PHASE II RCRA FACILITY INVESTIGATION SITE CHARACTERIZATION WORK PLAN EAST HELENA FACILITY

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SITE CHARACTERIZATION WORK PLAN
EAST HELENA FACILITY

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EAST HELENA FACILITY

1.0 INTRODUCTION

The East Helena Facility (the Facility) is a former custom lead smelter located in East Helena, Montana approximately three miles east of the City of Helena (Figure 1-1-1). The Facility began operations in 1888 and produced lead bullion from smelting of a variety of foreign and domestic concentrates, ores, fluxes, and other non-ferrous metal bearing materials. In addition to lead bullion, the Facility produced copper by-products and food-grade sulfuric acid. Plant operations were suspended in April 2001 and in August of 2005 ASARCO, LLC (Asarco) filed for Chapter 11 bankruptcy. Over the last 20+ years, extensive site clean-up activities have been undertaken at the Facility, including the demolition of numerous site structures. Ownership of the Facility was transferred from Asarco to the Montana Environmental Trust Group, LLC, as Trustee for the Montana Environmental Custodial Trust (the Custodial Trust) in December 2009 as part of the larger Asarco bankruptcy settlement agreement.

Previous investigations of the Facility have shown that surface and subsurface soils contain elevated concentrations of some metals, including cadmium, copper, lead and zinc, as well as arsenic. Groundwater monitoring on and downgradient of the Facility has also revealed a plume of elevated arsenic and a second selenium plume in groundwater extending north and northwestward from the Facility. The US Environmental Protection Agency (EPA) and the Montana Department of Environmental Quality (MDEQ) required Asarco to implement an extensive site investigation program and remediation activities at the Facility to address metals-impacted soils and groundwater. The Custodial Trust has assumed responsibility for completing these activities at the Facility.

This document represents a work plan for characterization of the East Helena Facility and surrounding area. The site characterization is intended to further quantify current site conditions in terms of soil and groundwater chemistry, and to further identify source areas for the groundwater plumes. The scope of work outlined in this document is one part of an ongoing Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) initiated by Asarco, and now being carried out by the Custodial Trust, under the direction of the EPA, as Lead-Agency for the Facility, in consultation with the MDEQ. Other portions of this Phase II RFI, namely an ecological risk assessment and a human health risk assessment, are being addressed in separate Phase II RFI work plans. Following is a brief description of the project background and history, and the East Helena Facility physical setting. A more detailed description of the project and Facility background is provided in Appendix A.

1.1 PROJECT BACKGROUND AND HISTORY

Previous investigations of the Facility have shown that surface and subsurface soils contain elevated concentrations of metals including, but not limited to, cadmium, copper, lead and zinc, as well as arsenic. In September 1984, the U.S. Environmental Protection Agency (EPA) listed the East Helena Facility on the National Priorities List (NPL) pursuant to Section 105 of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA). From 1984 through 1997, remedial actions conducted at the Facility by Asarco consisted of either voluntary actions or actions implemented as part of certain settlement agreements between EPA and Asarco under CERCLA. In 1997, EPA initiated a transfer of responsibility for on-going remedial activities at the Facility from its CERCLA program to its “corrective action” program under the Resource Conservation and Recovery Act (RCRA). A Consent Decree effective May 5, 1998 between EPA and Asarco (U.S. District Court, 1998) initiated the corrective action process in accordance with the RCRA program. As part of the Consent Decree, Asarco prepared a RCRA Current Conditions/Release Assessment (CC/RA) report (Hydrometrics, 1999a). The purpose of the RCRA CC/RA was to assess the completeness and quality of the existing data used to define, in whole or in part, the nature and extent of any hazardous waste and hazardous constituent releases, if any, at or migrating from the Facility.

Based on its review of the RCRA CC/RA, EPA determined that interim remedial measures were necessary and warranted for portions of the Facility, and a RCRA Interim Measures Work Plan (IMWP) was prepared (Hydrometrics, 1999b).

Concurrent with its approval of the RCRA IMWP, EPA determined that a RCRA Facility Investigation (RFI) was required for the Facility, with the RFI to be conducted in two phases. Objectives of the Phase I RFI included characterization and investigation of portions and aspects of the Facility not addressed as part of the interim measures process, and to provide sufficient data for development of corrective measures alternatives (see Phase I RFI Work Plan, Hydrometrics, 2000). Phase II of the RFI is intended to address site characterization issues not addressed in the Phase I RFI or other previous investigations and remedial actions (taken under RCRA and CERCLA), and an assessment of human health and ecological risk posed by the Facility. Information obtained through the Phase I and Phase II RFI will be used to prepare a RCRA Corrective Measures Study (CMS) for the East Helena Facility.

1.2 FACILITY SETTING AND FEATURES

The East Helena Facility is a former custom lead smelter located on approximately 142 acres. The Facility is located primarily on the Prickly Pear Creek alluvial plain, and is bounded to the south by Upper Lake and Lower Lake, to the east and northeast by Prickly Pear Creek, and on the west and southwest by uplands or foothills comprised of tertiary-age sediments. The Facility is bordered on the north by State Highway 12 and American Chemet (a manufacturer and marketer of metals-based chemicals), with the Town of East Helena located a short distance north of the Facility (Figure 1-1-1). Following is a brief discussion of Facility characteristics most relevant to the scope of work and objectives of this Phase II RFI Work Plan. Additional information on the Facility setting and characteristics is provided in Appendix A.

1.2.1 Surface Water

The East Helena Facility lies within the Prickly Pear Creek watershed, which is part of the Missouri River basin. Prickly Pear Creek flows along the east and northeast boundaries of the East Helena Facility from its headwaters in the Elkhorn and Boulder Mountains (about 30 miles south and west of the site) northward to Lake Helena (approximately seven miles north of the Facility). Prickly Pear Creek has been impacted by historical mining activities (upstream of and not associated with the Facility), resulting in elevated concentrations of some metals in stream water and sediments upgradient from the Facility as documented in other investigations (MDEQ, 2006; Baker and Baldigo, 1985).

Upper Lake is located at the extreme southern (hydrologically upgradient) end of the Facility (Figure 1-1-1) and is fed through diversion of flow from Prickly Pear Creek. Upper Lake discharges via return flow to the creek, seasonal discharge to the Wilson irrigation ditch, and through subsurface leakage to the local groundwater system. Upper Lake has been identified as a significant source of recharge to the groundwater system underlying the Facility. Past sampling has shown Upper Lake water to be of relatively good quality (low TDS and trace metal concentrations). Detailed sampling of Upper Lake water and sediments is included in the ecological risk assessment field sampling plan (Exponent, 2009a).

Wilson Ditch is an agricultural irrigation ditch extending from Upper Lake northwestward towards the Helena Valley (Figure 1-1-1). Prior to 1997, Wilson Ditch crossed the Facility in a buried concrete pipe. In 1997, the original pipe was replaced with an underground HDPE pipeline relocated immediately south of the Facility (Figure 1-1-1). Surface water and sediment sampling in Wilson Ditch is included in the ecological risk assessment field sampling plan (Exponent, 2009a).

Lower Lake is a former process water pond located immediately north of Upper Lake. Lower Lake receives recharge from precipitation, groundwater inflow and treated effluent from the Facility Water Treatment Plant (authorized under MPDES Permit No. MT-0030147). Outflow from Lower Lake occurs as seepage to the local groundwater system and evaporation. Seepage from Lower Lake has been identified as a historic source of metals loading to groundwater on the Facility, and possibly to adjacent Prickly Pear Creek. Lower Lake was the focus of an extensive remediation program in the mid-1990s including dredging of the lake sediments and placement of sediments in an on-site Corrective Action Management Unit (CAMU) landfill. As a result, dissolved arsenic concentrations in Lower Lake water have decreased from a range of 10 to 90 mg/L prior to 1995, to approximately 0.20 to 0.30 mg/L today. Lower Lake surface water and sediment sampling is included in the ecological risk assessment field sampling plan portion of the Phase II RFI (Exponent, 2009a), as is an assessment of potential impacts of Lower Lake seepage to adjacent Prickly Pear Creek water quality. The role of Lower Lake in the Facility hydrogeology and groundwater quality will be evaluated further under the Phase II RFI Site Characterization work plan.

1.2.2 Groundwater

Asarco has conducted groundwater and surface water monitoring at the East Helena Facility and surrounding area since 1984. The ongoing "Post-RI/FS Water Resources Monitoring Program" includes groundwater sampling at up to 160 monitoring wells (including 15 wells installed in 2009), several residential, municipal and industrial water supply wells, and surface water sampling on Prickly Pear Creek and Lower Lake. Relevant findings of the ongoing groundwater monitoring program are as follows:

- The primary aquifer on and downgradient of the Facility is an unconfined to semi-confined aquifer occupying unconsolidated alluvial/colluvial sediments. The majority of the Facility is underlain by a single sand and gravel aquifer with the aquifer base defined by a low permeability silt/clay layer. In the northern portion of the Facility, the aquifer becomes thicker with discontinuous fine-grained (silt) lenses occurring within the primary upper aquifer. In previous investigations (ACI, 2005), the upper aquifer was divided into a shallow aquifer and deeper 'intermediate' aquifer based on the presence of these fine-grained lenses. Based on further review of available information, including drilling of 15 additional wells in 2009, the shallow and deeper portions of the upper aquifer are believed to be in direct hydrologic communication and to act as a single shallow aquifer system.
- Groundwater at the site flows in a north to northwest direction from the Facility toward and west of East Helena.

- Primary sources of groundwater recharge include seepage from Upper Lake on the Facility, and seepage from Prickly Pear Creek north of the Facility. Other sources of recharge include precipitation recharge and groundwater inflow to the alluvial/colluvial aquifer from the surrounding foothills comprised of finer-grained tertiary sediments.
- Monitoring results have detected elevated arsenic concentrations in the shallow aquifer, with the mapped plume trending from the plant site to the north and northwest of the plant site. Previously identified arsenic source areas include: Lower Lake, the Speiss-Dross Plant Area, the Former Acid Plant, and Acid Plant Sediment Drying (APSD) Areas. All of these source areas have been the focus of extensive remediation efforts, including the recent (2006/07) encapsulation of contaminated soils in the Speiss-Dross and APSD areas within slurry walls (keyed into the underlying silt/clay layer) and temporary caps.
- In the past few years, elevated concentrations of selenium have also been detected in the shallow aquifer extending from the Facility to the north and northwest.
- The northward extent of the arsenic plume is reasonably well defined by past groundwater monitoring results. While site investigations in 2009 have led to better delineation of the selenium plume, the downgradient (northwest) extent of the plume has not yet been fully defined.

Full delineation of the selenium (and arsenic) groundwater plumes, as well as characterization of the plume characteristics and source areas, is a primary objective of the Phase II RFI work plan.

1.2.3 Facility Structures and Features

A number of current and historic Facility structures and features have been identified as sources or potential sources of metals loading to groundwater including: the acid plant area, the speiss-dross plant area, the ore storage areas, and the process water circuit, including Lower Lake. Another prominent feature at the Facility is the slag pile (a by-product of the smelting process), although the slag has not been shown to be a significant source of metals loading to groundwater in previous investigations. Many of these features have been addressed or removed through past site remediation efforts, including an extensive Facility demolition program. These current and historic features are described in previous documents, including the Comprehensive RI/FS document (Hydrometrics, 1990), the CC/RA report (Hydrometrics, 1999a) and the Phase I RFI report (ACI, 2005). The former and existing structures are shown in Figure 1-2-1 and discussed briefly below. A more detailed description of these features and the operational history of the Facility is provided in Appendix A.

Speiss/Dross Area: Primary features of the Speiss/Dross area, in terms of relevance to the RFI, include the speiss settling pond (the "Speiss Pond") and speiss granulating pit (the "Speiss Pit") formerly located immediately north of the dross plant (Figure 1-2-1). Until 1991, the Speiss Pond and Pit were used to store water for use in the speiss granulation process, where speiss (a molten copper bearing material) was poured into the granulation pit and sprayed with cool water from the Speiss Pond. The water then drained back to the Speiss Pond to be recirculated during the next granulation cycle. Leakage of process fluids from the speiss pit and pond have been identified as a historic source of metals loading to groundwater. Both of these areas were remediated and process water leakage terminated around 1990 as described below under the Process Water Circuit (Section 1.2.4).

Acid Plant Water Treatment Facility: The Acid Plant was used to produce food grade sulfuric acid for sale as a product. Prior to 1992, suspended sediments from the acid scrubbing process were settled in a concrete-lined settling pond and in-line settling tubs (dumpsters), and neutralized by lime application at the former acid reclaim facility. This system was identified as a source of process water leakage to groundwater, and a new Acid Plant Water Reclaim Facility was completed in November 1992. Remediation of the Acid Plant Area is described in Section 1.2.4.

Acid Plant Sediment Drying Area: From 1977 through 1991, sludge from the Acid Plant Water Treatment Plant was stored on the Acid Plant Sediment Drying (APSD) Pad north of Upper Lake (Figure 1-2-1). This area was identified as a source of arsenic loading to groundwater, and in July 1991, use of the APSD Pad was discontinued. In 2006, the APSD Pad area was encapsulated in a slurry wall (keyed into the low permeability clay layer acting as the aquifer base), and a temporary cap to isolate the impacted soils groundwater.

Ore Storage Areas: Two primary ore storage areas were used during smelter operations: the Upper Ore Storage Area and the Lower Ore Storage Area. The Upper Ore Storage Area was located in close proximity to Upper Lake and Lower Lake and contained stockpiles of ore and flux materials. Soil and construction debris stockpiles from historical plant operations were also stored in the area between Upper and Lower Lake (also referred to as Tito Park). Storage of materials in this area was discontinued in 1989 with all stockpiles placed in the Phase I CAMU in 2001.

The former Lower Ore Storage Area was located on the southeast portion the Facility (Figure 1-2-1) with ores and fluxes used in the smelting process stockpiled in this area. The area was also used to store soils from construction activities, and in the 1990s for temporary storage of soils and sediments excavated during various remedial actions. In 1989, a concentrate storage and handling building (ore storage building) was constructed. After this time, ores were stored in this building, while construction debris and soils excavated as part of construction and remediation activities continued to be stored in the Lower Ore Storage yard. In 2000, all sediments and debris were moved from the Lower Ore Storage Area to the Phase I CAMU cell.

Slag Pile: Slag is an iron silicate residue or by-product of the smelting process. Although it contains elevated concentrations of lead and zinc, these constituents are primarily bound in the chemically inert iron/silicate slag matrix. The slag pile is the largest feature on the smelter property, rising from 60 to 80 feet in height and containing an estimated 12 million tons of material. The slag pile consists of both fumed slag (slag that was processed to remove residual zinc) and unfumed slag (not processed for zinc). The effects of slag on water and air quality were investigated as part of the previous CERCLA RI/FS efforts, which concluded that the slag pile was not a major source of arsenic and selenium to groundwater.

Potential loading of contaminants to groundwater from the slag pile will be evaluated further during the Phase II investigation.

1.2.4 Process Water Circuit

Of particular interest to the ongoing site characterization and remediation programs at the Facility is the former process water circuit. The process circuit is no longer active, with the majority of system components abandoned through past site remediation activities. Historically, the normal operating process circuit included four process water ponds whose waters were found to contain elevated metals concentrations. Potential leakage from the former process water circuit has been identified as a historic source of metals loading to groundwater. The four process water ponds include:

- Former Acid Plant Settling Pond: The former Acid Plant Settling Pond was an approximately 68 foot by 35 foot by 9-foot deep concrete-lined structure used to settle particulates from the re-circulated scrubber fluids. In 1993, the “settling pond” was demolished and underlying soils excavated to depths up to 20 feet below grade, or about 10 feet below the water table. A total of 2200 cubic yards of soil were excavated and placed in the Phase I CAMU.
- Former Speiss Granulating Pond and Speiss Pit: Prior to its abandonment, cooling water stored in the former speiss pond was sprayed over molten speiss material located in the speiss pit. Both features were lined with concrete, with an HDPE liner installed in the speiss pond in 1988. In 1989 the Speiss pond was partially demolished and underlying soils excavated, and the pond replaced with a tank. The remainder of the pond was demolished and sediments removed in 1992, and the pond area covered with a concrete cap in 1993. The original granulating pit was abandoned in 1991, with the structure demolished and underlying soils excavated in 1995. All above-ground structures in the Speiss-Dross area were demolished in 2006. In 2007 the Speiss-Dross area was encapsulated within a slurry wall and temporary cap.
- Former Thornock Lake: Former Thornock Lake was an unlined process pond used to contain plant water and storm water runoff prior to 1987 after which it was replaced with a steel tank (Thornock Tank) housed within a concrete vault. Metals-impacted

sediments from the unlined former lake were excavated in two stages, the first in 1987 and the second in 1991. Excavation depths ranged up to approximately ten feet and the excavation area backfilled with clean earthen fill.

- Lower Lake: Lower Lake is approximately seven acres in surface area with a storage capacity of about 11 million gallons. Historically, Lower Lake was used to store water from the main plant process circuit. After construction of two one-million gallon storage tanks in 1989 and a high density sludge (HDS) water treatment plant in 1993, Asarco stopped using Lower Lake to store process water. Due to its historic use for storage of process fluids, water and sediments within Lower Lake were elevated in metals, leading to impacts to surrounding groundwater. To remedy this, Lower Lake sediments were dredged between 1994 and 1996, with the sediments dried and ultimately placed in the on-site CAMU Phase I Cell. Currently, Lower Lake receives flow from groundwater, precipitation and treated discharge from the HDS water treatment facility (MPDES Permit #MT-0030147). Outflows from Lower Lake are limited to subsurface seepage and evaporation.

The former and remaining process ponds are shown on Figure 1-2-1, and the process water circuit is described further in the CC/RA report (Hydrometrics, 1999a), and the Process Pond RI/FS document (Hydrometrics, 1989). Process circuit sediment and water data are included in Appendix B and C, respectively. The potential for ongoing groundwater impacts from the process water system will be examined as part of the Phase II RFI.

1.3 PROJECT SCOPE AND OBJECTIVES

This work plan addresses the site characterization portion of the Phase II RFI. The Phase II work plan represents a continuation of previous site characterization and evaluation programs, most notably the Comprehensive RI/FS, CC/RA report, and the Phase I RFI report, and relies heavily on data and information obtained through those programs.

Overall objectives of the Phase II site characterization include:

- Defining current site conditions in terms of the magnitude and extent of metals-impacted soils on the plant site, accounting for past and ongoing site remediation activities.
- Identifying and delineating source area(s) for the arsenic and selenium groundwater plumes.
- Evaluating the fate and transport of arsenic and selenium in the subsurface, and the current status and predicted future behavior of the groundwater plumes.
- Conducting a preliminary assessment of groundwater containment/treatment alternatives to control groundwater plume migration.
- Providing information and data required for completion of the human health and ecological risk assessment portions of the Phase II RFI, and an RCRA Corrective Measures Study.

The project objectives will be attained through detailed review and interpretation of existing information and development of a current conceptual model of the site (Section 2.0), implementation of a focused field sampling program based on the updated conceptual site model and project objectives (Section 3.0), and development of a numerical model of groundwater flow and contaminant transport for the East Helena Facility and surrounding area (Section 4.0). Supporting information is included as appendices to the work plan as referenced in the text. Although the site characterization activities detailed in this work plan will support completion of the risk assessment portion of the Phase II RFI, the risk assessments are being addressed in two separate work plans, including a June 2009 Baseline Ecological Risk Assessment Work Plan and Field Sampling and Analysis Plan (Exponent, 2009a), and a Human Health Risk Assessment Work Plan (Exponent, 2009b).

2.0 SUMMARY OF EXISTING CONDITIONS AND RELEVANT SOURCE AREA DATA

2.1 CURRENT SITE CONDITIONS

As described in Section 1.0 and Appendix A, the East Helena Facility has undergone significant changes over the past 20+ years due primarily to extensive site remediation activities and the 2001 plant shutdown. Remediation of the acid plant and speiss-dross process water facilities in the late 1980s-early 1990s, dredging of sediments from Lower Lake in the mid-1990s, elimination of the plant process fluids circuit, removal of the various soil, sediment and ore stockpiles from the plant site and placement in the Phase I CAMU cell in the early 2000s, construction of slurry walls at the Acid Plant Sediment area and Speiss/Dross area, and the current plant site demolition program with all wastes being placed in a second (Phase II) CAMU cell have all affected current conditions in terms of metals concentrations in on-site soils and potential groundwater plume source areas. In order to facilitate the review of relevant data incorporated into the updated site conceptual model, current site conditions are summarized below, followed by a summary of current soils chemistry data relevant to the Phase II RFI. A comprehensive project soils database is included in Appendix B, with all soils chemistry data segregated by “Remediated Areas-Data No Longer Current” and “Non-Remediated Areas,” meaning soils represented by these samples have not been removed thorough past remediation activities. A map of current and historic soil and water sampling locations is included in Exhibit 1.

