurately represent site conditions. Procedures have been developed for the water monitoring program to ensure that representative samples are collected. The *Standard Operating Procedures – Water and Environmental Sample Collection* manual contains procedures for all field activities, which are currently implemented.

4.2 ANALYTICAL PROCEDURES

Samples will be analyzed for the specified parameters identified by the individual project. Table 2 identifies the analytical method and target detection limits established for each parameter. Analytical methods are selected by laboratory personnel to meet the target detection limits where possible. Measurements to be conducted in the field may include measuring temperature, specific conductivity, pH, depth of water and flow rates. Methods for conducting measurements and requirements for sample containers, preservation and holding times for each sample are provided in the *Standard Operating Procedures – Water and Environmental Sample Collection* manual.

SECTION 5

DATA VERIFICATION, REDUCTION, AND REPORTING

Data verification is necessary to ensure the integrity of the data is maintained. An audit trail shall be developed for those data that require reduction. Data generated during field measurements, observations, and field instrument calibrations, should be written in indelible ink in a bound Field Logbook provided. Sampling crew personnel are responsible for proof reading all field data inputs. The Quality Assurance Manager will review a minimum of ten percent of data transfers to ensure the integrity of field documentation.

The Quality Assurance Manager will conduct data verification reviews to assess performance in achieving quality assurance objectives. Such reviews include a verification that: 1) the samples were analyzed and reported in the appropriate units; 2) the samples were properly preserved and did not exceed holding times; 3) quantitation limits were achieved; and, 4) method blanks have been analyzed and contain no cross contamination.

Data reduction for laboratory analyses will be conducted by the designated contract laboratory in accordance with EPA procedures for each method. Analytical results can be entered into the electronic data reporting system and delivered to the Quality Assurance Manager for uploading to the EDMS. Results will also be printed out on a Certificate of Analysis. After entering and/or uploading the data to the EDMS, the data will be archived on the network drive or on a writeable CD.

The Certificate of Analysis will be submitted to the Project Manager (for review) and filed in the Environmental Department Filing System. If a revised data report has been issued, changes to results in the EDMS will be documented in the notes status sections within each sampling event and a revised Certificate of Analysis will be submitted to the Project Manager. In the event a revised certificate is issued, the Quality Assurance Manager shall verify that the data stored on the EDMS matches that on the Certificate of Analysis.

A data control program will follow to ensure that all documents generated during each specific project are accounted for upon project completion. Accountable documents include: Field Log Books, Field Data Sheets, Analytical Request Sheet/Sample Chain of Custody, Sampling Log, correspondence, analytical reports, quality assurance reports, and audit reports. The Quality Assurance and each Project Managers are responsible for maintaining the Environmental Department Filing System. The Environmental Department Filing System is where all accountable documents will be filed and/or inventoried (with actual file locations noted).

Data will be available for reviewed as deemed necessary by each Project Manager and interpreted through the use of water quality contour maps, hydraulic head and water table maps, and/or simple statistics. A monthly review with a brief report identifying data outliers and corrections to the data will be generated.

SECTION 6
QUALITY CONTROL

6.1 QUALITY CONTROL CHECKS FOR FIELD ACTIVITIES

Samples used for Quality Control for field activities will consist of trip and equipment rinse blanks along with blind duplicates. Quality control samples are used to measure accuracy and precision affected by field activities. These activities are summarized below in more detail:

Trip Blanks

Trip blanks will consist of laboratory grade, deionized water (Type I reagent water) in each sample container along with the preservatives required for the analysis. Preservatives for each analyte are specified in the *Standard Operating Procedures – Water and Environmental Sample Collection* manual. The trip blank sample will be analyzed for the analytical suite with the most required analytes, to ensure all possible constituents are being evaluated. These blanks will be prepared by field samplers and accompany the Sampling Crew during the sampling process. The blanks will serve as a quality check on container cleanliness, external contamination, and the analytical method. Trip blanks will be collected every time an equipment blank sample is collected from any of the pieces of equipment. These blanks will be preserved, field tested, documented, and transported in the same manner as the routine samples.

Equipment Rinseate Blanks

Equipment rinseate blanks will be collected to ensure that sampling equipment is clean and that the potential for cross-contamination has been minimized by the equipment decontamination procedures. These blanks will be collected after the decontaminating process of a sampling device is complete. The sample will be collected from the last portion of deionized water rinse that has come in contact with the equipment. An equipment rinseate blank will be collected at a rate of one in every twenty (20) sample locations collected by each sampling device and in conjunction with a trip blank. The equipment blank sample will be analyzed for the analytical suite with the most required analytes, to ensure all possible constituents are being evaluated. For groundwater monitoring, equipment blanks will be collected from mobile equipment sampling. These blanks will be collected, preserved, field tested, documented, and transported in the same manner as the routine samples.

Blind Duplicates

Blind duplicate samples will be collected as an exact representation of a specific monitoring location. The duplicate sample will be taken at the same time and from the same source as the predetermined location to be compared. The duplicate will allow a determination of overall analytical precision for the designated laboratory. The blind duplicate samples will be collected at a rate of one in every ten (10) water samples collected from varying sample locations. These duplicates will be collected, preserved, field tested, documented, and transported in the same manner as the routine samples.

Procedures

The *Standard Operating Procedures – Water and Environmental Sample Collection* manual provides instructions for the collection and submittal of the QC samples described above. The analytical results for the field QC samples will be entered into the EDMS and evaluated monthly and routinely reported by the Quality Assurance Manager.

6.2 QUALITY CONTROL CHECKS FOR ANALYSES

Matrix spiking will be used to measure recoveries of analytes in order to monitor matrix efforts and for comparison to the established accuracy objective. All matrix spiking will be conducted by the designated laboratory as specified by the requirements of Arizona Department of Health Services.

Matrix Spike Samples

Matrix spike samples will be selected and spiked by laboratory personnel. Once a quarter a matrix spike sample will be submitted to the laboratory for analysis. The sample will be spiked in the laboratory with a known concentration. The spike will be used to measure the performance of the complete analytical system including potential chemical interference. Field matrix spikes may be submitted in cases where matrix problems that may be associated with particular samples (such as high TDS samples) are being evaluated by the specific project. Results from the matrix spike sample will indicate the validity of data results and the laboratory quality assurance manager will take corrective actions or omitted data as needed.

Laboratory Duplicates

Laboratory duplicate samples will be analyzed as an exact representation of a specific sample. The duplicate sample will be a spilt aliquot of a sample being prepared and analyzed within the same batch. These duplicates will measure precision of analytical performance. At least one duplicate will be spilt in every ten samples analyzed.

Reference Standards

At a frequency of one in every ten samples analyzed, a reference standard sample will be analyzed using a certified standard. The reference sample will be a commercial certified standard having the chemical composition similar to the water being submitted for analysis. This sample will be analyzed for the analytical suite with the most required analytes, to ensure all possible constituents are being evaluated

Internal Reference Samples

The use of several different internal reference standard samples is employed for laboratory quality assurance. The blanks are prepared in the laboratory with known concentrations of specific analytes with the intent of achieving recovery objectives with and/or without potential chemical interference. The purpose is to identify analytical shifts in data for samples with known problematic matrices. Internal reference samples include reagent, fortified, and interference blanks.

Procedures

All internal quality control checks to be performed by the designated laboratory will be in compliance with regulations enforced by the Arizona Department of Health Services. The Laboratory QA Manager will submit the results of these checks along with the results of the analysis for the batch of samples submitted.

6.3 PERFORMANCE AND SYSTEMS AUDITS

Audits are conducted periodically to determine the accuracy of the total measurement system or its component parts. System audits will be conducted to evaluate quality control procedures. Performance audits will be conducted for field methodologies established in the *Standard Operating Procedures – Water and Environmental Sample Collection* manual and for data management activities. Field activities include, but are not limited to, equipment calibration and maintenance, well evacuation, sample collection, and equipment decontamination.

The Quality Assurance Manager will schedule a minimum of one unannounced audit per year of the field data and sampling techniques employed. Additional audits can be conducted as deemed necessary when quality assurance objectives are in question. Systems audits will be based on a review and evaluation of an initial audit. Based on the findings from and response of this initial audit, corrective actions or consecutive audits may proceed. Periodic audits will monitor critical areas believed to need further emphasis.

Audits will be coordinated by the Quality Assurance Manager. Example checklists for performance audits of sample collection, field measurements, equipment decontamination, sample handling, and documentation are included in Exhibits 1, 2, 3, and 4, respectively. Audit plans, completed checklists, and reports will be kept in the Environmental Department Filing System.

Audit results will be reviewed and consolidated into a brief audit report which is filed in the Environmental Department filing system. Depending on results a post-audit meeting can be held with the audited sampling personnel. The meeting can allow the discussion of findings and resolution of any misunderstandings. A plan and schedule for corrective actions will be established during the meeting, as well as a follow-up audit if deemed necessary by the Quality Assurance Manager.

SECTION 7

CORRECTIVE ACTION

If audit findings or quality control checks indicate that quality assurance objectives are not being met, corrective actions will be taken as deemed necessary by the Quality Assurance Manager or the Project Manager. Such actions may include, but not limited to, re-sampling, re-analysis, and procedure changes. The appropriate Program Manager will be notified of the problem to discuss possible solutions.

The Quality Assurance Manager will ensure all necessary corrective actions are implemented, verify the outcome of these actions, and verify the effect on data produced. Documentation generated from these efforts should be forwarded to the appropriate Project Manager and filed in the Environmental Department filing system.

SECTION 8

QUALITY ASSURANCE REPORTING

The Quality Assurance Manager will prepare a brief annual report that includes results of quality assurance monitoring activities and audits of monitoring data quality, sampling and laboratory activities and any results of corrective actions that has taken place throughout the year. This brief report will address issues concerning accuracy, precision, completeness, representativeness, and comparability (PARCC) using the results of QC sample analyses, monitoring and audit results along with other potential sources that may not be mentioned in this document. These reports, along with any reports of audits and corrective actions, will be filed in the Environmental Department filing system. Copies will be sent to appropriate Project and Quality Assurance Managers.

Precision and Accuracy Objectives

DUPLICATE SAMPLES

Indicator Parameters, Major Anions, Major Cations, Metals:
Within 20% RPD or 4 times the PQL, whichever is greater

Organics:
Within 30% RPD or 4 times the PQL, whichever is greater

SPIKED SAMPLES*

Major Anions and Cations, Metals:
75% to 125% of the spiked analyte

Organics:
70% to 130% of the spiked analyte

*The spike objectives are generally for clean waters with less than 2000 mg/l TDS

BLANK SAMPLES

Less than the PQL (Practical Quantitation Level)

MASS BALANCES

TDS: Measured and observed TDS within 15%

Ion Balance:	*Anions sum as meq/L*	*Acceptance*
	0-3.0	±0.2 meq/L
	3.0-10.0	±2 RPD
	10 and greater	±5 RPD

DETECTION LIMITS

Target Detection for Metals and Organics:
Located on table QAQCP 2

NOTES:

RPD = Relative Percent Difference
MDL = Method Detection Limit
PQL = Practical Quantitation Level
MCL = Maximum Contaminant Level

Analytical Methods

Field

PARAMETER	ANALYTICAL METHOD	PRESERVATIVE	HOLDING TIME
pH	150.1	N/A	N/A
Temperature	170.1	N/A	N/A
Conductance	2510B	N/A	10 umho/cm
Depth to Water	N/A	N/A	0.01 ft

Laboratory

PARAMETER	ANALYTICAL METHOD	PRESERVATIVE	HOLDING TIME
TDS	SM 2540C/160.1	4°C	7 Days
TSS	160.2	4°C	7 Days
Total Coliform	SM9223B/9221D	4°C/$Na_2S_2O_3$	30 Hours
Fecal Coliform	SM 9222D	4°C/$Na_2S_2O_3$	6 Hours
Gross-Alpha	900.0, 9310	HNO_3 <2 pH	6 Months
Gross-Beta	900.0, 9310	HNO_3 <2 pH	6 Months
Radium 226	903.1	HNO_3 <2 pH	6 Months
Radium 228	904.0, 9320	HNO_3 <2 pH	6 Months
Uranium	200.8	HNO_3 <2 pH	6 Months
Chloride (Cl^-)	300.0, 325.2	4°C	28 Days
Cyanide	SM4500	4°C/ NaOH to >12 pH	14 Days
Fluoride (F^-)	SM 4500F	4°C	28 Days
Sulfate ($SO_4^=$)	300.0, 375	4°C	28 Days
Nitrate (NO_3^--N)	300.0, 352/353	4°C	48 Hours
Nitrite (NO_2^--N)	300.0, 354	4°C	48 Hours
Nitrogen - Nitrite + Nitrate	353	4°C /H_2SO_4 <2 pH	28 Days
Total Phosphorous	200.7	4°C /H_2SO_4 <2 pH	28 Days
Calcium (Ca)	200.7	HNO_3 <2 pH	6 Months
Magnesium (Mg)	200.7	HNO_3 <2 pH	6 Months
Potassium (K)	200.7	HNO_3 <2 pH	6 Months
Sodium (Na)	200.7	HNO_3 <2 pH	6 Months
Alkalinity (ALK)	SM 2320B	4°C	14 Days
Aluminum (Al)	200.7, 200.8	HNO_3 <2 pH	6 Months
Antimony (Sb)	200.7, 200.8	HNO_3 <2 pH	6 Months
Arsenic (As)	200.7, 200.8	HNO_3 <2 pH	6 Months
Barium (Ba)	200.7, 200.8	HNO_3 <2 pH	6 Months
Beryllium (Be)	200.7, 200.8	HNO_3 <2 pH	6 Months
Boron (B)	200.7		

Laboratory con't

PARAMETER	ANALYTICAL METHOD	PRESERVATIVE	HOLDING TIME
Cadmium (Cd)	200.7, 200.8	HNO_3 <2 pH	6 Months
Chromium (Cr)	200.7, 200.8	HNO_3 <2 pH	6 Months
Cobalt (Co)	200.7, 200.8	HNO_3 <2 pH	6 Months
Copper (Cu)	200.7, 200.8	HNO_3 <2 pH	6 Months
Iron (Fe)	200.7	HNO_3 <2 pH	6 Months
Lead (Pb)	200.7, 200.8	HNO_3 <2 pH	6 Months
Manganese (Mn)	200.7, 200.8	HNO_3 <2 pH	6 Months
Mercury (Hg)	200.7, 200.8, 245.1	HNO_3 <2 pH	6 Months
Molybdenum (Mo)	200.7, 200.8	HNO_3 <2 pH	6 Months
Nickel (Ni)	200.7, 200.8	HNO_3 <2 pH	6 Months
Selenium (Se)	200.7, 200.8	HNO_3 <2 pH	6 Months
Silver (Ag)	200.7, 200.8	HNO_3 <2 pH	6 Months
Thallium (Tl)	200.8	HNO_3 <2 pH	6 Months
Titanium (Ti)	200.7, 200.8	HNO_3 <2 pH	6 Months
Zinc (Zn)	200.7, 200.8	HNO_3 <2 pH	6 Months
Chemical Oxygen Demand	410.4	4°C /H_2SO_4 <2 pH	28 Days
Oil and Grease	413.2	4°C/HCl	28 Days
Biological Oxygen Demand	405.1	4°C	48 Hours
Benzene	524.2, 8021B	4°C/$C_6H_8O_6$ + HCl	14 Days
Toluene	524.2, 8021B	4°C/$C_6H_8O_6$ + HCl	14 Days
Ethylbenzene	524.2, 8021B	4°C/$C_6H_8O_6$ + HCl	14 Days
Naphthalene	524.2	4°C/$C_6H_8O_6$ + HCl	14 Days
Xylene	524.2, 8021B	4°C/$C_6H_8O_6$ + HCl	14 Days
Total Petroleum Hydrocarbons	SW8015, 418.1	4°C	28 Days
VOC	624/ SW 8260	4°C/$C_6H_8O_6$ + HCl	14 Days

