March, and April 1992 a hydrocarbon recovery system consisting of 21 wells was installed. Approximately 50 percent of the diesel spill volume has been recovered, and recovery operations are ongoing. Currently, the remediation system consists of a total of 36 monitor and/or recovery wells. Affected groundwater is pumped continuously from the spill area and processed by gravity separation in a tank. Diesel fuel separated from groundwater is stored in a tank. Volatile organics are removed from groundwater by an air stripper, and the treated groundwater is pumped into one of the original on-site 500,000 gallon aboveground storage tanks, which has been converted from diesel storage to water storage. The water is added as plant makeup water for process operations.

The remediation system has been in continuous operation since 1992. Approximately 22,000 gallons of the estimated 40,000 gallons of released diesel have been recovered and 7,500,000 gallons of diesel-affected groundwater treated. The system has prevented additional impacts on the surface waters of the American Canal.

The trend for this site has been a steady reduction of product thickness in the project monitor/recovery wells. The most current event (August 1998) indicated product thickness ranging from a sheen to 0.1 feet. Measurable thickness was encountered in only one recovery well (EP-19) during the August 1998 sampling event.

A plan "A" Risk-based Assessment for this site, prepared by Hydrometrics, Inc., was submitted to and accepted by the TNRCC in April 1997 (Hydrometrics, 1997b). According to the risk-based assessment, levels of constituents of concern were below established cleanup goals, and closure for the site could be requested upon attaining measurable thickness of diesel of less than 0.1 feet for the project site.

In line with the risk-based assessment, Hydrometrics proposes to discontinue recovery activities when diesel thicknesses become less than 0.1 feet. The groundwater pumping equipment will be removed from these locations for assessment, cleaning and repair (if necessary). Recovery well locations that are discontinued will be monitored daily during the workweek for the

occurrence of free product. The schedule is estimated as 4 weeks of daily monitoring, if no reoccurrence of diesel is measured, the schedule will then be weekly.

If the product thickness level at any particular recovery/monitor well location increases to 0.1 feet or greater, a recovery pump will be reinstalled and recovery operation at that location resumed. The recovery system will be operated until the next quarterly sampling event. Additional product thickness information will be reviewed and used to determine the status of recovery operations at that location, using the guidelines previously discussed.

When all recovery/monitor well locations continuously sustain product thickness levels of less than 0.1 feet for a period of six months, closure from the TNRCC will be sought, as outlined in the Diesel No. 1 Risk-based Site Assessment.

Diesel Investigation No. 2

On March 30, 1990, Hydrometrics, Inc. began investigation activities (Diesel Investigation No. 2) of an 18,000-gallon aboveground diesel storage tank, which was suspected of having a release of hydrocarbons, located near the former zinc fuming plant. The release was suspected to occur in the twenty feet of underground piping that connects the aboveground tank to a dispenser pump. A backhoe pit was excavated (March 30, 1990) adjacent to the underground piping to evaluate for potential leaks. Visible diesel staining was observed within the backhoe pit adjacent to the piping. The tank and all associated piping have been dismantled and removed from the facility.

On May 21, 1990, Hydrometrics, Inc. installed monitor well EP-21 (see Exhibit 1) adjacent to the 18,000 gallon diesel storage tank. Several hundredths of a foot of phase-separated hydrocarbons were encountered in this monitor well. During the period of August 6 to August 9, 1990, Hydrometrics installed six additional monitor wells, EP-22 through EP-27 (see Exhibit 1), to help determine the extent of diesel contamination from the 18,000 gallon tank. Only one of these additional wells, EP-25, contained phase-separated hydrocarbons. Several

other monitor wells (EP-49, EP-51, EP-52, EP-54 and EP-55) were installed to assess the plume extent.

During sampling activities in July 1993, phase-separated hydrocarbons were encountered in the downgradient monitor well EP-49.

During January 1994 Hydrometrics, Inc. installed eleven additional monitor wells to further delineate the Diesel No. 2 hydrocarbon plume in reaction to the occurrence of phase-separated hydrocarbons in well EP-49. Three of these monitor wells were installed at the Plant in the vicinity of the acid plant. One monitor well (EP-56) is located adjacent to the abandoned monitor well EP-52; one (EP-55) is near the acid plant stack; and one (EP-54) is at the plant fence, approximately 100 feet north of EP-49. The remaining eight monitor wells were installed in the old Smeltertown area just west of the Plant and along the west side of Paisano Drive. These wells were designated EP-57 through EP-64 (Exhibit 1). After wells EP-57 through EP-64 were installed, the plume was observed to have impacted monitor wells EP-57 and EP-58.

During the period of March through June of 1994, Hydrometrics, Inc. designed and installed a product recovery trench, an air sparge and soil vapor extraction (SVE) trench, and associated mechanical equipment to help contain and remove diesel fuel from the area of the former Smeltertown. The product recovery trench was placed just ahead of the leading edge of the phase-separated hydrocarbon plume to allow liquid-phase hydrocarbons to migrate into the recovery trench. The air sparge/SVE trench was placed downgradient of the dissolved hydrocarbon plume to provide the final removal of any dissolved hydrocarbons prior to groundwater entering the American Canal. This recovery system is currently operating.

During November and December 1997, in which work was conducted to evaluate the best remediation technology for the site. The study recommended a Dual-Phase Extraction system to recover the remaining product and remediate the affected soils in the Smeltertown portion of the product plume. Dual-phase recovery is extremely well suited for recovery of free product

and to address bound fuel in soils that may contribute to the free product and dissolved-phase plume during water elevation fluctuations. Dual-phase recovery creates a pressure gradient that forces groundwater to flow into the recovery well (area of least pressure).

Vacuum recovery wells composed of vertical wells spaced throughout the affected plume footprint will allow the entire plume area for Phase I (Smeltertown) to be addressed quickly. Vacuum recovery wells will be located in the field as follows:

1. A main header line will be established perpendicular to and in the approximate center of the product plume.
2. Individual vacuum recovery wells will be established from the central header to the 50-foot centers to the general extents of the product plume. The wells will header on 50-foot center to the general extents of the product plume in a rosette pattern.
3. The wells will terminate once unaffected soils are encountered in the field drilling activities. Wells will be installed to the anticipated water table depth, which will allow for the smear zone remediation during low water table periods.

The upgradient barrier will prevent the recharge of the Smeltertown area product plume and prevent continued contamination of this area once it has been remediated. The upgradient barrier well(s) will be installed in the vicinity of monitor wells EP-19 and EP-54. Wells will be constructed with PVC casing and screened over the entire interval in which product may be expected. Downhole pneumatic recovery pumps will be used to remove product and create a hydraulic barrier to prevent further downgradient travel towards Smeltertown.

Operation and maintenance of the downhole pneumatic system will be required in order to make adjustments for maximum effectiveness during groundwater elevation fluctuations. System protocol requires the operator to adjust the suction tube height and vacuum pressure to maximize product recovery while recovering as little water as possible.

A transmission waterline will be installed to discharge collected water (after primary treatment on the Smeltertown site) from the recovery system to either the Plant water treatment system or the Diesel No. 1 remediation site for use as makeup water. Preliminary water quality data, and criteria established by plant personnel, indicate that recovered water can likely be discharged directly to the Plant's makeup water system without further treatment.

Primary treatment will be performed at Smeltertown with a coalescing filter (depending on oil/water quality information to be gathered when the recovery system is operating on a mass scale) and an oil/water separator. These units are designed to process up to 15 gpm of total recovered fluids. It is anticipated that, under typical operating conditions, about five gpm will be discharged to the plant makeup water stream.

The system is anticipated to be unobtrusive. Equipment will be housed in a fenced enclosure adjacent to the existing equipment building constructed during Phase II. The privacy fence will be slatted to obstruct the system and ancillary equipment from public view. Wellheads will be secured and protected with steel casing, and vacuum/water pipelines will be buried.

1.5 INVESTIGATION AREAS

As part of the Agreed Order, specific areas on the facility were designated by the TNRCC as areas of concern based on historical and current operations and on the results of the 1994 and 1995 multimedia inspection and sampling events. These areas of concern are identified in the Remedial Investigation Work Plan as Investigation Areas. Investigation Areas are indicated in Exhibit 1. Table 1-4 provides a general description of the Investigation Areas.

The 1996 TNRCC Agreed Order indicated that evaluations of closed plant areas would be considered separately from the Remedial Investigation. The following plants at the site that have been closed: the lead plant, the cadmium plant, the zinc plant, the antimony plant and former copper plant operations (wedge roaster, reverberatory furnace and brick flues). Most of these plants and the related facilities have already been demolished. Closed Plant Evaluation Plans will be prepared for each area to summarize closure actions and outline

field sampling programs. Though these plans have not been submitted to the TNRCC yet, aspects of the field sampling programs will overlap the proposed Corrective Action Plan presented in this RI report.

The 1996 Agreed also specifically excluded the two ongoing diesel remedial programs (Diesel No. 1 and 2 investigation areas), although information gathered from boreholes and wells installed as part of the diesel remedial programs have been used for this RI report.

1.6 EXISTING OR POTENTIAL WASTE CONSTITUENTS

The elements of concern for soil and water are specified in the Agreed Order and in the Remedial Investigation Work Plan. These elements are referred to as Constituents of Concern (COCs) throughout this report and include the following:

- arsenic (As)
- cadmium (Cd)
- chromium (Cr)
- copper (Cu)
- iron (Fe)
- lead (Pb)
- selenium (Se)
- zinc (Zn)

Additional parameters of concern in groundwater include:

- pH
- specific conductivity (SC)
- total dissolved solids (TDS)

Additional waste constituents in soils and groundwater at the facility include organic chemicals associated with diesel fuel. The characterization of these constituents and corrective actions are being addressed through other environmental programs.

1.7 REMEDIAL INVESTIGATION WORK PLAN TASKS

The tasks outlined in the Remedial Investigation Work Plan were developed to identify contamination source areas, groundwater flow pathways, and the vertical and horizontal extents of constituents of concern. Proposed fieldwork included the following:

- Soil and groundwater sampling at the Converter Building Ventilation Baghouse.
- Soil and groundwater sampling at the Boneyard/Slag Area.
- Surface water sampling of ponded area in Slag Area.
- Soil and groundwater sampling at Acid Plants 1 and 2.
- Soil and groundwater sampling at the Front Slope Area.
- Soil and groundwater sampling in Smeltertown.
- Soil and groundwater sampling in areas outside of originally identified contaminant source areas, including potential background areas.
- Surface water sampling in the Rio Grande and American Canal.
- Soil sampling of the Bedding and Unloading Plants.
- Soil sampling of the Plant entrance.

Sampling and analysis procedures were described in the RI Work Plan and are not reproduced for this document. Descriptions of sampling and analysis protocols included the following:

- Sampling equipment and techniques.
- Procedures for taking measurements of water level elevations in the monitor wells.
- Procedures for detecting any phase-separated liquids and their thickness, if present.
- Well evacuation procedures, including purged water or water quality prior to sampling and handling.
- Sampling and analysis protocol for field measurements.
- Procedures for decontaminating sampling equipment between sampling events.
- Disposal of field-generated waste.
- Sample handling and preservation techniques, including chain of custody documentation.
- Sampling quality assurance/quality control (QA/QC) procedures.

Samples were submitted primarily for analysis of the parameters identified in the Agreed Order. Based upon the review of the RI Work Plan, TNRCC requested that additional Investigation Areas be added, specifically the Unloading/Bedding Wastewater Treatment area, process ponds 1, 5, and 6, and the sump located near the Plant entrance (TNRCC, 1997). Asarco addressed the TNRCC comments in their response letter and added the requested items to the remedial investigation activities (Asarco, 1997). Included in the Asarco response letter was a revised list of Investigation Areas (ten areas total) and a revised summary table of samples to be collected in each Investigation Area. The results of sampling and a description of identified contamination sources in each Investigation Area are presented in section 2.0 of this RI report.

Per the Agreed Order the following items are presented in this RI report:

- A detailed site history including previous site owners, previous known site activities, previous known waste management, and current waste management practices.

- A site characterization of the local soil, geology, groundwater, and surface water conditions based upon a literature review.
- Samples of environmental media to define background conditions, hydraulic gradient(s), source(s) of contamination, and the vertical and horizontal extent of contamination.
- Analytical results of samples using appropriate EPA-approved analytical methods. Appropriate quality assurance/quality control (QA/QC) sampling including field duplicates, equipment blanks, and trip blanks.
- Survey of Texas sensitive receptors (i.e., wells) within one-half mile radius of the property owned by Asarco between Interstate Highway 10 and West Paisano Drive in El Paso, Texas.
- Assessment of aquifer parameters (e.g., porosity, transmissivity, hydraulic conductivity and storativity).
- Figures and exhibits presenting facility structures, operations, and storage areas; sampling locations, including locations of soil borings and monitor wells; adjacent properties; all significant topographic features in the vicinity of the site; surface waters in the vicinity; and Investigation Areas.
- Copies of lithologic logs and well construction diagrams.
- Geologic cross-sections.
- Tabulations of all analytical results.
- Copies of the original laboratory data and data validation reports.
- Concentration and depth distribution graphs for constituents of concern identified in the Agreed Order.
- Groundwater contour maps showing hydraulic gradient, static water elevations, groundwater flow paths, and the thickness of any phase-separated liquids determined during the investigation.

- Identification of contaminant source areas.
- A general proposal for corrective action stating the Risk Reduction Standard to be achieved and a detailed schedule for remediation of any contaminated media identified during the assessment necessary to meet the selected Risk Reduction Standard.

2.0 REMEDIAL INVESTIGATION RESULTS

This section presents data gathered regarding soil, surface water and groundwater quality at the Plant and limited adjacent areas. Soil data are discussed first, followed by surface water data and groundwater data. The surface water data are discussed separately as naturally-occurring surface water bodies (i.e., the Rio Grande and American Canal) and as man-made bodies (i.e., the on-site ponds). Data gathered included data generated during field activities conducted in 1997 and 1998 as part of the Remedial Investigation and data obtained from previous studies and public agencies, such as the International Boundary Water Commission. Summary tables are presented in Appendices C (soil data), E (surface water data), F (groundwater level data), and G (groundwater quality data). Laboratory reports and the associated data validation reports are presented in Appendices I and J, respectively.

2.1 SOIL INVESTIGATION RESULTS

Soil samples were collected during the RI at the Investigation Areas related to soil assessments identified in the Remedial Investigation Work Plan (Hydrometrics, 1996). Samples were collected from soil borings, some which were converted to monitor wells. The Investigation Areas are indicated in Table 2-1.

One hundred-forty borings were drilled and sampled as part of the Remedial Investigation (see Exhibit 1 and Appendix B). Shallow soil borings were drilled using a truck-mounted hollow-stem auger drill, with the exception of boring RIBH-1, which was drilled using a reverse circulation, air-rotary technique utilizing a combination down-hole hammer bit and Stradex® casing advancer. Soil samples were collected every five feet for borings RIBH-1 through RIBH-10. Slag was not sampled from RIBH-1 through RIBH-10. For all other borings slag and soil samples were collected at four intervals below ground surface (0-2 inches; 18-30 inches; 36-48 inches; and 48-60 inches). A split-spoon sampling device measuring 2 feet in length and 1.6 inches in diameter was used to collect soil samples. Data collected from other boreholes and wells previously installed at the site, including wells EM-1 through EM-8, were used as appropriate for this report. Wells EM-1 through EM-8 were

constructed in 1985 under a separate order (TNRCC, 1996). Borings AB-1 through AB-5, which were advanced as part of a July 1996 investigation, were used in the investigation of the Front Slope Area (see Section 3.4). In addition, surface grab samples of sediments collected in October 1996 from Ponds 1, 5 and 6 are used in the investigation of the ponds (see Section 3.7).

Monitor wells EP-67 through EP-89 were installed as part of the Remedial Investigation. Wells were installed using a reverse circulation, air-rotary technique utilizing a combination down-hole hammer bit and Stradex® casing advancer with the exception of wells EP-80 and EP-81. This technique was selected because of its ability to drill through the slag, large boulders and bedrock present over most of the site. Wells EP-80 and EP-81 were drilled using a truck-mounted hollow-stem auger drill. These two wells are located on the floodplain north of Smeltertown. Well depth for each monitor well was determined during the soil boring and sampling activities. Generally, the water table was estimated from drill cuttings, and the boring was then advanced an additional 5 to 15 feet below the water table. Soil samples were collected at five-foot intervals during well construction using a split-spoon sampler. No slag samples were collected during the drilling and installation of the Monitor Wells.

Wells were constructed using 4-inch diameter, flush-threaded, Schedule 40 PVC for the riser and screen. The well screen was 0.020-inch machine-slotted PVC with a threaded bottom cap. Above the screen interval, solid riser was installed with an expanding well plug to seal the well casing. The annulus between the PVC and the outer well bore was filled with 12-20 sieve size sand to a depth of approximately 2 feet above the upper screen interval. Above this interval, bentonite chips were installed and hydrated to a depth of approximately 5 to 10 feet below ground level. The remaining annulus space was filled with concrete to the surface. Wells were completed with an 8-inch diameter, above-ground steel casing with locking cover approximately 2 to 4 feet above ground-level.

Upon completion, all monitor wells were developed by extracting three to ten well volumes of water. Development water was monitored for pH, specific conductivity, temperature and turbidity until parameter measurements stabilized, indicating representative water was being extracted from the aquifer. Development volumes were based on parameter stabilization and a visual observation of reduced turbidity. Well construction details for each well are presented in Table B-2, Appendix B.

One additional well (EP-90) was installed in December 1997 by redrilling well EP-74, which was destroyed during demolition activities at the lead plant and could not be salvaged. A State of Texas Well Report was completed by the well driller (Layne Christensen Company) and submitted to the TNRCC to document the well construction activities. Two wells (EM-1 and EM-8) were plugged and abandoned in August 1998 because groundwater levels had fallen below their monitoring levels. State of Texas Plugging Reports were completed by the well driller and submitted to the TNRCC. Appendix B presents the borehole and well construction details of all borings and wells installed at the facility tabulated on Tables B-1 and B-2, respectively. Appendix B also contains lithologic logs and well construction diagrams.

A total of 634 soil samples were collected, including samples used as Quality Assurance/Quality Control (QA/QC) samples. QA/QC samples were collected at a rate of about five percent, or one QA/QC sample per 20 samples. Selected soil samples were subsequently analyzed by the Asarco Technical Services Center in Salt Lake City. Sampling was conducted in accordance with the SOPs presented in the Work Plan. All samples were analyzed using x-ray fluorescence spectrometry (XRF) methods for analysis of total metals (arsenic, cadmium, chromium, copper, iron, lead, selenium and zinc). Laboratory QA/QC procedures required confirmation analysis of 1 in 20 samples collected using Waste Extraction Test (WET) chemistry methods for total metals analysis using HF extraction. Table C-1, Appendix C, presents a list of the sample locations, sample identifiers and sample depths. Analytical results are presented in Tables C-2 through C-10. Laboratory reports are presented in Appendix I.

Since no boreholes were drilled off-site during this investigation, well EP-86 is considered as the most representative background well, because it is the farthest north and hence is the farthest from site activities (see Figure 2-1). Soil samples were collected from this borehole at five-foot intervals from ground surface to 60 feet (see Table C-1). Each sample, including a duplicate sample collected at 60 feet bgs, was analyzed for arsenic, cadmium, chromium, copper, iron, lead, selenium and zinc (see Table C-10). Soil pH ranged from 8.4 to 10. No detectable concentrations of arsenic, cadmium, or selenium were reported above their respective detection limits of 20 milligrams per kilogram (mg/kg), 10 mg/kg and 10 mg/kg. Chromium was detected in less than half of the samples, at concentrations ranging from the detection limit of 30 mg/kg to 100 mg/kg. Copper was detected in slightly more than half of the samples, at concentrations ranging from just over the detection limit of 20 mg/kg to 76 mg/kg. Iron was detected in all samples at concentrations ranging from 7,000 mg/kg to 22,000 mg/kg. Lead was detected in all but the deepest samples at concentrations ranging from slightly above the detection limit of 10 mg/kg to 87 mg/kg. Zinc was detected in all samples at concentrations ranging from 18 mg/k to 100 mg/kg. Using these results as background concentrations, it appears that arsenic, cadmium and selenium do not naturally occur above detection limits at the site. Chromium, copper, iron, lead, and zinc are all naturally occurring at concentrations up to 100 mg/kg with the exception of iron which is present at high concentrations.