2.1.1 Remedial Activities

Remedial activities completed under the CERCLA and Interim Measures programs are summarized in Table A-1 of Appendix A. Several of the remedial activities have focused on known or suspected groundwater arsenic plume source areas, including the former Acid Plant, former Speiss-Dross Plant, Lower Lake, former Thornock Lake, and various former soil and sediment stockpiles. As described in Section 1.0, the Acid Plant settling pond, speiss pond and speiss pit, and Thornock Lake were remediated in the late 1980s-early 1990s, with additional soil removal activities completed through the 1990s. Metals-impacted soils in the Acid Plant sediment drying area and the Speiss-Dross Plant area were encapsulated within slurry walls (keyed into the ash/clay layer which forms the aquifer base) and temporary surface caps in 2006 and 2007, respectively (Table A-1).

Major improvements to Lower Lake came about through construction of two one-million gallon water storage tanks and associated cessation of process water discharges to Lower Lake in 1990, and dredging of contaminated sediments from Lower Lake between 2004 and 2006. As a result, dissolved arsenic concentrations in Lower Lake water, a known source of recharge to the groundwater system, have decreased from a range of 10 to 90 mg/L prior to 1995, to 0.20 to 0.30 mg/L today. The current arsenic concentrations are representative of groundwater flowing through Lower Lake today.

In 2001, the Phase I Corrective Action Management Unit (CAMU) repository cell was constructed and various soil and construction debris stockpiles relocated from the plant site to the CAMU. In all, more than 100,000 cubic yards of contaminated, soil, sediment and ore stockpiles were moved from the Lower Ore Storage Area, the Upper Ore Storage Area, and the Tito Park area between Upper and Lower Lake. More recently, Asarco has been implementing a plant site demolition program to remove structures from the Facility, with demolition debris being placed in a second (Phase II) CAMU cell. As of the end of 2009, approximately 56,000 cubic yards (79,000 tons) of demolition debris has been placed under a temporary cover in the Phase II CAMU cell (Table 2-1-1). The groundwater arsenic plume source areas identified in the CC/RA and RFI Phase I reports, and previously remediated areas are shown in Figure 1-2-1.

2.1.2 Current Site Infrastructure

The existing Facility infrastructure, including plant site structures, ground surface conditions and underground utilities, may have implications for surface water/groundwater flow, contaminant transport, and access for sample collection and testing at the Facility. As a result, the following information must be incorporated into the Phase II RFI planning and implementation. The following information on the Facility infrastructure is also intended to

TABLE 2-1-1. PHASE II CAMU CELL FILL MATERIALS AND VOLUMES

Building/Area	Weight (lbs)	Weight (tons)	Volume (cubic yards)
2008			
Acid Plant	8025983	4013	2540
Bag House	35229347	17615	11149
Bailey Building Stored Waste	7126880	3563	2255
Barnum Building Stored Waste	9036569	4518	2860
Ore Storage Stored Waste	24712980	12356	7821
Ringling Building	1601500	801	507
Spray Dryer	183700	92	58
Blast Furnace Flue	13571680	6786	4295
Monier Flue	9482300	4741	3001
Other/Cleanup	9438440	4719	2987
2008 Total	**99488639**	**49744**	**37471**
2009			
Acid Dust Silo	75320	38	24
Crushing Mill	5953880	2977	1884
Sample Mill	10485700	5243	3318
Hopto Pad	6909010	3455	2186
Breaking Floor/Highline	4203940	2102	1330
Ore Storage RR Track Area	2326600	1163	736
Ore Storage Walls Demolition	1794080	897	568
200' Stack	3855800	1928	1220
400' Stack	14409160	7205	4560
425' Stack	7316160	3658	2315
Railroad Ties	326300	163	103
Ore Storage Cleaning	508200	254	161
Ore Storage Baghouse Cleaning	13680	7	4
Ore Storage Sump Cleaning	28640	14	9
Crushing Mill Cleaning	69480	35	22
Sample Mill Cleaning	26080	13	8
Hopto Pad Cleaning	89480	45	28
Bailey Building Cleaning	16720	8	5
Cement Silo Cleaning	11900	6	4
Coke Hopper Cleaning	10780	5	3
Direct Smelt Building Cleaning	127000	64	40
High Grade Cleaning	9100	5	3
Scale House Cleaning	8680	4	3
Water Treatment Plant Sump Cleaning	12080	6	4
Sump Near Scale House Cleaning	18500	9	6
Sump South of Barnum Cleaning	32160	16	10
Debris Around Bailey Building Cleaning	15960	8	5
Million Gallon Tank Cleaning	2400	1	1
Roadway Sweepings	8960	4	3
2009 Total	**58665750**	**29333**	**18565**
Total Hauled to CAMU Phase II as of 12/31/2009	**158154389**	**79077**	**56036**

address in part EPA's request for a review of this information. A more detailed analysis of the existing infrastructure and implications for the Phase II RFI objectives will be performed as part of the Phase II investigation.

The demolition activities to date began in 2004 and were completed in November of 2009. Thus far the majority of structures have been razed to ground level, soils excavated from beneath the former structure footprints based on post-demolition soil sampling data, and demolition areas capped with temporary HDPE liners. Figure 2-1-1 shows portions of the plant site where demolition has taken place. Figure 2-1-2 shows the extent of temporary HDPE site caps installed through 2009. Figure 2-1-3 shows the historic distribution of underground utilities and conduits beneath the Facility, and utilities/conduits that have been removed, or backfilled/plugged as part of the Facility demolition program. The distribution of former and remaining underground utilities and conduits, and the potential role they may play on the site hydrology and groundwater contamination will be evaluated in the Phase II RFI.

2.2 RELEVANT SOILS DATA

In order to aid in delineation of metals-impacted soils on the Facility and potential source areas for the groundwater plumes, a detailed review of existing plant site soils data was performed. Much of the existing soils data was previously compiled and reviewed as part of the RFI Phase I study (ACI, 2005), with the Phase I data compilation and review summarized below. Additional sources of plant site soils data obtained since the Phase I study, namely the 2007/08 plant site demolition-related soil sampling and 2008 monitoring well drilling soils data, are also discussed below. In addition to aiding in delineation of metals-impacted soils and potential groundwater plume source areas, the compilation and review of plant site soils data is also used in development of the Phase II field sampling program, and will be used in the updated groundwater flow and contaminant transport model.

Soils investigations have been conducted as part of numerous programs over the last three decades at the East Helena Facility. These investigations have involved collection of soil samples at varying depth intervals, analyzed for differing sets of parameters based on the objectives of the particular investigation. All current and relevant soils data is presented in the soil database in Appendix B. In order to give a focused visual illustration of the scope of available relevant soil chemistry data, results of soil analyses presented in the Phase I RFI were combined with data from subsequent investigations (the 2007-2009 demolition soil sampling and monitoring well installation programs noted above) to produce Figures 2-2-1, 2-2-2, 2-2-3, and 2-2-4. These figures show 90th percentile concentrations of total arsenic and total selenium in soils for unsaturated zone and saturated zone soil samples; in other words, for a given soil sampling location (test pit, monitoring well, soil boring, etc.), available data for all samples collected from the unsaturated zone was combined and a 90th percentile value calculated and plotted at the sampling location, with a similar calculation performed for saturated zone samples. This method of presenting an overview of relevant soils data was developed based on the following considerations: Arsenic and selenium are the primary contaminants of concern in groundwater at the site (as further discussed below), therefore potential remaining source areas for these constituents need to be further defined. Although other metals occur at elevated concentrations in site soils and groundwater, their concentrations are typically correlated with arsenic. For selenium, the soil maps also demonstrate the need for additional data collection, as discussed further in subsequent sections of this Work Plan. Differentiation of concentrations in unsaturated soils and saturated zone soils may aid in assessing the pathway of any ongoing releases to groundwater (i.e., infiltration vs. desorption). This information has also been valuable for developing the Phase II sampling program (Section 3.0) and should aid in the subsequent preparation of the CMS for the Facility.

The calculated 90th percentile was selected as a representative statistic for soil concentrations in order to provide an indication of the "higher" values observed at each location, without relying on the extreme upper end (maximum) of the data set. In many locations highly elevated concentrations of metals in surface soils decrease rapidly with depth. The use of the 90th percentile in Figures 2-2-1, 2-2-2, 2-2-3, and 2-2-4 is intended for visual presentation only, and not intended to suggest this statistic is appropriate for use in site risk assessments or for selection of corrective measures.

2.2.1.1 Phase I RFI and Prior Soil Sampling Data

The Phase I RFI Report (ACI, 2005) included a compilation of all plant site soils data collected up to that time, including detailed soil sampling conducted specifically for the Phase I study, and data collected through previous monitoring well drilling or other site activities. Specifically, the Phase I RFI soil sampling program targeted areas where additional data needs had been identified during preparation of the CC/RA (Hydrometrics, 1999a). As part of the Phase I RFI, both surface soil and subsurface soil samples were collected and analyzed for total metals, with selected samples subjected to additional testing to determine the potential for adsorption and/or leaching of contaminants of concern. Typically, total metals analyzed included arsenic, cadmium, copper, lead, iron, manganese, and zinc. Results for all surface and subsurface soil sampling conducted as part of the Phase I RFI were presented and discussed in the Phase I RFI Report (ACI, 2005).

As described in the Phase I RFI Report, additional surface soil data collection needs were documented for the following areas[1]:

- The former Lower Ore Storage Area in the western portion of the plant site (potentially impacted from ore and concentrate stored in the area prior to 1989);
- The former Upper Ore Storage Area in the area between Upper and Lower Lakes (Tito Park) in the southeast portion of the plant site (potentially impacted from ore and concentrate stored in the area prior to 1989);
- Rail corridor areas;

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[1] In addition to the soil sampling needs identified in the Phase I RFI, EPA has requested additional soil samples for the Phase II RFI in the following areas: Prickly Pear Creek, Wilson Ditch, slag pile, former acid plant wastewater pond, rail car staging area, former Thornock Lake, Tito Park, Upper and Lower Lake sediments/soils, former thawhouse and the former zinc plant area.

- Miscellaneous unpaved areas within the plant site boundary; and
- Unpaved areas adjacent to the plant site boundary.

Under the Phase I RFI Work Plan, a total of 664 soil samples from 111 sampling locations were collected. The results of the Phase I RFI surface soil samples are provided in Appendix B. Summary statistics for this Phase I RFI surface soil sample data set are in Table 2-2-1. Consistent with previous soil investigations, the Phase I RFI found that, in most locations, metals concentrations are highest in surface or near-surface samples, and decrease relatively rapidly with depth. For example, the median arsenic concentration for all Phase I RFI samples in the 0-4 inch depth interval was 1028 mg/kg, with median concentrations decreasing over subsequent depth intervals to 49 mg/kg at the 5-8 foot depth interval (Table 2-2-1). The deepest interval (8-11 feet) showed a higher median arsenic concentration (181 mg/kg) than several of the shallower intervals; however, this median is based on a much smaller data set (four samples total) compared with shallower depth intervals (31 to 183 samples total). Other soil constituents showed similar trends with depth (Table 2-2-1).

Table 2-2-1 also shows median and 90th percentile concentrations of arsenic, cadmium, copper, lead, and zinc for each of the specific areas noted above (Lower Ore Storage, Upper Ore Storage, Rail Corridor, Unpaved Plant Site, and Unpaved Off-Plant areas). Median concentrations of total arsenic and metals were generally highest in the Upper Ore Storage area (located between Upper and Lower Lakes), while 90th percentile concentrations of metals were highest in the rail corridor areas. Off-plant locations showed median and 90th percentile concentrations about ten times lower than locations within the plant site (Table 2-2-1). As noted in the Phase I RFI report (ACI, 2005), the Upper Ore Storage Area is one location on the plant site where elevated concentrations of arsenic and metals tend to persist at depth, rather than decreasing with depth as observed across most of the site.

During the Phase I RFI and the Interim Measures (IM) groundwater investigation immediately preceding the Phase I RFI, 52 monitoring wells and 4 subsurface soil borings (not completed as monitoring wells) were installed from 1999 through 2002. Subsurface soil

Table 2-2-1. Phase I RFI Surface Soil Summary Statistics

Depth Interval (bgs)	***Median Concentration (mg/kg) -- All Phase I RFI Surface Soil Samples***				
	Arsenic	**Cadmium**	**Copper**	**Lead**	**Zinc**
0-4"	1028	1225	3225	10875	7916
4-12"	503	239	1319	7125	6263
1-2'	338	111	790	3219	4166
2-3'	130	44	396	1193	1731
3-5'	165	51	286	1885	1000
5-8'	49	32	116	1593	1354
8-11'	181	8	669	182	360

Median and 90th Percentile Concentrations (mg/kg) By Area										
Sampling Area	**Arsenic**		**Cadmium**		**Copper**		**Lead**		**Zinc**	
	Median	**90th %ile**	**Median**	**90th %ile**	**Median**	**90th %ile**	**Median**	**90th %ile**	**Median**	**90th %ile**
Lower Ore Storage	197	1496	38	646	401	2461	2277	13093	2576	12258
Upper Ore Storage	962	3180	353	1310	2003	5307	11531	25887	5757	13210
Rail Corridor	526	3511	276	1646	1368	9166	6700	39780	8750	25446
Unpaved Plant Site	244	1897	77	613	701	4292	2724	19720	1873	20516
Unpaved Off-Plant	41	259	10	81	112	904	307	2473	290	1970

samples for chemical analysis were collected during these investigations to provide additional information regarding potential impacts on groundwater quality, including adsorption and leaching characteristics of saturated and unsaturated zone sediments in various portions of the plant site and in downgradient areas. When combined with the existing subsurface soil data set generated during previous site characterization efforts, beginning with the Comprehensive RI/FS (Hydrometrics, 1990), subsurface soil data are available for over 130 monitoring well drill holes and 38 soil borings and test pits (ACI, 2005). All subsurface soil data are presented in Appendix B. Exhibit 2, adapted from the Phase I RFI report, shows total soil arsenic concentrations with depth for all subsurface sampling locations at the time the Phase I RFI was prepared. The data presented on Exhibit 2 was combined with that obtained during subsequent investigations to generate the summary arsenic soil concentration maps shown in Figures 2-2-1 and 2-2-2.

Summary statistics for saturated zone and unsaturated zone subsurface soil samples, segregated into previously identified source areas, were presented in the Phase I RFI Report. Median arsenic and metals concentrations in the unsaturated zone were highest in the Acid Plant area, including the former Acid Plant Sediment Drying Area (4867 mg/kg arsenic, 149 mg/kg cadmium, 2033 mg/kg copper, 8969 mg/kg lead, and 3930 mg/kg zinc; ACI, 2005). Saturated zone soil samples were most elevated in the Acid Plant area based on median concentrations (846 mg/kg arsenic, 281 mg/kg copper, 1498 mg/kg lead, 1189 mg/kg zinc), and the Speiss Handling area (140 mg/kg cadmium).

In some instances, soil arsenic and metals concentrations in saturated zone soils exceed concentrations in shallower vadose zone soils, or even ground surface concentrations (ACI, 2005). Analysis of the arsenic data presented on Figures 2-2-1 and 2-2-2 shows that, of the 78 locations with both saturated and unsaturated zone soil arsenic data, 16 of these locations showed 90th percentile saturated zone values that exceeded 90th percentile unsaturated zone values by a factor of 1.4 or more, up to a maximum of 12.8 (unsaturated zone 90th percentile concentration of 18 mg/kg, saturated zone 90th percentile concentration of 231 mg/kg). The lower metals concentrations within the vadose zone as compared to underlying saturated zone soils suggest sequestration of arsenic transported through the vadose zone or in groundwater from historic Facility source areas, including the former acid plant area, speiss-dross plant area, ore storage areas, and process water circuit.

2.2.1.2 2007/08 Plant Site Demolition Soil Sampling Data

As part of ongoing cleaning and demolition activities at the Asarco East Helena Smelter, and in accordance with the RCRA Consent Decree, soil samples were collected in September and October 2007, and in October 2008 from demolition footprint and exposed soil areas in the thaw house, main office, blast furnace baghouse, blast furnace flue, Monier flue, and acid plant stack areas of the plant site. Procedures for sampling and analysis of surface and subsurface soils, and the results of the 2007 sampling effort in the thaw house and main office areas, were described in the 2008 Interim Measures Work Plan Addendum – Blast Furnace Flue and Monier Flue Cleaning and Demolition and Demolition Foot Print Exposed Areas Soil Sampling (Asarco, 2008).

Prior to sampling, visually obvious dust (indicated by dark gray or black color and fine-grained in texture) within the demolition footprint areas was removed. This included the removal of three feet of soil from the footprint of the Blast Furnace Flue and Monier Flue, and the removal of six feet of soil from below the footprint of the main office building. In addition, subsurface soils in a small section of the Blast Furnace Flue were excavated to depths of up to 12 feet below grade. This soil removal was conducted to eliminate the visual presence of brick and visibly contaminated soils. All excavated soils were hauled to the CAMU Phase 2 Cell. Following soil sampling activities, an interim cap was placed over the 2008 demolition areas (Hydrometrics, 2009a), including fumed slag graded and rolled to create positive drainage.

Demolition footprint soil sampling locations are shown on Figure 2-1-1. Complete analytical results for the 2007/2008 demolition footprint exposed area soil sampling were reported in the 2008 Interim Measures Work Plan Addendum (Asarco, 2008) for the thaw house and main office areas, and in a subsequent summary report (Hydrometrics, 2009a) for the blast furnace baghouse, blast furnace flue, Monier flue, and acid plant stack areas. A tabular summary of indicator metals concentrations (both totals and SPLP results) for the demolition footprint exposed areas sampling is in Appendix B. Summary statistics for the 2007/2008 soil sampling associated with demolition activities are shown in Table 2-2-2.

As shown in Table 2-2-2, average soil metals concentrations varied across several orders of magnitude among the various demolition footprint sampling areas. Average arsenic concentrations ranged from 24 mg/kg in the thaw house area to 1413 mg/kg within the Monier flue footprint, with a maximum concentration of 29,400 mg/kg observed within the blast furnace flue footprint. Similarly, average lead concentrations ranged from 963 mg/kg in the thaw house area to 13,765 mg/kg in the Monier flue footprint. In general, the highest soil metals concentrations occurred in samples collected below the Monier and blast furnace flues. The maximum concentrations of cadmium, copper, lead, selenium, and zinc all were obtained from samples in the Monier flue area (Appendix B). Concentrations of selenium in soil were relatively low throughout the demolition areas, with average concentrations ranging from 19 mg/kg in the thaw house area to 121 mg/kg in the Monier flue area. Out of the 147 demolition area soil samples analyzed for selenium, only 10 samples exceeded 100 mg/kg (Appendix B), and the overall median selenium concentration for all 2007/2008 samples is 27 mg/kg.

Concentrations of supplemental metals (presented in the 2008 summary report) were generally detectable but low, with a few exceptions. As with the indicator metals suite, elevated supplemental metals concentrations were primarily located in the Monier flue and blast furnace flue areas. However, the two surface soil samples (0-4 inch interval) from the acid plant stack area did show unusually high concentrations of total mercury (280 and 550 mg/kg). Mercury concentrations at depth (12-15 foot interval) at these locations decreased to 2.4 mg/kg and 0.05 mg/kg.

Metals concentrations in SPLP (synthetic precipitation leaching procedure) extracts (measured on the deepest interval sampled at each sampling location) were almost all below

Table 2-2-2. 2007/2008 Demolition Footprint Exposed Area Soil Sampling Summary Statistics

Location	Statistic	As (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Se (mg/kg)	Zn (mg/kg)
Thaw House	*Minimum*	5	1	5	5	8	29
	Maximum	130	380	370	13000	30	13000
	Average	24	38	45	963	19	1050
Main Office Area	*Minimum*	17	3	48	27	NA	58
	Maximum	1500	310	5900	18000	NA	6300
	Average	216	48	773	2445	NA	960
Acid Plant Stack Area	*Minimum*	21	1	14	16	5	42
	Maximum	1000	435	1020	7630	48	8370
	Average	129	63	195	1251	26	1191
Blast Furnace Baghouse	*Minimum*	7	1	10	7	5	33
	Maximum	3520	17300	4380	42300	164	23100
	Average	520	1096	309	3579	35	2301
Blast Furnace Flue	*Minimum*	14	1	12	14	5	20
	Maximum	29400	11200	11100	53400	133	22200
	Average	1375	851	449	2938	24	1843
Monier Flue	*Minimum*	7	9	19	43	5	36
	Maximum	11500	75300	17100	59200	1310	113000
	Average	1413	7396	2128	13765	121	13302

NOTE: Below detect results replaced with values equal to the detection limit for statistical calculations.

reporting limits, indicating relatively low metals leaching potential from soils at depth (Appendix B). The only samples showing any appreciable leaching potential were obtained from the blast furnace flue area, where SPLP arsenic concentrations ranged from <0.1 to 5.5 mg/L. SPLP-extractable concentrations of other metals from blast furnace flue area samples were near or below SPLP reporting limits (0.1 mg/L).