Critical Values for T_n in the Test for Outliers

Number of Observations	Upper 5% Significance Level	Upper 0.1% Significance Level
3	1.133	1.155
4	1.463	1.499
5	1.672	1.78
6	1.822	2.011
7	1.938	2.201
8	2.032	2.358
9	2.11	2.492
10	2.176	2.606
11	2.234	2.705
12	2.285	2.791
13	2.331	2.867
14	2.371	2.935
15	2.409	2.997
16	2.443	3.042
17	2.475	3.103
18	2.504	3.149
19	2.532	3.191
20	2.557	3.23
21	2.58	3.266
22	2.603	3.3
23	2.624	3.332
24	2.644	3.362
25	2.663	3.389
26	2.681	3.415
27	2.698	3.44
28	2.714	3.464
29	2.73	3.486
30	2.745	3.507
31	2.759	3.528
32	2.773	3.546
33	2.786	3.565
34	2.799	3.582
35	2.811	3.599
36	2.823	3.616
37	2.835	3.631
38	2.846	3.646
39	2.857	3.66
40	2.866	3.673
41	2.877	3.687
42	2.887	3.7
43	2.896	3.712
44	2.905	3.724
45	2.914	3.736
46	2.923	3.747
47	2.931	3.757
48	2.94	3.768
49	2.948	3.779
50	2.956	3.789
51	2.964	3.798
52	2.971	3.808
53	2.978	3.816
54	2.986	3.825
55	2.992	3.834
56	3	3.842
57	3.006	3.851
58	3.013	3.858
59	3.019	3.867
60	3.025	3.874
61	3.032	3.882
62	3.037	3.889
63	3.044	3.896
64	3.049	3.903
65	3.055	3.91
66	3.061	3.917
67	3.066	3.923
68	3.071	3.93
69	3.076	3.936
70	3.082	3.942
71	3.087	3.948
72	3.092	3.954
73	3.098	3.96
74	3.102	3.965
75	3.107	3.971
76	3.111	3.977
77	3.117	3.982
78	3.121	3.987
79	3.125	3.992
80	3.13	3.998
81	3.134	4.002
82	3.139	4.007
83	3.143	4.012
84	3.147	4.017
85	3.151	4.021
86	3.155	4.026
87	3.16	4.031
88	3.163	4.035
89	3.167	4.039
90	3.171	4.044

Number of Observations	Upper 5% Significance Level	Upper 0.1% Significance Level
91	3.174	4.049
92	3.179	4.053
93	3.182	4.057
94	3.186	4.06
95	3.189	4.064
96	3.193	4.069
97	3.196	4.073
98	3.201	4.076
99	3.204	4.08
100	3.207	4.084
101	3.21	4.088
102	3.214	4.092
103	3.217	4.095
104	3.22	4.098
105	3.224	4.102
106	3.227	4.105
107	3.23	4.109
108	3.233	4.112
109	3.236	4.116
110	3.239	4.119
111	3.242	4.122
112	3.245	4.125
113	3.248	4.129
114	3.251	4.132
115	3.254	4.135
116	3.257	4.138
117	3.259	4.141
118	3.262	4.144
119	3.265	4.148
120	3.267	4.15
121	3.27	4.153
122	3.273	4.156
123	3.276	4.159
124	3.279	4.161
125	3.281	4.164
126	3.284	4.166
127	3.286	4.169
128	3.289	4.173
129	3.291	4.175
130	3.294	4.178
131	3.296	4.18
132	3.298	4.183
133	3.302	4.185
134	3.304	4.188
135	3.306	4.19
136	3.309	4.193
137	3.311	4.196
138	3.313	4.198
139	3.315	4.2
140	3.318	4.203
141	3.32	4.205
142	3.322	4.207
143	3.324	4.209
144	3.326	4.212
145	3.328	4.214
146	3.331	4.216
147	3.334	4.219

Standard Operating Procedures – Water and Environmental Sample Collection
Phelps Dodge Sierrita

March 2005

Standard operating procedures for environmental sample collection are specified in the following text. Procedures of this type allow the processes of data collection to be uniform. In turn the adherence to these procedures will permit proper analysis of data collected.

Table of Contents

Sample Documentation and Handling

This section contains standard operating procedures for proper documentation of sampling activities and proper sample handling as outlined in the sections listed below.

Procedure DH-A: Field Log Book

Record appropriate information in a Field Log Book for reconstruction of events associated with environmental sampling as they happened. Entries to Field Log Books will be made with blue or black indelible ink. Prepare and use Field Log Book as follows:

1. A weather/water resistant bound book should be used. Consecutively number the pages, if they are not already numbered.

2. Enter the following information on the cover of each book.

    - The name of the organization to which the book belongs (Phelps Dodge Sierrita).
    - The type of sampling the book will be used for. e.g. Groundwater Sampling
    - Start Date
    - End Date

3. Upon arriving at each sampling location, a new page should be started and contain the following information:

    - Sample location identification number if it exists (Well number, or sample location number).
    - Description of site. This must be done if no identification number is given.
    - Date and time of arrival at sampling location.
    - Personnel present at sampling location.
    - Ambient weather conditions (temperature, wind speed/direction, precipitation, etc)
    - Condition of sampling location (is well and cement pad in good condition, is sampling point damaged or in poor condition).
    - Equipment models and serial numbers. (e.g. mobile equipment)
    - Calibration results at site (if done daily, reference page number calibration results for the day are recorded on)
    - Equipment decontamination and/or maintenance conducted.
    - Equipment problems and actions taken to correct them.
    - Additional observations or conditions about the sampling event, which may affect sample integrity. (e.g. time to purge and flow rate)
    - If a duplicate is taken then the identification of the duplicate should be recorded.
    - Time/Date sampling conducted (If the same as arrival, date not required)
    - Time/Date sampling site was vacated.
    - Photograph location of file or film, a description of the contents for any photograph taken (if any) during event.

4. Enter any other information that may be pertinent to the sampling activity.

Procedure DH-B: Sample Identification

A sample coding system will be used to identify each sample location. The coding system will ensure all samples collected from an identified location will be able to be located and retrieved for tracking of parameters analyzed for each sampling event.

Sample locations may be identified by a sample identification number (All well locations are identified). Within this sample identification number is a unique coding of alphanumeric characters used for providing a delineation of area, medium, and/or location of the sample site.

For some existing sites sample identification numbers have already been assigned to them, using varying methods for identification.

The method of establishing sample location identifications can be done through designating an alphanumeric identification acronym, followed by unique numeric sample identification.

New sample locations can be designated as outlined:

Sample Identification for New Sites

— —	— — —
Area \ Type Designation	**Numeric Location Identifier**

Area \ Type Designation Acronym

The area \ type designation acronym consists of a one or two-letter code, which identifies the specific area or type of site at Phelps Dodge Sierrita and its surrounding areas. Approved area / type designation codes area identified in table DH-A. Other acronyms may be used, with the approval of the Environment, Land and Water (ELW) Department, if they are consistent with this procedure and will create less confusion.

Numeric Location Identifier

The numeric sample identification is unique to the location of each established sample site throughout the sampling network. It identifies a specific sampling location. This number must be obtained from the ELW Department. For instance, a replacement well will have an "A" following the numeric identifier of the original well.

The sample identification is a unique numbering system that delineates each location throughout the Phelps Dodge Sierrita property. Therefore, one group must manage the identification of the locations for proper management in the PDSI comprehensive environmental database. Identifications may be obtained for new sample locations through the ELW Department.

Procedure DH-C: Sample Container Preparation

Use certified clean, laboratory clean or properly decontaminated sample containers for all environmental samples. Have all sample containers prepared prior to sampling event.

1. If the sample containers are provided from the laboratory ensure they have already been cleaned and the preservatives are inside of the container. (Lab may put the preservatives in a small vial inside of the sample container.)

2. Select the proper containers and preservatives for each parameter to be analyzed as specified in Table DH-B for each sample.

3. If non-laboratory provided containers are used then prepare sample containers by rinsing three times with de-ionized water.

4. Add proper preservatives to appropriate containers while in lab to reduce further exposure to potential contaminants. Use proper personal protective equipment (i.e. safety glasses w/ side shields, chemical resistant gloves, chemical resistant clothing, etc.) while using care handling the preservatives.

5. Mark containers containing preservatives with what they are containing. (e.g. HNO_3)

6. Label containers as prescribed by Procedure DH-D.

Procedure DH-D: Sample Labeling

Labeling of sample containers should be done either directly on the sample container or on a water proof label. Whether the labeling is directly on the bottle or on a label, permanent indelible ink will be utilized to prevent any smearing or loss of sample container information. The following information must be included on each sample container. Some containers may have a sticker that can be placed on the sample container these can substitute for writing directly on the sample container.

1. Write the sample site identification as prescribed by Procedure DH-B (if not a duplicate, trip blank, or equipment blank.) Use procedures QC-A, B, C for duplicate, trip blank, or equipment blanks.

2. Analysis to be completed on each specific portion of sample (i.e. total metals, dissolved metals, etc).

3. Preservative added to sample container as specified in Procedure DH-F.

4. Date (mmddyy) and Time (hhmm) sample was collected (for a duplicate, trip blank, or equipment blank this information is contained in the sample identifier as described in procedures QC-A, B, C and is not required.)

5. Sampler Name

Procedure DH-E: Sample Analytical Request and Chain of Custody

Analytical requests and Sample Chain of Custody can be documented on the approved Chain of Custody sheet (Figure DH-A) or an equivalent sheet. The Analytical Request Sheet will be filled out by the sampler, prior to submitting the samples to the analytical laboratory and/or relinquishing custody to a courier. The form will be filled out as follows:

Sample ID:	Sample Identification (Alphanumeric location ID)
Time:	Time sample was collected.
Date:	Date sample was collected.
# of Containers:	Enter total number of containers in each sample set.
Field Data:	Final reading of field data recorded while sampling.
Preservative:	Indicate number of bottles in sample set preserved with specific preservative.
Analysis Requested:	Enter pre-determined suite of analyses or specific analytes to be completed.
Sample Submitted By:	Name of Sampler
Report Results To:	Name of Project Manager or person requesting the analysis results.
Surrendered By:	Signature of individual surrendering the sample to analytical laboratory or courier.
Received By:	Signature of laboratory staff member or courier receiving sample set.
Comments/ Special Instructions	Additional comments and/or instructions.

After collection, samples will be stored in a secure manner, which would prevent any tampering or potential damage to containers, until they can be delivered to the analytical laboratory conducting the analysis. Laboratory personnel will note any damaged containers, container number discrepancies, form or label discrepancies, and presence of ice in cooler (if required) at time of delivery. Laboratory Manager or Supervisor will contact Project Manager or person receiving data to resolve any discrepancies.

Procedure DH-F: Sample Preservation and Packaging

Proper sample preservation and packaging is essential in obtaining optimal quality assurance of the analysis being performed on a sample. Sample container, preservative, and holding time requirements must be met in order to ensure the integrity of the analysis being performed. Table DH-B specifies required containers, preservatives, and holding times for a variety of analytical parameters.

1. If required to keep sample chilled, place samples in cooler with sufficient ice to ensure sample will be delivered to the analytical laboratory with residual ice remaining.

2. Place "cooler temperature check" (1 oz bottle containing water) in cooler for laboratory to ensure temperature is adequate for proper preservation upon delivery.

3. Secure Chain of Custody/Analytical Request Sheet inside of cooler (in a Ziploc® plastic bag) for shipment to analytical laboratory.

4. Samples being submitted to external analytical laboratories may require some additional securing with tape and/or seals to prevent container breakage or tampering.

5. Ship the samples with respect for the holding time of each requested parameter.

Procedure DH-G: Collecting a sample

Environmental samples should be collected uniformly so that samples are representative of the actual conditions and data collected from analysis is precise.

- An overview inspection of the site location, considering site condition, security, weather, should be recorded into the log book as prescribed in procedure DH-A.
- Prepare sample containers as prescribed in procedure DH-C.
- Label all sample containers as prescribed in procedure DH-D.
- Wear PPE as needed for safety.
- Setup sample containers near the sample location so that samples can be taken quickly with minimal time between samples.

Filtered Sample:

1. Allow sampling point to flow if necessary as prescribed by procedure WS-A, or for several minutes to ensure a representative sample is being collected.
2. Install a new unused 0.45µg filter on the sample location.
3. Start flow if required. Once the initial flow has passed through the filter begin collecting samples one at a time into the proper container as specified in table DH-B.
4. Be sure not to introduce contaminates from the cap when closing the sample containers. Cap each sample container immediately after the sample is collected and place it in the shade if possible. Continue until all samples are collected.
5. Place samples into a cooler with ice to cool them as close to $4^{O}C$ as possible as specified in table DH-B.

Unfiltered Sample:

1. Allow sampling point to flow if necessary as prescribed by procedure WS-A, or for several minutes to ensure a representative sample is being collected.
2. Start flow if required, and then begin to collect samples one at a time into the proper containers as specified in table DH-B.

3. Be sure not to introduce contaminates from the cap when closing the sample containers. Cap each sample container immediately after the sample is collected and place it in the shade it possible. Continue until all samples are collected.