The minimum, maximum and average concentrations of the analyzed parameters for all soil samples collected during the remedial investigation are summarized in Table 2-2. These concentrations are based upon all soil samples analyzed, using one-half the detection limit for a non-detected constituent to calculate the average. Another source of comparable background concentrations in soils is a study published by the US Geological Survey which presents analytical results of soils collected throughout the United States (USGS, 1984). Based upon that study, average concentrations of the eight metals of concern at the site are higher than typical background concentrations, with the exceptions of iron and chromium,

which are only slightly higher. No average concentration was established for soil pH and cadmium.

The pH values detected in soil samples ranged from 5 to 10.2, with an average of 8.5. The minimum metal concentrations were below the respective detection limits, with the exception of iron, which was detected at a minimum concentration of 5,000 mg/kg. The maximum concentrations detected ranged up to 260,000 mg/kg for an iron analysis. The highest metal concentrations detected were iron concentrations, with an average concentration of 30,524 mg/kg for all soil samples collected. The average concentrations of arsenic, cadmium, chromium, copper, lead, selenium and zinc were 616 mg/kg, 124 mg/kg, 86 mg/kg, 4,362 mg/kg, 2,447 mg/kg, 22 mg/kg and 2,695 mg/kg, respectively. All of the average metal concentrations calculated for the site are higher than the background concentrations detected in well EP-86 soil samples and the average background concentrations reported by the USGS. Analytical results for all soil samples are presented in Appendix C, Tables C-2 through C-10, respectively, for Investigation Areas 1, 2, 3, 4, 5, 8, and 10, remedial investigation borings, and monitor wells.

2.1.1 Distribution of Constituents of Concern in Soil

Per the Agreed Order issued by the TNRCC, the constituents of concern at the Plant are arsenic, cadmium, chromium, copper, iron, selenium, zinc, lead, pH, specific conductivity and total dissolved solids (TNRCC, 1996). Two of the constituents of concern, specific conductivity and total dissolved solids, apply only to water.

Concentrations are generally highest in the upper soils, typically from ground surface to five or ten feet bgs, as illustrated on graphs presented in Appendix D. For example, arsenic is detected in concentrations greater than 5,000 mg/kg at ground surface along the central-western edge of the facility, near the Acid Plant. Arsenic occurs at concentrations greater than 5,000 mg/kg in only a very limited area at four feet bgs in this area. Some metal distributions, especially iron and chromium, are erratic because they are probably naturally-occurring concentrations. Metals detected in concentrations which are higher than the soil

remediation levels for nonresidential areas are arsenic, cadmium, copper and lead. Though these are not applicable standards, they provide an indication that arsenic, cadmium, copper and lead are the constituents of concern at the site. Depth distributions for all eight metals analyzed are presented in Appendix D for soil samples collected during the monitor well construction, including wells EP-67 through EP-90.

2.2 SURFACE WATER INVESTIGATION RESULTS

2.2.1 Regional Surface Water

As part of the remedial investigation, surface water quality in the vicinity of the Plant was assessed. There are two prominent surface water bodies in the vicinity of the Facility (Figure 2-2): 1) the Rio Grande, which serves as the international boundary between the United States and Mexico; and 2) the American Canal, which is used by the United States to remove its water allotment from the Rio Grande. The canal is concrete-lined, and is approximately nine feet deep (IBWC, 1998). Recharge to the surface water is from upstream dam releases, precipitation, surface runoff, and groundwater.

Surface runoff in the area is primarily controlled by drainages locally known as "arroyos", which are dry except during heavy rain events. The five main arroyos located at the Plant have been designated for the purpose of this report as Parker Brothers Arroyo, Ponds 5 and 6 Arroyo, Pond 1 Arroyo, South Terrace Area Arroyo, and Acid Plant Arroyo (see Figure 2-3). The arroyos have been filled over time with a variety of fill materials, including slag cooled-in-place and redeposited slag, crushed rock, brick, metal, concrete fragments, and native soils. The fill zones are generally dense or firm, but also contain loose zones in many locations (Sergent, Hauskins & Beckwith, 1976).

Surface water flow and quality in the Rio Grande near the vicinity of the Plant are subject to the following influences:

- Effluent discharged from the sewer disposal facility (Northwest Waste Water Treatment Plant) located northwest of Smeltertown

- The American Dam, which diverts part of the Rio Grande to the American Canal. The American Canal removes the US allocation of water from the Rio Grande
- Shallow groundwater recharge along the Rio Grande
- The International Dam, located south of the University of Texas at El Paso, which diverts water to the Franklin Canal; it is also the location at which Mexico removes water from the Rio Grande
- The Haskell R. Street Waste Water Treatment Plant, located on Delta Street approximately 1 mile downstream of Asarco
- Seasonal irrigation releases to the Rio Grande from the Elephant Butte Reservoir as regulated by the Elephant Butte Irrigation District.

Historically, surface water also may have been affected by stormwater runoff from the Plant; currently runoff, however, is controlled by berms, pads and sumps. There is a potential for stormwater runoff to leave the Plant near the Plant entrance, however, that potential source will be controlled when the proposed surface drainage improvements (Dames and Moore, 1998) are made.

Surface water at the site, in the American Canal and in the Rio Grande has been sampled by Hydrometrics as part of this investigation and as part of on-going monitoring conducted by the International Boundary Water Commission (IBWC). IBWC data obtained as part of the remedial investigation included water quality data for two locations in the Rio Grande for the years 1995 through May 1998 and flow data in the Rio Grande at three locations for the years 1889 through May 1998 (IBWC, 1998).

Hydrometrics sampled ten surface water locations in the Rio Grande and American Canal quarterly between August 1997 and May 1998. Three sampling locations (SEP-1, SEP-3 and SEP-7) are located in the American Canal. Seven sampling locations (SEP-2, SEP-4, SEP-9, SEP-10, SEP-11, SEP-12 and SEP-13) are located in the Rio Grande. The surface water sample locations are shown on Figure 2-2. Permanent rods located three to five feet from the

American Canal and Rio Grande are surveyed and used as reference points during sampling. The actual sample locations are within the canal and river, hence the locations on Figure 2-3 are the permanent rod locations rather than that of the river.

2.2.2 On-site Process Water Facilities

Three unlined water ponds and a stormwater evaporation pond are located within the Asarco site boundaries. Pond 1 is located on the southwestern portion of the facility with Pond 5 at the approximate center. Pond 6 is located at the northern center and the stormwater evaporation pond ("Rubber Pond") near the facility entrance (Asarco, 1996). Pond 1, historically, has been used for storage of river water. Pond 5 was used as fresh water storage and is currently dry. The water was derived from city water and is used mainly as a source for dust suppression activities. Acid plant cooling tower blowdown, contact and non-contact cooling water, stormwater and city water are stored in Pond 6 for recycling and make-up water. Stormwater from the southern part of the property is retained for evaporation in the Rubber Pond, which is double-lined and has a leak detection collection system. The Rubber Pond was not included in this site investigation. Ponds 1, 5 and 6 will be closed after the stormwater collection and reuse system is completed. Another closed depression (SEP-14) is located at the Plant near the northeastern property boundary, however it was dry during each of the sampling quarters. Water in the closed depression either evaporates or seeps into the ground.

Hydrometrics, Inc. sampled each of the on-site water ponds (Ponds 1, 5 and 6) quarterly between August 1997 and May 1998. The pond locations are shown on Exhibit 1.

2.2.3 Surface Water Quality Results

Results of the surface water quality sampling and flow gauging are discussed below. A reference list of the analytical parameters, units of measurement and abbreviations is presented in Table 2-3 to supplement the data received from IBWC.

2.2.4 IBWC Data

IBWC provided water quality data for the period 1995 through May 1998 for two locations on the Rio Grande: 1) at Courchesne Bridge, which is located upstream of the site, approximately 9.5 miles above the Haskell R. Street Waste Water Treatment Plant and 2) across from Bowie High School football field, which is located downstream from the site and about 1.5 miles above the Haskell R. Street Waste Water Treatment Plant (see Figure 2-2). Though the Bowie High School location is significantly downgradient from the site, the data are discussed in general. The Courchesne Bridge location is the upgradient sampling point on the Rio Grande closest to the Asarco site.

Parameters tested at each location included dissolved oxygen (DO), pH, biochemical oxygen demand (BOD), fecal coliform, chloride, TDS, sulfate, SC, total hardness, ammonia, turbidity and temperature. Samples were collected and analyzed on a weekly basis. The 1997 and 1998 results for the Rio Grande location at Courchesne Bridge are presented in Table 2-4. Based upon the Courchesne Bridge data for the period of January 1997 through May 1998, the average analytical concentrations were 9.0 mg/l DO; 7.9 pH; 3 mg/l BOD; 340 colony-forming units per 100 ml for fecal coliform; 146 mg/l chloride; 761 mg/l TDS; 254 mg/l sulfate; 1,279 microsiemens per centimeter (µS/cm) specific conductivity (SC); 293 mg/l total hardness; 0.1 mg/l ammonia; 115 NTUs turbidity; and 59° F for temperature (Appendix E).

For the same period, the average surface water parameter concentrations at the Rio Grande location across from Bowie High School were 9.0 mg/l DO; 8.1 pH; 4 mg/l BOD; 394 colony-forming units per 100 ml for fecal coliform; 141 mg/l chloride; 767 mg/l TDS; 235 mg/l sulfate; 1,270 µS/cm SC; 288 mg/l total hardness; 0.3 mg/l ammonia; 86 NTUs turbidity; and 60° F for temperature (Table 2-5 and Appendix E).

The surface water quality results at both locations are similar, which indicates that in the reach of the Rio Grande between the two sampling points, there is little additional influence on the water quality. The parameter exhibiting the largest variance is turbidity, which

averaged 115 Nephelometric Turbidity Units (NTUs) upstream from the facility at Courchesne Bridge and 86 NTUs downstream from the facility at Bowie High School. Graphs illustrating the results of a single sampling event during August of each year at each sampling location are presented in Figures 2-4 through 2-9. The greatest difference in results for these single sampling events is in the fecal coliform results, which ranged from 0 to 1,900 colony-forming units per 100 ml at the location near Bowie High School.

Average concentrations at both locations are summarized in Table 2-6. The averages were calculated using samples collected during the weekly monitoring events between January 1997 and May 1998.

2.2.5 Results of On-Site Pond and Surface Water Sampling by Hydrometrics

Water quality data collected by Hydrometrics at the on-site ponds and at locations within the American Canal (sample locations designated as SEP-7, SEP-1 and SEP-3, upstream to downstream) and within the Rio Grande (sample locations SEP-9, SEP-10, SEP-11, SEP-2, SEP-12, SEP-13, and SEP-4, upstream to downstream) are presented in Appendix E. The surface water sample locations are presented in Figure 2-3. Samples were analyzed in the field for dissolved oxygen, pH, electrical conductivity and water temperature, plus laboratory analyses of pH, electrical conductivity, total dissolved solids, total suspended solids, calcium, magnesium, sodium, potassium, total alkalinity as $CaCO_3$, bicarbonate, carbonate, sulfate, chloride, fluoride, nitrate and nitrite as N, and dissolved metals (i.e., arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver and zinc) for selected samples. The analytical results are summarized in Tables E-1 through E-3, Appendix E.

Each on-site pond and surface water location was sampled quarterly from August 1997 through May 1998. The minimum, maximum and average concentrations of each parameter are summarized in Table 2-7. The average concentrations were calculated using one-half the detection limit for nondetectable results. If the average concentration is less than the detection limit, the detection limit is indicated.

2.2.6 Rio Grande Surface Water Sampling Results

Rio Grande surface water was sampled at seven locations, designated as SEP-9, SEP-10, SEP-11, SEP-2, SEP-12, SEP-13, and SEP-4 (upstream to downstream), and samples were analyzed for the parameters listed in Table 2-7.

Dissolved oxygen results ranged from 0 to 7.64 mg/l. Results for pH ranged from 7.9 to 8.5. Electrical conductivity ranged from 814 micromhos per centimeter (µmhos/cm) to 1,993 µmhos/cm. TDS ranged from 526 mg/l to 1,337 mg/l. Total suspended solids (TSS) ranged from 16 mg/l to 432 mg/l. General mineral concentrations of calcium, magnesium, sodium, and potassium ranged from 60 mg/l to 107 mg/l; 14 mg/l to 27 mg/l; 100 mg/l to 286 mg/l; and 7.4mg/l to 14 mg/l, respectively. Total alkalinity results ranged from 162 mg/l to 235 mg/l. Bicarbonate and carbonate results ranged from 178 mg/l to 299 mg/l and 0.5 mg/l to 17 mg/l, respectively. Sulfate ranged from 131 mg/l to 436 mg/l. Chloride ranged from 67 mg/l to 255 mg/l. Fluoride ranged from 0.57 mg/l to 0.82 mg/l. Nitrate and nitrite (as nitrogen) ranged from 0.21 mg/l to 6.5mg/l.

Dissolved metal concentrations, including arsenic, cadmium, chromium, copper, iron, lead, selenium and zinc, ranged from below the detection limit of 0.005 mg/l to 0.011 mg/l; are all below the detection limit of 0.005; are all below the detection limit of 0.005 mg/l; are all below the detection limit of 0.025 mg/l; are all below the detection limit of 0.1 mg/l; all were below the detection limit of 0.003 mg/l; all were at or below the detection limit of 0.005 mg/l; and ranged from below the detection limit of 0.02 mg/l to 0.035 mg/l, respectively.

Total recoverable metal concentrations, including arsenic, cadmium, chromium, copper, iron, lead, selenium and zinc, ranged from below the detection limit of 0.003 mg/l to 5.9 mg/l. The arsenic concentrations ranged from below the detection limit of 0.005 mg/l to 0.015 mg/l. Cadmium concentrations ranged from below the detection limit of 0.005 mg/l to 0.008 mg/l. Chromium concentrations were all below the detection limit of 0.01mg/l. Copper concentrations ranged from below the detection limit of 0.025 mg/l to 0.026 mg/l. Iron was

detected at concentrations ranging from 0.15 mg/l to 5.9 mg/l. Lead concentrations ranged from below the detection limit 0.003mg/l to 0.014 mg/l. Selenium concentrations ranged from below the detection limit of 0.005 mg/l to 0.006 mg/l. Zinc concentrations ranged from below the detection limit of 0.02 mg/l to 0.042 mg/l.

Most of the metal results from the Rio Grande samples are below the detection limit and the MCLs (Appendix E, Table E-3).

2.2.7 American Canal Surface Water Sampling Results

Within the American Canal, surface water samples were collected at SEP-7, SEP-1 and SEP-3, upstream to downstream. Samples were analyzed for common ions, dissolved metals and total recoverable metals. Results are presented in Appendix E.

Dissolved oxygen results ranged from 4.97 mg/l to 12.4 mg/l. Results for pH ranged from 7.6 to 8.5. Electrical conductivity ranged from 896 µmhos/cm to 5,410 µmhos/cm. Total dissolved solids ranged from 594 mg/l to 3,979 mg/l. Total suspended solids ranged from 13 mg/l to 275 mg/l. General mineral concentrations of calcium, magnesium, sodium, and potassium ranged from 62 mg/l to 225 mg/l; 15 mg/l to 94 mg/l; 114 mg/l to 965 mg/l; and 6.9 mg/l to 67 mg/l, respectively. Total alkalinity results ranged from 172 mg/l to 388 mg/l. Bicarbonate and carbonate results ranged from 205 mg/l to 381 mg/l and 0.5 mg/l to 11 mg/l, respectively. Sulfate ranged from 156 mg/l to 1,839 mg/l. Chloride ranged from 75 mg/l to 679 mg/l. Fluoride ranged from 0.65 mg/l to 2.3 mg/l. Nitrate and nitrite (as nitrogen) ranged from 0.21 mg/l to 12 mg/l.

Dissolved metal concentrations, including arsenic, cadmium, chromium, copper, iron, lead, selenium and zinc, ranged from below the detection limit of 0.005 mg/l to 0.082 mg/l; ranged from below the detection limit of 0.005 mg/l to 0.13 mg/l; are all below the detection limit of 0.01 mg/l; are all below the detection limit of 0.025 mg/l; are all below the detection limit of 0.1 mg/l; ranged from below the detection limit of 0.003 mg/l to 0.004 mg/l; ranged

from below the detection limit of 0.005 mg/l to 0.2 mg/l; and ranged from below the detection limit of 0.02 mg/l to 0.022 mg/l, respectively.

Total recoverable metal concentrations, including arsenic, cadmium, chromium, copper, iron, lead, selenium and zinc, ranged from below the detection limit of 0.003 mg/l to 4.7 mg/l. Arsenic concentrations ranged from 0.005 mg/l to 1.6 mg/l. Cadmium concentrations ranged from below the detection limit of 0.005 mg/l to 0.019 mg/l. Chromium concentrations were all below the detection limit of 0.01mg/l. Copper concentrations ranged from below the detection limit of 0.025 mg/l to 0.043 mg/l. Iron concentrations ranged from below the detection limit of 0.1 mg/l to 4.7 mg/l. Lead concentrations ranged from below the detection limit 0.003 mg/l to 0.021 mg/l. Selenium concentrations ranged from below the detection limit of 0.005 mg/l to 0.36 mg/l. Zinc concentrations ranged from below the detection limit of 0.02 mg/l to 0.068 mg/l.

2.2.8 On-site Pond Water and Sediment Sampling Results

The three water ponds at the Plant were not designated as part of the initial Remedial Investigation Work Plan (Hydrometrics, 1996); however, they were incorporated into the site assessment based upon the request of TNRCC (1997). Water samples were collected from Ponds 1, 5 and 6 (see Figure 3-8). The closed depression in the northern portion of the Plant (location SEP-14) was dry during all sampling events.

Dissolved oxygen results ranged from 5.29 mg/l to 8.33 mg/l. Results for pH ranged from 7.2 to 9.1. Electrical conductivity ranged from 975 µmhos/cm to 50,100 µmhos/cm. Total dissolved solids ranged from 644 mg/l to 53,664 mg/l. Total suspended solids ranged from 1.8 mg/l to 41 mg/l. General mineral concentrations of calcium, magnesium, sodium, and potassium ranged from 35 mg/l to 526 mg/l; 3.2 mg/l to 274 mg/l; 154 mg/l to 16.140 mg/l; and 6.3 mg/l to 715 mg/l, respectively. Total alkalinity results ranged from 73 mg/l to 154 mg/l. Bicarbonate and carbonate results ranged from 61 mg/l to 256 mg/l and 0.5 mg/l to 25 mg/l, respectively. Sulfate ranged from 193 mg/l to 36,326 mg/l. Chloride ranged from 137

mg/l to 2,853 mg/l. Fluoride ranged from 0.91 mg/l to 30 mg/l. Nitrogen ranged from 0.025 mg/l to 34 mg/l.

Dissolved metal concentrations, including arsenic, cadmium, chromium, copper, iron, lead, selenium and zinc, ranged from 0.064 mg/l to 3.7 mg/l; ranged from 0.021 mg/l to 22 mg/l; are all below the detection limit of 0.01 mg/l; ranged from 0.2 mg/l to 1 mg/l; ranged from below the detection limit of 0.1 mg/l to 0.76 mg/l; ranged from 0.004 mg/l to 0.26 mg/l; ranged from below the detection limit of 0.010 mg/l to 1.7 mg/l; and ranged from 0.16 mg/l to 137 mg/l, respectively.

The on-site pond water was not sampled for total recoverable metals because off-site surface water is not directly affected by the ponds. Any impact to off-site surface water can be related to groundwater sources.

Sediments in Ponds 1, 5 and 6 were sampled in 1996 and analyzed for total recoverable metals (Hydrometrics, 1997a). The sediment samples were collected at three locations in each pond from about the upper four inches of sediment. Results indicated elevated metal concentrations in the pond sediments; however, it was believed that the pond water would be the primary source of groundwater contamination and that pond sediments would constitute a minor contributor. The sediment results are presented in Table 2-8.

2.2.9 Comparison of On-site Pond and Surface Water Sampling Results

In all cases, concentrations in the pond water samples were higher than in the Rio Grande and American Canal surface water samples, with Pond 1 having the highest concentrations of the three ponds sampled. The higher concentrations collected from Pond 1 are attributed to initial concentrations in the water stored in the pond and subsequent water evaporation during all sampling events. The relative concentrations of general minerals in each pond are illustrated on Figure 2-10, which presents the general minerals results (i.e., TDS, TSS, temperature, calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, chloride, fluoride and nitrate-nitrite) for Ponds 1, 5 and 6.