As noted during previous soils investigations on the plant site, soil metals concentrations in the demolition footprint soil sampling areas decreased rapidly with increasing depth. Figure 2-2-5 summarizes this trend, showing median and 90th percentile arsenic, lead concentrations as a function of sample depth for the complete 2007/2008 demolition footprint data set. The decrease in total concentrations with depth is apparent on Figure 2-2-5, showing concentrations decreasing significantly within the upper two feet of the soil column, followed by less dramatic but still progressive decreases throughout the deeper intervals. At some individual sites, particularly in the higher concentration areas (Monier and blast furnace flues), soil metals concentrations show increases from one sampling interval to the next deeper interval (Appendix B). These areas suggest either (1) vertical (downward) transport of contaminants through the soil column via infiltration and leaching, and/or (2) migration of contaminants from upgradient areas, where soil test pits intersected the water table.

2.2.1.3 <u>2008 Drilling Program Soil Sampling Data</u>

In coordination with EPA and MDEQ, Asarco conducted a supplemental groundwater investigation in 2008 that included installation and sampling of monitoring wells within and downgradient of the Asarco East Helena Facility. The program was implemented in accordance with an Interim Measures Work Plan Addendum (Asarco, 2008). As noted in the Work Plan Addendum, the objectives of the supplemental investigation were:

- To determine the spatial extent of elevated groundwater selenium in the downgradient area north and west of the plant site;
- To determine the spatial extent of the low concentration groundwater arsenic plume north of the City of East Helena;

- To evaluate the slag pile as a potential source of elevated groundwater selenium; and
- To supplement the existing plant site monitoring well network west of the slag pile area.

In support of these objectives, four monitoring wells were installed on the plant site (DH-68, DH-69, DH-70, and DH-71), and nine monitoring wells were installed in the area north and west of East Helena (EH-66, EH-67, EH-68, EH-69, EH-118, EH-119, EH-120, EH-121, and EH-122) in 2008.

Soil core samples collected at two to five-foot intervals during monitoring well drilling were submitted to the laboratory for analysis of total metals. Summary statistics for the 2008 monitoring well soil sampling are summarized in Table 2-2-3 for the suite of indicator metals that were analyzed at all sample depths. Complete analytical results are in Appendix B.

Plant site monitoring wells DH-68 and DH-69 (located in the slag pile) and DH-70 (located in the central part of the plant site) showed substantially higher soil metals concentrations than plant site well DH-71, located further west and lateral to the primary groundwater arsenic plume (Appendix B). Figures 2-2-6, 2-2-7 and 2-2-8 show depth-concentration profiles for total arsenic, lead, and selenium for the wells installed in 2008, including both plant site wells and downgradient wells. Elevated soil metals concentrations persisted through most of the total well depth at the holes drilled through the slag pile (DH-68 and DH-69), then decreased rapidly below the slag. Metals concentrations in soil also remained elevated at well DH-70 to a depth of about 17 to 20 feet, then showed similar rapid decreases. The well log for DH-70 indicates fill mixed with slag was present to a depth of approximately 20 feet, accounting for the elevated subsurface soil metals concentrations. Conversely, well DH-71 soil data indicated high concentrations near the surface (1-3 foot interval), and lower concentrations throughout the rest of the soil column (Appendix B).

Metals concentrations in monitoring well soil samples from the downgradient area (EH series wells) were much lower than concentrations for plant site wells. Average arsenic

Table 2-2-3. 2008 Monitoring Well Soil Sampling Summary Statistics

Location	Statistic	As (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Se (mg/kg)	Zn (mg/kg)
DH-68	*Minimum*	5.6	1.5	14.5	18.8	18.2	97
	Maximum	671	225	3310	41600	112	48800
	Average	232	44	1087	11922	76	35004
DH-69	*Minimum*	9.8	2.2	20.3	37	23.1	140
	Maximum	629	149	2640	30200	106	65600
	Average	317	42	1283	13934	67	42513
DH-70	*Minimum*	12.5	1.4	14.2	15.8	15.8	84.6
	Maximum	507	45.1	2540	21700	76.2	69000
	Average	268	22	1096	9690	47	31870
DH-71	*Minimum*	5.6	1	5	10.3	15.7	26.8
	Maximum	319	480	1150	5260	57.5	7710
	Average	72	57	148	607	35	924
EH-67	*Minimum*	5	1	17.8	5	5	31
	Maximum	6.1	7.3	48.9	39.6	141	89.4
	Average	5	4	35	28	26	49
EH-68	*Minimum*	5	1	12	5.3	5	23.5
	Maximum	19.1	4.9	81.5	166	35.1	123
	Average	10	3	35	38	19	63
EH-69	*Minimum*	5	1	14	5	5	16.4
	Maximum	7.8	5.8	106	25.6	40.4	68.6
	Average	5	2	48	11	15	53
EH-118	*Minimum*	5	1	5	5	5	22.2
	Maximum	27	6.4	64.8	90.2	51	114
	Average	8	3	25	15	28	44
EH-119	*Minimum*	5	1	11.2	5	5	15.3
	Maximum	15.6	5.1	52.7	74.9	55.1	108
	Average	7	3	25	13	21	41
EH-120	*Minimum*	5	1	8.3	5	5	14.6
	Maximum	17.8	5.7	52.7	79.5	39.5	82.6
	Average	7	3	29	14	21	45
EH-121	*Minimum*	6	1	9.8	ND	8	14
	Maximum	32.1	6.5	58.9	ND	76.1	70.6
	Average	22	3	29	ND	42	39
EH-122	*Minimum*	5	1	15.5	5	5	29.9
	Maximum	15.2	5.2	67.4	109	59.2	81
	Average	7	3	33	18	39	55

NOTES: Below detect results replaced with values equal to the detection limit for statistical calculations.
ND = no data available

concentrations in downgradient well soil samples ranged from 5 mg/kg at EH-67 to 22 mg/kg at EH-121, with similarly low concentrations observed for other indicator metals, including selenium, with average concentrations of 15 to 42 mg/kg, and lead, with average concentrations of 11 to 38 mg/kg (Table 2-2-3). The depth-concentration profiles in Figures 2-2-6, 2-2-7, and 2-2-8 for arsenic, selenium, and lead also suggest less difference between plant site and downgradient soil concentrations for selenium compared with arsenic and lead. Maximum arsenic and lead concentrations in the plant site monitoring well soil samples were 100 to 1000 times higher than downgradient well soil samples (with higher concentrations present in samples obtained from wells drilled through the slag), while maximum selenium concentrations in the plant site samples were similar to or only slightly higher than the downgradient samples. For the 2008 monitoring well soil sample data set, maximum and average selenium concentrations for plant site and downgradient monitoring wells were as follows:

- Plant Site Wells: Maximum Se = 57.5 – 112 mg/kg
  Average Se = 35 – 76 mg/kg
- Downgradient Wells: Maximum Se = 35.1 – 141 mg/kg
  Average Se = 15 – 42 mg/kg.

2.3 CONCEPTUAL MODEL

Based on the available information and data summarized above and in previous documents, an updated conceptual site model (CSM) has been developed for the East Helena Facility. The CSM encompasses current knowledge and theory of site hydrogeology, the distribution and magnitude of soil-borne contaminants that may act as sources to the arsenic and selenium groundwater plumes, and arsenic/selenium migration in groundwater and the status and behavior of the groundwater plumes. The updated CSM is presented below. This information forms the basis for the proposed Phase II site characterization program outlined in Section 3.0, and will be used in development of the numerical groundwater flow model outlined in Section 4.0.

2.3.1 Hydrogeology

The hydrogeology of the East Helena Facility and surrounding area has been described in prior reports including the CC/RA (Hydrometrics, 1999a) and the Phase I RFI report (ACI, 2005), as well as various publications (USGS, 1992). To date, more than 150 monitoring wells have been installed on and around the Facility, including 13 wells in 2008 and 15 wells in 2009. The following discussion of groundwater in and around the Facility is based on the information collected over the past 30 years, and the new data collected and information obtained in 2008/09. Figure 2-3-1 shows the current East Helena Facility monitoring well network, including the 2009-installed wells.

2.3.1.1 Geology/Hydrostratigraphy

Figure 2-3-2 shows the surficial geology in and around the East Helena Facility. Important features of the local geology include: the large area of alluvium (Qa on Figure 2-3-2) extending along Prickly Pear Creek from south of the East Helena Facility northward to the Helena Valley; the uplands or foothills comprised of tertiary sediments (OgtS and OgS) south, east and west of the Facility; and the intervening Qac deposits consisting of a mixture of alluvium and tertiary sediments. The alluvium consists of relatively clean sand and gravel, and due to the relatively small amount of silt and clay, has a relatively high permeability. The alluvium is a primary groundwater-bearing unit on and north of the Facility. The tertiary sediments have a much higher silt/clay content than the alluvium, and therefore have a much lower permeability. The tertiary foothills surrounding the Facility, and much of the Helena Valley, provide recharge to the alluvial aquifer through seepage of groundwater from the tertiary sediments into the alluvial groundwater system. This source of recharge to the alluvial aquifer is believed to influence groundwater chemistry as well as flow, on and north of the Facility.

Lastly, the alluvium/colluvium (Qac) is a mixture of alluvium derived from Prickly Pear Creek, and finer grained sediments eroded from the tertiary sediment foothills. This transition from alluvium to alluvium/colluvium as one moves from Prickly Pear Creek towards the foothills is gradual as opposed to the abrupt change reflected on the geologic map. The increase in fine sediment contact with distance from the creek was evident in the 2009 monitoring well drilling program in Lamping Field, and is believed to impart control on groundwater flow, and possibly groundwater chemistry, in this area.

Exhibit 3 presents the three geologic cross sections depicting subsurface conditions on and north of the Facility. Cross sections A and B are updated versions of two cross sections presented in the Phase I RFI report, with additional information obtained from the 2008/09 drilling programs added. Cross section C (Figure 2-3-3) is a new cross section depicting stratigraphic relationships between the Lamping Field area where Asarco has drilled a number of monitoring wells in 2008 and 2009, and the East Helena Public Water Supply (PWS) wells located north of Lamping Field. The stratigraphy recorded in the Lamping Field area through the 2008/09 drilling programs is generally consistent with that recorded through previous drilling on the Facility. One difference detected through the newer wells to the north is a transition in the low permeability layer forming the base of the shallow/intermediate aquifer. On the plant site, the low permeability unit is a primarily competent white tuffaceous ash altered to clay in places, whereas north of the Facility this unit is a tan/brown silt/clay (cross section A-A’). This south to north transition is believed to be the result of mixing and reworking of the ash unit to the north with alluvial and fine-grained tertiary sediments eroded from the uplands immediately south and west of Lamping Field.

Cross section C-C’ depicts the stratigraphy further to the north and to a greater depth based on well completion logs for the East Helena PWS wells. Although the accuracy of information included on the PWS well logs is uncertain, the information does indicate an additional water-bearing unit a relatively short distance beneath the silt/clay unit documented at a depth of about 70 feet below ground surface (bgs) in the Lamping Field monitoring wells. Section 3.0 of this work plan calls for installation of a deep well in Lamping Field to better assess the thickness and characteristics of the silt/clay unit in this area, and hydrogeologic conditions at depth beneath the silt/clay unit.

There are a number of other points of interest on the cross sections. Similar to information provided in the Phase I RFI report for the north Plant site and East Helena area, the cross sections show the silty to sandy clay layer separating the shallow and intermediate aquifers (at a depth of about 30 feet bgs) to be discontinuous in the Lamping Field area. Based on this information, the shallow and intermediate aquifers are now interpreted as a single hydrogeologic unit as opposed to two separate aquifers as in the Phase I RFI and previous reports.

Cross section C-C’ extends north of Lamping Field and Prickly Pear Creek and includes stratigraphic information from two public water supply wells and one private well. Of particular interest is the significant difference in groundwater elevations immediately adjacent to the creek as compared to the creek stage. The static water in monitoring well EH-130, located about 250 feet south of Prickly Pear Creek is 40 feet below ground surface, or about 20 feet below the creek level. Well EH-131, located less than 100 feet north of the active channel system, has a static water level of 23 feet bgs and the creek water level. The significantly lower groundwater elevations adjacent to the creek are reflective of the losing nature of Prickly Pear Creek in this area. This relationship has implications for groundwater flow and plume migration (i.e., groundwater mounding beneath the creek may preclude northward groundwater flow and plume migration), groundwater geochemistry (leakage of surface water to the aquifer provides a source of high redox water to the aquifer), and for the susceptibility of Prickly Pear Creek to water quality impacts from the Facility. Section 3.0 of this work plan includes a scope of work for evaluation of groundwater/surface water interactions intended in part to address these questions.

Another point of interest on the site stratigraphy is reflected in cross section B-B’. During drilling of the 2009 monitoring wells, the percentage of fine grained sediment (silt/clay) in the alluvium increased from east to west, presumably due to an increase in fine grained tertiary sediments eroded from the uplands west of Lamping Field. The increase in fine sediment content from east to west corresponds to the transition from alluvium to alluvium/colluvium shown on Figure 2-3-2, and likely imparts some constraints on groundwater flow and plume migration, to the west.

2.3.1.2 Groundwater Occurrence and Flow

The hydrostratigraphy and individual aquifers identified at the Facility are described in the Phase I RFI report and include:

> The shallow aquifer: An unconfined aquifer extending from the water table downward to the first low permeability layer. The top of the shallow aquifer ranges in depth from approximately 10 feet or less bgs near Upper Lake on the south plant site, to 30 to 40 feet bgs in Lamping Field north of the Facility. Discontinuous silt/clay lenses occur at depths of 35 to 40 feet bgs in the northern portion of the plant site (north of well DH-66, Figure 2-3-1) and extending northward into the Lamping Field area.
>
> The base of the shallow aquifer is defined by a low permeability silt/clay layer ranging in depth from about 30 feet bgs on the south plant site (near Upper Lake), to 70 to 75 feet bgs north of the plant site in Lamping Field. Previous drilling activities have shown the basal silt/clay unit to contain varying amounts of altered white volcanic ash on the plant site. Figure 2-3-4 includes a contour map of the silt/clay unit surface based on information obtained from the East Helena Facility monitoring well drilling program and information obtained from private and public water supply well completion logs. As described in Section 1.2.2, separation of the shallow aquifer into a separate shallow and intermediate aquifer as described in previous reports (ACI, 2005) has been discontinued due to the lack of hydrologic separation between the upper and lower portions of the shallow aquifer.
>
> The deep aquifer: A confined aquifer is located beneath the continuous ash/clay layer. Based on well DH-18, completed in the deep aquifer in the central portion of the plant site, the ash/clay layer is unsaturated from approximately 45 feet to 55 feet bgs, with saturated conditions (deep aquifer) occurring at about 55 feet bgs. Additional

information regarding the depth to the deep aquifer north of the Facility is proposed in the Phase II site characterization program (see Section 3).

Groundwater at the East Helena Facility flows in a north to northwest direction from the Upper Lake area towards and west of East Helena. Figure 2-3-5 shows the November 2008 groundwater potentiometric surface for the shallow aquifer on and north of the Facility. The configuration of the November 2008 potentiometric surface is representative of the potentiometric surface plotted for both the wet and dry season in previous years. Figure 2-3-6 shows a more detailed potentiometric map of the Lamping Field area for June 2009 based on the 15 additional monitoring wells installed in 2009 and a number of surface water elevation monitoring points established on Prickly Pear Creek.

The primary source of recharge to the plant site shallow aquifer is subsurface seepage from Upper Lake. Groundwater flow through the plant site follows two general flowpaths; due north from Upper Lake through Lower Lake and beneath the slag pile on the east side of the plant site, and northwestward from Upper Lake through the former Acid Plant and Speiss-Dross Plant on the west side of the plant site. These general flow patterns continue north of the site as well with groundwater flow primarily northward on the east side of Prickly Pear Creek and northwestward on the west side of the creek (Figure 2-3-5). This northwest groundwater flow direction correlates closely with the arsenic and selenium groundwater plumes in this area, and with an erosional trough (or paleo-channel) in the top of the ash/clay layer identified through drill logs. This erosional feature is believed to represent an ancestral channel of Prickly Pear Creek (Figure 2-3-4), and may influence groundwater flow through the shallow aquifer. Additional detail on the silt/clay surface will be obtained through additional drilling in the Phase II investigation.

Besides seepage from Upper Lake, another significant source of groundwater recharge is leakage from Prickly Pear Creek. Surface water recharge to the aquifer near the Facility has been evaluated in previous reports, including the CC/RA report (Hydrometrics, 1999a) and the Phase I RFI report (ACI, 2005). In both cases, the rate of leakage from the creek adjacent to and immediately north of the Facility was determined to be within the level of error associated with streamflow measurement methods, precluding detailed assessment of surface water seepage rates in these areas. Further downstream however, in the vicinity of Lamping Field, synoptic streamflow monitoring has shown that Prickly Pear Creek looses a significant quantity of water to the subsurface. Figure 2-3-7 shows results of a detailed synoptic streamflow survey conducted on Prickly Pear Creek in 1987. Similar to the Phase I RFI data, streamflow rates were relatively consistent from upstream to downstream adjacent to and immediately downstream of the plant site. Further downstream however, streamflow rates decreased from 15.4 to 9.0 cubic feet per second (cfs) and then to 5.9 cfs, over a total distance of about 3,000 feet. This loss of streamflow equates to about 4,250 gpm of surface water recharge to the shallow/intermediate aquifer in the Lamping Field area. Section 3.0 of this work plan includes a detailed assessment of groundwater/surface water interactions in the project area to better quantify the direction and magnitude of seepage between Prickly Pear Creek and the shallow/intermediate aquifer. Although leakage from Upper Lake and Prickly Pear Creek are the largest sources of recharge, the shallow/intermediate aquifer is also recharged to a lesser extent through precipitation infiltration and from groundwater inflow from the relatively low permeability tertiary sediment foothills south and west of the Facility.

2.3.1.3 <u>Aquifer Hydraulic Characteristics</u>

Horizontal hydraulic gradients vary from east to west and from north to south through the project area. On the plant site, horizontal gradients range from 0.017 ft/ft on the east side of the plant, to 0.025 ft/ft on the west side of the plant based on the November 2008 potentiometric surface (Figure 2-3-5). North of the plant site, gradients range from 0.014 ft/ft east of Prickly Pear Creek, to 0.012 ft/ft west of the creek.

Figure 2-3-8 shows vertical hydraulic gradients on and north of the plant site for November 2008 and May 2009. Vertical gradients were calculated from groundwater level data obtained from wells located in close proximity to each other and completed at different intervals within the shallow/intermediate aquifer. As shown on the figure, vertical gradients are primarily oriented downward in the shallow/intermediate system, indicating a downward component of groundwater flow. The largest downward gradient occurs in well pair EH-52/EH-102, north of the plant site and east of Prickly Pear Creek (approximately 0.12 ft/ft). Vertical gradients at other well pairs are typically on the order of 0.01 ft/ft or less. The vertical gradient at plant site wells DH-13 and DH-18, the only well pair completed in the shallow and deep aquifers, is upward in both November 2008 (+0.061 ft/ft) and May 2009 (+0.082 ft/ft). This upward gradient should prevent cross contamination of the deep aquifer from the overlying shallow/intermediate aquifer plumes on the plant site. The Phase II scope of work includes installation of additional monitoring wells to better delineate three dimensional groundwater flow and contaminant transport pathways, and better delineate groundwater source areas at the Facility.

The hydraulic conductivity (or permeability) of the shallow/intermediate aquifer has been determined through on-site aquifer testing as reported in the Phase I RFI and other reports, with data obtained from more than 83 aquifer pumping tests and slug tests completed at the Facility. The aquifer test results show the hydraulic conductivity of the shallow aquifer ranging from 2.0 ft/day to 700 ft/day. Significant heterogeneity is evident in the aquifer permeability, with test results showing order of magnitude differences in permeability within relatively short distances (ACI, 2005). The highest hydraulic conductivity values occur in the west plant site area, which includes the former Acid Plant and Speiss-Dross source areas. The west plant site area also exhibits the greatest horizontal hydraulic gradients, meaning groundwater flow rates are greatest as well. The higher groundwater flow rate may be related to an ancestral channel of Prickly Pear Creek extending northwest through the west plant site. The average hydraulic conductivity values by area are shown on Figure 2-3-5.

2.3.1.4 Groundwater Flow Rates and Flux

Based on the hydraulic conductivity and hydraulic gradient information shown on Figure 2-3-5, groundwater flow rates are estimated for various portions of the Facility. The apparent groundwater velocity (specific discharge) is calculated as the product of the hydraulic gradient times the hydraulic conductivity, while the average linear velocity, or velocity of an actual water particle in the aquifer equals the apparent velocity divided by the effective porosity. The groundwater flux, or volume of flow per time, is equal to the apparent groundwater velocity times the aquifer cross sectional area (width times saturated depth).

The groundwater velocity and flux rates are summarized in Table 2-3-1 for the east plant site, west plant site, east downgradient area and west downgradient areas as shown on Figure 2-3-5.