4. Place samples into a cooler with ice to cool them as close to 4^{O}C as possible as specified in table DH-B.

Table DH-A: Approved area / type designation codes

Code	Type of Site
BW	Monitor Well
I	TB Industrial Well
IW	Interceptor Well
M	TB Monitor Well
MH	Monitor Well
PZ	Piezometer
S	Production Well
ESP	Production Well

Table DH-B: Sample Containers, Preservation Techniques, and Holding Times

ANALYTE		CONTAINER [1]	PRESERVATION	MAXIMUM HOLDING TIME
Alkalinity		P, G	Store on Ice[2]	14 Days
BOD		P, G	Store on Ice[2]	48 Hours
Chloride		P, G	Store on Ice[2]	28 Days
Chromium		P	Store on Ice[2]	24 Hours
Coliform		P (Sterilyzed)	Store on Ice[2]	6 Hrs - NPDES 48 Hrs - Drinking
Corrosively		P		14 Days
Cyanide		P	Store on Ice[2], NaOH to pH > 12, Store in Dark.	48 Hours Non-preserved w/ NaOH, 14 Days Preserved.
Fluoride		P, G	Store on Ice[2]	28 Days
Hydrocarbons Chlorinated		G	Store on Ice[2]	7 Days
Hydrogen Ion (pH)		P, G	None	Analyze As Soon As Possible
Ignitability		G,M		14 Days
Mercury		P, G	HNO_3, to pH < 2	28 Days
Metals, except Mercury		P, G	HNO_3, to pH < 2	6 Months
Nitrate		P, G	Store on Ice[2]	48 Hours - Non Preserved
Nitrite		P, G	Store on Ice[2]	48 Hours
$NO_2 + NO_3$		P, G	Store on Ice[2]	48 Hours, 28 Days w/ H_2SO_4
Oil & Grease		G	Store on Ice[2], H_2SO_4 to pH < 2	28 Days
Organics				
	PCB	AG	Store on Ice[2], pH 5 - 9	7 Days
	Pesticides	VOA	Store on Ice[2], $Na_2S_2O_3$ If residual Cl^- present	7 Days
	PAH	AG	Store on Ice, $Na_2S_2O_3$ If residual Cl^- present	7 Days
	BTEX	VOA	Store on Ice[2]	14 Days
	TPH	G	Store on Ice[2], HCl	28 Days
	VOC	VOA	Store on Ice[2], HCl < 2, $Na_2S_2O_3$ If residual Cl^- present	7 Days
Phenolics		G	Store on Ice, H_2SO_4 to pH < 2	28 Days
Phosphate		P, G	Store on Ice[2]	48 Hours
Radionucleides		P, G	HNO^3, to pH < 2	6 Months
Silica		P	Store on Ice[2]	28 Days
Sulfate		P, G	Store on Ice[2], if pH is < than 4.5 preserve w/ HCl	28 Days
TCLP		AG	None unless specified by lab	7 Days
TDS		P, G	Store on Ice[2]	7 Days
TSS		P, G	Store on Ice[2]	7 Days
[1] Polyethylene (P), Glass (G), Amber Glass (AG), Volitile Organic Amber (VOA), Metal (M)				
[2] or Refrigerate				

Figure DH-A: **Chain of Custody Sheet**

COC Number: ____________

P.O. Box 527, Green Valley, AZ 85622

					Preservatives						Field Data						
Lab Use Only	Location	Date	Time	# of Cont.	HNO_3	H_2SO_4	NaOH	HCL	Unpres.		pH	Cond	Temp				***Analysis Requested***

Sample Submitted By: ____________ Telephone No. ____________ Fax No. ____________

Report Results To: ____________ Telephone No. ____________ Fax No. ____________

Samples Submitted on Ice: Yes / No

Laboratory Name and Address:

Surrendered By: ____________ Received By: ____________ Date: ____________ Time: ____________

Surrendered By: ____________ Received By: ____________ Date: ____________ Time: ____________

Comments/Special Instructions: ____________

Equipment Decontamination and Maintenance

This section contains standard operating procedures for proper decontamination and maintenance of sampling equipment and instruments as outlined in the sections listed below.

Procedure DM-A: Equipment Decontamination

Decontamination of environmental sampling equipment is essential in obtaining quality representative data from characterized and non-characterized sampling locations. All equipment used in collection should be decontaminated prior to each use. Decontamination of field sampling equipment such as; stainless steel buckets, bailers, pumps, dippers, scoops, Coliwasas, triers, and augers shall be conducted before and between every sampling event and at the end of each day. Materials needed for effective decontamination of equipment is listed below:

- Phosphate Free Cleaning Detergents (Liquinox®)
- Potable Water
- Deionized Water
- Water storage containers for large volumes of soapy, potable, and deionized water in transport.
- Buckets for use in washing and rinsing of equipment.
- Protective gloves.
- Proper personal protective equipment (i.e. safety glasses w/ side shields, chemical resistant gloves, chemical resistant clothing, etc.) while handling dangerous chemicals.
- Paper towels or cloth towels for cleaning all outside surfaces or surfaces that do not come in with the sample.
- Plastic garbage bags for storage of disposable items (gloves, paper towels, containers, etc.).

Decontaminate non-disposable sampling equipment such as stainless steel buckets, bailers, dippers, scoops, Coliwasas, triers, and augers as described below:

1. Use proper personal protective equipment (i.e. safety glasses w/ side shields, chemical resistant gloves, chemical resistant clothing, etc.) using care while handling detergents and other chemicals.

2. Manually scrub exterior with non-phosphate detergent/potable water mixture.

3. If there is an interior (bailers, Coliwasas, etc.), flush with non-phosphate detergent/potable water mixture

4. Rinse with potable water until all detergent and residue is removed.

5. Rinse with deionized water.

6. Air dry.

7. Place all disposable items in plastic bag and take to appropriate disposal receptacle.

Decontaminate mobile monitoring well pumps and non-disposable hoses as described below:

1. Use proper personal protective equipment (i.e. safety glasses w/ side shields, chemical resistant gloves, chemical resistant clothing, etc.) using care while handling detergents and other chemicals.

2. Manually scrub exterior portion of hose, which was immersed in the well water, with non-phosphate detergent/potable water mixture.

3. Pump non-phosphate detergent/potable water mixture through pump and tubing until it discharges from the discharge hose.

4. Rinse exterior portion of hose, which was immersed in the well, with potable water until all detergent and residue is removed.

5. Pump potable water through pump and tubing until all detergent and residue is removed from interior.

6. Rinse exterior portion of hose which was immersed in the well water with deionized water.

7. Pump deionized water through pump and tubing until sufficient rinsing has been achieved or at a minimum until it discharges from the discharge hose.

8. Air Dry exterior.

9. Place all disposable items in plastic bag and take to appropriate disposal receptacle.

If excessive amounts of grime or residue are present on the exterior of a pump and/or tubing, a pressure sprayer can periodically be used to remove any buildup.

Decontaminate meters and/or probes to meters used for general field measurements as described below:

1. Use proper personal protective equipment (i.e. safety glasses w/ side shields, chemical resistant gloves, chemical resistant clothing, etc.) using care while handling detergents and other chemicals.

2. Rinse meters and/or meters probes for several seconds with deionized water between each reading.

3. Periodically, glassware used for sample collection and/or field measurements should be immersed in a 10% hydrochloric acid solution, followed by manual scrubbing to remove any residual residue.

Procedure DM-B: Equipment Maintenance

Routine equipment and instrument maintenance is essential in ensuring efficient, accurate data is obtained in environmental sampling. Refer to equipment and instrument manuals for determination of proper scheduling and preventative maintenance for each piece of equipment and instrument. General routine preventative maintenance shall be conducted as follows:

1. Store equipment and instruments in secure, dry place, away from weather and dust.
2. Remove dirt and residual grime acquired in transport.
3. Keep sensitive parts (membranes, electrical, etc.) covered, to protect from weather, dust, and other hazards while in field.
4. Inspect all equipment for potential problems (cracked and clogged tubing, electrical wiring, pump impellers, etc.).
5. Keep battery packs for equipment charged and ready to use, replace as necessary.

Quality Assurance Quality Control Practices

This section contains standard operating procedures for proper quality control of samples and equipment as outlined in the sections listed below.

Procedure QC-A: Blind Duplicates

Duplicate samples will be collected by alternately filling pre-marked containers of the designated sample location and the duplicate. For example, if a container preserved for total metals for the designated sample location is being filled, the container preserved for total metals for the duplicate shall immediately follow. This method will be followed for each subsequent container of the sampling sets to ensure both sampling sets are representative of each other. Duplicate samples will consists of the exact same containers and analysis for which the original designated sampling location is being analyzed.

Duplicates will be collected at a rate of one in every ten samples collected from varying sample locations. The sample identification for duplicates will consist of the three-letter acronym DUP, followed by the date (mmddyy) and alpha identifier. (e.g. DUP091404D this would identify the fourth duplicate sample taken on September 14, 2004)

Selection of the specific locations for duplicate sample collection will be at the discretion of the sampler. However, sites should represent the general, overall water quality for the entire site. To ensure overall water quality control objectives are being met, sample location selection should be conducted by rotating designation areas according to the last area sampled. For example, if a groundwater sample was collected within the IW designation on the last duplicate round, the next duplicate would be collected from a location in another area designation.

Duplicate samples shall be recorded in the field logbook on the same page of the sample being duplicated as prescribed by procedure DH-A in this manual. Proper documentation is necessary to ensure proper quality control can be obtained through contrast analysis.

Procedure QC-B: Trip Blanks

Trip blank samples will be collected by filling pre-marked containers with de-ionized water and placing them in the same cooler as all subsequent samples collected for that day. Samples will be kept on ice and accompany the sampler(s) throughout the day of sampling to ensure contaminants are not affecting the integrity of the samples while in storage and transport. The exact same container will be used for Trip blanks along with an equivalent analysis to the original sample submitted to the lab.

Trip blanks will be collected every time an equipment blank sample is collected from any of the pieces of equipment. The sample identification for trip blanks is TB then the date (mmddyy) and an alpha identifier. (e.g. TB052805A would identify the first trip blank from May 28, 2005)

Trip blanks shall include all of the same procedures as a sample being collected from a designated sampling location, including container rinsing and preservation, and field measurements. All information regarding a trip blank will be recorded in the field log book on the same page as the equipment blank taken in conjunction with this sample. Proper documentation is necessary to ensure proper quality control can be obtained through contrast analysis.

Procedure QC-C: Equipment Blanks

Equipment blank samples will be collected by filling pre-marked containers with de-ionized water, which has been run through, on, or over equipment that has been decontaminated as prescribed in procedure DM-A. The sample will be collected from the final rinse of de-ionized water in the decontamination process. To ensure accuracy of QC efforts, decontamination of equipment should be done to no more or less extent than that which is done during normal decontamination between sampling events. The exact same container will be used for Equipment blanks along with an equivalent analysis to the original sample submitted to the lab.

Equipment blanks are to be performed on non-dedicated, non-disposable equipment such as; stainless steel buckets, bailers, pumps, dippers, scoops, Coliwasas, triers, and augers. Equipment like dedicated monitoring well pumps or disposable bailers do not require routine decontamination or equipment blank samples, as long as the disposable items are disposed of between each sampling site and not reused.

Equipment blanks will be collected at a rate of one in every twenty sample locations collected by each sampling device and in conjunction with a trip blank as prescribed in procedure QC-B. The sample identification for equipment blanks will consist of the three-letter acronym EQB, followed by the date (mmddyy) and an alpha identifier. (e.g. EQB030604A would identify the first equipment blank taken on March 6, 2004)

Equipment blanks shall include all of the same procedures as a sample being collected from a designated sampling location, including container rinsing and preservation, and field measurements. All information regarding an equipment blank will be recorded in the field log book on the same page as the trip blank taken in conjunction with this sample. Proper documentation is necessary to ensure proper quality control can be obtained through contrast analysis.

Well Specific Procedures

This section contains standard operating procedures for sites that are wells as outlined in the sections listed below.

Procedure WS-A: Depth to Water

Depth to water measurements should be taken at each well at a frequency specified in the PDSI sampling plan. The static water level is the level of the water in the well before pumping has taken place. It is a measurement of the water level in the target aquifer. The pumping water level is the level of the water at which the pumping and recharge rates are in equilibrium and the water level no longer varies. The depth to water should be measured from the predetermined measuring point. The measuring point is the north side of the top of the well casing. This point should be marked on the top of the casing. This measurement should be taken to within one hundredth of a foot using a depth to water sounder. Depth to water measurements should be done by following these procedures.

1. Proper decontamination should be done on the depth to water sounder as prescribed in procedure DM-A.
2. Locate the measuring point; if not marked then determine north.
3. Allow the sounder to go down the well until it indicates the probe is in water.
4. Obtain reading from tape to within one hundredth (1/100) of a foot.
5. Record reading in field notebook and electronically in the handheld or on the field data sheet.
6. Properly decontaminate the depth to water sounder as prescribed in procedure DM-A.

Static Water level

- Depth to water measurements should be taken before any pumping occurs to be sure that the static non-pumping water level is obtained.

Pumping Water level

- Depth to water measurements for a pumping well should be taken after the pump has been running for at least 3 purge volumes.

Procedure WS-B: Groundwater Well Evacuation

For wells of known construction, evacuate a minimum of three (3) standing well casings and sand pack porosity volumes to help ensure the collection of a sample which is representative of the target aquifer. The removal of at least three volumes is believed to achieve a representative sample of the water with in the target aquifer. Once three standing well casings have been purged stop pumping once the given indicator parameters have stabilized, limiting the evacuation to five volumes. This prevents the stressing of the well and introduction of ground water from another area within the aquifer. If the well goes dry during evacuation, allow the water level to recover and re-evacuate, if possible, until it is believed that a representative sample from the aquifer can be collected. The following steps should be followed to ensure a representative sample is collected during each sampling round.

6. Conduct an overview inspection of the site location. Consider well and concrete pad condition, security of well and weather conditions while at the site. Document information as prescribed by procedure DH-A.

7. Determine the static water level as described in procedure WS-A.

8. Calculate purge volume of well from the following procedure

   The purge volume is calculated as follows. All hand calculations should be done in the field log book. The handheld computer may do the calculations if provided all of the necessary information.

   a. Measure the inside diameter of the well casing if unknown.

   b. Determine the depth to the bottom of the casing.

   c. Determine the length of the screened interval.

   d. Determine the porosity of the sand pack. If the actual porosity is not available then assume that $\eta = 0.3$.

   e. Determine the Diameter of the borehole.

   f. Calculate the standing water volume as follows;

      - V = Volume of standing water (gallons)
      - L = Length of screened interval (ft)
      - η = Assumed porosity of sand pack
      - Z_W = depth to water (ft)
      - Z_C = depth to bottom of casing (ft)
      - D_B = Diameter of the borehole (ft)

- D_C = Diameter of the casing (ft)

$$V = 1.87\pi\left[(Z_C - Z_W)D_C^2 + \eta L\left(D_B^2 - D_C^2\right)\right]$$

  g. Multiply the volume of standing water by (3) to obtain the minimum purge volume.

  h. Multiply the volume of standing water by (5) to obtain the maximum purge volume.

9. If well has dedicated pump, install proper equipment (hoses, fittings, etc.) If well does not have a dedicated pump, install decontaminated portable pump in well, connect appropriate equipment and control devices. Ensure that the portable equipment has been decontaminated before use, as described in procedure DC-A.

10. Turn on pump, and adjust flow rate to maintain steady flow to minimize the chance of pumping well dry. Do not run the pump while the all the valves are closed, this may cause damage to the pump. When organic constituents are to be analyzed, do not pump or bail the well to dryness or cause recharge water to cascade vigorously down the sides of the screen or lower the water level below the level of the pump.

11. While evacuating record measurements of conductivity, pH, and water temperature after the removal of each well volume. This is done so that it can be known as to when a representative sample can be collected. Once these values have stabilized then collection of the sample can be done. If (5) standing well volumes have been purged then it is assumed that a representative sample from the correct location in the aquifer can be obtained. Record the interval reading values along with the total purged volume in the handheld computer and in the log book.

12. Collect sample(s) for predetermined analytes from pump discharge as prescribed in procedure DH-G.

13. Once sampling is completed turn off the pump and close the valves on the well. Disconnect all mobile equipment. Follow decontamination procedure DC-A as needed for portable reusable equipment.

