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LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
ADI	acceptable daily intake
AIC	acceptable intake for chronic exposure
AIS	acceptable intake for subchronic exposure
ALA-D	delta-amino-levulinic acid dehydratase
American Chemet	American Chemet Corporation
ARAR	applicable or relevant and appropriate requirement
Asarco	ASARCO, Incorporated
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	Ambient Water Quality Criteria
BCF	bioconcentration factor
BDL	below detection level
$CaCO_3$	calcium carbonate
CAG	Carcinogenic Assessment Group
CDC/MDHES	Centers for Disease Control/Montana Department of Health and Environmental Sciences
CEC	cation exchange capacity
cfs	cubic feet per second
cm^2	square centimeter
COEC	Commission of the European Communities
CPF	cancer potency factor
CRL	cancer risk level
DFWP	Department of Fish, Wildlife, and Parks
DNA	deoxyribonucleic acid
EA	endangerment assessment
EPA	U.S. Environmental Protection Agency
ESE	Environmental Science and Engineering, Inc.
FS	feasibility study
ft	foot
g	gram
g/day	grams per day
GI	gastrointestinal
HEAST	Health Effects Assessment Summary Tables
HI	hazard index

ICRP	International Commission for Radiological Protection
IQ	intelligence quotient
kg	kilogram
kg/day	kilograms per day
kg/mg	kilograms per milligram
LC50	lethal concentration for 50 percent of the exposed population
L/day	liters per day
L/mg	liters per milligram
LOAEL	lowest-observed-adverse-effect level
LOEL	lowest-observed-effect level
MCLG	maximum concentration limit goal
MDHES	Montana Department of Health and Environmental Sciences
m^3/day	cubic meters per day
MED	minimum effective dose
mg	milligram
mg/cm^2	milligrams per square centimeter
mg/cm^2/hr	milligrams per square centimeter per hour
mg/day	milligrams per day
mg/kg	milligrams per kilogram
mg/kg-bw	milligrams per kilogram of body weight
mg/kg-bw/day	milligrams per kilogram of body weight per day
mg/kg/day	milligrams per kilogram per day
mg/L	milligrams per liter
mg/m^3	milligrams per cubic meter
m^3/hr	cubic meters per hour
m^3/mg	cubic meters per milligram
MOS	margin of safety
MSMA	monosodium methanearsonate
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NEL	no-effect level
NOAEL	no-observed-adverse-effect level
NOEL	no-observed-effect level
NRC	National Research Council

OHEA	Office of Health and Environmental Assessment
OSHA	Occupational Safety and Health Act
PbB	blood lead levels
PEL	permissible exposure level
ppm	parts per million
RfD	reference dose
RfD/AIC	reference dose/acceptable intake for chronic exposures
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
RMCL	recommended maximum concentration limit
ROD	record of decision
SAB	Science Advisory Board
SIP	State Implementation Plan
SMCL	secondary maximum contaminant level
SPHEM	Superfund Public Health Evaluation Manual
TDS	total dissolved solids
TLV	threshold limit value
TWA-TLV	time-weighted average threshold limit value
ug	microgram
ug/day	micrograms per day
ug/dL	micrograms per deciliter
ug/g	micrograms per gram
ug/kg/day	micrograms per kilogram per day
ug/L	micrograms per liter
ug/m^3	micrograms per cubic meter
USDA	U.S. Department of Agriculture
WHO	World Health Organization
WQB	Water Quality Bureau
WRM	water resource monitoring

EXECUTIVE SUMMARY

INTRODUCTION

In September, 1984, the Environmental Protection Agency (EPA) listed the East Helena Site on the National Priorities List (NPL) pursuant to Section 105 of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA). As a result, a number of investigations have been conducted by EPA and Asarco to identify media potentially impacted by past smelter operations.

In 1987, the East Helena Site was segregated into operable units. The purpose of the operable unit approach was to expedite remedial investigation/feasibility studies (RI/FS) on well characterized units while additional study continued on others. The operable units for the East Helena Site are:

Process Fluids (includes Process Ponds and Process Fluids Circuits sub-units)

Groundwater

Surface Soils/Surface Water (includes Plant Site Soil, Residential East Helena Soils, limited Helena Valley Soils, Prickly Pear Creek, Wilson Ditch, Vegetation, Cattle, Fish, and Waterfowl sub-units)

Slag Pile

Ore Storage Areas.

Asarco has expedited the RI/FS for the Process Pond subunit with the final Process Pond RI/FS report submitted to EPA September 8, 1989, and the Record of Decision (ROD) completed by EPA in November 1989. The remaining operable units and sub-units are addressed in this Comprehensive RI/FS report. The Comprehensive RI/FS was conducted in accordance with the Comprehensive Remedial Investigation/ Feasibility Study Work Plan. RI/FS activities were performed with oversight by and approval of EPA under the authority of CERCLA and the Superfund Amendments and Reauthorization Act of 1986 (SARA).

SITE DESCRIPTION

Site Location

The East Helena Site includes: the East Helena community and areas immediately adjacent in the Helena Valley, and the Asarco plant, which is located just south of the community of East Helena. The plant has operated as a primary lead smelter for over 100 years and recovers base metals using a pyrometallurgical process.

Surface Water Systems and Hydrology

The Asarco plant is adjacent to Prickly Pear Creek, which flows to the north through the community of East Helena, the Helena Valley, and into Lake Helena. Other major surface water features include: Upper Lake, located south of the plant; Lower Lake, process pond located immediately north of Upper Lake; and Wilson Ditch, an irrigation diversion from Upper Lake. The plant and the East Helena community are underlain by unconsolidated alluvium deposited by ancestral Prickly Pear Creek. The alluvial deposits have variable permeabilities and consist of layers and mixtures of cobbles, gravel, sand, silt and clay. Underlying the alluvium, and present in exposures west and north of the plant and the East Helena community are fine-grained Tertiary volcanic ash tuff deposits, which have low permeabilities, and which have weathered to a fine clay in some locations.

SCOPE OF INVESTIGATION ACTIVITIES

Process Fluid Circuits

The process pond sub-unit remedial investigation is included in the Process Pond RI/FS report and is not discussed here. Investigation activities associated with the Process Circuit sub-unit included: identification of main plant process circuits; water sample collection of circuit process fluids; and pressure line and drain line leakage tests.

Groundwater

The groundwater investigation included: collection of stratigraphic samples from 63 soil core drill holes and 10 test pits; drilling and construction of 51 monitoring wells and piezometers; groundwater sampling and analysis of 41 monitoring wells and 33 privately owned wells; and aquifer testing of 38 monitoring wells.

Surface Soil/Surface Water

The surface soil/surface water remedial investigation included: collection and analysis of 26 soils samples from within the plant site; collection and analysis of 24 East Helena soil samples to supplement soil data collected by EPA during the Phase I soils RI, and the CDC/MDHES Child Lead Study; flow measurement, water sampling and analysis of Prickly Pear Creek, Upper Lake and Wilson Ditch; instrumentation of 6 monitoring wells and 1 station on Prickly Pear Creek to evaluate surface water/groundwater interrelationships; plant site surface water drainage mapping and double ring infiltrometer test; collection and analysis of vegetable samples from both residential gardens and Helena Valley grains; sampling and analysis of Helena Valley cattle; sampling and analysis of fish in Prickly Pear Creek and Lake Helena; and a waterfowl/sediment comparison literature review, and a biological inventory for Upper Lake.

Slag Pile

The slag pile investigation included: slag infiltration test basin construction; infiltration water sampling and analysis; slag material sampling and analysis; and air quality sampling and analysis.

Ore Storage Area

The Ore Storage Area investigation was included as part of plant site groundwater and surface soil/surface water investigation activities. Air quality samples were also collected and analyzed.

RESULTS OF THE INVESTIGATION

Process Fluid Circuits

Pressure line testing and drain line flow measurement and inspection indicate leakage occurs from these process fluid lines. Generally, water from the process fluid circuits are sodium-sulfate type, and have moderately high concentrations of TDS, metals and arsenic. Concentrations of TDS, metals and arsenic are variable over time. The process fluids are used in a variety of ore processing operations in the plant, and for dust suppression in plant processing and ore storage areas.

Groundwater

Water quality sampling showed shallow groundwater (upper 10 feet of saturation) under the plant and to some extent under East Helena has elevated arsenic concentrations. Water samples from the next water bearing zone underlying the shallow aquifer do not have elevated arsenic concentrations. Arsenic concentrations in private wells were generally low and were below MCLs for arsenic. All but two private wells are no longer used as domestic water supplies and have been replaced with city water. The two private wells that remain in use have little potential to be impacted by groundwater.

A northwest trending, relatively high concentration arsenic plume has been delineated in the shallow alluvial groundwater system on the plant site. Primary sources of this plume include the speiss granulating pond and pit, the acid plant water treatment facility and its associated sediment drying areas. Losses from the process fluid circuits also contribute to this arsenic plume. This multi-source plume is superimposed on a relatively broader, lower concentration arsenic plume that is associated with Lower Lake. The lower concentration plume also extends to the north and northwest, in the general direction of groundwater flow. Arsenic concentrations are significantly reduced in East Helena and are near or below MCLs (0.05 mg/l) at the north edge of the community. Calculated groundwater flow, and groundwater and stratigraphic geochemical analyses indicate geochemical and physical reactions with arsenic are attenuating the arsenic plumes.

COMPREHENSIVE REMEDIAL INVESTIGATION/FEASIBILITY STUDY

ASARCO INCORPORATED
EAST HELENA, MONTANA

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March 30, 1990

Surface Soils/Surface Water

Plant Site Soils

Plant site soil sample analyses indicate the highest metals concentrations are in areas associated with storage, loading and handling of ore. On-going dust management programs are implemented to reduce plant site air-borne dust as well as reduce off-plant dust migration.

Residential Soils

Forty-two surface soil samples were collected during 1984 and 1987 in residential East Helena. Fifteen metals were analyzed and lead and cadmium concentrations were the most elevated. Residential soil samples also were collected in 1983 by CDC (Center for Disease Control) and MDHES (Montana Department of Health and Environmental Sciences). Lead and other metals concentrations generally decrease with increased distance from the plant.

Helena Valley Soils

Helena Valley soils were also sampled in 1984 as part of the EPA Phase I Soil RI; this data indicates fields east of the plant have the highest metals concentrations.

Surface Water - Prickly Pear Creek, Upper Lake, Wilson Ditch, and Overland Runoff

Surface water and bottom sediment samples were collected from Prickly Pear Creek, Upper Lake, and Wilson Ditch. Prickly Pear Creek water quality upstream of the plant is generally good, but contains some arsenic and metals as a result of upstream mining and land disturbances. Lower Lake, a process pond located adjacent to Prickly Pear Creek, is a source of minor arsenic concentration and load increases to the stream (remediation of Lower Lake is addressed in the Process Pond RI/FS). With the exception of impacts from Lower Lake, measurable arsenic or metals concentration increases in Prickly Pear Creek were not observed. A portion of the creek is diverted upstream of the plant to Upper Lake for plant use and to supply 2 to 3.5 cfs of irrigation water to Wilson Ditch. The water quality of Upper Lake and Wilson Ditch is essentially the same as Prickly Pear Creek above the plant. Prickly Pear Creek, Upper Lake and Wilson Ditch all have elevated metals concentrations in bottom sediment with Wilson Ditch having the highest concentrations and Prickly Pear Creek the lowest.

Overland runoff from short, intense summer thunderstorms were collected at locations inside and outside the plant site. All samples had considerable suspended sediment and elevated concentrations of metals and arsenic, with higher concentrations within the plant site. Plant site runoff is either contained within the plant site system or potentially drains off the plant property to the northwest but does not reach Prickly Pear Creek. The potential for off property runoff impacts to Prickly Pear Creek was also examined using the Universal Soil Loss Equation runoff model; results of the calculations indicate that overland runoff from drainages south of the plant have the highest potential for creek impacts, although they are most likely insignificant compared to potential erosion in the Prickly Pear Creek channel.

Vegetation

Vegetable garden and wheat grain sampling indicate elevated levels of arsenic, cadmium and lead. In garden vegetables, arsenic and metals concentrations were highest in leafy green vegetables. Elevated metals concentrations in grains were generally highest nearest the plant.

Cattle

Results of cattle sampling and analysis indicate that cadmium is elevated in the kidney and liver of Helena Valley cattle. However, cadmium levels of kidney from the control herd at Townsend were also elevated. Trace element concentrations in muscle tissue are within the typical range of national data published by the USDA.

Fish

Arsenic and metals concentrations in Prickly Pear Creek and Lake Helena fish are typical for fish in Montana and are within the national norm. The one exception was zinc, which was slightly elevated compared to other Montana studies, but near background levels for fish in the United States.

Upper Lake Waterfowl and Biological Assessments

Based on a comparison with a waterfowl study for the Warm Springs Ponds site, the potential risk to human receptors from waterfowl residing on Upper Lake is low. Metals concentrations of waterfowl sampled from Warm Springs Ponds were not considered significant and metal concentrations in the Upper Lake environment are lower than Warm Springs Ponds. Therefore, the impact to Upper Lake waterfowl should be similar to or less than waterfowl impacts at Warm Springs. Access and hunting restrictions at Upper Lake also reduce the potential for human consumption of waterfowl residing at Upper Lake.

The biological assessment showed Upper Lake provides a diverse mixture of habitats including 5 wetland habitats and 5 upland habitats in the 176 acre study area. Upper Lake supports a good diversity of wildlife species; 79 to 82 species of birds, mammals and reptiles were recorded during the study. No sightings of federally-listed endangered or threatened species were recorded.

Slag Pile

The potential for groundwater, surface water or air quality impacts from slag are low. Analyses of water collected in slag infiltration collection test basins, and from slag laboratory test leachate indicate arsenic and metals concentrations are relatively low, and are not the source of elevated arsenic concentrations in groundwater. Test basin precipitation collection rates indicate only a fraction of precipitation may actually infiltrate the slag pile. Results of surface water sampling indicate no measurable impacts to Prickly Pear Creek from the slag pile. Air quality monitoring and a Chemical Mass Balance/Source Apportionment (CMB/SA) evaluation indicate slag pouring contributed only minor amounts of lead particulate. New slag disposal procedures consisting of solidification into ingots prior to disposal should significantly reduce air quality impacts from the slag pile.

Ore Storage Area

Groundwater and surface water impacts from the ore storage area are discussed above. Based on the CMB/SA, the ore storage areas contributed 30 to 35 percent of lead particulate measured in East Helena. Other major contributors to lead particulate include East Helena plant road dust (21 percent) and the American Chemet pyromet stack (13 percent). Lead particulate is expected to decrease dramatically with the implementation of ore handling in the new ore storage building.

ENDANGERMENT ASSESSMENT ANALYSES

The Comprehensive Endangerment Assessment (EA) addresses current and future exposures to the selected indicator chemicals: arsenic, cadmium, copper, iron, lead, manganese, and zinc. Various scenarios were examined for representative (using mean concentration data in soil, sediments, surface and ground waters, and air) and maximum (using maximum concentration data from environmental media) exposures to children, youth, and adults in off-plant site areas. Representative exposure analyses indicated that soil ingestion, inhalation of outdoor and indoor air, and vegetable consumption resulted in potential carcinogenic risks for children. Vegetable consumption was the only exposure scenario which resulted in potential carcinogenic risks for youth. For adults, potential carcinogenic risks were associated with exposures to the indicator chemicals through inhalation, soil ingestion, vegetable consumption, and dermal contact with soil. Integration of this information into an analysis of the potential carcinogenic risks for lifetime exposure to the indicator chemicals shows that potential risks exist from exposure through soil ingestion, inhalation, and vegetable consumption. For noncarcinogenic risks, potential hazards were evident for adult and lifetime exposures only. Noncarcinogenic risks for children and youth were below the hazard level.

In environmental receptors (including aquatic life, vegetation, livestock and wildlife), cadmium, copper and arsenic were found to exceed appropriate ambient water quality criteria. Copper and lead were found to exceed the daily intakes estimated to be noninjurious to livestock and wildlife.

Remedial design goals were developed which outlined recommended cleanup levels that would avoid excessive exposures and risks to human and ecological receptors. In the case of ground and surface waters, the remedial design goals are set by the chemical-specific applicable or relevant and appropriate requirements developed in Section 9.0. For soils, sediments, and air, the design goals were established through the health-based risk assessment. Because lead is the critical chemical of concern for exposure of children, it was selected as the target chemical around which design goals were developed. Using this approach, target soil lead concentration levels which would result in corresponding blood lead levels not greater than 10 ug/dl were developed. Cleanup to lead concentration levels in soil which result in a corresponding level of 10 ug/dl blood lead is expected to provide an acceptable exposure to other metals that is protective of human health.

POST RI INVESTIGATIONS

Several investigations were conducted to examine the treatability of groundwater and soils at the East Helena Site including: bench scale treatability testing of groundwater; bench scale testing of chemical fixation of metals in soils; field deep tilling and revegetation experiments on small test plots in areas with elevated soil metals; and bench scale treatability testing of electro-reclamation of soils. Generally, testing indicates that treatment of groundwater by coprecipitation, and soil treatment by chemical fixation is possible on a laboratory scale. Deep tilling resulted in moderate reductions of surface soil metals; however in conjunction with revegetation, deep tilling could help immobilize soil metals. Results of preliminary testing of soil metals removal by electro-reclamation suggest this technique may not be effective on East Helena area soils.

CONCLUSIONS

Based on the result of the Comprehensive Feasibility Study, the following implementation of remedial actions are recommended:

Process Fluid Circuits

The process circuit remedial actions would consist of replacement of existing pressure lines, drains and sumps with a new process water transportation network. Secondary containment and leak detection systems will be included in the replaced system.

Groundwater

The groundwater remedial action would consist of continued monitoring using the existing groundwater monitoring well network. With the implementation of process pond alternatives for Lower Lake, the speiss granulating pond and pit, the acid plant water treatment facility and former Thornock Lake as described in the Process Ponds RI/FS, and replacement of the process fluid circuits described above, arsenic sources to groundwater would be isolated or removed and groundwater quality is expected to improve. Monitoring will provide necessary information to evaluate the effectiveness of process fluid remedial actions.

Surface Soil/Surface Water

Plant Site Soils

Plant site soils remedial actions would consist of soil pH adjustment and paving to prevent potential migration of metals to groundwater, and drainage controls to prevent off site runoff. The ore storage and handling building is already constructed and will reduce airborne lead particulates.

East Helena Residential Soils

Remedial actions for East Helena residential area soils would consist of paving exposed alleyways and unpaved streets to reduce dust, sodding areas with sparse lawn cover, and excavation of soil in vegetable and flower garden plots.

Helena Valley Soils

Remedial actions for areas east of the plant with elevated soil metals consist of fencing to prohibit access and subsequent exposure. Public education would be implemented to ensure the public is aware of the potential hazards of entering the fenced areas.

Prickly Pear Creek

No action would be implemented for Prickly Pear Creek. The RI did not demonstrate impacts other than slight arsenic loading associated with Lower Lake, which were addressed by the Process Ponds RI/FS.

Wilson Ditch

The recommended remedial action for Wilson Ditch consists of backfilling 4000 feet of the ditch below the plant to prevent potential exposure to metals in bottom sediments. An alternate creek diversion lift station would provide irrigation water to downstream users of the existing ditch north of the backfilled portion.

Vegetation

With the implementation of soil removal of garden plots and replacement with clean soil, no action would be required for garden vegetables. Public education has already been implemented as an interim measure for residential gardens. Continued public education concerning elevated metals in grain grown near the plant would be implemented.

Cattle

Because metal concentrations in cattle muscle tissue were within typical values cited by the USDA, no action is required. Public education should be implemented to notify the public of elevated cadmium in kidney and liver in both East Helena cattle as well as cattle from outside the area potentially impacted by the plant.

Fish

No action is required for fish because metals concentrations were generally low and typical for fish in Montana.

Waterfowl

No action is required for waterfowl because the potential risk to human receptors is very low.

Slag Pile

No action is necessary for remediation of the slag pile. The RI showed slag does not have a significant impact to groundwater, surface water or air quality.

Ore Storage Area

Ore storage remedial actions are addressed as part of plant site soils actions above.

COMPREHENSIVE REMEDIAL INVESTIGATION/FEASIBILITY STUDY
ASARCO INCORPORATED
EAST HELENA, MONTANA

1.0 INTRODUCTION

A Comprehensive Remedial Investigation/Feasibility Study Work Plan (RI/FS Work Plan) for the East Helena site was submitted by ASARCO Incorporated (Asarco) to the United States Environmental Protection Agency (EPA) in September 1987. This plan addressed the entire East Helena Site (including plant site and off-plant site) on an operable unit basis. The operable units delineated for the East Helena Site are: process fluids, groundwater, surface water, slag pile and the ore storage area. Asarco received final approval of the RI/FS Work Plan from EPA on November 30, 1987.

As described in the Comprehensive RI/FS Work Plan, the process fluids operable unit consists of two subunits; the process ponds, and the process fluid transport circuits. Asarco has expedited the remedial investigation (RI) and feasibility study (FS) for the process pond subunit. The final Process Ponds RI/FS report was submitted by Asarco to EPA on September 8, 1989. The Record of Decision (ROD) for the process ponds subunit was completed by the EPA in November, 1989. The remaining operable units are addressed in this Comprehensive RI/FS report.

1.1 SITE DESCRIPTION AND HISTORY

The Asarco East Helena Plant is located adjacent to Prickly Pear Creek, just south of the community of East Helena (Figure 1-1-1). The plant, which has operated for 100 years, recovers base metals from ore concentrates using pyrometallurgical processes. The plant is a primary lead smelter and has also recovered zinc in the recent past.

Major features at the plant include: the slag pile, ore storage areas and water storage ponds. Figure 1-1-2 is an air photo of the East Helena Plant identifying its major features.

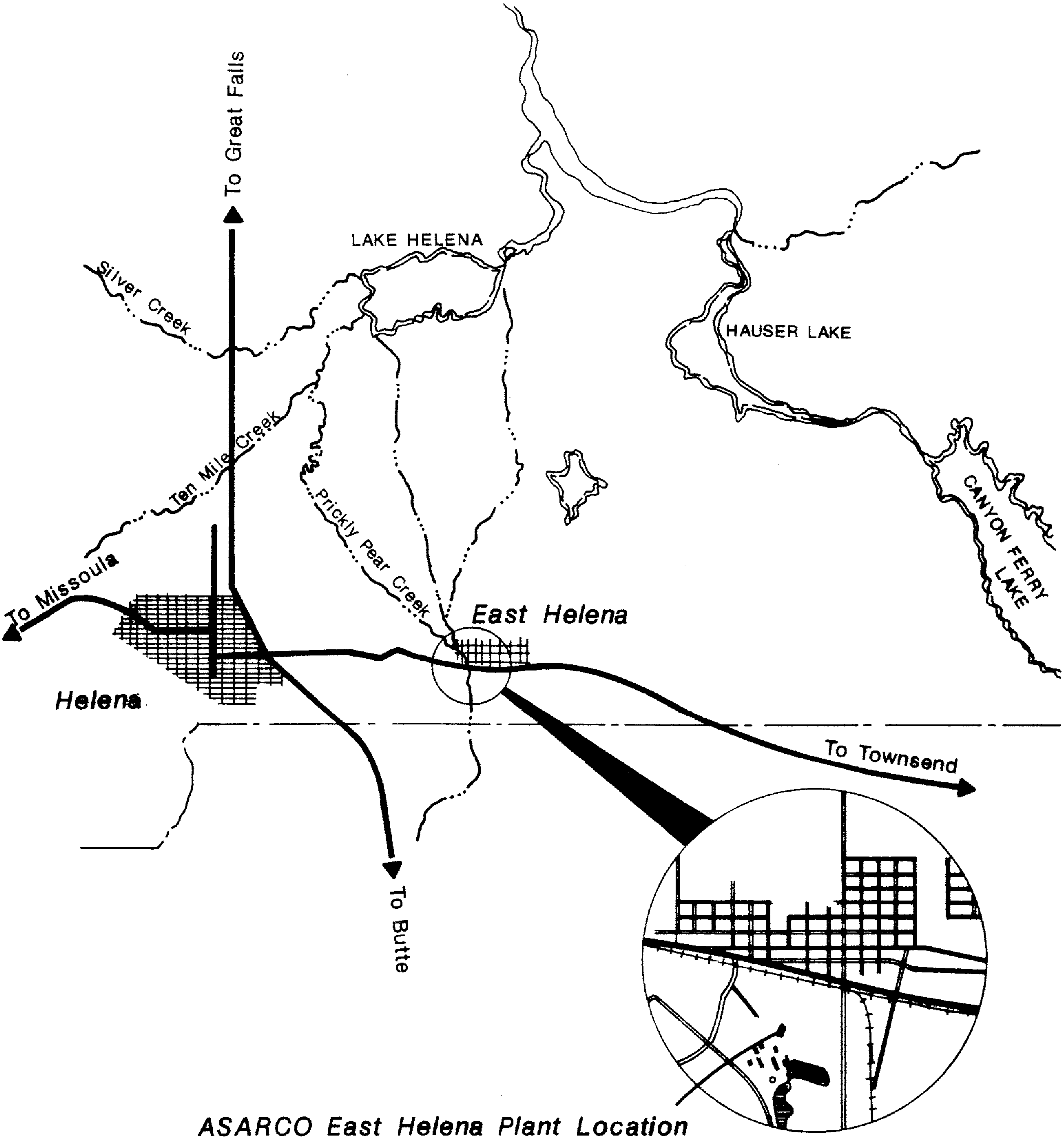
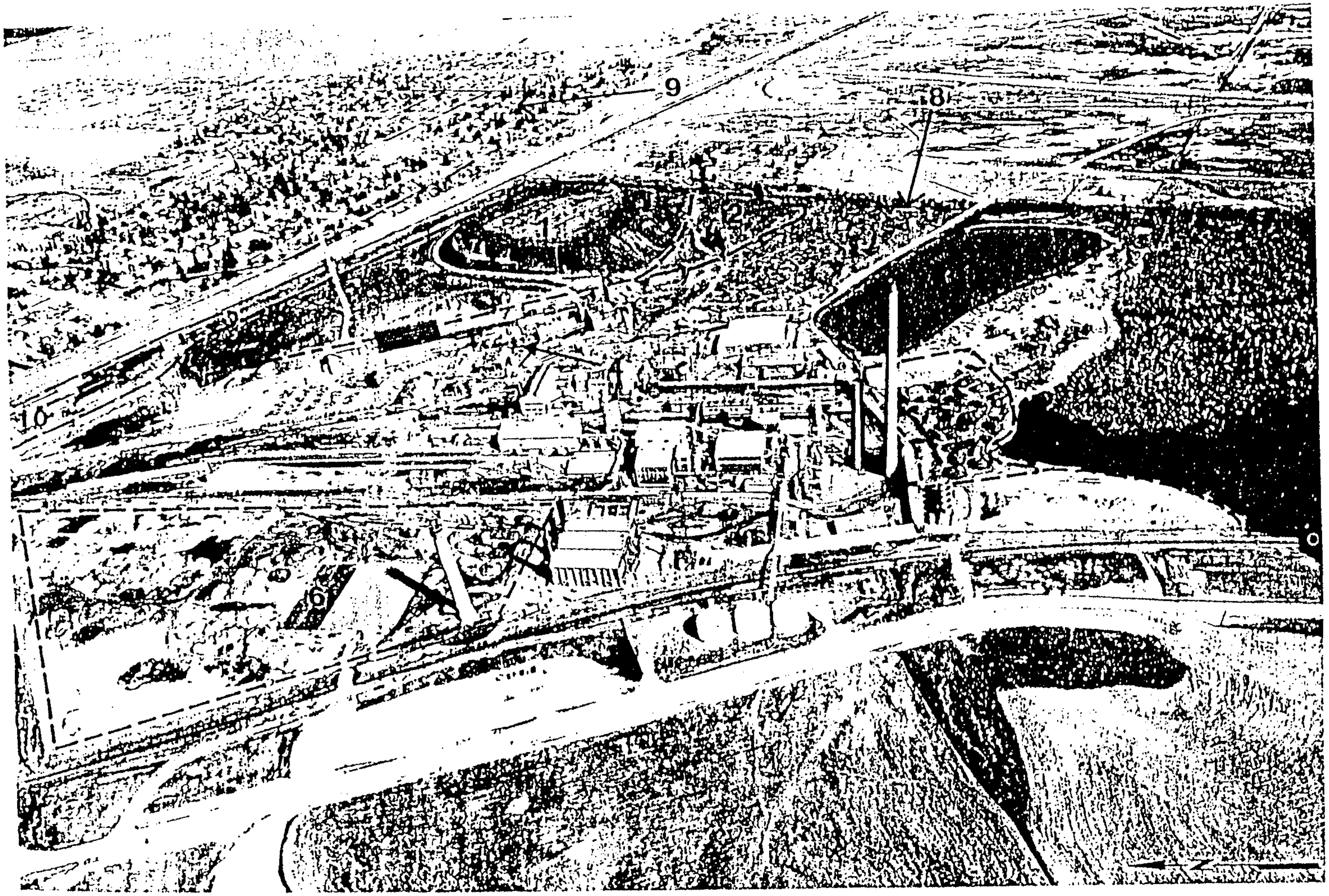


Figure 1-1-1: Location Map



Source of Photo: ASARCO Corp. Photo, 1980

LEGEND

1) FUMED SLAG PILE
2) UNFUMED SLAG PILE
3) LOWER LAKE
4) FORMER THORNOCK LAKE
5) UPPER ORE STORAGE AREA
6) LOWER ORE STORAGE AREA
7) UPPER LAKE
8) PRICKLY PEAR CREEK
9) EAST HELENA
10) AMERICAN CHEMET

Figure 1-1-2: Air Photo of ASARCO East Helena Plant Site Area

1.1.1 Hydrogeology

The East Helena Plant is located on the southern edge of the Helena Valley. This 100-square mile intermontane basin is filled with sediments of Tertiary and Quaternary geological age. Prickly Pear Creek has deposited a large, north sloping, alluvial fan from its entry point on the south side of the valley. Surface water and groundwater in the East Helena Plant area flow from south to north, exiting in the northeastern corner of the Helena Valley into Lake Helena (Hydrometrics, 1986a).