TABLE 2-3-1. SUMMARY OF HYDRAULIC PARAMETERS AND ESTIMATED GROUNDWATER FLOW RATES FOR VARIOUS PORTIONS OF THE FACILITY

Parameter (units)	**East Plant Site**	**West Plant Site**	**East Downgradient**	**West Downgradient**
Horizontal Hydraulic Gradient	0.017	0.025	0.14	0.012
Hydraulic Conductivity(ft/day)	110	160	140	100
Flowpath Width (ft)	1000	700	1500	2500
Saturated Thickness (ft)	15	10	50	40
GW Velocity (ft/day)	1.8	4.0	1.9	1.2
Avg. Linear Velocity (ft/day)	9.2	20	9.7	6.0
GW Flux (ft^3/day)	27,730	28,000	144,800	119,000
GW Flux (gpm)	144	145	750	620

* Avg. Linear Velocity assumes the effective porosity of 0.2.

As shown in the above table, groundwater flow of flux rates increase significantly from the plant site to downgradient of the plant site. This increase reflects recharge to the groundwater system from precipitation recharge, groundwater inflow from the surrounding (and possibly the underlying) tertiary sediments, and leakage from Prickly Pear Creek.

As discussed in Section 2.3.1.2, measured leakage from Prickly Pear Creek north of the plant site was approximately 4,250 gpm in August 1987. Assuming half of the stream leakage flows to the east and half to the west, the rate of surface water recharge to the Lamping Field groundwater system is on the order of 2,100 gpm, or roughly three times the groundwater flux (620 gpm) between the plant site and Lamping Field (West Downgradient area in Table 2-3-1). This influx of surface water not only has a significant effect on groundwater flow and plume orientation in the Lamping Field area, but may also influence the plume concentrations through dilution and through influx of a large quantity of high dissolved oxygen/high reduction/oxidation potential (redox) water which is expected to affect arsenic and selenium mobility in groundwater as discussed below.

2.3.2 Groundwater Geochemistry and Plume Status

2.3.2.1 General Chemistry of Arsenic and Selenium

Arsenic and selenium are the primary contaminants of concern in groundwater at the East Helena Facility. Both arsenic and selenium can occur in multiple oxidation states and chemical species, and their fate and transport in groundwater systems is thus closely linked to geochemical conditions within the aquifer. Brief discussions of the geochemistry of arsenic and selenium are presented below, to provide context for an evaluation of the current groundwater plume status at the Facility, and to aid in development of the Phase II RFI site characterization sampling and analytical program. Recent evaluations of arsenic and selenium geochemistry and potential attenuation processes affecting contaminant mobility in groundwater have been compiled by and on behalf of the U.S. EPA (EPA, 2007; Langmuir et al., 2005). In addition, the environmental chemistry and behavior of arsenic and selenium have been thoroughly reviewed by Plant et al. (2007). These references, along with results from previous site investigations, provide the basis for the following discussion.

Arsenic

The general environmental geochemistry of arsenic and its relationship to site-specific conditions has been previously reviewed in the CERCLA Comprehensive RI/FS (Hydrometrics, 1990), the RCRA CC/RA (Hydrometrics, 1999a), and the Phase I RFI (ACI, 2005). The aqueous speciation of arsenic is dominated by the oxyanions arsenate ($H_nAsO_4^{n-3}$) under oxidizing conditions, and arsenite ($H_nAsO_3^{n-3}$) under reducing conditions, although thioarsenic (sulfur-containing) species may occur under sulfate-reducing conditions with depleted iron concentrations (EPA, 2007). Arsenate species include arsenic in the +5 oxidation state (As(V)), and arsenite species include arsenic in the +3 oxidation state (As(III)). The level of protonation of arsenate and arsenite is a function of pH, as shown on the arsenic stability diagram (E_H-pH diagram) in Figure 2-3-9.

Arsenic transport in groundwater is typically controlled via adsorption/desorption and coprecipitation mechanisms. In practice, adsorption and coprecipitation mechanisms may be difficult to distinguish via typical analytical data collected as part of environmental investigations (Langmuir et al., 2005). As noted in EPA (2007), precipitation of pure phase arsenic minerals is improbable in most groundwater systems outside of source areas; however, coprecipitation with oxides and/or sulfides of metals such as iron is considered to be a likely sink for arsenic in groundwater in redox transition zones (i.e., where aquifer conditions change from reducing to oxidizing, or vice-versa). Both As (III) and As (V) have been reported to coprecipitate with hydrous iron and manganese oxides. The long-term stability of arsenic coprecipitated within the aquifer will necessarily be dependent on potential changes in redox, pH, and ionic composition of groundwater as contaminant source areas are removed or otherwise mitigated, and groundwater geochemical conditions approach a "natural" steady-state.

Adsorption of both arsenate and arsenite is strongly pH dependent, and is also influenced by the concentration of other anions in solution that may compete for adsorption sites on aquifer materials. Langmuir et al. (2005) noted that arsenate adsorbed to hydrous ferric oxide is strongly bound at pH values below 8, and desorbed between pH 9 and 11. The iron oxides and sulfides noted above as potential coprecipitating minerals with arsenic are also apparently predominant as adsorptive materials in oxidizing and reducing conditions, respectively (EPA, 2007). Other potential adsorbents such as clays or organic materials may be less important adsorptive controls for anions such as arsenate and arsenite, due to their negative surface charge under the range of natural pHs.

The Phase I RFI (ACI, 2005) noted that several lines of evidence suggest and adsorption and/or coprecipitation of arsenic with iron and manganese oxides in the subsurface is probably the principal mechanism for attenuation of arsenic in groundwater at the East Helena Facility. These lines of evidence include:

- Abundance of iron and manganese oxides in shallow aquifer sediments;
- Enrichment of arsenic in iron and manganese mineral phases, determined through sequential extraction analyses of saturated zone aquifer sediments; and
- Trends in dissolved iron and manganese concentrations along the groundwater flow path that suggest removal via oxidation/precipitation, providing the conditions for coprecipitation of arsenic with iron and manganese minerals, and the formation of additional adsorptive capacity (metal oxide/hydroxide surfaces) within the aquifer.

Selenium

Similar to arsenic, selenium may exist in multiple oxidation states in the aqueous phase, including selenide (Se(II-)), elemental selenium (Se(0)), selenite (Se(IV)), and selenate (Se(VI)) (EPA, 2007). The Se(IV) and Se(VI) states commonly occur as the oxyanions SeO_3^{2-} (selenite) and SeO_4^{2-} (selenate). Selenium speciation and, consequently, selenium mobility in groundwater is highly dependent on pH and redox conditions, as illustrated by the E_H-pH diagram in Figure 2-3-9.

In contrast with arsenic, attenuation of selenium in soils is, in general, highly correlated with the extent of its reduction (EPA, 2007). Selenite is strongly adsorbed by hydrous ferrous oxides (Plant et al., 2007), although sorption decreases significantly above pH values of about 8.5. EPA (2007) describes the behavior of selenate (the more oxidized form) as analogous to sulfate, with little adsorption and high mobility, while selenite behavior is more similar to phosphate, with a strong affinity for adsorptive surfaces. Elemental selenium (Se(0)) or highly insoluble metal selenides may also precipitate under more reducing conditions, resulting in very low dissolved selenium concentrations in groundwater. Reoxidation of elemental selenium to more mobile selenite or selenate oxyanions is relatively slow, suggesting that Se(0) phases formed in soil may be important long-term sinks for selenium (EPA, 2007).

In summary, both arsenic and selenium are redox sensitive elements that may occur in several oxidation states depending primarily on pH and redox conditions in groundwater and aquifer materials. They commonly exist as oxyanions in solution, and are adsorbed to metals oxides and/or sulfides to varying degrees, with attenuation behavior depending again on the pH and redox status of groundwater. One of the chief differences in the geochemical behavior of selenium compared with arsenic is the relative immobility of selenium under reducing conditions (Plant et al., 2007), since the selenite, elemental selenium, and selenide forms are all highly attenuated through adsorption or precipitation reactions.

2.3.2.2 Current Hydrogeochemistry and Plume Status

The current arsenic and selenium groundwater plumes originating from the Asarco East Helena Facility are shown on Figures 2-3-10 and 2-3-11, respectively. The concentration isocontours in these figures are based on the most recent comprehensive set of groundwater data collected at the site in May/June 2009. The general orientation of the arsenic and selenium plumes is the same, as both extend from the southeastern portion of the plant site toward the northwest, and are relatively narrow laterally compared with the plume length. The lower concentration arsenic plume (represented by the 0.010 and 0.050 mg/L contour) is broader and extends further to the east than the selenium plume (Figure 2-3-10).

As discussed above in Section 2.3.2.1, the mobility of both arsenic and selenium in groundwater systems is typically strongly related to subsurface pH and redox conditions. At the East Helena Facility, the shallow groundwater system on the upgradient (southeast) end of the plant site is dominated by influx of fresh, relatively oxygenated water from Upper Lake. Upper Lake itself is created by a diversion of Prickly Pear Creek surface water upstream of the plant site, and thus water quality in Upper Lake is similar to Prickly Pear Creek water quality, with a near-neutral to slightly alkaline pH, relatively low conductivity, and low but occasionally detectable concentrations of arsenic (<0.003 to 0.010 mg/L). Selenium concentrations in Upper Lake/Prickly Pear Creek water are not well-characterized, due to a lack of analytical data collected to date.

Groundwater is impacted by a variety of historic source areas as it flows beneath the Facility, and arsenic concentrations eventually reach a maximum of over 100 mg/L in the central portion of the plant site near the former Speiss Handling area (Figure 2-3-10). Groundwater selenium concentrations reach a maximum on the order of about 1 to 3 mg/L in the vicinity of the thaw house and concentrate storage and handling building on the western side of the plant site (Figure 2-3-11). Downgradient of the Asarco East Helena Facility, additional influx of oxygenated water to the groundwater system occurs as Prickly Pear Creek loses water to shallow groundwater (see Section 2.3.1). Arsenic concentrations in groundwater decrease rapidly, by approximately three orders of magnitude (1000-fold) within about 1200 feet. The current extent of the 0.010 mg/L plume is limited to the area south of Clinton Street on the northern edge of East Helena, and the area east of 4th Avenue (Wylie Drive) on the western edge of East Helena. Selenium concentrations, in contrast, persist further to the north; as shown on Figure 2-3-11, the northern extent of the selenium plume (as represented by the 0.050 mg/L contour) has not yet been fully defined.

Analysis of arsenic speciation during past groundwater monitoring events has shown that the high concentration arsenic plume consists primarily of As (III), and that with increasing distance downgradient and toward the lateral edges of the plume, As (V) becomes predominant as total arsenic concentrations decrease. Selenium speciation groundwater data show that virtually all dissolved selenium in groundwater consists of the oxidized (selenate or Se (VI) form). This is consistent with the general observation that oxidized forms of selenium are relatively mobile in groundwater, while reduced forms are largely removed from solution through precipitation or adsorption reactions.

The relationship of groundwater redox status and the arsenic and selenium plume geometry is shown in Figure 2-3-12. Groundwater redox potentials based on the ratios of As (III) and As (V) at six representative wells in November 2008 were calculated and plotted on a map showing the 1.0 mg/L arsenic contour and the 0.050 mg/L selenium contour. The main high concentration groundwater arsenic plume occurs in a highly reducing environment (approximately -250 mV, based on data from well DH-33), while dissolved selenium concentrations are quite low in this zone of low E_H groundwater. With increasing distance downgradient and laterally from the high arsenic concentration plume, arsenic speciation ratios indicate increasingly oxidizing conditions and decreasing arsenic concentrations. These lateral (and downgradient) areas are also where the higher concentrations of selenium in groundwater are observed. Figure 2-3-12 highlights the contrasting behavior of arsenic and selenium: arsenic concentrations are highest (i.e., arsenic is most mobile) under relatively reducing conditions, while selenium concentrations are highest under relatively oxidizing conditions. Thus, the area of highest arsenic concentrations in groundwater beneath the East Helena Facility correlates well with low selenium concentrations.

A number of the historic source areas on the plant site are also associated with variable pH values (relative to the typical natural range of about 6.5 to 8.5). Acid Plant area groundwater historically showed pH values less than 5, while Speiss Handling area groundwater has shown pH values greater than 9. Fluctuations in pH can also affect the fate and transport of arsenic, selenium, and other constituents in groundwater; however, changes in redox condition appear to be the primary controls on contaminant mobility at the Asarco East Helena Facility. The E_H/pH diagram for selenium (Figure 2-3-9) indicates that under a wide range of pH conditions, E_H values on the order of –250 mV (as observed at well DH-33) would promote formation of elemental selenium (Se (0)) and/or selenide, which readily precipitates as highly insoluble metal selenides. The predominant species of arsenic under reducing conditions (arsenite) likely occurs as the uncharged protonated form $H_3AsO_3^0$ under mildly reducing conditions (Figure 2-3-9), a relatively mobile form of arsenic due to the lack of electrostatic interaction with potential adsorbents.

Overall, the speciation data and arsenic/selenium plume configurations suggest the following conceptual model for arsenic and selenium transport in groundwater:

1. Upgradient of the plant site, oxidizing water from Prickly Pear Creek via Upper Lake contributes appreciable flux to the groundwater system.

2. Historic and/or ongoing source areas within the plant (discussed further below) elevate arsenic and selenium concentrations in groundwater underneath the southeast and central portions of the plant site.
3. Reducing conditions in groundwater promote removal of selenium from groundwater in the central portion of the plume and high mobility of arsenic through the plant site.
4. As groundwater moves downgradient, influx of oxidizing water from Prickly Pear Creek, dilution with unimpacted groundwater, and interaction with aquifer materials moderate the E_H/pH conditions of groundwater, and oxidizing conditions are reestablished. Selenium mobility is enhanced under these conditions, while arsenic mobility is attenuated, by conversion to As (V) and subsequent adsorption or coprecipitation.

The predominance of As (III) in the reduced groundwater zone could function as the cause of reducing conditions, rather than simply reflecting reducing conditions originating from or imposed by some other source. High dissolved arsenic concentrations (on the order of 50 to 100 mg/L or as high as 0.001 mol/L), dominated by As (III), could be sufficient to “poise” the E_H of groundwater beneath the site, in the absence of high concentrations of other redox active constituents. In this case, the ultimate source of arsenic to groundwater (i.e., arsenic sulfides in residual ore material, historically adsorbed arsenic in the vadose or saturated soil zones) would be the primary control on arsenic speciation, at least near the source area. Identification of ultimate (historic and/or ongoing) arsenic sources to groundwater is discussed further below.

In addition to the present spatial extent (geometry) of the groundwater contaminant plumes, an evaluation of plume status should consider temporal trends, and whether the plume appears to be expanding, stable, or contracting. Figure 2-3-13 compares the 10 mg/L and 0.010 mg/L groundwater isocontours from November 2002 (adapted from the plume maps presented in the Phase I RFI) and from May 2009. As shown on the figure, the downgradient margins of the arsenic plume (represented by the 0.010 mg/L contour) have shown very little change over the period between 2002 and 2009. The higher concentrations plume closer to the historic source areas, represented by the 10 mg/L contour, appears to have shown a slight contraction (Figure 2-3-13), or at least clearly shows no signs of expansion. The relative stability of the downgradient arsenic plume and the slight contraction of the higher concentration plume nearer the historic source areas is consistent with both the removal or other mitigation of identified sources that has occurred at the plant site (Section 1.2), and with ongoing arsenic attenuation at the plume front through adsorption and/or coprecipitation mechanisms.

Temporal trends in arsenic concentration for individual wells in historic source areas, and at the northern extent of the “higher concentration” (10 mg/L) arsenic plume are shown on Figure 2-3-14. Wells near the former Acid Plant and former Speiss/Dross area have shown relatively consistent decreases in arsenic concentration over time. Wells downgradient of Lower Lake showed decreasing groundwater arsenic concentrations in the late 1980s and early 1990s, with the rate of decrease slowing significantly after about 1995. Finally, arsenic trends in two wells along Pacific Street on the southern end of East Helena are shown as representative of trends downgradient of the plant site. At well EH-60, arsenic concentrations increased from about 1987 through 2001, and have decreased consistently in subsequent years. Well EH-100, located one city block east of EH-60, had very low arsenic concentrations when initially sampled in 1986, but when the well was added to the routine monitoring list again in 2001, arsenic concentrations had increased significantly (Figure 2-3-14). Concentrations at this well are now similar to or slightly higher than concentrations at well EH-60, although arsenic concentrations at EH-100 show significantly more seasonal variability than concentrations at well EH-60.

Time-concentration trends for groundwater selenium beneath and adjacent to the East Helena Facility are not well-defined at this time, since selenium only recently was identified as a constituent of concern at the site and there is little historical groundwater selenium data to compare with current concentrations. One of the main objectives of the Phase II RFI is to better define the spatial extent of selenium in groundwater, along with potential selenium sources. As sampling activities to achieve these objectives are conducted at the site, additional selenium data will be collected to better delineate current conditions and long-term trends.

2.3.3 Groundwater Contaminant Source Areas

Assessment of potential contaminant sources to groundwater at the East Helena Facility has been conducted on numerous occasions as part of past site investigation and remediation activities. Identified historic sources of groundwater contamination (for arsenic in particular), and associated remedial activities targeting these source areas are discussed in Section 1.2 of this Work Plan. An updated evaluation of remaining potential groundwater contaminant source areas is presented in this section, including a preliminary assessment of selenium sources, along with additional review of potential remaining sources of arsenic based on the analysis of site soils data in Section 2.2.

Figure 2-3-15 combines the current (May 2009) groundwater arsenic plume, represented by the 0.010 mg/L isocontour and the 10 mg/L isocontour lines, with the calculated 90th percentile soil arsenic concentrations for saturated zone soils. Figure 2-3-16 presents similar information for selenium, with the 1.0 mg/L and 0.05 mg/L selenium isocontours shown. Both groundwater plumes appear to originate in the southeastern portion of the plant site, although the arsenic plume currently extends further upgradient, into the area between Upper Lake and Lower Lake (the former Upper Ore Storage area, also known as Tito Park). Soil arsenic concentrations in saturated zone samples from the Tito Park area show 90th percentile concentrations as high as 2200 mg/kg at a site along the northern margin of Upper Lake (Figure 2-3-15). Unsaturated zone soil arsenic concentrations in this area are also elevated, with 90th percentile concentrations typically exceeding 1000 mg/kg, and some in excess of 10,000 mg/kg (Figure 2-2-6). These results indicate that soils in the Tito Park area may be an ongoing source of arsenic loading to groundwater.

Additional potential source areas for arsenic in groundwater are indicated by the overlap of the higher concentration arsenic groundwater contour (10 mg/L) with elevated saturated zone arsenic concentrations in the former Acid Plant and Acid Plant Sediment Drying Area and the former Speiss Handling Area (Figure 2-3-15). Soil samples collected in the vicinity of the Acid Plant, including both historic samples and samples collected during recent demolition activities show that saturated zone 90th percentile soil arsenic concentrations exceed 500 mg/kg throughout much of the area, with one sample from historic well APSD-13 (now abandoned) showing a 90th percentile concentration of 13,211 mg/kg. In the central portion of the plant site near the former Speiss Handling area, saturated zone arsenic concentrations are slightly less elevated, with 90th percentile concentrations ranging from about 150 mg/kg to 700 mg/kg (Figure 2-3-15). Elevated saturated zone soil arsenic concentrations persist in a downgradient (northwest) direction along the axis of the arsenic plume, with 90th percentile concentrations of 1173 mg/kg arsenic and 627 mg/kg arsenic observed at locations approximately 400 feet and 800 feet downgradient of the former Speiss Handling area.

In contrast to arsenic, saturated zone (and unsaturated zone) soil data for selenium are very limited (Figure 2-3-16). The available data for selenium do not indicate elevated saturated zone selenium concentrations, as all 90th percentile concentrations are less than 60 mg/kg, even for samples located near the apparent selenium source area (the upgradient end of the selenium plume near Tito Park and the former Acid Plant / Acid Plant Sediment Drying Area). Unsaturated zone selenium samples collected during plant demolition activities from the Monier Flue footprint near the upgradient end of the selenium plume showed 90th percentile selenium concentrations ranging from 166 to 561 mg/kg (Figure 2-2-7). Additional investigation will be required to determine whether site soils are acting as a source of selenium loading to groundwater (Section 3.0).

Past sampling of the plant process water circuit shows metals concentrations within the process circuit to be elevated and variable by location. As shown in Table 2-3-2, arsenic and selenium concentrations were highest in the Speiss Area followed by the Acid Plant Area. Since the Speiss Granulation Pit and Pond and the Acid Plant Settling Pond are both known to have been sources of process water leakage to the subsurface prior to the process Facility upgrades and soil remediation, process water leakage from these areas are a likely historic source of arsenic and selenium loading to the Facility groundwater. As discussed in Section

1.0, the Speiss Pit and Pond and the Acid Plant Pond were replaced with competent tanks in around 1990 and 1993, respectively, arsenic and selenium loading to groundwater from these two sources should have ceased around that time.