14. Secure the well by replacing lock on protective casing.

APPENDIX B

BESST, INC. HYDROBOOSTER SYSTEM

BESST INC.
GLOBAL SUBSURFACE TECHNOLOGIES

Dye Tracer Flow Velocity Profiling and HydroBooster™ Groundwater Sampling

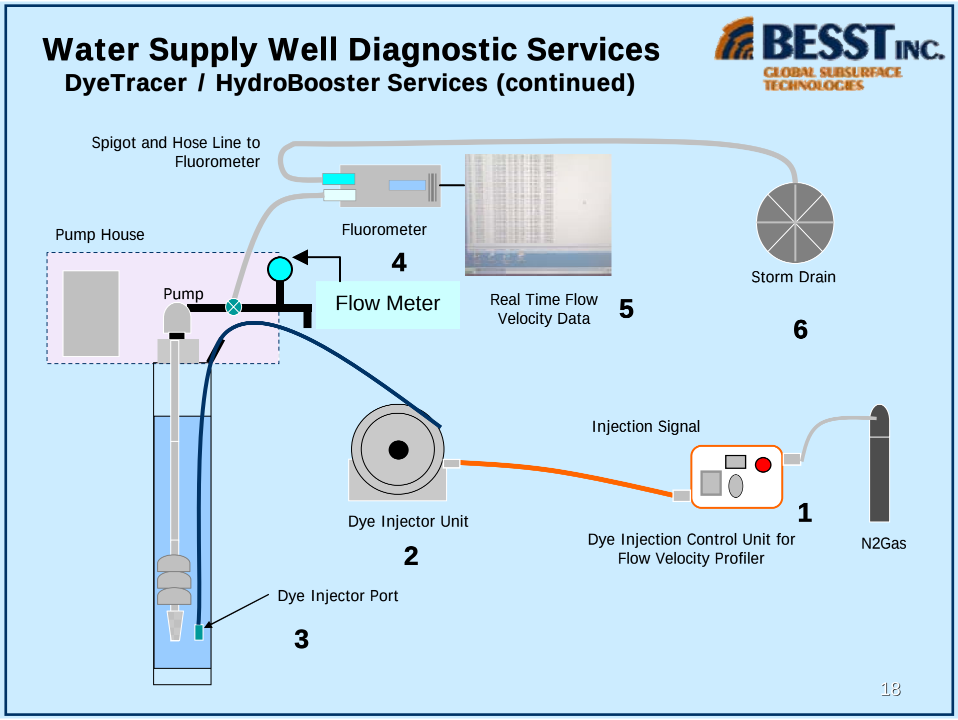
1. Dye Tracer Flow Velocity Profiling – General Description

The Dye Tracer Flow Velocity Profiling System (DT) is a USGS method and apparatus patented technology and was constructed and is operated by BESST, Inc. under exclusive license from the USGS. The technology has the ability to provide a dynamic flow velocity profile from virtually any type of production, remediation or monitoring well <u>without first having to remove the pump from the well.</u> The end result of the method produces a quantitative groundwater production profile of water influx along a well screen under dynamic flow pumping conditions along the entire well screen. The velocity and production profiles generated by this technology are comparable to profiles generated by spinner logging tools under dynamic flow conditions. The setup schematic for the Dye Tracer (DT) system is presented in Figure 1.

The DT system is composed of six main components:

a. Flexible Dye Injection Hose w/ Injection Nozzle
b. Motorized Hose Spool for deploying and retrieving the dye injection tubing w/ nozzle
c. Injection Pump / w/ Pneumatically Controlled Solenoid for the injection pump and Valve Switching Unit
d. Injection Control Unit
e. 10-AU Fluorometer from Turner Designs
f. Rhodamine Red Dye (NSF 60 Approved)

Figure 1: Schematic of Dye Tracer Flow Velocity Profiling System



Water Supply Well Diagnostic Services
DyeTracer / HydroBooster Services (continued)

1.1 Planning and Field Preparation

The first step in operation of the DT system is access to the well of interest. Preparation consists of communication between the consultant, water purveyor and BESST in order to determine the most suitable access points into the well – between the pump column and interior well casing wall. Schematics of the pump and pump house and multiple photos of the well head are typically reviewed before the start of any project. Once reviewed, a planned approach is agreed to before commencement of work.

The DT tubing and injection nozzle typically ranges between ½-inch to ¾-inch in diameter. The small diameter and flexibility of the tubing and nozzle assembly make it possible to bypass the pump column, down-hole impeller bowls and / or electric pump motors. A key factor in successfully inserting the injection tubing and nozzle is the attachment of a small diameter steel cable or weighted chain to a metal loop located and attached just below the injection nozzle. The weight attachment makes it possible to move the DT tubing up and down in the well without turning off the pump.

In typical applications, the DT tubing is lowered through a mechanical counter that indicates the depth of the injection nozzle. The injection process can be started near the top of the pump or impeller bowls or from the bottom of the well screen. Injection points are typically laid out on a 10- to 20-foot vertical grid in order to obtain enough data points to vertically profile production along the well screen.

Prior to well injection, 50 ml of Rhodamine Red (RR) (from Bright Dyes, Inc.) is injected into a 5-Gallon bottle of DI water. The solution from the RR bottle is then fed by the injection pump (IP) to the injection line until the line is completely filled with the RR solution. When released into a well, each second of injection by the Injection Control Unit (ICU) is equivalent to approximately 20 ml of RR released from the injection nozzle (IN). Figure 2 below shows a typical setup for the DT system at a production well location in northern Nevada.

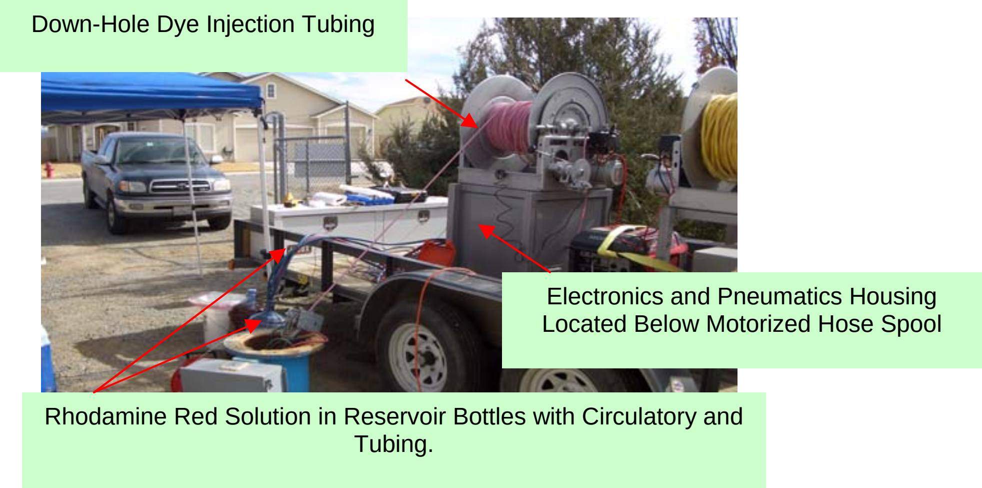


Figure 2: Typical trailer setup for Dye Tracer Flow Velocity Profiling System – at a location in northern, Nevada.

While the system is in non-injection mode and idling, the RR solution is circulated in the RR reservoir bottle to prevent air bubbles from entering the liquid and being injected into the well. Additionally, an electronic float sensor is placed within the RR reservoir bottle to prevent air from being drawn into the injection line. As a result, when the RR solution is drawn down to the lower third of the RR bottle, the injection pump automatically shuts off. More RR solution is then added to the bottle before RR injection is continued. Introduction of air into the injection line is undesirable since air bubbles can cause delays in the return time of the RR to the fluorometer.

1.2 General Description of Equipment

The fluorometer used for the velocity profiling is a Model 10-AU from Turner Designs and is shown in Figure 3. The 10-AU Fluorometer measures the concentration of various analytes in samples of interest via fluorescence. In the case of dynamic flow velocity analysis for wells, the analyte of interest is artificially introduced in order to measure the peak concentration return times of rhodamine red from the release point to the fluorometer via the discharge path of the pumping well. The return concentrations are typically in the part per billion range. Light or exciting light from a light source within the fluorometer is passed through a color filter specific to rhodamine red, that transmits light of the chosen wavelength range (color). The wavelength of the exciting light that falls on the sample is set by the choice of the light source and the excitation filter. The emitted light radiates in a sphere from the light source and is directed towards the 10-AU detector through an emission filter. The purpose of the emission filter is to prevent any scattered exciting light from reaching the detector (photomultiplier tube) and to pass the emitted color that is specific to the analyte of interest. The concentration of the RR solution is directly proportional to the signal response received by the fluorescing light emitted by the rhodamine red that is received by the detector. The concentration is typically reported on an analog display panel located on the front of the 10-AU (Turner Designs, 1996).

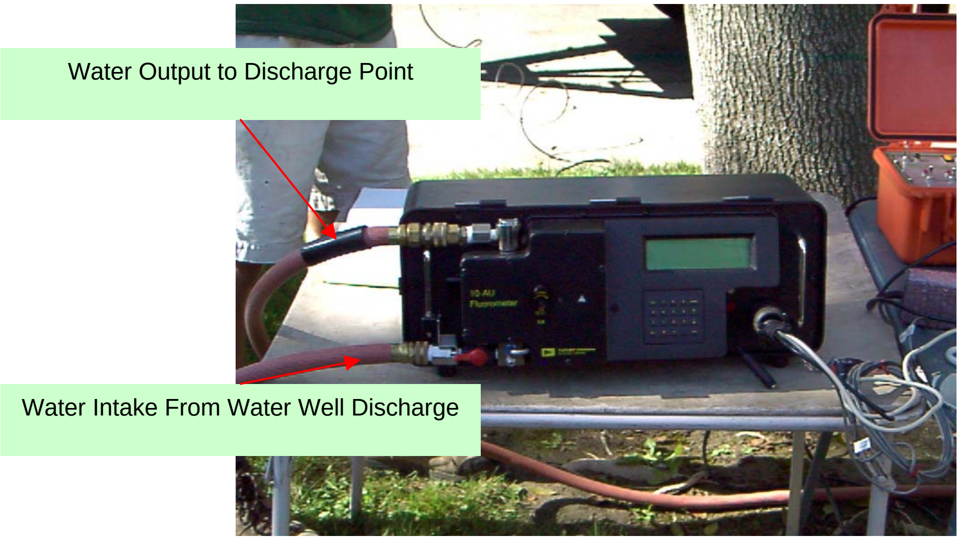


Figure 3: Model 10-AU fluorometer from Turner Designs.

To-the-second consistency of injection time, and bubble free RR injection solution is the key to establishing meaningful and reproducible results for defining dynamic flow velocity measurements in any well under study. Figure 4 shows a BESST, Inc. injection control unit for tightly regulating injection pulse times. Figures 5 and 6 provide a more detailed look of the circulatory system of the dye injector.

Figure 4: Dye Injection Control Unit for to-the-second regulation of dye injection pulses.

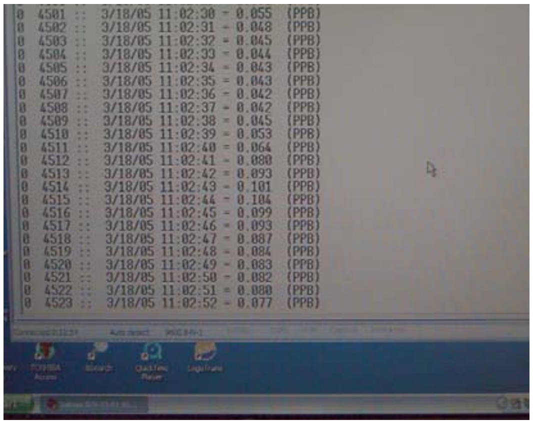
Figure 5: Electrical and Pneumatics components inside housing are controlled by the Dye Injection Control Unit (Figure 4). The housing contains injection pump, injection pressure regulator, pneumatically controlled valve switching solenoid, fuse box, electrical circuits and primary and secondary valve control units.

Figure 6: Bottle to right contains primary RR reservoir. When the large oval red button is depressed on the Dye Injection Control Unit (Figure 4), the RR solution is fed from the red tube, then to the injection pump, and finally through the injection nozzle and into the well. When the injection pump is idling, the RR solution circulates through the blue tube and red tube in the primary RR reservoir bottle. The secondary RR bottle receives excess RR that is not used during an injection pulse.

1.3 Injection Procedure

Prior to the first dye injection, the well of concern is typically pumped at the specified pumping rate for the flow velocity test until draw down stabilization inside the well has been reached. Periodic readings are recorded from a flow meter attached to the discharge line. Ideally, the flow meter is attached to the discharge line at a distance of at least 10 feet from the well head in order to minimize the effect of pipe fluid turbulence on the flow meter reading.

The first step in the dye injection process is to lower the injection tubing and nozzle through a mechanical counter to the first injection point in the well. Often times, the injection process starts from the well bottom – since the weighted end of the injection tubing is used to verify the actual well depth. Therefore, as a matter of convenience, the first injection point is typically near the bottom of the well. The injection points are then executed along a vertical ascending grid. At the point of dye injection, the release time is manually noted in a field log. Each release time is selected from a scrolling time and concentration log which appears on a laptop screen – the laptop being directly connected to the fluorometer. The communication of this information through the laptop is facilitated through the laptop's default communication software called Hyperlink. An example of the laptop display is shown in Figure 7 below.



```
0  4501 ::  3/18/05 11:02:30 = 0.055  (PPB)
0  4502 ::  3/18/05 11:02:31 = 0.048  (PPB)
0  4503 ::  3/18/05 11:02:32 = 0.045  (PPB)
0  4504 ::  3/18/05 11:02:33 = 0.044  (PPB)
0  4505 ::  3/18/05 11:02:34 = 0.043  (PPB)
0  4506 ::  3/18/05 11:02:35 = 0.043  (PPB)
0  4507 ::  3/18/05 11:02:36 = 0.042  (PPB)
0  4508 ::  3/18/05 11:02:37 = 0.042  (PPB)
0  4509 ::  3/18/05 11:02:38 = 0.045  (PPB)
0  4510 ::  3/18/05 11:02:39 = 0.053  (PPB)
0  4511 ::  3/18/05 11:02:40 = 0.064  (PPB)
0  4512 ::  3/18/05 11:02:41 = 0.080  (PPB)
0  4513 ::  3/18/05 11:02:42 = 0.093  (PPB)
0  4514 ::  3/18/05 11:02:43 = 0.101  (PPB)
0  4515 ::  3/18/05 11:02:44 = 0.104  (PPB)
0  4516 ::  3/18/05 11:02:45 = 0.099  (PPB)
0  4517 ::  3/18/05 11:02:46 = 0.093  (PPB)
0  4518 ::  3/18/05 11:02:47 = 0.087  (PPB)
0  4519 ::  3/18/05 11:02:48 = 0.084  (PPB)
0  4520 ::  3/18/05 11:02:49 = 0.083  (PPB)
0  4521 ::  3/18/05 11:02:50 = 0.082  (PPB)
0  4522 ::  3/18/05 11:02:51 = 0.080  (PPB)
0  4523 ::  3/18/05 11:02:52 = 0.077  (PPB)
```

Figure 7: Streaming Laptop Hyperlink Communication Display from AU-10 Fluorometer. Date, time and concentration value are reported and stored in continuous scrolling format.