The deposits of Tertiary age are often referred to as "lake beds" and consist of gray and tan clays and silts with occasional sand and gravel layers (Lorenz and Swenson, 1951). Schmidt (1986) describes these Tertiary deposits as older stream and lake deposits consisting of gravel, sand, silt, clay, bentonite and volcanic ash and states they may be more than 500 meters (approximately 1,600 feet) thick in the central part of the Helena Valley. In the central Helena Valley, these deposits commonly are overlain by up to 200 feet of unconsolidated, stream-deposited Quaternary alluvium consisting of layers and mixtures of silt, sand and gravel from tributary drainages including Ten Mile Creek, Last Chance Gulch and Prickly Pear Creek. The Helena Valley is bounded by Precambrian metasedimentary rocks, Paleozoic and Mesozoic age sedimentary rocks, and igneous rocks of Tertiary age.

Layers and mixtures of Quaternary silt, sand and gravel in the Helena Valley form a complex, but generally hydraulically interconnected, system of unconfined and semi-confined aquifers. Shallow clay layers may restrict vertical movement of groundwater from shallow to deeper zones (Moreland and Leonard, 1980). Generally, the underlying Tertiary-age deposits are less permeable than the overlying Quaternary sands and gravels and usually contain groundwater under confined or semi-confined conditions.

The East Helena Plant is located on unconsolidated Quaternary alluvium from the Prickly Pear Creek drainage, which is underlain by fine-grained Tertiary deposits. These Tertiary deposits consist mainly of yellow-white to light-gray, compact, silicaceous, volcanic ash. Tertiary ash deposits are well exposed in a road cut along U.S. Highway 12 about one-half mile west of East Helena (Schmidt, 1986) and are also exposed in an outcrop near the Helena Airport's southeastern boundary, about 2 miles west of East Helena. Surficial geology of the East Helena area is shown in Figure 1-1-3.

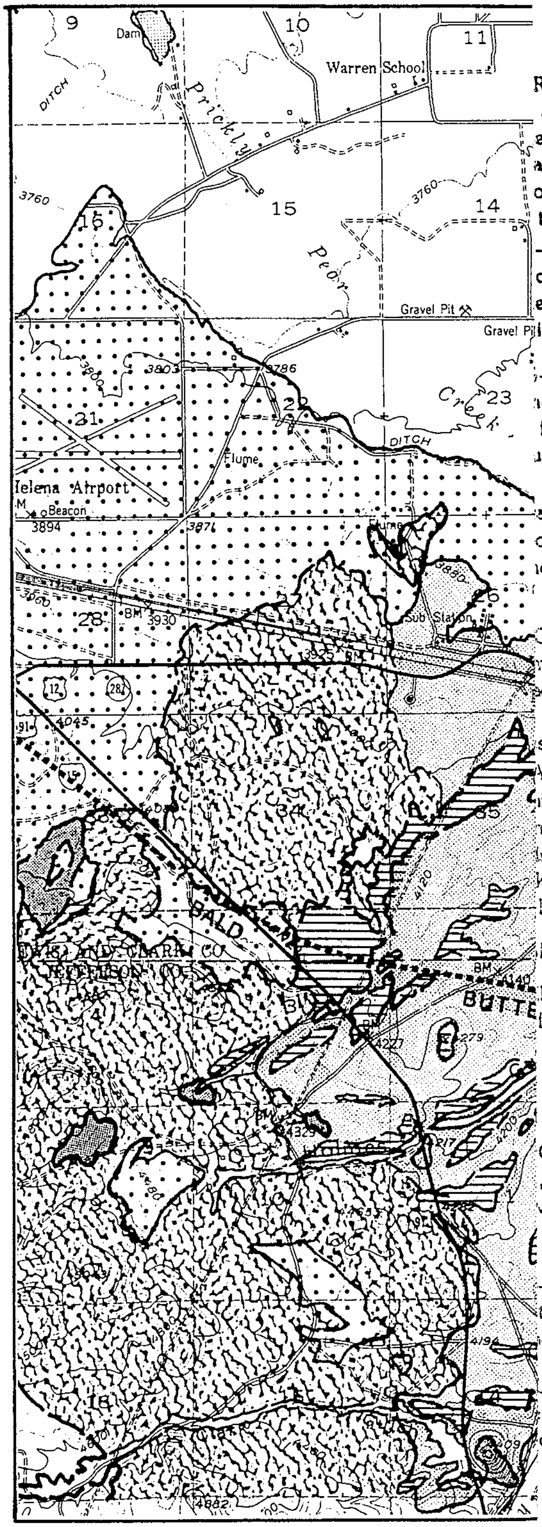
1.1.2 Soils

Soils in the East Helena area are described in the EPA's draft RI report for soils, crops and livestock (EPA, August 1986d). Soils in the Helena Valley developed on valley fill derived from surrounding mountain ranges, and on lake sediments of Tertiary age. The silt and clay soils are moderately calcareous and have little organic matter. Soil profiles are only poorly to moderately developed. Soils in the Canyon Ferry Lake area, to the east of Helena, are rich in tuffaceous materials of volcanic origin. The grassland soils are alluvial mollisols, inceptisols, and entisols. The forest soils can generally be defined as alfisols.

1.1.3 Climate

The climate of the Helena Valley, including the East Helena Plant area, may be described as modified continental. Modifying characteristics include invasion by Pacific Ocean air masses, drainage of cool air into the valley from surrounding mountains, and protecting mountains in all directions. Seasons typically consist of cold winters, wet springs, and warm summers with moderate thunderstorm activity. Much of the moisture in the area comes in the form of late spring and early summer rain and there are significant winter snow accumulations at higher elevations. There are no site specific precipitation and evaporation data from the East Helena Plant prior to 1986. However, the U.S. Weather Bureau station at the Helena Airport, approximately three miles from the East Helena Plant has been collecting meteorological data since the early 1900's. In 1986, collection of precipitation and wind data was initiated by Asarco on the East Helena plant site. Evaporation data has been collected since May of 1987 when a Class A evaporation station was installed adjacent to Lower Lake.

Mean monthly temperatures during the period 1951 to 1980 recorded at the U.S. Weather Bureau station in Helena, are in Figure 1-1-4. Average



Refuse fill in old city trash dump northwest and piles of smelter slag at East Helena.
ed and unstratified, loosely compacted,
as much as 3 m thick; smelter slag unsorted
oderately well compacted, uncemented, and
thick

—Piles of coarse, washed gravel, commonly
constituting waste rock from placer-mining
ed and unstratified; loosely compacted and
imum thickness about 6 m

—Gravel, sand, silt, and clay in stream beds,
id in alluvial fans; mostly well sorted sandy
firmly compacted; uncemented to weakly
um thickness unknown but probably as much

avel, sand, silt, and clay on steep to gentle
orly sorted clayey gravel; loosely to firmly
ented to weakly cemented; maximum thick-
probably as much as 6 m

Gravel, sand, silt, and clay on terrace surfaces
ns, in ancient alluvial fans, and on remnants
ces; mostly poorly to moderately well sorted
firmly compacted and weakly cemented;
ss about 20 m

ND LAKE DEPOSITS—Gravel, sand, silt,
ite, and volcanic ash, well-sorted and evenly
npacted, weakly to moderately well cement-
s and becomes plastic when wetted; maxi-
known but probably more than 500 m thick
Helena Valley

EDROCK

DROCK—Limestone, dolomite, shale, and
firm, and dense; permanently and strongly

CK—Mostly coarse grained crystalline granitic
, and dense; permanently and strongly
weathered to loose granular soil

—Dashed where inferred; dotted where
thrown side; D, downthrown side; queried
certain

T—Arrows show inferred relative direction
ment. Dashed where inferred; dotted where
d where location uncertain

Figure 1-1-3. Map of East Helena Quadrangle, Montana, Showing Distribution of Surficial Deposits and Bedrock

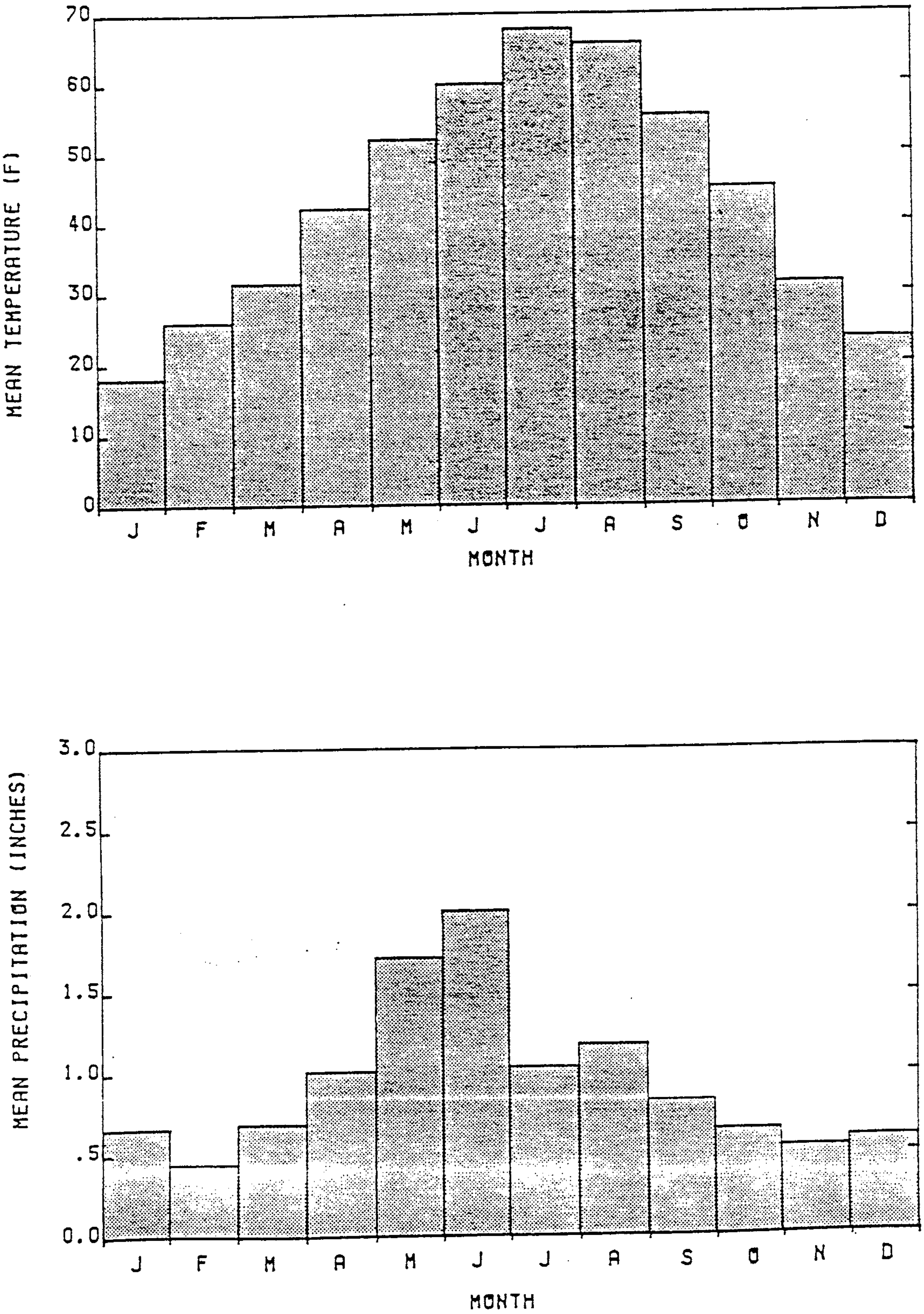


Figure 1-1-4: Mean Monthly Temperatures and Precipitation at Helena (1951-1980)

SOURCE OF INFORMATION: U.S. Department of Commerce monthly maximum and minimum temperatures measured during 1951 to 1980 were 67.9°F in July and 18.1°F in January.

Total precipitation varies widely throughout the Helena area, from a semi-arid total of less than 10 inches in the northern and eastern portions of the valley, to a sub-humid 30 inches or more along the Continental Divide to the west. Monthly precipitation totals for the period 1951 to 1980 and the period 1983 through 1988 are shown in Figure 1-1-4 and Table 1-1-1, respectively. The greatest amount of precipitation normally occurs in May and June, with precipitation fairly evenly distributed throughout the remainder of the year. Precipitation occurs primarily as snow from November through March and primarily as rain the remainder of the year.

Mean annual evaporation for shallow lakes and reservoirs, estimated by the U.S. Soil Conservation Service (1974) for the Helena area, is approximately 36 to 38 inches. This publication, however, provides no information on seasonal distribution. Table 1-1-2 contains evaporation data for the months May through October, 1980 through 1985, measured at the U.S. Weather Bureau station near Canyon Ferry reservoir east of Helena. Evaporation and precipitation data for the months May through October, 1987 and 1988, from the evaporation station located on the East Helena Plant site is in Appendix 1-1 and evaporation data are summarized in Table 1-1-3. Highest evaporation for both stations occurs in July and August with monthly totals from seven to eleven inches. Data on wind speed and direction has been collected at the East Helena Plant as part of the Montana State Implementation Plan (SIP) for particulates in the East Helena area. Results of this air wind speed and direction data are summarized in Appendix 1-2. In the East Helena area, wind direction is from the south the majority of the time. Westerly winds are the next most common wind direction. Highest wind speeds also occur from the west.

Comparison of data from the Canyon Ferry weather station and the East Helena Plant shows the East Helena Site has more evaporation with monthly differences as much as 3 inches.

TABLE 1-1-1. MEAN MONTHLY PRECIPITATION AT HELENA, MONTANA 1980-1989

Month	1951-1980 Average	1983	1984	1985	1986	1987	1988	1989
January	0.66	0.24	0.17	0.16	0.32	0.00	0.27	1.42
February	0.44	0.07	0.15	0.38	1.20	0.03	0.50	0.82
March	0.69	0.36	0.49	0.32	0.49	1.18	0.45	1.35
April	1.01	0.29	1.45	0.46	1.08	0.76	1.32	0.72
May	1.72	1.79	1.03	0.75	0.83	1.90	1.82	1.00
June	2.01	2.20	2.14	0.08	1.56	1.50	1.50	1.79
July	1.04	3.48	0.11	0.10	1.37	2.88	0.36	1.55
August	1.18	2.67	1.11	2.64	1.84	0.38	0.02	1.61
September	0.83	1.56	0.73	2.11	2.45	0.80	2.09	1.31
October	0.65	0.35	0.74	0.76	0.03	0.05	0.69	0.54
November	0.54	0.26	0.47	0.84	0.54	0.12	0.69	0.26
December	0.60	0.76	0.41	0.35	0.38	0.42	0.32	0.48
Annual	11.37	14.03	9.00	8.95	12.09	10.03	10.03	12.85

*Station Helena WSO AP

NA = Not Available

Source: U.S. Department of Commerce. Climatological Data Annual Summary for Montana, 1980-1989. NOAA

TABLE 1-1-2. EVAPORATION DATA FOR HELENA, MONTANA 1980-1989

Year	May	June	July	August	Sept.	Oct.	Total
1989	--	6.80	8.41	5.70	NA	NA	NA
1988	5.57	7.94	10.25	8.18	4.27	--	36.21
1987	5.18	7.71	6.57	6.55	4.79	--	30.80
1986	--	6.38	7.00	6.94	2.90	1.85	25.07
1985	--	7.90	9.21	5.36	3.0	--	25.47
1984	--	5.52	8.14	7.38	4.24	--	25.28
1983	--	5.79	6.41	6.02	3.99	--	22.21
1982	4.59	4.88	7.51	8.39	4.48	1.55	31.40
1981	--	5.88	8.14	7.90	4.73	--	26.65
1980	5.26	5.32	7.06	6.37	3.78	--	27.79
Average	5.15	6.41	7.87	6.88	4.96	1.70	27.87

NA = Not Available

Source: U.S. Department of Commerce. Climatological Data Annual Summary for Montana, 1980-1989, NOAA

Station located at Canyon Ferry Dam.

TABLE 1-1-3 AEH EVAPORATION PAN DATA SUMMARY (INCHES)

	May	June	July	Aug	Sept	Oct	Total
1987	0.97[1]	10.63	9.81	7.93	4.92	1.36[2]	35.62
1988	4.05[3]	10.09	10.54[4]	10.54[4]	3.48[5]	--	38.70

[1] Starting May 18

[2] Ending October 7

[3] Starting May 20

[4] Extrapolated data

[5] Ending September 22

1.1.4 Water Resources

The Helena Valley is part of the Missouri River basin. Several major reservoirs, including Canyon Ferry Lake, Hauser Lake, Holter Lake and Lake Helena are located near the northern extent of the Helena Valley and are part of the Missouri River system (Figure 1-1-1). Major streams that enter the Helena Valley, including Prickly Pear Creek, drain into Lake Helena.

Groundwater in the Helena Valley generally moves north and east toward Lake Helena, which is a discharge point for the valley groundwater system (Wilke and Coffin, 1973). Groundwater recharge in the Helena Valley comes from precipitation on the valley floor and surrounding mountains and from streams and irrigation canals that cross the valley floor. These streams and canals generally lose significant quantities of surface water into the underlying groundwater system.

In the vicinity of the East Helena Plant, groundwater in the unconsolidated Quaternary deposits generally flows to the north and receives recharge from Prickly Pear Creek as the stream enters the valley near East Helena (Figure 1-1-1).

Surface water resources in the East Helena Plant area include Prickly Pear Creek and several small ponds and lakes (Figure 1-1-5). Prickly Pear Creek flows along the east and north boundaries of the East Helena Plant. This perennial stream has its headwaters in the Elkhorn and Boulder Mountains about 30 miles south and west of the plant. Prickly Pear Creek drains into Lake Helena approximately seven miles north of the plant site.

Other surface water features at the East Helena Plant site include Upper Lake, Lower Lake and Wilson Ditch. Lower Lake was used for collection and storage of process waters. Upper Lake receives flow from a diversion on Prickly Pear Creek about one-half mile south of the plant. Upper Lake provides plant make-up water and supplies irrigation water to Wilson Ditch. Flow into Wilson Ditch is controlled with a headgate at Upper Lake; water enters an underground pipeline and travels a distance of

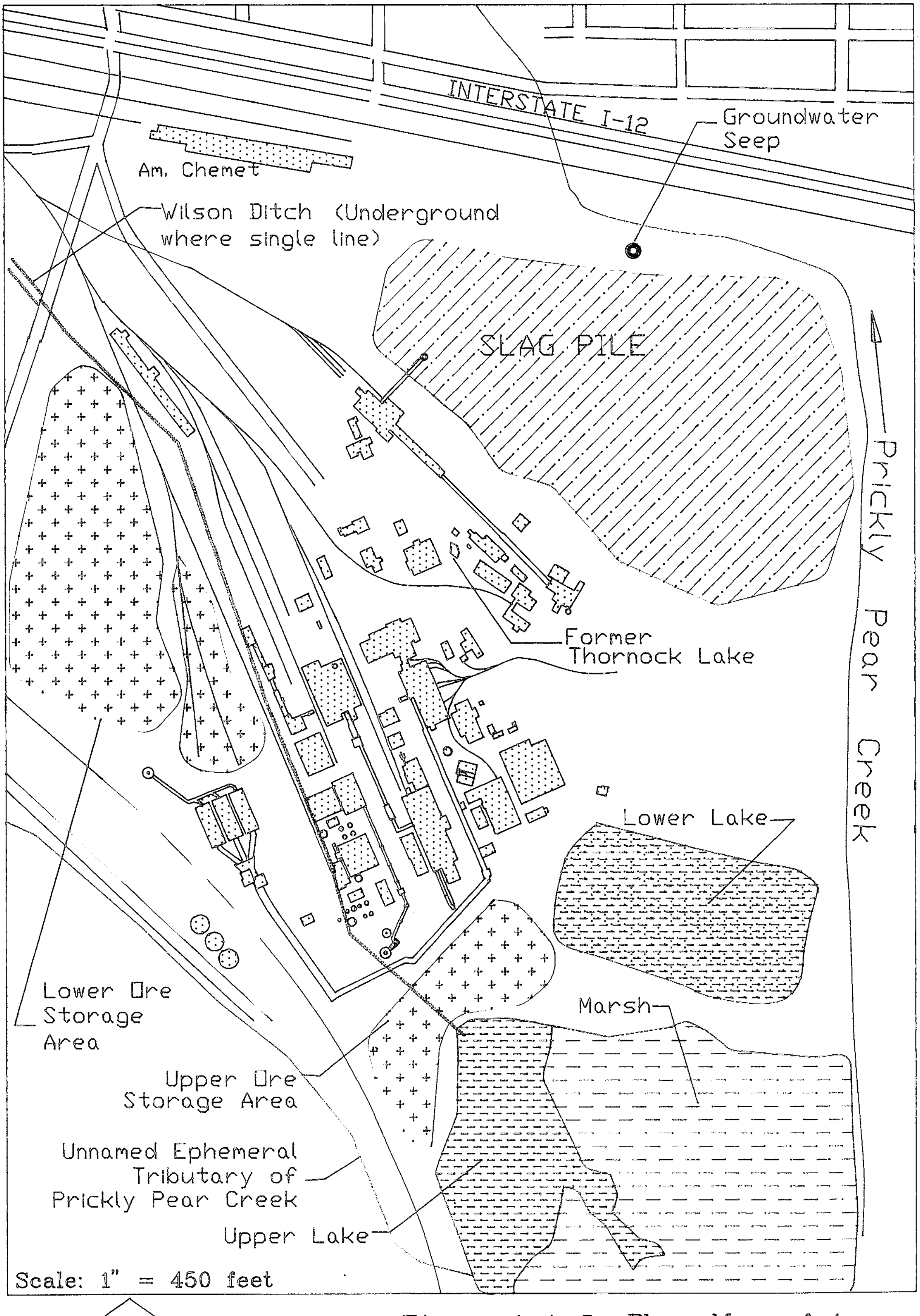


Figure 1-1-5: Plan Map of Asarco East Helena Plant Area

2,300 feet beneath the plant and then surfaces in an open ditch at the western property boundary.

1.2 PREVIOUS INVESTIGATIONS

Geology and hydrology of the Helena Valley area have been described in a number of previous reports. Descriptions of the Helena area geology are detailed in Pardee and Schrader (1933), Lorenz and Swenson (1951), Knopf (1963) and Schmidt (1977). Earthquake hazards in the Helena Valley are evaluated by Stickney and Bingler (1981), and Schmidt (1986). Groundwater resources in the valley, including water quality, are discussed by Lorenz and Swenson (1951), Wilke and Coffin (1973), Moreland and others (1979), and Moreland and Leonard (1980).

Assessments of groundwater availability for municipal use have been made by Botz (1971) and Hydrometrics (1983 and 1984d). Unconsolidated valley fill deposits in the Helena Valley have been the primary focus of previous groundwater studies.

Prickly Pear Creek is adjacent to the East Helena Plant and has been the subject of numerous studies. Traynor (1969), Pedersen (1977), the Montana Water Quality Bureau (MWQB, 1981) and Baker and Baldigo (1984 and 1985) have assessed impacts to Prickly Pear Creek. These impacts are primarily associated with previous mining activities. Additional groundwater and surface water quality data are on file with the Montana Water Quality Bureau (WQB) and U.S. Geological Survey (USGS).

Water quality samples have been collected by Hydrometrics from Spring Creek, Clancy Creek and several smaller tributaries in the upper Prickly Pear Creek drainage. Results of testing these samples have been reported by Centennial Minerals, Inc. (1984), and are summarized in the Draft Environmental Impact Statement (DEIS) for the Montana Tunnels Project (Montana DSL, 1985). Stiller and Associates (1983) investigated water resources near abandoned metal mines in the Wickes-Corbin Mining District in a tributary to upper Prickly Pear Creek.

The USGS maintains a continuous streamflow recording station on Prickly Pear Creek approximately five miles upstream of East Helena. Streamflow data from this station are summarized annually in the USGS Water Resources Data Volumes for Montana.

Documents previously prepared as part of the East Helena Plant site investigation include:

1) Process Pond Remedial Investigation/Feasibility Study, Draft, by Hydrometrics, September 8, 1989.

2) Treatability Testing Work Plan for the Asarco East Helena Comprehensive Feasibility Study by Hydrometrics and Roy F. Weston, August 1989.

3) Pilot Scale Testing Work Plan for In Situ Treatment of Lower Lake by Hydrometrics, December 1989.

4) Quality Assurance Project Plan for Air Quality Monitoring, ASARCO, Inc., East Helena, Montana by Hydrometrics, January, 1989.

5) Comprehensive Preliminary Feasibility Study, Phase I, Asarco East Helena by Hydrometrics, April 1, 1988.

6) Comprehensive Remedial Investigation/Feasibility Study Plan, Asarco East Helena Plant by Hydrometrics, October, 1987.

7) Process Pond Remedial Investigation/Feasibility Study Work Plan, Asarco East Helena by Hydrometrics, June, 1987.

8) Water Resources Investigation Asarco East Helena Plant Phase II Remedial Investigation Work Plan by Hydrometrics, August 19, 1986.

9) Final Draft Remedial Investigation of Soils, Vegetation and Livestock for Asarco, East Helena Smelter Site by EPA, August 1986.

10) Draft Field Operations Plan (FOP), Wildlife Studies, Phase I RI, Asarco, Montana RI/FS, East Helena, Montana by EPA, July 3, 1986.

11) Report on Water Resources Monitoring Asarco East Helena Plant - Draft by Hydrometrics, February 7, 1986.

12) Final Quality Assurance Program Plan for Phase I RI, Asarco Montana RI/FS (East Helena Smelter) by EPA, June 17, 1985.

13) Quality Assurance Program Plan Asarco East Helena Plant Water Resources Investigation by Hydrometrics, September 21, 1984.

14) Hydrological Investigation of the Asarco East Helena Water Resources Monitoring Plan by Hydrometrics, June 29, 1984.

1.3 PURPOSE AND SCOPE

This report presents data and information obtained during the remedial investigation of all designated operable units at the East Helena Site. With the exception of the process ponds operable sub-unit, information from previous water resources investigation phases (Phase I Water Resources Monitoring; Phase II Water Resources Monitoring) and information from activities performed pursuant to the Comprehensive RI/FS Work Plan are included in this report. Data, information and conclusions for the process ponds operable subunit are in the Process Ponds RI/FS report submitted to the EPA September 8, 1989. Some information from the Process Ponds RI/FS report is included in this report where relevant to the remedial investigation of other operable units.