TABLE 2-3-2. PROCESS WATER ARSENIC AND SELENIUM CONCENTRATIONS FROM 1998

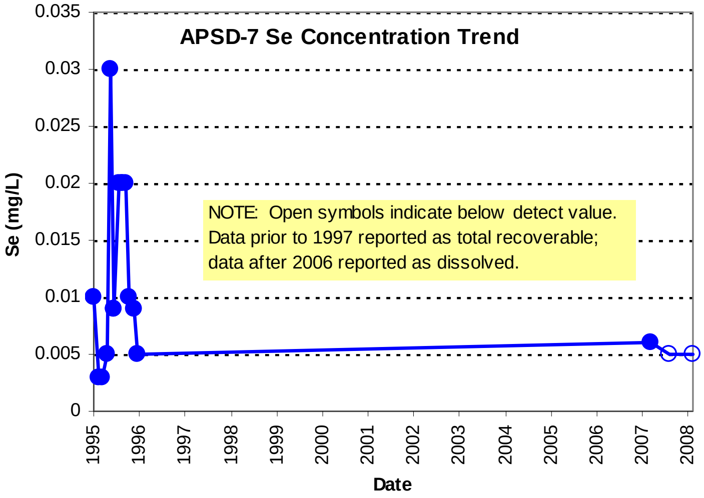
	Plant Water Circuit		**Acid Plant Circuit**		**Speiss Area**		**Lower Lake**
	Plant Water	Dross Plant Collection Sump	Scrubber Blowdown Water	Neutralized Scrubber Blowdown	Speiss Tank	Speiss Tank Secondary Containment	
Arsenic	1.4	0.29	1867	1716	3871	1464	0.049
Selenium	0.47	0.35	5.9	5.3	43	39	na

All concentration are dissolved fraction in mg/L
na – not available

Based on the plant site history, the current configuration of the arsenic and selenium plumes in groundwater, available soils data, and the geochemical controls on selenium and arsenic mobility in groundwater, a preliminary hypothesis regarding contaminant loading to groundwater at the Facility has been developed for arsenic and selenium.

<u>Arsenic Loading</u> – Historic releases of process water in the Acid Plant and Speiss Handling areas, and via Lower Lake likely comprised a significant percentage of historic arsenic loading to groundwater. Since arsenic is highly attenuated in the subsurface, these releases contributed arsenic loads to both groundwater and to saturated and unsaturated zone soils. Given that the upper end of the arsenic plume is upgradient of Lower Lake and the Acid Plant, it appears that storage of high arsenic concentration materials in the Tito Park Area was also a historic source of arsenic to both underlying soils and to groundwater. Following mitigation of process water releases, removal of materials from Tito Park, and cessation of plant operations, the arsenic historically loaded onto site soils has continued to function as a source of arsenic loading to groundwater, although due to the elimination of the most significant direct loading sources (process water) the arsenic plume is currently stable, and the high concentration portion of the plume shows some indication of contraction.

<u>Selenium Loading</u> – Similar to arsenic, elevated concentrations of selenium in process water likely resulted in historic releases of selenium to groundwater. Selenium is much less easily attenuated compared to arsenic in the subsurface (default K_d of about 5.0 L/kg compared with about 29 L/kg for arsenic; Langmuir et al., 2005), therefore loading of selenium onto soils through process water releases was probably much less significant than for arsenic, except perhaps in the highly reduced central portion of the arsenic plume where selenium concentrations in groundwater are low. On the eastern portion of the plant site, the selenium plume appears to have migrated about 1200 feet downgradient of Lower Lake (Figure 2-3-11), and concentrations at well APSD-7 near the northeast corner of Lower Lake have generally decreased, as shown on the time-concentration plot below. Based on a K_d of 5.0 for selenium and the reported groundwater seepage velocity near the upgradient end of the plant site (Table 2-3-2), selenium could be expected to migrate approximately 1200 feet in 14 years, which corresponds approximately to the period of Lower Lake remediation. Thus, the current plume configuration on the eastern plant site is consistent with a historic release of selenium currently propagating through the groundwater system with minimal attenuation.



On the western side of the selenium plume, the plume centroid (area of highest concentration) also appears to have migrated some distance downgradient, suggesting that the most significant source of selenium to groundwater may have been removed (process water). However, the selenium plume extends upgradient and the upper end of the plume is approximately coincident with the arsenic plume, indicating some ongoing loading of selenium to groundwater. Elevated concentrations of selenium in unsaturated zone soils (collected during the Monier Flue demolition) have also been observed in this area. This suggests that site soils may be acting as a continuing low-level source of selenium to groundwater on the western portion of the plant site. One of the primary objectives of the Phase II RFI investigation is to collect additional selenium data to better define any ongoing selenium sources to groundwater, and to refine our understanding of the mechanisms governing selenium distribution in site groundwater.

3.0 PHASE II SAMPLING AND TESTING PROGRAM

Based on the project objectives outlined in Section 1.3 and the Conceptual Site Model in Section 2.3, a focused field sampling and testing program has been developed for the Phase II RFI. Proposed field sampling activities include: surface and subsurface soil sampling and analysis (Section 3.1), monitoring well drilling and testing (Section 3.2), and an evaluation of groundwater/surface water interactions in and around the East Helena Facility (Section 3.3). Additional studies planned under the Phase II RFI include an evaluation of the source of groundwater arsenic in southwest Lamping Field (Section 3.4) and treatability testing for assessing potential approaches for removal of arsenic and selenium from groundwater (Section 3.5).

In addition to the scope of work described below, the Custodial Trust is currently evaluating groundwater flow and geochemistry in the tertiary sediment foothills south and west of the Facility, and is conducting seasonal groundwater and surface water monitoring under the Post-RI/FS Water Resources Monitoring Program. Additional soil, sediment and surface water monitoring activities are also proposed in the baseline ecological risk assessment field sampling plan (Exponent, 2009a). Results of these ongoing investigations will be coordinated with, and incorporated into, the Phase II RFI program to maximize program efficiencies and project results.

The following sections describe the field investigations and other evaluations proposed under the Phase II RFI. Field and laboratory procedures for the Phase II Site Characterization program are detailed in the accompanying Quality Assurance Project Plan (QAPP) and Field Sampling and Analysis Plan (FSAP) (Hydrometrics, 2010a and 2010b).

3.1 SOIL SAMPLING

Extensive soil sampling has previously been conducted at the Facility during past investigations, dating back to the 1980s. The most recent (and current) surface soil dataset is the Phase I RFI soil sampling described in Section 2.2.1, supplemented by the ongoing demolition footprint soil sampling described in Section 2.2.2. Subsurface soil chemistry data was also reviewed in the Phase I RFI Report (ACI, 2003), and in Section 2.2 of this Work Plan. Additional surface and subsurface soil sampling is planned as part of the Phase II RFI, to address identified data gaps, to augment the existing soils database, and to support risk assessment activities, evaluation of current source areas, and further refinement of the conceptual site model and groundwater flow and transport model.

3.1.1 Surface Soil Sampling

Phase II RFI surface soil sampling will be conducted at selected locations previously sampled during the Phase I RFI, and at all Phase II subsurface soil boring and monitoring well locations. Objectives of the Phase II surface soil sampling include:

- Provide soil chemistry data from previously sampled locations for an expanded list of metals, as requested by the U.S. EPA;
- Provide current information to determine if site activities have generated significant changes in surficial soil metal concentrations since sampling was last conducted under the Phase I RFI and Interim Measures programs; and
- Provide information for use in the Human Health and Ecological Risk Assessments.

The Phase II surface soil sampling program will include collection of samples from the 0-6 inch, 6-30 inch and 30-60 inch depth intervals to provide the information necessary for evaluation of various exposure scenarios under the Phase Ii risk assessments.

3.1.1.1 Sampling Locations

Proposed Phase II surface soil sampling sites are shown in Figure 3-1-1 (Facility and surrounding area samples), and described in Table 3-1-1. Within the Facility and surrounding area, a total of 78 soil grab samples will be collected from 26 sites previously sampled under the Phase I RFI (Figure 3-1-1). These sampling areas are described below.

Plant Perimeter Area: The Plant Perimeter Area encompasses the area surrounding the Facility. Soil samples will be collected from six sites within the Plant Perimeter Area, with

TABLE 3-1-1. PHASE II RFI SURFACE SOIL SAMPLING LOCATIONS

AREA	SAMPLE SITES
Facility and Surrounding Area Samples	
Plant Perimeter Soils	UOPSS-2 UOPSS-4 UOPSS-9 UOPSS-12 UOPSS-17 UOPSS-20
Tito Park	UOSS-8 UOSS-10 UOSS-14
Lower Ore Storage Area	LOS SS-3 LOS SS-8 LOS SS-9 LOS SS-15
Rail Car Staging Area	RCSA-2 RCSA-5 RCSA-8
Former On Site Rail Corridors	RCSS-5 RCSS-7 RCSS-22 RCSS-25
Misc. Unpaved Areas	UPS SS-5 UPS SS-9 UPS SS-11 UPS SS-12
Acid Plant	SS-28
Thornock Lake	TL-003

two sites each along the north and west plant boundaries, and one each along the south and east boundaries (Figure 3-1-1). Selected sites represent a range of observed metals concentrations (low concentration to high concentration sites) as recorded during the Phase I sampling, and should provide a similar range of concentrations for the expanded list of metals.

Tito Park: Tito Park refers to the area between Upper and Lower Lake where metals-bearing soils/sediment were historically stockpiled until removal and placement in the Phase I CAMU. Three Phase I surface soil sample locations, representing a range of metals concentrations, will be resampled in the Phase II program (Figure 3-1-1).

Lower Ore Storage Area: The Lower Ore Storage Area is located in the western portion of the Facility (Figure 1-2-1). Metals-bearing ore and soils were historically stockpiled in this area in the past until removal and placement in the Phase I CAMU. Four surface soil sampling sites are located within the Lower Ore Storage Area (Figure 3-1-1), with three of these sites exhibiting relatively high metals concentrations in previous samples and one exhibiting relatively low concentrations.

Rail Car Staging Area: Three sites will be resampled during Phase II in the Rail Car Staging Area located west of the Facility. The three sites span the previously sampled area from east to west (Figure 3-1-1).

Former On-Site Rail Corridors: Four sites will be resampled from the former On-Site Rail Corridors in the west-central portion of the Facility (Figure 3-1-1). The Phase II sample results will be used to document current conditions in these areas.

Miscellaneous Unpaved Areas: Four sites will be resampled from various unpaved portions of the Facility (Figure 3-1-1). The Phase II sample results will be used to document current conditions where site remediation has occurred since the previous samples were collected.

<u>Acid Plant/Former Thornock Lake</u>: One site will be resampled at the Acid Plant, and one in the Former Thornock Lake area (Figure 3-1-1). Both of these areas have undergone remediation (soil removal) in the past, so the Phase II results will help document current site conditions for the expanded list of metals.

3.1.1.2 <u>Sampling Methodology</u>

<u>Facility and Surrounding Area Samples</u>

At each surface soil sampling location, a test pit will be excavated with a backhoe to 60-inch depth. Soil samples will be collected from the specified depth intervals (0-6 inch, 6-30 inch and 30-60 inch), with each sample being a composite of four grab samples collected from each of the pit walls at the specified interval. Sample collection details, including sampling methodology, documentation, field QC, and sample analyses are included in the separately submitted FSAP and QAPP.

3.1.2 Subsurface Soil Sampling

Installation of 22 soil borings and associated soil sampling is proposed in various locations across the facility as part of the Phase II RFI. Soil samples will be analyzed for total metals, with selected samples analyzed for metals leaching and adsorption characteristics. The objective of the subsurface soil sampling and testing program is to provide additional information on the distribution of metals in subsurface soils, and the relationship of soil concentrations to the observed groundwater arsenic and selenium plumes. In addition, all borings will be advanced to sufficient depths to determine the total depth to the low permeability silt/clay layer underlying the shallow alluvial aquifer beneath the Facility. In addition to the subsurface soil samples, surface soil samples (0-6 inch, 6-30 inch and 30-60 inch) will be collected at each soil boring location in addition to the 26 surface soil sites described in Section 3.1.1.

3.1.2.1 <u>Sampling Locations</u>

Proposed Phase II RFI soil boring locations are shown on Figure 3-1-2. Soil boring locations were selected based on the current groundwater plume configurations for arsenic and selenium, the distribution of available soils data for arsenic and selenium, and the need for additional data to test the assumptions of the conceptual site model presented in Section 2.3. As discussed in Section 2.3, current soil and groundwater arsenic and selenium data suggest that site soils may be acting as an ongoing source of arsenic to groundwater, but that the current groundwater selenium plume may be a transient plume resulting from historic process water-related sources, that is currently migrating downgradient with minimal continued loading from site soils or other sources. The subsurface soil sampling is intended in part to determine if this is in fact the case, or if elevated selenium concentrations do exist in site soils, and if so, act as a continuing source of selenium loading to groundwater.

Specific objectives of the Phase II RFI data collection for each of the boring locations (Figure 3-1-2) are as follows:

- Lower Lake Soil Boring (RFI2SB-1):
    - Investigate arsenic and selenium in soils as potential sources of the eastern plant site groundwater selenium plume (extending from beneath the slag pile to north of the facility, Figure 2-3-11) and low concentration arsenic plume (extending from Tito Park northward beneath the slag pile, Figure 2-3-10);
    - Investigate the potential for seepage from Lower Lake to adjacent Prickly Pear Creek;
    - Provide subsurface soil data for expanded list of metals; and
    - Determine depth to silt/clay unit (base of shallow aquifer).

- Tito Park Soil Borings (RFI2SB-2, RFI2SB-3, RFI2SB-22):
    - Further characterize soils between Upper and Lower Lake, where prior sampling has shown elevated arsenic concentrations in unsaturated and saturated zone soils;
    - Obtain selenium concentration data in unsaturated and saturated zone soils upgradient of documented selenium plume;
    - Provide subsurface soil data for expanded list of metals; and
    - Determine depth to silt/clay unit (base of shallow aquifer).

- <u>Acid Plant/Monier Flue/Blast Furnace Flue Soil Borings (RFI2SB-4, RFI2SB-5, RFI2SB-6, RFI2SB-18)</u>:
    - Further define unsaturated and saturated zone arsenic and selenium soil concentrations in an identified arsenic source area, and near the upgradient end of the west plant site selenium plume;
    - Evaluate vertical extent of identified elevated concentrations of soil selenium in former Monier Flue footprint (from 2007/08 Plant Site Demolition Soil Sampling, Section 2.2.1.2);
    - Provide subsurface soil data for expanded list of metals; and
    - Determine depth to silt/clay unit (base of shallow aquifer).

- <u>Central Plant Soil Borings (RFI2SB-7, RFI2SB-8)</u>:
    - Assess current soil chemistry in saturated and unsaturated zone soils within primary groundwater arsenic plume, to evaluate potential ongoing arsenic loading to groundwater through desorption (or other release mechanisms) from historically impacted soils;
    - Measure selenium soil concentrations (and forms) in reduced groundwater zone, to evaluate potential formation of reduced forms of selenium (elemental selenium or selenides) as sinks for removal of selenium from groundwater;
    - Provide subsurface soil data for expanded list of metals; and
    - Determine depth to silt/clay unit (base of shallow aquifer).

- <u>Western Plant Area Soil Borings (RFI2SB-9, RFI2SB-10)</u>:
    - Evaluate soil selenium concentrations near the western selenium plume centroid (area of highest groundwater selenium concentration), to determine if soils are acting as ongoing sources of selenium to groundwater;
    - Provide subsurface soil data for expanded list of metals; and
    - Determine depth to silt/clay unit (base of shallow aquifer).

- West of Plant Site (RFI2SB-11):
    - Assess current soil chemistry in saturated and unsaturated zone soils between plant site and railcar staging area;
    - Provide subsurface soil data for expanded list of metals; and
    - Determine depth to silt/clay unit (base of shallow aquifer).

- Former Zinc Plant Soil Borings (RFI2SB-12, RFI2SB-13, RFI2SB-14, RFI2SB-15):
    - Assess current soil chemistry in saturated and unsaturated zone soils at former zinc plant and along western edge of slag pile;
    - Provide subsurface soil data for expanded list of metals; and
    - Determine depth to silt/clay unit (base of shallow aquifer).

- Between Ore Storage Building and former Zinc Plant (RFI2SB-16, RFI2SB-17):
    - Assess current soil chemistry in saturated and unsaturated zone soils between the ore storage building and former zinc plant;
    - Provide subsurface soil data for expanded list of metals (and BTEX if any visual staining or petroleum odor is noted in soils); and
    - Determine depth to silt/clay unit (base of shallow aquifer).

- Former Thornock Lake (RFI2SB-19):
    - Assess current soil chemistry in saturated and unsaturated zone soils within footprint of former Thornock Lake process pond;
    - Provide subsurface soil data for expanded list of metals; and
    - Determine depth to silt/clay unit (base of shallow aquifer).

- Former Administration Building (RFI2SB-20):
    - Assess current soil chemistry in saturated and unsaturated zone soils within footprint of former Admin Building;
    - Provide subsurface soil data for expanded list of metals; and
    - Determine depth to silt/clay unit (base of shallow aquifer).

- Northern Plant Site (RFI2SB-21):
    - Assess current soil chemistry in saturated and unsaturated zone soils in vicinity of pilot PRB;
    - Provide subsurface soil data for expanded list of metals; and
    - Determine depth to silt/clay unit (base of shallow aquifer).

Prior to drilling the soil borings, a field reconnaissance will be performed with GPS coordinates and photos recorded at each proposed soil boring location. This information will be provided to EPA for review and approval of proposed drilling locations prior to the start of drilling. A number of proposed soil borings are located within the footprints of former Facility buildings which were razed during the recent plant site demolition program. Drilling in these areas will require removal of the temporary liners placed after the building demolition and (in some cases) regrading of backfill materials to allow drill rig access, and replacement of the temporary liner. Also, as noted above, soil samples from RFI2SB-17 and RFI2SB-17 will be analyzed for hydrocarbon constituents benzene, toluene, ethylbenzene and xylenes if soil samples exhibit any staining or odors indicative of potential hydrocarbon contamination.

3.1.2.2 Sampling Methodology

Sample collection methodology for soil borings will be identical to that used for soil sampling during monitoring well installation (Section 3.2). Soil borings will be drilled using an air rotary drilling system, and subsurface soil samples will be collected using a split-spoon sampler to document the subsurface lithology, and provide samples for analysis. Soil samples will be collected every five feet from ground surface to borehole total depth. Samples from additional intervals will be collected as warranted to correspond to significant changes in lithology or visual evidence of soils contamination. As noted above, soil borings will be advanced into the top of the silt/clay layer to aid in more detailed mapping of the shallow aquifer base. All drilling activities will be supervised by a geologist or other qualified scientist familiar with the East Helena Facility and the project objectives. Drill cuttings and split spoon samples will be logged to provide a continuous record of subsurface lithology at each boring location.

Soil samples collected from split spoons will be double-bagged in labeled Ziploc-type bags immediately after retrieval. Because soil boring samples will potentially be subjected to extraction and/or adsorption tests in addition to total metals characterization, efforts will be made to maintain the geochemical integrity of subsurface soil samples, principally to avoid oxidation of reduced sediments under surface conditions. Field personnel will exclude air from the sample containers (bags) to the extent feasible, will seal bags tightly, reinforcing closures with tape as necessary, and will store bagged samples on ice or under refrigeration and in the dark. Sample collection, storage, documentation and analytical details are included in the project QAPP (Hydrometrics, 2010a) and FSAP (Hydrometrics, 2010b).

3.1.3 Phase II RFI Soil Sampling Analytical Parameters, Methods, and Reporting Limits

All surface and subsurface soil samples collected during the Phase II RFI will be analyzed for total metals concentrations using wet chemistry analytical techniques (acid digestion followed by an appropriate technique for determining metals concentrations in the digestate). Soil pH will also be measured on all Phase II RFI soil samples. Following a review of total metals results, selected subsurface soil samples will also be analyzed for leachable arsenic and selenium concentrations and adsorptive capacity through a program of extraction/ adsorption testing.

3.1.3.1 Total Metals Analysis

Table 3-1-2 includes the total metals analytical parameter list and project required detection limits (PRDLs) for the proposed Phase II RFI soil sampling and testing program. The PRDLs are designed to meet all of the Phase II site characterization objectives, including comparison to previously collected data, and to meet Human Health and Ecological Risk Assessment needs as warranted. The parameters and PRDLs in Table 3-1-2 have been established based on the requirements and objectives of the various sample collection

TABLE 3-1-2. ANALYTICAL PARAMETER LIST AND PROJECT REQUIRED DETECTION LIMITS FOR SOIL SAMPLES – ASARCO EAST HELENA FACILITY PHASE II RFI

Total Metals Analysis

Parameter	**Analytical Method**[(1)]	**Surface Soil Sample PRDL (mg/kg)**	**Soil Boring Sample PRDL (mg/kg)**
Aluminum (Al)	SW 3050/6010B/6020	100	5
Antimony (Sb)	SW 3050/6010B/6020	0.1	5
Arsenic (As)	SW 3050/6010B/6020	0.1	5
Barium (Ba)	SW 3050/6010B/6020	100	5
Beryllium (Be)	SW 3050/6010B/6020	10	5
Cadmium (Cd)	SW 3050/6010B/6020	0.1	1
Chromium (Cr)	SW 3050/6010B/6020	5	5
Cobalt (Co)	SW 3050/6010B/6020	1	5
Copper (Cu)	SW 3050/6010B/6020	5	5
Gold	SW 3050/6010B/6020	5	5
Iron (Fe)	SW 3050/6010B/6020	100	5
Lead (Pb)	SW 3050/6010B/6020	1	5
Manganese (Mn)	SW 3050/6010B/6020	10	5
Mercury (Hg)	SW 7471/6010B/6020	0.05	1
Nickel (Ni)	SW 3050/6010B/6020	5	5
Selenium (Se)	SW 3050/6010B/6020	0.5	5
Silver (Ag)	SW 3050/6010B/6020	2	5
Tellurium	SW 3050/6010B/6020	1	1
Thallium (Tl)	SW 3050/6010B/6020	0.1	1
Vanadium (V)	SW 3050/6010B/6020	1	5
Zinc (Zn)	SW 3050/6010B/6020	5	5
PH	SW 9045	0.1 s.u.	0.1 s.u.