The parameters of pH, SC, TDS, temperature, sulfate and chloride were analyzed for the pond samples, the Rio Grande surface samples collected by Hydrometrics, Inc. and the Rio Grande sample collected by IBWC at Courchesne Bridge during November and December 1997. These results are summarized in Table 2-9.

The results indicate that Pond 1 has the highest concentrations, followed by Pond 6 and sample locations SEP-1 and SEP-3. Locations SEP-1 and SEP-3 are both located in the American Canal. The other samples had lower concentrations and were similar to each other. The analytical data are presented in Figure 2-11.

Water and surface water data for general mineral samples collected from Ponds 1, 5 and 6, Rio Grande locations SEP-2, SEP-4, SEP-7, SEP-9, SEP-10, SEP-11, SEP-12 and SEP-13, and American Canal locations SEP-1, SEP-3 and SEP-7 were plotted on Piper diagrams (Figures 2-17 through 2-25). Piper diagrams are used to visually present cation and anion compositions of multiple samples on a single graph, thus allowing trends in data to be visually determined. Based upon the Piper diagram for Ponds 5 and 6, both waters are of similar composition to each other and to the Pond 1 sample (Figures 2-18 and 2-19, respectively). Piper diagrams for other surface water samples are discussed in more detail in a later section of this report.

Rio Grande samples collected in August 1997 and February 1998 are plotted on two separate diagrams (Figures 2-22 and 2-23). Rio Grande samples are similar to each other for each individual sample time; however, the geochemistries vary between summer and winter sampling events. The summer samples (August 1997, Figure 2-22) have higher carbonate-bicarbonate concentrations and lower chloride concentrations compared to the winter samples (February 1998, Figure 2-23). Rio Grande water geochemistry is probably influenced by increased flow during the summer and reduced flow during the winter due to dam releases, snow melt, and higher precipitation during the summer.

American Canal samples have similar geochemistries during the summer (increased flow) and slightly dissimilar geochemistries during the winter (low flow) (Figures 2-24 and 2-25, respectively). During the winter, the sample collected at location SEP-7, which is the farthest upstream in the American Canal, had higher carbonate-bicarbonate and chloride concentrations than samples collected at downstream locations SEP-1 and SEP-3.

2.2.10 Rio Grande Flow Data

IBWC maintains a database with mean daily flow measurements at three points in the Rio Grande. Flow data, measured in mean daily discharge in cubic meters per second, is available for the following locations and time periods:

- At the Courchesne Bridge for the period 1889 through May 1998
- At the Pump House below the American Dam for the period 1938 through May 1998
- At the American Dam diversion to the American Canal for the period 1938 through May 1998.

Only the data from 1995 through 1998 were considered for this report. The data are presented in Table 2-10 and shown graphically on Figure 2-12.

The upgradient location at Courchesne Bridge had the highest mean daily flow rates, and the downstream location at the Pump House had the lowest mean daily flow rates. Daily flow rates are highest at Courchesne Bridge because it is located upstream from the American Dam diversion. At the American Dam, water is diverted from the Rio Grande to the American Canal for use by the U.S. The highest flow volumes were noted in July and August, 1995. During this time, the mean daily discharge volumes ranged up to 110 cubic meters per second at Courchesne Bridge. Other sources of flow to the Rio Grande include the Northwest Waste Water Treatment Plant, located about one mile northwest and upstream of the Plant. Water from the Rio Grande is diverted via the American Canal to the Haskell R. Street Waste Water Plant, located about nine miles southeast and downstream of the Plant.

The depth-to-water data for wells located adjacent to the Rio Grande (i.e., wells EP-4 through EP-7) and in wells located in the historic Smeltertown area (i.e., wells EP-60 through EP-66) were compared to the Rio Grande flow data to determine whether a correlation existed. Table 2-11 presents the depth-to-water data for 1995 through 1998. Figures 2-13 and 2-14 graphically illustrate the water level measurements in wells EP-4 through EP-7 and EP-60 through EP-66, respectively.

Depths to water in wells EP-4 through EP-7, located adjacent to the Rio Grande from about the Pump House to the eastern edge of the site boundary, fluctuated in a similar manner. Water levels were highest annually in August and lowest during January and February. Depths to water ranged from highs of about 4.5 feet to lows of slightly more than 9 feet (Figure 2-13).

Depths to water in wells EP-60 through EP-66, located in the historic Smeltertown area and adjacent to the American Canal, exhibited similar fluctuations with the exception of EP-62. Well EP-62 exhibited a sharp decrease in water level in September 1995 (Figure 2-14), which may be a result of seasonal controls of the Rio Grande. Overall, however, water levels were highest annually in August and lowest in January.

Since the Rio Grande flow volumes are generally highest in summer and lowest in winter, the groundwater in the immediate area tends to recharge more during summer and less in winter. This correlation is evidenced by the higher water levels in the adjacent wells during August, following the higher discharge volumes in the Rio Grande and lower water levels in January and February, following a period of decreased discharge volumes in the Rio Grande.

2.2.11 Trends of Water Quality Parameters and Flow Data in the Rio Grande

Analytical data from water quality samples collected at sampling locations in the Rio Grande at Bowie High Football Stadium and at Courchesne Bridge were reviewed to determine whether analytical results were related to flow volumes. The general trend of flow rates is

presented in Table 2-12. Flow increases in the summer months and decreases during the winter. Figures 2-15 and 2-16 present the general data during 1997 for samples collected at the Bowie High Football Stadium and Courchesne Bridge locations, respectively. Analytical data include dissolved oxygen, pH, biochemical oxygen demand, fecal coliform, chloride, TDS, sulfate, electrical conductivity, total hardness, ammonia, turbidity and temperature.

Overall, the analytical trends between the two sampling locations appear to be similar. One notable exception is a sharp increase in the turbidity in September 1997 at both locations, but particularly at the Bowie High School location (see Figures 2-15 and 2-16). Concentrations of most parameters appear to increase during January and February, which corresponds to periods of lowest flow volumes. Concentrations are decreased during the summer months, which corresponds to a period of highest flow volumes.

The relationship of decreased concentrations during high flow periods and increased concentrations during low flow periods also occurs in the Franklin (American) Canal. Sampling points SEP-7, SEP-3 and SEP-1 are located upgradient to downgradient in the American Canal adjacent to the Plant. Concentrations of trace arsenic are related to the flow rates measured in the American Canal, as shown in Table 2-13. Arsenic concentrations decreased during times of high flow rates and increased during times of low flow rates. This is likely related to dilution resulting from high flow events.

2.2.12 Distribution of Constituents of Concern in Process Pond Water and Surface Water Bodies

Constituents of concern designated by the TNRCC for this facility are arsenic, cadmium, chromium, copper, iron, lead, selenium and zinc, with parameters of concern being pH, specific conductivity and total dissolved solids. The federal drinking water standards (maximum contaminant levels) for each of these parameters are tabulated in Table 2-14 for discussion purposes. Only primary drinking water standards are enforceable. The secondary standards and action levels are included for discussion purposes, but are not enforceable standards.

On-site pond water and surface water was sampled and analyzed for the eleven parameters noted above. The analytical results are tabulated in Appendix E. Arsenic was detected above its MCL of 0.05 mg/l in samples collected from Pond 1, Pond 5, Pond 6, SEP-1 and SEP-3. SEP-1 and SEP-3 are located downgradient in the American Canal, and only had elevated levels of arsenic during the December and February sampling events, indicating that concentrations increased during periods of low flow in the Rio Grande. Flow in the American Canal during the winter is restricted, which indicates that the water samples collected in December and February are not representative of water in the American Canal. It is probable that the water sample results are elevated because the metals have been concentrated due to evaporation or are related to sediments in the canal bottom. Only the samples collected during high flow events can be considered as representative of the American Canal waters.

Cadmium was detected above the MCL of 0.005 mg/l in samples collected from Pond 1, Pond 5, Pond 6, SEP-1 (one sample only collected during February 1998) and SEP-3 (one sample only collected during November 1997).

Chromium was not detected above the detection limit of 0.01 mg/l in the surface water samples. The MCL for chromium is 0.1 mg/l. Copper was not detected above the Texas action level of 1 mg/l. Iron was detected above the secondary MCL of 0.3 mg/l in one sample collected from Pond 6 in December 1997. Lead was detected above the action level of 0.015 mg/l in samples collected from Ponds 1, 5 and 6. Only one Rio Grande sample (SEP-7) had a detectable occurrence of lead. The May 1998 sample for SEP-7 exhibited a lead concentration of 0.004 mg/l, which is at the detection limit.

Selenium was detected above the MCL of 0.05 mg/l in samples collected from Pond 1, Pond 5, Pond 6, SEP-1 and SEP-3. The samples from SEP-1 and SEP-3 exhibited elevated selenium concentrations during the November and February sampling events. The secondary MCL of 5 mg/l for zinc was exceeded only in samples collected from Pond 1.

The State of Texas secondary MCL of greater than 7.0 pH was met in all surface water samples. The federal upper limit of 8.5 pH was exceeded only in single samples collected from Ponds 5 and 6. Total Dissolved Solids were detected above the federal secondary MCL of 500 mg/l in all surface water samples. The Texas secondary MCL of 1,000 mg/l for TDS was exceeded in all November 1997 samples, some February 1998 samples, and in all of the samples collected from Ponds 1 and 6.

Overall, the surface water samples exhibited higher concentrations during the winter months, probably due to evaporation in the ponds and decreased flow (hence less dilution) in the Rio Grande. Six constituents of concern were detected at concentrations above federal and/or state regulatory standards: arsenic, cadmium, iron, lead, selenium and zinc. Chromium and copper were not detected above established regulatory standards. It is probable that the initial elevated concentrations of metals in off-site surface water resulted from historical stormwater and airborne transport of contaminated materials.

2.3 GROUNDWATER INVESTIGATION RESULTS

2.3.1 Local Geology

As part of the Remedial Investigation, the geology of the facility was assessed. The investigation utilized reference materials from Asarco's engineering department, subsurface information gathered during the remedial investigation field work, and data collected during previous investigations and remedial activities. The drilling logs were utilized to generate cross-sections across the Plant, as located in Figure 2-26. Seven cross-sections were developed (Figures 2-27 through 2-33). Each cross-section illustrates the subsurface geology and identifies subsurface features that may be conducive to groundwater migration and transport of constituents. Below is a general description of the geologic/hydrogeologic units of the plant area as developed from a literature review based on previous work (Hydro-Search, 1985) and this study. The geologic units at the facility in order of youngest to oldest (generally shallow to deep) are described below.

1. Rio Grande Alluvial Aquifer (Smeltertown Area): Consists of reworked colluvial and terrace deposits. In the upper 20 feet, composition of the unit is predominately sand, silts and clays. This unit is 86 feet thick in El Paso Canyon (Slichter, 1905).

2. Arroyo Colluvial (Plant Area and East of I-10): The colluvial fill in these arroyos on the Plant Site generally consists of well-graded silty sands, gravels, cobbles and boulders. Some portions of the unit contain cement of "caliche" calcium carbonate (Lovejoy, 1976). Locally, this unit is estimated to be 300-400 feet thick in the canyon (Rose, 1953). In the vicinity of the plant, the thickness of this unit is estimated to be between 150 feet and 200 feet.

3. Bedrock (Campus Andesite and Areas beneath the Arroyo Colluvial and Rio Grande Alluvial Aquifer): The bedrock unit consists of Tertiary andesites (laccolith), Cretaceous sandstones, shales, limestones and siltstones. The primary porosity of these units is expected to be very low. However, fractures and solution features in limestone units may enhance the hydraulic conductivity in zones of heavy faulting or in solution zones.

These geologic units also represent hydrogeological units and may be designated as aquifers and/or potential aquifers.

2.3.2 Local Hydrogeology

The aquifer located underneath the El Paso Plant is composed primarily of interbedded and mixed sand, gravels, boulders and bedrock. Water is derived from the Rio Grande and considered separate from the Hueco and Mesilla Bolsons. There are a few locations (floodplain of Smeltertown) of finer-grained sediments (e.g., silts and clays). The aquifer is considered saline, with a total dissolved solid (TDS) concentration ranging from 3,000 mg/l to 10,000 mg/l.

Groundwater flow direction is from the east-northeast to the west-southwest. As the groundwater approaches the Rio Grande, the direction changes to a southerly route which

approximates the direction of the Rio Grande at the Plant. Depth to groundwater is dependent on location within the Plant. The depth of groundwater at the Plant is 40 to 60 feet below ground surface (bgs), depending on the elevation of the plant above the floodplain (30 to 50 feet). On the Rio Grande floodplain (Smeltertown), the depth to groundwater is approximately 10 feet bgs. Aquifer elevations fluctuate in conjunction with the amount of water in the Rio Grande and the American Canal. These fluctuations are a result of seasonal releases of water from Elephant Butte Dam, near Truth or Consequences, New Mexico, which is approximately 100 miles north of El Paso. In the spring, water is released for irrigation purposes and, in the fall, water releases are restricted to conserve water over the winter months. There is minimal recharge into the aquifers from precipitation.

Data from 65 moniter wells were used to determine groundwater elevation, water quality and hydrogeology of the site. The goals of the groundwater investigation included delineating hydrogeologic units, determining groundwater flowpaths and measuring groundwater velocities. The results are presented in this section.

2.3.3 Aquifer Characteristics

Investigations and data analysis of groundwater data were performed to evaluate:

- Groundwater flow direction
- Groundwater gradients
- Preferential groundwater pathways
- Aquifer parameters (conductivity, storativity, transmissivity).

2.3.4 Groundwater Flow Direction

Elevation data was collected from the monitor wells and the surface water sampling locations along the American Canal and the Rio Grande quarterly during the first year of monitoring under the Agreed Order (August 1997, November 1997, February 1998 and May 1998). Depths to groundwater ranged from 5.00 feet bgs measured in well EP-4 in February 1998 to

77.95 feet bgs measured in well EM-1 in November 1997. Well EP-4 is located near the Pump House gauging station and is adjacent to the Rio Grande. Well EM-1 is located along the eastern edge of the facility. In general, wells located in the floodplain along the Rio Grande had shallow depths to groundwater, whereas wells located up the hill at the Plant had deeper depths to groundwater. Quarterly groundwater elevation maps are presented in Figures 2-34, 2-35, 2-36 and 2-37. Groundwater and surface water level measurement data are presented in Appendix F.

Groundwater contours were relatively similar throughout the first year of monitoring. The groundwater contours generally parallel the historic arroyo contours, especially the Acid Plant Arroyo. Figure 2-3 presents the historic locations of the arroyos superimposed on the current site configuration, based upon the 1891 topographic map for the area (Sergent, Hauskins & Beckwith, 1984). The overall groundwater flow direction is from east to west. Groundwater flow is controlled by the alluvial fans of the Campus Andesite and the Franklin Mountains, as well as by the tilted beds of the laccolith structure of the Campus Andesite.

Groundwater elevations are influenced by the Rio Grande. Seasonal irrigation releases, and corresponding increases and decreases in surface water levels in the Rio Grande, directly affect the local groundwater elevations at the Plant (Hydrometrics, 1998).

2.3.5 Groundwater Gradients

Hydraulic gradients were calculated, based on the groundwater contour map prepared for each quarter (Figures 2-34, 2-35, 2-36, and 2-37). The average gradient across the plant is 0.013 (foot per foot). The relatively steep gradient in some areas reflects the impact of the steeply inclined arroyos and alluvial fans. Table 2-15 presents a summary of hydraulic gradients calculated for areas on the site.

2.3.6 Preferential Groundwater Pathways

Based on the groundwater gradients indicated by the groundwater elevation maps and on results of the analytical sampling, it appears that the preferred pathway for groundwater flow

at the site is via the arroyos. Portions of the site, including the arroyos, have been backfilled with smelter debris and slag during the history of the Plant to create more surface area for plant expansion. Areas with elevated metal concentrations are detected within the buried arroyos, as illustrated in Figure 2-38, which presents the arsenic concentrations in surface water and groundwater samples collected in May 1998. Of the eight separate areas of detectable arsenic concentrations, all can be correlated to historic arroyos.

2.3.7 Aquifer Testing

Aquifer tests were performed at various wells at the El Paso Smelter Site and Smeltertown to support the Remedial Investigation groundwater study. Data collected as part of the Remedial Investigation were used in conjunction with previous data to assess the hydrogeology of the Plant (Hydro-Search, 1985).

In May 1998, aquifer tests were performed to provide additional information about the hydrogeology of the El Paso Plant Site. These tests were performed using a low pumping rate because slug tests performed during October 1997 indicated that the wells of interest were in regions of similar, low hydraulic conductivity. The aquifer tests were performed in accordance with general aquifer test guidelines outlined in Hydrometrics' Standard Operating Procedure HF-SOP-08. Listed in Table 2-16 are wells used in aquifer testing, showing test date, total well depth, saturated thickness and target aquifer for each well.

The data for these testing events were collected using In-Situ, Inc.'s Model SP-4000 Troll Intelligent Probes and analyzed using Firmware Version 6.01. These models are pressure transducers that can be preprogrammed for automatic test starts. During testing, data were periodically downloaded from the probe to a notebook computer to determine the quality of data from the test, as well as to optimize the time required for the test.

Once these data were collected and downloaded to a computer using In-Situ's Win-Situ version 2.13, the data were processed using automatic curve-matching software. The two types of curve matching software used for this task were Geraghty and Miller, Inc.'s Aqtesolv

program version 2.01 (Geraghty and Miller, 1995) and Waterloo Hydrologic, Inc.'s Aquifer Test for Windows, version 2.50 (Waterloo Hydrogeologic, Inc., undated). Field data and analyses are presented in Appendix H.

2.3.8 Analysis Of Aquifer Test Data

Several assumptions were made during the data analysis. Many of the methods used to analyze aquifer test data require confined, homogeneous, isotropic aquifers of infinite areal extent penetrated by a fully penetrating well. In addition to these general assumptions typically used in the analysis of aquifer test data, site-specific conditions were considered.

The Theis recovery method of aquifer test data analysis was used for most of the test wells because, in most cases, the pumping well was also the observation well. When drawdown data from a pumping well are used for the analysis of aquifer properties, transmissivity may be underestimated because of the increase in drawdown at the pumping well. Therefore, the analysis of the recovery test data from the aquifer tests was used as the basis for the determination of aquifer properties of the different hydrogeologic units.

2.3.9 Results Of Aquifer Testing

The results of these tests confirm and increase the understanding of the hydrogeologic system under the Plant. These data are presented in Table 2-17.

Hydraulic conductivities calculated for the three different hydrogeologic units in the vicinity of the Plant are comparable to ranges of conductivities published for these aquifer types. The hydraulic conductivity of the Rio Grande Alluvial hydrogeologic unit (6×10^{-3} cm/s) is consistent with published ranges of 10^{-3} cm/s to 10^{-6} cm/s for silty sands and fine sands (Fetter, 1994). The hydraulic conductivities calculated for the Arroyo Colluvial hydrogeologic unit ranged from 10^{-3} cm/s to 2.5×10^{-4} cm/s, which includes values lower than those calculated for the Rio Grande Alluvial.

The Arroyo Colluvial hydrogeologic unit is generally not as well-sorted as the Rio Grande Alluvial. The higher percentage of fines in the Arroyo Colluvial reduces the hydraulic conductivity.

2.3.10 Groundwater Quality

Groundwater samples were collected from 68 monitor wells using various techniques and equipment. The wells were sampled according to the Remedial Investigation Work Plan, Sampling Analysis Plan (Hydrometrics, 1996). All monitor wells were gauged for depth to water, product thickness and total depth of the monitor well prior to sampling. The data were used to calculate the purge volume (approximately three well volumes). Depending upon well conditions, the well was purged using low-flow purging techniques or higher rates of purging. Each well was purged using one of the following: a dedicated bailer, a pneumatic pump, a 12-volt DC pump or a 2-inch submersible pump.

During purging of the monitor wells, groundwater parameters were measured using either an in-line electronic probe or a separate meter. Parameters measured in the field included pH, temperature, specific conductivity, and dissolved oxygen. Groundwater samples were collected after the parameters stabilized or upon removal of the full three well volumes.