Data, information and conclusions from the Phase I soils, livestock and vegetation investigation activities are in the Phase I Soils, Vegetation and Livestock RI report (EPA, 1987a). Where relevant, some data from the Phase I Soils RI report are included in this report.

An assessment of Applicable or Relevant and Appropriate Requirements (ARARs) is included in Section 9.0. This section includes an ARARs list and selection of chemical specific ARARs, location specific ARARs, and action specific ARARs for all East Helena Site operable units.

An endangerment assessment addressing all operable units is included in Section 10.0. This assessment considers site exposure mechanisms and toxicity effects on human health and the environment. The assessment is quantitative and considers all potential exposure pathways for the East Helena Site.

This report also includes a feasibility study for all operable units. A preliminary screening (Phase I FS) of remedial action options has already been conducted and was presented in the Comprehensive Preliminary Feasibility Study (Hydrometrics, April 1, 1988a). The Phase II and Phase III Feasibility Study was conducted in accordance with EPA guidelines (October 1988) and is presented in this Comprehensive RI/FS report. This report includes a description of the screening process of post-Phase I alternatives and presents remedial action recommendations. With the exception of the process ponds operable sub-unit, which was addressed in the Process Ponds FS, all operable units are considered in the Feasibility Study presented in this report.

2.0 METHODOLOGY

The Comprehensive Remedial Investigation was conducted in accordance with work plans approved by EPA, including: the Comprehensive RI/FS Work Plan; the Water Resources Investigation (WRI) Phase II RI Work Plan; the East Helena Water Resources Monitoring Plan (Phase I), and the Water Resources Quality Assurance Program Plan (QAPP). Each of the work plans was undertaken in accordance with EPA guidance. Any additions to or modifications of the work plans were implemented only upon approval by EPA. Throughout the study process, every effort has been made to conform to and comply with EPA guidance, methodology and requirements; Asarco does not necessarily agree with all of these guidance documents, methodologies and requirements but has adhered to them as required by EPA.

2.1 PROCESS FLUIDS REMEDIAL INVESTIGATION

The Remedial Investigation/Feasibility Study for the plant process fluids was divided into two sub-units; the process ponds and the process fluids transport circuits.

2.1.1 Process Ponds

The Process Pond Remedial Investigation consisted of:

1) Collection and analyses of water samples from four process fluid ponds: Lower Lake, former Thornock Lake, the speiss granulating pond and pit, and the acid plant water treatment facility. Fluid samples were collected from two sites on Lower Lake (LL-1 and LL-2), and random locations within Lower Lake; one site at the speiss granulating pond (SP-1); and three sample sites associated with the acid plant water treatment facility (AP-1, AP-2 and AP-3); and random points in former Thornock Lake prior to its replacement by a steel recirculation holding tank in fall 1986. Process Pond sample site locations are shown in Figure 2-1-1, sample site photographs are in Appendix 2-1, and Analytical results are in Appendix 2-2.

2) Collection and analyses of bottom sediment samples and stratigraphic samples. Bottom sediment samples were collected from Lower Lake, former Thornock Lake, and the speiss granulating pond. Stratigraphic samples were collected from 14 drill holes in and adjacent to the four process ponds. Drill

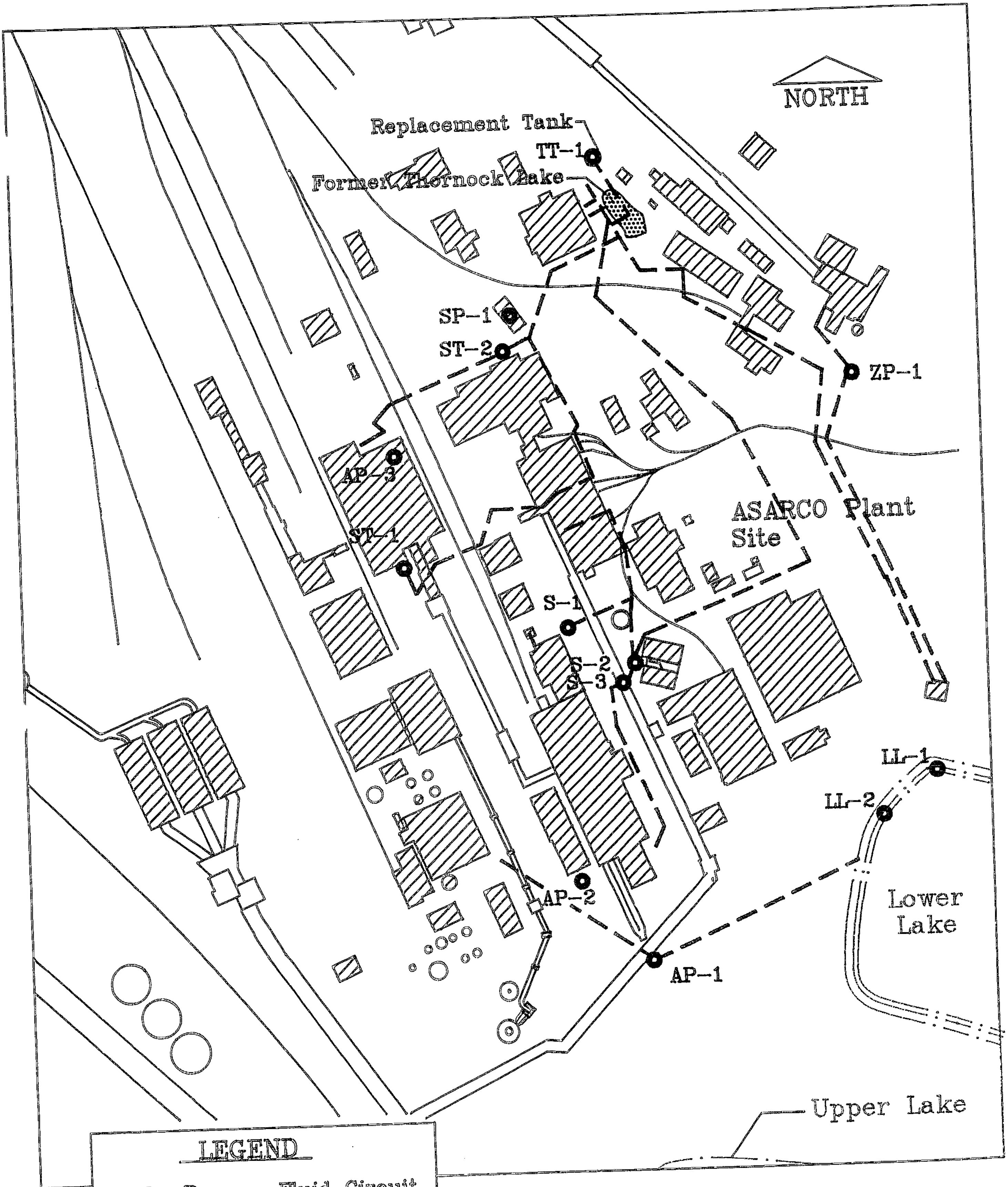


Figure 2-1-1: Process Fluid Circuit Sample Sites

hole locations are shown on Figure 2-1-2. Drill holes and monitoring wells associated with the Process Pond RI are discussed in detail in Section 4.0.

3) A plant water balance investigation to determine the gains or losses of the main plant process circuit into and out of Lower Lake, and to determine the storage capacity for storm runoff containment.

Process fluids sample collection, bottom sediment and stratigraphy sampling, and the water balance investigation were conducted in accordance with methodologies outlined in the Comprehensive RI/FS Work Plan, the Water Resources Monitoring Plan (Phase I), and the QAPP. The methodologies used in the process pond remedial investigation are described in detail in the Process Pond RI/FS report.

2.1.2 Process Fluids Circuits

The Comprehensive RI/FS Work Plan identified four major fluids circuits in the East Helena plant:

1. the main plant process water circuit;
2. the acid plant and sinter plant circuit;
3. the blast furnace and dross plant; and
4. the City of East Helena municipal water supply.

A general plant water-system layout is in Exhibit 10.

The components of each of these major fluids circuits are described below.

<u>The Main Plant Process Water Circuits</u>

The main plant process water distribution system consists of several components:

1) <u>The process water distribution system</u>. The main plant process water distribution system is the major pressurized transport circuit in the plant. This system supplies water from above ground storage tanks under high pressure to the various plant processes (tanks were recently constructed to replace Lower

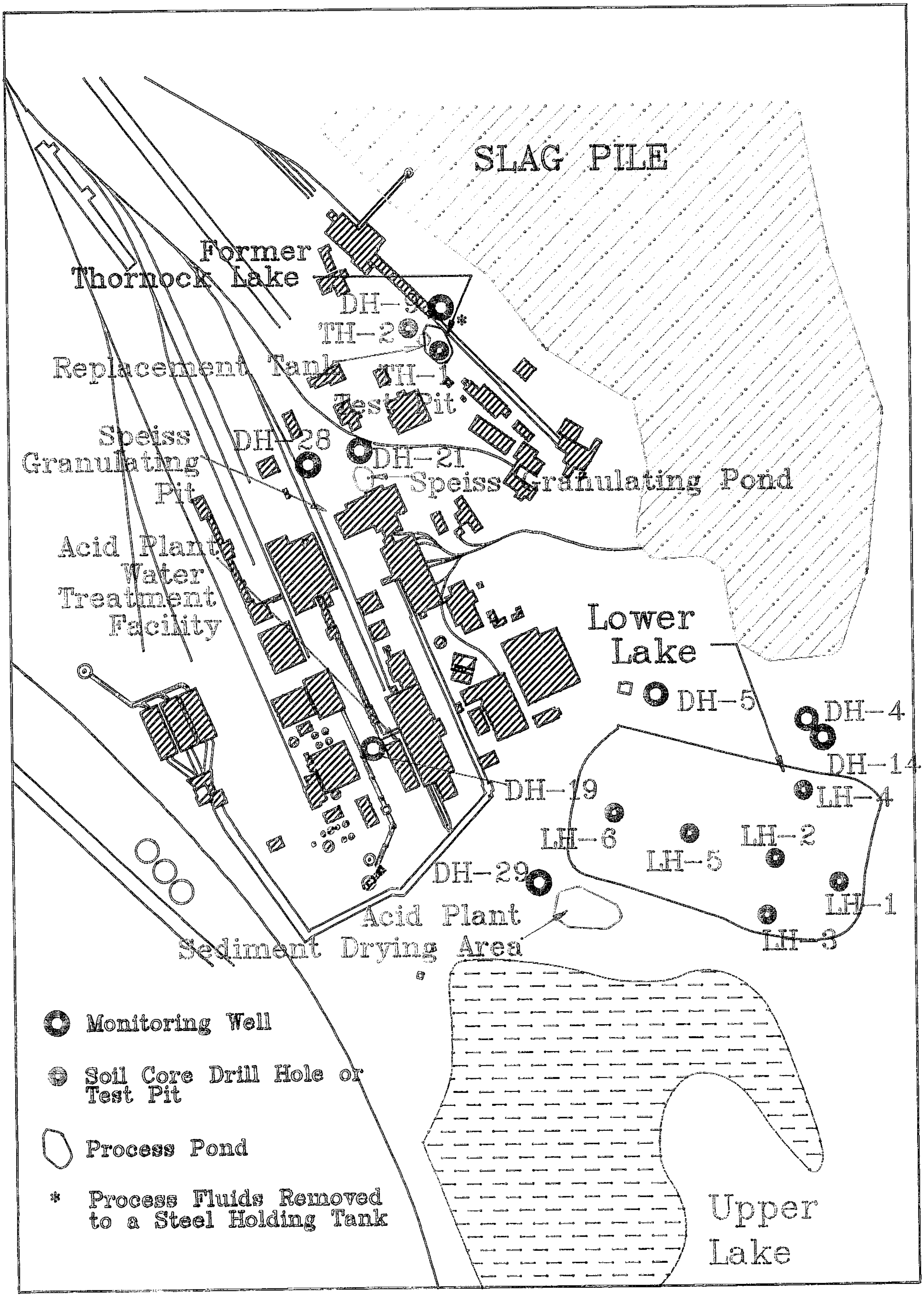


Figure 2-1-2: Process Pond Drill Holes and Monitoring Wells

Lake as part of process ponds remedial actions. Details are described in the Process Ponds RI/FS). Major uses of process waters are for washdown, cooling, fire protection, plant area dust suppression, and ore storage area dust suppression.

2) <u>Process water drain collection system</u>. A system of concrete or PVC sumps and drains collects process waters after use for washdown, coolant, or plant area dust suppression (see Exhibit 10). Process water from the north end of the plant drains directly to Thornock Tank (sample site TT-1, see Section 2.1.2.1) near former Thornock Lake. The remaining portion either drains or is pumped to a sump (S-2) near the main pumphouse. This sump serves as a collection point for a number of drains, and overflows into a 12-inch PVC pipe to Thornock Tank. Water from Thornock Tank is then pumped to the Lower Lake replacement tanks for cooling and suspended sediment settling. Major inputs to the main process water drain system are: acid plant washdown, sinter plant washdown, the truck wash sump (TW-1, see Section 2.1.2.1), the ore storage and mixing area, collection system pipelines, the sump near the main pumphouse (sample site S-2, see Section 2.1.2.1), and Thornock Tank.

Acid Plant and Sinter Plant Circuit

Components of the acid plant and sinter plant circuits are: the acid plant water treatment facility, the scrubber pads and scrubber drains, and the acid plant water treatment plant return lines to the sinter plant. Water scrubbers and electrostatic precipitators in the acid plant remove dust from gases produced in the sintering process. Acidic fluids resulting from the scrubbing process drain by gravity from the scrubber pads, through the scrubber drain line, to the acid plant water treatment facility. Particulates in these fluids are removed through a series of settling dumpsters and a large settling pond (see the Process Pond RI/FS report.) After the particulates have been removed, and the pH neutralized, some of the fluid is pumped to the sinter plant for use, with the remainder recirculated in the scrubbing process.

Acid Plant and Dross Plant Circuit

The blast furnace/dross plant circuit is a closed loop system. Water in this circuit is used for furnace water jackets, and for bearing and flue cooling. A small amount of makeup water is added from the main process water circuit.

City of East Helena Potable Water Supply

Potable water is supplied by the City of East Helena to the plant in a four-inch-diameter line (see Exhibit 10). The majority of this flow is used for lavatories and drinking fountains, and exits the plant via the City of East Helena sanitary sewer system. A portion of the city water is used in the changehouse, the sample mill (Exhibit 10) and for freeze-prevention bleeders discharges to the main process water system.

The process fluids circuits remedial investigation consisted of the following major components as described in the Comprehensive RI/FS Work Plan:

1) Sample collection and analysis of water and sediment in the main plant process fluids circuit drains to determine water quality.
2) Main process fluid pressure line leakage tests.
3) Assessment of leakage from the main process water collection drain system.

2.1.2.1 Process Fluid Circuit Water Quality

Water samples from the process fluid circuits were collected in accordance with methodologies outlined in the Comprehensive RI/FS Work Plan and the QAPP. As part of the process fluid circuit investigation, fluid samples were collected from eight drain or sump sites (AP-1, S-1, S-2, S-3, ST-1, ST-2, TT-1 and ZP-1). Sample site locations are shown in Figure 2-1-1, sample site descriptions are in Table 2-1-1, and sample site photographs are in Appendix 2-1.

Table 2-1-2 summarizes water sampling from the process fluid circuit drains and includes analytical schedules and sample collection dates. The parameter lists for process fluid circuit sampling is in Table 2-1-3 and analytical results are in Appendix 3-1.

TABLE 2-1-1. PROCESS FLUID SAMPLING SITE DESCRIPTION

Sampling Site	Description	Location
AP-1	Acid Plant drain	South of blast furnace flue
S-1	Ore Mixing Area drain sump	Near northeast corner of Breaking Floor building
S-2	South Plant collection sump	West of Main Plant pumphouse
S-3	Ore Mixing Area drain sump	West of S-2 under blast furnace flue
ST-1	Sinter Plant drain sump	South of Sinter Plant
ST-2	Sinter Plant drain sump	North of Drossing Plant building
TT-1	Thornock Tank	Northeast of Changehouse
ZP-1	Zinc Plant drain	South of Zinc Plant furnace building

Table 2-1-2 SUMMARY OF PROCESS FLUID CIRCUIT WATER SAMPLING

SITE DESCRIPTION	SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE
Acid Plant Drain	AP-1	10-20-87	C**	DOES	No
	AP-1	10-20-87	C*	WYRHR	No
	AP-1	11-4-87	C	DOES	NO
	AP-1	11-17-87	P	DOES	NO
	AP-1	11-17-87	C+SP	RMAL	NO
	AP-1	11-30-87	C	DOES	YES
	AP-1	12-15-87	C	DOES	NO
Ore Mixing Area Drain Sump	S-1	1-13-87	C***	DOES	NO
	S-1	1-21-87	C***	DOES	No
	S-1	5-14-87	C***	CHMTC	No
	S-1	5-14-87	C***	DOES	No
	S-1	10-21-87	C*	DOES	No
	S-1	11-6-87	C	DOES	No
	S-1	11-18-87	C	DOES	No
	S-1	11-18-87	C+SP****	RMAL	No
	S-1	11-30-87	C	DOES	No
	S-1	11-30-87	C*	WYRHR	No
	S-1	12-15-87	C	DOES	No
South Plant Collection Sump	S-2	12-30-86	C***	DOES	No
	S-2	12-30-86	C***	CHMTC	No
	S-2	5-14-87	C***	CHMTC	No
	S-2	5-14-87	C***	DOES	No
	S-2	10-20-87	C**	DOES	YES
	S-2	11-6-87	C	DOES	NO
	S-2	11-18-87	C+SP****	RMAL	YES
	S-2	11-18-87	C(3)	DOES	YES
	S-2	12-1-87	C****	WYRHR	YES
	S-2	12-1-87	C	DOES	YES
	S-2	12-15-87	C	DOES	NO
Ore Mixing Area Drain Sump	S-3	10-20-87	C+BS**	DOES	NO
	S-3	10-20-87	C**	WYHRH	NO
	S-3	11-6-87	C	DOES	No
	S-3	11-18-87	C(3)	DOES	No
	S-3	11-18-87	C+SP****	RMAL	No
	S-3	12-1-87	C	DOES	NO
	S-3	12-15-87	C	DOES	YES

Table 2-1-2 SUMMARY OF PROCESS FLUID CIRCUIT WATER SAMPLING (continued)

SITE DESCRIPTION	SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE
Sinter Plant Drain Sump	ST-1	12-30-86	C***	DOES	No
	ST-1	2-20-87	C***	DOES	No
	ST-1	5-13-87	C***	DOES	No
	ST-1	5-13-87	C***	CHMTC	NO
	ST-1	5-14-87	C***	DOES	NO
	ST-1	10-21-87	C	DOES	No
	ST-1	11-4-87	C	WYRHR	NO
	ST-1	11-4-87	C*	DOES	YES
	ST-1	11-17-87	C	DOES	NO
	ST-1	11-17-87	C+SP****	RMAL	NO
	ST-1	11-30-87	C	DOES	NO
	ST-1	12-15-87	C	DOES	NO
Sinter Plant Drain Sump	ST-2	10-21-87	C+BS**	DOES	No
	ST-2	10-21-87	C**	WYRHR	No
	ST-2	11-6-87	C	DOES	No
	ST-2	11-19-87	C(3)	DOES	No
	ST-2	11-19-87	C+SP****	RMAL	No
	ST-2	12-1-87	C	DOES	No
	ST-2	12-15-87	C	DOES	YES
	ST-2	12-15-87	C**	WYRHR	YES
Thornock Tank	TT-1	10-20-87	C+BS**	DOES	No
	TT-1	10-20-87	C**	WYRHR	
	TT-1	11-4-87	C	DOES	No
	TT-1	11-18-87	C	DOES	No
	TT-1	11-18-87	C**	RMAL	
	TT-1	12-1-87	C	DOES	No
	TT-1	12-15-87	C	DOES	No
Zinc Plant Drain	ZP-1	10-21-87	C**	DOES	No
	ZP-1	10-21-87	C**	WYRHR	No
	ZP-1	11-4-87	C	DOES	No
	ZP-1	11-17-87	C(3)	DOES	No
	ZP-1	11-17-87	C+SP****	RMAL	No
	ZP-1	11-30-87	C	DOES	No
Truck Wash Sump	TW-1	5-13-87	C***	DOES	No
	TW-1	5-13-87	C***	CHMTC	No
Speiss Granulating Circuit	SP-2	5-13-87	C***	DOES	No
	SP-2	5-13-87	C***	CHMTC	No

Table 2-1-2 SUMMARY OF PROCESS FLUID CIRCUIT WATER SAMPLING
(continued)

SITE DESCRIPTION	SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE

NOTES:

(1) C = Complete analysis. Additional field parameters were measured as part of the process pond RI activities-October through December 1987 (See Table 2-2).
P = Partial analysis.
SP = Special analysis.
BS = Bottom sediment analysis.
(See Table 2-1-2 for the lists of parameters for process pond analysis.

(2) See Table 2-1-3 for the analytical parameter list.

(3) Special suite of metals were analyzed by the EPA CLP laboratory. Metals analysis by the Asarco DOES laboratory not required.

* = EPA split CLP laboratory analysis with common ions analyzed as both total and dissolved. Only dissolved common ions were required by the Comprehensive RI/FS Work Plan.

** = Asarco DOES laboratory analysis with common ions analyzed as both total and dissolved. Only dissolved common ions were required by the Comprehensive RI/FS Work Plan.

*** = Sample was collected prior to establishment of criteria in the Comprehensive RI/FS Work Plan.

**** = Anions were not analyzed by the EPA CLP laboratory.

TABLE 2-1-3. PROCESS FLUID SAMPLE PARAMETER LIST

COMPLETE ANALYSIS*

Specific Electrical
  Conductivity (field and lab)
Total Dissolved Solids (TDS)
Total Suspended Solids (TSS)
Dissolved Oxygen

Calcium (Ca)
Magnesium (Mg)
Sodium (Na)
Potassium (K)
Temperature

Bicarbonate (HCO_3)
Carbonate (CO_3)
Sulfate (SO_4)
Chloride (Cl)
pH (field and lab)
Settleable Matter

METALS

Arsenic (As)
Cadmium (Cd)

Copper (Cu)
Iron (Fe)

Lead (Pb)
Manganese (Mn)

Zinc (Zn)

PARTIAL ANALYSIS *

Specific Electrical
  Conductivity (field and lab)
Total Dissolved Solids (TDS)
Total Suspended Solids (TSS)
Dissolved Oxygen
pH (field and lab)
Flow or Stage

Arsenic (As)
Lead (Pb)
Zinc (Zn)
Cadmium (Cd)
Temperature
Eh

SPECIAL ANALYSIS *

Aluminum (Al)
Antimony (Sb)
Arsenic (As)
Barium (Ba)
Beryllium (Be)
Cadmium (Cd)

Calcium (Ca)
Chromium (Cr)
Cobalt (Co)
Copper (Cu)
Iron (Fe)
Lead (Pb)

Magnesium (Mg)
Manganese (Mn)
Mercury (Hg)
Nickel (Ni)
Potassium (K)
Selenium (Se)

Silver (Ag)
Sodium (Na)
Thallium (Tl)
Tin (Sn)
Vanadium (V)
Zinc (Zn)

* All metals measured as both total and dissolved.

One bottom sediment sediment sample was collected from each of three process fluid sampling sites (S-3, ST-2 and TT-1). Bottom sediment from process circuit drain sumps (S-3 and ST-1), and from Thornock Tank (TT-1) was sampled concurrently with sampling of the process fluid circuit water. Sampling dates are in Table 2-1-2 and analytical results are in Appendix 3-1.

2.1.2.2 Main Process Fluid Line Leakage Tests

High pressure lines of the main process water distribution system were pressure tested for leakage in October 1985 as part of the Plant Water Balance conducted for the Montana Water Quality Bureau. Exhibit 11 shows measuring points and valves used in isolating sections. Leaking valves at the time of testing precluded a quantitative assessment of leakage. A more extensive assessment of pressure lines was conducted in 1988 and 1989 in accordance with the Comprehensive RI/FS Work Plan. Quantitative estimates were made of leakage using the method developed by Hunt (1985). The results of pressure line testing are discussed in Section 3.2.

Additional water samples were collected at two sites (SP-2 and TT-1). These sites were collected before development of the Comprehensive RI/FS Work Plan; however, sampling site information and analytical results are included in Table 2-1-1, Table 2-1-2, and Appendix 3-1.

Collection, preservation and storage of samples were in accordance with EPA (1982 and 1986b) recommendations, which are outlined in the Water Resources QAPP. Process fluid samples collected by Hydrometrics were shipped to the Asarco Salt Lake City, Department of Environmental Services (DOES) laboratory for analysis. Split samples were processed and shipped by EPA representatives to EPA contract laboratories: California Analytical Laboratories (CAL), Rocky Mountain Analytical Laboratory (RMAL) or Weyerhaeuser (WYRHR) for analysis.

2.1.2.3 Assessment of Leakage From the Main Process Water Drain System

The locations of drains and sumps on the Plant maps were verified in the field and an updated map was prepared to assist in identification of potential sources of leakage in the process water drain line system. Flow measurements were taken at or near the beginning and end points of drains, where possible. Flows were estimated using a bucket and stopwatch, a Marsh-McBirney flow meter, a small weir, or a small flume installed in conduits and ditches. A number of drain lines are buried and inacessible where they pass underneath buildings. Where flow measurements could not be taken, lines were inspected, if possible, for potential signs of leakage. Although the use of a remote video camera was proposed in the Comprehensive RI/FS Work Plan, drain passages were either too small, too shallow or had too many obstructions for successful inspection by this method. To the extent possible, records of drain construction, types of joints, susceptibility to damage, approximate age, estimated flow, and overall condition were assembled and examined.

2.2 GROUNDWATER REMEDIAL INVESTIGATION

The groundwater Remedial Investigation was conducted in three phases in accordance with the Water Resources Monitoring Plan (1984b), the Water Resources Investigation Phase II Work Plan (1986b), the Comprehensive RI/FS Plan (1987b) and the project QAPP (1984c). Results of the first phase of water resources investigation activities were presented in the Draft Water Resources Monitoring Report (February 7, 1986). Information and data collected during all phases of the groundwater RI are included in this report.

The hydrogeological setting was interpreted using available information from private wells, from soil core drill holes, and from monitoring wells and piezometers constructed in the East Helena area. The quality of groundwater as well as aquifer characteristics and subsurface geology were examined in detail to determine the hydraulics and geochemistry of the groundwater system.

A well inventory was conducted to provide hydrogeologic information for the study area (Appendix 4-1). Additional and more complete information on study area hydrogeological conditions are provided by monitoring wells, piezometers and soil cores completed during the remedial investigation. Appendix 4-1 includes information on private wells in addition to the monitoring wells completed as part of the RI investigation. Private well, monitoring well, piezometer, and soil core drill hole locations are shown on Exhibit 1.

2.2.1 Stratigraphic Sampling

Stratigraphic samples were collected from 63 soil core drill holes to examine geological and groundwater conditions in the study area. The drilling program was conducted in four phases; fall-winter 1984, fall-winter 1986, spring 1987, and fall-winter 1987. Of the drill holes sampled, 43 were completed as 4-inch-diameter monitoring wells and 8 were completed as 2-inch-diameter piezometers. Monitoring well, piezometer and drill hole locations are shown on Exhibit 3. Drill hole geologic and construction logs are in Appendix 4-1. Monitoring wells, piezometers and soil core sample holes were completed in accordance with the Comprehensive RI/FS Work Plan, the WRM Work Plan, and the Phase II WRI Work Plan.

Drilling and sampling techniques for most of the drill holes were the same methods developed as standard project procedures and are described in the Phase I and Phase II WRM Work Plans. Drilling was conducted using a forward rotary drill rig with top drive hammer to advance drill holes through cobbles and boulders that are typical of the study area. As the hole was advanced, driving of casing was often necessary because of caving. Soil sample cores were collected using a split spoon at intervals specified in the Comprehensive RI/FS Work Plan, the Phase II WRI Work Plan, the Phase I WRM Work Plan, or as conditions allowed. Abundant cobbles and boulders often prohibited collection of sample cores. Soil core sampling conducted as part of the activities outlined in the Comprehensive RI/FS Work Plan (spring 1987 and fall/winter 1987) were collected at two-foot intervals from 0 to 10 feet and at 5-foot intervals at depths greater than 10 feet. Stratigraphic samples collected as part of activities outlined in the Phase II WRI Work Plan were generally collected at five-foot intervals or at changes in stratigraphy. Stratigraphic samples collected during the fall/winter 1984 sampling period were collected using Phase I WRM protocol and sampling was limited by available techniques. Soil core drill holes, not completed as monitoring wells or piezometers, were plugged with granular bentonite or a bentonite slurry following completion of sampling. Monitoring well and piezometer completion details are discussed in Section 2.2.2.