Extraction/Adsorption/Leach Testing Analysis

Parameter	**Analytical Method**[(1)]	**Extractant/Leach Solution PRDL (mg/L)**
Arsenic (As)	EPA 200.8/200.9	0.005
Selenium (Se)	EPA 200.8/200.9	0.005
PH	EPA 150.1	0.1 s.u.

(1) Laboratory analytical methods are from EPA’s *Test Methods for Analysis of Solid Waste (SW-846)* or *Methods for Chemical Analysis of Water and Wastes* (1987). Equivalent procedures may be used as long as detection limits are achieved.

activities proposed under the Phase II RFI. Table 3-1-2 applies to the following sample types:

> Surface Soil Samples -- Total Metals (Section 3.1.1) – Surface soil samples collected as described in Section 3.1 will be analyzed for an expanded list of metals parameters, to support risk assessment needs. The list of parameters and PRDLs for surface soil samples are consistent with the EPA Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. Analysis of surface soil samples for these parameters at these PRDLs will allow inclusion of Phase II surface soil data in the site risk assessment.
>
> Subsurface Soil Samples -- Total Metals (Sections 3.1.2 and 3.2) – Soil samples collected during installation of monitoring wells (Section 3.2) and soil borings (Section 3.1.2) will be analyzed for the same expanded set of total metals parameters as surface soil samples. However, since risk assessment is not a target data use for these samples, total metals PRDLs for soil boring samples will be based on standard laboratory reporting limits, to be consistent with previous results obtained for the site.

3.1.3.2 Extraction/Adsorption Testing and Analysis

Selected subsurface soil samples collected during installation of monitoring wells and soil borings will also be subjected to a variety of leaching and/or adsorption testing procedures, as discussed in the pertinent sections below. These tests are intended to provide information to support groundwater modeling, and to refine the conceptual site model for arsenic and selenium, the primary constituents of concern at the facility. As shown in Table 3-1-2, standard arsenic and selenium reporting limits for aqueous samples (0.005 mg/L) will be used during the analysis of leaching/adsorption testing samples, along with measurement of pH. These PRDLs are sufficiently sensitive to provide the required information on leachable/adsorbable concentrations of arsenic and selenium.

Based on the results for total arsenic and selenium obtained from each soil boring and monitoring well location, samples will be selected for adsorption/desorption and leach testing. The proposed program of leachate and sorption testing is consistent with that performed as part of the Phase I RFI (Hydrometrics, 2000). Objectives of the adsorption/desorption and leach testing program are as follows:

- Characterize the relative availability of soil arsenic and selenium in potential source areas to groundwater;
- Assess adsorption/desorption attenuation mechanisms for arsenic and selenium in different areas of the facility, and the relationship of attenuation mechanisms to the configuration of the groundwater arsenic and selenium plumes; and
- Support updated groundwater transport modeling efforts for arsenic and selenium (Section 4.0).

In general, selection of samples for sorption/leach testing will be based on the highest observed concentrations of arsenic and/or selenium at a particular location in both the unsaturated zone and the saturated zone. At least one unsaturated zone sample from each soil boring and on-site monitoring well will be tested using EPA Method 1312 (the Synthetic Precipitation Leaching Procedure or SPLP), while selected saturated zone samples (at least one from each boring and on-site monitoring well) will be analyzed using three methods: sequential extraction, sequential batch leach testing, and batch adsorption testing. Additional details regarding each of these procedures are outlined below and in the project QAPP (Hydrometrics, 2010a).

Unsaturated Zone Samples

SPLP (Synthetic Precipitation Leaching Procedure) Analyses – SPLP will be used to estimate the potential arsenic and selenium loading from site soils to groundwater via infiltration through the vadose zone. Previous site characterization efforts, including the Phase I RFI, have utilized the SPLP test to approximate the “readily leachable” mass of contaminants within the unsaturated zone. The Phase II RFI data will supplement previous data for arsenic, and will provide new information on potential selenium impacts to groundwater from unsaturated zone soils.

Saturated Zone Samples

Sequential Extraction Analyses – Similar to the Phase I RFI, sequential extractions of saturated zone soils will be used to determine the percentage of total arsenic and selenium held in different operationally-defined solid phases (i.e., water soluble, weak cation exchange, iron and manganese hydroxides, or residual phases). Soil samples collected during previous investigations have been tested using sequential extraction for arsenic as part of the RI/FS and Phase I RFI. Additional tests for both arsenic and selenium will be conducted on Phase II RFI samples to provide results for saturated zone soils at each soil boring and monitoring well location, supplementing previous data for arsenic and providing new information on the phase association of selenium in soils. Arsenic is generally more strongly attenuated than selenium in the subsurface (see Section 2.3.3), and the Phase II RFI data will allow comparison of relative removal rates of arsenic and selenium, and comparison of solid-phase concentrations in various forms with groundwater concentrations, to allow refinement of the conceptual site model.

Sequential Batch Leach Tests – Sequential batch leach tests will be used to assess changes in arsenic and selenium leaching rates as a saturated zone soil is exposed to progressive leaching by unimpacted (i.e., upgradient) groundwater. Sequential batch leach tests will be conducted on saturated zone soils in lieu of SPLP testing. As noted in the Phase I RFI Work Plan (Hydrometrics, 2000), source area and transport area soils have been impacted by previous process water releases at the site, including high and low pH values in certain areas, and it is likely that aquifer materials have been altered by groundwater. With the elimination of process water sources, aquifer materials will progressively be leached with relatively fresh groundwater, potentially remobilizing arsenic or (probably to a lesser extent) selenium.

Sequential batch leach testing will consist of repeated batch leach testing of soils following SPLP methodology, but using upgradient groundwater from the site (Upper Lake) as the leaching solution. The exact number of extractions to be performed on each saturated zone soil sample will be determined based on initial leaching results.

Batch Adsorption Tests – Batch adsorption testing will be used to estimate the adsorption parameters of aquifer materials for arsenic and selenium. Arsenic adsorption was previously studied during the Phase I RFI. Additional testing for arsenic and selenium as part of the Phase II RFI will allow calculation of site-specific distribution coefficients for use in the updated groundwater transport model. Test solutions will utilize groundwater from the facility, and the adsorption tests will be conducted under varying dilution ratios in accordance with EPA method 530/SW-87/006-F (EPA, 1992).

3.2 MONITORING WELL DRILLING AND COMPLETION

Additional monitoring wells will be installed as part of the RFI Phase II investigation. In general, the purpose of the additional wells is to: 1) provide detailed information on three-dimension groundwater flow at the site, 2) further delineate source areas for the arsenic and selenium groundwater plumes, and the three dimensional plume configuration, and 3) further delineate the top of the silt/clay unit which serves as the base of the shallow aquifer, and is believed to influence groundwater flow and plume migration on and downgradient of the Facility. A description of well locations, completion details, borehole sample collection and groundwater monitoring is detailed below.

3.2.1 Proposed Well Locations And Depths

The proposed wells are listed in Table 3-2-1 and are shown on Figure 3-1-3. The eight additional monitoring wells will be located in areas where additional information is needed to evaluate the conceptual model and further delineate arsenic and selenium plumes in groundwater.

Well DH-72 will be completed at the top of the silt/clay unit underlying the shallow aquifer. DH-72 will be paired with existing well DH-59 to evaluate the vertical distribution of pressure head and water quality in the area upgradient of the Speiss/Dross area and downgradient of the Acid Plant. Three wells (DH-74, -75, and -76) will be drilled through the slag pile to evaluate the groundwater quality beneath the slag and to determine the flow and geochemical vertical gradients (through paired wells DH-74 and DH-75) in this area.

TABLE 3-2-1. PROPOSED MONITORING WELL COMPLETION DETAILS

Proposed Well Designation	Target Aquifer	Anticipated Depth (ft)	Purpose
DH-72	Intermediate	60	Evaluate intermediate plume on plant site and evaluate vertical gradients (flow and geochemical)
DH-73	Shallow	25	Delineate shallow plumes near base of slag pile.
DH-74	Shallow	110	Delineate shallow plumes under slag pile. Paired with DH-75 to evaluate vertical gradients (flow and geochemical).
DH-75	Intermediate	140	Delineate intermediate plume under slag pile. Paired with DH-74 to evaluate vertical gradients (flow and geochemical).
DH-76	Shallow	100	Delineate upgradient extents of selenium plume beneath slag pile
EH-70	Shallow	50	Delineate shallow plumes and evaluate vertical gradients (flow and geochemical) in Lamping Field.
EH-138	Intermediate	80	Delineate northwest selenium plume boundary
EH-139	Intermediate	80	Delineate northwest selenium plume boundary
EH-140	Deep	120+	Evaluate water quality in deep system and vertical flow gradients.

Note: Subsurface soil samples will be collected at a minimum of 5-foot intervals during the installation of new monitoring wells and analyzed for the full list of metals. Surface soil samples to be collected at 0-6 inch, 6-30 inch and 30-60 inch depth intervals at all new well locations.

One additional on-site well (DH-73) will be completed near existing well DH-9 to help delineate the plume geometry between the slag pile and speiss/dross area.

Up to four off-site wells are proposed to evaluate groundwater quality and vertical gradients in Lamping Field northwest of the plant site. Well EH-70 will be paired with existing well EH-125 to evaluate vertical hydraulic and geochemical gradients in the center of Lamping Field and the downgradient portion of the selenium plume. Well EH-70 will be completed in the first 10 feet of the saturated zone, or about 20 feet higher than existing well EH-125. Wells EH-138 and EH-139 will be completed north of the selenium plume front (as currently defined) to further delineate the extent of the selenium plume. The EH-138 and EH-139 well locations have been selected based on current knowledge of groundwater flow and plume characteristics at the site. Note however, that the proposed locations may be adjusted based on site access restrictions, or on additional selenium concentration data to be collected near the currently-defined plume front during the spring/early summer of 2010.

A ninth well, listed as EH-140 in Table 3-2-1, may be drilled into the basal silt/clay unit to better define the hydrostratigraphy north of the plant site. Specifically, drilling and completion of EH-140 would help determine the composition and thickness of the silt/clay unit at the base of the shallow aquifer north of the plant site, and if the silt/clay unit is underlain by a “deep” aquifer as documented on the plant site. This information would in turn be used to determine if the silt/clay unit acts as a competent barrier to vertical groundwater flow north of the plant site, and a barrier to the potential downward migration of contaminants from the shallow aquifer to a deeper groundwater system believed to be tapped by a number of public water supply (PWS) wells further north (see Figure D-1, Appendix D).

Due to obvious concerns with drilling through a competent aquitard (the silt/clay unit) underlying a contaminant plume, an assessment of the hydrogeology surrounding the PWS wells will be completed prior to completing a deep monitoring well. The hydrologic assessment will include a review of the hydrostratigraphy and groundwater flow patterns around the PWS wells to determine if the PWS wells could be impacted if the arsenic or selenium plumes migrated northward in the future. The assessment will be based on existing information obtained from well completion logs and published reports, with some additional data collection, such as groundwater elevations in nearby wells. Based on results of the hydrologic evaluation, the merits of a deep monitoring well, as well as the optimum location and completion details, will be determined. The hydrologic evaluation will be completed in July so the well could be drilled in late summer 2010, if needed.

3.2.2 Drilling and Construction of New Monitoring Wells

Phase II RFI monitoring wells will be drilled using air rotary methods to penetrate the boulders, cobbles, and gravel typical of the East Helena area. Table 3-2-2 summarizes proposed monitoring well construction details. All wells will be constructed of 2-inch ID (inside diameter) NFS-approved schedule 40 PVC with flush threaded joint couplings and factory slotted screen. Shallow wells will be completed 10 feet into the saturated zone, and intermediate wells will be screened across the bottom 10 feet of the aquifer, with the borehole annulus backfilled with silica sand from the well bottom to three feet above the top of screen to provide a filter pack. The remainder of the borehole annulus will be backfilled with bentonite chips/pellets or bentonite slurry to seal the borehole annulus and prevent fluid migration along the outer well casing. All well construction and grouting details will be consistent with State of Montana monitoring well construction regulations (ARM 36.21.800) while maintaining consistency with previous well construction procedures for the project. Well drilling, construction and documentation procedures will be consistent with the EPA-approved Interim Measures Work Plan, East Helena Facility (Hydrometrics, 1999b), and the RCRA Facility Investigation (RFI) Work Plan (Hydrometrics, 2000). All drilling will be supervised by a qualified scientist or engineer, with detailed lithologic and construction logs recorded during drilling. Figures 3-2-1 and 3-2-2 show typical construction details for shallow and intermediate aquifer monitoring wells, respectively.

Subsurface soil samples will be collected at all well locations using a split-spoon sampler to document the subsurface lithology and provide samples for analysis. Soil samples will be collected every five feet from ground surface to borehole total depth. Samples from additional intervals may be collected as warranted to correspond to significant changes in lithology. In addition to the subsurface soil samples, surface soil samples (0-6 inch, 6-30 inch and 30-60 inch) will be collected at each monitoring well location.

As noted in Section 3.1.3, all soil samples obtained during monitoring well drilling will be analyzed for total metals. Based on the results for total arsenic and selenium obtained from each soil boring, a subset of samples from on-site wells will be selected for the program of

TABLE 3-2-2. MONITORING WELL CONSTRUCTION DETAILS

Well	Casing Size/ Type	Expected Depth	Screen Type/ Length	Expected Screen Interval	Sandpack Type/Length	Expected Sandpack Interval
DH-72	2” ID Schedule 40 PVC, flush thread	60 ft	2” ID Sch. 40 PVC, 10-slot, flush tread/10 ft	50 to 60 ft	10/20 Colorado Silica Sand/ 13 ft	47 to 60 ft
DH-73	2” ID Schedule 40 PVC, flush thread	25 ft	2” ID Sch. 40 PVC, 10-slot, flush tread/10 ft	15 to 25 ft	10/20 Colorado Silica Sand/ 13 ft	12 to 25 ft
DH-74	2” ID Schedule 40 PVC, flush thread	110 ft	2” ID Sch. 40 PVC, 10-slot, flush tread/10 ft	100 to 110 ft	10/20 Colorado Silica Sand/ 13 ft	97 to 110 ft
DH-75	2” ID Schedule 40 PVC, flush thread	140 ft	2” ID Sch. 40 PVC, 10-slot, flush tread/10 ft	130 to 140 ft	10/20 Colorado Silica Sand/ 13 ft	127 to 140 ft
DH-76	2” ID Schedule 40 PVC, flush thread	100 ft	2” ID Sch. 40 PVC, 10-slot, flush tread/10 ft	90 to 100 ft	10/20 Colorado Silica Sand/ 13 ft	87 to 100 ft
EH-70	2” ID Schedule 40 PVC, flush thread	50 ft	2” ID Sch. 40 PVC, 10-slot, flush tread/10 ft	40 to 50 ft	10/20 Colorado Silica Sand/ 13 ft	37 to 50 ft
EH-138	2” ID Schedule 40 PVC, flush thread	80+ ft	2” ID Sch. 40 PVC, 10-slot, flush tread/10 ft	70 to 80 ft	10/20 Colorado Silica Sand/ 13 ft	67 to 80 ft
EH-139	2” ID Schedule 40 PVC, flush thread	80+ ft	2” ID Sch. 40 PVC, 10-slot, flush tread/10 ft	70 to 80 ft	10/20 Colorado Silica Sand/ 13 ft	67 to 80 ft
EH-140	2” ID Schedule 40 PVC, flush thread	120+ ft	2” ID Sch. 40 PVC, 10-slot, flush tread/10 ft	110 to 120 ft	10/20 Colorado Silica Sand/ 13 ft	107 to 120 ft

All depths in feet below ground surface.
The need and location for EH-140 to be determined following hydrologic evaluation of PWS wells.

sorption/leach testing described in Section 3.1.3.2. A minimum of one unsaturated zone sample from each on-site well boring will be analyzed for leachable arsenic and selenium. A minimum of one saturated zone sample from each on-site well boring will be tested using the sequential extraction, sequential batch leach, and batch adsorption procedures outlined above for soil boring samples.

At each off-site well boring, two soil samples collected from the saturated zone (one near the water table surface and one near the bottom of the aquifer) will be tested using only the batch adsorption procedure described in Section 3.1.3.2, to evaluate the attenuation capacity of soils at the leading edge of the plumes. SPLP testing of unsaturated zone samples, sequential extraction, and sequential batch leach tests will not be conducted on off-site well soil samples.

3.2.3 Supplemental Groundwater Monitoring and Testing Program

Following well construction, the new monitoring wells will be developed, tested and sampled in accordance with procedures and techniques defined in the project QAPP and FSAP (Hydrometrics, 2010a and b). Well development will include repeated surging and bailing to remove fine sediment from the screened interval and improve the hydraulic connection with the aquifer. The new monitoring wells will also be incorporated into the Post-RI/FS Groundwater Quality Monitoring Program.

In addition to water quality sampling, slug testing will be conducted on the new wells to determine the aquifer hydraulic conductivity. Testing will be conducted in accordance with procedures described in the Interim Measures Work Plan, East Helena Facility (Hydrometrics, 1999b), and the RCRA Facility Investigation (RFI) Work Plan (Hydrometrics, 2000). All new wells will also be surveyed for horizontal and vertical control.

3.3 EVALUATION OF GROUNDWATER/SURFACE WATER INTERACTIONS

As noted in Section 2.3.1.2, synoptic streamflow monitoring has documented a significant decrease in Prickly Pear Creek flow north of the Facility. This loss of water from the creek provides a significant source of recharge to the shallow/intermediate aquifer north of the facility. Similar streamflow monitoring adjacent to the Facility concluded that the rate of surface water seepage to the groundwater system in this area (or vice versa) were within the level of error associated with streamflow measurements, and were therefore inconclusive in regards to the rate and direction of flow between the creek and local groundwater system. Both the direction and rate of flow between Prickly Pear Creek and shallow/intermediate aquifer is of interest in quantifying groundwater flow and contaminant fate and transport in and around the Facility. For these reasons, a detailed evaluation of groundwater/surface water interactions will be completed for Prickly Pear Creek adjacent to and north of the Facility. Objectives of the groundwater/surface water interactions evaluation include:

1. Quantify the direction and rate of flow between Prickly Pear Creek and the groundwater system adjacent to and north of the Facility.
2. Identify areas of groundwater recharge, and potential contaminant transport, to the creek.
3. Evaluate the effect of seepage from the creek on groundwater flow directions and plume migration directions and rates north of the Facility.
4. Provide information on leakage rates from Prickly Pear Creek to the shallow/intermediate aquifer (or vice versa) for use in set up and calibration of the numerical groundwater flow model discussed in Section 4.0.

In order to meet these objectives, the groundwater/surface water interactions investigation includes detailed synoptic streamflow monitoring along the targeted segment of the creek, detailed surface water/groundwater level monitoring to quantify hydraulic gradients between the creek and the groundwater system, and installation of “mini-piezometers” within the active channel. The investigation components are described below. On a related note, a detailed assessment of groundwater flow between Lower Lake and Prickly Pear Creek, including installation of piezometers adjacent to and within the creek, and sampling of hyporeic zone water quality, is included in the baseline ecological risk assessment work plan (Exponent, 2009a).

3.3.1 Synoptic Streamflow Monitoring

A synoptic streamflow survey will be conducted on Prickly Pear Creek under baseflow conditions (late summer or fall) to document changes in streamflow through the study area. In a synoptic streamflow survey, streamflow measurements are recorded at closely spaced intervals along a stream in as short a time period as possible to provide a point-in-time snapshot of streamflow rates along the stream reach of interest. An increase in flow between two adjacent sites (after accounting for tributary inflows or diversions within the subreach) indicates an influx of groundwater to the stream, while a decrease in flow indicates leakage from the stream to the subsurface. Synoptic streamflow surveys are typically conducted under baseflow conditions to avoid interference from overland surface runoff or shallow subsurface interflow, which can affect spatial streamflow patterns during the wet season, but are not indicative of groundwater/surface water interactions.