Samples were collected in 1000-milliliter and 500-milliliter polyethylene containers. Parameters listed under "commons" (see Appendix G) were collected in a one-liter polyethylene container with no preservative. Groundwater collected for the analyses of nitrates ("nutrients", Appendix G) were collected using a 500-milliliter container that was field-preserved with sulfuric acid. Dissolved metals analytical samples were collected in a 500-milliliter container, field-filtered using a peristaltic pump and an in-line 0.45-micron filter, and preserved using nitric acid. Samples for total recoverable metals were collected at the SEP locations along the American Canal and the Rio Grande, each in a one-liter bottle preserved using nitric acid.

All bottles were labeled with the identification number, date, time collected, name of

sampler, type of preservative used and the analysis to be performed. After the samples were containerized, the bottles were placed in an ice-filled cooler with completed chain-of-custody forms and shipped via Federal Express to Asarco's Technical Services Center in Salt Lake City, Utah for analysis. Laboratory analyses performed on groundwater samples collected from the monitor wells and surface water locations included the parameters listed below:

- pH
- Specific Conductivity
- Temperature
- Total Dissolved Solids
- Total Suspended Solids
- Bicarbonate
- Carbonate
- Sulfate
- Chloride
- Fluoride
- Calcium
- Magnesium
- Sodium
- Potassium
- Dissolved Oxygen

Parameters of pH, temperature and specific conductivity were measured in the field as well as in the laboratory. Dissolved oxygen was measured only in the field. The calculated average concentrations for the entire site, based on all groundwater samples, are presented below. The average concentrations were calculated using one-half the detection limit for nondetectable results. Laboratory reports are presented in Appendix I, and data are summarized in tables in Appendix G.

Summary of Groundwater Concentration Averages (mg/l)

pH	Specific Conductivity	As	Cd	Cr	Cu	Fe	Pb	Se	Zn
7.6	6,101	7.67	0.64	0.01	0.07	25.51	0.004	0.45	17.61

mg/l = milligrams per liter.

The data were utilized to evaluate potential source areas of metals. High specific conductivity results mirrored the locations of elevated values of arsenic. In addition, the data were used to evaluate the potential for the three ponds to impact groundwater, to determine whether the arroyos exhibited the same groundwater chemistries, and to determine whether on-site groundwater chemistry is altering or influencing the waters of the American Canal and the Rio Grande. Geochemical data were assessed using a modified method developed by

Arthur Piper (Piper, 1944). The Piper method was chosen as the preferred assessment tool because it allows for the graphical presentation of a large number of analytical samples on a single graph. Major groupings or trends in the analytical data can be discerned based on the Piper diagram. For this investigation, a single groundwater analysis from multiple wells located in the same buried arroyo was plotted on a single Piper diagram to assess whether geochemical similarities were present. The Piper method is based on a multiple trilinear diagram that graphically represents groundwater geochemistries. The original Piper method has been modified such that the concentration of TDS is not represented on the diagram.

The Piper diagram represents relative concentrations of major constituents, namely calcium, magnesium, sodium and potassium cations, as well as sulfate, chloride, carbonate and bicarbonate anions, converted as percentages in milliequivalents per liter. Figures 2-17 through 2-25 present Piper diagrams for each of the five major arroyos (Parker Brothers, Ponds 5 and 6, Pond 1, South Terrace Area, and Acid Plant), plus the Rio Grande and the American Canal.

2.3.11 Groundwater Chemical Comparison (Pond 1 Arroyo)

Pond 1 is constructed from a dammed arroyo located on the western property boundary and on the northern edge of the South Terrace Area. The water in the pond was from the Rio Grande and has been utilized for general plant water supply. The chemical data for Pond 1 and monitor wells EM-2, EM-4, EP-12, EP-13, EP-14, EP-15, EP-29 and EP-43, all located within or near the limits of the arroyo, were plotted on a Piper diagram for comparison (Figure 2-19). Water collected from Pond 1, and groundwater collected from wells in the area, are chemically similar. The water results for Pond 1 plot just outside the monitor well data. The differences between the Pond 1 results and the monitor well data can be attributed to evaporation of pond water, which causes increased pH, salinity (i.e., increased potassium and sodium concentrations) and generally increased concentrations of common ions. The pond geochemistry also has been affected by the addition of water that had accumulated in the area of the bedding and unloading plant due to excessive dust suppression and rainfall.

2.3.12 Groundwater Chemical Comparison (Ponds 5 and 6 Arroyo)

Water samples from Ponds 5 and 6, and from monitor wells EM-5, EM-6, EP-26, EP-56 and EP-77, were plotted on the same Piper diagram to compare geochemistries (Figure 2-18). All samples plot similarly, suggesting a common water source. The ponds are located at the head of an arroyo drainage at the plant. As with most arroyos on the plant, this one has been dammed twice to construct the ponds, as well as being backfilled with facility debris and slag.

2.3.13 Groundwater Chemical Comparison (South Terrace Area Arroyo)

The arroyo in this location is approximately in the middle of the South Terrace Area. Prior to being filled with slag, the plant entrance was located in this arroyo. Monitor wells EP-20, EP-70 and EP-72 were used in assessing groundwater quality in this arroyo. The results of the data were plotted on a Piper diagram (Figure 2-20). Based on the plots, it is inferred that the groundwater in each of the monitor wells is generated from the same source.

2.3.14 Groundwater Chemical Comparison (Acid Plant Arroyo)

The area of the acid plant arroyo extends from the former Zinc Plant operations area to the western property boundary. This arroyo has been filled with facility debris and slag. Monitor wells EP-21, EP-22, EP-23, EP-25, EP-49, EP-53, EP-54, EP-55, EP-73 and EP-76 were used to compare water chemistry. Using a Piper diagram, the results indicate a similar groundwater source, with the exception of wells EP-21 and EP-25, and to a lesser degree well EP-49 (see Figure 2-21). These three monitor well locations are at the eastern reaches of the arroyo (EP-21) in the center of the arroyo east of Acid Plant No. 1 (EP-25) and at the mouth of the arroyo near the Acid Plant Mist Precipitator Building (EP-49). Each of these three monitor wells exhibit measurable amounts of diesel, which may be affecting groundwater geochemistry.

2.3.15 Groundwater Chemical Comparison (Parker Brothers Arroyo)

Parker Brothers Arroyo is the western confluence of two other arroyos that extend from the flank of the Franklin Mountains. Monitor wells EP-78, EP-81, EP-82, EP-83 and EP-85

were plotted on the same Piper diagram (Figure 2-17). The geochemistries of wells EP-78, EP-82, EP-83 and EP-85 are relatively similar; however, well EP-81 data are somewhat different from those of the rest of the samples. Well EP-81 contains the most carbonate-bicarbonate type groundwater of the group. Well EP-81 is located downgradient of the other wells and is primarily at the confluence of the Arroyo and sediments of the Rio Grande floodplain.

2.3.16 Distribution of Constituents of Concern in Groundwater

Constituents of concern designated by the TNRCC for this facility are arsenic, cadmium, chromium, copper, iron, lead, selenium, zinc, pH, specific conductivity and total dissolved solids. The federal and state drinking water standards (maximum contaminant levels) for each of these parameters are presented in Table 2-14 for discussion purposes. These standards do not apply directly to the Plant, because none of the groundwater at the site is used for drinking water.

The federal standards for arsenic, cadmium, lead (action level) and selenium were exceeded in one or more groundwater samples collected at the facility during the first year of monitoring. The analytical results are tabulated in Appendix G. The May 1998 groundwater data for arsenic, cadmium, lead and selenium are presented in Figures 2-38 through 2-41. Detectable concentrations of arsenic occurred in 59 groundwater samples and 8 surface water samples collected during the most recent quarterly sampling event, conducted in May 1998 (see Appendices E and G). Arsenic occurred at concentrations above its respective MCL of 0.05 mg/l in an arroyo located in the northeastern portion of the site (well EP-84), plus over most of the western half of the facility, including Smeltertown. Arsenic occurred at levels above 5 mg/l in six isolated areas, as shown on Figure 2-38. These areas include an area located downgradient of the closed depression 14 (well EP-76); near the Boneyard/Slag (Wells EP-53 and EP-75); near Acid Plant 2 (wells EP-55, EP-54 and EP-49); downgradient of Ponds 5 and 6 (well EP-77); on the southwestern edge of Smeltertown (well EP-66); and north of Pond 1 (EP-13).

Detectable concentrations of cadmium occurred in four surface water samples and sixteen groundwater samples collected during the May 1998 sampling event. Analytical results are presented in Appendices E and G, respectively. Cadmium was detected above its MCL of 0.005 mg/l over a less extensive area than arsenic, but occurred in the arroyo upgradient of the Parker Brothers Arroyo, and in unconnected areas in the western half of the facility. Cadmium was detected above 0.5 mg/l in six separate areas: the vicinity of the Boneyard/Slag (well EP-53); Acid Plant 1 (well EP-54); south of Acid Plant 1 (wells EP-52 and EP-51); west of the former Lead Plant (well EP-26); north of Pond 1 (well EP-13); and in Pond 1 (Pond 1 surface water sample). The cadmium results are presented in Figure 2-39.

Detectable concentrations of lead occurred in three surface water samples and ten groundwater wells during the May 1998 sampling event (Figure 2-40). Analytical results are presented in Appendices E and G, respectively. Lead was detected above the federal action level of 0.015 mg/l in six separate areas at the facility, including Ponds 1, 5, and 6; Acid Plant 1 (well EP-49); south of Acid Plant 1 (well EP-52); and west of the former Lead Plant (well EP-26). The lead occurrence is less extensive than either arsenic or cadmium.

Detectable concentrations of selenium occurred in three surface water samples and 52 groundwater wells during the May 1998 sampling event (Figure 2-41). Analytical results are presented in Appendices C and E, respectively. Selenium was detected above its MCL of 0.05 mg/l over most of the facility, except in the northern portion. Selenium was detected above 0.5 mg/l in six areas of the site, including north of the Boneyard/Slag (wells EP-53 and EP-75); at Acid Plant 2 (well EP-73); in Smeltertown (well EP-64); near the former Sinter Plant (well EP-74); north of Pond 1 (well EP-13) and at Pond 1 (Pond 1 surface water and wells EP-12 and EP-35).

No other constituents of concern exceeded their respective MCLs, with the following exceptions:

- One sample collected from well EP-49 in November 1997 exceeded the MCL for chromium.
- The same sample collected from well EP-49 exceeded the Federal Action and Texas secondary MCL for copper. Another single sample collected from well EP-51 in February 1998 exceeded the MCL for copper.
- The secondary MCL for iron (0.3 mg/l) was exceeded in samples collected from wells EM-5, EM-7, EP-21, EP-23, EP-24, EP-25, EP-29, EP-4, EP-43, EP-49, EP-5, EP-51, EP-52, EP-54, EP-55, EP-57, EP-58, EP-60, EP-61, EP-7, and EP-75.
- The secondary MCL for zinc (5 mg/l) was exceeded in samples collected from wells EP-49, EP-51, EP-54, and EP-55.
- All laboratory results for pH were higher than 7, the Texas secondary MCL for pH. The only samples outside the pH range of 6.5 to 8.5 (federal secondary MCL) were those samples collected from well EP-49.
- All wells exhibited TDS concentrations above both the federal and state secondary MCL, with the exception of well EP-87.

2.4 INTERACTIONS BETWEEN ON-SITE PONDS, SURFACE WATER BODIES AND GROUNDWATER

Data gathered from two surface water bodies in the vicinity of the Plant (the Rio Grande and the American Canal) and the on-site ponds were considered in assessing the potential impact of surface water on groundwater. Information gathered during the Remedial Investigation indicates that the process pond water and groundwater are interconnected. The surface water bodies in the vicinity of the Plant (i.e., the American Canal and the Rio Grande) affect groundwater.

2.4.1 Impact of Process Ponds on Groundwater

Groundwater in the vicinity of the process ponds appears to be impacted by elevated metal concentrations related to the process pond water.

2.4.2 Impacts from Plant Runoff

Surface runoff from the sump located near the Plant entrance may move off-site to the American Canal, however, this potential source will be controlled by the proposed stormwater improvements project scheduled to start in late 1998.

2.4.3 Impacts of Affected Groundwater on the American Canal and Rio Grande

Groundwater containing elevated metal concentrations is moving towards the American Canal and the Rio Grande. Groundwater gradients are generally rather flat in the floodplain around the Rio Grande (i.e., historic Smeltertown) as shown in Figures 2-34 through 2-37, but surface water elevations are slightly higher than groundwater elevations, indicating that the Rio Grande might have recharged the groundwater system at the time the water level data were collected. Farther downstream, however, the surface water elevations are slightly lower than groundwater elevations, suggesting that groundwater may recharge the surface water system. Further evidence of interconnection between the surface water and groundwater systems are the seasonal fluctuations exhibited by both the Rio Grande and adjacent groundwater wells. Wells in the former Smeltertown area fluctuated with the Rio Grande, which has increased flows during the summer due to upstream releases.

2.5 GROUNDWATER FATE AND TRANSPORT MODEL

The fate of trace elements in soils depends upon soil chemical and physical properties, and especially on element speciation. Soil processes include dissolution, sorption, complexation, migration, precipitation, occlusion, diffusion into minerals, binding by organic substances, absorption and sorption by microbiota, and volatilization. The most important factors governing the soil processes are soil pH and redox potential (Kabata-Pendias and Pendias, 1992).

Trace elements may be transported long distances aerially, making it difficult to estimate natural background concentrations. For the purposes of site characterization and remedial investigation, on-site concentrations are considered to be related to smelter operations.

Contributions from off-site sources, including industrial facilities in Mexico, are unknown. Pathways for trace metal exposure at the Plant and the surrounding area are (1) through the air as dust and (2) in surface and subsurface water. Biological mobilization and immobilization will not be a factor, because little vegetation exists at the site and human intake is minimized via implemented health and safety procedures. Elemental metals will not be broken down in the environment, but can be changed from one form to another. Species transformation will be controlled by soil binding sites, pH, and concentrations of complexing anions and competing cations. Low pH values generally increase mobilization of metals, whereas neutral or moderately basic pH values generally immobilize metals through processes such as sorption to solid surfaces and increased precipitation (decreased solubility). One important exception to this generalization is arsenic, which is more mobile in a high pH environment. Arsenic is also sensitive to redox conditions and will be more mobile in a reducing environment.

Metals may be present in water as free ions or complex ions, and both forms will be transported with groundwater flow. The actual rate of transport is dependent upon local conditions such as confining layers, recharge and discharge, and potential for binding sites.

2.5.1 Purpose and Scope

The purpose of the groundwater fate and transport model is to estimate the migration of metals from the Plant to the American Canal and the Rio Grande. Source area removal scenarios are also evaluated using fate and transport models.

Four metals (arsenic, cadmium, lead, and selenium) were considered for this modeling effort. Based on the results of the soil and groundwater sampling conducted during the Remedial Investigation, only arsenic and selenium appear to be located along pathways that may affect off-site surface water bodies. Arsenic concentrations are elevated in soils and groundwater in some areas, and there appear to be several locations at which elevated concentrations occur downgradient of contaminant source areas near surface water bodies (i.e., the American Canal and the Rio Grande). Selenium also occurs in groundwater associated with adjacent

contaminant source areas, but downgradient surface water bodies indicated limited occurrences of elevated selenium. Current data suggest that cadmium and lead are relatively immobile in this groundwater system, and that there is no significant migration of these metals at the site at this time. As a consequence of the limited impact of selenium and the immobility of cadmium and lead, arsenic is the chemical constituent modeled for this investigation.

Two arsenic source areas have been selected for modeling based on the availability of calibration data, and to provide typical migration scenarios in the vicinity of the Plant. Potential impacts to surface water resources (the Rio Grande and the American Canal) have been estimated for two preliminary source areas identified during the Remedial Investigation. These assumptions are described below in the discussion of the conceptual models. The two source areas modeled are as follows:

- Source Area 1 - Acid Plant Area, specifically the Acid Plant Mist Precipitator
- Source Area 2 - Ponds 5 and 6 Arroyo.

Using conservative assumptions for permeability and the partition coefficient, the models are used to predict arsenic migration potential.

2.5.2 Conceptual Models

Using the data presented in this Remedial Investigation, an evaluation of potential pathways, mechanisms controlling potential migration from source areas along these pathways, and the effects of impacted groundwater on the American Canal and the Rio Grande was performed. The conceptual models are based on the data and information gathered during the first year of monitoring for the Remedial Investigation (August 1997 through May 1998). In many cases, only one data point (in the case of soil sampling) or one year of monitoring data exists for the parameters of interest. Also, in many cases historic events in source areas have not been documented. There may be other data, including processes that may contribute to the current distribution of parameters at the Plant, not addressed by the model.

The surface water receptors located downgradient from on-site source areas have been identified as the American Canal and the Rio Grande. Flow data for the American Canal and the Rio Grande indicate that these waters are regulated by upstream reservoirs. Flow in the American Canal and the Rio Grande is reduced annually from the second week in September to the third week in March. There is immeasurable flow from some of the weep holes along the American Canal for approximately one month after flow is shut off, but no measurable groundwater discharge occurs at any time during this period of the year based upon one year of field observations. In addition, groundwater elevations appear to be at or below the bottom of the canal during the low flow period (see Cross-Sections B-B', C-C', D-D' and E-E'; and Figures 2-28, 2-29, 2-30 and 2-31, respectively). During high flows in the American Canal, the water elevation in the canal is approximately eight feet above the bottom of the canal. The intersection of groundwater with the bottom of the American Canal occurs at monitor well EP-66 (May through October). The difference between groundwater and surface water elevations near the canal prevents any groundwater flow from entering the canal during high flows. Because there is no measured discharge of groundwater to the canal during low flows and a negative gradient between the groundwater and the canal during high flows, groundwater cannot impact the American Canal at the Plant. Consequently, the Rio Grande is the only potential surface water receptor of groundwater downgradient of the source areas at the Plant.

The methodology used to develop the conceptual models for the analytical fate and transport models involved several steps. Data gathered for this RI was reviewed along with historical data and anecdotal evidence of plant operations, practices and site uses to determine potential source areas. Arsenic was selected for modeling because of its pervasive nature at the site and its mobility. The next phase of the approach was to determine pathways from source areas to surface water receptors off site using potentiometric surface maps and water quality data from wells downgradient of source areas. Finally, arsenic loading analysis was performed to evaluate potential groundwater impacts to surface water receptors.

Based on the screening criteria listed above, two arsenic source areas were selected: the Acid Plant Area and Ponds 5 and 6. Conceptual models based on these source areas are discussed in the following sections.

2.5.2.1 Conceptual Model 1: Acid Plant Area (Acid Plant Mist Precipitator) to Rio Grande (SEP-10)

The first arsenic migration model pathway is from the Acid Plant Mist Precipitator Building westward towards the Rio Grande (Figure 2-42). Soil arsenic concentrations in the vicinity of the Acid Plant Mist Precipitator Building are some of the highest on the site and are greater than 5,000 mg/kg at many locations. The Acid Plant Mist Precipitator Building has been located at the Plant since approximately 1974. In 1995 there were two documented releases of acid water containing elevated concentrations of arsenic and other metals (Hydrometrics, 1997). Asarco personnel have estimated the volume of water released to be between 50 and 100 gallons. Based on this information, the arsenic concentration in this water is assumed to be elevated.

Arsenic in groundwater downgradient of the Acid Plant Mist Precipitator Building is likely derived from one or more sources of arsenic at this location via chemical transport mechanism. The first source of arsenic for this area is ambient soil, which in some locations is extremely high in arsenic. In addition to the arsenic in this acid water, the acid itself lowers the pH of the water in the unsaturated zone and mobilizes additional arsenic from the soil and slag. Accidental acid releases to the air can also influence transport if there is a connection between the ground surface and the unsaturated zone. The extent of this connection in the source area is not believed to be significant because most of the area is paved or is covered by buildings. However, there may be discrete conduits for migration consisting of cracks in pavement, uncovered topographic lows, unsealed stormwater drains, and leaking seals in and around building foundations.