Additional stratigraphic samples were also collected from backhoe test pits to augment soil profile data bases from 10 drill holes completed during early phases of investigation activities. A total of 10 test pits were excavated near existing drill hole locations. Test pit locations are shown in Figure 2-2-1. Samples were collected at the following increments: 0-4 inches, 4-12 inches (1 foot), 1-2 feet, 2-3 feet, 3-4 feet and 4-5 feet.

Drilling methods for collection of soil core samples from six Lower Lake drill holes (LL-1, LL-2, LL-3, LL-4, LL-5, LL-6) were somewhat different than the standard drilling equipment and techniques used for the majority of the project drilling program. Drilling at Lower Lake was performed using a small, barge-mounted, top drive, rotary drill rig. Using the drive and wash method described in the Comprehensive RI/FS Work Plan, three-inch steel casing was driven though relatively soft bottom sediments and underlying fine-grained strata. Drilling was terminated when coarse grained gravels and cobbles were encountered and casing could not be advanced. Generally, about 14 to 17 feet of fine-grained sediments overlie the gravels and cobbles under Lower Lake. Pellet and chunk bentonite was applied around the steel casing at the pond bottom surface to avoid contamination of stratigraphic samples from downward percolation of process fluids outside the steel casing annulus (see Appendix 4-2). Drilling water was pumped to the barge via a pipeline from Prickly Pear Creek to avoid contamination of deeper strata during the drilling procedure. Sediment samples were collected at two foot intervals using a split spoon. Following completion of sample collection, pellet and chunk bentonite was poured down the inside of the steel casing to plug the hole. The upper five feet of casing was removed with the remaining casing abandoned after sample collection.

Soil cores and cuttings from all RI drill holes were examined for lithology, grain size, texture, and color following procedures outlined in the QAPP. Sample cores (and sometimes cuttings) were placed in appropriate glass containers and sent to the DOES laboratory for analysis of chemical parameters.

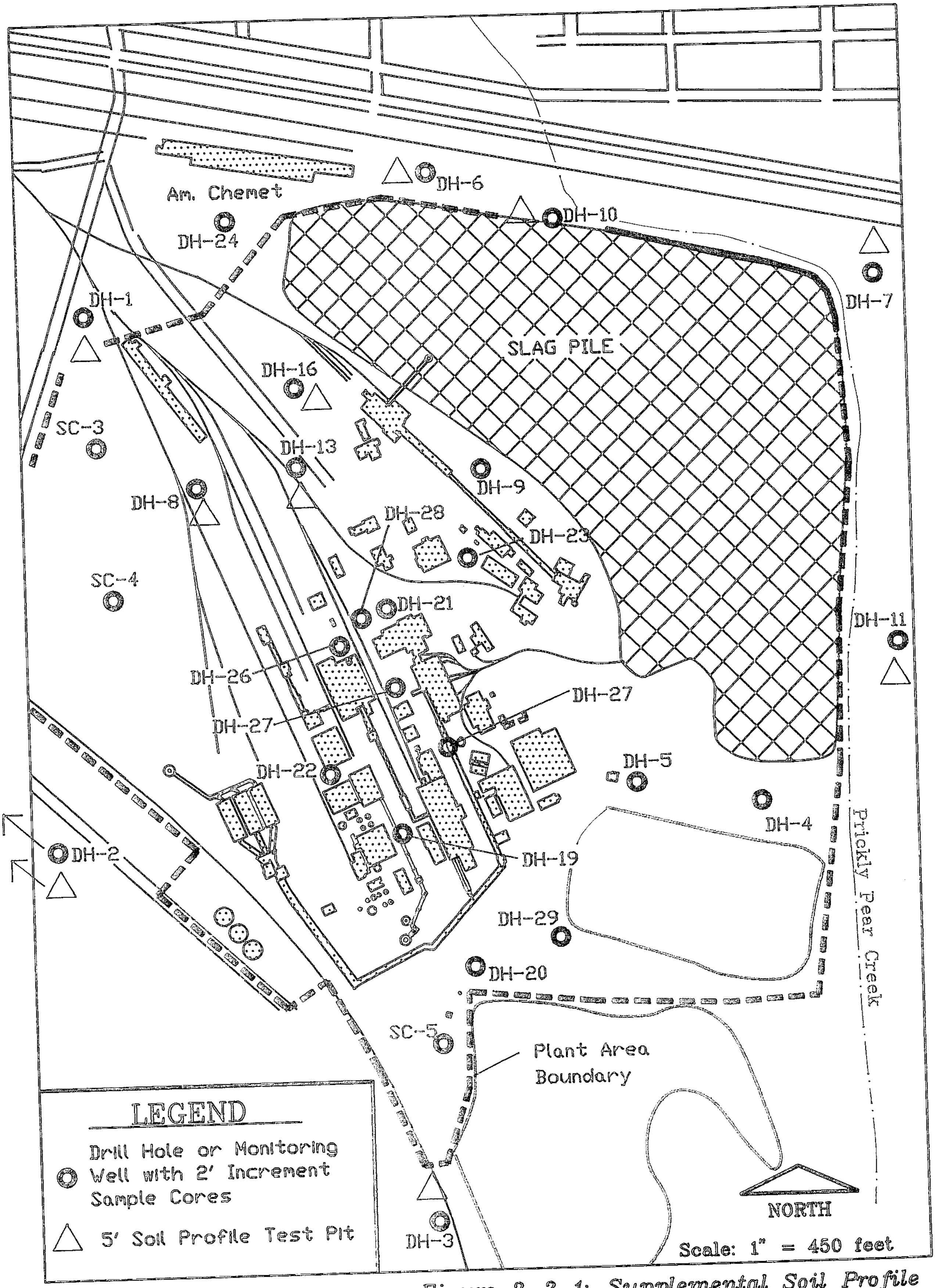


Figure 2-2-1: Supplemental Soil Profile Test Pit Locations

Table 2-2-1 summarizes the stratigraphic sampling programs and the stratigraphic sample analytical schedules are in Table 2-2-2. Stratigraphic sample splits were retained by EPA personnel and sent to EPA contract laboratories for analysis. Selected samples were also sent to Northern Engineering and Testing (NET) of Billings, Montana, and Braun Engineering of Billings, Montana, for analysis of physical parameters. Stratigraphic sample chemical and physical analytical results are in Appendix 4-3.

Physical parameters tested on selected core samples include particle size, cation exchange capacity and laboratory permeability. Analyses of physical parameters were limited by the size of the available sample. In order to provide as much material as possible for physical testing, similar materials from some samples were combined.

Leachate analyses also were conducted on selected samples using a sequential metal extraction technique as described by Sondag (1981) and Chao (1984). Selected samples also were analyzed using the EP Toxicity Analytical Method. Results of these analyses are in Appendix 4-4.

2.2.2 Monitoring Well and Piezometer Drilling, Construction, Completion and Development

Monitoring well and piezometer construction was conducted in accordance with the Comprehensive RI/FS Work Plan, the Phase II WRM Work Plan and the Phase I WRM Work Plan. Construction methods for monitoring wells and piezometers were chosen to ensure groundwater samples would be representative of actual aquifer conditions. Generally, three types of monitoring wells were constructed as part of the groundwater remedial investigation: shallow monitoring wells, intermediate monitoring wells, and deep monitoring wells.

<u>Shallow Monitoring Well Construction</u>

Shallow monitoring wells were installed in the most shallow zone of saturation, generally the upper 5 to 20 feet of saturation. Shallow monitoring well construction details are shown in Figure 2-2-2 and monitoring well construction logs are in Appendix 4-2. Well casing was NSF approved Schedule 40 PVC with flush joints and threaded couplings.

Table 2-2-1

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
DH-1	DH-1-1	12-21-87	1100	0-0.3	G/TP	Sand, silt, some gravel	TE, TE-SP	DOES, VERSR	
	DH-1-2 R	12-21-87	1115	0-0.3	G/TP		TE, TE-SP	DOES, VERSR	
	DH-1-3	12-21-87	1120	0.3-1	G/TP		TE	DOES	
	DH-1-4	12-21-87	1125	1-2	G/TP		TE	DOES	
	DH-1-5	12-21-87	1130	2-3	G/TP		TE, TE-SP	DOES, VERSR	
	DH-1-6	12-21-87	1135	3-4	G/TP		TE	DOES	
	DH-1-7	12-21-87	1140	4-5	G/TP		TE, TE-SP	DOES, VERSR	
	DH-1-8 BB	12-21-87	1145	-	-		TE, TE-SP	DOES, VERSR	
	DH-1-9 CCB	12-21-87	1150	-	-		TE, TE-SP	DOES, VERSR	
	DH-1-10 SD	12-21-87	1200	-	-		TE	DOES	
	-	11-14-84	1200	5-6.5	SS/AUG		TE1, PP1, TE-SP	DOES, NET, RMA	
	-	11-14-84	1215	10-11.5	SS/AUG		TE1, PP1, TE-SP	DOES, NET, RMA	
	-	11-14-84	1300	15-16.5	SS/AUG	Gravel and clay	TE1, PP1, TE-SP	DOES, NET, RMA	
	R	11-14-84	-	15-16.5	SS/AUG		TE-SP	RMA	
	-	11-14-84	-	18-19.5	SS/AUG ?		TE-SP	RMA	No field record of RMA sample.
	-	11-17-84	1430	19.5-21	SS/AUG	Gravel and cobbles	TE1, TE-SP	DOES, RMA	
	DH-1-3	12-06-84	1450	20-28	G/ROT		TE1, TE-SP	DOES, RMA	
	DH-1-4	12-06-84	1505	29	G/ROT		TE1	DOES	
DH-2	DH-2-1	12-21-87	1215	0-0.3	G/TP	Sand, Silty	TE, TE-SP	DOES, VERSR	
	DH-2-2	12-21-87	1220	0.3-1	G/TP		TE	DOES	
	DH-2-3	12-21-87	1225	1-2	G/TP		TE	DOES	
	DH-2-4	12-21-87	1230	2-3	G/TP		TE	DOES	
	DH-2-5	12-21-87	1235	3-4	G/TP		TE, TE-SP	DOES, VERSR	
	DH-2-6 R	12-21-87	1240	3-4	G/TP		TE	DOES	
	DH-2-7	12-21-87	1245	4-5	G/TP		TE, TE-SP	DOES, VERSR	
	DH-2-8	12-21-87	1250	BB	-		TE	DOES	
	DH-2-9	12-21-87	1255	CBB	-		TE	DOES	
	-	11-26-84	1133	8-9.5	SS/AUG	Gravel, sandy	TE1, PP1	DOES, NET	
	-	11-26-84	1151	10-11.5	SS/AUG		TE1, PP1, TE-SP	DOES, NET, RMA	
	-	11-26-84	1204	15-16.5	SS/AUG	Silt, sandy	TE1, PP1, TE-SP	DOES, NET, RMA	Combined with 20-21.5 and 25-26.5 for physical parameter testing.
	-	11-26-84	-	16.5-18	SS/AUG		TE-SP	RMA	No field record of RMA sample.
	-	11-26-84	1230	20-21.5	SS/AUG		TE1, PP1, TE-SP	DOES, NET, RMA	Combined with 16-26.5 and 25-26.5 for physical parameter testing.
	-	11-26-84	1255	25-26.5	SS/AUG		TE1, PP1, TE-SP	DOES, NET, RMA	Combined with 16-26.5 and 20-21.5 for physical parameter testing.
	DH-2-6	12-08-84	1440	37-40	G/ROT	Gravel and Cobbles.	TE1, TE-SP	DOES, RMA	RMA sample interval reported 39-40.
	DH-2-7	12-08-84	1645	55-60	G/ROT	Gravel and clay	TE1	DOES	

Notes:

(1) R = Replicate, BB = Bottle Blank, CCB = Cross Contamination Blank, SD = Blind Field Standard.

(2) G = Grab Sample, SS = Split Spoon, TP = Test Pit, Aug = Soil Auger, ROT = Air Rotary Drill Rig.

(3) Lithology descriptions are general only. Detailed lithologic descriptions are in Appendix 4.

(4) TE = Trace Elements - Standard Analysis, TE1 = Trace Elements per WRM Phase I Program, TE-SP = Trace Elements Special Analysis, PP = Physical Parameters.
SE = Sequential Extraction Analysis. See Table 2-2-2 for sample analytical schedules.

(5) DOES = Asarco's Department Of Environmental Services Laboratory; VERSR = Versar, an EPA CLP laboratory; RMA = Rocky Mountain Analytical, an EPA CLP laboratory.
NET = Northern Engineering and Testing, physical parameters testing.

Table 2-2-1
(continued)

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
DH-3	DH-3-1	12-21-87	1300	0-0.3	G/TP	Silt, clayey	TE, TE-SP	DOES, VERSR	
	DH-3-2	12-21-87	1305	0.3-1	G/TP		TE	DOES	
	DH-3-3	12-21-87	1310	0.3-1 R	G/TP		TE	DOES	
	DH-3-4	12-21-87	1315	1-2	G/TP		TE, TE-SP	DOES, VERSR	
	DH-3-5	12-21-87	1320	2-3	G/TP		TE	DOES	
	DH-3-6	12-21-87	1325	3-4	G/TP		TE	DOES	
	DH-3-7	12-21-87	1330	4-5	G/TP		TE, TE-SP	DOES, VERSR	
	DH-3-8	12-21-87	1335	BB	-		TE	DOES	
	DH-3-9	12-21-87	1340	CCB	-		TE	DOES	
	-	11-26-84	1515	6.5-8	SS/AUG		TE1, PP1, TE-SP	DOES, NET, RMA	Sample and replicate labeled 8-9.5 combined for physical testing.
	-	11-26-84	1521	8-9.5 R	SS/AUG		TE1, PP1	DOES, NET	
	DH-3-4	12-10-84	1020	33-36	G/ROT	Clay ash.	TE1, TE-SP	DOES, RMA	
	DH-3-5	12-10-84	1135	50-53	G/ROT		TE1, TE-SP	DOES, RMA	
DH-4	-	11-27-84	1020	9-10.5	SS/AUG	Slag	TE1	DOES	
	-	11-27-84	1020	9-9.1	SS/AUG		TE-SP	RMA	
	-	11-27-84	1035	13-14.5	SS/AUG	Clay	TE1, PP1, TE-SP	DOES, NET, RMA	
	-	11-27-84	1105	19-21.5	SS/AUG	Sand and gravel	PP1	NET	
DH-5	-	11-27-84	1309	6-7.5	SS/AUG	Slag	TE1, PP1, TE-SP		
	-	11-27-84	1347	18-19.5	SS/AUG	Clay	TE1, PP1, TE-SP		
DH-6	DH-6-1	12-21-87	1610	0-0.3	G/TP	Gravel and sand.	TE, TE-SP	DOES, VERSR	
	DH-6-2	12-21-87	1615	0.3-1	G/TP		TE	DOES	
	DH-6-3	12-21-87	1620	1-2	G/TP		TE	DOES	
	DH-6-4	12-21-87	1625	1-2 R	G/TP		TE	DOES	
	DH-6-5	12-21-87	1630	2-3	G/TP		TE, TE-SP	DOES, VERSR	
	DH-6-6	12-21-87	1645	3-4	G/TP		TE	DOES	
	DH-6-7	12-21-87	1650	4-5	G/TP		TE, TE-SP	DOES, VERSR	
	DH-6-8	12-21-87	1655	BB	-		TE	DOES	
	DH-6-9	12-21-87	1700	CCB	-		TE	DOES	
	DH-6-1	11-27-84	1600	7-8.5	SS/AUG	Sand and Gravel	TE1	DOES	
	DH-6-2	12-11-84	1630	16-19	G/ROT	Sand	TE1	DOES	

Notes:

(1) R = Replicate, BB = Bottle Blank, CCB = Cross Contamination Blank, SD = Blind Field Standard.

(2) G = Grab Sample, SS = Split Spoon, TP = Test Pit, Aug = Soil Auger, ROT = Air Rotary Drill Rig.

(3) Lithology descriptions are general only. Detailed lithologic descriptions are in Appendix 4.

(4) TE = Trace Elements - Standard Analysis, TE1 = Trace Elements per WRM Phase I Program, TE-SP = Trace Elements Special Analysis, PP = Physical Parameters.
SE = Sequential Extraction Analysis. See Table 2-2-2 for sample analytical schedules.

(5) DOES = Asarco's Department Of Environmental Services Laboratory; VERSR = Versar, an EPA CLP laboratory; RMA = Rocky Mountain Analytical, an EPA CLP laboratory.
NET = Northern Engineering and Testing, physical parameters testing.

Table 2-2-1
(continued)

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
DH-7	DH-7-1	12-21-87	1430	0-0.3	G/TP	Sand and gravel	TE, TE-SP	DOES, VERSR	
	DH-7-2	12-21-87	1435	0.3-1	G/TP		TE	DOES	
	DH-7-3	12-21-87	1440	1-2	G/TP		TE	DOES	
	DH-7-4	12-21-87	1445	2-3	G/TP		TE, TE-SP	DOES, VERSR	
	DH-7-5	12-21-87	1450	2-3 R	G/TP		TE	DOES	
	DH-7-6	12-21-87	1455	3-4	G/TP		TE	DOES	
	DH-7-7	12-21-87	1500	4-5	G/TP		TE, TE-SP	DOES, VERSR	
	DH-7-8	12-21-87	1505	BB	-		TE	DOES	
	DH-7-9	12-21-87	1510	CCB	-		TE	DOES	
	DH-7-1	11-28-84	0850	6-7.5	SS/AUG	Gravel and sand	TE1, TE-SP	DOES, RMA	
	DH-7-2	12-12-84	1545	18-26	G/ROT		TE1	DOES	
	DH-7-3	12-12-84	1555	18-26 R	G/ROT		TE1	DOES	
	-	12-12-84	-	18-20	G/ROT		TE-SP	RMA	
DH-8	DH-8-1	11-28-84	1020	6-5.7	SS/AUG	Clay and sand	TE1, TE-SP		Sample depth interval reported by RMA is 6-8.5 ft.
	DH-8-2	11-28-84	1030	10-11.5	SS/AUG	Silt and sand	TE1, PP1, TE-SP		
	DH-8-3	11-28-84	1048	15-16.5	SS/AUG	Gravel and sand	TE1, PP1, TE-SP		
	DH-8-4	01-04-85	1430	35-38	G/ROT	Sand	TE1		
	DH-8-5	01-04-85	1430	39-41	G/ROT	Sand and clay	TE1		
	DH-8-6	01-04-85	1500	41-43	G/ROT	Gravel	TE1		
DH-9	DH-9-1	11-28-84	1225	7-8.5	SS/AUG	Slag	TE1, TE-SP	DOES, RMA	
	DH-9-2	11-28-84	1245	10-11.5	SS/AUG	Gravel	TE1, TE-SP	DOES, RMA	
DH-10	DH-10-1	12-21-87	1525	0-0.3	G/TP	Sand	TE, TE-SP	DOES, VERSR	
	DH-10-2	12-21-87	1530	0.3-1	G/TP		TE	DOES	
	DH-10-3	12-21-87	1535	1-2	G/TP		TE	DOES	
	DH-10-4	12-21-87	1540	1-2 R	G/TP		TE, TE-SP	DOES, VERSR	
	DH-10-5	12-21-87	1545	2-3	G/TP		TE	DOES	
	DH-10-6	12-21-87	1550	3-4	G/TP		TE	DOES	
	DH-10-7	12-21-87	1555	4-5	G/TP		TE, TE-SP	DOES, VERSR	
	DH-10-8	12-21-87	1600	BB	-		TE	DOES	
	DH-10-9	12-21-87	1605	CCB	-		TE	DOES	
	DH-10-1	11-28-84	1428	6.5-8	SS/AUG	Sand and gravel	TE1	DOES	

Notes: (1) R = Replicate, BB = Bottle Blank, CCB = Cross Contamination Blank, SD = Blind Field Standard.

(2) G = Grab Sample, SS = Split Spoon, TP = Test Pit, Aug = Soil Auger, ROT = Air Rotary Drill Rig.

(3) Lithology descriptions are general only. Detailed lithologic descriptions are in Appendix 4.

(4) TE = Trace Elements - Standard Analysis, TE1 = Trace Elements per WRM Phase I Program, TE-SP = Trace Elements Special Analysis, PP1 = Physical Parameters No. 1
SE = Sequential Extraction Analysis. See Table 2-2-2 for sample analytical schedules.

(5) DOES = Asarco's Department Of Environmental Services Laboratory; VERSR = Versar, an EPA CLP laboratory; RMA = Rocky Mountain Analytical, an EPA CLP laboratory.
NET = Northern Engineering and Testing, physical parameters testing.

Table 2-2-1
(continued)

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
DH-11	DH-11-1	12-21-87	1345	0-0.3	G/TP	Sand	TE, TE-SP	DOES, VERSR	
	DH-11-2	12-21-87	1350	0.3-1	G/TP		TE	DOES	
	DH-11-3	12-21-87	1355	1-2	G/TP		TE	DOES	
	DH-11-4	12-21-87	1400	1-2 R	G/TP		TE	DOES	
	DH-11-5	12-21-87	1405	2-3	G/TP		TE, TE-SP	DOES, VERSR	
	DH-11-6	12-21-87	1410	3-4	G/TP		TE	DOES	
	DH-11-7	12-21-87	1415	4-5	G/TP		TE, TE-SP	DOES, VERSR	
	DH-11-8	12-21-87	1420	BB	-		TE	DOES	
	DH-11-9	12-21-87	1425	CCB	-		TE	DOES	
	DH-11-1	01-06-85	1553	20-21	G/ROT	Cobbles and gravel	TE1	DOES	
	DH-11-2	01-06-85	1660	20-21 R	G/ROT		TE1	DOES	
DH-13	DH-13-1	12-22-87	1010	0-0.3	G/TP	Gravel and cobbles, sand, silt, clay	TE, TE-SP	DOES, VERSR	
	DH-13-2	12-22-87	1015	0.3-1	G/TP		TE	DOES	
	DH-13-3	12-22-87	1020	1-2	G/TP		TE, TE-SP	DOES, VERSR	
	DH-13-4	12-22-87	1025	1-2 R	G/TP		TE, TE-SP	DOES, VERSR	
	DH-13-5	12-22-87	1030	2-3	G/TP		TE	DOES	
	DH-13-6	12-22-87	1040	3-4	G/TP		TE	DOES	
	DH-13-7	12-22-87	1045	4-5	G/TP		TE, TE-SP	DOES, VERSR	
	DH-13-8	12-22-87	1050	BB	-		TE, TE-SP	DOES, VERSR	
	DH-13-9	12-22-87	1055	CCB	-		TE, TE-SP	DOES, VERSR	
	DH-13-1	11-01-86	1250	10-10.5	SS/ROT		TE-SP	RMA	
	DH-13-2	11-01-86	1330	15-15.5	SS/ROT		TE-SP	RMA	
	DH-13-3	11-01-86	1400	20-21.5	SS/ROT		TE-SP	RMA	
	DH-13-4	11-01-86	1600	25-25.5	SS/ROT		SE, TE-SP	DOES, RMA	
	DH-13-5	11-02-86	1530	30-31.5	SS/ROT		SE, SE R, TE-SP	DOES, RMA	
	DH-13-6	11-02-86	1600	35-36	SS/ROT		TE-SP	RMA	
	DH-13-7	11-03-86	0900	40-41	SS/ROT		TE-SP	RMA	
	DH-13-8	11-03-86	0950	45-46.5	SS/ROT		TE-SP	RMA	
DH-14-1	DH-14-1	10-21-86	1545	25-26	SS/ROT	Gravel, sand, silt.	TE, PP2, TE-SP	DOES, BRN, RMA	Combined with DH-14-2 for physical parameters testing.
	DH-14-2	10-21-86	1730	30-30.5	SS/ROT		PP2, TE-SP	BRN, RMA	Combined with DH-14-1 for physical parameters testing.
	DH-14-3	10-22-86	0845	40-41	SS/ROT		TE-SP	RMA	
	DH-14-4	10-22-86	0930	45-46.5	SS/ROT		TE-SP	RMA	
	DH-14-5	10-22-86	1045	50-51.5	SS/ROT		TE-SP	RMA	

Notes: (1) R = Replicate, BB = Bottle Blank, CCB = Cross Contamination Blank, SD = Blind Field Standard.

(2) G = Grab Sample, SS = Split Spoon, TP = Test Pit, Aug = Soil Auger, ROT = Air Rotary Drill Rig.

(3) Lithology descriptions are general only. Detailed lithologic descriptions are in Appendix 4.

(4) TE = Trace Elements - Standard Analysis, TE1 = Trace Elements per WRM Phase I Program, TE-SP = Trace Elements Special Analysis, PP2 = Physical Parameters No. 2
SE = Sequential Extraction Analysis. See Table 2-2-2 for sample analytical schedules. R = Replicate analysis

(5) DOES = Asarco's Department Of Environmental Services Laboratory; VERSR = Versar, an EPA CLP laboratory; RMA = Rocky Mountain Analytical, an EPA CLP laboratory.
BRN = Braun Engineering Testing, physical parameters testing.

Table 2-2-1
(continued)

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
DH-15	DH-15-1	10-31-86	0945	25-26	SS/ROT	Gravel, sand, silt.	SE, TE-SP	DOES, RMA	
	DH-15-2	10-31-86	1100	30-30.5	SS/ROT		TE-SP	RMA	
	DH-15-3	10-31-86	1300	40-41	SS/ROT		TE-SP	RMA	
	DH-15-4	10-31-86	1530	45-46.5	SS/ROT		TE-SP	RMA	
	DH-15-5	10-31-86	1645	50-51.5	SS/ROT		TE-SP	RMA	
DH-16	DH-16-1	11-20-86	1045	10-11.0	SS/ROT	Gravel, sand, silt.	TE-SP	RMA	
	DH-16-2	11-20-86	1115	15-16	SS/ROT		TE-SP	RMA	
	DH-16-3	11-20-86	1145	20-20.5	SS/ROT		TE-SP	RMA	
	DH-16-4	11-20-86	1224	25-26	SS/ROT		TE-SP	RMA	
	DH-16-5	11-20-86	1245	30-31.5	SS/ROT		SE, TE-SP	DOES, RMA	
DH-17	DH-17-1	12-22-87	0920	0-0.3	G/TP	Gravel, sand, silt.	TE, TE-SP	DOES, VERSR	
	DH-17-2	12-22-87	0926	0.3-1	G/TP		TE	DOES	
	DH-17-3	12-22-87	0930	1-2	G/TP		TE	DOES	
	DH-17-4	12-22-87	0935	1-2 R	G/TP		TE	DOES	
	DH-17-5	12-22-87	0940	2-3	G/TP		TE, TE-SP	DOES, VERSR	
	DH-17-6	12-22-87	0945	3-4	G/TP		TE	DOES	
	DH-17-7	12-22-87	0950	4-5	G/TP		TE, TE-SP	DOES, VERSR	
	DH-17-8	12-22-87	0955	BB	-		TE	DOES	
	DH-17-9	12-22-87	1000	CCB	-		TE	DOES	
	DH-17-1	11-25-86	1250	27-28	SS/ROT		TE-SP	RMA	
	DH-17-2	11-25-86	1630	35-36.5	SS/ROT		SE, TE-SP	DOES, RMA	
	DH-17-3	11-26-86	0950	41-42.5	SS/ROT		SE, TE-SP	DOES, RMA	
DH-18	DH-18-2	12-2-86	1115	50-51.5	SS/ROT	Silt and clay	TE-SP, PP2	RMA, BRN	Combined with DH-18-3 for physical parameters testing.
	DH-18-3	12-2-86	1200	55-57	SS/ROT		TE-SP, PP2	RMA, BRN	Combined with DH-18-2 for physical parameters testing.
	DH-18-4	12-2-86	1300	60-61	SS/ROT	Ash	TE-SP	RMA	
	DH-18-5	12-2-86	1320	65-65.5	SS/ROT		TE-SP	RMA	
DH-19	DH-19-1	04-22-87	1030	0-1.5	SS/ROT	Fill	TE	DOES	
	DH-19-2	04-22-87	1050	2-3.5	SS/ROT		TE	DOES	
	DH-19-3	04-22-87	1115	4-5.5	SS/ROT		TE	DOES	
	DH-19-4	04-22-87	1215	6-5.5	SS/ROT	Gravel and sand	TE	DOES	
	DH-19-5	04-22-87	1315	8-9.5	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-19-6	04-22-87	1330	10-11	SS/ROT		TE	DOES	
	DH-19-7	04-22-87	1350	15-16	SS/ROT	Cobbles and gravel	TE	DOES	
	DH-19-8	04-22-87	1415	20-21	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-19-9	04-22-87	1600	25-26	SS/ROT		TE	DOES	

Notes: (1) R = Replicate, BB = Bottle Blank, CCB = Cross Contamination Blank, SD = Blind Field Standard.