Figure 3-3-1 shows the proposed streamflow monitoring stations for the synoptic stream gaging event. The streamflow monitoring network is similar to that utilized in a previous streamflow monitoring event (Section 2.3.1.2), with a few exceptions. An additional site has been added between sites PPC-3 and PPC-5, and immediately upstream of the diversion to Upper Lake. An additional site is also denoted on a side channel of Prickly Pear Creek north of PPC-36A, if flow is present in the side channel at the time of the survey. In addition to the sites shown on Figure 3-3-1, all inflows to and diversions from Prickly Pear Creek will be measured to allow for accurate determination of changes in streamflow from upstream to downstream through the area. As shown in Figure 3-3-1, the synoptic streamflow monitoring program includes a minimum of 14 streamflow monitoring sites.

Flow measurements will be recorded at each site using one of the following methods, depending on flow rates and channel configuration:

1. Area-velocity method using a Marsh-McBirney flow meter and wading rod, with discharge calculated by the USGS midsection/six tenths-depth method.
2. Portable flume (90° V-notch flume or parshall flume), with discharge calculated from standard rating tables.

Based on site conditions, it is anticipated that most or all flow measurements will require use of the current-velocity method. Portable flumes may be used if smaller tributary inflows or diversions are present during the monitoring event.

In addition to streamflow measurements, water quality field parameters will be recorded at each site including water pH, specific conductance, temperature, and dissolved oxygen. These parameter values can sometimes serve as an indicator of influxes of groundwater to surface waters. All streamflow monitoring sites will be photographed during the synoptic event and GPS coordinates recorded to allow for mapping and relocation of sites in the future.

3.3.2 Groundwater/Surface Water Level Monitoring

Another direct method for assessing groundwater/surface water interactions is through comparison of surface water levels (elevations) to groundwater levels immediately adjacent to the surface water body. If groundwater levels are lower than creek levels, this indicates a potential for leakage from the creek to groundwater, while groundwater levels higher than creek levels indicate the opposite. It is important to note that a positive hydraulic gradient in either direction alone does not indicate seepage into or out of a creek is occurring. In addition to the gradient, a conduit (i.e., permeable material) must be present for flow to occur.

The existing monitoring well network, and quarterly groundwater level monitoring currently being conducted under the Post-RI/FS Monitoring Program, provides valuable information on groundwater levels relative to Prickly Pear Creek. The potentiometric map of the East Helena/Lamping Field area shown in Figure 2-3-6 shows that groundwater levels north of the Facility generally are below the adjacent creek levels, indicating a potential for leakage from the creek. The sharp curvature in the groundwater potentiometric contours in the vicinity of the creek, correlating to an increase in groundwater levels beneath the creek, is strong evidence of leakage from the creek to the groundwater system. What is not known at this time is the height of groundwater mounding beneath the creek, or if the alluvial sediments are fully saturated from the base of the creek bed all the way down to the water table (as assumed in the Figure 2-3-6 potentiometric surface). If saturated conditions exist from the base of the creek bed down to the water table, or if the groundwater mound beneath the creek is sufficiently high, this mounding would produce an effective hydraulic boundary, or barrier to groundwater flow (and plume migration) beneath the creek.

The first component of the water level monitoring program will include designating a number of existing wells located in close proximity to the creek as groundwater/surface water level monitoring stations. Each of these wells will be paired with a surface water stage monitoring device to be installed in Prickly Pear Creek adjacent to the well to provide corresponding groundwater/surface water level data. The creek stage monitoring devices will include a graduated staff gage mounted on a metal post driven into the channel bottom, with a stilling tube (perforated one-inch diameter PVC pipe) also mounted onto the post. The staff gage will allow for rapid visual reading of the creek stage in conjunction with periodic groundwater level measurements, while the stilling tube will allow for installation of a pressure sensitive transducer for continuous water level and water temperature recording. Continuous water level monitoring in both the creek and adjacent monitoring wells may be warranted, at least during the spring runoff period, to allow for detailed evaluation of the water level trends and the timing of these trends in the creek and adjacent groundwater system. Wells to be utilized for the water level monitoring program, in upstream to downstream order, include DH-11, DH-53, DH-10A, EH-54, EH-127 and EH-131 (Figure 3-3-1).

The second component of the water level monitoring program involves installation of shallow piezometers at various points along the stream bank to assess groundwater levels, and saturated conditions, immediately adjacent to the creek. Whereas the network of existing monitoring wells will be used to determine the general direction and magnitude of hydraulic gradients between the creek and the shallow/intermediate aquifer, the piezometers will be used to evaluate the height of groundwater mounding beneath the creek, and whether or not the mound extends up to the channel bottom.

The piezometers will be installed with a pickup truck-mounted direct-push drill rig to facilitate access to the creek. Currently, four piezometers are proposed, with the piezometers corresponding to select groundwater/surface water monitoring stations described above (Figure 3-3-1). The piezometers will be installed in a “nested” fashion, with three piezometers installed at each of the four locations. Each nest will include piezometers completed at 5 to 10 feet, 15 to 20 feet, and 25 to 30 feet below ground surface, to determine the degree of saturation at the various levels, and provide detailed information on vertical hydraulic gradients next to the creek. The piezometers may also be used to obtain water quality data from shallow groundwater adjacent to the creek, and for determination of hydraulic conductivity of soils/sediment near the creek for use in the numerical groundwater flow model (Section 4.0), and possibly for calculation of seepage rates based on a flow-net analysis (USGS, 2008).

3.3.3 Potentiomanometer Installation

Lastly, the groundwater/surface water interaction study includes placement of potentiomanometers, or mini-piezometers, within the active channel of Prickly Pear Creek. As described in USGS, 2008, a mini-piezometer is simply a solid pipe or rigid tube which is open on the bottom and may include perforations over the lower few inches. The tube is driven into the creek bed a sufficient distance to obtain a good hydraulic seal between the tube bottom and the surface water. Water levels measurements of the underlying groundwater system (and/or hyporeic zone) are obtained inside the mini-piezometer, and compared to the surface water levels on the outside of the piezometer. The difference in water levels determines the direction and magnitude of vertical hydraulic gradient between the stream and the underlying groundwater system.

The mini-piezometers will be constructed as described in USGS, 2008 and shown in Figure 3-3-2. Each mini-piezometer will be fitted with stilling tube to dampen waves and facilitate accurate measurement of surface water levels, and a sampling tube for possible water sample collection. Mini-piezometers will located in areas where the surface water-groundwater flux is expected to be small, and the synoptic stream gaging or flow net analyses described above may not prove conclusive. This includes the stream segment adjacent to and immediately north of the Facility, between the new streamflow site upstream of the Upper Lake inflow diversion, and PPC-7 (Figure 3-3-1). The exact locations will depend on stream substrate characteristics, since installation may not be possible in areas with large gravels or cobbles. In all, two to three mini-piezometers are proposed in this subreach, if suitable locations are identified. This is in addition to the three mini-piezometers proposed for installation in Prickly Pear Creek adjacent to Lower Lake in the ecological risk assessment work plan (Exponent, 2009a).

The synoptic stream gaging, water level and flow net analyses, and potentiomanometer installation outlined above is expected to provide adequate information to meet the study objectives. If additional information is deemed necessary, more sophisticated techniques, such as installation of seepage meters in the streambed, or evaluation of water temperature gradients in the stream, groundwater system and hyporeic zone can be considered for implementation.

3.4 EVALUATION OF SOURCE OF ARSENIC IN SOUTHWEST LAMPING FIELD

As described in Section 2.3.1, 13 monitoring wells were installed in 2008 and 15 in 2009, with several of these wells located in the Lamping Field area north of the Facility. The addition of these wells to the monitoring network has increased our current understanding of the hydrostratigraphy, groundwater flow directions, and groundwater plume configuration in this area. Of particular interest are arsenic concentrations in two wells (EH-128 and EH-132) located in the southwest portion of Lamping Field. These two wells are located just east of Wilson Ditch, and near the base of the tertiary sediment foothills flanking the Helena Valley. Stratigraphic logs for both of these wells includes unconsolidated silty/sands and gravels, representative of the mixed alluvium/colluvium shown as Qac on Figure 2-3-2.

Figure 3-4-1 shows the detailed potentiometric surface and May/June 2009 arsenic plume configuration for the Lamping Field area. Besides showing the control on plume migration and configuration imparted by the groundwater flow field, the map also shows two distinct portions of the arsenic plume, including the main plume emanating from the plant site to the southeast, and a separate higher concentration arsenic area defined by wells EH-128 and EH-132 in the southwest portion of Lamping Field. Arsenic concentrations in this area (34 ppb at EH-128 and 30 ppb at EH-132 in June 2009) are significantly higher than concentrations at EH-57A, EH-118, EH-119 and EH-124 located to the east (all less than 5.0 ppb), leading to what appears to be two distinct arsenic plumes. Based on the potentiometric surface and generalized groundwater flow directions, the EH-128/EH-132 elevated arsenic area is hydrologically downgradient of the Seaver Park subdivision, where a number of private wells have been found to contain arsenic concentrations in excess of 10 ppb. The source of elevated arsenic concentrations in the Seaver Park area is currently being evaluated by the Custodial Trust, with natural geochemical conditions within the tertiary sediments identified as a potential source. Based on the location of EH-128 and EH-132 relative to the tertiary foothills and Seaver Park, and the apparent separation of the EH-128/EH-132 plume area from the main plume originating from the plant site, naturally elevated arsenic concentrations in the upgradient tertiary sediment groundwater may, at least in part, be the source of arsenic in this area. Due to the proximity of Wilson Ditch, current or historic seepage from the ditch could be another potential source, although water quality data from the ditch would indicate that ditch water is not a source (Table 3-4-1). Whatever the source of arsenic, the lack of selenium in groundwater at EH-128 and EH-132 suggests that the source is distinct from the plant site source, since arsenic-bearing groundwater emanating from the plant site is also elevated in selenium.

TABLE 3-4-1. TOTAL METALS CONCENTRATIONS IN WILSON DITCH WATER (SITE WD-2) UPSTREAM OF LAMPING FIELD

Parameter	Units	6/4/01	6/20/02
pH	s.u.	8.4	8.8
Arsenic	mg/L	<0.005	0.007
Cadmium	mg/L	<0.001	0.002
Copper	mg/L	<0.004	0.007
Lead	mg/L	0.007	0.03
Zinc	mg/L	0.03	0.1

The Phase II RFI will include an evaluation of source(s) of elevated arsenic in the southwest Lamping Field area. The evaluation will include synoptic stream gaging and installation of piezometers along the ditch to evaluate potential seepage to the subsurface, and monitoring of groundwater levels to assess possible recharge to the groundwater system from ditch flow.

3.4.1 Streamflow and Water Level Monitoring

A synoptic streamflow survey will be conducted on Wilson Ditch in the vicinity of EH-128 and EH-132 to evaluate potential seepage from the ditch, and if such seepage could impact groundwater quality. Based on past sampling, water quality in Wilson Ditch is generally of good quality (similar to Upper Lake and Prickly Pear Creek), so the potential loading mechanism would be leaching of arsenic from the ditch sediments or underlying soils, as opposed to the ditch water itself.

A total of five streamflow monitoring sites are proposed on Wilson Ditch as shown in Figure 3-4-1. The monitoring network includes two previously established water quality sampling sites (WD-3 and WD-4) and three new sites located within and north of the EH-128/EH-132 area. Monitoring sites WD-3 and WD-4 are also scheduled for sampling in the baseline ecological risk assessment work plan (Exponent, 2009a), including surface water quality sampling, sediment chemistry sampling, and streamflow measurement.

The synoptic streamflow monitoring will follow the protocol outlined in Section 3.3 for Prickly Pear Creek. Streamflow measurements will be recorded using the area-velocity method and a Marsh McBirney flow meter. Flows will be measured in as short a time period as possible, with any tributary inflows or diversions also measured to allow for accurate determination of seepage losses to the subsurface. Water quality samples will also be collected at the upstream and downstream-most sites, to document the ditch water quality throughout the area of interest. Ditch water samples will be analyzed for the expanded surface analytical schedule included in the Post RI/FS Water Resources Monitoring Program (Hydrometrics, 2009b). The synoptic streamflow monitoring would occur in late summer or fall, after the spring wet season but before the ditch flow is shut off, typically in October.

Static water levels will also be monitored in EH-128 and EH-132 to evaluate possible influences on groundwater levels from Wilson Ditch flow. Groundwater levels will be recorded automatically in each well with a pressure sensitive transducer capable of recording water levels (and water temperature) to the nearest 0.01 feet. Water levels will be recorded during the entire irrigation season, beginning approximately two weeks prior to and ending two weeks after the scheduled start up and shut down of flow. Water levels will be recorded every four hours for two weeks prior to and two weeks after the spring startup and fall shutdown of flow (when potential influences of ditch flows on groundwater levels should be most apparent) with the recording interval decreased to 12 hours during the intervening period. The ditch water level will also be recorded daily during the key spring startup and fall shutdown periods.

3.4.2 Piezometer Installation

Depending on results of the ditch flow and water level monitoring described above, one or more sets of piezometers may be installed immediately adjacent to Wilson Ditch. Similar to the Prickly Pear Creek piezometers described in Section 3.3, the objective of the piezometers would be to evaluate saturated conditions and vertical hydraulic gradients beneath the ditch. The piezometers would only be installed in the synoptic streamflow monitoring or groundwater level monitored indicated significant seepage is occurring from Wilson Ditch.

Piezometer installation would occur with a direct push drill rig or air rotary drill rig, depending on subsurface conditions. One to two piezometer sets would be installed in the vicinity of EH-128/EH-132, with each set including piezometers completed at 5 to 10 feet, 15 to 20 feet and 25 to 30 feet below ground surface. The piezometers could also serve for collection of groundwater samples (if saturated conditions exist), and for collection of soil samples (for metals analyses) during drilling. The decision whether or not to install the piezometers will be made based on the ditch flow and water level data, and in consultation with the oversight agencies. Pending results of the investigation outlined above, additional monitoring wells may also be proposed south of EH-128 (in the vicinity of WD-3, Figure 3-4-1) and south of Highway 12 to assess upgradient groundwater quality as part of the background groundwater chemistry evaluation currently in progress.

3.5 GROUNDWATER TREATABILITY TESTING

At the request of EPA, a conceptual treatability testing program and preliminary testing schedule to evaluate treatment of facility groundwater for arsenic and selenium has been developed as part of this Phase II RFI Work Plan. Prior to implementation of treatability testing, additional details regarding specific testing objectives, procedures, and methods will be outlined in Treatability Testing Work Plans for agency review and approval.

The treatability testing proposed under this Phase II RFI Work Plan will complement a number of previous or ongoing groundwater treatability test programs at the facility. Previous treatability testing has focused primarily on arsenic, including an air injection (sparging) program conducted near the downgradient facility boundary as part of Interim Measures; jar test for arsenic removal conducted by CDM in 2007; and ongoing permeable reactive barrier (PRB) pilot testing being conducted by EPA at the Facility (EPA, 2008). ARCADIS has also recently reviewed alternatives for in situ treatment of arsenic and selenium at the facility. Each of these programs is summarized briefly below.

1. <u>Interim Measures Air Sparge Testing</u> – Testing was conducted under Interim Measures to evaluate the effectiveness of air injection to promote in situ arsenic

removal near the downgradient facility boundary. Results indicated that air injection was effective at removing arsenic from groundwater, particularly when initial groundwater quality included elevated concentrations of dissolved iron. Removal percentages were not sufficient to achieve water quality standards in groundwater. Addition of supplemental iron reagent to enhance removal via sparging was also effective, although pH depression caused by iron precipitation inhibited arsenic removal at iron concentrations beyond a certain threshold.

2. <u>2007 CDM Jar Tests</u> – Jar testing conducted by CDM in 2007 evaluated the effectiveness of different adsorption media at removing arsenic from site groundwater in a permeable reactive barrier. While several different effective media were identified, testing also indicated that treatment effectiveness might be offset by implementability issues (volume requirements, physical limitations).
3. <u>EPA Permeable Reactive Barrier</u> – The pilot-scale PRB installed by EPA using zero-valent iron as the reactive medium has shown effectiveness at removing arsenic from groundwater, from >25 mg/L upgradient to <0.1 to 2 mg/L within the PRB. Removal mechanisms have been shown to be complex and varied in the field, compared with laboratory results; sorption of arsenic to iron oxyhydroxides and sulfides are indicated as the primary removal mechanisms (EPA, 2008).

Treatability testing conducted as part of the Phase II RFI will include treatment effectiveness and implementability investigations for both arsenic and selenium, with more of a focus on selenium, since testing programs to date have not considered selenium treatment. The general tasks to be conducted for groundwater treatability testing will include the following:

- A literature review to identify possible in situ and ex situ treatment technologies will be conducted. EPA (2007) has identified a number of effective technologies for selenium, including above-ground adsorption, ion exchange, or chemical reduction systems, or installation of Se-reactive PRBs. Zero-valent iron has been demonstrated as an effective PRB medium for selenium in both laboratory and field testing. Treatment effectiveness for selenium is likely to be highly dependent on selenium speciation; current data indicate that selenium in groundwater at the site is dominated by the oxidized form (selenate), which is the form most amenable to anion exchange methods. The results of the literature review will be summarized, including selection of treatment methods for laboratory testing.

- Laboratory-scale treatability testing programs for selected treatment methods will be developed following the literature review. Testing results for arsenic and/or selenium will be evaluated and presented in laboratory treatability testing reports. Preliminary evaluations of implementability will also be conducted at this stage. Treatment methods showing favorable results in terms of removal rates and implementability may be further evaluated through pilot-scale testing, if warranted.
- ARCADIS has provided the Custodial Trust with a conceptual strategy for in situ treatment of groundwater, involving a sequence of redox manipulations, introduction of soluble iron, removal of contaminants (arsenic and selenium) via coprecipitation. Site-specific testing of this method has not occurred at this point.

The literature review is currently in progress, and will continue while the Phase II RFI Work Plan is under review. Upon approval of the work plan, or notice to proceed with the treatability testing portion of the plan, specific bench scale testing will be designed and conducted, with pilot scale testing performed based on the literature review and bench scale testing results. The literature review and bench scale testing could occur during the 2009/2010 fall and winter, with on site pilot testing occurring during the 2010 field season.

4.0 GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL

4.1 UPDATE OF NUMERICAL GROUNDWATER MODEL

As part of the Phase II RFI, Asarco will update the previous numerical model developed for the East Helena plant site and surrounding area. The Phase II RFI model will be updated to reflect current data and site conditions and used to evaluate the groundwater flow system and the fate and transport of arsenic and selenium. Objectives of the updated groundwater modeling effort will include:

1. Update the previous groundwater model to simulate the current flow field (distribution of hydraulic head) and groundwater flow rate (flux through the aquifer and groundwater/surface water interaction) over the expanded model domain;
2. Simulate the current arsenic and selenium plume geometry in terms of the distribution, concentrations and apparent migration rates observed for arsenic and selenium in recent years; and
3. Conduct predictive simulations for general assessment of various groundwater management/treatment scenarios to assess the potential effectiveness, the aquifer response, and preliminary design considerations for the various management/ treatment scenarios, to be developed.

Although it may be appropriate to use the Phase II RFI model to evaluate regional effects of potential corrective measures and preliminary design considerations for various management/treatment scenarios, an expanded modeling effort may be necessary to complete a thorough corrective measures design analysis.

4.2 PREVIOUS MODEL DEVELOPMENT

Asarco has previously developed numerical groundwater flow and transport models for the site as part of the CERCLA RI/FS (Hydrometrics, 1990) and Phase I RFI (ACI, 2005) and used the models to evaluate the potential for long-term migration of arsenic due to process water-related sources. Historically, process water-related sources have accounted for the majority of the arsenic released from the site.

The 1990 RI/FS transport model used retardation coefficients to simulate geochemical attenuation of arsenic in the groundwater system. This effectively slowed down the rate of arsenic transport in the model to account for temporary sorption of arsenic on aquifer material. This method of simulating geochemical attenuation assumes that all arsenic attenuation is completely reversible (i.e., all arsenic that is attenuated or removed from groundwater by soils is later released to groundwater). However, sequential extraction analyses of site soils (conducted as part of the 1990 RI/FS) indicate that arsenic attenuation on the site is not completely reversible and that a significant portion of the arsenic is present in stable phases that are not easily remobilized. Because complete reversibility was assumed in the model, the RI/FS concluded that the model was overly conservative in its assessment of the long-term potential for arsenic migration in groundwater.

Asarco implemented numerous corrective measures to reduce or eliminate process water sources and collected additional information on groundwater flow and geochemistry after the completion of the 1990 CERCLA Comprehensive RI/FS. As part of the Phase I RFI, the 1990 CERCLA Comprehensive RI/FS transport model was updated to incorporate the corrective measures in the conceptual model and reflect current data and site conditions. Modifications from the original 1990 CERCLA Comprehensive RI/FS model included:

- Expansion to a three dimensional model that simulates water quality in both the shallow and intermediate aquifers;
- Extension of the model grid to the north and west of the former Asarco plant site to further assess potential migration pathways for arsenic in the City of East Helena area;
- Use of updated hydrologic properties based on additional drilling and aquifer test results;
- Use of updated geochemical transport parameters based on soil adsorption and leachability test results; and
- Addition of secondary sources of arsenic to the transport model to account for arsenic contributions from Asarco plant site soils based on soil leachability test results.