Three downgradient wells from the source area that were used to calibrate the model: Wells EP-49, EP-58 and EP-64 (see Exhibit 1). One year (four sampling events) of chemical data

at these sites was used. It is unclear whether chemical concentrations are currently increasing or decreasing at the wells. Thus, data for these wells was averaged for the period of record and assumed to be increasing as a source input for the modeling effort. This creates the framework for a conservative model for the current contaminant conditions. Finally, the downgradient surface water receptor site is SEP-10, located on the Rio Grande (see Figure 2-3). This modeled area does not include arsenic concentrations from EP-62. EP-62 was excluded due to its increase in arsenic concentration rather than the general decrease in concentration from EP-49.

The initial starting conditions for Source Area 1 were gathered from the data collected for the Remedial Investigation. Aquifer characteristics are presented in Section 2.3. Source area and pathway geometry is taken from Figure 2-42, and arsenic loads were initially calculated from the source area concentrations at the nearest downgradient well. These calculations are presented in Appendix K. A summary of model parameters is in Table 2-18.

2.5.2.2 Conceptual Model 2: Ponds 5 & 6 to EP-66 to the American Canal (SEP-1) and Rio Grande (SEP-11)

The second source area used for this simulation extends from Pond 6 to Pond 5, then continues downgradient to the Rio Grande near SEP-11 (Figure 2-42). Ponds 5 and 6 have been in place since the 1910s; Pond 6 is located upgradient from Pond 5. Pond 5 has been used to store fresh water, and Pond 6 is part of the process water circuit. Water from Pond 6 is also being used for anode cooling. Average arsenic concentrations in these ponds from data collected for this remedial investigation are 0.11 mg/l for Pond 5 and 2.25 mg/l for Pond 6 (see Section 2.0). These concentrations are assumed to be conservative for the period of pond operation. Both ponds are unlined and are assumed to have communication with groundwater. The arsenic load from the ponds to groundwater was estimated from the arsenic concentrations in groundwater at wells immediately downgradient of the ponds.

Three downgradient wells (EM-5, EP-77, and EP-90) were used to calibrate this model. Data for these wells were averaged for the period of record and assumed to be increasing for initial

source input of the modeling effort. The potential downgradient surface water receptor used in the model is SEP-11, located on the Rio Grande just downgradient of the source area site (see Figure 2-42).

The initial conditions for conceptual model 2 were delineated from data collected for the Remedial Investigation. Aquifer characteristics are presented in Section 2.3; source area and migration pathway geometry is taken from Figure 2-42; and arsenic loads were initially calculated from the source area concentrations at the nearest downgradient well. These calculations are presented in Appendix K. A summary of these initial parameters is presented in Table 2-19.

2.5.3 Methods

Modeling was conducted using the computer program PLUME2D, Version 4.06. PLUME2D is an analytical model that simulates two-dimensional solute transport in a uniform flow field based on a solution of the general advection dispersion equation developed by Wilson and Miller (1978). Model documentation and supporting references are provided in Appendix K. Contaminant loading can be simulated in the model using up to twenty point sources. The model has provisions to account for geochemical retardation, dispersivity and decay. Model input parameters include average groundwater seepage velocity, aquifer thickness, porosity, longitudinal and lateral dispersivity, retardation factor, decay rate, and loading rates at individual point sources.

Initial conditions and generalized contaminant migration pathway geometry was set up in PLUME2D for each of the source areas of interest. These starting conditions were then adjusted so that the model estimated current conditions at the site.

The parameters needed to construct an analytical transport solution were either estimated from site data collected to support the remedial investigation or estimated from published tables of data from sites having similar characteristics during model calibration. All parameters used were conservatively selected.

Another program, PLUME, (based on analytical solution presented in Wilson and Miller, 1978) was used to remove the source loading to evaluate the effects of source control scenarios at the site. This model was first tested with the model calibration data from Source Area 1 to insure that it provided the same results as PLUME2D. It was then used to evaluate these scenarios (see Appendix K for comparison plots and output files). Source removal scenarios were evaluated at the time of maximum concentration at the downgradient surface water bodies. This analytical computer model estimated the time of migration from point source to the Rio Grande. A model was also performed to estimate the distribution of arsenic from the point source area to the surface water location. All model output files, calibration plots and future scenarios are presented in Appendix K.

Some sensitivity analysis was conducted to evaluate the effect of parameter uncertainty on the model predictions. When varied individually, model results were found to be most sensitive to the retardation factor and source terms. In general, increases in retardation require a corresponding increase in the loading rate in order to produce a reasonable agreement with present arsenic concentrations in groundwater. Increasing the retardation coefficient results in longer arrival times at downgradient surface water receptors and reduces peak arsenic concentrations. With increasing retardation factors, geochemical fixation can become a significant factor on predicted arsenic concentrations due to the large travel times.

2.5.4 Assumptions

The assumptions required by the model code to estimate this analytical model (for horizontal integration) are:

- The porous medium is homogeneous and isotropic with respect to its hydraulic and transport characteristics.
- The aquifer is infinite in areal extent.
- One-dimensional steady state uniform regional flow in x-direction (i.e., groundwater recharge rates and discharge from pollution source do not influence flow field).

- Pollutants are distributed instantaneously over the entire aquifer thickness beneath the source.
- Injection rate is continuous and constant (may be modified by superposition).
- Fluid density and viscosity of the source and the aquifer are identical and constant in time and space.
- There is no solute advection or dispersion across lateral boundaries (e.g., into or out of confining layers).

In addition to these model assumptions, it was assumed that current source area concentrations and loads are greater than or equal to historic values. This assumption produces a conservative or worst case scenario model by assuming that concentrations are increasing over time (versus being at steady state or decreasing). In addition, decay was not used in these models because there is no physical decay of arsenic. There may be, however, attenuation and precipitation of arsenic compounds as the water chemistry along the flowpaths changes. The effects of these processes on arsenic mobility at the Plant were not taken into account in these models.

The model predictions assume that 100 percent of the arsenic in source area soils will eventually reach the Rio Grande. This happens because the geochemical attenuation in the aquifer is assumed to be 100 percent reversible (i.e., arsenic is only retarded, not removed from the system). Actual arsenic loading to the Rio Grande would be lower than these model predictions, however, since only a fraction of the total arsenic in source area soils is potentially leachable. Attenuation of arsenic in soils or aquifer material would result in a proportional decrease in predicted arsenic loads at the Rio Grande.

Finally, these migration pathways were modeled with the assumption that there were only single discrete sources. There may be additional sources along these flowpaths, however, due to all of the human activity and the infrastructure at the Plant, as well as broad distribution of arsenic in soils over the Plant.

2.5.5 Calibration Results

The models were calibrated using conservative adjustments in source loading rate and source geometry. Aquifer characteristics and porosity were not adjusted from values measured in the field. The retardation factor was initially calculated from a partition coefficient (K_d) median of soil versus groundwater arsenic concentrations (10 l/kg, Table K-2 in Appendix K). There are very few areas where soil samples were collected below the water table and, with the exception of Monitor Well EP-77, none of these samples is located in areas that were modeled. The large initial retardation factor did not allow for arsenic to migrate in high enough concentrations for the limited period of time that correlates with historic source data. Subsequently, the partition coefficient was reduced to the minimum value of about 4 l/kg, reducing the retardation factor by approximately one half. Other parameters were more conservative in order to calibrate the models to observed data.

Model calibration appears to be very sensitive to the location and load applied at point sources. Model calibration may be feasible at higher retardation factors or lower source loads if the source area is shifted downgradient. Further refinement of model parameters would require additional source area verification. The sensitivity of model predictions to the uncertainty of input parameters was previously discussed in Section 2.5.3.

Dispersion coefficients that are not aquifer constants are a function of the heterogeneity of the aquifer, stratification, fractures or joints, or other nonuniform characteristics along flowpaths. The term that combines these effects on the transport of molecules over distance with time is dispersivity (D). Because the factors that cause dispersion are more pronounced over greater distances, the value of dispersivity increases with the distance that the molecule travels; hence, it is scale-dependent. The relatively high values for dispersivity create a larger, but less concentrated plume, which generally corresponds to what is understood about arsenic at the Plant Site (assuming limited, concentrated source areas rather than diffuse source regions). Other variations to the initial model input parameters are discussed individually in the respective model sections.

2.5.5.1 Conceptual Model 1

The analytical model for Source Area 1 was developed from the initial input parameters that were refined to approximate current conditions at the site. In order to allow the model to estimate current arsenic conditions, the source loading rate was quadrupled from the initial value of two pounds per day to eight pounds per day. The source area geometry was modified slightly from four inputs to two, and the dispersivities established for this model were used for the entire Plant area. The calibration parameters are presented in Table 2-20.

2.5.5.2 Conceptual Model 2

The model calibration consisted of adjusting the source loading rate at Pond 6 two hundred percent and increasing the apparent loading due to Pond 5 by two orders of magnitude. Dispersivity values remained constant. The calibration parameters are presented in Table 2-21.

2.5.6 Water Chemistry along Pathways

Average concentrations of selected water quality parameters are shown in Table 2-22 for groundwater in the areas upgradient, within, and downgradient of presumed source areas on the Plant. Also shown in Table 2-22 are average concentrations for Ponds 5 and 6. Major ion compositions of the sites shown in Table 2-22 are summarized on the Piper diagrams for Source Areas 1 and 2 (Figure 2-43).

2.5.6.1 Source Area 1

Water quality upgradient of the Acid Plant Mist Precipitator source area (well EP-21) is characterized by a slightly basic pH, low concentrations of arsenic, iron and other metals, and a major ion chemistry dominated by sodium and bicarbonate. As groundwater moves into the region near the Acid Plant Mist Precipitator, both pH and bicarbonate concentrations decrease, while metals and arsenic concentrations increase. The addition of calcium and sulfate to groundwater is also apparent. Downgradient of the Acid Plant Area, arsenic, iron, and other metal concentrations decrease rapidly to concentrations similar to the upgradient

values (Figure 2-44). Bicarbonate and sodium concentrations increase, while other major ion concentrations (i.e., sulfate, chloride, calcium) remain similar to concentrations observed near the Acid Plant. Water quality trends with distance upgradient and downgradient of Source Area 1 are shown in Figure 2-44.

The water chemistry data suggest a significant influx of acidic, metals- and arsenic-bearing water in the region near the Acid Plant Mist Precipitator, causing a decrease in pH, a decrease in bicarbonate as alkalinity in groundwater is consumed by added acids, and an increase in metals and sulfate concentrations. Calcium concentrations also increase, perhaps as a result of acid-related dissolution of calcite cements within the aquifer matrix. As groundwater continues downgradient, pH increases, as does bicarbonate concentration. This neutralization process may have several sources:

1) Sodium carbonate (soda ash) is used to neutralize acids in the Acid Plant process loop; residual amounts of this substance could be introduced to groundwater through spills or interaction of precipitation with sodium carbonate in area soils.

2) Further dissolution of carbonate minerals in the subsurface.

As pH increases, metals become less soluble and rapidly precipitate out or adsorb to aquifer materials. The coincident decrease of iron and arsenic concentrations suggests that, as iron oxides and hydroxides precipitate, they coprecipitate or adsorb arsenic, thereby removing arsenic from solution and resulting in a pronounced decrease in arsenic concentrations downgradient of the source area. Average arsenic concentrations decreased from 315 mg/l at EP-49 to 3.7 mg/l at EP-58, about 300 feet downgradient. Similarly, iron concentrations decreased from 1,907 mg/l to 1.37 mg/l. Both parameters continue to decrease farther downgradient.

Adsorption/coprecipitation with ferric oxides and hydroxides has been observed to be an effective removal mechanism for arsenic in many subsurface environments. Data suggest that this process is occurring downgradient of the Acid Plant Mist Precipitator source area,

mitigating the migration of arsenic. However, the process of geochemical removal from groundwater is difficult to model successfully in groundwater transport models; the groundwater model used for Source Area 1 does not include a factor to account for irreversible removal of arsenic from groundwater (modeled as decay). Thus, the model assumptions are conservative, as some arsenic load may be unavailable to groundwater after removal as a ferric hydroxide coprecipitate.

2.5.6.2 Source Area 2

Water quality upgradient of Ponds 5 and 6 is dominated by sodium and sulfate, with low but detectable concentrations of iron, arsenic and zinc. Groundwater pH in this region is basic (average of 8.03 at well EP-88). As water moves downgradient, past Ponds 5 and 6, pH decreases slightly to 7.31 at EP-90, and arsenic concentrations increase near Pond 6 (1.65 mg/l at EM-5), and increase again near Pond 5 (5.68 mg/l at EP-77), before decreasing downgradient at EP-90 (0.167 mg/l). The major ion chemistry of upgradient and downgradient groundwater, as well as pond water, is somewhat similar (Figure 2-43), and the influence of pond water on groundwater is apparent: Pond 6 water quality resembles that in well EM-5 very closely; well EP-77 water quality is intermediate between Ponds 6 and 5; and well EP-90 water quality resembles that of Pond 5 closely.

Groundwater chemistry in the Source Area 2 flowpath differs from that in Source Area 1 in that no highly acidic inputs are apparent; pH remains relatively constant, although it decreases slightly from upgradient to downgradient. Water quality trends along the flowpath are shown on Figure 2-45. Sodium concentrations consistently decrease, perhaps reflecting inputs from pond water, which appears to be more dilute than groundwater. Water sources for Pond 5 historically have been city drinking water, while Pond 6 is process water, primarily from the Anode Cooling Area. Arsenic and iron concentrations show a similar relationship to that observed in Source Area 1, although concentrations are much lower in Source Area 2. Both parameters increase near source areas, then decrease downgradient. Therefore, similar attenuation mechanisms may be responsible for arsenic removal along this flowpath (i.e., coprecipitation with or adsorption on iron oxides/hydroxides). However, the

process may be slightly less efficient due to the lower concentrations of iron, and the lack of a marked change in pH to promote rapid precipitation of iron. In Source Area 1, arsenic concentrations decrease about two orders of magnitude over a distance of about 300 feet (EP-49 to EP-58). In Source Area 2, arsenic concentrations decrease about 30 times over a distance of 500 feet (EP-77 to EP-90). Nevertheless, this amounts to a 97 percent decrease in arsenic downgradient of Source Area 2.

The presence of higher average arsenic concentrations in groundwater in Source Area 2 relative to the presumed sources (Ponds 5 and 6) suggests. The pond water is the primary source of arsenic to groundwater, and concentrations in the ponds vary over a wider range than observed during the Remedial Investigation data collection period. Pond sediments or contaminated soils beneath or around the ponds may contribute arsenic to groundwater through infiltration of leaking pond water or precipitation.

2.5.7 Future Scenarios

After the models were calibrated to current conditions at each site, they were rerun using the time when the maximum concentration would reach the Rio Grande. Time varied from 280 years for Source Area 1 to 540 years for Source Area 2. Concentrations and loads in groundwater due to these two sources were then calculated, as well as the respective concentrations and loading in the Rio Grande from the two source areas. The resultant concentrations and loads in the Rio Grande were then compared to the condition if no action were taken to mitigate the effects of the source area loading. The results are discussed below and summarized in Table 2-22.

2.5.7.1 Source Area 1

The conservative groundwater fate and transport model predicts a maximum concentration of 7 mg/l at the Rio Grande from Source Area 1 based upon a release in 1980 and 280 years of contaminant migration, corresponding to a calendar date of 2260. The calculated concentrations over the length of the migration pathway and the resultant load at this date are presented in Table 2-23. Arsenic concentrations of 0.019 mg/l and load of 0.146 kg/day are

estimated in the Rio Grande if sources are controlled, and arsenic concentrations and load of 0.087 mg/l and 0.678 kg/day, respectively, are estimated without source control. Calculations for these values are presented in Appendix K. Concentrations and loads are approximately three times higher than current concentrations and loads in the Rio Grande. If there is no source mitigation, the model predicts concentrations and loads in the Rio Grande about 15 times higher than current conditions after 280 years.

2.5.7.2 Source Area 2

Source Area 2 modeling predicts a maximum concentration of 0.44 mg/l based upon a release in 1930 and 540 years of source loading. This arrival time corresponds to a date of 2470. The calculated concentrations over the length of the migration pathway and the resultant load at this date are presented in table 2-23. Arsenic concentrations of 0.0066 mg/l and a load of 0.052 kg/day are estimated if the source is controlled, and arsenic concentrations and loads of 0.0075 mg/l and 0.058 kg/day, respectively, are estimated if there is no source control. Calculations are presented in Appendix K. These values increase the arsenic concentration and load by approximately 10 percent. These values would be about 25 percent higher with no source remediation.

2.5.8 Sensitivity Considerations

The aforementioned results show that, for the conservative nature of the modeling assumptions, there may be a quantifiable impact on the Rio Grande from the area surrounding the Acid Plant Mist Precipitator Building. This conclusion must be qualified, however, considering the amount and type of available data and the present understanding of the water chemistry along the groundwater pathway from these sources. Foremost, it is important to consider the limited information on arsenic migration at this site. The conclusions are based on only one year's worth of data, which simply provide a "snapshot" of arsenic concentrations in time; available data are inadequate to determine whether these concentrations are at steady state, are decreasing over time or increasing over time. The analytical model results were very conservative by design and, consequently, predict impacts on the Rio Grande.

When the water chemistry data along the described pathways are taken into account, it is apparent that several of the assumptions used to calibrate the model are overstated. For example, the data indicate that arsenic mobility from Source Area 1 is greatly affected by the change in pH or the neutralization of groundwater and the accompanying precipitation of ferric oxides downgradient from the source. The efficient removal of arsenic from groundwater along the pathway from Source Area 1 through adsorption and/or coprecipitation with iron oxides is not taken into account in the model. Therefore, the analytical model for the source area does not accurately reflect the behavior of arsenic along this pathway and may overestimate any surface water impacts.

The water chemistry along the pathway from Source Area 2 is slightly different. There appears to be some attenuation of arsenic in groundwater by aquifer materials and/or iron precipitation, but not to the extent observed for Source Area 1. Concentrations of iron and arsenic in Source Area 2 are much lower than in Source Area 1. However, the model suggests that, given a relatively low concentration but continuous source of metals to groundwater from the ponds or adjacent soils, there is potential for future impacts to surface water from Source Area 2.

3.0 RELATIONSHIP BETWEEN SMELTER OPERATIONS AND POTENTIAL SOURCE AREAS AND MATERIALS

This section of the report provides an expanded description of materials associated with Investigation Areas and other potential source areas identified as a result of the remedial investigation. Current smelter operations, historical records, site reconnaissance, soil and groundwater analytical data were evaluated to characterize potential source areas and materials, to identify release mechanisms, and to better understand the transport and exposure pathways associated with these materials. Information presented in this section of the report provides the basis for developing Corrective Action Objectives, Corrective Action Alternatives and Corrective Action Measures presented in Section 4.0.

Materials associated with potential source areas are separated into three source material categories based on metal concentrations, distribution and volume of materials, visual characteristics, impacts to water resources, and degree of potential toxicity. A material category scheme is useful in the evaluation of Corrective Action Measures used to remediate source areas. Source area materials are defined as Category I, Category II, or Category III as follows:

Category I: Category I materials are residual by-products typically associated with specific current and past smelter operations. Based on the results of the remedial investigation, Category I materials are associated with distinctly elevated concentrations of metals in underlying groundwater. Category I materials include but are not limited to the following:

- Sulfuric acid.
- Acid Plant Scrubber Water/Solids (from leaks, etc.).
- Acid Plant Water Treatment Plant Filter Cake.
- Liquid leakage from process gas flues going to the Acid Plants.
- Leachate from sulfuric acid reacting with slag fill material.

- Cottrell dust (Reverb, Roaster, Converter, ConTop, Sinter Plant).
- Spray Chamber Dusts (Reverb, Roaster, Converter, ConTop).
- Converter Building Ventilation Baghouse Dust.
- Baghouse and other dusts from former Lead Plant and Sinter Plant Operations.
- Feed Materials including lead and copper concentrates, East Helena speiss and matte.
- Fines in Slag Storage Area.

Category II: Category II materials are large volumes of diluted residual by-products (most of the same materials listed for Category I). Category II materials also include smelter debris such as brick, flues and other materials from demolition of smelter facilities taken out of commission in the past which have residual concentrations of metals. Category II materials generally have lower concentrations of metals than Category I materials. Based on the results of the remedial investigation, Category II materials do not currently represent a source of metals to the underlying groundwater, but could become a potential source in the future if conditions on the surface are not properly managed.

Category III: Category III materials are copper slag and fumed lead slag.

Areas and volumes of source materials subject to corrective action measures are discussed and delineated in Section 4 of this report.