(2) G = Grab Sample, SS = Split Spoon, TP = Test Pit, Aug = Soil Auger, ROT = Air Rotary Drill Rig.

(3) Lithology descriptions are general only. Detailed lithologic descriptions are in Appendix 4.

(4) TE = Trace Elements - Standard Analysis, TE1 = Trace Elements per WRM Phase I Program, TE-SP = Trace Elements Special Analysis, PP2 = Physical Parameters No. 2
SE = Sequential Extraction Analysis. See Table 2-2-2 for sample analytical schedules.

(5) DOES = Anaconda's Department Of Environmental Services Laboratory; VERSR = Versar, an EPA CLP laboratory; RMA = Rocky Mountain Analytical, an EPA CLP laboratory.

Table 2-2-1
(continued)

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
DH-20	DH-20-1	04-24-87	0850	0-1.5	SS/ROT	Fill	TE	DOES	
	DH-20-2	04-24-87	0910	2-3.5	SS/ROT		TE	DOES	
	DH-20-3	04-24-87	0915	4-5.5	SS/ROT		TE	DOES	
	DH-20-4	04-24-87	0920	6-7.5	SS/ROT	Cobbles and gravel.	TE	DOES	
	DH-20-5	04-24-87	1010	8-9.5	SS/ROT		TE	DOES	
	DH-20-6	04-24-87	1015	10-11.5	SS/ROT		TE	DOES	
	DH-20-7	04-24-87	1045	15-16	SS/ROT		TE	DOES	
	DH-20-8	04-24-87	1055	20-21.5	SS/ROT		TE	DOES	
	DH-20-9	04-24-87	1300	25-26	SS/ROT		TE, TE-SP	DOES, VERSR	
DH-21	DH 21-1	04-23-87	1008	0-1.5	SS/ROT	Fill	TE	DOES	
	DH-21-2	04-23-87	1030	2-3.5	SS/ROT	Cobbles and gravel	TE	DOES	
	DH-21-3	04-23-87	1050	4-5.5	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-21-4	04-23-87	1100	6-7.5	SS/ROT		TE	DOES	
	DH-21-5	04-23-87	1145	8-9.5	SS/ROT		TE	DOES	
	DH-21-6	04-23-87	1200	10-11.5	SS/ROT		TE	DOES	
	DH-21-7	04-23-87	1230	15-16	SS/ROT		TE	DOES	
	DH-21-8	04-23-87	1315	20-21.5	SS/ROT		TE	DOES	
	DH-21-9	04-23-87	1350	25-26	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-21-10	04-23-87	1420	30-31	SS/ROT				
DH-22	DH-22-1	04-27-87	1030	0-1.5	SS/ROT	Fill	TE	DOES	
	DH-22-2	04-27-87	1045	2-3.5	SS/ROT		TE	DOES	
	DH-22-3	04-27-87	1100	4-5.5	SS/ROT		TE	DOES	
	DH-22-4	04-27-87	1110	6-7.5	SS/ROT		TE	DOES	
	DH-22-5	04-27-87	1120	8-9.5	SS/ROT		TE	DOES	
	DH-22-6	04-27-87	1140	10-11.5	SS/ROT	Gravel, silt, sand	TE, TE-SP	DOES, VERSR	
	DH-22-7	04-27-87	1200	15-16.5	SS/ROT		TE	DOES	
	DH-22-8	04-27-87	1230	20-21.5	SS/ROT		TE	DOES	
	DH-22-9	04-27-87	1500	25-26	SS/ROT		TE	DOES	
	DH-22-10	04-27-87	1515	30-31.5	SS/ROT		TE	DOES	
	DH-22-11	04-27-87	1525	35-36.5	SS/ROT		TE, TE-SP	DOES, VERSR	
DH-23	DH-23-1	04-28-87	0915	0-1.5	SS/ROT	Fill	TE	DOES	
	DH-23-2	04-28-87	0930	2-3.5	SS/ROT	Slag	TE	DOES	
	DH-23-3	04-28-87	0945	4-5.5	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-23-4	04-28-87	0955	6-7.5	SS/ROT		TE	DOES	
	DH-23-6	04-28-87	1200	15-16	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-23-7	04-28-87	1245	20-21.5	SS/ROT		TE	DOES	

Notes: (1) R = Replicate, BB = Bottle Blank, CCB = Cross Contamination Blank, SD = Blind Field Standard.

(2) G = Grab Sample, SS = Split Spoon, TP = Test Pit, Aug = Soil Auger, ROT = Air Rotary Drill Rig.

(3) Lithology descriptions are general only. Detailed lithologic descriptions are in Appendix 4.

(4) TE = Trace Elements - Standard Analysis, TE1 = Trace Elements per WRM Phase I Program, TE-SP = Trace Elements Special Analysis, PP2 = Physical Parameters No. 2
SE = Sequential Extraction Analysis. See Table 2-2-2 for sample analytical schedules.

(5) DOES = Asarco's Department Of Environmental Services Laboratory; VERSR = Versar, an EPA CLP laboratory; RMA = Rocky Mountain Analytical, an EPA CLP laboratory.

Table 2-2-1 STRATIGRAPHIC SAMPLING SUMMARY
(continued)

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
DH-24	DH-24-1	04-30-87	0845	0-1.5	SS/ROT	Sand, silt	TE	DOES	
	DH-24-2	04-30-87	0900	2-3.5	SS/ROT		TE	DOES	
	DH-24-3	04-30-87	0905	4-5.5	SS/ROT		TE	DOES	
	DH-24-4	04-30-87	0920	6-7.5	SS/ROT	Cobbles and gravel	TE	DOES	
	DH-24-5	04-30-87	0945	8-9.5	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-24-6	04-30-87	1400	10-11.5	SS/ROT		TE	DOES	
	DH-24-8	04-30-87	1440	20-21.5	SS/ROT		TE	DOES	
	DH-24-9	04-30-87	1500	25-26.5	SS/ROT		TE	DOES	
	DH-24-10	04-30-87	1545	30-31.5	SS/ROT		TE	DOES	
	DH-24-11	04-30-87	1615	35-36	SS/ROT		TE, TE-SP	DOES, VERSR	
DH-26	DH-26-1	04-28-87	1500	2-3.5	SS/ROT	Fill	TE	DOES	
	DH-26-2	04-28-87	1600	4-5.5	SS/ROT		TE	DOES	
	DH-26-3	04-28-87	1615	6-7.5	SS/ROT	Cobbles and gravel	TE, TE-SP	DOES, VERSR	
	DH-26-4	04-28-87	1630	8-9.5	SS/ROT		TE	DOES	
	DH-26-5	04-28-87	1645	10-11.5	SS/ROT		TE	DOES	
	DH-26-6	04-28-87	1710	15-16	SS/ROT		TE	DOES	
	DH-26-7	04-28-87	1730	20-21.5	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-26-8	04-29-87	1200	25-26	SS/ROT		TE	DOES	
DH-27	DH-27-1	05-01-87	0940	2-3.5	SS/ROT	Gravel, sand, silt	TE	DOES	
	DH-27-2	05-01-87	1000	4-5.5	SS/ROT		TE	DOES	
	DH-27-3	05-01-87	1018	6-7.5	SS/ROT		TE, TE-SP, TE-SP R	DOES, VERSR	
	DH-27-4	05-01-87	1100	8-9.5	SS/ROT		TE	DOES	
	DH-27-5	05-01-87	1110	10-11.5	SS/ROT		TE	DOES	
	DH-27-6	05-01-87	1130	15-16	SS/ROT		TE	DOES	
	DH-27-7	05-01-87	1200	20-21	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-27-8	05-01-87	1300	25-26.5	SS/ROT		TE	DOES	
	DH-27-9	05-01-87	1305	30-31.5	SS/ROT		TE	DOES	

Notes: (1) R = Replicate, BB = Bottle Blank, CCB = Cross Contamination Blank, SD = Blind Field Standard.

(2) G = Grab Sample, SS = Split Spoon, TP = Test Pit, Aug = Soil Auger, ROT = Air Rotary Drill Rig.

(3) Lithology descriptions are general only. Detailed lithologic descriptions are in Appendix 4.

(4) TE = Trace Elements - Standard Analysis, TE1 = Trace Elements per WRM Phase I Program, TE-SP = Trace Elements Special Analysis, PP2 = Physical Parameters No. 2
R = Replicate Analysis, SE = Sequential Extraction Analysis. See Table 2-2-2 for sample analytical schedules.

(5) DOES = Asarco's Department Of Environmental Services Laboratory; VERSR = Versar, an EPA CLP laboratory; RMA = Rocky Mountain Analytical, an EPA CLP laboratory.
BRN = Braun Engineering Testing, physical parameters testing.

Table 2-2-1
(continued)

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
DH-28	DH-28-1	12-11-87	1336	1-3	SS/ROT	Gravel, sand, silt	TE	DOES	
	DH-28-2	12-11-87	1415	3-4	SS/ROT		TE	DOES	
	DH-28-3	12-11-87	1430	4-6	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-28-4	12-11-87	1445	8-10	SS/ROT		TE	DOES	
	DH-28-6	12-11-87	1545	10-12	SS/ROT		TE	DOES	
	DH-28-7	12-14-87	1100	15-16	SS/ROT		TE	DOES	
	DH-28-C	12-14-87	-	22-25	SS/ROT		TE	DOES	
	DH-28-9	12-14-87	1145	24-26	SS/ROT		TE	DOES	
	DH-28-10	12-14-87	1345	30-31	SS/ROT		TE, TE-SP	DOES, VERSR	
	DH-28-11	12-14-87	1530	36-38	SS/ROT		TE, TE-SP	DOES, VERSR	
DH-29	DH-29-1	12-10-87	1500	0-2	SS/ROT	Gravel, sand, silt	TE	DOES	
	DH-29-2	12-10-87	1515	2-4	SS/ROT		TE	DOES	
	DH-29-3	12-10-87	1530	4-6	SS/ROT		TE	DOES	
	DH-29-4	12-10-87	1545	6-8	SS/ROT		TE, TE-SP, TE-SP R	DOES, VERSR	
	DH-29-5	12-11-87	0930	8-10	SS/ROT		TE	DOES	
	DH-29-6	12-11-87	1000	10-12	SS/ROT		TE	DOES	
	DH-29-7	12-11-87	1100	17-19	SS/ROT		TE, TE-SP, TE-SP R	DOES, VERSR	
EH-100	EH-100-2	11-04-86	1000	10-10.5	SS/ROT	Gravel, sand, silt	TE-SP	RMA	
	EH-100-3	11-04-86	1020	15-16.5	SS/ROT		TE-SP	RMA	
	EH-100-4	11-04-86	1030	20-20.5	SS/ROT		TE-SP	RMA	
	EH-100-5	11-04-86	1040	25-25.5	SS/ROT		TE-SP	RMA	
	EH-100-6	11-04-86	1100	30-31.5	SS/ROT		TE-SP, TE & SE	RMA, DOES	
	EH-100-7	11-04-86	1110	35-36.5	SS/ROT		TE-SP	RMA	
	EH-100-8	11-04-86	1030	40-41.5	SS/ROT		TE-SP	RMA	
	EH-100-9	11-04-86	1150	45-46.5	SS/ROT		TE-SP	RMA	
	EH-100-10	11-04-86	1240	50-50.8	SS/ROT		TE-SP, TE	RMA, DOES	
	EH-100-11	11-05-86	1245	55-56	SS/ROT		TE-SP	RMA	
	EH-100-12	11-05-86	1320	60-61	SS/ROT		TE-SP	RMA	
EH-101	EH-101-2	10-22-86	1600	10-11.5	SS/ROT	Sand	TE-SP	RMA	
	EH-101-3	10-22-86	1700	15-16	SS/ROT	Gravel	TE-SP, SE	RMA, DOES	
	EH-101-4	10-22-86	1730	20-21	SS/ROT		TE-SP	RMA	
EH-102	EH-102-1	11-06-86	1415	5-6	SS/ROT	Gravel, sand, silt	TE-SP, SE	RMA, DOES	
	EH-102-2	11-06-86	1445	10-11.5	SS/ROT		TE-SP	RMA	
	EH-102-5	11-07-86	0900	25-25.5	SS/ROT		TE-SP	RMA	
	EH-102-7	11-07-86	2015	35-36	SS/ROT		TE-SP	RMA	

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(4) TE = Trace Elements - Standard Analysis, TE1 = Trace Elements per WRM Phase I Program, TE-SP = Trace Elements Special Analysis, PP2 = Physical Parameters No. 2
R = Replicate Analysis, SE = Sequential Extraction Analysis. See Table 2-2-2 for sample analytical schedules.

(5) DOES = [illegible] Department Of Environmental Services Laboratory; VERSR = Versar, an EPA CLP laboratory; RMA = Rocky Mountain Analytical, an EPA CLP laboratory

Table 2-2-1
(continued)

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
EH-57	EH-57-1	05-04-87	1000	0-1.5	SS/ROT	Silt	TE	DOES	
	EH-57-2	05-04-87	1020	2-3.5	SS/ROT		TE	DOES	
	EH-57-3	05-04-87	1030	4-5.5	SS/ROT		TE	DOES	
	EH-57-4	05-04-87	1040	6-7.5	SS/ROT	Gravel & cobbles	TE	DOES	
	EH-57-5	05-04-87	1100	8-9.5	SS/ROT		TE	DOES	
	EH-57-6	05-04-87	1110	10-11.5	SS/ROT		TE	DOES	
	EH-57-7	05-04-87	1130	15-16.5	SS/ROT		TE	DOES	
	EH-57-8	05-04-87	1150	20-21.5	SS/ROT		TE	DOES	
	EH-57-9	05-04-87	1240	25-26	SS/ROT		TE	DOES	
	EH-57-10	05-04-87	1245	30-31	SS/ROT		TE	DOES	
	EH-57-11	05-04-87	1320	35-36	SS/ROT		TE, TE-SP	DOES, VERSR	
EH-59	EH-59-1	05-06-87	0945	0-1.5	SS/ROT	Fill	TE	DOES	
	EH-59-2	05-06-87	0950	2-3.5	SS/ROT	Clay, Sandy	TE, TE-SP	DOES, VERSR	
	EH-59-3	05-06-87	1000	4-5.5	SS/ROT		TE	DOES	
	EH-59-4	05-06-87	1010	6-7.5	SS/ROT	Gravel & cobbles	TE	DOES	
	EH-59-5	05-06-87	1030	8-9.5	SS/ROT		TE, TE-SP	DOES, VERSR	
	EH-59-6	05-06-87	1045	10-11.5	SS/ROT		TE	DOES	
	EH-59-7	05-06-87	1125	15-16	SS/ROT		TE	DOES	
	EH-59-8	05-06-87	1140	18-19	SS/ROT		TE	DOES	
EH-60	EH-60-1	12-01-87	0915	0-2	SS/ROT	Silt, clay	TE	DOES	
	EH-61-2	12-01-87	0930	2-4	SS/ROT		TE	DOES	
EH-61	EH-61-1	11-25-87	0915	5-7	SS/ROT	Gravel, sand, silt	TE	DOES	
	EH-61-2	11-25-87	1040	10-10.5	SS/ROT		TE	DOES	
	EH-61-3	11-25-87	1115	15-16.5	SS/ROT		TE	DOES	
	EH-61-4	11-25-87	1215	24-25.6	SS/ROT		TE	DOES	
	EH-61-5	11-25-87	1445	30-31.5	SS/ROT		TE, TE-SP, TE-SP R	DOES, VERSR	
	EH-61-6	11-30-87	1215	35-36.5	SS/ROT		TE	DOES	
	EH-61-7	11-30-87	1245	45-47	SS/ROT		TE	DOES	
SC-1	SC-1-1	11-13-87	1510	60-61.5	SS/ROT	Clay and ash	PP2	BRN	Combined with SC-1-2 and 3 for physical parameters testing.
	SC-1-2	11-13-87	1515	65-67	SS/ROT		TE, PP2	VERSR, BRN	Combined with SC-1-1 and 3 for physical parameters testing.
	SC-1-3	11-13-87	1450	60-61	SS/ROT		PP2	BRN	Combined with SC-1-1 and 3 for physical parameters testing.
	SC-1-4	11-16-87	1107	75-77	SS/ROT		TE	DOES	

Notes:

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R = Replicate Analysis, SE = Sequential Extraction Analysis. See Table 2-2-2 for sample analytical schedules.

(5) DOES = Asarco's Department Of Environmental Services Laboratory; VERSR = Versar, an EPA CLP laboratory; RMA = Rocky Mountain Analytical, an EPA CLP laboratory.
BRN = Braun Engineering Testing, physical parameters testing.

Table 2-2-1
(continued)

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
SC-2	SC-2-2	11-18-87	1445	53-54.5	SS/ROT	Gravel, sand, clay	TE	DOES	
	SC-2-5	11-19-87	1130	74-76	SS/ROT		TE-SP, PP2	VERSR, BRN	Combined with SC-2-6 and 7 for physical parameters testing.
	SC-2-6	11-19-87	1200	80-82	SS/ROT	Weathered ash	TE, PP2	DOES, BRN	Combined with SC-2-5 and 7 for physical parameters testing.
	SC-2-7	11-19-87	1300	85-87	SS/ROT		PP2	BRN	Combined with SC-2-6 and 5 for physical parameters testing.
SC-3	SC-3-1	12-08-87	0945	0-2	SS/ROT	Clay, silty	TE	DOES	
	SC-3-2	12-08-87	1000	2-4	SS/ROT		TE, TE-SP,PP2	DOES, VERSR, BRN	Combined with SC-3-4 and SC-3-5 for testing of physical parameters.
	SC-3-3	12-08-87	1010	4-6	SS/ROT		TE, PP2	DOES, BRN	Combined with SC-2-5,6 and 7 for testing of physical parameters.
	SC-3-4	12-08-87	1020	6-8	SS/ROT		TE, PP2	DOES, BRN	Combined with SC-3-2 and SC-3-5 for testing of physical parameters.
	SC-3-5	12-08-87	1035	8-10	SS/ROT		TE, PP2	DOES, BRN	Combined with SC-3-4 and SC-3-2 for testing of physical parameters.
	SC-3-6	12-08-87	1045	10-12	SS/ROT	Gravel and cobbles	TE, TE-SP	DOES, VERSR	
	SC-3-7	12-08-87	1100	15-17	SS/ROT		TE	DOES	
	SC-3-8	12-08-87	1230	20-22	SS/ROT		TE	DOES	
	SC-3-9	12-08-87	1345	24-25	SS/ROT		TE	DOES	
	SC-3-10	12-08-87	1415	26-28	SS/ROT	Ash	TE, TE-SP, PP2	DOES, VERSR, BRN	Combined with SC-4-9 for testing of physical parameters.
SC-4	SC-4-1	12-08-87	1545	0-2	SS/ROT	Silt, clay	TE, TE-SP	DOES, VERSR	
	SC-4-2	12-08-87	1600	2-4	SS/ROT		TE, PP2	DOES, BRN	Combined with SC-4-3 for testing of physical parameters.
	SC-4-3	12-08-87	1615	4-6	SS/ROT	Gravel, cobbles,	TE, TE-SP,PP2	DOES, VERSR, BRN	Combined with SC-4-2 for testing of physical parameters.
	SC-4-4	12-08-87	1630	6-8	SS/ROT	sand & silt	TE	DOES	
	SC-4-5	12-08-87	1645	8-10	SS/ROT		TE	DOES	
	SC-4-6	12-08-87	1700	13-15	SS/ROT		TE	DOES	
	SC-4-7	12-09-87	0930	15-17	SS/ROT		TE	DOES	
	SC-4-8	12-09-87	1000	20-21	SS/ROT		TE	DOES	
	SC-4-9	12-09-87	1045	24-26	SS/ROT		TE, PP2	DOES, BRN	Combined with SC-3-10 for testing of physical parameters.
SC-5	SC-5-1	12-10-87	1100	0-2	SS/ROT	Fill	TE	DOES	
	SC-5-2	12-10-87	1115	2-4	SS/ROT		TE	DOES	
	SC-5-3	12-10-87	1125	4-6	SS/ROT	Gravel, cobbles,	TE	DOES	
	SC-5-4	12-10-87	1140	6-8	SS/ROT	sand & silt	TE, TE-SP	DOES, VERSR	
	SC-5-5	12-10-87	1200	10-12	SS/ROT		TE	DOES	
	SC-5-6	12-10-87	1230	15-17	SS/ROT		TE	DOES	
	SC-5-7	12-10-87	1300	20-22	SS/ROT	Clay, ash.	TE, TE-SP	DOES, VERSR	
LH-1	LH-1-1	10-29-87	0930	5-6.5	SS/DW	Silt, clay	TE, TE-SP	DOES, VERSR	
	LH-1-2	10-29-87	1030	7-8.5	SS/DW		TE, PP-2	DOES, BRN	
	LH-1-3	10-29-87	1300	9-10.5	SS/DW		TE, PP-2	DOES, BRN	
	LH-1-4	10-29-87	1315	13-14.5	SS/DW		TE, TE-SP, PP-2	DOES, VERSR, BRN	
	LH-1-5	10-29-87	1415	15-16.5	SS/DW	Sand	TE, PP-2	DOES, BRN	
	LH-1-6	10-29-87	1500	17-18.5	SS/DW	Gravel, Sand	TE, TE-SP	DOES, VERSR	

Notes: (1) R = Replicate, BB = Bottle Blank, CCB = Cross Contamination Blank, SD = Blind Field Standard.

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SE = Sequential Extraction Analysis. See Table 2-2-2 for sample analytical schedules.

Table 2-2-1
(continued)

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
LH-2	LH-2-1	10-30-87	1145	4.5-6	SS/DW	Silt, clay	TE, TE-SP	DOES, VERSR	
	LH-2-2	10-30-87	1230	6.5-8.5	SS/DW		TE	DOES	
	LH-2-3	10-30-87	1300	8.5-10.5	SS/DW		TE	DOES	
	LH-2-4	10-30-87	1400	10.5-12	SS/DW		TE	DOES	
	LH-2-4A	10-30-87	1400	12	SS/DW		TE, TE-SP	DOES, VERSR	
	LH-2-5	10-30-87	1430	12.5-14	SS/DW		TE	DOES	
	LH-2-6	10-30-87	1530	14-16	SS/DW		TE	DOES	
	LH-2-7	10-30-87	1600	16-18	SS/DW	Sand	TE	DOES	
	LH-2-8	10-30-87	1730	19-20	SS/DW	Gravel, Sand	TE, TE-SP	DOES, VERSR	
LH-3	LH-3-1	11-02-87	1230	5.5-7.5	SS/DW	Silt, clay	TE, TE-SP	DOES, VERSR	
	LH-3-2	11-02-87	1330	7.5-9.5	SS/DW		TE	DOES	
	LH-3-3	11-02-87	1400	9.5-11.5	SS/DW		TE	DOES	
	LH-3-4	11-02-87	1445	11.5-13.5	SS/DW		TE	DOES	
	LH-3-4A	11-02-87	1445	13.5	SS/DW		TE	DOES	
	LH-3-5	11-02-87	1515	13.5-15.5	SS/DW		TE, TE-SP	DOES, VERSR	
	LH-3-6	11-02-87	1545	15.5-17.5	SS/DW		TE	DOES	
	LH-3-7	11-02-87	1630	17.5-19.5	SS/DW	Gravel and sand	TE, TE-SP	DOES, VERSR	
LH-4	LH-4-1	11-03-87	1045	4.5-6.5	SS/DW	Silt, clay	TE, TE-SP TE-SP R	DOES, VERSR	
	LH-4-2	11-03-87	1130	6.5-8.5	SS/DW		TE	DOES	
	LH-4-3	11-03-87	1145	8.5-10.5	SS/DW		TE	DOES	
	LH-4-4	11-03-87	1215	10.5-12.5	SS/DW		TE	DOES	
	LH-4-5	11-03-87	1230	12.5-14.5	SS/DW		TE, TE-SP	DOES, VERSR	
	LH-4-6	11-03-87	1400	14.5-16.5	SS/DW		TE	DOES	
	LH-4-7	11-03-87	1430	16.5-18.5	SS/DW		TE	DOES	
	LH-4-8	11-03-87	1445	18.5-20.5	SS/DW		TE	DOES	
	LH-4-9	11-03-87	1530	20.5-22.5	SS/DW	Gravel and sand	TE, TE-SP	DOES, VERSR	
LH-5	LH-5-1	11-04-87	1100	4.5-5	SS/DW	Silt, clay	TE, TE-SP	DOES, VERSR	
	LH-5-1A	11-04-87	1100	5-6.5	SS/DW		TE	DOES	
	LH-5-2	11-04-87	1130	6.5-8.5	SS/DW		TE	DOES	
	LH-5-3	11-04-87	1200	8.5-10.5	SS/DW		TE	DOES	
	LH-5-4	11-04-87	1220	10.5-12.5	SS/DW		TE	DOES	
	LH-5-5	11-04-87	1330	12.5-14.5	SS/DW		TE, TE-SP	DOES, VERSR	
	LH-5-6	11-04-87	1400	14.5-16.5	SS/DW		TE	DOES	
	LH-5-7	11-04-87	1430	16.5-18.5	SS/DW	Gravel and sand	TE, TE-SP	DOES, VERSR	

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BRN = Braun Engineering Testing, physical parameters testing.

Table 2-2-1
(continued)

STRATIGRAPHIC SAMPLING SUMMARY

SAMPLE SITE	SAMPLE NUMBER (1)	SAMPLE DATE	SAMPLE TIME	SAMPLE INTERVAL (ft. below GS)	SAMPLE TYPE and METHOD (2)	GENERAL SAMPLE LITHOLOGY (3)	ANALYSES CONDUCTED (4)	LABORATORY (5)	COMMENTS
LH-6	LH-6-1	11-06-87	0915	6-8	SS/DW	Silt, clay	TE, TE-SP	DOES, VERSR	
	LH-6-2	11-06-87	1000	8-9	SS/DW		TE	DOES	
	LH-6-2A	11-06-87	1000	9-10	SS/DW		TE, PP2	DOES, BRN	
	LH-6-3	11-06-87	1015	11.5-13.5	SS/DW		TE, TE-SP, PP2	DOES, VERSR, BRN	Combined with LH-3,4, and 5 for testing of physical parameters.
	LH-6-4	11-06-87	1100	14-16	SS/DW		TE, PP2	DOES, BRN	Combined with LH-2A,4, and 5 for testing of physical parameters.
	LH-6-5	11-06-87	1130	16-18	SS/DW		TE, PP2	DOES, BRN	Combined with LH-3,2A, and 5 for testing of physical parameters.
	LH-6-6	11-06-87	1300	19-21	SS/DW	Gravel and sand	TE, TE-SP	DOES, VERSR	Combined with LH-3,4, and 2A for testing of physical parameters.
TH-1	TH-1-1	12-18-87	0930	1-2	G/TP	Clay	TE, TE-SP, PP2	DOES, VERSR, BRN	Combined with TH-1-2 and 3 for testing of physical parameters.
	TH-1-2	12-18-87	0930	2-3	G/TP		TE, PP2	DOES, BRN	Combined with TH-1-1 and 3 for testing of physical parameters.
	TH-1-3	12-18-87	0930	3-4	G/TP		TE, PP2	DOES, BRN	Combined with TH-1-2 and 1 for testing of physical parameters.
	TH-1-4	12-18-87	0930	4-5	G/TP		TE	DOES	
TH-2	TH-2-1	12-18-87	1000	0.5-2	SS/ROT	Fill	TE	DOES	
	TH-2-2	12-18-87	1015	2-4	SS/ROT		TE	DOES	
	TH-2-3	12-18-87	1030	4-6	SS/ROT		TE	DOES	
	TH-2-4	12-18-87	1045	6-8	SS/ROT	Sand	TE, TE-SP	DOES, VERSR	
	TH-2-5	12-18-87	1100	8-10	SS/ROT	Gravel and cobbles	TE	DOES	
	TH-2-6	12-18-87	1115	10-12	SS/ROT		TE	DOES	
	TH-2-7	12-18-87	1130	15-17	SS/ROT		TE, TE-SP	DOES, VERSR	
	TH-2-8	12-18-87	1200	20-21	SS/ROT		TE	DOES	
	TH-2-9	12-18-87	1430	25-27	SS/ROT		TE	DOES	

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Table 2-2-2 STRATIGRAPHIC SAMPLE ANALYTICAL SCHEDULES

CHEMICAL PARAMETERS

Trace Elements - Standard Analysis *

Arsenic (As)	Cadmium (Cd)	Copper (Cu)	Iron (Fe)
Lead (Pb)	Manganese (Mn)	Zinc (Zn)	pH **

Trace Elements - WRM Phase I Program

Antimony (Sb)	Arsenic (As)	Barium (Ba)	Cadmium (Cd)
Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Iron (Fe)
Lead (Pb)	Manganese (Mn)	Mercury (Hg)	Silver (Ag)
Vanadium (V)	Zinc (Zn)		

Trace Elements - Special Analysis

Antimony (Sb)	Arsenic (As)	Barium (Ba)	Cadmium (Cd)
Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Iron (Fe)
Lead (Pb)	Manganese (Mn)	Mercury (Hg)	Silver (Ag)
Vanadium (V)	Zinc (Zn)	Aluminum (Al)	Beryllium (Be)
Calcium (Ca)	Magnesium (Mg)	Nickel (Ni)	Potassium (K)
Selenium (Se)	Sodium (Na)	Thallium (Tl)	Tin (Sn)

PHYSICAL PARAMETERS

Physical Parameters List No 1

Partical Size	Cation Exchange Capacity	Laboratory Permeability	Specific Gravity ***
Porosity ***	Plasticity ***		

Physical Parameters List No 2

Partical Size	Cation Exchange Capacity	Laboratory Permeability

Notes:

* = These elements were also analyzed for sequential extraction analyses of selected samples.