The Phase I RFI model concluded that the arsenic plume in the shallow groundwater system would move approximately one block (150 feet) over 50 years. Based on groundwater monitoring and additional investigations the model appears to have effectively simulated the shallow arsenic plume as there has been little to no movement of the arsenic plume in the shallow aquifer beyond seasonal changes. The Phase I RFI model had similar predictive analysis of arsenic migration rates (one block over 50 years) in the intermediate aquifer. Although subsequent monitoring has shown increases in arsenic concentrations in wells in the middle of the plume, there has been little to no movement observed at the leading edge of the intermediate arsenic plume. As in the 1990 CERCLA Comprehensive RI/FS model, the Phase I RFI model used retardation factors to simulate the attenuation of arsenic and is considered to be conservative.

Since completing the Phase I RFI modeling effort, numerous investigations have been completed that have provided further information on aquifer characteristics and the fate and transport of metals. In addition, corrective actions (e.g. installation of slurry walls) have been implemented that have altered the site hydrogeology. The 1990 Comprehensive RI/FS model and the Phase I RFI model both evaluated the fate and transport of arsenic. However, in subsequent investigations selenium has been detected at elevated concentrations in groundwater. The Phase II RFI model will therefore be updated to reflect current data and site conditions and evaluate the fate and transport of arsenic and selenium.

4.3 DATA NEEDS

Data from previous investigations provide a significant baseline for defining most of the model parameters for groundwater flow and arsenic transport. A detailed groundwater/ surface water interaction study, discussed in Section 3.4, will provide data for the conceptual and numerical models to better simulate groundwater flow throughout the modeled area. The model will be expanded to include soil related source terms for selenium, which will require further evaluation of the behavior of selenium in groundwater, including leachability and attenuation capacity of site soils. Recent investigations have shown that the groundwater and surface water interaction, specifically with the downgradient portion of Prickly Pear Creek, may have a large effect on the groundwater flow and transport of constituents at the leading edge of the arsenic and selenium plumes. The Phase II RFI includes a number of tasks aimed specifically at providing additional information on the groundwater flow system and mobility of metals in the unsaturated and saturated soils. These analyses include a groundwater/ surface water interaction investigation, and conducting sequential extractions and batch adsorption tests on soils samples from on-site and off-site boreholes. Details of the above investigations are discussed in Sections 3.4 and 3.3, respectively.

4.4 MODEL DEVELOPMENT

Development of a numerical model needs to consider the complex hydrogeologic and geochemical characteristics of the Facility and aquifer system. Groundwater flow and transport of contaminants at the Facility are very complex and will require some flexibility in the development of the specific modeling approach until data collected as part of the Phase II RFI investigation are fully analyzed. Although a few details of model development will need to be updated based on Phase II findings, we have outlined an initial approach to model construction and approach below, with the understanding that modifications may need to be made based on data collected as part of the Phase II RFI investigation and further information gained in model development.

4.4.1 Model Selection

The original 1990 CERCLA Comprehensive RI/FS modeling analysis utilized Plasm and Random Walk models for flow and transport modeling. In the development of the Phase I RFI model the original models were replaced by MODFLOW 2000 (version 1.1) for simulation of the physical flow system and MT3D (Modular 3-D Transport Model, version 4.0) for evaluation of contaminant transport processes. These models were selected because of their comprehensive capabilities for simulating advection, dispersion/diffusion, and chemical reactions of contaminants in groundwater flow systems under a wide range of hydrogeological conditions.

The Phase II RFI model will also use MODFLOW 2000 to simulate the physical flow system. MODFLOW 2000 is an updated version of the U.S. Geological Survey's, modular 3D finite difference ground-water flow model, MODFLOW (McDonald and Harbaugh, 1988; Hill, 1992). For evaluation of contaminant transport processes the model will be upgraded to MT3DMS (Modular Transport 3-D-Multiple Species), which is an upgraded version of MT3D (Zheng, 1990) that can simulate the advection, dispersion, and chemical reactions of multiple species in groundwater. To facilitate model development and data processing the flow and transport models will be implemented using the software program GMS (Groundwater Modeling System, version 6.5).

4.4.2 Model Domain/Grid

The initial model domain will encompass the entire East Helena Facility and extend downgradient beyond the groundwater study area. Upper Lake will be used as the southern flow boundary of the model. The model will extend from Upper Lake to the north, and expand west and east, following the principal direction of groundwater flow and encompass the alluvial groundwater system. The eastern/western boundaries of the model will be associated with geologic and hydrologic features such as the boundary of the alluvium to the southwest, and areas of parallel flow that are outside of the influence from anticipated stresses applied to the model. The downgradient boundary of the model will be located approximately 0.5 miles north of Canyon Ferry Road, which will allow simulations to encompass the East Helena Public Water Supply wells, and is anticipated to be outside of areas that may be effected by stresses applied to the model. Figure 4-4-1 shows the model domain that is projected for the initial model development.

A variable spaced grid will be developed for the model. Refinement points will be used to discretize the grid in areas where high geochemical gradients are present (speiss/dross and acid plant areas), which will allow the model to more accurately simulate the plumes. Refinement points will also be included in areas where potential remedial controls will be evaluated, and downgradient areas of the plume where sharp geochemical gradients require higher model resolution. The refinement points will be set up with a base cell size of 20 feet and a multiplier of 1.1 to allow for variable grid spacing to a maximum size of 100 feet. This will limit changes in the grid spacing to a factor of 1.5 times the adjacent cell dimensions and avoid discretization into long skinny cells which can result in instability and/or introduce errors into the model. Additional refinements of the model grid may be required for transport analysis to establish thresholds (peclet number $\leq$1) for max grid dimensions based on dispersion coefficients to avoid mathematical instability (numerical dispersion).

On average the saturated thickness of the alluvial system is approximately 30 feet with a maximum thickness of approximately 60 feet. Based on the permeability characteristics of the primary hydrostratigraphic units and the vertical geochemical gradients within the aquifer, six model layers should be sufficient for vertical discretization of the model. Higher K units can typically be simulated with one or two layers since flow in these units is primarily horizontal. Greater discretization is required to accurately simulate vertical flow and transport, particularly when focusing on vertical flow through one or more semi-confining units since this may require simulation of very tightly spaced flow and concentration contours over discrete distances. Discretization into six layers will allow for an average cell thickness of 5 feet and an approximate maximum cell thickness of 10 feet. These thicknesses should be sufficient to allow the model to accurately simulate vertical flow and transport within the primary hydrostratigraphic units based on the observed hydraulic and geochemical gradients, however, the model will be refined as necessary during calibration.

4.4.3 Boundary Conditions

Boundary conditions will be used to simulate hydrogeologic conditions at the extents of the model domain. The upgradient portion of the model will be bounded to the south by Upper Lake, which will be simulated using a constant head boundary. A constant head boundary is appropriate to simulate the hydrologic effects of this large water body as it is a primary source for groundwater recharge in the vicinity of the Facility, and produces a relatively constant water level elevation in this area.

The western boundary of the model will generally parallel the surface exposure of Tertiary deposits that define the limits of the shallow alluvial groundwater system on the western side of the Facility. The western boundary of the model will continue in this northwest direction until it reaches a point just north of HWY 12 where it will follow the general groundwater flow trend to the north. The eastern boundary of the model will extend in the northeast direction paralleling the general flow direction. The western and eastern boundaries of the model will be simulated with no-flow boundaries. A general head boundary will be used to simulate the downgradient limits on the north end of the model. General head boundaries help limit the size of a model by allowing water levels at the model boundary to fluctuate due to internal stresses in the model, limiting boundary condition effects within the modeled area. A general head boundary uses an assigned head value and a conductance to calculate groundwater flux at the model boundary based on fixed conditions at a more distant hydrologic boundary. Lake Helena is a natural drain for the Helena Valley alluvial system and has relatively constant water level values and will be used as the reference elevation for the general head boundary. Based on topographic maps the water level at Lake Helena is 3655 feet above mean sea level; this will be the initial head value assigned to the downgradient general head boundary. The conductance for a general head boundary is calculated based on the following equation:

$$C_{(GHB)}=(T*w)/(b*D)$$

Where:

- T = Transmissivity (ft^2/day);
- w = width (ft);
- b = thickness (ft); and
- D = Distance between model boundary and hydrologic feature (ft).

In GMS, the model calculates the width and thickness for each cell and requires you to input a conductance value based on T/D. The average hydraulic conductivity of water-yielding zones in the Helena Valley have been documented at approximately 200 ft/day, with an assumed thickness of 50 feet (USGS, 1992). Based on the resultant average transmissivity value and the distance to Lake Helena (24,500 feet), a general head conductance value of 0.4 ft^2/day/ft will be assigned to the downgradient boundary.

4.4.4 Sources and Sinks

Sources and sinks included in the model will consist of surface water bodies that interact with the groundwater system, and recharge effects from precipitation and other source for infiltration. The primary sources of recharge to the aquifer system are through infiltration from surface water bodies, irrigation water (canals and irrigation application), and precipitation. Surface water bodies (Prickly Pear Creek and Lower Lake) will be simulated using river cells, which allow the model to simulate recharge and/or discharge to the groundwater system depending on the relative difference between groundwater versus surface water elevations at that location. Streambed conductance will be calculated based on the following equation:

$$C_{(SB)}=KLW/M$$

Where:

- K=Hydraulic Conductivity of Riverbed Material (ft/day);
- L=Length of reach (ft) – calculated by model;
- W=Width of river (ft); and
- M=Thickness of Riverbed (ft).

Streambed hydraulic conductivities can be a difficult parameter to quantify accurately; therefore multiple tests will be used to establish an empirical value for different sections of Prickly Pear Creek and Lower Lake. These will include sieve tests of the bed material, seepage runs (Prickly Pear Creek only), and insitu-permeameter tests (Prickly Pear Creek only), which will be conducted as part of the groundwater/surface water interaction study as discussed in Section 3.4.

In the Phase I RFI groundwater flow model, an areal recharge rate in the city of Helena and other peripheral areas were assumed to equal 10% of the annual precipitation (1.1 in/yr), which is a typical default assumption for this region. The Phase II model will initially use the above assumption for model development, however precipitation infiltration rates will be further evaluated during model calibration.

Infiltration of precipitation within the Facility has the potential to greatly affect groundwater quality, as infiltrated water can leach metals from subsurface soils. Therefore a more detailed analysis was previously conducted as part of the Phase I RFI model. Recharge of on-site precipitation and dust suppression was evaluated for three areas; paved, unpaved, and areas where dust suppression water is applied. The EPA Hydrologic Evaluation of Landfill Performance (HELP) model was used to estimate infiltration rates under these varying conditions. Details of the HELP model analysis are discussed in detail in Section 5.4.1.4 of the Phase I RFI (ACI, 2005). Dust suppression is currently limited to demolition activities and is occurs in short periods, therefore dust suppression water will not be applied to the updated model to evaluate current conditions and predictive simulations. The Phase II RFI will utilize the results of the HELP model for infiltration of precipitation for on-site areas as is outlined in Table 4-4-1.

TABLE 4-4-1. HELP MODEL RESULTS

Soil	Precipitation (in/yr)	Runoff (in/yr)	Evapotranspiration (in/yr)	Infiltration to Water Table (in/yr)
Paved	10.89	2.14	8.51	0.009
Unpaved	10.89	0.43	9.57	0.183

Demolition activities include provisions for capping to limit the amount of infiltration in areas where soils were exposed. An infiltration rate of 0 in/yr will be assigned to these capped areas as well as other areas where capping will potentially be implemented in future corrective measures (for predictive simulations).

The expanded model domain will also encompass areas that include irrigated land and the Helena Valley Irrigation Canal. Irrigated lands have the potential to infiltrate more water than non-irrigated land, therefore recharge rates in these areas will be assigned based on the type of irrigation practices in use and established water use efficiencies.

The Helena Valley canal is located in the northern portion of the model domain. Infiltration from the canal has been documented at approximately 0.63 (ft^3/sec)/mile (USGS, 1992). This infiltration rate will be applied to the model for the initial model development and may be refined during model calibration. The significance of other potential sources of infiltration recharge, such as infiltration losses from the municipal water distribution system, may be assessed during model development and calibration.

4.4.5 Hydraulic Parameters

The hydraulic properties will be assigned based on the major hydrostratigraphic units defined by the conceptual model and discretized into the mode layers using the MODFLOW-2000 hydrogeologic-unit flow (HUF) package (USGS, 2000). The HUF is similar to the Layer Property Flow (LPF) package used in the Phase I RFI model as they both compute cell-to-cell conductances from the layer geometry and aquifer properties. The HUF package allows the vertical stratigraphy of the hydrologic system to be defined independent from the model grid. Using the HUF package the user establishes multiple hydrogeologic units with different hydrogeologic properties (hydraulic conductivity, anisotropy, specific yield, and specific storage) in the model. The top elevation of the model is defined by the first HUF array. The underlying HUF arrays define the thickness of different hydrogeologic units. Hydrogeologic unit thicknesses are allowed to equal zero, making it possible to simulate complex heterogeneities, including pinched out units and embedded lenses. The HUF arrays (with multiple hydrogeologic units) are imposed on the model grid, the model then uses the units within a cell to calculate the effective hydraulic properties resulting in a cell-to-cell conductance value. Using the HUF package will provide a tool to simulate the complex heterogeneities of groundwater system in the modeled area.

In the RFI Phase II model, the hydrogeologic unit geometry will be determined based on information on the site stratigraphy. Four hydrogeologic units (Sand/Gravel, Sand, Silt/Clay, and Ash/Tertiary) will be established for the initial model development. The use of additional units will be considered based on data collected as part of the RFI Phase II investigation and model calibration. Hydraulic parameters will be assigned to each unit based on data collected from site monitoring wells and established literature values. Table 4-4-2 summarizes the average and/or range of values for hydraulic parameters for each unit that will be used in the initial model development.

TABLE 4-4-2. SUMMARY OF HYDRAULIC PARAMETERS TO BE USED IN MODEL DEVELOPMENT

Hydrogeologic Unit	Hydraulic Conductivity (ft/day)		Specific Yield	Specific Storage (1/ft)	Porosity
	Range	Avg.	Range	Range	Range
Sand	50 - 100	70	0.15 - 0.25	$1 \ast 10^{-5}$-$1 \ast 10^{-8}$	0.25 - 0.4
Sand & Gravel	100 - 700	200	0.2 - 0.3	$1 \ast 10^{-5}$-$1 \ast 10^{-8}$	0.15 - 0.35
Silt	0.1 - 3	NA	0.05 - 0.2	$1 \ast 10^{-5}$-$1 \ast 10^{-8}$	0.35 - 0.45
Ash/Tertiary	0.001 - 0.01	NA	0.02 - 0.05	$1 \ast 10^{-5}$-$1 \ast 10^{-8}$	0.35 - 0.5

NA: Not available, will be evaluated in the Phase II RFI investigation and historic data.

Additional parameter values such as longitudinal dispersivity, vertical and horizontal anisotropy, and bulk density will be evaluated during model development.

4.4.6 Transport Parameters

The transport analysis of arsenic and selenium is especially complex and many of the transport parameters to be used in the model will be determined based on results of the Phase II RFI investigation. In general transport is simulated based on the processes of advection, physical dispersion, and chemical reaction. Advective transport is essentially the movement of a solute with groundwater. It is calculated in MT3D by taking velocity vectors generated by the flow model and adding effects of physical dispersion and chemical reaction, which are calculated separately by the transport model and require assignment of separate input parameters. The transport model also requires source terms for arsenic and selenium released to groundwater. These include contributions of arsenic and selenium sources in the saturated zone, unsaturated zone sources, and process water sources. Parameters associated with physical dispersion, chemical reaction, and source terms were evaluated in the Phase I RFI for arsenic. The parameters related to physical dispersion and properties associated with arsenic that were used in the Phase I model will be utilized in the initial development of the transport model and may be refined based on model development and additional data collection. Transport parameters associated with selenium will be evaluated using results from field investigations, sequential extraction and batch adsorption tests conducted as part of the Phase II RFI investigation (see Section 3.3).

4.4.7 Calibration and Sensitivity Analysis

The groundwater flow model will first be calibrated to steady state conditions. Historic and current groundwater monitoring is conducted on the majority of the 160 plus monitoring wells at and surrounding the Facility during May and November. The model will initially be calibrated to a historic November data set. The November data has a sufficient number of observation points and is assumed to be at a relatively steady state during that time. Following calibration of the flow model to steady state conditions, a transient groundwater flow model will be calibrated based on field observations collected during February, May, August, and November over the past several years. The transient model will simulate seasonal changes in the groundwater system.

Calibration of the flow model will be evaluated on a qualitative and quantitative basis. Calibration of groundwater flow will be evaluated qualitatively by comparing observed and simulated potentiometric surfaces (gradient and direction) and quantitatively by using observation points to compare observed vs. simulated heads, as well as through evaluation of groundwater losses and/or gains to surface water, and groundwater flux through specified areas.

Primary and secondary calibration targets will be established for quantitative analysis based on observed data and standard targets used in the industry (e.g. simulated heads within 10% of observed). Separate calibration targets will be established for the steady state and transient flow models. Primary calibration targets will be applied to areas of interest as well as areas where sufficient data is available to achieve the targets. Where there is insufficient data for some parameters or data that has less precision it may be necessary to evaluate the calibration of these areas using secondary targets. The primary and secondary calibration targets will be determined prior to model development based on a review of data collected in previous investigations and that collected as part of the Phase II RFI investigation.

Calibration of the transport model will be evaluated against observed water quality trends to assess the ability of the model to reproduce the general plume geometry, observed concentration gradients, and observed concentration trends overtime. Plume geometry and concentration gradients predicted by the transport simulations will be evaluated by comparing the results to plume maps developed from monitoring well data during different seasons. The ability of the model to accurately reproduce temporal changes in water quality will be evaluated by examining seasonal and long-term water quality changes at locations within the interior of the plume and at the downgradient limits of the plume. The calibration assessment of selenium transport will be limited to some extent by the length of historic record for monitoring data, which extends back only two years.

In addition to model calibration, sensitivity analyses will be conducted to quantify the uncertainty in the calibrated model caused by estimates of parameters used in the model. Calibrated parameters (e.g. hydraulic conductivities) will be changed within previously established possible ranges that are based on both empirical data and/or literature values. Model sensitivity will be measured by assessing the effect of a parameter change on the average measure of error. At a minimum, sensitivity will be measured based on head and transport velocities. Additional parameters such as groundwater flux, groundwater/surface water interaction (flux and location), and plume geometry may also be evaluated in the sensitivity analysis.

4.4.8 Predictive Simulations

Following calibration of the steady state, transient, and transport models, the model will be used for predictive simulations. Predictive simulations will evaluate future migration of the plumes and the effect of potential remedial alternatives for arsenic and selenium mitigation. The remedial alternatives designated for evaluation will be developed in conjunction with EPA following completion of the Phase II RFI field investigation and prior to model development.

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FIGURES

APPENDIX A

ASARCO EAST HELENA
FACILITY AND PROJECT BACKGROUND INFORMATION

APPENDIX B

COMPILATION OF EXISTING SOILS DATA

APPENDIX B-1.	**EAST HELENA PLANT SOILS NON-REMEDIATED AREAS**
APPENDIX B-2.	**EAST HELENA PLANT SOILS REMEDIATED AREAS/NOT CURRENT**
APPENDIX B-3.	**2007/2008 DEMOLITION FOOTPRINT SOIL SAMPLE INDICATOR METALS SUMMARY TABLE**
APPENDIX B-4.	**2008 MONITORING WELL SOIL SAMPLE INDICATOR METALS SUMMARY TABLE**

APPENDIX B IS INCLUDED ON CD ONLY.

APPENDIX C

COMPILATION OF EXISTING WATER DATA

APPENDIX C-1.	**EAST HELENA WATER HISTORICAL MONITORING WELL DATA**
APPENDIX C-2.	**EAST HELENA WATER HISTORICAL ORGANIC DATA**
APPENDIX C-3.	**EAST HELENA WATER HISTORICAL PRIVATE WELL DATA**
APPENDIX C-4.	**EAST HELENA WATER HISTORICAL SURFACE WATER DATA**
APPENDIX C-5.	**EAST HELENA WATER HISTORICAL PLANT SITE RUNOFF DATA**
APPENDIX C-6.	**EAST HELENA WATER HISTORICAL PLANT SITE PROCESS WATER DATA**

APPENDIX C IS INCLUDED ON CD ONLY.

APPENDIX D

WATER WELL AND USAGE INVENTORY

APPENDIX E

INVENTORY OF RISK STUDIES FOR THE FACILITY

APPENDIX E REPORTS ARE LOCATED ON THE CD ONLY.

EXHIBIT 1. CURRENT AND HISTORIC SAMPLING LOCATIONS

(DWG. NO. 105408H006)

EXHIBIT 2 ARSENIC CONCENTRATIONS IN SURFACE AND SUBSURFACE SOILS

(DWG. NO. 105408H028)

EXHIBIT 3. GEOLOGIC CROSS SECTIONS

(DWG. NO. 105408H009)