Figure 8: Laptop connected to 10-AU

1.4 Data Requirements

During the course of completing the vertical dye injection grid, some of the injection points are repeated in order to establish travel time and velocity reproducibility. Once all of the injection points are completed, the data is entered into an Excel spreadsheet with built-in data calculations that facilitate the generation of the flow profile – using the Excel chart function. The basic equation (Izbicki, 2000) used for calculating flow velocity is:

$Q= (V\pi r^2)$

where,

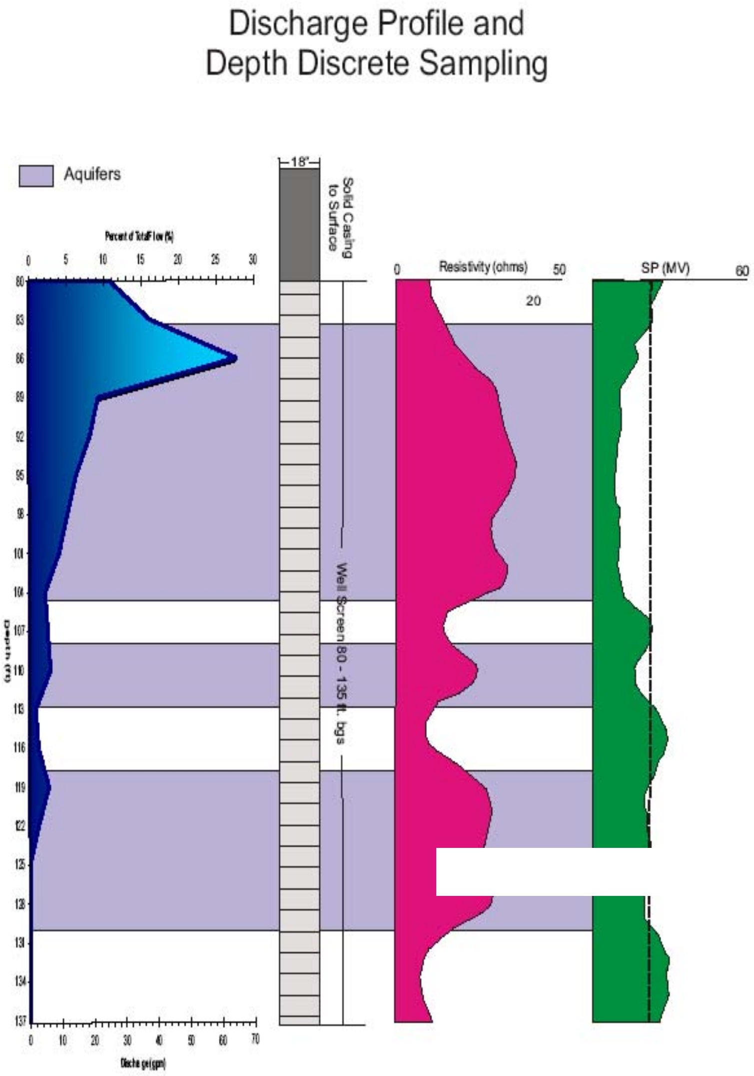
$V = (d_2-d_1) / (t_2-t_1)$

Q = flow in gallons per minute (gpm)
d = injection depth
d_2 = injection depth # 2
d_1 = injection depth # 1
t = travel time of peak tracer concentration from release point to detector
t_2 = return time for rhodamine red peak to fluorometer detector for d_2 injection point
t_1 = return time for rhodamine red peak to fluorometer detector for d_1 injection point

Other factors that are required for the solution and interpretation of the results are well diameter, pump diameter, pump column diameter and length, depth of pump intake, well screen interval(s), and length of well screen located above the pump. Other pieces of information that can play a role in the interpretation of the results are driller's logs from when the well bore was drilled and any geophysical logs such as resistivity short and long normal, spontaneous potential (SP), gamma ray, neutron, caliper, video surveys and others.

As far as data plotting, there are various types of valid presentation formats. One type of format (presented in Figure 9) plots depth on the y-axis, percent flow on the top x-axis and GPM discharge on the bottom x-axis. Additionally, lithologic and geophysical information are presented in co-plots to the right in order to correlate lithologic and geophysical properties to production.

Figure 9: Blue curve displays flow profile of production well – where injection depth points are shown along y-axis. Top x-axis shows percent contribution with depth and bottom x-axis shows discharge with depth in GPM. Magenta shaded curve displays resistivity in ohms and green-shaded curve shows spontaneous potential (SP) in millivolts (MV).



2. HydroBooster™ Groundwater Sampling – General Description

The HydroBooster™ pump is a high-lift gas displacement pump that was designed by BESST, Inc. for the USGS for collecting groundwater samples from active production wells without having to remove the pump (USGS, 2004). The HydroBooster™ pump spans from 6 to 18-inches in length (depending on model) and ranges in diameter from ½-inch to 7/8-inch. The pump can be connected to any type of tubing (i.e. Teflon, polyethylene, nylon, etc.). For high pressure applications, the tubing can consist of regular nylon, or even nylon reinforced with fiber glass or Kevlar for ultra high pressure applications to 3,000+ feet BGS. Figure 10 shows an example of a HydroBooster™ application at a site in the California Central Valley for a production well under study for vertical distribution of nitrate contamination.

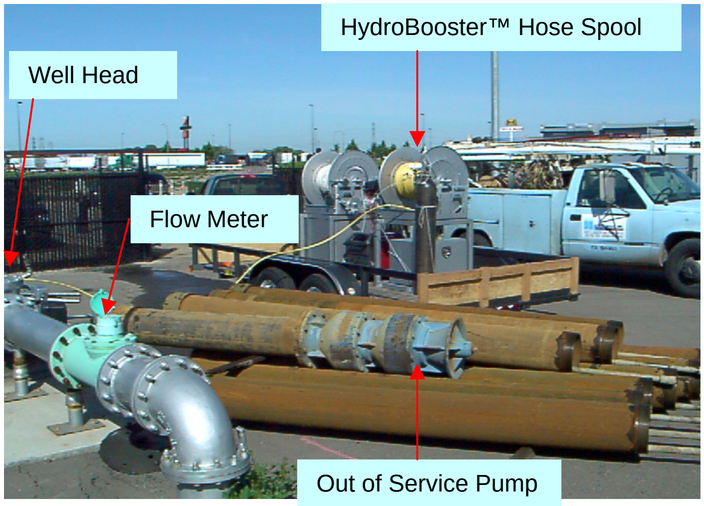


Figure 10: Setup of the HydroBooster system at a groundwater production well in the California Central Valley. Groundwater samples were collected in conjunction with running a smaller electric pump inside the well contemporaneously with the sampling process. The main production pump was removed sometime prior to the testing and is shown in foreground (blue housing). The production well was under study for vertical distribution of nitrate contamination. Note the flexibility of the HydroBooster system leading up to the well head.

As with the Dye Tracer Flow Velocity Unit, the tubing for the HydroBooster™ system is flexible, permitting access into various types of production well settings without having to remove the pump. The different types of BESST pump models used for groundwater sampling in production wells (as well as small diameter and Westbay Multi Port wells) is shown in Figure 11. The pneumatic lift formula used for the gas displacement pump is the following:

Minimum Pneumatic Lift Pressure = X'/[(2.31'/PSI) x 1.1]

where,

X= depth of pump below ground surface
2.31' / PSI = approximate linear gradient of water pressure at sea level and assuming a specific gravity of 1.

1.1 = Correction factor used for increasing lift pressure by 10% to compensate for friction loss of the water inside the sample return line.

Figure 11: Various models of BESSt miniaturized gas displacement pumps for HydroBooster system.

The gas displacement principle that operates the pumps utilizes a single valve located directly below a Y-tube junction between the gas-in and sample return lines. When the pump with bundle is submerged within the well water, the single valve cracks open at about 1/3-PSI water pressure. Groundwater from the well fills both the gas-in and sample return lines simultaneously through the bottom of the one-way valve. When the pump is lowered to its final destination inside the well, water rising inside the two lines eventually rises to a point of static equilibrium. The groundwater in the two lines is pumped from the system by releasing gas at the calculated minimum pneumatic lift pressure. As the groundwater dispenses from the sample return line, flow is continuous until all of the groundwater in the gas-in and sample return lines is discharged. During pressurization, the stainless steel poppet inside the pump's valve chamber is forced to seat against an o-ring located at the bottom of the chamber – and therefore preventing back flow back out through the bottom of the valve. As a result, the water in the sample return line is pushed by the water in the gas-in line in a “u-path”, and ascends up the sample return line as a single slug. When all of the groundwater has exited the sample return line, the back end of the water slug is followed by the compressed gas that was pushing the entire slug. At this point, the end of the discharge line sputters – signaling the end of the purge cycle. The gas pressure is then turned off and released – allowing new water from the well to refill both the gas-in and sample return lines. The procedure is typically repeated three times and the sample collected on the fourth purge cycle. This technique allows for the two lines to be cleaned by the water at each sample collection depth.

APPENDIX C

ASTM 2488 – DESCRIPTION AND IDENTIFICATION OF SOILS

Designation: D 2488 – 00

Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)[1]

This standard is issued under the fixed designation D 2488; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This practice covers procedures for the description of soils for engineering purposes.

1.2 This practice also describes a procedure for identifying soils, at the option of the user, based on the classification system described in Test Method D 2487. The identification is based on visual examination and manual tests. It must be clearly stated in reporting an identification that it is based on visual-manual procedures.

1.2.1 When precise classification of soils for engineering purposes is required, the procedures prescribed in Test Method D 2487 shall be used.

1.2.2 In this practice, the identification portion assigning a group symbol and name is limited to soil particles smaller than 3 in. (75 mm).

1.2.3 The identification portion of this practice is limited to naturally occurring soils (disturbed and undisturbed).

NOTE 1—This practice may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. (see Appendix X2).

1.3 The descriptive information in this practice may be used with other soil classification systems or for materials other than naturally occurring soils.

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements see Section 8.

1.6 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

D 1452 Practice for Soil Investigation and Sampling by Auger Borings[2]

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils[2]

D 1587 Practice for Thin-Walled Tube Sampling of Soils[2]

D 2113 Practice for Diamond Core Drilling for Site Investigation[2]

D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[2]

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and rock as Used in Engineering Design and Construction[3]

D 4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)[2]

3. Terminology

3.1 *Definitions*—Except as listed below, all definitions are in accordance with Terminology D 653.

NOTE 2—For particles retained on a 3-in. (75-mm) US standard sieve, the following definitions are suggested:
Cobbles—particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) sieve, and
Boulders—particles of rock that will not pass a 12-in. (300-mm) square opening.

3.1.1 *clay*—soil passing a No. 200 (75-μm) sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air-dry. For classification, a clay is a fine-grained soil, or the

---

[1] This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

Current edition approved Feb. 10, 2000. Published May 2000. Originally published as D 2488 – 66 T. Last previous edition D 2488 – 93$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] *Annual Book of ASTM Standards*, Vol 04.09.

***A Summary of Changes section appears at the end of this standard.**

fine-grained portion of a soil, with a plasticity index equal to or greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line (see Fig. 3 of Test Method D 2487).

3.1.2 *gravel*—particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

coarse—passes a 3-in. (75-mm) sieve and is retained on a ¾-in. (19-mm) sieve.

fine—passes a ¾-in. (19-mm) sieve and is retained on a No. 4 (4.75-mm) sieve.

3.1.3 *organic clay*—a clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay, except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.4 *organic silt*—a silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.5 *peat*—a soil composed primarily of vegetable tissue in various stages of decomposition usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

3.1.6 *sand*—particles of rock that will pass a No. 4 (4.75-mm) sieve and be retained on a No. 200 (75-µm) sieve with the following subdivisions:

coarse—passes a No. 4 (4.75-mm) sieve and is retained on a No. 10 (2.00-mm) sieve.

medium—passes a No. 10 (2.00-mm) sieve and is retained on a No. 40 (425-µm) sieve.

fine—passes a No. 40 (425-µm) sieve and is retained on a No. 200 (75-µm) sieve.

3.1.7 *silt*—soil passing a No. 200 (75-µm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less than 4, or the plot of plasticity index versus liquid limit falls below the "A" line (see Fig. 3 of Test Method D 2487).

4. Summary of Practice

4.1 Using visual examination and simple manual tests, this practice gives standardized criteria and procedures for describing and identifying soils.

4.2 The soil can be given an identification by assigning a group symbol(s) and name. The flow charts, Fig. 1a and Fig. 1b for fine-grained soils, and Fig. 2, for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name. If the soil has properties which do not distinctly place it into a specific group, borderline symbols may be used, see Appendix X3.

NOTE 3—It is suggested that a distinction be made between *dual symbols* and *borderline symbols.*

Dual Symbol—A dual symbol is two symbols separated by a hyphen, for example, GP-GM, SW-SC, CL-ML used to indicate that the soil has been identified as having the properties of a classification in accordance with Test Method D 2487 where two symbols are required. Two symbols are required when the soil has between 5 and 12 % fines or when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

Borderline Symbol—A borderline symbol is two symbols separated by a slash, for example, CL/CH, GM/SM, CL/ML. A borderline symbol should be used to indicate that the soil has been identified as having properties that do not distinctly place the soil into a specific group (see Appendix X3).

5. Significance and Use

5.1 The descriptive information required in this practice can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

5.2 The descriptive information required in this practice should be used to supplement the classification of a soil as determined by Test Method D 2487.

5.3 This practice may be used in identifying soils using the classification group symbols and names as prescribed in Test Method D 2487. Since the names and symbols used in this practice to identify the soils are the same as those used in Test Method D 2487, it shall be clearly stated in reports and all other appropriate documents, that the classification symbol and name are based on visual-manual procedures.

5.4 This practice is to be used not only for identification of soils in the field, but also in the office, laboratory, or wherever soil samples are inspected and described.

5.5 This practice has particular value in grouping similar soil samples so that only a minimum number of laboratory tests need be run for positive soil classification.

NOTE 4—The ability to describe and identify soils correctly is learned more readily under the guidance of experienced personnel, but it may also be acquired systematically by comparing numerical laboratory test results for typical soils of each type with their visual and manual characteristics.

5.6 When describing and identifying soil samples from a given boring, test pit, or group of borings or pits, it is not necessary to follow all of the procedures in this practice for every sample. Soils which appear to be similar can be grouped together; one sample completely described and identified with the others referred to as similar based on performing only a few of the descriptive and identification procedures described in this practice.

5.7 This practice may be used in combination with Practice D 4083 when working with frozen soils.

NOTE 5—Notwithstanding the statements on precision and bias contained in this standard: The precision of this test method is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D 3740 does not in itself assure reliable testing. Reliable testing depends on several factors; Practice D 3740 provides a means for evaluating some of those factors.