** = Measured as part of the Comprehensive RI/FS program.

*** = Limited sample material prohibited analysis for these physical parameters.

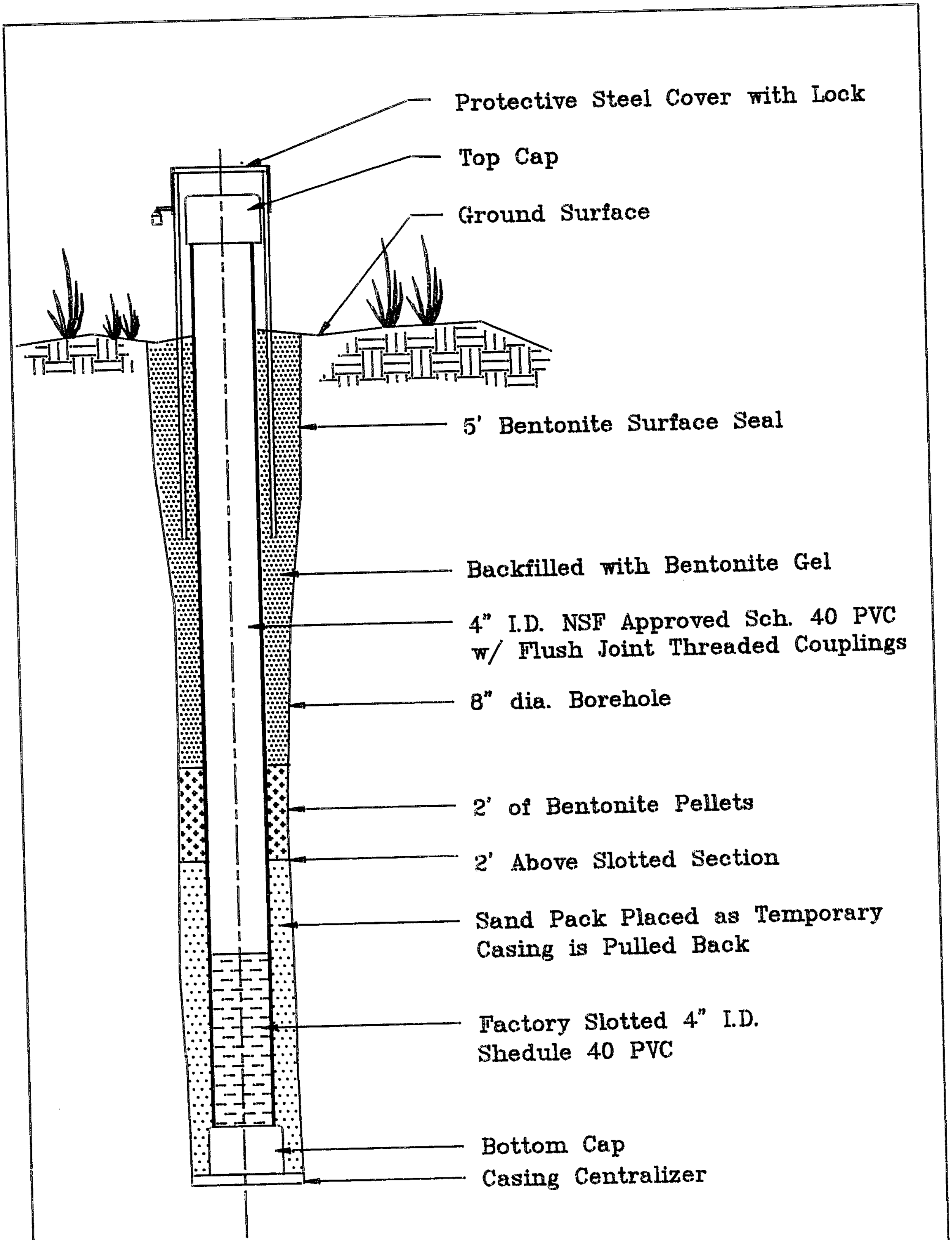


Figure 2-2-2: Typical Shallow Monitoring Well Construction

Factory slotted casing or screen was used in the target monitoring zone. When feasible, the target zone was perforated to intercept the upper 5 to 10 feet of the saturated zone with consideration given to well development and expected water table fluctuations.

Construction generally included temporary installation of 6-inch or 8-inch steel casing. The steel casing was slowly withdrawn as the annulus between the slotted PVC casing and the steel was sand packed, exposing the sand pack and the slotted casing to the aquifer. Sand packs usually extended 2 to 3 feet above the top of the slotted casing. Generally, the remaining steel casing was pulled out of the hole while pellet, granular, gel and/or slurry bentonite was added to the annulus. The well was secured by installation of a steel cap with a locking lid.

Intermediate Monitoring Well Construction

Intermediate monitoring wells generally were installed in the next water bearing zone beneath the shallow aquifer. However, in some cases such as shallow monitoring wells DH-13 and DH-17, intermediate monitoring well completion techniques were used to prevent downward migration of contaminants in soils above the saturated zone. Typical intermediate monitoring well construction details are shown in Figure 2-2-3. Well casing was NSF approved Schedule 40 PVC with bell joints. In the target monitoring zone, factory slotted casing or screen was used. When feasible, the target zone was perforated to intercept the upper 5 to 10 feet of the aquifer. Intermediate well construction included:

1) Installation of a 5-foot-long section of 10-inch or 12-inch steel casing to avoid contamination from shallow soils.

2) Drilling and driving 8-inch steel casing through the shallow aquifer and keying the casing into finer-grained material underlying the shallow aquifer. Generally, casing was driven several feet into the fine-grained unit.

3) Drilling a 6-inch diameter hole beneath the bottom of the 8-inch casing. The 6-inch hole extended to the target zone in the intermediate aquifer. If the hole remained open, a 4-inch

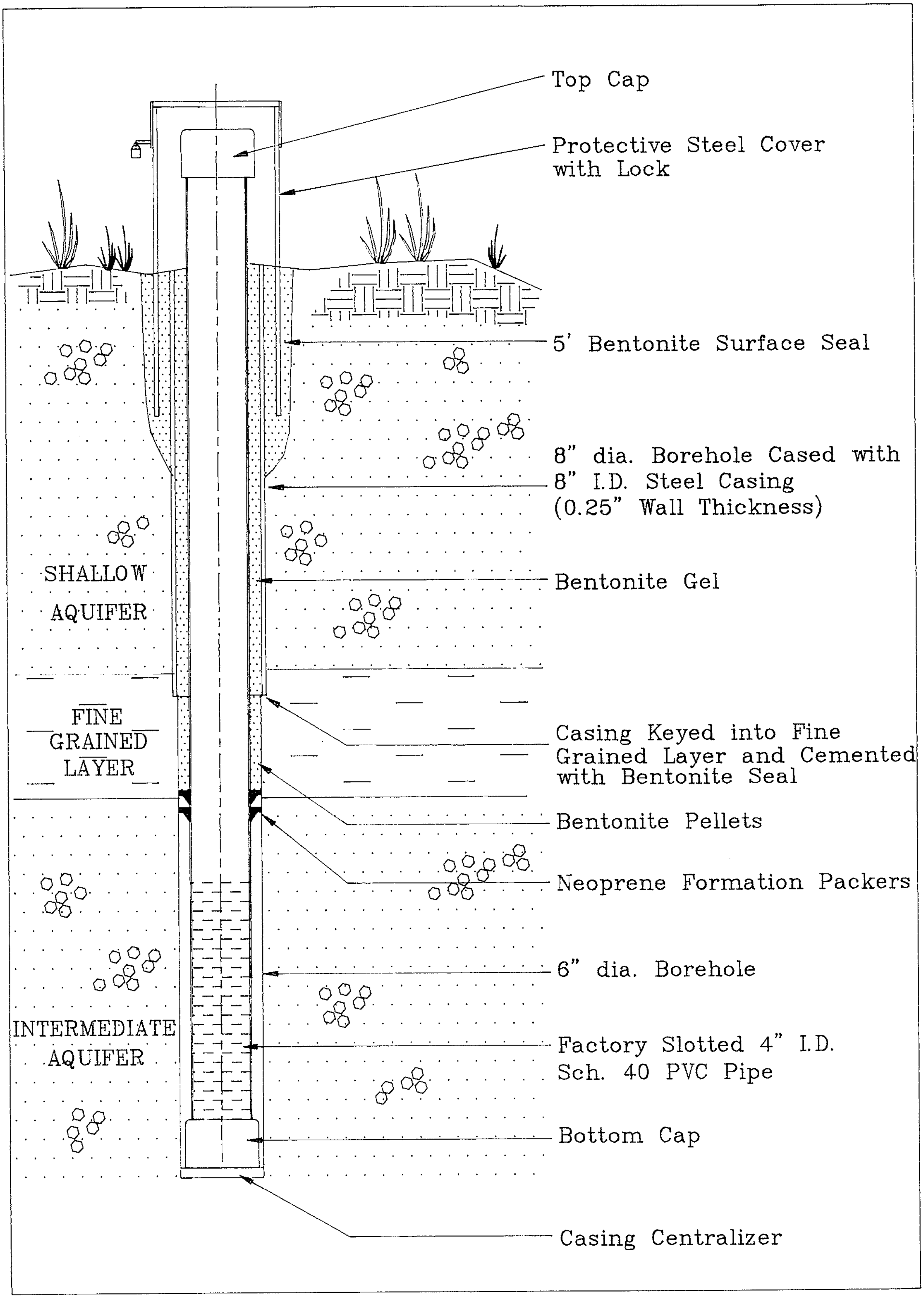


Figure 2-2-3: Typical Intermediate Monitoring Well Construction

NSF approved PVC casing with screen was inserted into the 6 inch drill hole. The annulus above the target zone was sealed using neoprene packers, followed by pellet, granular, gel and/or slurry bentonite. If the 6-inch hole caved, then 6-inch steel casing was driven during drilling and the well was completed by withdrawal of the steel casing to expose the 4-inch PVC screen to the aquifer. The remainder of the completion was as previously described. A steel locking lid was installed.

Deep Monitoring Well Construction

One monitoring well, DH-18, was constructed in a water bearing zone underlying the shallow and intermediate aquifers. Deep monitoring well construction details are shown in Figure 2-2-4. Drilling and monitoring well completion techniques for the deep well are similar to that used for the intermediate monitoring wells. Ten-inch steel casing was driven through the shallow aquifer and keyed into a finer grained material. Eight-inch steel casing was then driven through the intermediate zone and keyed into fine-grained, volcanic ash and clay underlying the intermediate unit. Beneath the intermediate unit, a six-inch drill hole was advanced into underlying strata and a monitoring well was installed using the same procedures described for intermediate monitoring well construction above.

Piezometer Installation

Nine 2-inch I.D. piezometers were installed near existing monitoring wells to help evaluate aquifer hydraulic characteristics. Six piezometers (P-1, P-2, P-3, P-4, P-5 and P-6) were installed in shallow strata. Two piezometers (P-8 and P-9) were installed in fine-grained units separating shallow and intermediate water bearing zones to assess vertical migration rates. One piezometer (P-7) was constructed in a deep soil core sampling drill hole (SC-1). Piezometer construction techniques were similar to those used for monitoring wells. Piezometers were drilled using a forward rotary rig with a top drive hammer. Piezometer construction details are shown in Figures 2-2-5 and 2-2-6, and in Appendix 4-2. Piezometer casing was Schedule 40 PVC with bell joints.

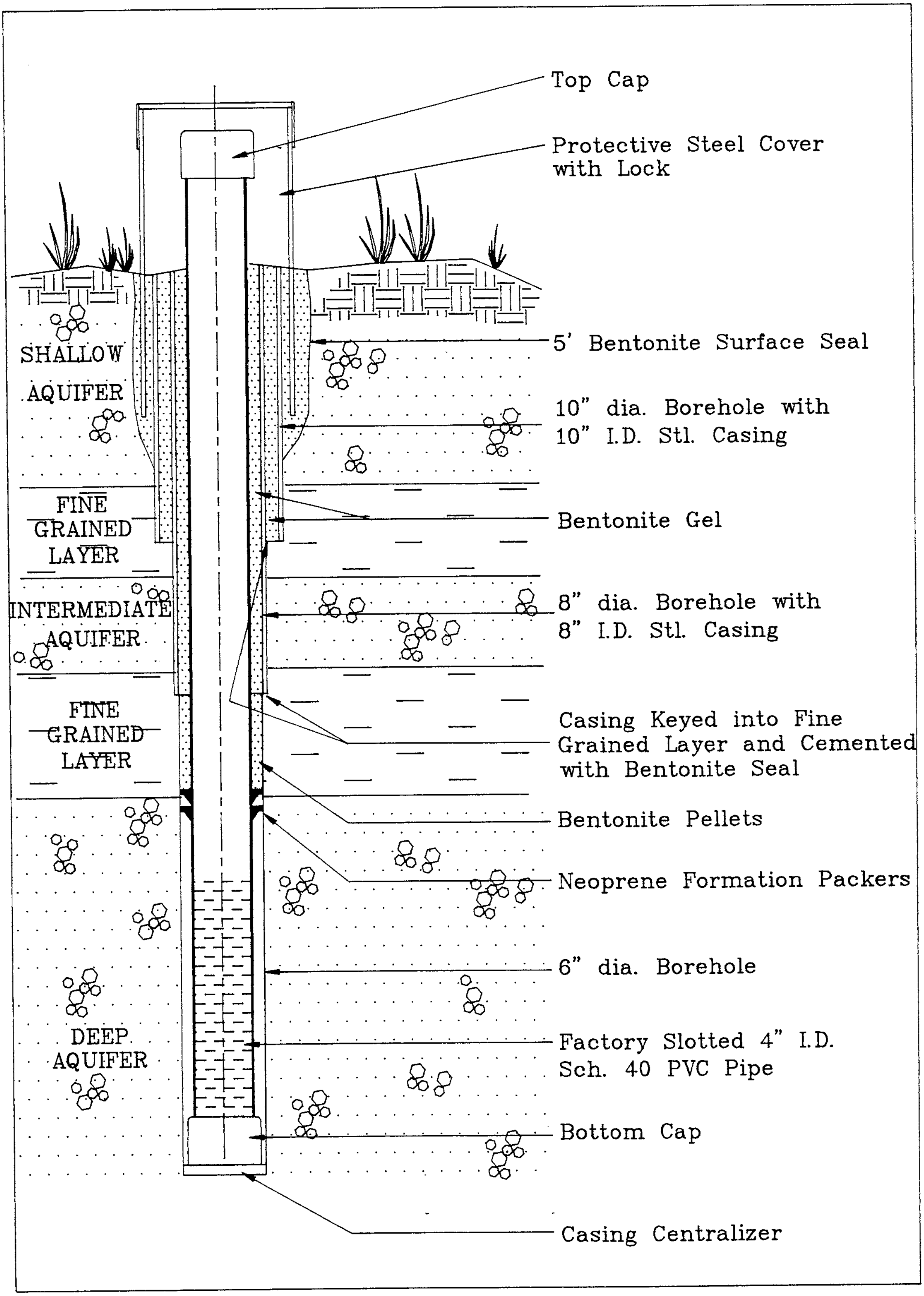


Figure 2-2-4: Typical Deep Monitoring Well Construction

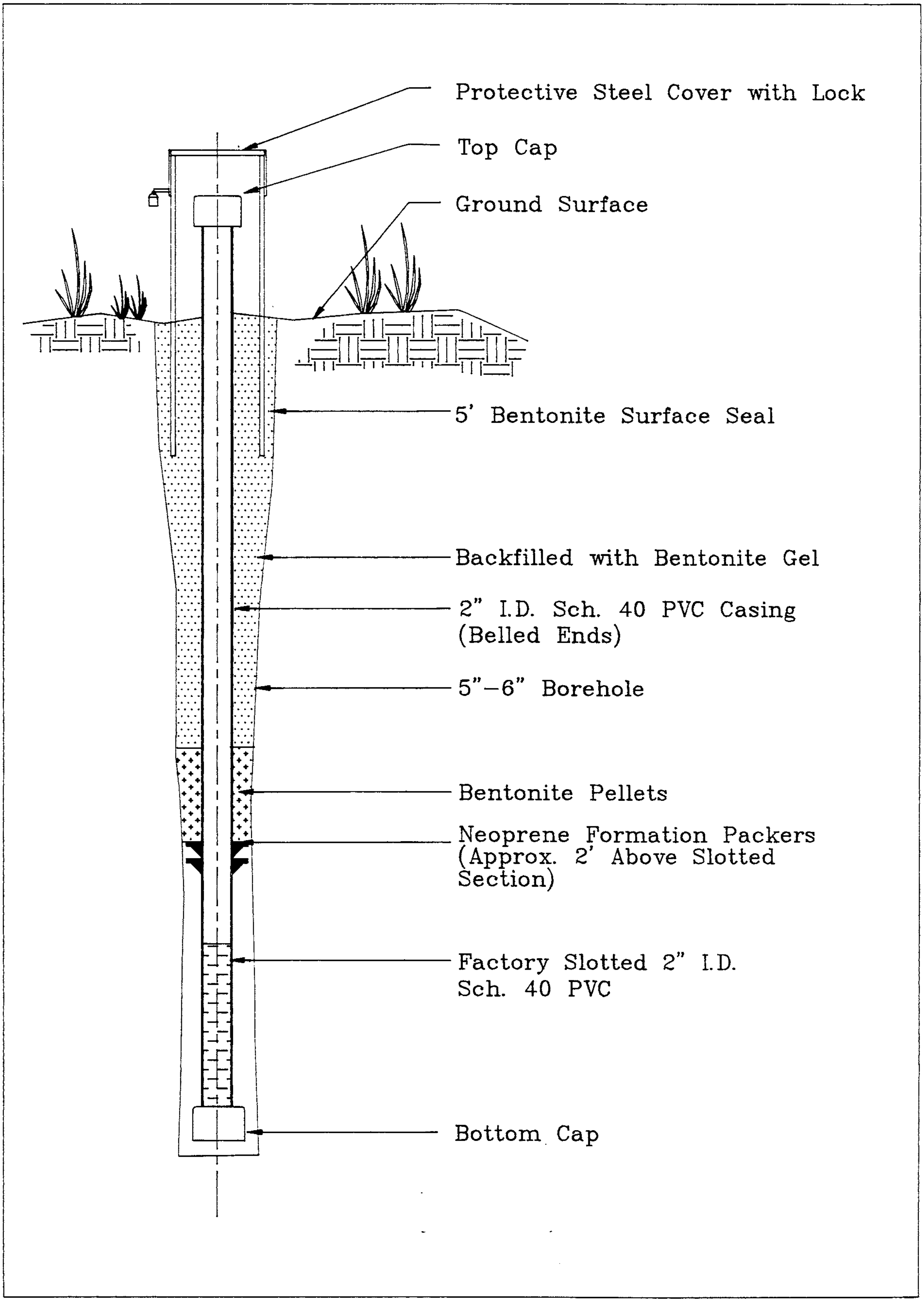


Figure 2–2–5: Typical Shallow Aquifer Piezometer

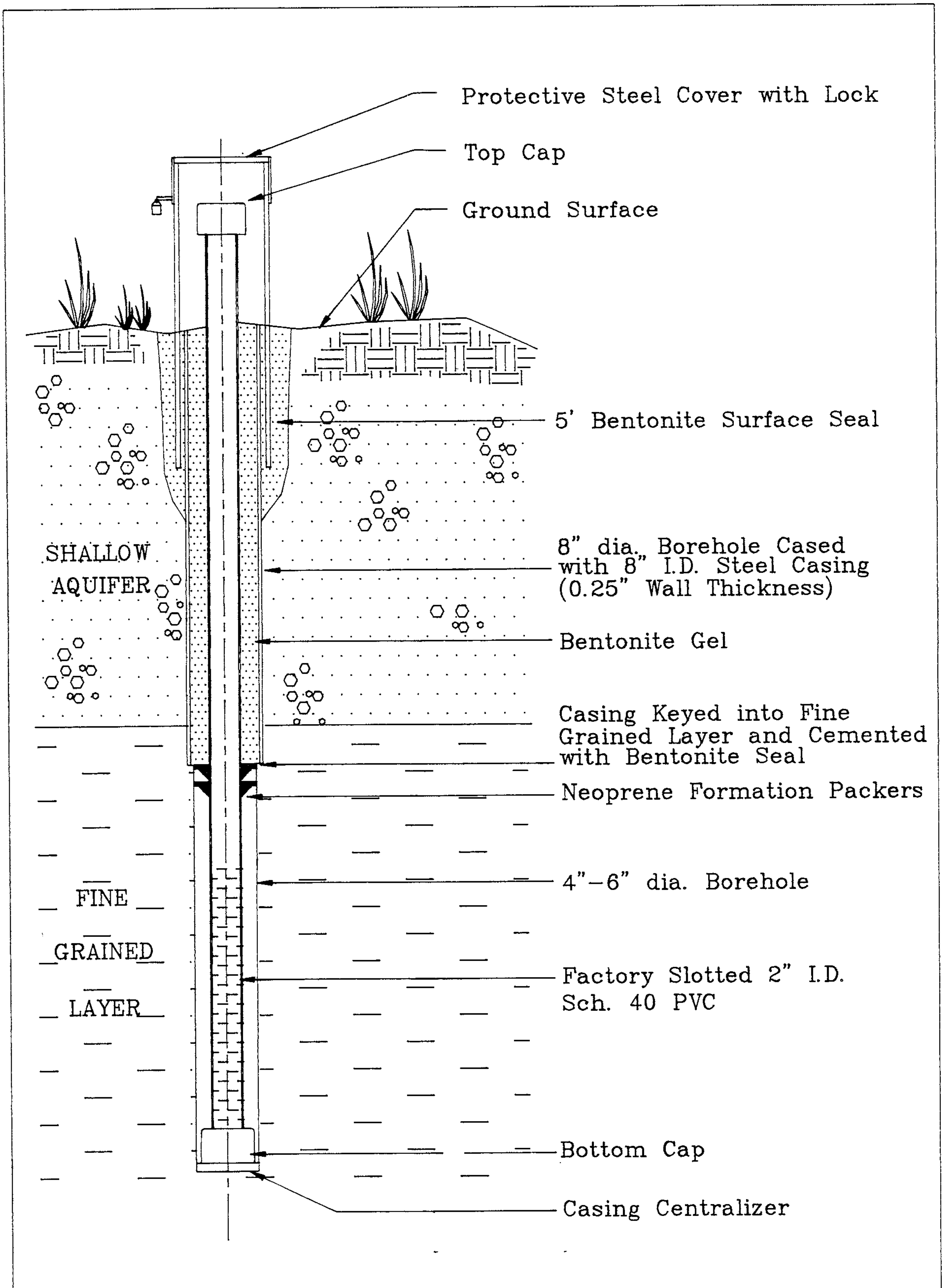


Figure 2–2–6: Typical Fine Grained Layer Piezometer

Slotted casing was used in the monitoring zone. Piezometers in the shallow, water-bearing zone were screened in the same interval as the nearby monitoring wells.

Monitoring Well and Piezometer Development

All wells and piezometers were developed by bailing to hydraulically surge the well, remove drilling debris and establish a good hydraulic connection with the aquifer. Development by bailing allowed easy decontamination of equipment between wells and also minimized disturbance to groundwater geochemistry. A minimum of 12 well casing volumes of water were removed from each well during development.

2.2.3 Groundwater Sampling and Analysis

A total of 41 monitoring wells and 33 privately owned wells were sampled for groundwater quality. Well locations are shown on Exhibit 1 and sample site photographs are in Appendix 2-1. The sampling frequency and analytical schedules for groundwater monitoring sites were designated in the Comprehensive RI/FS Work Plan, the Phase I WRM Work Plan and Phase II WRI Work Plan. Samples were collected during several sampling campaigns from fall 1984 through spring 1988 and, at EPA's request, several revisions were made to scheduled monitoring programs. Table 2-2-3 summarizes groundwater sampling from 1984 through 1988. The parameter list for groundwater sampling is in Table 2-2-4. All groundwater analyses are in Appendix 4-5.

Samples were collected in accordance with techniques outlined in the QAPP and the WRM work plans. Samples were collected after removal of at least three well bore volumes of water. Water from monitoring wells during the initial sampling campaign (fall 1984) was collected using a PVC bailer in accordance with the Phase I WRM Work Plan. The majority of water samples obtained during the remainder of Phase I activities (1985) and during the WRI Phase II and Comprehensive RI activities (1986 through 1988) were collected using a positive displacement teflon, teflon and stainless steel, or PVC bladder pump. The bladder pump eliminates or minimizes turbulent mixing which can occur when a bailer is plunged into the water column. Turbulent mixing caused by bailing often causes sediment to enter the well or re-suspends sediment in the well.