3.1 CONVERTER BUILDING/BAGHOUSE AREA (INVESTIGATION AREA 1)

3.1.1 Background/Operations

Investigation Area 1 is south of the Acid Plant Mist Precipitator Building and west of the Converter Building Ventilation Baghouse (Figure 3-1). Investigation Area 1 includes Medford Sump, which is used to control storm/process water from the Acid Plant and the Converter Building Ventilation Baghouse area. Investigation Area 1 was identified by the TNRCC as an area of concern because, at the time of the 1994 and 1995 multimedia

inspection and sampling event, spent spray chamber saddles were stored in this area, and samples of the saddles contained elevated concentrations of metals (TNRCC, 1996).

3.1.2 Soil

A total of 20 soil samples were collected from Investigation Area 1, from five borehole locations (Figure 3-1). Soil sample analysis results for Investigation Area 1 are summarized in Table 3-1.

Arsenic and lead appear to be the primary constituents of concern, with the highest concentrations occurring in samples collected from borehole SSIA1-1 south of the Acid Plant (Investigation Area 3) and from borehole SSIA1-2, near Medford Sump. Arsenic levels at these two locations range from 2,600 mg/kg to 22,000 mg/kg. At the deepest interval (4 to 5 feet), the concentrations are 2,600 mg/kg (SSIA1-1) and 22,000 mg/kg (SSIA1-2). Composition of the four- to five-foot interval sample is slag for SSIA1-1 and soil for SSIA1-2. Lead concentrations for the samples range from 15 mg/kg (SSIA1-1) to 20,000 mg/kg (SSIA1-2). At the deepest interval (4 to 5 feet), lead concentrations are 4,000 mg/kg (SSIA1-1) and 20,000 mg/kg (SSIA1-2). Metal concentrations are generally elevated throughout the soil profile in Investigation Area 1.

Sample location SSIA1-2 is within the basin area for the sump pump station, which is referred to as Medford Sump. Medford Sump accumulates by-products of the smelter operations, including released Acid Plant scrubber water, liquid leakage from process gas flues, sulfuric acid, leachate from low pH waters interacting with slag, Cottrell dust and concentrates from the converters. Soil in the area of the Medford Sump contains the highest concentrations of metals observed for the entire investigation, which is attributed to the accumulation and percolation of stormwater and/or process water. Borings immediately outside the Medford Sump area have lower metal concentrations in the first five feet.

3.1.3 Groundwater

Groundwater samples collected from Investigation Area 1 were collected from monitor wells EP-51 and EP-52 (Figure 3-1). A summary of groundwater monitoring results (averaged over four monitoring events) for Investigation Area 1 is in Table 3-2.

Monitor well EP-51 is south of Medford Sump. Monitor well EP-52 is near the cooling towers northeast of Medford Sump. The MCLs for arsenic, cadmium and selenium are exceeded in these monitor wells. The action level for lead is exceeded in EP-52. For EP-51, average arsenic, cadmium, lead and selenium concentrations are 2.17 mg/l, 0.89 mg/l, 0.003 mg/l and 0.17 mg/l, respectively. For EP-52, arsenic, cadmium, lead, and selenium concentration are 1.29 mg/l, 0.68 mg/l, 0.044 mg/l and 0.33 mg/l, respectively. Groundwater flows from east to west across this area.

The primary hydrogeologic feature of Investigation Area 1 is a slag and soil backfilled arroyo. The arroyo is approximately 200 feet long, 200 feet wide, and 60 feet deep. The arroyo is documented in topographic maps from 1891 (Figure 2-3). There are numerous arroyos on the Plant that historically have been backfilled to create new surface area for plant operations. The arroyos appear to channel and control unsaturated and to some extent, saturated groundwater flow beneath the Plant. Relatively higher concentrations of metals in groundwater also appear to be associated with the arroyos.

In terms of elevation, Medford Sump is the lowest feature in Investigation Area 1. As previously discussed, Medford Sump is an accumulator of by-products of current smelter operations; these by-products are considered to be a source of metals to groundwater associated with the uncontrolled release of acids. The Medford Sump area has been slated for upgrades in conjunction with plant-wide stormwater control improvements. As will be discussed in Section 4, these improvements, in combination with source material removal, will eliminate or reduce the potential for metals to migrate to the groundwater.

3.1.4 Summary

The Medford Sump area soils have been impacted by releases of Acid Plant scrubber water, liquid leakage from process gas flues interacting with slag, Cottrell dust and concentrates from the converters that accumulate in Medford Sump. Medford Sump, which is the lowest point in the investigation area, is constructed over a slag-backfilled arroyo and may be subject to leaks. Therefore, Medford Sump and associated basin soils appear to be a source of metals to the groundwater. Based on results and observations discussion in this section, soils in the Medford Sump basin area are classified as Category I materials.

3.2 BONEYARD (INVESTIGATION AREA 2)

3.2.1 Background/Operations

Investigation Area 2 is a boneyard (heavy equipment storage yard) in a slag pile storage area near Slag Road and the current slag-dumping area (Figure 3-2). During the 1994 and 1995 multimedia inspection and sampling event, the TNRCC was concerned about the type of material stored in the Boneyard, which at the time included drums of mixed materials, mist eliminator candles, saddles, fiberglass reinforced flues, plastic saddles and other miscellaneous equipment. The TNRCC was concerned that materials underlying the Boneyard, thought to consist of native soil, might be impacted by the stored items. Since the 1994 and 1995 multimedia inspection and sampling event, the plant has only a few pieces of heavy machinery components at the site. By October 1995, all materials stored in the Boneyard during the 1994 and 1995 TNRCC sampling events have been removed from the Boneyard.

Historically, a layer of soil material was placed in the area of the Boneyard to provide a suitable surface for the heavy equipment storage. As a result of the remedial investigation, the soil cover was determined to be approximately 1.5 feet thick, overlying lead slag to a depth of 35 to 45 feet bgs.

Investigation Area 2 has been separated into two sub-areas (Figure 3-2). Sub-area 1 includes the actual Boneyard area. Sub-area 2 is a larger area utilized for the storage of slag. Sub-area

2 includes an area east of Interstate Highway 10 underneath the train trestles near the intersection of Executive Center Drive and Paisano Drive. Sub-area 2 is also the site of a slag-crushing/recycling operations (Parker Brothers).

3.2.2 Sub-area 1 Soil

Sub-area 1 soils are characterized by one five-foot soil boring and two monitor wells (Figure 3-2). In accordance with the Remedial Investigation Work Plan, only soil samples were collected from monitor well boreholes beginning at depths of 35 and 45 feet, respectively, a function of the thickness of the slag, which was logged but not sampled. For near-surface samples (i.e., 0 to 1.5 feet), arsenic and lead concentrations were 400 mg/kg and 1,500 mg/kg, respectively. Samples collected from the 1.5- to 2.5-foot interval had 1,200 mg/kg for arsenic and 180 mg/kg lead (Appendix C, Table C-3).

Soil samples collected from monitor well boreholes EP-75 and EP-76 at depths of 35 and 45 feet bgs in Sub-area 1 of Investigation Area 1 had arsenic concentrations which ranged from 220 mg/kg to 1,800 mg/kg and lead concentrations which ranged from 28 mg/kg to 490 mg/kg (Appendix C, Table C-10). The pH for these samples ranged from 8.6 to 9.7, higher than most samples collected from other areas of the plant.

The primary source material associated with Sub-area 2 is probably sludge from the Acid Plants, which may have historically been stored in this area. The higher pH observed may be attributed to the use of limerock (54% CaO) to neutralize the acid plant sludge during storage. The remaining material was gathered and reclaimed as smelter feed material. The higher pH values could mobilize arsenic. An expanded soil investigation of this area will be required, to ascertain the extent of metals and the specific nature and origin of source materials.

3.2.3 Sub-area 1 Groundwater

Groundwater in Sub-area 1 of Investigation Area 2 is characterized by monitor wells EP-53, EP-75 and EP-76 (Figure 3-2). Groundwater sample analysis results (averaged over four monitor events) for Investigation Area 2, Sub-area 1 are in Table 3-3.

Groundwater is encountered at approximately 55 feet below the top of monitor well casings. Arsenic and selenium are the primary constituents of concern for this area. Arsenic concentrations were highest in EP-53 and lower in upgradient wells (EP-75 and EP-76). Groundwater pH in these monitor wells averaged 7.1 for EP-53, 7.3 for EP-75, and 7.5 for EP-76.

The Boneyard overlies a slag-backfilled arroyo. The arroyo, which drains to the Parker Brothers slag-crushing/recycling operations area, then to the Rio Grande, is referred to as the Parker Brothers Arroyo (Figure 2-3). Groundwater flow direction is from east to west. As discussed for Sub-area 1 Soil, Acid Plant liquids and solids, may be the primary sources of arsenic and selenium in groundwater.

3.2.4 Sub-area 2 Soil

Sub-area 2 encompasses the arroyo discussed above, portions of which have been backfilled with slag and plant demolition debris. In addition, Sub-area 2 of Investigation Area 1 includes a slag-crushing/recycling operations (Parker Brothers). Union Pacific and Burlington Northern Santa Fe Railroads maintain rail lines through the eastern portion of Sub-area 2. These rail lines form the western boundary of Investigation Area 2. A catch basin or closed depression created by the railroad grade in the slag storage area, ponds water at times. The closed depression accumulates slag fines and residues from other types of plant debris, such as brick, conveyor belts, and wood, which were observed at the edge of the closed depression. The closed depression may be a recharge zone and may accumulate source materials that could contribute metals to the groundwater associated with the underlying backfilled arroyo.

As part of the remedial investigation, Sub-area 2 of Investigation Area 2 included five monitor wells, six soil borings to groundwater, one surface water sample, and one surface soil sample. Sample collection sites for Sub-area 2 of Investigation Area 2 (Figure 3-2) include the following:

Monitor Well Borehole Samples:	EP-78, EP-79, EP-81, EP-83 and EP-85
Soil Borings:	RIBH-1, RIBH-2, RIBH-3, RIBH-4, RIBH-5 and RIBH-6
Surface Water Location:	SEP-14 (closed depression) not sampled to date
Surface Soil Sample:	SSIA2-2 (surface sample of EP-78)

As in the case of Sub-area 1, soil samples collected from soil borings and monitor well boreholes were collected from depth intervals at which slag was not encountered. With the exception of SSIA2-2, all borings were advanced to groundwater. A summary of borehole sample analysis results (arithmetic mean averaged over all intervals from a given borehole) for Sub-area 2, Investigation Area 2 is in Table 3-4.

Groundwater was encountered at 2 feet bgs and at approximately 0.5 feet below the slag. For all borehole samples, arsenic and lead concentrations decreased to lower levels within 10 feet of the bottom of the slag. The exceptions are samples collected from EP-79 in which arsenic and lead concentrations were highest in the sample collected at 25 feet bgs. This may be attributed to the historical addition of fill material containing elevated concentrations of metals at this level, which was covered with slag in subsequent years.

3.2.5 Sub-area 2 Groundwater

Groundwater in Sub-area 2 of Investigation Area 2 appears to be influenced by an arroyo as previously described and characterized by monitor wells EP-78, EP-79, EP-81, EP-83, and EP-85 (Figure 3-2). The arroyo trends upgradient from EP-80 and EP-81 to EP-78. The arroyo underlying Sub-area 2 spurs, with one branch toward the north and one toward the south. The groundwater flow direction is from east to west. A summary of groundwater sample analysis results (averaged over four monitoring events) collected from designated monitor wells within Sub-area 2 is in Table 3-5.

The MCL for arsenic is exceeded in groundwater and concentrations range from 0.007 mg/l to 5.85 mg/l. Arsenic is the primary constituent of concern for Investigation Area 2, Sub-area 2. The arsenic concentration gradient characterized by monitor wells in Sub-area 2 suggests that the source of arsenic in groundwater is downgradient from EP-83 (EP-83 is the most upgradient well in the Investigation Area). The highest concentration of arsenic in groundwater is in monitor well EP-78 (5.8 mg/l), which is downgradient of the closed depression (SEP-14), and decreases in downgradient wells. Water samples from the closed depression were not collected during the remedial investigation because it was dry. Removal of sediments that may have accumulated in the closed depression, elimination of the closed depression, and re-establishment of proper drainage in Sub-area 2 would probably eliminate or greatly reduce the potential for metals migration to groundwater.

3.2.6 Summary

The historic storage of Acid Plant solids and liquids in this area may represent a potential source of metals to groundwater. Due to elevated concentrations of arsenic and selenium observed in groundwater underlying this area, any source materials encountered would be characterized as Category I. With the exception of sediments in the closed depression in the slag storage area (Sub-area 2), and stormwater (which collects there at times), copper slag is the predominant material and does not in itself represent a source of metals to the groundwater. Therefore, the slag storage area materials would be classified as Category III

material. Sediments from the closed depression would probably be classified as Category I, although additional sampling would be required to verify this.

3.3 ACID PLANT 1 AND 2 (INVESTIGATION AREA 3)

3.3.1 Background/Operations

Investigation Area 3 includes Acid Plants 1 and 2, which are in the northwestern portion of the Plant property (Figure 3-3). The Acid Plants are used to remove sulfur dioxide from gases generated during the copper smelting process, producing sulfuric acid as a by-product. The sulfuric acid is cooled and transported via pipeline to the Bulk Acid Storage Area. Historically, there have been periodic releases of liquids from process gas flues, sulfuric acid, scrubber water from the Acid Plants in Investigation Area 3. These fluids have a very low pH, which reacts with the underlying soil and slag materials. The resulting leachate may be high in soluble metals, which can migrate to the groundwater.

3.3.2 Soil

Investigation Area 3 soils are characterized by samples collected from 11 soil borings (Figure 3-3) to a total depth of five feet. One of the boreholes (EP-73) was extended to 78 feet bgs and was converted to a monitor well. One soil borehole was limited to a depth of three feet due to auger refusal upon contact with slag. Soil sample analysis results for Investigation Area 3 are summarized in Table 3-6.

Arsenic and lead are the primary constituents of concern in soil for this Investigation Area. Generally, concentrations of metals decrease with depth (also see depth-versus-concentration graphs in Appendix D). Arsenic concentrations in surface samples (0 - 2 inches) ranged from nondetectable to 7,800 mg/kg, and lead values ranged from 220 mg/kg to 19,000 mg/kg, averaged over all samples. At the maximum depth interval (4 - 5 feet bgs), arsenic concentrations ranged from nondetectable to 1,400 mg/kg in soil with a maximum concentration of 3,500 mg/kg in slag. Lead concentrations ranged from 45 mg/kg to 1,800 mg/kg in soil, with a maximum value of 20,000 mg/kg in slag. The pH of soil borehole samples ranged from 6.5 to 10.

Borehole samples were collected from EP-73, beginning at a depth of 15 feet bgs. Above this depth, slag was logged, but not sampled. The maximum concentration of arsenic in borehole samples from EP-73 was at 35 feet bgs and was near background (24 mg/kg). Lead concentrations in borehole samples from EP-73 ranged from a maximum of 2,400 mg/kg at 20 feet bgs to nondetectable at 78 feet bgs.

3.3.3 Groundwater

Groundwater in the vicinity of the Acid Plants is characterized by monitor wells EP-25, EP-49, EP-52, EP-54, EP-55 and EP-73. Groundwater sample analysis results for these wells (averaged over four quarterly monitoring events) are summarized in Table 3-7.

Groundwater flow direction in Investigation Area 3, from east to west, appears to be influenced by an arroyo originating there. The arroyo, which is referred to as the Acid Plant Arroyo (see Figure 2-3), is backfilled with slag, plant debris, and soil; it is also part of the Diesel No. 2 Remediation Site. The highest concentration of arsenic in groundwater for the entire Plant (315 mg/l) is in samples collected from monitor well EP-49. Monitor well EP-49 is completed at the headwaters of the arroyo, a feature that appears to influence the accumulation of metals.

3.3.4 Summary

The periodic release of low pH/high metal fluids associated with the gas cleaning sections and sulfuric acid from the Acid Plants, and the reaction of these fluids with underlying soil and slag materials and subsequent leaching, has resulted in elevated concentrations of metals, particularly arsenic, in groundwater below Investigation Area 3. These fluids, as well as some localized areas of soil having elevated concentrations of metals in and around the acid processing facilities, are classified as Category I materials.

3.4 FRONT SLOPE/WESTERN PLANT BOUNDARY (INVESTIGATION AREA 4)

3.4.1 Background/Operations

Investigation Area 4 includes the western boundary of the Plant and is referred to as the Front Slope (Figure 3-4). The Front Slope is composed mostly of poured slag, which forms a relatively steep slope between smelter facilities and Paisano Drive. At the base of the slope is a long flat area, which is the easement for the Burlington Northern & Santa Fe Railway. This area tends to accumulate stormwater runoff from the Plant and releases of smelting process by-products from above.

Based on the results of the remedial investigation, there are five distinct areas within Investigation Area 4 that may represent sources of metals to groundwater (see Figure 3-5):

- Downslope of the Acid Plants
- Downslope of Medford Sump
- Downslope of the Closed Lead Plant Baghouse
- Downslope of the Sinter Plant Gas Cleaning and Sample Mill
- Downslope of the South Terrace

3.4.2 Soil Downslope of the Acid Plants

This area is downslope of Investigation Area 3. On two occasions in 1995, there were releases of acid plant scrubber water. The scrubber water release percolated downward, surfaced at the base of the slope and ponded at the easement. A soil investigation was conducted in July 1996 to evaluate the extent of affected materials. The results of this investigation are reported here. Soil sample locations are shown in Figure 3-4. Analytical results for soil samples collected as part of the acid spill investigation are summarized in Table 3-8.

During the scrubber water spill investigation, the depth to groundwater along the easement was found to be approximately 10 to 13 feet bgs, and it was presumed that the ponded water

could have migrated to the water table. Concentrations of metals and sulfate generally decreased from the surface to the groundwater level. The highest concentrations of arsenic (the primary constituent of concern) were in the surface five feet and ranged from 28 mg/kg to 2,920 mg/kg. Arsenic concentrations in samples collected at the groundwater level (11 to 13 feet bgs) ranged from nondetectable to 585 mg/kg.

3.4.3 Soil Downslope of Medford Sump

This area is downslope and southwest of the Acid Plant Mist Precipitator Building and downslope and west of the Converter Building Ventilation Baghouse (Figure 3-4). The area is also downslope of Medford Sump in Investigation Area 1.

As part of the remedial investigation, soils downslope of Medford Sump were characterized by soil samples collected from boreholes SSIA4-1, SSIA4-2, SSIA4-3 and SSIA4-4 (Figure 3-4). Soil analysis results from downslope of Medford Sump in Table 3-9.

As described in Section 3.1, the highest concentrations of metals for the Plant are from the Medford Sump area. Arsenic and lead concentrations in soils below Medford Sump are higher in the surface and tend to decrease (relative to surface concentrations) at depth (Appendix D). Elevated concentrations of metals in soils downslope of Medford Sump are attributed to releases and accumulations of smelter by-products such as liquids from process gas flues, scrubber water and acid/slag leachate, and Cottrell dust.

3.4.4 Soil Downslope of Lead Plant

Investigation Area 4 is downslope of the lead plant and, more specifically, the lead plant baghouse. In 1978, an accidental release of flue dust occurred when a newly installed flue collapsed. The flue, which had filled with flue dust and moisture, failed due to excessive weight. The flue fell onto the rail lines and portions of Paisano Drive. Flue dust in the form of mud accumulated in the area of Investigation Area 4, characterized by soil borings SSIA4-7, SSIA4-8, SSIA4-9, SSIA4-10 and SSIA4-11 (Figure 3-4). The results of soil analyses of samples from these borings (averaged over all borings) are summarized in Table 3-10.

Maximum arsenic, cadmium, and lead concentrations in surface soils downslope of the Lead Plant are 17,000 mg/kg, 980 mg/kg, and 49,000 mg/kg, respectively. Arsenic and metal concentrations generally decrease with depth (Appendix D). Lead plant flue and baghouse dust is probably the primary source material in soil downslope of the lead plant.

3.4.5 Soil Downslope of Sinter Gas Cleaning and Sample Mill

Investigation Area 4 is northwest and downslope of the Sample Mill Area. North of the Sample Mill is an ore-processing area for historic lead operations. Soils downslope of the Sample Mill are characterized by soil borings SSIA4-12, SSIA4-13, SSIA4-14, SSIA4-15 and SSIA4-16 (Figure 3-4). The results of soil analyses of samples from these borings are in Table 3-11.