6. Apparatus

6.1 *Required Apparatus*:

6.1.1 *Pocket Knife or Small Spatula.*

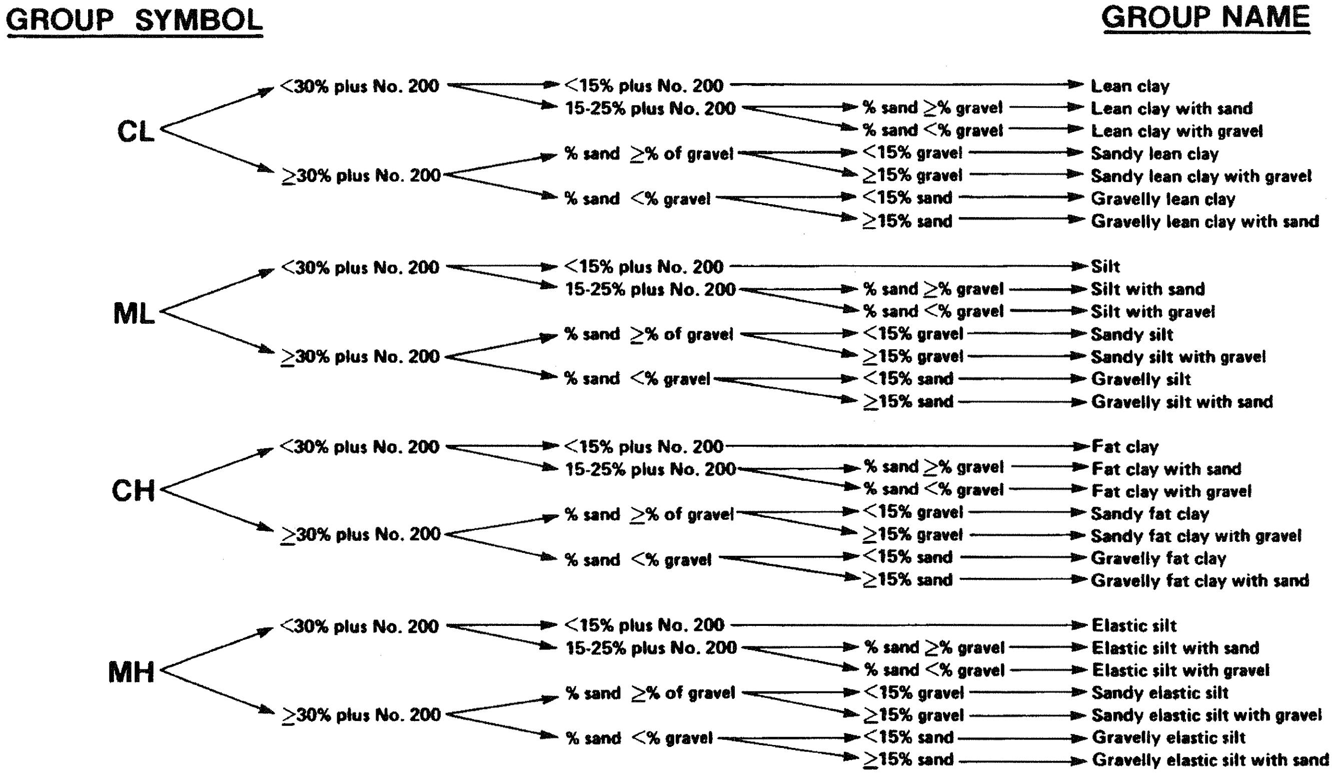
6.2 *Useful Auxiliary Apparatus*:

6.2.1 *Small Test Tube and Stopper* (or jar with a lid).

6.2.2 *Small Hand Lens.*

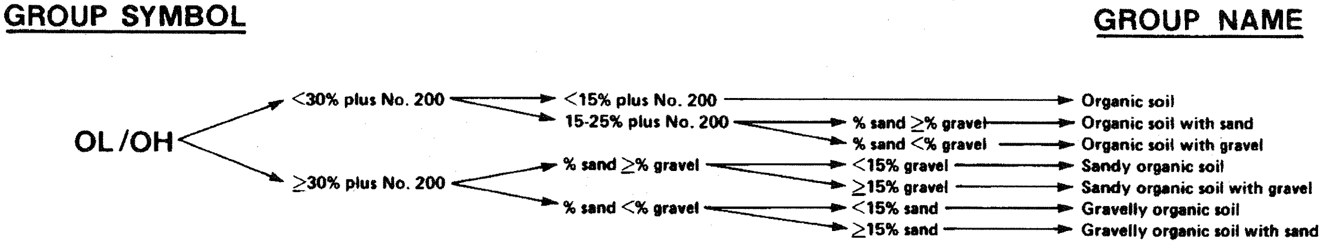
7. Reagents

7.1 *Purity of Water*—Unless otherwise indicated, references



NOTE 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1a Flow Chart for Identifying Inorganic Fine-Grained Soil (50 % or more fines)



NOTE 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1 b Flow Chart for Identifying Organic Fine-Grained Soil (50 % or more fines)

to water shall be understood to mean water from a city water supply or natural source, including non-potable water.

7.2 *Hydrochloric Acid*—A small bottle of dilute hydrochloric acid, HCl, one part HCl (10 *N*) to three parts water (This reagent is optional for use with this practice). See Section 8.

8. Safety Precautions

8.1 When preparing the dilute HCl solution of one part concentrated hydrochloric acid (10 *N*) to three parts of distilled water, slowly add acid into water following necessary safety precautions. Handle with caution and store safely. If solution comes into contact with the skin, rinse thoroughly with water.

8.2 **Caution**—Do not add water to acid.

9. Sampling

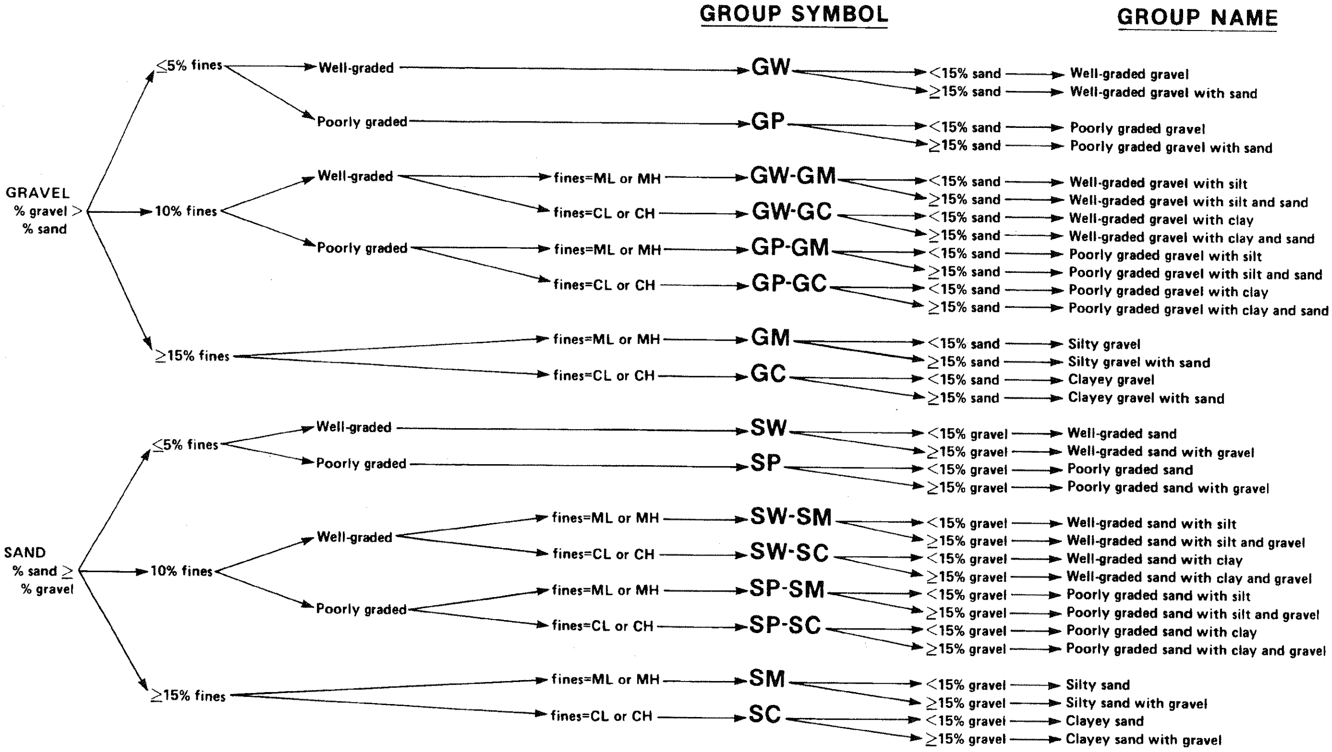
9.1 The sample shall be considered to be representative of the stratum from which it was obtained by an appropriate, accepted, or standard procedure.

NOTE 6—Preferably, the sampling procedure should be identified as having been conducted in accordance with Practices D 1452, D 1587, or D 2113, or Test Method D 1586.

9.2 The sample shall be carefully identified as to origin.

NOTE 7—Remarks as to the origin may take the form of a boring number and sample number in conjunction with a job number, a geologic stratum, a pedologic horizon or a location description with respect to a permanent monument, a grid system or a station number and offset with respect to a stated centerline and a depth or elevation.

9.3 For accurate description and identification, the minimum amount of the specimen to be examined shall be in accordance with the following schedule:



NOTE 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 2 Flow Chart for Identifying Coarse-Grained Soils (less than 50 % fines)

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, Dry Weight
4.75 mm (No. 4)	100 g (0.25 lb)
9.5 mm (⅜ in.)	200 g (0.5 lb)
19.0 mm (¾ in.)	1.0 kg (2.2 lb)
38.1 mm (1½ in.)	8.0 kg (18 lb)
75.0 mm (3 in.)	60.0 kg (132 lb)

NOTE 8—If random isolated particles are encountered that are significantly larger than the particles in the soil matrix, the soil matrix can be accurately described and identified in accordance with the preceeding schedule.

TABLE 1 Criteria for Describing Angularity of Coarse-Grained Particles (see Fig. 3)

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

9.4 If the field sample or specimen being examined is smaller than the minimum recommended amount, the report shall include an appropriate remark.

10. Descriptive Information for Soils

10.1 *Angularity*—Describe the angularity of the sand (coarse sizes only), gravel, cobbles, and boulders, as angular, subangular, subrounded, or rounded in accordance with the criteria in Table 1 and Fig. 3. A range of angularity may be stated, such as: subrounded to rounded.

10.2 *Shape*—Describe the shape of the gravel, cobbles, and boulders as flat, elongated, or flat and elongated if they meet the criteria in Table 2 and Fig. 4. Otherwise, do not mention the shape. Indicate the fraction of the particles that have the shape, such as: one-third of the gravel particles are flat.

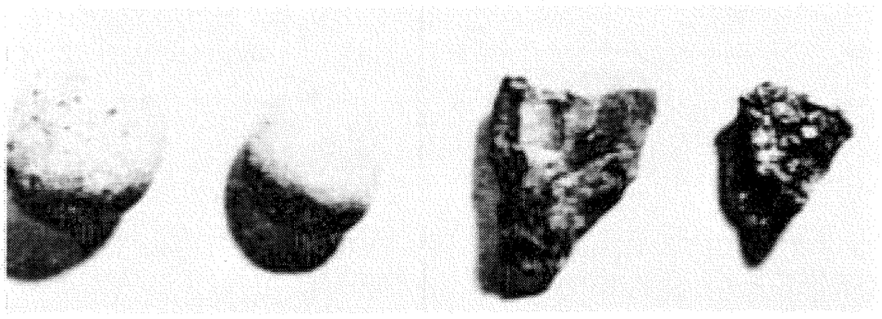
10.3 *Color*—Describe the color. Color is an important property in identifying organic soils, and within a given locality it may also be useful in identifying materials of similar geologic origin. If the sample contains layers or patches of varying colors, this shall be noted and all representative colors shall be described. The color shall be described for moist samples. If the color represents a dry condition, this shall be stated in the report.

10.4 *Odor*—Describe the odor if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples, but if the samples are dried, the odor may often be revived by heating a moistened sample. If the odor is unusual (petroleum product, chemical, and the like), it shall be described.

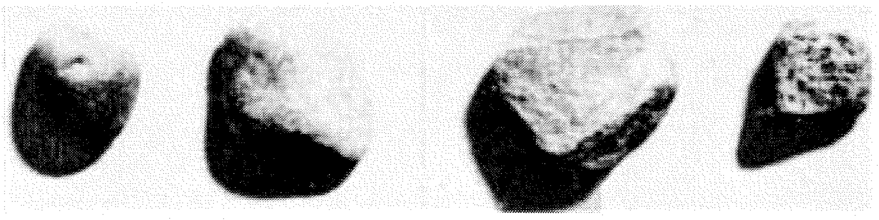
10.5 *Moisture Condition*—Describe the moisture condition as dry, moist, or wet, in accordance with the criteria in Table 3.

10.6 *HCl Reaction*—Describe the reaction with HCl as none, weak, or strong, in accordance with the critera in Table 4. Since calcium carbonate is a common cementing agent, a report of its presence on the basis of the reaction with dilute hydrochloric acid is important.

10.7 *Consistency*—For intact fine-grained soil, describe the



(a) Rounded (b) Angular



(c) Subrounded (d) Subangular

FIG. 3 Typical Angularity of Bulky Grains

TABLE 2 Criteria for Describing Particle Shape (see Fig. 4)

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

consistency as very soft, soft, firm, hard, or very hard, in accordance with the criteria in Table 5. This observation is inappropriate for soils with significant amounts of gravel.

10.8 *Cementation*—Describe the cementation of intact coarse-grained soils as weak, moderate, or strong, in accordance with the criteria in Table 6.

10.9 *Structure*—Describe the structure of intact soils in accordance with the criteria in Table 7.

10.10 *Range of Particle Sizes*—For gravel and sand components, describe the range of particle sizes within each component as defined in 3.1.2 and 3.1.6. For example, about 20 % fine to coarse gravel, about 40 % fine to coarse sand.

10.11 *Maximum Particle Size*—Describe the maximum particle size found in the sample in accordance with the following information:

10.11.1 *Sand Size*—If the maximum particle size is a sand size, describe as fine, medium, or coarse as defined in 3.1.6. For example: maximum particle size, medium sand.

10.11.2 *Gravel Size*—If the maximum particle size is a gravel size, describe the maximum particle size as the smallest sieve opening that the particle will pass. For example, maximum particle size, 1½ in. (will pass a 1½-in. square opening but not a ¾-in. square opening).

10.11.3 *Cobble or Boulder Size*—If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle. For example: maximum dimension, 18 in. (450 mm).

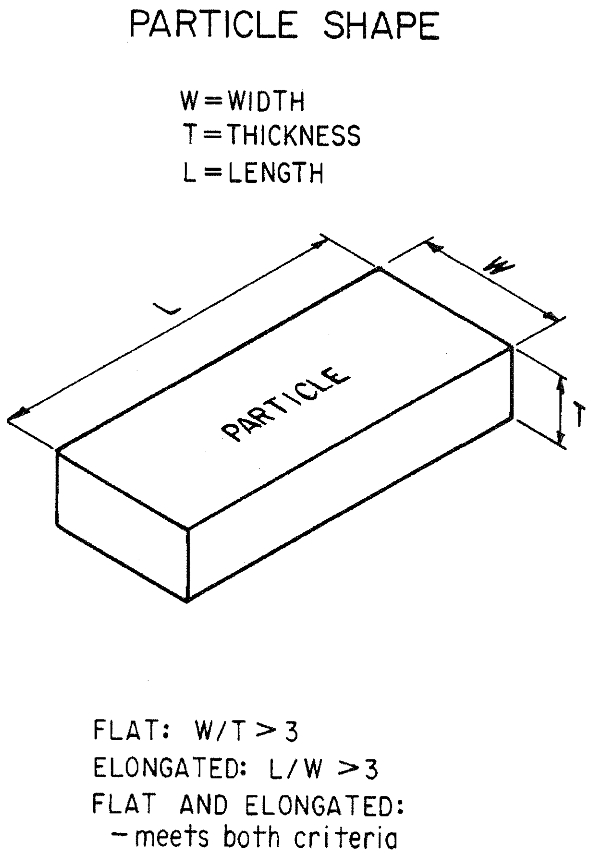


FIG. 4 Criteria for Particle Shape

10.12 *Hardness*—Describe the hardness of coarse sand and larger particles as hard, or state what happens when the

TABLE 3 Criteria for Describing Moisture Condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

TABLE 4 Criteria for Describing the Reaction With HCl

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

TABLE 5 Criteria for Describing Consistency

Description	Criteria
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about ¼in. (6 mm)
Hard	Thumb will not indent soil but readily indented with thumbnail
Very hard	Thumbnail will not indent soil

TABLE 6 Criteria for Describing Cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

TABLE 7 Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

particles are hit by a hammer, for example, gravel-size particles fracture with considerable hammer blow, some gravel-size particles crumble with hammer blow. "Hard" means particles do not crack, fracture, or crumble under a hammer blow.