Table 2-2-3 SUMMARY OF GROUNDWATER SAMPLING

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
DH-1	01-15-85	S	DOES	YES	B
DH-1	01-15-85	S+SP	CAL	YES	B
DH-1	04-10-85	P	DOES	NO	B
DH-1	06-13-85	S	DOES	NO	B
DH-1	08-12-85	P	DOES	NO	B
DH-1	11-18-86	S	DOES	NO	BP
DH-1	11-18-86	P	RMA	NO	BP
DH-1	06-02-87	P	DOES	YES	BP
DH-1	11-18-87	S	DOES	NO	BP
DH-1	11-18-87	C	WYRHR	NO	BP
DH-1	04-25-87	P	DOES	NO	BP
DH-2	01-18-85	S	DOES	NO	B
DH-2	01-18-85	S+SP	CAL	NO	B
DH-2	04-10-85	P	DOES	NO	B
DH-2	06-12-85	S	DOES	NO	B
DH-2	08-13-85	P	DOES	NO	B
DH-2	11-18-86	P	DOES	NO	BP
DH-2	11-18-86	S	RMA	NO	BP
DH-2	06-03-87	S	DOES	YES	BP
DH-2	11-24-87	S+01+04	DOES + LKS	NO	BP+B
DH-2	05-03-88	P	DOES	NO	BP
DH-3	01-18-85	S	DOES	YES	B
DH-3	01-18-85	S+SP	CAL	YES	B
DH-3	04-10-85	P	DOES	NO	B
DH-3	06-12-85	S	DOES	YES	B
DH-3	08-15-85	P	DOES	NO	B
DH-3	08-15-85	P	DOES	NO	BP
DH-3	08-15-85	S+SP	JTC	NO	B
DH-3	08-15-85	S+SP	JTC	NO	BP
DH-3	11-18-86	P	DOES	NO	BP
DH-3	11-18-86	S	RMA	NO	BP
DH-3	06-02-87	S	DOES	NO	BP
DH-3	06-02-87	S	CHMTC	NO	BP
DH-3	11-19-87	S	DOES	NO	BP
DH-3	12-07-87	01	LKS	NO	BP+B
DH-3	04-25-88	P	DOES	NO	BP
DH-3	04-25-88	P	DOES	YES	BP
DH-3	12-08-88	P2+01	DOES + ATI	NO	
DH-4	01-16-85	S	DOES	YES	B
DH-4	01-16-85	S+SP	CAL	NO	B
DH-4	04-09-85	P	DOES	NO	B
DH-4	04-09-85	S+SP	JTC	YES	B
DH-4	06-11-85	S	DOES	YES	B
DH-4	06-11-85	S+SP	JTC	YES	B

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
DH-4	11-19-86	P	DOES	NO	BP
DH-4	11-19-86	P	RMA	NO	BP
DH-4	06-04-87	S	DOES	NO	BP
DH-4	11-19-87	S	DOES	NO	BP
DH-4	11-19-87	S	WYRHR	YES	BP
DH-4	04-29-88	P	DOES	NO	BP
DH-5	01-17-75	S	DOES	YES	B
DH-5	01-17-85	S+SP	CAL	YES	B
DH-5	04-09-85	P	DOES	NO	B
DH-5	04-09-85	S+SP	JTC	YES	B
DH-5	06-11-85	S	DOES	NO	B
DH-5	06-11-85	S+SP	JTC	NO	B
DH-5	08-13-85	P	DOES	YES	B
DH-5	11-24-86	P	DOES	NO	BP
DH-5	11-24-86	C	RMA	NO	BP
DH-5	06-03-87	C	DOES	NO	BP
DH-5	11-20-87	C	DOES	YES	BP
DH-5	04-27-88	P	DOES	YES	BP
DH-6	01-16-85	S	DOES	NO	B
DH-6	01-16-85	S+SP	CAL	NO	B
DH-6	01-21-85	S+SP	CAL	NO	B
DH-6	04-08-85	P	DOES	NO	B
DH-6	06-13-85	S	DOES	YES	B
DH-6	08-12-85	P	DOES	NO	B
DH-6	11-25-86	P	DOES	YES	BP
DH-6	11-25-86	S	RMA	YES	BP
DH-6	06-04-87	S	CHMTC	NO	BP
DH-6	06-04-87	S	DOES	NO	BP
DH-6	11-20-77	S	DOES	NO	BP
DH-6	12-07-87	01	LKS	NO	BP+B
DH-6	04-29-88	P	DOES	NO	BP
DH-7	01-18-85	S	DOES	NO	B
DH-7	01-18-85	S+SP	CAL	NO	B
DH-7	01-21-85	S+SP	CAL	NO	B
DH-7	04-08-85	P	DOES	NO	B
DH-7	06-14-85	S	DOES	NO	BP
	08-14-85	P	DOES	YES	B
	08-14-85	P	DOES	YES	BP
DH-7	08-14-85	S+SP	JTC	NO	B
DH-7	08-14-85	S+SP	JTC	NO	BP

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
DH-7	11-19-86	P	DOES	YES	BP
DH-7	11-19-86	S	RMA	YES	BP
DH-7	11-19-86	S	WYRHR	NO	BP
DH-7	05-21-87	S	DOES	YES	BP
DH-7	11-20-87	S	WYRHR	NO	BP
DH-7	11-20-87	S	DOES	NO	BP
DH-7	04-27-88	S	DOES	NO	BP
DH-8	01-17-85	S	DOES	NO	B
DH-8	01-17-85	S+SP	CAL	NO	B
DH-8	04-10-85	P	DOES	NO	B
DH-8	06-14-85	D	DOES	NO	B
DH-8	08-15-85	P	DOES	NO	B
DH-8	08-15-85	P	DOES	NO	BP
DH-8	08-15-85	S+SP	JTC	NO	B
DH-8	08-15-85	S+SP	JTC	NO	BP
DH-8	11-24-86	P	DOES	NO	BP
DH-8	11-24-86	S	RMA	NO	BP
DH-8	06-03-87	S	DOES	NO	BP
DH-8	11-22-87	S	DOES	NO	BP
DH-8	05-02-88	P	DOES	NO	BP
DH-9	01-18-85	S	DOES	NO	B
DH-9	01-18-85	S+SP	CAL	NO	B
DH-9	04-09-85	P	DOES	NO	B
DH-9	06-11-85	S	DOES	NO	B
DH-9	06-11-85	S+SP	JTC	NO	B
DH-9	08-13-85	P	DOES	NO	B
DH-9	11-25-86	P	DOES	NO	B
DH-9	11-25-86	S	RMA	NO	B
DH-9	06-05-87	S	DOES	NO	B
DH-9	11-23-87	S	DOES	YES	B
DH-9	05-02-88	P	DOES	NO	B
DH-10	01-16-85	S	DOES	NO	B
DH-10	01-18-85	S+SP	CAL	NO	B
DH-10	01-21-85	S+SP	CAL	NO	B
DH-10	04-08-85	P	DOES	NO	B
DH-10	06-15-85	S	DOES	NO	B
DH-10	08-13-85	P	DOES	NO	B
DH-10	11-18-86	P	DOES	NO	B
DH-10	11-18-86	S	RMA	NO	B
DH-10	06-03-87	S	DOES	NO	B
DH-10	11-19-87	S	DOES	NO	BP
DH-10	11-19-87	S	WYRHR	NO	BP
DH-10	04-27-88	P	DOES	NO	BP

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
DH-11	01-15-85*	S	DOES	YES	B
DH-11	01-21-85	S+SP	CAL*	YES	SP
DH-11	04-08-85	P	DOES	NO	B
DH-11	06-15-85	S	DOES	YES	B
DH-11	08-14-85	P	DOES	NO	B
DH-11	08-14-85	P	DOES	NO	BP
DH-11	08-14-85	S+SP	JTC	NO	B
DH-11	08-14-85	S+SP	JTC	NO	BP
DH-11	11-19-86	P	DOES	NO	BP
DH-11	11-19-86	S	RMA	NO	BP
DH-11	05-21-86	S	DOES	NO	BP
DH-11	11-19-87	S	DOES	NO	BP
DH-11	04-25-88	P	DOES	NO	BP
DH-12	11-13-86	S	DOES	NO	B
DH-12	11-13-86	S	RMA	NO	B
DH-12	01-28-87	S	DOES	NO	B
DH-12	06-09-87	S+01	DOES + LKS	NO	B
DH-12	06-09-87	S	CHMTC	NO	B
DH-12	08-16-87	S	DOES	NO	B
DH-12	08-17-87	01	LKS	NO	
DH-12	11-25-87	S	DOES	NO	B
DH-13	11-07-86	S	DOES	NO	BP
DH-13	11-07-86	S	RMA	NO	BP
DH-13	01-28-87	S	DOES	NO	BP
DH-13	01-28-87	S	CHMTC	NO	BP
DH-13	06-09-87	S	DOES	NO	BP
DH-13	08-13-87	S	DOES	YES	BP
DH-13	08-17-87	01	LKS	NO	BP+B
DH-13	11-25-87	S	DOES	YES	BP
DH-13	11-25-87	S	WYRHR	YES	BP
DH-13	05-02-88	P	DOES	NO	BP
DH-13	12-22-88	P2+01+03+04+05	DOES + ATI	YES	BP
DH-14	11-04-86	S	DOES	YES	BP
DH-14	11-04-86	S	RMA	YES	BP
DH-14	01-26-87	S	DOES	YES	BP
DH-14	04-02-87	*	DOES	YES	SP
DH-14	06-05-87	S	DOES	YES	BP
DH-14	08-11-87	S	DOES	YES	BP
DH-14	08-11-87	S	WYRHR	YES	BP
DH-14	11-19-87	S	DOES	NO	BP
DH-14	04-29-88	S	DOES	YES	BP

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
DH-15	11-06-86	S	DOES	YES	BP
DH-15	11-06-86	S	RMA	YES	BP
DH-15	01-27-87	S	DOES	YES	BP
DH-15	05-12-87	S	DOES	NO	BP
DH-15	06-04-87	S	VERSR	NO	BP
DH-15	06-04-87	S	DOES	YES	BP
DH-15	06-04-87	S	CHMTC	YES	BP
DH-15	06-29-87	*	DOES	NO	SP
DH-15	08-12-87	S	DOES	YES	BP
DH-15	11-19-87	S	DOES	NO	BP
DH-15	04-27-88	S	DOES	NO	BP
DH-16	11-24-87	S	DOES	NO	B
DH-17	12-01-86	S	DOES	YES	BP
DH-17	12-01-86	S	RMA	YES	BP
DH-17	01-29-87	S	DOES	NO	BP
DH-17	06-09-87	S	CHMTC	NO	BP
DH-17	06-09-87	S	DOES	NO	BP
DH-17	08-17-87	S+01	DOES + LKS	NO	BP+B
DH-17	04-19-88	S+01+04+05	DOES + ATI	YES	BP
DH-17	12-21-88	P2+01	DOES + ATI	NO	BP
DH-18	12-08-86	S	DOES	NO	BP
DH-18	12-08-86	S	RMA	YES	BP
DH-18	01-27-87	S	CHMTC	NO	BP
DH-18	01-27-87	S	DOES	NO	BP
DH-18	06-09-87	S	DOES	YES	BP
DH-18	08-11-87	S	DOES	NO	BP
DH-18	11-23-87	S	DOES	NO	BP
DH-18	05-02-88	P	DOES	NO	BP

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
DH-19	06-11-87	S	DOES	NO	BP
DH-19	06-11-87	S	CHMTC	NO	BP
DH-19	08-12-87	S	DOES	NO	BP
DH-19	08-12-87	S	WYRHR	NO	BP
DH-19	11-30-87	S	DOES	YES	BP
DH-19	05-03-88	P	DOES	NO	BP
DH-20	05-12-87	S	DOES	YES	BP
DH-20	05-12-87	S	CHMTC	YES	BP
DH-20	06-30-87	*	DOES	NO	BP
DH-20	08-11-87	S	DOES	YES	BP
DH-20	11-23-87	S	DOES	NO	BP
DH-20	12-07-87	01	LKS	NO	BP+B
DH-20	04-29-88	S	DOES	NO	BP
DH-21	04-27-87	S	DOES	NO	BP
DH-21	06-09-87	S+01	DOES + LKS	NO	BP+B
DH-21	06-09-87	S	CHMTC	NO	BP
DH-21	08-24-87	S+01	DOES + LKS	YES	BP+B
DH-21	11-30-87	S+01+04	DOES + LKS	NO	BP+B
DH-21	04-19-88	S+01	DOES + LKS	NO	BP
DH-22	06-11-87	S	DOES	NO	BP
DH-22	06-11-87	S	CHMTC	NO	BP
DH-22	08-12-87	S	DOES	NO	BP
DH-22	11-23-87	S	DOES	NO	BP
DH-22	05-03-88	S	DOES	NO	BP
DH-23	05-13-87	S	DOES	NO	BP
DH-23	05-13-87	S	CHMTC	NO	BP
DH-23	08-12-87	S	DOES	NO	BP
DH-23	11-25-87	S	DOES	NO	BP
DH-23	11-25-87	S	WYRHR	NO	BP
DH-23	05-02-88	P	DOES	YES	BP
DH-24	06-11-87	S	DOES	YES	BP
DH-24	06-11-87	S	CHMTC	YES	BP
DH-24	08-12-87	S	WYRHR	NO	BP
DH-24	08-12-87	S	DOES	NO	BP
DH-24	11-24-87	S+01	DOES + LKS	NO	BP
DH-24	04-19-88	P+01	DOES + LKS	NO	BP
DH-24	12-21-88	P2+01+05	DOES + ATI	NO	BP

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
DH-26	06-09-87	S+01+02	DOES + LKS	NO	BP
DH-26	08-17-87	S	WYRHR	YES	BP
DH-26	08-17-87	S+01+02	DOES + LKS	YES	BP
DH-26	11-23-87	S	DOES	NO	BP
DH-26	05-03-88	P	DOES	YES	BP
DH-27	06-09-87	S+01	DOES + LKS	NO	BP
DH-27	06-09-87	S	CHMTC	NO	BP
DH-27	08-17-87	S+01	DOES + LKS	NO	BP
DH-27	11-23-87	S+01+04	DOES + LKS	NO	BP
DH-27	05-03-88	P	DOES	NO	BP
DH-28	12-18-87	S	DOES	YES	BP
DH-28	12-18-87	S	WYRHR	YES	BP
DH-28	05-03-88	P	DOES	NO	BP
DH-29	12-18-87	S	DOES	NO	BP
DH-29	12-18-87	S	WYRHR	NO	BP
DH-29	04-29-88	P	DOES	NO	BP
EH-50	11-07-86	S	DOES	YES	BP
EH-50	11-07-86	S	RMA	NO	BP
EH-50	02-02-87	S	DOES	NO	BP
EH-50	04-22-87	S	DOES	NO	BP
EH-50	05-11-87	S	DOES	NO	BP
EH-50	08-10-87	S	DOES	NO	BP
EH-50	11-07-87	S	RMA	NO	BP
EH-50	11-17-87	S	DOES	YES	BP
EH-50	11-17-87	S	WYRHR	YES	BP
EH-50	04-15-88	P	DOES	NO	BP
EH-51	10-30-86	S	DOES	NO	BP
EH-51	10-30-86	S	RMA	NO	BP
EH-51	02-03-87	S	DOES	YES	BP
EH-51	04-24-87	S	DOES	YES	BP
EH-51	04-24-87	S	CHMTC	YES	BP
EH-51	08-10-87	S	DOES	NO	BP
EH-51	11-16-87	P **	DOES	YES	BP
EH-51	12-07-87	01	LKS	NO	BP+B
EH-51	04-20-88	P	DOES	NO	BP

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
EH-52	11-11-86	S	DOES	NO	BP
EH-52	11-16-86	S	RMA	NO	BP
EH-52	11-18-86	S	DOES	YES	BP
EH-52	11-18-86	S	RMA	YES	BP
EH-52	02-04-87	S	CHMTC	NO	BP
EH-52	02-04-87	S	DOES	NO	BP
EH-52	05-06-87	S	DOES	NO	BP
EH-52	08-07-87	S	DOES	YES	BP
EH-52	08-07-87	S	WYRHR	YES	BP
EH-52	11-07-87	S	DOES	YES	BP
EH-52	12-07-87	01	LKS	NO	BP+B
EH-52	04-20-88	P	DOES	YES	BP
EH-53	11-13-86	S	DOES	NO	BP
EH-53	11-13-86	S	DOES	YES	BP
EH-53	11-13-86	S	RMA	YES	BP
EH-53	11-13-86	S	DOES	NO	BP
EH-53	02-03-87	S	DOES	NO	BP
EH-53	04-21-87	S	DOES	YES	BP
EH-53	04-21-87	S	WYRHR	NO	BP
EH-53	08-07-87	S	DOES	NO	BP
EH-53	08-07-87	S	DOES	NO	BP
EH-53	11-16-87	P **	DOES	NO	BP
EH-53	04-13-88	P	DOES	NO	BP
EH-54	11-24-86	S	DOES	YES	BP
EH-54	11-24-86	S	RMA	YES	BP
EH-54	02-05-87	S	DOES	NO	BP
EH-54	02-05-87	S	CHMTC	NO	BP
EH-54	04-21-87	S	CHMTC	NO	BP
EH-54	04-21-87	S	DOES	NO	BP
EH-54	08-07-87	S	DOES	YES	BP
EH-54	11-16-87	S	WYRHR	NO	BP
EH-54	11-16-87	P **	DOES	NO	BP
EH-54	12-07-87	01	LKS	NO	BP+B
EH-54	04-13-88	P	DOES	YES	BP
EH-57A	12-03-87	S	DOES	YES	BP
EH-57A	12-03-87	S	WYRHR	YES	BP
EH-57A	04-13-88	P	DOES	NO	BP

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
EH-58	12-08-86	S	DOES	YES	BP
EH-58	12-08-86	S	RMA	NO	BP
EH-58	02-04-87	S	DOES	NO	BP
EH-58	02-04-87	S	CHMTC	NO	BP
EH-58	04-23-87	S	DOES	NO	BP
EH-58	04-23-87	S	DOES	NO	BP
EH-58	08-10-87	S	DOES	YES	BP
EH-58	11-17-87	P **	DOES	NO	BP
EH-58	04-15-88	P	DOES	YES	BP
EH-59	05-13-87	S	DOES	YES	BP
EH-59	05-13-87	S	CHMTC	YES	BP
EH-59	06-26-87	*	DOES	NO	SB
EH-59	08-07-87	S	WYRHR	NO	BP
EH-59	08-07-87	S	DOES	NO	BP
EH-59	11-17-87	P **	DOES	NO	BP
EH-59	04-13-88	P	DOES	NO	BP
EH-60	12-02-87	S+01	DOES + LKS	YES	BP
EH-60	12-02-87	S	WYRHR	YES	BP
EH-60	04-18-88	P	DOES	NO	BP
EH-60	05-04-88	01	ATI	NO	BP
EH-60	12-14-88	P2+01	DOES + ATI	NO	BP
EH-61	12-02-87	S+01	DOES + LKS	NO	BP
EH-61	12-02-87	S	WYRHR	NO	BP
EH-61	04-18-88	P+01+03+05	DOES + ATI	YES	BP
EH-61	12-15-88	P+01+03+05	DOES + ATI	NO	BP
EH-62	12-02-87	S	DOES	NO	BP
EH-62	12-02-87	S	WYRHR	NO	BP
EH-62	04-15-88	P	DOES	NO	BP
EH-62	12-22-88	P2+01	DOES + ATI	NO	BP
EH-100	11-11-86	S	DOES	YES	BP
EH-100	11-11-86	S	RMA	YES	BP
EH-100	02-02-87	S	DOES	YES	BP
EH-100	04-07-87	*	DOES	YES	SP
EH-100	04-22-87	S	DOES	YES	BP
EH-100	08-10-87	S	DOES	NO	BP
EH-100	11-17-87	S	WYRHR	NO	BP
EH-100	11-17-87	P **	DOES	NO	SP
EH-100	04-15-88	P	DOES	NO	BP

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
EH-101	10-23-87	*	DOES	NO	SP
EH-101	10-30-86	S	DOES	YES	BP
EH-101	10-30-86	S	RMA	YES	BP
EH-101	02-03-87	S	DOES	NO	BP
EH-101	04-15-87	S	DOES	NO	SP
EH-101	04-15-87	*	DOES	NO	SP
EH-101	04-15-87	*	DOES	YES	SP
EH-101	04-23-87	S	CHMTC	NO	BP
EH-101	04-23-87	S	DOES	NO	BP
EH-101	08-10-87	S	DOES	NO	BP
EH-101	11-16-87	P **	DOES	NO	BP
EH-101	04-20-88	P	DOES	NO	BP
EH-102	11-11-86	S	DOES	NO	BP
EH-102	11-11-86	S	RMA	NO	BP
EH-102	02-04-87	S	DOES	YES	BP
EH-102	02-04-87	S	CHMTC	YES	BP
EH-102	04-13-87	*	DOES	YES	SP
EH-102	04-23-87	S	DOES	NO	BP
EH-102	08-07-87	S	DOES	NO	BP
EH-102	11-16-87	P **	DOES	NO	BP
EH-102	04-20-88	P	DOES	NO	BP
Am. Chemet-1	10-27-87	P	DOES	NO	EP
Am. Chemet-1	04-12-88	P ***	DOES	NO	EP
Am. Chemet-2	11-03-84	S	DOES	NO	EP
Am. Chemet-2	05-13-85	P	DOES	NO	EP
Am. Chemet-2	10-10-86	P	DOES	NO	EP
Am. Chemet-2	10-10-86	S	RMA	NO	EP
Am. Chemet-2	05-05-87	S	DOES	NO	EP
Am. Chemet-2	10-27-87	S	DOES	YES	EP
Am. Chemet-2	10-27-87	P ***	WYRHR	YES	EP
Am. Chemet-3	11-03-84	S	DOES	NO	EP
Am. Chemet-3	05-13-85	P	DOES	NO	EP
Am. Chemet-4	10-14-86	P	DOES	NO	EP
Am. Chemet-4	10-14-86	S	RMA	NO	EP
Am. Chemet-4	05-05-87	S	DOES	NO	EP
Asarco Well	01-29-87	S	DOES	YES	EP
Asarco Well	01-29-87	P ***	CHMTC	NO	EP
Asarco Well	03-16-87	S	DOES	YES	EP
Asarco Well	05-05-87	S	DOES	NO	EP
Asarco Well	05-05-87	S	CHMTC	NO	EP

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
Berry	05-14-85	S	DOES	NO	EP
Berry	10-14-86	P	DOES	NO	EP
Berry	10-14-86	S	RMA	NO	EP
Berry	04-28-87	P	DOES	NO	EP
Berry	04-06-88	P	DOES	NO	EP
Burnham	11-02-85	S	DOES	NO	EP
Burnham	11-02-85	S+SP	CAL	NO	EP
Burnham	05-13-85	P	DOES	YES	EP
Duel	11-02-84	S	DOES	YES	EP
Duel	05-14-85	S	DOES	NO	EP
Duel	10-14-86	P	DOES	NO	EP
Duel	10-14-86	S	RMA	NO	EP
Duel	04-28-87	P	DOES	NO	EP
Duel	11-03-87	P **	DOES	NO	EP
Duel	04-07-88	P	DOES	NO	EP
E.H. City No. 1	12-02-86	P	DOES	YES	EP
E.H. City No. 1	12-02-86	S	RMA	NO	EP
E.H. City No. 1	01-29-87	S	DOES	NO	EP
E.H. City No. 1	04-29-87	P	DOES	NO	EP
E.H. City No. 1	04-29-87	P ***	CHMTC	NO	EP
E.H. City No. 1	08-03-87	S	DOES	YES	EP
E.H. City No. 1	04-12-88	P	DOES	YES	EP
E.H. City No. 2	12-02-86	P	DOES	NO	EP
E.H. City No. 2	12-02-86	S	RMA	YES	EP
E.H. City No. 2	04-29-87	P ***	CHMTC	NO	EP
E.H. City No. 2	04-29-87	P	DOES	NO	EP
E.H. City No. 2	08-03-87	S	DOES	NO	EP
E.H. City No. 2	04-12-88	P	DOES	NO	EP
Ernst	05-14-85	S	DOES	NO	EP
Ernst	05-14-85	S+SP	JTC	NO	EP
Ernst	10-14-86	P	DOES	NO	EP
Ernst	10-14-86	S	RMA	NO	EP
Ernst	04-28-87	P	DOES	NO	EP
Ernst	04-28-87	P ***	CHMTC	NO	EP
Ernst	11-02-87	P	DOES	NO	EP
Ernst	04-06-88	P	DOES	YES	EP
Flage	05-14-85	S	DOES	NO	EP
Flage	04-07-88	S	DOES	NO	EP
Helfert	11-03-84	S	DOES	YES	EP
Helfert	05-13-85	P	DOES	NO	EP
Helfert	10-10-86	P	DOES	NO	EP
Helfert	10-10-86	S	RMA	NO	EP
Helfert	05-05-87	S	DOES	YES	EP
Helfert	11-03-87	P **	DOES	NO	EP
Helfert	04-08-88	S	WYRHR	NO	EP
Helfert	04-08-88	P **	DOES	YES	EP

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
Hoff	05-14-85	S+SP	JTC	NO	EP
Hoff	10-14-86	P	DOES	NO	EP
Hoff	10-14-86	S	RMA	NO	EP
Hoff	04-28-87	P	DOES	YES	EP
Hoff	04-28-87	P	DOES	NO	EP
D. Hulst	11-03-84	S	DOES	NO	EP
D. Hulst	05-13-85	P	DOES	NO	EP
D. Hulst	10-10-86	P	DOES	YES	EP
D. Hulst	10-10-86	S	RMA	YES	EP
D. Hulst	01-29-87	S	DOES	NO	EP
D. Hulst	03-16-87	S	DOES	NO	EP
D. Hulst	05-06-87	P ***	CHMTC	NO	EP
D. Hulst	05-06-87	S	DOES	NO	EP
D. Hulst	07-27-88	S	DOES	YES	EP
K. Hulst	02-03-87	S	DOES	NO	EP
K. Hulst	05-06-87	S	DOES	NO	EP
K. Hulst	05-06-87	P ***	CHMTC	NO	EP
K. Hulst	07-27-88	S	DOES	NO	EP
L. Hulst	02-03-87	S	DOES	NO	EP
L. Hulst	05-06-87	S	DOES	YES	EP
L. Hulst	05-06-87	P ***	CHMTC	YES	EP
L. Hulst	07-27-88	S	DOES	NO	EP
Jensen A-2	05-14-85	S	DOES	YES	EP
Jensen A-2	05-14-85	S+SP	JTC	NO	EP
Jensen A-2	10-14-86	P	DOES	YES	EP
Jensen A-2	10-14-86	S	RMA	NO	EP
Jensen A-2	04-28-87	P	DOES	NO	EP
Jensen A-2	11-02-87	P	DOES	NO	EP
Jensen A-2	04-07-88	P **	DOES	NO	EP
Kammerman	02-06-87	S	DOES	YES	EP
Kammerman	02-06-87	P	CHMTC	NO	EP
Lamping C	11-03-84	S	DOES	NO	EP
Lamping C	11-03-84	S+SP	CAL	NO	EP
Lamping C	05-13-85	P	DOES	NO	EP
Lamping F-1	11-02-84	S	DOES	NO	EP
Lamping F-1	05-14-85	S	DOES	NO	EP
Lamping R	05-14-85	S	DOES	NO	EP
Lamping R	10-14-86	P	DOES	NO	
Lamping R	10-14-86	S	RMA	NO	
Lamping R	04-28-87	P	DOES	NO	
Lamping R	04-06-88	P **	DOES	NO	

Table 2-2-3
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
Manion	11-02-84	S	DOES	NO	EP
Manion	05-14-85	P	DOES	NO	EP
Manion	05-14-85	S+SP	JTC	NO	EP
Manion	10-14-86	P	DOES	NO	
Manion	10-14-86	S	RMA	NO	
Manion	04-28-87	P	DOES	NO	
Manion	04-28-87	P ***	CHMTC	NO	
Mc Donald	11-02-84	S	DOES	NO	EP
Mc Donald	05-13-85	P	DOES	NO	EP
Nordstrom	05-14-85	S	DOES	NO	EP
Nordstrom	10-14-86	P	DOES	NO	
Nordstrom	10-14-86	S	RMA	NO	
Nordstrom	04-28-87	P	DOES	NO	
Romasko	05-14-85	S	DOES	NO	EP
Romasko	10-14-86	P	DOES	NO	
Romasko	10-14-86	S	RMA	NO	
Romasko	04-28-87	P	DOES	NO	
Romasko	11-02-87	P **	DOES	NO	
Romasko	04-06-88	P **	DOES	NO	
Simac	02-05-87	S	DOES	YES	
Simac	05-05-87	S	DOES	NO	
Simac	05-05-87	P ***	CHMTC	NO	
Simac	11-03-87	P **	DOES	NO	
Simac	04-12-88	P **	DOES	NO	
St. Clair	04-29-87	P	DOES	YES	
St. Clair	04-29-87	P ***	CHMTC	YES	
St. Clair	11-03-87	S	WYRHR	NO	
St. Clair	11-03-87	P	DOES	NO	
St. Clair	04-08-88	P **	DOES	NO	
Vetsch	05-14-85	S	DOES	NO	EP
Vetsch	10-14-86	P	DOES	NO	
Vetsch	10-14-86	S	RMA	NO	
Vetsch	04-28-87	P	DOES	NO	
Vetsch	11-02-87	P **	DOES	NO	
Vetsch	04-06-88	P **	DOES	NO	
Walter Well	02-03-87	S	DOES	NO	
Walter Well	11-03-87	P **	DOES	YES	
Walter Well	11-03-87	S	WYRHR	YES	
Walter Well	04-07-88	P **	DOES	NO	
Weston	05-14-85	S	DOES	NO	EP
Weston	10-14-86	P	DOES	NO	
Weston	10-14-86	S	RMA	NO	
Weston	04-28-87	P	DOES	NO	
Weston	11-02-87	P **	DOES	NO	
Weston	04-06-87	P **	DOES	NO	

Table 2-2-3
(continued)

	SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE	SAMPLE METHOD (3)
Wojcik		10-14-86	P	RMA	NO	
Wojcik		04-28-87	S	DOES	NO	
Wojcik		11-03-87	P	DOES	YES	
Wojcik		11-03-87	P **	DOES	NO	
Wojcik		04-07-88	P **	DOES	NO	

Notes

(1) S = Standard analysis
P = partial analysis
SP = special analysis
* = Analysis of selected parameters during aquifer testing
** = Partial analysis + additional parameters
*** = Standard metals analysis minus the standard common ions list
P2 = Post RI parameter list
01 = Organic analysis for oil and grease or total petroleum hydrocarbons
02 = Organic analysis for BTX or BTEX
03 = Organic analysis for volatile organi contaminants
04 = Organic analysis for semi-volatile contaminants
05 = Organic analysis for identification of fuel constituents

(2) DOES = Asarco's Department of Environmental Services
CAL = California Analytical Lab
JTC = JTC Environmental Consultants
RMA = Rocky Mountain Analytical laboratory
CHMTC = Chem Tech laboratory
VERSR = Versar laboratory
LKS = Laucks laboratory (organic parameters)
ATI = Analytical Technologies Inc (organic parameters)

(3) BP = Bladder Pump
EP = Existing Pump
SP = Submersible Pump

Table 2-2-4

GROUNDWATER SAMPLE PARAMETER LIST

INORGANIC PARAMETERS

STANDARD ANALYSES

Specific Electrical Conductivity (field and lab)
pH (field and lab)
Total Dissolved Solids (TDS)
Total Suspended Solids (TSS)

Static Water Level
Dissolved Oxygen
Temperature
Eh **

Calcium (Ca)
Magnesium (Mg)
Potassium (K)
Bicarbonate (HCO3)
Carbonate (CO3)
Sulfate (SO4)
Chloride (Cl)

Arsenic (As)*
Arsenic III (As III)* **
Arsenic V (As V)* **
Cadmium (Cd)*
Copper (Cu)*
Lead (Pb)*

Iron (Fe)*
Iron II (Fe II)* **
Iron III (Fe III)* **
Manganese (Mn) *
Zinc (Zn)*

PARTIAL ANALYSES

Specific Electrical Conductivity (field and lab)
pH (field and lab)
Total Dissolved Solids (TDS)
Total Suspended Solids (TSS)

Static Water Level
Dissolved Oxygen
Temperature
Eh **

Bicarbonate (HCO3)
Sulfate (SO4)

Arsenic (As)*
Arsenic III (As III)* **
Arsenic V (As V)* **
Cadmium (Cd)*
Lead (Pb)*

Iron (Fe)*
Iron II (Fe II)* **
Iron III (Fe III)* **
Zinc (Zn)*

SPECIAL METALS ANALYSES

Aluminum (Al) *
Antimony (Sb) *
Arsenic (As) *
Barium (Ba) *
Beryllium (Be) *

Cadmium (Cd) *
Calcium (Ca) *
Chromium (Cr) *
Cobalt (Co) *
Copper (Cu) *

Iron (Fe) *
Lead (Pb)
Magnesium (Mg) *
Manganese (Mn) *
Mercury (Hg) *

Nickel (Ni) *
Potassium (K) *
Selenium (Se) *
Silver (Ag) *
Sodium (Na) *

Thallium (Tl) *
Tin (Sn) *
Vanadium (V) *
Zinc (Zn) *

ORGANIC PARAMETERS****

(03)
EPA method 624 for volatile organics

(02)
BTX or BTEX

(04)
EPA method 625 for semi-volatile organics

(05)
GC-FID
Fuel Finger Print

(01)
Total Petroleum Hydrocarbons or Oil and Grease

* All metals measured as dissolved.