Arsenic concentrations in surface soil samples ranged from 480 mg/kg to 4,800 mg/kg, and lead concentrations ranged from 5,900 mg/kg to 14,000 mg/kg. At depth (4 to 5 feet bgs), arsenic concentrations ranged from nondetectable to 110 mg/kg, and lead concentrations ranged from 18 mg/kg to 3,200 mg/kg. Concentrates and dust transported in stormwater and historic deposition of fugitive dust from the Plant are the probable source materials in soil downslope of the Sample Mill.

3.4.6 Groundwater Downslope of Sinter Plant Gas Cleaning and Sample Mill

There were no monitor wells installed specifically to characterize groundwater for the area downslope of the Sample Mill. However, upgradient well EP-13 and nearby well EP-29 (Figure 3-4) were used to characterize groundwater for this area. Groundwater sample analysis results for these wells (averaged over four quarterly monitoring events) are summarized in Table 3-12.

Monitor well EP-13, which is within the Sample Mill area, has average arsenic, cadmium, lead, and selenium concentrations of 44.8 mg/l, 0.75 mg/l, 0.004 mg/l, and 6.4 mg/l, respectively. Monitor well EP-29, which is near the area downslope of the Sample Mill, has

average arsenic, cadmium, lead, and selenium concentrations of 0.32 mg/l, 0.003 mg/l, 0.0015 mg/l, and 0.168 mg/l, respectively. It appears that groundwater may be impacted by source materials associated with the Sinter Plant Gas Cleaning and Sample Mill area and that soil in the area downslope of the Sample Mill area may have little or no effect on groundwater. However, additional groundwater investigations are recommended, to better access potential impacts.

3.4.7 Soil Downslope of South Terrace Area

The area downslope of the South Terrace Area was originally an arroyo and part of the original entrance to the plant. This area is on the southwest portion of the property (Figure 3-4) and once included housing facilities for Plant personnel. The area also has been historically used as a storage area for ore and concentrates and as a construction staging area. Soils in the area downslope of the South Terrace Area are characterized by soil borings SSIA4-22, SSIA4-23, SSIA4-24, SSIA4-25, SSIA4-26, SSIA4-27 and SSIA4-28 (Figure 3-4). The results of soil analyses of samples from these borings are summarized in Table 3-13.

Concentrations of arsenic in surface soils (0 to 2 inches bgs) ranged from 120 mg/kg to 380 mg/kg, and lead ranged from 1,800 mg/kg to 9,400 mg/kg. At depth (4 to 5 feet bgs) arsenic concentrations ranged from nondetectable to 120 mg/kg, and lead ranged from 75 mg/kg to 620 mg/kg. Like other downslope areas, concentrations are highest in the surface and tend to decrease with depth. Although, concentrations at 4 to 5 feet bgs tend to be higher than for samples 1.5 to 3 feet bgs and 3 to 4 feet bgs. This is attributed to historic construction activities in the area and associated soil disturbance. Since the original plant entrance was closed, the arroyo has been filled in, the railroad right-of-way has been regraded, and the American Canal has been installed.

The primary source of metals in soil downslope of the South Terrace Area is concentrate. Concentrates may have been transported via stormwater runoff or transported as fugitive dust.

3.4.8 Groundwater Downslope of South Terrace Area

Groundwater in the area downslope of the South Terrace Area is characterized by monitor wells EP-20, EP-70, EP-71 and EP-72 (Figure 3-4). EP-20 was originally installed as part of the Diesel No. 1 Remediation Site. The remaining wells were installed as part of the remedial investigation. Groundwater sample analysis results for these wells (averaged over four quarterly monitoring events) are summarized in Table 3-14.

Arsenic levels in these wells exceed the MCL, but are generally lower than in other wells associated with source areas. As in the case of the area downslope of the Sample Mill, soil in this area may not impact groundwater as much as upgradient facilities and soils.

3.4.9 Summary

Investigation Area 4, which includes the western boundary of the Plant, is composed mostly of poured slag and forms a relatively steep slope between smelter facilities above it and the long, relatively flat area at the base of the slope (area of stormwater runoff). This area tends to accumulate stormwater runoff/sediments and releases of smelting process by-products from Plant operations above.

Monitor wells were not specifically installed to evaluate groundwater impacts from Investigation Area 4. However, based on soil investigation results, groundwater results for surrounding monitor wells, information on current and historic Plant operations and events, and the potential origin of source materials, Investigation Area 4 was divided into five distinct source areas. Source materials within each of the source areas are classified as follows:

Source Area	Source Material Category
Soil Downslope of the Acid Plants	I
Soil Downslope of Medford Sump	I
Soil Downslope of Lead Plant Baghouse	I
Soil Downslope of Sampling Mill	I
Soil Downslope of South Terrace Area	II

3.5 HISTORIC SMELTERTOWN (INVESTIGATION AREA 5)

3.5.1 Background/Location

Smeltertown is located west of the Plant boundary and Paisano Drive (Figure 3-5). This area was historically used generally as private housing for plant employees and their families. In 1972 the town was demolished and the families relocated. The area north of the original Smeltertown is currently used by IBWC for field offices since the 1920's and by Asarco for warehousing and Diesel No. 2 remediation activities. The area also contains a softball field used by Asarco employees.

3.5.2 Soil

Investigation Area 5 soils are characterized by samples from 19 soil borings and monitor well EP-80 (Figure 3-5). The results of borehole sample analyses are summarized in Table 3-15.

Average arsenic and lead concentrations in surface samples (0 - 2 inches) ranged from nondetectable to 240 mg/kg and from nondetectable to 4,200 mg/kg, respectively. Average concentrations of arsenic and lead at depth (4 - 5 feet) ranged from nondetectable to 60 mg/kg and from 11 mg/kg to 810 mg/kg, respectively. Overall, lead appears to be the primary constituents of concern for this area. Surface soil concentrations of lead tend to be higher (greater than 1,000 mg/kg) in the southern portion of Investigation Area 5, as characterized by soil borings SSIA5-1, SSIA5-3, SSIA5-4, SSIA5-5, SSIA5-7, SSIA5-8, and SSIA5-10 (Appendix C, Table C-6). This area has probably been impacted by historic operations of the Lead Plant, and possibly by site soil importation, grading for the development of the area for housing. With some exceptions (SSIA5-4 and SSIA5-19), elevated arsenic and metal

concentrations are limited to the surface (1 - 2 feet bgs) and decrease rapidly to near background levels at depth (Appendix D). Metal concentrations in Investigation Area 5 soils are generally much lower than in other Investigation Areas and are primarily limited to the surface.

3.5.3 Groundwater

Investigation Area 5 groundwater is characterized by monitor wells EP-57, EP-58, EP-59, EP-60, EP-61, EP-62, EP-63, EP-64, EP-65, EP-66 and EP-80 (Figure 3-5). All of these wells, with the exception of EP-80, were originally installed in conjunction with the investigation of the Diesel #2 Remediation Site. Groundwater sample analysis results for these wells (averaged over four quarterly monitoring events) are summarized in Table 3-16.

Concentrations in groundwater are not uniform across Investigation Area 5. Monitor wells EP-57, EP-58 and EP-59, which are closest to the Plant, and wells EP-62 and EP-66, which are the greatest distance from the Plant (Figure 3-5), exceeded the MCL for arsenic. The remaining wells (EP-60, EP-61, EP-63, EP-64 and EP-65) have concentrations that are near or slightly above background. The observed variations in concentrations in groundwater are attributed in part to geology. Aquifer materials in the middle portion of Investigation Area 5 tend to have a clayey composition, which may inhibit the migration or accumulation of metals in groundwater. Groundwater flow direction is to the west and southwest. Arsenic measured in Investigation Area 5 monitor wells, in particular, EP-66, may originate from upgradient source areas.

3.5.4 Summary

Arsenic and other metal concentrations (primarily lead) in Investigation Area 5 soils are elevated in surficial soils (1 to 2 feet bgs) and tend to decrease rapidly to near background levels at depth. The probable source of lead is from the historic lead operations. Monitor wells in this area have elevated concentrations of arsenic, and there are known sources of arsenic to groundwater at upgradient sites. Investigation Area 5 soils are classified as Category II materials.

3.6 GROUNDWATER (INVESTIGATION AREA 6)

Investigation Area 6 includes groundwater resources characterized as part of the Remedial Investigation. Site groundwater characteristics are discussed in detail in Section 2.3 of this report. Groundwater characteristics associated with specific investigation and source areas are discussed in Section 3.0. Based on the results of the Remedial Investigation, groundwater has been impacted by smelter operations in selected areas.

3.7 SURFACE WATER (INVESTIGATION AREA 7)

Investigation Area 7 includes naturally occurring surface water bodies (i.e., American Canal and Rio Grande). Surface water characteristics are discussed in detail in Section 2.2 of this report. Although some isolated occurrences of elevated nonmetal water quality parameters have been detected in the American Canal and in the Rio Grande, there are no MCL exceedences. Groundwater with elevated metal concentrations from source areas associated with smelter operations does not appear to have impacted the American Canal or Rio Grande.

3.8 UNLOADING/BEDDING BUILDINGS (INVESTIGATION AREA 8)

3.8.1 Background/Location

Investigation Area 8 consists of the Unloading and Bedding Buildings, railroad spurs and associated facilities in the central portion of the Plant (Figure 3-6). The unloading and bedding buildings have been in operation since 1978. All incoming and outgoing products pass through this area. During the 1994 and 1995 multimedia inspection and sampling event, the TNRCC was concerned about the large amounts of potentially hazardous materials handled and stored in the area.

3.8.2 Soil

Investigation Area 8 soils are characterized by 31 soil borings (Figure 3-6). The maximum borehole depth was five feet or less due to auger refusal (poured slag). The results of soil analysis for samples from these borings are summarized in Table 3-17.

Arsenic, cadmium, and lead concentrations in the surface (0 to 2 inches) ranged from nondetectable or background to 6,600 mg/kg, 1,800 mg/kg, and 25,000 mg/kg, respectively. Arsenic, cadmium, and lead concentrations at depth (4 to 5 feet bgs) ranged from nondetectable to 3,100 mg/kg, 530 mg/kg, and 22,000 mg/kg, respectively. A variety of raw materials, products and by-products is handled and/or stored in this area. Potential source materials include but are not limited to the following:

- Copper and lead concentrates
- Cottrell and baghouse dusts
- East Helena speiss and matte
- Scrap copper
- Steel scrap processing area
- Water treatment solids
- Solids collected from bedding washdown system

3.8.3 Groundwater

Groundwater in Investigation Area 8 is characterized by monitor wells EP-15, EP-67, EP-70 and EP-72 (Figure 3-6). Monitor well EP-15 was originally installed as part of the Diesel No. 1 investigation. Groundwater sample analysis results for these wells (averaged over four quarterly monitoring events) are summarized in Table 3-18.

Monitor wells EP-70 and EP-72 are completed in the upper reaches of the arroyo once used as an entrance to the Plant, which has since been backfilled with slag. Groundwater in these wells exceeded the MCL for arsenic. Investigation Area 8 is similar to Investigation Area 1 (Converter Building Ventilation Baghouse), Investigation Area 2 (Boneyard/Slag Storage), and Investigation Area 3 (Acid Plants) with respect to higher concentrations of metals in soils, but has comparatively lower concentrations of metals in associated underlying groundwater. This may be attributed to the fact that the facilities of Investigation Area 8 are

not constructed over a backfilled arroyo like the facilities in Investigation Areas 1, 2 and 3. Therefore, metals are less likely to migrate and accumulate in groundwater beneath the facilities of Investigation Area 8.

3.8.4 Summary

Investigation Area 8 has elevated concentrations of metals in the upper five feet of the soil. Investigation Area 8 soils have been impacted by a variety of source materials that are products and by-products transported in and out of the Plant. Although soil concentrations of metals are relatively high, the underlying groundwater has not been impacted to the extent observed for other investigation areas having similar soil concentrations. This is due in part to the construction of Investigation Area 8 facilities over a nonarroyo area. Soil materials in Investigation Area 8 are classified as Category II.

3.9 PONDS 1, 5 AND 6 (INVESTIGATION AREA 9)

3.9.1 Background

The Plant has three on-site ponds, referred to as Pond 1, Pond 5, and Pond 6 (Figure 2-3). Pond 1 was historically used for water storage from the Rio Grande, Pond 5 (dry) was used to store fresh make-up water (city of El Paso supplied) for compressor cooling and boiler feed water makeup, and Pond 6 is used for fire water, process, stormwater and cooling tower blowdown and anode cooling water. The three ponds were constructed in naturally occurring arroyos that formerly existed throughout the Plant. Pond 1 is located in a small-scale arroyo (Pond 1 Arroyo) Pond 5 and Pond 6 were built within different dendritic branches of the same arroyo (Ponds 5 and 6 Arroyo). These arroyos are delineated in Figure 2-3.

In accordance with the Remedial Investigation Work Plan, three ponds were to be investigated as part of the recently completed remedial investigation. The ponds were to be drained and samples collected from sediments to determine the extent and concentrations of metals. However, the schedule for investigation of the ponds had to be modified due to delays in the design of a new stormwater collection and reuse project.

Asarco mailed a formal request to the TNRCC on March 23, 1998, to delay the investigation of the ponds. Asarco requested that the investigation of the ponds be delayed until the water is removed from each pond and the new stormwater control facilities are built. Pond 5 had all water removed and its sediments are being allowed to dry out. The new stormwater facilities are scheduled to be completed during the first quarter of 2000, at which time the existing ponds will be sampled in accordance with the Remedial Investigation Work Plan. As an interim measure, Asarco proposed to use the results of an internal study conducted by Hydrometrics to characterize pond water quality (Hydrometrics, 1997a). The results of this study are summarized in Section 3.9.2.

3.9.2 Pond Sediment

On July 15, 1996, three grab samples of sediment were collected from each of the three ponds (nine samples total). Grab samples were collected approximately 15 feet from the shoreline of each pond using a 32 oz. polyethylene bottle attached to the end of a pole expandable to 24 feet in length. The samples were collected under water from approximately the upper four inches of sediment. Sediment sample locations are shown in Figure 3-8 and are labeled A (Pond 1), B (Pond 5), and C (Pond 6). Sediment samples were submitted under Chain of Custody to the Asarco Technical Services Laboratory in Salt Lake City, Utah. Sediment analysis results are reported in Table 2-8.

Pond 1 sediments have average arsenic, cadmium, and lead concentrations of 3,667 mg/kg, 928 mg/kg, and 6,150 mg/kg, respectively. Pond 5 sediments have average arsenic, cadmium, and lead concentrations of 2,455 mg/kg, 1,158 mg/kg, and 33,725 mg/kg, respectively. Pond 6 sediments have average arsenic, cadmium, and lead concentrations of 2,637 mg/kg, 1,038 mg/kg, and 8,002 mg/kg, respectively. Historically, all three ponds have received stormwater runoff from the Plant. Pond 5 is currently dry and measures have been taken to minimize future collection of stormwater. Stormwater comes in contact with a variety of source materials that originate from former lead and current copper smelter operations and facilities. The stormwater runoff carries sediments enriched with metals. The sediments accumulate in the ponds and, in turn, becomes a source material. Pond 6 is used

for fire, process water and anode cooling. Water returned to the pond from anode cooling may contain CuO. In addition, stormwater being collected in Pond 6 is high in metals due to sediment load. Therefore, the water in the ponds can also represent a potential source of metals or can influence the mobility of metals in sediments.

3.9.3 Pond Water

Water samples were collected from Ponds 1, 5, and 6 on a quarterly basis as part of the remedial investigation. Pond water sample analysis results (dissolved concentrations averaged over four quarterly monitoring events) are summarized in Table 3-19.

Section 2.2.3 of this report discussed the relationship between water quality in the on-site ponds and groundwater in monitor wells used to characterize groundwater in underlying arroyos. A comparison of the water chemistry of the ponds and underlying groundwater indicates some similarities. Therefore, water in the ponds may be a source of metals in groundwater.

3.9.4 Groundwater

Groundwater in Investigation Area 9 (Pond 1 Arroyo) is characterized by monitor wells EP-14, EP-29, EP-12, EM-4, EM-2, EP-35, and EP-43. Groundwater in Investigation Area 9 (Ponds 5 and 6 Arroyo) is characterized by monitor wells EM-5, EM-6, EP-77, EP-56, EP-26 and EP-66. The EM-designated monitor wells were installed in 1985 under a separate Texas Department of Water Resources (TDWR) Order. Groundwater sample analysis results for these wells (averaged over four quarterly monitoring events) are summarized in Table 3-20a (Pond 1 Arroyo) and Table 3-20b (Ponds 5 and 6 Arroyo).

The MCL for arsenic and selenium (0.05 mg/l each) were exceeded in Pond 1 wells. The action level for lead (0.015 mg/l) was exceeded in monitor wells EM-4 and EP-12. In Pond 1 wells, arsenic and selenium concentrations ranged from 0.01 mg/l to 1.267 mg/l, and from 0.005 mg/l to 3.675 mg/l, respectively. The MCL for arsenic, cadmium and selenium, and the action level for lead, were exceeded in Ponds 5 and 6 monitor wells. In Ponds 5 and 6

wells, average arsenic concentrations ranged from 0.027 mg/l to 10.93 mg/l, average cadmium concentrations ranged from 0.003 mg/l to 0.620 mg/l, average lead concentrations ranged from 0.012 mg/l to 0.109 mg/l, and average selenium concentrations ranged from 0.013 mg/l to 0.115 mg/l. Metal concentrations in Ponds 5 and 6 monitor wells were generally higher compared to metal concentrations in Pond 1 wells. Elevated metal concentrations in these monitor wells are attributed to the migration of metals from pond sediments and water to the underlying groundwater.

3.9.5 Summary

On-site process ponds contain sediments originating from Plant stormwater. Plant stormwater comes in contact with a variety of source materials on the surface that originate from former lead and current copper smelter operations and facilities. Therefore, Plant stormwater runoff carries sediments enriched with metals. The sediments that have accumulated in the ponds, and the water in the ponds, are sources of metals that migrate to the underlying groundwater. Pond sediments are classified as Category I material.

3.10 STORMWATER DRAIN (PLANT ENTRANCE) (INVESTIGATION AREA 10)

3.10.1 Background/Location

Investigation Area 10 is at the southern boundary of the plant and includes the vehicle entrance to the Plant and a stormwater drain system consisting of a sump, a lift pump, and an interceptor trench that crosses the plant entrance road (Figure 3-7). The stormwater system drains the truck staging area, portions of the South Terrace storage area, and other potential stormwater overflow in areas that would normally experience flow into the lined stormwater pond (Rubber Pond) near the Plant entrance (Figure 3-7). During periods of heavy rainfall, stormwater overflow from this area can enter the American Canal. The TNRCC has expressed a concern about the overflow from Investigation Area 10.

3.10.2 Soil

Investigation Area 10 soils are characterized by eight soil borings (Figure 3-7). Soil borings were advanced to a depth of five feet or less due to auger refusal. Soil analysis results from Investigation Area 10 are summarized in Table 3-21.

Arsenic and lead are the predominant constituents of concern in Investigation Area 10. Arsenic and lead concentrations in surface samples (0 to 2 inches) ranged from 190 mg/kg to 750 mg/kg, and from 1,800 mg/kg to 5,700 mg/kg, respectively. Arsenic and lead concentrations at depth (1.5 to 5 feet bgs) ranged from nondetectable to 710 mg/kg, and from 25 mg/kg to 1,300 mg/kg, respectively. Elevated metal concentrations are generally limited to the surface and generally decrease with depth (Appendix D). Some exceptions to this trend are probably a result of historic roadway and other construction activities that have mixed the soils.

The sources of metals in the surface soils in Investigation area 10 soils is probably stormwater sediments. Stormwater carries sediments that have been in contact with source materials associated with smelter operations and facilities. Overflows of stormwater from this area could possibly, in turn, transport metal-enriched sediments to the American Canal.

3.10.3 Groundwater

Monitor wells were not installed specifically to characterize groundwater in Investigation Area 10. However, the concentration and distribution of metals in soils and depth to groundwater make soils an unlikely source of metals.