10.13 Additional comments shall be noted, such as the presence of roots or root holes, difficulty in drilling or augering hole, caving of trench or hole, or the presence of mica.

10.14 A local or commercial name or a geologic interpretation of the soil, or both, may be added if identified as such.

10.15 A classification or identification of the soil in accordance with other classification systems may be added if identified as such.

11. Identification of Peat

11.1 A sample composed primarily of vegetable tissue in various stages of decomposition that has a fibrous to amorphous texture, usually a dark brown to black color, and an organic odor, shall be designated as a highly organic soil and shall be identified as peat, PT, and not subjected to the identification procedures described hereafter.

12. Preparation for Identification

12.1 The soil identification portion of this practice is based on the portion of the soil sample that will pass a 3-in. (75-mm) sieve. The larger than 3-in. (75-mm) particles must be removed, manually, for a loose sample, or mentally, for an intact sample before classifying the soil.

12.2 Estimate and note the percentage of cobbles and the percentage of boulders. Performed visually, these estimates will be on the basis of volume percentage.

NOTE 9—Since the percentages of the particle-size distribution in Test Method D 2487 are by dry weight, and the estimates of percentages for gravel, sand, and fines in this practice are by dry weight, it is recommended that the report state that the percentages of cobbles and boulders are by volume.

12.3 Of the fraction of the soil smaller than 3 in. (75 mm), estimate and note the percentage, by dry weight, of the gravel, sand, and fines (see Appendix X4 for suggested procedures).

NOTE 10—Since the particle-size components appear visually on the basis of volume, considerable experience is required to estimate the percentages on the basis of dry weight. Frequent comparisons with laboratory particle-size analyses should be made.

12.3.1 The percentages shall be estimated to the closest 5 %. The percentages of gravel, sand, and fines must add up to 100 %.

12.3.2 If one of the components is present but not in sufficient quantity to be considered 5 % of the smaller than 3-in. (75-mm) portion, indicate its presence by the term *trace*, for example, trace of fines. A trace is not to be considered in the total of 100 % for the components.

13. Preliminary Identification

13.1 The soil is *fine grained* if it contains 50 % or more fines. Follow the procedures for identifying fine-grained soils of Section 14.

13.2 The soil is *coarse grained* if it contains less than 50 % fines. Follow the procedures for identifying coarse-grained soils of Section 15.

14. Procedure for Identifying Fine-Grained Soils

14.1 Select a representative sample of the material for examination. Remove particles larger than the No. 40 sieve (medium sand and larger) until a specimen equivalent to about a handful of material is available. Use this specimen for performing the dry strength, dilatancy, and toughness tests.

14.2 *Dry Strength*:

14.2.1 From the specimen, select enough material to mold into a ball about 1 in. (25 mm) in diameter. Mold the material until it has the consistency of putty, adding water if necessary.

14.2.2 From the molded material, make at least three test specimens. A test specimen shall be a ball of material about ½ in. (12 mm) in diameter. Allow the test specimens to dry in air, or sun, or by artificial means, as long as the temperature does not exceed 60°C.

14.2.3 If the test specimen contains natural dry lumps, those that are about ½ in. (12 mm) in diameter may be used in place of the molded balls.

NOTE 11—The process of molding and drying usually produces higher strengths than are found in natural dry lumps of soil.

14.2.4 Test the strength of the dry balls or lumps by crushing between the fingers. Note the strength as none, low, medium, high, or very high in accorance with the criteria in Table 8. If natural dry lumps are used, do not use the results of any of the lumps that are found to contain particles of coarse sand.

14.2.5 The presence of high-strength water-soluble cementing materials, such as calcium carbonate, may cause exceptionally high dry strengths. The presence of calcium carbonate can usually be detected from the intensity of the reaction with dilute hydrochloric acid (see 10.6).

14.3 *Dilatancy*:

14.3.1 From the specimen, select enough material to mold into a ball about ½ in. (12 mm) in diameter. Mold the material, adding water if necessary, until it has a soft, but not sticky, consistency.

14.3.2 Smooth the soil ball in the palm of one hand with the blade of a knife or small spatula. Shake horizontally, striking the side of the hand vigorously against the other hand several times. Note the reaction of water appearing on the surface of the soil. Squeeze the sample by closing the hand or pinching the soil between the fingers, and note the reaction as none, slow, or rapid in accordance with the criteria in Table 9. The reaction is the speed with which water appears while shaking, and disappears while squeezing.

14.4 *Toughness*:

14.4.1 Following the completion of the dilatancy test, the test specimen is shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about ⅛ in. (3 mm) in diameter. (If the sample is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation.) Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about ⅛ in. The thread will crumble at a diameter of ⅛ in. when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

14.4.2 Describe the toughness of the thread and lump as low, medium, or high in accordance with the criteria in Table 10.

TABLE 8 Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface

TABLE 9 Criteria for Describing Dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

14.5 *Plasticity*—On the basis of observations made during the toughness test, describe the plasticity of the material in accordance with the criteria given in Table 11.

14.6 Decide whether the soil is an *inorganic* or an *organic* fine-grained soil (see 14.8). If inorganic, follow the steps given in 14.7.

14.7 *Identification of Inorganic Fine-Grained Soils*:

14.7.1 Identify the soil as a *lean clay*, CL, if the soil has medium to high dry strength, no or slow dilatancy, and medium toughness and plasticity (see Table 12).

14.7.2 Identify the soil as a *fat clay*, CH, if the soil has high to very high dry strength, no dilatancy, and high toughness and plasticity (see Table 12).

14.7.3 Identify the soil as a *silt*, ML, if the soil has no to low dry strength, slow to rapid dilatancy, and low toughness and plasticity, or is nonplastic (see Table 12).

14.7.4 Identify the soil as an *elastic silt*, MH, if the soil has low to medium dry strength, no to slow dilatancy, and low to medium toughness and plasticity (see Table 12).

NOTE 12—These properties are similar to those for a lean clay. However, the silt will dry quickly on the hand and have a smooth, silky feel when dry. Some soils that would classify as MH in accordance with the criteria in Test Method D 2487 are visually difficult to distinguish from lean clays, CL. It may be necessary to perform laboratory testing for proper identification.

14.8 *Identification of Organic Fine-Grained Soils*:

14.8.1 Identify the soil as an *organic soil*, OL/OH, if the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soils will change color, for example, black to brown, when exposed to the air. Some organic soils will lighten in color significantly when air dried. Organic soils normally will not have a high toughness or plasticity. The thread for the toughness test will be spongy.

NOTE 13—In some cases, through practice and experience, it may be possible to further identify the organic soils as organic silts or organic clays, OL or OH. Correlations between the dilatancy, dry strength, toughness tests, and laboratory tests can be made to identify organic soils in certain deposits of similar materials of known geologic origin.

TABLE 10 Criteria for Describing Toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

TABLE 11 Criteria for Describing Plasticity

Description	Criteria
Nonplastic	A ⅛-in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

TABLE 12 Identification of Inorganic Fine-Grained Soils from Manual Tests

Soil Symbol	Dry Strength	Dilatancy	Toughness
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High

14.9 If the soil is estimated to have 15 to 25 % sand or gravel, or both, the words "with sand" or "with gravel" (whichever is more predominant) shall be added to the group name. For example: "lean clay with sand, CL" or "silt with gravel, ML" (see Fig. 1a and Fig. 1b). If the percentage of sand is equal to the percentage of gravel, use "with sand."

14.10 If the soil is estimated to have 30 % or more sand or gravel, or both, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if there appears to be more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand. For example: "sandy lean clay, CL", "gravelly fat clay, CH", or "sandy silt, ML" (see Fig. 1a and Fig. 1b). If the percentage of sand is equal to the percent of gravel, use "sandy."

15. Procedure for Identifying Coarse-Grained Soils

(Contains less than 50 % fines)

15.1 The soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand.

15.2 The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage of sand.

15.3 The soil is a *clean gravel* or *clean sand* if the percentage of fines is estimated to be 5 % or less.

15.3.1 Identify the soil as a *well-graded gravel*, GW, or as a *well-graded sand*, SW, if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes.

15.3.2 Identify the soil as a *poorly graded gravel*, GP, or as a *poorly graded sand*, SP, if it consists predominantly of one size (uniformly graded), or it has a wide range of sizes with some intermediate sizes obviously missing (gap or skip graded).

15.4 The soil is either a *gravel with fines* or a *sand with fines* if the percentage of fines is estimated to be 15 % or more.

15.4.1 Identify the soil as a *clayey gravel*, GC, or a *clayey sand*, SC, if the fines are clayey as determined by the procedures in Section 14.

15.4.2 Identify the soil as a *silty gravel*, GM, or a *silty sand*, SM, if the fines are silty as determined by the procedures in Section 14.

15.5 If the soil is estimated to contain 10 % fines, give the soil a dual identification using two group symbols.

15.5.1 The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, SM).

15.5.2 The group name shall correspond to the first group symbol plus the words "with clay" or "with silt" to indicate the plasticity characteristics of the fines. For example: "well-graded gravel with clay, GW-GC" or "poorly graded sand with silt, SP-SM" (see Fig. 2).

15.6 If the specimen is predominantly sand or gravel but contains an estimated 15 % or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example: "poorly graded gravel with sand, GP" or "clayey sand with gravel, SC" (see Fig. 2).

15.7 If the field sample contains any cobbles or boulders, or both, the words "with cobbles" or "with cobbles and boulders" shall be added to the group name. For example: "silty gravel with cobbles, GM."

16. Report

16.1 The report shall include the information as to origin, and the items indicated in Table 13.

NOTE 14—*Example: Clayey Gravel with Sand and Cobbles, GC*—About 50 % fine to coarse, subrounded to subangular gravel; about 30 % fine to coarse, subrounded sand; about 20 % fines with medium plasticity, high dry strength, no dilatancy, medium toughness; weak reaction with HCl; original field sample had about 5 % (by volume) subrounded cobbles, maximum dimension, 150 mm.

In-Place Conditions—Firm, homogeneous, dry, brown

Geologic Interpretation—Alluvial fan

TABLE 13 Checklist for Description of Soils

1. Group name
2. Group symbol
3. Percent of cobbles or boulders, or both (by volume)
4. Percent of gravel, sand, or fines, or all three (by dry weight)
5. Particle-size range:
   Gravel—fine, coarse
   Sand—fine, medium, coarse
6. Particle angularity: angular, subangular, subrounded, rounded
7. Particle shape: (if appropriate) flat, elongated, flat and elongated
8. Maximum particle size or dimension
9. Hardness of coarse sand and larger particles
10. Plasticity of fines: nonplastic, low, medium, high
11. Dry strength: none, low, medium, high, very high
12. Dilatancy: none, slow, rapid
13. Toughness: low, medium, high
14. Color (in moist condition)
15. Odor (mention only if organic or unusual)
16. Moisture: dry, moist, wet
17. Reaction with HCl: none, weak, strong

For intact samples:

18. Consistency (fine-grained soils only): very soft, soft, firm, hard, very hard
19. Structure: stratified, laminated, fissured, slickensided, lensed, homogeneous
20. Cementation: weak, moderate, strong
21. Local name
22. Geologic interpretation
23. Additional comments: presence of roots or root holes, presence of mica, gypsum, etc., surface coatings on coarse-grained particles, caving or sloughing of auger hole or trench sides, difficulty in augering or excavating, etc.

NOTE 15—Other examples of soil descriptions and identification are given in Appendix X1 and Appendix X2.

NOTE 16—If desired, the percentages of gravel, sand, and fines may be stated in terms indicating a range of percentages, as follows:

Trace—Particles are present but estimated to be less than 5 %
Few—5 to 10 %
Little—15 to 25 %
Some—30 to 45 %
Mostly—50 to 100 %

16.2 If, in the soil description, the soil is identified using a classification group symbol and name as described in Test Method D 2487, it must be distinctly and clearly stated in log forms, summary tables, reports, and the like, that the symbol and name are based on visual-manual procedures.

17. Precision and Bias

17.1 This practice provides qualitative information only, therefore, a precision and bias statement is not applicable.

18. Keywords

18.1 classification; clay; gravel; organic soils; sand; silt; soil classification; soil description; visual classification

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF VISUAL SOIL DESCRIPTIONS

X1.1 The following examples show how the information required in 16.1 can be reported. The information that is included in descriptions should be based on individual circumstances and need.

X1.1.1 *Well-Graded Gravel with Sand (GW)*—About 75 % fine to coarse, hard, subangular gravel; about 25 % fine to coarse, hard, subangular sand; trace of fines; maximum size, 75 mm, brown, dry; no reaction with HCl.

X1.1.2 *Silty Sand with Gravel (SM)*—About 60 % predominantly fine sand; about 25 % silty fines with low plasticity, low dry strength, rapid dilatancy, and low toughness; about 15 % fine, hard, subrounded gravel, a few gravel-size particles fractured with hammer blow; maximum size, 25 mm; no reaction with HCl (Note—Field sample size smaller than recommended).

In-Place Conditions—Firm, stratified and contains lenses of silt 1 to 2 in. (25 to 50 mm) thick, moist, brown to gray; in-place density 106 lb/ft^3; in-place moisture 9 %.

X1.1.3 *Organic Soil (OL/OH)*—About 100 % fines with low plasticity, slow dilatancy, low dry strength, and low toughness; wet, dark brown, organic odor; weak reaction with HCl.

X1.1.4 *Silty Sand with Organic Fines (SM)*—About 75 % fine to coarse, hard, subangular reddish sand; about 25 % organic and silty dark brown nonplastic fines with no dry strength and slow dilatancy; wet; maximum size, coarse sand; weak reaction with HCl.

X1.1.5 *Poorly Graded Gravel with Silt, Sand, Cobbles and Boulders (GP-GM)*—About 75 % fine to coarse, hard, subrounded to subangular gravel; about 15 % fine, hard, subrounded to subangular sand; about 10 % silty nonplastic fines; moist, brown; no reaction with HCl; original field sample had about 5 % (by volume) hard, subrounded cobbles and a trace of hard, subrounded boulders, with a maximum dimension of 18 in. (450 mm).

X2. USING THE IDENTIFICATION PROCEDURE AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SHELLS, SLAG, CRUSHED ROCK, AND THE LIKE

X2.1 The identification procedure may be used as a descriptive system applied to materials that exist in-situ as shale, claystone, sandstone, siltstone, mudstone, etc., but convert to soils after field or laboratory processing (crushing, slaking, and the like).

X2.2 Materials such as shells, crushed rock, slag, and the like, should be identified as such. However, the procedures used in this practice for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, an identification using a group name and symbol according to this practice may be assigned to aid in describing the material.

X2.3 The group symbol(s) and group names should be placed in quotation marks or noted with some type of distinguishing symbol. See examples.

X2.4 Examples of how group names and symbols can be incororated into a descriptive system for materials that are not naturally occurring soils are as follows:

X2.4.1 *Shale Chunks*—Retrieved as 2 to 4-in. (50 to 100-mm) pieces of shale from power auger hole, dry, brown, no reaction with HCl. After slaking in water for 24 h, material identified as "Sandy Lean Clay (CL)"; about 60 % fines with medium plasticity, high dry strength, no dilatancy, and medium toughness; about 35 % fine to medium, hard sand; about 5 % gravel-size pieces of shale.

X2.4.2 *Crushed Sandstone*—Product of commercial crushing operation; "Poorly Graded Sand with Silt (SP-SM)"; about 90 % fine to medium sand; about 10 % nonplastic fines; dry, reddish-brown, strong reaction with HCl.

X2.4.3 *Broken Shells*—About 60 % gravel-size broken shells; about 30 % sand and sand-size shell pieces; about 10 % fines; "Poorly Graded Gravel with Sand (GP)."

X2.4.4 *Crushed Rock*—Processed from gravel and cobbles in Pit No. 7; "Poorly Graded Gravel (GP)"; about 90 % fine, hard, angular gravel-size particles; about 10 % coarse, hard, angular sand-size particles; dry, tan; no reaction with HCl.

X3. SUGGESTED PROCEDURE FOR USING A BORDERLINE SYMBOL FOR SOILS WITH TWO POSSIBLE IDENTIFICATIONS.

X3.1 Since this practice is based on estimates of particle size distribution and plasticity characteristics, it may be difficult to clearly identify the soil as belonging to one category. To indicate that the soil may fall into one of two possible basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example: SC/CL or CL/CH.

X3.1.1 A borderline symbol may be used when the percentage of fines is estimated to be between 45 and 55 %. One symbol should be for a coarse-grained soil with fines and the other for a fine-grained soil. For example: GM/ML or CL/SC.

X3.1.2 A borderline symbol may be used when the percentage of sand and the percentage of gravel are estimated to be about the same. For example: GP/SP, SC/GC, GM/SM. It is practically impossible to have a soil that would have a borderline symbol of GW/SW.

X3.1.3 A borderline symbol may be used when the soil could be either well graded or poorly graded. For example: GW/GP, SW/SP.

X3.1.4 A borderline symbol may be used when the soil could either be a silt or a clay. For example: CL/ML, CH/MH, SC/SM.

X3.1.5 A borderline symbol may be used when a fine-grained soil has properties that indicate that it is at the boundary between a soil of low compressibility and a soil of high compressibility. For example: CL/CH, MH/ML.

X3.2 The order of the borderline symbols should reflect similarity to surrounding or adjacent soils. For example: soils in a borrow area have been identified as CH. One sample is considered to have a borderline symbol of CL and CH. To show similarity, the borderline symbol should be CH/CL.

X3.3 The group name for a soil with a borderline symbol should be the group name for the first symbol, except for:

CL/CH lean to fat clay
ML/CL clayey silt
CL/ML silty clay

X3.4 The use of a borderline symbol should not be used indiscriminately. Every effort shall be made to first place the soil into a single group.

X4. SUGGESTED PROCEDURES FOR ESTIMATING THE PERCENTAGES OF GRAVEL, SAND, AND FINES IN A SOIL SAMPLE

X4.1 *Jar Method*—The relative percentage of coarse- and fine-grained material may be estimated by thoroughly shaking a mixture of soil and water in a test tube or jar, and then allowing the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 s. The relative proportions can be estimated from the relative volume of each size separate. This method should be correlated to particle-size laboratory determinations.

X4.2 *Visual Method*—Mentally visualize the gravel size particles placed in a sack (or other container) or sacks. Then, do the same with the sand size particles and the fines. Then, mentally compare the number of sacks to estimate the percentage of plus No. 4 sieve size and minus No. 4 sieve size present. The percentages of sand and fines in the minus sieve size No. 4 material can then be estimated from the wash test (X4.3).

X4.3 *Wash Test (for relative percentages of sand and fines)*—Select and moisten enough minus No. 4 sieve size material to form a 1-in (25-mm) cube of soil. Cut the cube in half, set one-half to the side, and place the other half in a small dish. Wash and decant the fines out of the material in the dish until the wash water is clear and then compare the two samples and estimate the percentage of sand and fines. Remember that the percentage is based on weight, not volume. However, the volume comparison will provide a reasonable indication of grain size percentages.

X4.3.1 While washing, it may be necessary to break down lumps of fines with the finger to get the correct percentages.

X5. ABBREVIATED SOIL CLASSIFICATION SYMBOLS

X5.1 In some cases, because of lack of space, an abbreviated system may be useful to indicate the soil classification symbol and name. Examples of such cases would be graphical logs, databases, tables, etc.

X5.2 This abbreviated system is not a substitute for the full name and descriptive information but can be used in supplementary presentations when the complete description is referenced.

X5.3 The abbreviated system should consist of the soil classification symbol based on this standard with appropriate lower case letter prefixes and suffixes as:

Prefix:	Suffix:
s = sandy	s = with sand
g = gravelly	g = with gravel
	c = with cobbles
	b = with boulders

X5.4 The soil classification symbol is to be enclosed in parenthesis. Some examples would be:

Group Symbol and Full Name	Abbreviated
CL, Sandy lean clay	s(CL)
SP-SM, Poorly graded sand with silt and gravel	(SP-SM)g
GP, poorly graded gravel with sand, cobbles, and boulders	(GP)scb
ML, gravelly silt with sand and cobbles	g(ML)sc

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition ($1993^{\epsilon 1}$) that may impact the use of this standard.

(1) Added Practice D 3740 to Section 2.

(2) Added Note 5 under 5.7 and renumbered subsequent notes.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).

APPENDIX D

ADEQ DATA QUALIFIERS

Arizona Laboratory Data Qualifiers

Revision 1.0

03/20/2002

(Developed by the Technical Subcommittee of the Arizona Environmental Laboratory Advisory Committee. This is a revised list with additional qualifiers added to the original list dated 12/11/2000)

Microbiology:

A1 = Too numerous to count.

A2 = Sample incubation period exceeded method requirement.

A3 = Sample incubation period was shorter than method requirement.

A4 = Target organism detected in associated method blank.

A5 = Incubator/water bath temperature was outside method requirements.

A6 = Target organism not detected in associated positive control.

A7 = Micro sample received without adequate headspace.

Method blank:

B1 = Target analyte detected in method blank at or above the method reporting limit.

B2 = Non-target analyte detected in method blank and sample, producing interference.

B3 = Target analyte detected in calibration blank at or above the method reporting limit.

B4 = Target analyte detected in blank at/above method acceptance criteria.

B5 = Target analyte detected in method blank at or above the method reporting limit, but below trigger level or MCL.

B6 = Target analyte detected in calibration blank at or above the method reporting limit, but below trigger level or MCL.

B7 = Target analyte detected in method blank at or above the method reporting limit. Concentration found in the sample was 10 times above the concentration found in the method blank.

Confirmation:

C1 = Confirmatory analysis not performed as required by the method.

C2 = Confirmatory analysis not performed. Confirmation of analyte presence established by site historical data.

C3 = Qualitative confirmation performed. See case narrative.

C4 = Confirmatory analysis was past holding time.

C5 = Confirmatory analysis was past holding time. Original result not confirmed.

Dilution:

D1 = Sample required dilution due to matrix interference. See case narrative.

D2 = Sample required dilution due to high concentration of target analyte.

D3 = Sample dilution required due to insufficient sample.

D4 = Minimum reporting level (MRL) adjusted to reflect sample amount received and analyzed.

Estimated concentration:

E1 = Concentration estimated. Analyte exceeded calibration range. Reanalysis not possible due to insufficient sample.

E2 = Concentration estimated. Analyte exceeded calibration range. Reanalysis not performed due to sample matrix.

E3 = Concentration estimated. Analyte exceeded calibration range. Reanalysis not performed due to holding time requirements.

E4 = Concentration estimated. Analyte was detected below laboratory minimum reporting level (MRL).

E5 = Concentration estimated. Analyte was detected below laboratory minimum reporting level (MRL), but not confirmed by alternate analysis.

E6 = Concentration estimated. Internal standard recoveries did not meet method acceptance criteria.

E7 = Concentration estimated. Internal standard recoveries did not meet laboratory acceptance criteria.

Hold time:

H1 = Sample analysis performed past holding time. See case narrative.

H2 = Initial analysis within holding time. Reanalysis for the required dilution was past holding time.

H3 = Sample was received and analyzed past holding time.

H4 = Sample was extracted past required extraction holding time, but analyzed within analysis holding time. See case narrative.

BOD:

K1 = The sample dilutions set-up for the BOD analysis did not meet the oxygen depletion criteria of at least 2 mg/L. Any reported result is an estimated value.

K2 = The sample dilutions set up for the BOD analysis did not meet the criteria of a residual dissolved oxygen of at least 1 mg/L. Any reported result is an estimated value.

K3 = The seed depletion was outside the method acceptance limits.

K4 = The seed depletion was outside the method and laboratory acceptance limits. The reported result is an estimated value.

K5 = The dilution water D.O. depletion was > 0.2 mg/L.

K6 = Glucose/glutamic acid BOD was below method acceptance criteria.

K7 = A discrepancy between the BOD and COD results has been verified by reanalysis of the sample for COD.

K8 = Glucose/glutamic acid BOD was above method acceptance levels.

Laboratory fortified blank/blank spike:

L1 = The associated blank spike recovery was above laboratory acceptance limits. See case narrative.

L2 = The associated blank spike recovery was below laboratory acceptance limits. See case narrative.

L3 = The associated blank spike recovery was above method acceptance limits. See case narrative.

L4 = The associated blank spike recovery was below method acceptance limits. See case narrative.

Note: The L1, L2, L3 & L4 footnotes need to be added to all corresponding analytes for a sample.

Matrix spike:

M1 = Matrix spike recovery was high, the method control sample recovery was acceptable.

M2 = Matrix spike recovery was low, the method control sample recovery was acceptable.

M3 = The accuracy of the spike recovery value is reduced since the analyte concentration in the sample is disproportionate to spike level. The method control sample recovery was acceptable.

M4 = The analysis of the spiked sample required a dilution such that the spike concentration was diluted below the reporting limit. The method control sample recovery was acceptable.

M5 = Analyte concentration was determined by the method of standard addition (MSA).

M6 = Matrix spike recovery was high. Data reported per ADEQ policy 0154.000.

M7 = Matrix spike recovery was low. Data reported per ADEQ policy 0154.000.

General:

N1 = See case narrative.

N2 = See corrective action report.

Sample quality:

Q1 = Sample integrity was not maintained. See case narrative.

Q2 = Sample received with head space.

Q3 = Sample received with improper chemical preservation.

Q4 = Sample received and analyzed without chemical preservation.

Q5 = Sample received with inadequate chemical preservation, but preserved by the laboratory.

Q6 = Sample was received above recommended temperature.

Q7 = Sample inadequately dechlorinated.

Q8 = Insufficient sample received to meet method QC requirements. QC requirements satisfy ADEQ policies 0154 and 0155.

Q9 = Insufficient sample received to meet method QC requirements.

Q10= Sample received in inappropriate sample container.

Q11= Sample is heterogeneous. Sample homogeneity could not be readily achieved using routine laboratory practices.

Duplicates:

R1 = RPD exceeded the method control limit. See case narrative.

R2 = RPD exceeded the laboratory control limit. See case narrative.

R3 = Sample RPD between the primary and confirmatory analysis exceeded 40%. Per EPA Method 8000B, the higher value was reported.

R4 = MS/MSD RPD exceeded the method control limit. Recovery met acceptance criteria.

R5 = MS/MSD RPD exceeded the laboratory control limit. Recovery met acceptance criteria.

R6 = LFB/LFBD RPD exceeded the method control limit. Recovery met acceptance criteria.

R7 = LFB/LFBD RPD exceeded the laboratory control limit. Recovery met acceptance criteria.

R8 = Sample RPD exceeded the method control limit.

R9 = Sample RPD exceeded the laboratory control limit.

Surrogate:

S1 = Surrogate recovery was above laboratory acceptance limits, but within method acceptance limits.

S2 = Surrogate recovery was above laboratory and method acceptance limits.

S3 = Surrogate recovery was above laboratory acceptance limits, but within method acceptance limits. No target analytes were detected in the sample.

S4 = Surrogate recovery was above laboratory and method acceptance limits. No target analytes were detected in the sample.

S5 = Surrogate recovery was below laboratory acceptance limits, but within method acceptance limits.

S6 = Surrogate recovery was below laboratory and method acceptance limits. Reextraction and/or reanalysis confirms low recovery caused by matrix effect.

S7 = Surrogate recovery was below laboratory and method acceptance limits. Unable to confirm matrix effect.

S8 = The analysis of the sample required a dilution such that the surrogate concentration was diluted below the method acceptance criteria. The method control sample recovery was acceptable.

S9 = The analysis of the sample required a dilution such that the surrogate concentration was diluted below the laboratory acceptance criteria. The method control sample recovery was acceptable.

S10 = Surrogate recovery was above laboratory and method acceptance limits. See Case narrative.

S11 = Surrogate recovery was high. Data reported per ADEQ policy 0154.000.

S12 = Surrogate recovery was low. Data reported per ADEQ policy 0154.000.

Method/analyte discrepancies:

T1 = Method promulgated by EPA, but not by ADHS at this time.

T2 = Cited ADHS licensed method does not contain this analyte as part of method compound list.

T3 = Method not promulgated either by EPA or ADHS.

T4 = Tentatively identified compound. Concentration is estimated and based on the closest internal standard.

Calibration verification:

V1 = CCV recovery was above method acceptance limits. This target analyte was not detected in the sample.

V2 = CCV recovery was above method acceptance limits. This target analyte was detected in the sample. The sample could not be reanalyzed due to insufficient sample.

V3 = CCV recovery was above method acceptance limits. This target analyte was detected in the sample, but the sample was not reanalyzed. See case narrative.

V4 = CCV recovery was below method acceptance limits. The sample could not be reanalyzed due to insufficient sample.

V5 = CCV recovery after a group of samples was above acceptance limits. This target analyte was not detected in the sample. Acceptable per EPA Method 8000B.

V6 = Data reported from one-pont calibration criteria per ADEQ policy 0155.000.

V7 = Calibration verification recovery was above the method control limit for this analyte, however the average % difference or % drift for all the analytes met method criteria.

V8 = Calibration verification recovery was below the method control limit for this analyte, however the average % difference or % drift for all the analytes met method criteria.

Calibration:

W1 = The % RSD for this compound was above 15%. The average % RSD for all compounds in the calibration met the 15% criteria as specified in EPA method 8000B.