3.10.4 Summary

The plant entrance and stormwater drain within Investigation Area 10 have elevated metals in surface soils, probably sediments in stormwater runoff. Stormwater overflows could possibly transport metals in soils from this area to the American Canal. Metals in soils from this area are an unlikely source of metals to groundwater. Soil in Investigation Area 10 is classified as Category II material.

3.11 OTHER POTENTIAL SOURCE AREAS

Based on a review of groundwater and soil investigation results, there are five additional areas having elevated concentrations of metals in soils and groundwater not originally identified as investigation areas. These areas, which require additional soil and/or groundwater investigations to adequately define the extent and distribution of potential source materials, are identified as follows (Figure 3-9):

- Southern Arroyo (characterized by EP-84)
- Closed depression designated as SEP-14 (in Sub-area 2, Investigation Area 2)
- Boneyard (below base of slag)
- Sample Mill Area (characterized by EP-13)
- South Terrace Area

In addition to these potential source areas, evaluations of closed plants may also identify additional potential source areas.

3.11.1 Southern Arroyo

The Southern Arroyo is east of the Plant (Figure 3-9). Historically, this area was used for storage of plant construction materials and demolition debris. Monitor well EP-84, originally installed as a background well, has 0.53 mg/l of arsenic averaged over four quarterly monitoring events.

3.11.2 Closed Depression Designated as SEP-14 (Sub-area 2, Investigation Area 2)

As described in Section 3.2.1, this closed depression is in a slag storage and processing area of Sub-area 2, Investigation Area 2 (Figure 3-9). The closed depression was formed as a result of construction-related activities and, in particular, the establishment of a railroad grade. The railroad grade forms a dam that intercepts the drainage of an arroyo.

Historically, the arroyo was used for storage of plant debris from the Plant and from the local community. In the early 1980's, bottom sediments from Pond 6 were dredged and stored on the south side of the Number 9 bridge area just north of EP-82. The area to the west of the closed depression is a slag-crushing/recycling plant operated by Parker Brothers, Inc.

Although the closed depression has been dry since the initiation of the remedial investigation, metals concentrations in samples of soil and groundwater (EP-78) collected from this area are elevated. It is suspected that the closed depression may accumulate fines associated with slag, demolition debris, and other smelter or nonsmelter-related materials.

3.11.3 Boneyard (below base of Lead Slag Dump)

The Boneyard (Figure 3-9) was previously described in Section 3.2.1 as Sub-area 1, Investigation Area 2. The Boneyard is constructed over an arroyo that has been backfilled with slag. Historically, this area was used to store Acid Plant sludge/water. Limerock was used to neutralize this material. Borehole samples collected below the slag and groundwater from monitor wells EP-75 and EP-76 contain elevated concentrations of metals, arsenic in particular. Residual material from the Acid Plants in this area may be a source of metals impacting groundwater.

3.11.4 Sample Mill Area

The Sample Mill Area is located southwest of the Lead Plant area (Figure 3-9) and was historically used as a Leach Plant to remove chlorine from Lead Baghouse dusts prior to their addition as feed material. The Leach Plant was a modified water treatment plant utilizing a drum filter system to remove the suspended solids from the liquid. The liquid after the leaching process was stored in an above ground tank and then transferred to one of the process ponds. The area is located above a small back-filled arroyo. The average arsenic concentration in EP-13 is 44.8 mg/l. Residues and spillage associated with this process may be a source of metals to groundwater.

3.11.5 South Terrace Area

The South Terrace Area is in the southwestern portion of the Plant (Figure 3-9). The South Terrace Area is generally a flat area of the plant that has historically been utilized for the storage of concentrates, silica fluxes, and temporary storage of plant equipment. Located within the central portion of the South Terrace Area is an arroyo that has been back-filled with slag in order to create additional storage area. Based on the historical usage of the area, these materials may results in elevated concentrations of metals in soils and groundwater.

Currently, the area is being prepared for the construction of a new stormwater collection pond as part of the new Stormwater Collection and Reuse project. Concentrates are stored at the northeast portion in rubber lined concrete cells.

4.0 GENERAL PROPOSAL FOR CORRECTIVE ACTION

In accordance with the Agreed Order, this section of the report presents a general proposal for corrective action. The general proposal for corrective action includes a summary of risk assessment results and identifies Corrective Action Objectives and preliminary Corrective Action Goals. This is followed by a discussion of corrective action technologies and process options. Corrective Action Alternatives are identified as most applicable to the Plant based on an evaluation of effectiveness, implementability, and cost. Finally, Corrective Action Measures that would be taken to remediate source areas and achieve Corrective Action Objectives, are identified and proposed for each known source area.

4.1 PRELIMINARY CORRECTIVE ACTION GOALS AND OBJECTIVES

4.1.1 Risk Evaluation and Preliminary Corrective Action Goals

Appendix L provides a site-specific risk assessment for the Asarco El Paso smelter site. The objective of the risk assessment is to identify mechanisms of present and future potential exposure to materials released to the environment by the Asarco El Paso Copper Smelter, and to provide preliminary, media-specific cleanup levels which are protective of potentially adverse effects to human health and the environment. Conclusions regarding risks, excerpted from Section 5.6 of Appendix L, are as follows:

- No imminent health threats as a result of environmental contamination from the Asarco El Paso Smelter site are identified. Potential worker risks from exposure to soil are appropriately managed, there is no exposure to groundwater, and metals concentrations in surface water are below health-based levels of concern (MCLs and Fresh Water Chronic Criteria).
- Cleanup objectives should focus on prevention of future impacts to the American Canal and the Rio Grande, consistent with the requirement of Texas Surface Water Quality Standards. MCLs are the applicable standard for the American Canal, while both MCLs and Fresh Water Chronic Criteria are applicable to the Rio Grande. Nondegradation and related load limitations (TMDLs) also apply.

- Possible sources of metals identified during low water flow in the American Canal should be further evaluated.

4.1.2 Corrective Action Objectives

Plant improvements such as the Stormwater Collection and Reuse project and Corrective Action Measures to remediate source areas, are an integral part of the overall corrective action approach. Plant improvements provide opportunities for management of smelter/source materials and reduce potential environmental risks. Corrective Action Objectives for the Asarco El Paso Smelter are as follows:

1. Reduce the potential for exposure to metals by plant workers and the public.
2. Minimize the potential for transport of metals to the groundwater.
3. Prevent increases in metal concentrations in the American Canal and the Rio Grande resulting from the migration of metals in groundwater, surfacewater, and wind-blown dust from the Plant.

4.2 CORRECTIVE ACTION TECHNOLOGIES AND PROCESS OPTIONS

This section summarizes information on performance, relative costs, applicability, efficiencies, operation and maintenance, and site-specific implementability of remedial technologies for soil and groundwater. Sources of information used in the literature review include compendiums of treatment technologies, the National Technologies (NTIS) database, the Site Innovative Technology Evaluation (SITE) demonstration program, treatability studies conducted at other Asarco sites having metal constituents similar to those at the Asarco El Paso Smelter, and data provided by vendors. Other technologies may be available that are not considered in this section, but the information presented is intended to be the most applicable to the Asarco El Paso Smelter site.

4.2.1 Soil

Soils on the Asarco El Paso Smelter site and in the associated study area formed in colluvium and fluvial sediments. The colluvial sediments were generated by the erosion of a laccolith locally known as the "Campus Andesite." The laccolith is located to the east of the plant, with the sediments laid to the west where it mixes with the fluvial sediments of the Rio Grande. Alluvial floodplain deposits are found along the Rio Grande below the smelter site. The stream deposits generally consist of silt, sand, and gravel. Surface soils within the Plant have been drastically disturbed, affected by the construction and operation of smelting and ore-handling facilities over a period of approximately 111 years. In particular, facilities construction and the deposition of slag from smelting operations has covered the majority of the original surface soils in the study area. The results of the on-site investigation indicate the principal source of arsenic and metals in soils to be related to historic smelter features and activities associated with the Asarco El Paso Smelter operation.

Several remedial process options could be considered in developing remedial alternatives for the Asarco El Paso Smelter site. Based on the results of the remedial investigation, the primary constituents of concern for soil are arsenic, cadmium, lead, and selenium. In some cases, specific treatment alternatives have been explored for similar smelter sites, and treatability test results are briefly discussed where relevant. Bioreclamation is not applicable to remediation of inorganics in soil and is not discussed in this section. Cost evaluations are relative to other remedial options and are general only.

4.2.1.1 Isolation/Containment

Isolation and containment technologies entail isolation of affected soils by excavation and removal, isolation through stormwater control, and caps that may include pavement, concrete, clay, synthetic liners, or clean soil and revegetation. Of all the remedial technologies considered for soil in this proposal for remedial action, source isolation probably has the greatest applicability to the Asarco El Paso Smelter site. Consistent with use of the site for industrial purposes, construction methods and materials used in the improvement of the site could provide effective isolation and containment of source materials. Potential future

redevelopment at affected Plant property to other industrial or commercial uses may be consistent with the U.S. Environmental Protection Agency's Brownfields concept (U.S.E.P.A., 1995).

Asphalt/Concrete Cap

Capping soil with asphalt or concrete effectively limits potential exposure to arsenic- and lead-affected soil and prevents downward percolation of arsenic and metals to the groundwater system. This process option is relatively easy to implement, especially if much of the site is already paved, or if there are plans for improvement of the site. Cost for asphalt or concrete capping is moderate relative to other process options. The relative cost for an asphalt cap ranges from $8 to $10 per square foot, and approximately $30 per square yard for concrete, including base materials but not site preparation and grading.

Clay and Synthetic Membranes

Additional options for capping material include clay (e.g., bentonite), that prevents infiltration to groundwater but is not implementable by itself in high traffic areas. Synthetic membrane capping such as a geomembrane liner prevents infiltration to groundwater and is not susceptible to weathering and cracking, unlike asphalt, concrete, and clay/bentonite. However, a synthetic membrane is not as easy to implement and is higher in cost. A typical cost for a synthetic membrane liner is $0.60 per square foot. Synthetic liners are typically used in conjunction with a clean soil cap and a lateral drainage layer of gravel at an additional cost of approximately $30 per cubic yard of material.

Clean Soil and Vegetation

A clean soil and vegetative cover is a low-cost process option that effectively limits exposure to affected soils and reduces the potential for migration of arsenic and metals. The effectiveness of limiting infiltration to groundwater is dependent on climate (rainfall and evapotranspiration), subsurface lithology, and capping application. The cost of importing clean soil for capping purposes is approximately $20 per cubic yard, depending on

availability and distance to a suitable source. The cost for establishing a permanent native vegetative cover can range from $200 to $800 per acre.

Stormwater Control

Surface water control can be accomplished through site grading and the construction of ditches, pipelines, sumps and ponds. The construction of stormwater improvements at the Asarco El Paso Smelter, referred to as the Stormwater Collection and Reuse Project, are scheduled to begin in late 1998 or early 1999 (Dames and Moore, 1998). The new stormwater control facilities will effectively isolate surface water from contact with potential source areas and will route stormwater to a reuse system. Underground reinforced concrete pipe (RCP) storm drains range from $11 to $30 per linear foot, depending on the size of pipe required to handle stormwater runoff from the site. Lined stormwater ponds range from $2.00 to $3.50 per square foot. The estimated cost of the entire proposed stormwater project is $9,000,000.

Excavation and Removal

Excavation and removal of contaminated soil with a backhoe, in the case of deep excavation, or with a front end loader, in the case of shallow excavation, is an effective and easily implemented method of remediation and by itself has a relatively low cost. However, excavated materials must be appropriately managed. Depending on the characteristics of the excavated materials, disposal may be as simple as transporting the materials to an on-site fill, placement in an on-site RCRA or solid waste landfill, or may require transport to an off-site RCRA or solid waste landfill. Excavated materials may also require treatment prior to disposal. Accordingly, excavation treatment options can range in cost from $50 to $500 per ton of soil removed.

4.2.1.2 Physical Treatment

Physical treatments include soil flushing and washing, acid leaching, chelation, and electro-osmosis, but are not considered practical options for the Asarco El Paso smelter site because

the costs for these options have not been well defined for large scale use and will not be addressed here.

Soil Flushing/Washing

Soil flushing for in-situ treatment, or soil washing of excavated soil, are methods of extracting constituents of concern from the surface of the soil. Either is accomplished by passing extractant solvents through the affected soil. Solvents may include water, acids or bases, chelating agents, and oxidizing or reducing agents.

Acid Leach Washing

Acid leach washing has been explored at the Asarco Tacoma Smelter site in Ruston, Washington (Hydrometrics, 1992a) for soil containing arsenic and metals. Treatability tests for Ruston soil demonstrated modest reductions in soil arsenic and metal concentrations in oversized fractions of soil greater than 200 micrometers in size. Separation and washing of the oversize fractions resulted in 40 percent to 60 percent reductions in arsenic concentrations in soils. There are a number of technical obstacles associated with this treatment, including high post-treatment leachability, effective washing of entire soil mass, large water requirements, recovery of wash fluids and sludges, treatment of fine grain fraction, and treatment and/or disposal of wash fluids and sludges. In-situ obstacles include a high potential for groundwater contamination. Well recovery systems would have to be implemented in order to contain and recover wash fluids and metals. In addition, soil pores can clog, making complete arsenic and metal removal even more difficult.

Chelation

Chelating is a physical treatment process in which a chelating chemical is used to solubilize metals from soil. Chelating agents are commercially available, and can be chosen for their affinity to particular metals. The effectiveness of this treatment is dependent on soil chemistry. This method may not work as well for the removal of arsenic as for the removal of other metals (Hydrometrics, 1992a).

Electro-Osmosis

Electro-osmosis decontamination concentrates or separates ionic species by exposing the material to an electric field. In an in-situ process, anodes and cathodes are inserted in the ground, and loosely held ions are displaced to their respective electrodes. Heavy metals present in soils can be leached or precipitated out of solution by electrolysis, oxidation and reduction reactions, or by ionic migration. Soils having higher electrical conductivity, such as saturated soils, are more suitable for this treatment. This method has been examined on a laboratory scale, and applicability in the field is questionable. Data suggest that electro-osmosis decontamination is effective on fine-grained soils of low permeability. Treatment on coarse soils such as those found typically at smelter sites showed an arsenic concentration reduction of only 10 percent (Hydrometrics, 1992a).

4.2.1.3 Chemical Neutralization/Fixation/Stabilization

Neutralization/fixation/stabilization processes alter the chemical characteristics of waste material such that the toxic and hazardous constituents are immobilized, either by changing the constituents into immobile forms, binding them to an immobile, insoluble matrix, and/or binding them in a matrix such that the constituents are not exposed on the material surface. Chemical treatment methods can employ relatively simple technology, such as the application of limestone amendments to adjust pH, to processes that involve more complex soil chemical reactions.

Chemical Neutralization

Chemical neutralization is used to control pH and the mobility of arsenic and other metals in soil. A commonly used process is the addition of crushed limestone as a soil amendment. Limestone raises the pH of soils in which acidic conditions are limited to shallow soils. In-situ application of neutralization agents such as limestone may have limited application for some surface soil situations, particularly involving vacant lots that contain affected soils. This process would probably not be effective for Plant soils having high arsenic concentrations. The costs of application and incorporation of crushed limestone ranges from $20 to $60 per acre.

Another type of neutralization involves the use of deep tillage. Deep tillage techniques can be used to mix arsenic and other metals with naturally-occurring limestone or select additives with affected surface soils (Hydrometrics, 1995b). Again, this method is restricted to open areas in which arsenic and metal concentrations are distributed in surface soils. In addition, this process is not easily implemented if there are numerous subsurface utilities and other obstructions. The cost of deep tillage ranges from $125 to $250 per acre plus the cost of the amendments.

Siliceous Chemicals

Siliceous chemicals can be used to fix and solidify polyvalent metal ions such as arsenic and lead via reactions between silicates and positively charged metals. Several siliceous processes are commercially available and have been previously demonstrated to be effective. In one process by Chemfix Technologies, Inc., the waste is blended in a reaction vessel with water-soluble silicates in the presence of a siliceous setting agent. The resulting three-dimensional polymer matrix is characterized by strong ionic bonding and cross-linking between layers of silicon-oxygen chains. In limited laboratory scale treatability testing of Tacoma plant soils, effective reduction of leachability to below Toxic Characterization Leaching Procedure (TCLP) criteria was accomplished using a similar commercial process available from Toxco (Hydrometrics, 1992a). This process has been successfully implemented at other sites, including several Superfund sites at which metals were of concern. This process has been successfully implemented at another smelter site near Omaha, Nebraska (Hydrometrics, 1996). Treatment costs range from $100 to $200 per ton of soil.

Pozzolan Processes

In pozzolan processes, arsenic and metals are bound in pozzolan-type matrices by physical sorption or chemisorption, yielding a stabilized material. The advantages of this technique include plentiful and inexpensive raw materials, improved waste handling, minimal required pretreatment, and products adequate for landfill disposal. A disadvantage is that leachate

control is variable. Soil chemistry, particularly sulfate and arsenate concentrations, can interfere with pozzolan processes; however, there are several commercial venders that have successfully used these processes for fixation of arsenic and metals in soils. The lime-based pozzolan process stabilizes waste by combination with a large amount of siliceous material and a setting agent such as lime, cement or gypsum. Portland cement-based pozzolan stabilizes waste by incorporating it in a cement matrix.

Treatability tests examined three variations of chemical fixation for the soil at the Asarco Tacoma Smelter site located in the municipalities of Ruston and Tacoma, Washington (Hydrometrics, 1993). The treatments were incorporation of soil into Portland cement, a commercial cement-based pozzolan process, and a commercial siliceous-based fixation process (Hydrometrics, 1993). Two of the three fixation processes investigated in the treatability testing effort were not able to obtain anticipated treatment objectives for arsenic. All of the processes investigated were able to successfully immobilize metals, including lead; one out of three (commercial cement-based pozzolan process) was successful in achieving treatment objectives for arsenic. A commercial cement-based process by Eurocan was able to achieve post-treatment TCLP results for arsenic below TCLP criteria of 5 mg/l. Treatment costs for this process are high, about four times as high as the anticipated cost associated with standard soil cement treatment.

Treatability testing for cement and lime stabilization of sludge was performed for a former process pond at Asarco's lead smelter in East Helena, Montana (Hydrometrics, 1995a). Treatment was achieved that successfully passed TCLP criteria using cement/lime combinations at a 30 percent additive ratio. Phosphate addition to the cement, either in the form of phosphoric acid or fertilizer, has been shown to dramatically reduce lead mobility in soils, reducing leachate lead concentration by two orders of magnitude (Hydrometrics, 1996a). One drawback is that arsenic is mobilized as a result of phosphate addition.

In general, stabilization of wastes containing arsenic and other metals, depends on the site-specific soil matrix. Consequently, prior to implementation of a particular method, pilot

studies are required in order to verify the effectiveness of the treatment technology. Pozzolan treatment costs typically range from $50 to $200 per ton of soil.

4.2.1.4 Thermal Destruction

Thermal destruction processes do not destroy metals, but they can potentially immobilize metals. These technologies generally are more costly than other potential treatment alternatives because of high energy costs. Many of the processes, such as flame reactor or plasma torch vitrification, are still in the development phase, and the practicability of these technologies has not yet been completely determined. The use of a blast furnace has been effective for soil treatment and disposal, and is a viable option at an active smelter site such as the Asarco El Paso Smelter site.

4.2.1.5 Vitrification Stabilization

Vitrification is a process that uses either electrical current or fueled oxidation systems to fuse soils into a vitrified block. Laboratory and pilot scale field testings indicate that the treatment is effective in reducing soil metal leachability; however, this process requires large energy inputs and is still in the development phase.

4.2.2 Groundwater

As discussed in Section 1.2.4, the aquifer underlying the Plant is composed primarily of interbedded and mixed sand, gravels, boulders, and bedrock. Water is derived from the Rio Grande and considered separate from the Hueco Bolson and Mesilla Bolson regional aquifers. In some cases, such as the floodplain of historical Smeltertown, finer grained sediments (silts and clays) exist. Groundwater flow direction is from the east-northeast to the west-southwest. As groundwater approaches the Rio Grande, the direction changes to a southerly route, which approximates the direction of the Rio Grande flow. Depth to groundwater is dependent on location within the Plant. The depth of groundwater at the Plant is 40 to 60 feet below ground surface (bgs), depending on the elevation of the Plant above the floodplain (30 feet to 50 feet). On the Rio Grande floodplain (historical Smeltertown), the depth to groundwater is approximately 10 feet bgs.