** Parameter measured as part of WRM Phase II and Comprehensive Remedial Investigation activities. Not measured during WRM Phase I activities. Not measured by EPA CLP laboratories.

*** Parameter measured as part of Phase I groundwater resources monitoring only. Not measured during Phase II WRM or as part of Comprehensive Remedial Investigation activities.

**** Organic parameter measurements were conducted in WRM Phase II and Comprehensive RI activities. Designation organic code (example 01) corresponds to the sampling analysis code in Table 2-3-4. The complete organic parameter list is in Appendix 6.

A comparison of bladder pump sampling and sampling using a bailer was conducted in the Draft WRM report (Hydrometrics 1986a). Results of this comparison showed there was no significant or statistical difference between the two sampling techniques for the parameters measured during the Phase I investigation.

Selected wells were also sampled for organic parameters (see Table 2-2-3). These samples were obtained by stainless steel bailer or using a stainless steel and Teflon bladder pump in accordance with the Comprehensive RI/FS Work Plan.

Sampling equipment and procedures (see Section 2.7 QUALITY ASSURANCE AND QUALITY CONTROL) were selected to minimize changes in the sample chemical and physical characteristics. Collection, preservation and storage of samples were in accordance with EPA (1982 and 1986b) recommendations, which are outlined in the project QAPP and QAPP addendums. Groundwater samples collected by Hydrometrics were shipped to the DOES laboratory for analysis. Split samples were processed and shipped by EPA representatives to EPA contract laboratories: California Analytical Laboratories (CAL), JTC Environmental Consultants (JTC), Rocky Mountain Analytical (RMA), Versar Laboratory (Versr) or Weyerhaeuser (WYRHR) for analysis.

2.2.4 Aquifer Testing

Aquifer tests were conducted on a total of 38 monitoring wells to determine aquifer hydraulic characteristics. Aquifer testing included both single well tests and long-term multiple well aquifer tests. Wells with sufficient yield were pumped at a constant discharge rate using a submersible or centrifugal pump. Water level decline was measured during pumping and water level recovery was measured after pumping ceased. Multiple well testing included two long-term aquifer tests conducted in accordance with the Comprehensive RI/FS Work Plan. Two wells, DH-13 and DH-17, were tested by pumping at constant rates. Water levels in local monitoring wells and piezometers were monitored for drawdown during pumping and also during recovery after pumping ceased.

Aquifer test data from single and multiple well pumping tests were analyzed using standard straight-line techniques described by Cooper and Jacob (1946) and by Jacob (1963). Observed water level drawdown in wells completed in unconfined strata was adjusted for decreasing transmissivity using the technique described by Walton (1970). A well was considered completed in a semi-confined or confined aquifer if lithological logs (Appendix 4-2) indicated the aquifer was overlain by fine-grained sediments and water levels were above the perforated interval.

Wells with low yields were tested using the slug removal technique described by Cooper and others (1967). Hydraulic data from low yield wells were obtained by measuring water level recovery (residual drawdown) following the instantaneous removal of a known volume ("slug") of water.

The constant discharge pumping tests and slug removal tests are considered valid for obtaining estimates of hydraulic properties of the medium in the vicinity of the well tested. Test results are summarized in Table 2-2-5 and graphical plots of test data are in Appendix 4-6.

Table 2-2-5

AQUIFER TEST SUMMARY

TESTED WELL NO.	OBSER-VATION WELL NO.	DEPTH (ft)	PERFORATED INTERVAL (ft)	STATIC WATER LEVEL BELOW GS (ft)	TEST DATE	TEST TYPE(1)	DURATION (min)	MAXIMUM DRAWDOWN (ft)	DISCHARGE RATE (gpm)	TRANSMIS-SIVITY (gpd/ft)	PERMEA-BILITY (gpd/ft2)	STORAGE COEFFIC.	COMMENTS
DH-1		50	40-50	33.9	10-23-85	Slug/Cooper	27	7.69		300	30		Instantaneous removal of 5 gallon slug.
DH-2		65.5	55.5-65-5	57.27	10-32-85	Slug/Cooper	21	6.17		320	39		Instantaneous removal of 4 gallon slug.
DH-3		54	50-54	29.35	8-20-85	Slug/Cooper	61	7.69		45	11		Instantaneous removal of 5 gallon slug.
DH-4		23	17-23	9.38	10-24-85	Jacob DD Jacob RDD	215 80	3.82	10.5	9,120 6,990	1,520 1,170		Apparent recharge or leakage at approx. 120 minutes.
DH-5		17	9-17	12.61	11-25-85	Jacob DD Jacob RDD	115 75	3.19	5.3	1630 950	370 220		Apparent barrier boundary; heterogeneous system.
DH-6		25	15-25	11.98	11-6-85	Jacob DD Jacob RDD	45 59	6.42	75	52,800 51,500	5,300 5,200		Discharge transported from site; test terminated when storage capacity exceeded; possible barrier at approx. 35 minutes.
DH-7		28.5	18.5-28.5	17.80	9-5-85	Jacob DD Jacob RDD	249 93	4.27	5.28	17,700 16,500	1,770 1,650		Apparent recharge at approx. 5 minutes; limited head available for test; rapid recovery.
DH-8		49	39-49	36.95	10-25-85	Jacob DD Jacob RDD	250 43	5.62	14.28	21,400 15,100	2,140 1,510		Apparent barrier boundary at approx. 150 minutes.
DH-10		10	5-10	5.48	11-20-85	Jacob DD Jacob RDD	117 37	2.77	6.5	2,340 2,040	540 470		Limited water column.
DH-11		29	19-29	14.52	8-20-98	Jacob DD Jacob RDD	105 49	6.33	8.8	12,700 14,300	1,270 1,430		Apparent recharge or leakage at approx. 60 min.; recovery incomplete; poor straight-line plot.
DH-13		45	35-45	31.28	3-15-88	Jacob DD Jacob RDD	450 880	8.3	30	11,450 9,810	1,145 980		Apparent barrier boundary at approx. 120 min. Gradual discharge decrease 120 to 440 min. Discharge surging as water level reached pump intake. Froth build up on top of water column

Table 2-2-5
(continued)

AQUIFER TEST SUMMARY

TESTED WELL NO.	OBSERVATION WELL NO.	DEPTH (ft)	PERFORATED INTERVAL (ft)	STATIC WATER LEVEL BELOW GS (ft)	TEST DATE	TEST TYPE(1)	DURATION (min)	MAXIMUM DRAWDOWN (ft)	DISCHARGE RATE (gpm)	TRANSMISSIVITY (gpd/ft)	PERMEABILITY (gpd/ft2)	STORAGE COEFFIC.	COMMENTS
DH-13	P-1	45	35-45	31.13	3-15-88	Jacob DD Jacob RDD	450 880	0.96		39,260 14,480	3,930 1,450	0.0009	Apparent boundary observed for both observation wells P-1 and P-2.
	P-2	45	35-45	30.45	3-15-88	Jacob DD Jacob RDD	450 880	1.44		24,690 10,900	2,470 1,090	0.0015	
	DH-12	30	20-30	Dry	3-15-88	None	450	0					Dry.
	DH-18	63.5	55.5-63.5	30.98	3-15-88	None	450	0					No response.
	DH-16	32	23-32	Dry	3-15-88	None	450	0					No response.
	DH-17	42	32-42	30.42	3-15-88	None	450	0					No response.
	DH-8	49	39-49	40.79	3-15-88	None	450	0					No response.
	P-3	41	31-41	30.21	3-15-88	None	450	0					No response.
	P-4	41	31-41	31.06	3-15-88	None	450	0					No response.
	DH-21	35	27-35	25.01	3-15-88	None	450	0					No response.
	DH-23	20	10-20	12.81	3-15-88	None	450	0					No response.
DH-14		46	34-46	8.74	4-1-87	Jacob DD Jacob RDD	376 116	4.3	15.85	910 570	76 48		Apparent multiple recharge or leakage boundaries.
	DH-4	23	17-23	11.36	4-1-87	Monitored Response	376 116	0.39					DH-4 monitored to observe response of shallow unit during test of deeper unit. Response was immediate and consistent during pumping.

Table 2-2-5
(continued)

AQUIFER TEST SUMMARY

TESTED WELL NO.	OBSERVATION WELL NO.	DEPTH (ft)	PERFORATED INTERVAL (ft)	STATIC WATER LEVEL BELOW GS (ft)	TEST DATE	TEST TYPE(1)	DURATION (min)	MAXIMUM DRAWDOWN (ft)	DISCHARGE RATE (gpm)	TRANSMISSIVITY (gpd/ft)	PERMEABILITY (gpd/ft2)	STORAGE COEFFIC.	COMMENTS
DH-15		50	41.5-50	12.82	6-29-87	Jacob DD Jacob RDD	270 10	13.88	5.01	570	67		Apparent recharge or leakage boundary at approx. 75 min. Recovery influenced by leakage /recharge and is probably not representative.
	DH-6	25	15-25			Monitored Response	270 10	.07					DH-6 monitored to observe response of shallow unit during pumping of deeper unit.
DH-17		41	31-41	30.42	3-17-87	Jacob DD Jocob RDD	1,330 475	3.4	18	14,880 22,920	1,490 2,290		Good drawdown plots.
	P-3	41	31-41	30.21	3-17-87	Jacob DD Jocob RDD	1,338 475	0.47		19,750 25,760	1,975 25,80	0.05	
	P-4	41	31-41	31.07	3-17-87	Jacob DD Jocob RDD	1,338 475	0.49		16,790 26,340	1,680 2,630	0.05	
	DH-16	32	23-32	Dry	3-17-87	None	1,338	0					No response.
	DH-13	45	35-45	31.28	3-17-87	None	1,338	0					No response.
	DH-12	30	20-30	Dry	3-17-87	None	1,338	0					No response.
	DH-18	63.5	55.5-63.5	30.98	3-17-87	None	1,338	0					No response.
	P-1	45	35-45	31.13	3-17-87	None	1,338	0					No response.
	P-2	45	35-45	30.45	3-17-87	None	1,338	0					No response.
	DH-8	49	39-49	40.79	3-17-87	None	1,338	0					No response.
	DH-24	35	27-35	29.44	3-17-87	None	1,338	0.02					Drawdown extrapolated from continuous recorder chart.

Table 2-2-5
(continued)

AQUIFER TEST SUMMARY

TESTED WELL NO.	OBSER-VATION WELL NO.	DEPTH (ft)	PERFORATED INTERVAL (ft)	STATIC WATER LEVEL BELOW GS (ft)	TEST DATE	TEST TYPE(1)	DURATION (min)	MAXIMUM DRAWDOWN (ft)	DISCHARGE RATE (gpm)	TRANSMIS-SIVITY (gpd/ft)	PERMEA-BILITY (gpd/ft2)	STORAGE COEFFIC.	COMMENTS
DH-19		30	20-30	17.16	3-9-88	Jacob DD Jacob RDD	240 80	4.47	5	3,200 2,880	320 290		
DH-20		31	21-31	15.71	6-30-87	Jacob DD Jacob RDD	240 120	4.08	17	9,010 10,710	900 1,070		Apparent barrier boundary at about 110 minutes.
DH-21		29	19-29	22.19	12-4-87	Slug/Cooper	7.5	3.47		1,190	132		Good curve match.
DH-22		34	24-34	26.0	2-10-88	Jacob DD	240	1.77	2.2	3,470	434		No recovery test.
DH-23		20	10-20	11.3	10-8-87	Jacob DD	70	0.01	85				Well completed in cavernous slag. No significant drawdown observed while pumping.
DH-24		35	27-35	29.39	3-22-88	Jacob DD Jacob RDD	250 65	2.63	7.8	8,590 13,990	1,530 2,490		Early adjustment of pumping rate necessary.
DH-26		35	25-35	26.49	2-29-88	Jacob DD Jacob RDD	189 30	2.23	3	6,930 5,840	814 686		Test limited by available water column.
DH-27		29	19-29	16.15	2-24-88	Jacob DD Jacob RDD	234 60	7.47	6	3,760 4,700	376 470		Good recovery test.
DH-28		36	26-36	28.96	2-29-88	Jacob DD Jacob RDD	189 75	5.42	4	7,310 3,870	1,040 550		Apparent barrier boundary at approx. 120 min. Test duration limited by available water column.
DH-29		17	7-17	8.67	2-8-88	Jacob DD	240	4.25	7	4,200	500		

Table 2-2-5
(continued)

AQUIFER TEST SUMMARY

TESTED WELL NO.	OBSERVATION WELL NO.	DEPTH (ft)	PERFORATED INTERVAL (ft)	STATIC WATER LEVEL BELOW GS (ft)	TEST DATE	TEST TYPE(1)	DURATION (min)	MAXIMUM DRAWDOWN (ft)	DISCHARGE RATE (gpm)	TRANSMISSIVITY (gpd/ft)	PERMEABILITY (gpd/ft2)	STORAGE COEFFIC.	COMMENTS
EH-50		45	25-45	28.11	5-11-88	Jacob DD	200	8.62	3	1,300	77		Pumping rate final adjustment after 25 minutes.
EH-51		30	20-30	14.45	3-4-88	Jacob DD Jacob RDD	340	6.57	9.1	20,670 22,520	2,070 2,250		
	P-6	30	20-30	15.30		Jacob DD Jacob RDD	315	0.94		17,190 19,388	1,720 1,940	0.000001	
	P-9	34	31-34	14.34		Monitored Response	315	1.17					
	EH-101	35	35-45	15.41		Monitored Response	315	0.18					
EH-52		13	5-13	8.0	1-28-88	Jacob DD	260	0.52	2	8,290	1,660		Very quick recovery after pumping. Apparent leakage or recharge boundary at about 100 minutes.
	P-5	13	5-13	7.95		Jacob DD	250	0.07		14,740	2,950	0.03	
	P-8	21	14-21	7.95		Monitored Response	250	0.18					Monitored response of underlying clay unit to pumping of shallow unit.
	EH-102	35	25-35	8.9		Monitored Response	250	0					No response.
EH-53		35	25-35	28.18	3/12/87	Slug/Cooper	10	5.34		690	100		
EH-54		18	8-18	10.06	3/12/87	Slug/Cooper	30	6.03		260	35		

Table 2-2-5
(continued)

AQUIFER TEST SUMMARY

TESTED WELL NO.	OBSER-VATION WELL NO.	DEPTH (ft)	PERFORATED INTERVAL (ft)	STATIC WATER LEVEL BELOW GS (ft)	TEST DATE	TEST TYPE(1)	DURATION (min)	MAXIMUM DRAWDOWN (ft)	DISCHARGE RATE (gpm)	TRANSMIS-SIVITY (gpd/ft)	PERMEA-BILITY (gpd/ft2)	STORAGE COEFFIC.	COMMENTS
EH-57A		45	35-45	35.98	1-8-88	Jacob DD Jacob RDD	300 42	1.43	16	28,500 25,680	3,160 2,850		
EH-58		31	21-31	14.3	4-8-87	Jacob DD	295	26.44	17.6	3,460	346		
EH-59		18	8-18	7.4	6-26-87	Jacob DD Jacob RDD	300 8	7.0	2.9	750 1,200	75 120		Very rapid recovery.
EH-60		29	22-28	22.60	2-4-88	Jacob DD	260	1.87	6	14,870	2,800		Apparent barrier boundary at approx. 80 minutes.
EH-61		45	36-45	23.65	3-24-88	Jacob DD Jacob RDD	280 22	13.07	8.8	3,930 5,120	390 510		
EH-62		46.5	25-45	25.78	1-20-88	Jacob DD Jacob RDD	280 36	5.88	55	73,370 187,670	3,820		Apparent barrier boundary at about 60 minutes. Recovery not representative of aquifer characteristics; not monitored long enough.
EH-100		60	52-60	27.9	4-6-87	Jacob DD	1200	10.79	16.7	7,580	950		Apparent barrier boundary at about 120 minutes. Recovery erratic and not used for calculation of aquifer characteristics.
EH-101		45	35-45	15.41	1-26-88	Jacob DD	322	19.57	10.3	1360	136		Apparent barrier boundary at about 180 minutes. Recovery rapid and not used for calculation of aquifer characteristics.
	EH-51	30	10-30	15.03		Monitored Response	322	0.25					EH-51 and P-6 were measured to monitor response of shallow unit. P-9 was measured to monitor response of fine grained layer between shallow and intermediate unit. P-9 responded immediately when pumping started.
	P-6	30	10-30	15.03		Monitored Response	322	0.18					
	P-9	34	31-34	14.64		Monitored Response	322	0.3					

Table 2-2-5
(continued)

AQUIFER TEST SUMMARY

TESTED WELL NO.	OBSERVATION WELL NO.	DEPTH (ft)	PERFORATED INTERVAL (ft)	STATIC WATER LEVEL BELOW GS (ft)	TEST DATE	TEST TYPE(1)	DURATION (min)	MAXIMUM DRAWDOWN (ft)	DISCHARGE RATE (gpm)	TRANSMISSIVITY (gpd/ft)	PERMEABILITY (gpd/ft2)	STORAGE COEFFIC.	COMMENTS
EH-102		35	25-35	9.23	4-14-87	Jacob DD Jacob RDD	73 52	7.46	17.6	8,820 9,355	880 935		
				8.91	1/21/88	Jacob DD	240	6.94	17.6	8,800	880		
	EH-52	13	5-13	8.04	1/21/88	Monitored Response	240	0					No response.
	P-5	13	5-13	8.02	1/21/88	Monitored Response	240	0					No response.
	P-8	21	14-21	8.04	1/21/88	Monitored Response	240	0					No response.

1. Slug test analyzed using method by Cooper and others (1967); Constant discharge drawdown (DD) test analyzed using method by Cooper and Jacob (1946); constant discharge residual drawdown (RDD) test analyzed using methed by Jacob (1963).

2. Permeability values calculated by dividing measured transmissivity by saturated thickness penetrated.

NOTES:

A) See Appendix 5 for graphical plots of aquifer test data.

B) Drawdown measurements for wells completed in unconfined aquifers are adjusted for decreasing transmissivity (Walton, 1970; p. 224).

C) GS = ground surface.

2.3 SURFACE SOIL/SURFACE WATER REMEDIAL INVESTIGATION

The elements of the Surface Soil/Surface Water operable unit include; on-site and off-site surface soils, surface water, cattle, vegetation, waterfowl and fish.

2.3.1 Surface Soils

The three primary objectives of the surface soils investigation were to (1) determine the metal content in surface soils within the plant boundaries and ore storage areas that have the potential to produce wind-borne particulates, (2) more accurately map the spatial distribution of surface soil contaminants in the East Helena area, and (3) determine the amount of contaminated surface soil that could enter the Prickly Pear Creek system during a storm event.

A general description of surface soil sampling and analytical methods for both Plant site and East Helena soils is presented below. More detailed descriptions of sampling and analytical methods can be found in the Comprehensive RI Work Plan (Hydrometrics, 1987) and the various laboratory protocols (Neuman, 1987; Robbins, 1987; Stanga, 1987). The methods used to estimate surface soil erosion potentials in the Prickly Pear Creek system are included as part of the results and discussion in Section 5.2.4.

2.3.1.1 Plant Site Surface Soil Sampling

Twenty-six soil samples were collected from six use areas within the plant. Sample sites were chosen to provide thorough coverage of all areas in the plant that have potential to produce wind-borne dust. The potential dust producing areas and sampling sites were mutually determined by Asarco and EPA RI project team members. At each sampling site, three samples were collected at locations approximately ten meters due north, south, and west of a center stake. The three soil samples were collected from the 0-1 inch depth with stainless steel spoons, composited on a clean plastic sheet and placed in an eight-ounce I-Chem glass jar. All tools were cleaned and new latex gloves donned between each sampling. Samples were stored in coolers with blue ice during field work and transferred into cold storage at the end of each day.

Sampling, packaging, and shipping of samples were done as specified in the Comprehensive RI/FS Work Plan (Hydrometrics Inc., 1987). All samples were sent under chain-of-custody to the DOES laboratory for analysis.

2.3.1.2 East Helena Surface Soil Sampling

The sampling methods used for the East Helena residential soil sampling are based on the protocol outlined in the East Helena, Montana Child Health Study work plan (MDHES, 1983) and followed the standard operating procedures in the Comprehensive RI/FS Work Plan (Hydrometrics, 1987). A primary objective of the East Helena sampling was to correlate the elemental concentrations measured in 1983 during the Child Lead Study with those measured in 1987 for the Comprehensive RI. Therefore, twenty sample sites were chosen to represent a wide range of the elemental concentrations measured and to duplicate sites sampled during the CDC/MDHES Child Lead Study (MDHES 1986). In addition, surface soils from two East Helena area schools and two parks were sampled.

A Clements JMC soil probe was used for all sampling. New acetate liners were inserted into the barrel of the probe between each sampling. The samples were extruded directly into the liner when the probe was inserted into the soil. The liner was then removed and capped with the sampled soil remaining inside and untouched by sampling personnel.

Residential sample locations were defined by a 0.7 square meter wooden rectangle placed in approximately the same place that was sampled by the CDC/MDHES sampling team in 1983. Cores from 0-2 inches were taken from each corner of the rectangle. Front, back, and side yards were sampled, with front and back yard samples being composited. A total of eight cores were therefore composited for the front/back yard samples. For side yards, two cores were collected in each corner of the rectangle (eight total) in order to collect sufficient sample material.

Playground and park sample locations were defined by creating two perpendicular transects of approximately thirty meters in length, crossing each other at their center to form a large X. A core was collected every ten meters along each transect.

After collection, the samples were prepared in Bozeman, Montana by removing the grass and dense root layer with a plastic knife, collecting the 0-1 inch sample from directly below the dense root zone, and compositing with the other subsample cores.

Packaging and shipping of samples were done as specified in the Comprehensive RI/FS Work Plan (Hydrometrics Inc. 1987). All samples were sent under chain-of-custody to the DOES laboratory for analysis.

2.3.1.3 Analysis of Surface Soil Samples

All soil samples collected from the plant and within East Helena were prepared by drying at 150 degrees fahrenheit to constant weight; the samples were then sieved, pulverized, and sieved again to pass through an 80-mesh screen. Digestion was performed through a sequential process of nitric acid and nitric/hydrogen peroxide baths. Samples were analyzed for total silver (Ag), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), manganese (Mn), lead (Pb), antimony (Sb), selenium (Se), thallium (Tl), and zinc (Zn) using flame atomic absorption or graphite furnace atomic absorption. The general methods for sample preparation, digestion and analysis are provided in the Contract Laboratory Program (CLP) Statement of Work (U.S. EPA, 1984b). The exact analytical procedures used by DOES are detailed in the laboratory analytical protocol developed through a series of correspondence between Asarco and EPA's oversight contractors (Neuman, 1987; Robbins, 1987; and Stanga, 1987).

2.3.2 Surface Water

The remedial investigation of surface waters in the study area was conducted in three phases in accordance with the Water Resources Monitoring Plan (WRM Phase I, 1984b), the Water Resources Investigation Phase II Work Plan (WRI Phase II, 1986b), the Comprehensive RI/FS Work Plan (1987b), and in accordance with the project QAPP and QAPP work plan addendums. Results of the first phase of water resources investigation activities were presented in the draft WRI report (February 7, 1986). All data and information collected during all phases of the surface water remedial investigation are included in this report.

Numerous monitoring stations were established to evaluate the surface water system in the vicinity of the plant. Those sites are located on Prickly Pear Creek, Upper Lake, Wilson Ditch and Seep-1. The surface water investigation included flow measurement synoptic runs (seepage runs), surface water quality sampling, and stream and pond bottom sediment sampling. The surface water investigation also included evaluation of surface water and groundwater interrelationships, evaluation of surface water uses, and an evaluation of the flux of metals bearing soils into Prickly Pear Creek during runoff events.

2.3.2.1 Flow Measurement

Surface water flow was measured periodically at seven sites on Prickly Pear Creek (PPC-3 through PPC-9), and at two sites on Wilson Ditch (WD-2 and WD-3) during the Phase I WRM investigation. Additional flow measurements of Prickly Pear Creek and three other irrigation ditches were conducted during three synoptic runs as part of the WRI Phase II investigation activities. These synoptic runs included 18 measurement stations between PPC-3 (above Upper Lake) and PPC-38A (about 0.75 miles northwest of East Helena). Surface water sites are shown on Figure 2-3-1 and sample site photographs and descriptions are in Appendix 2-1.

Flows were measured concurrently with water sample collection. With the exception of site PPC-35A, which was equipped with a Parshall flume, site flow measurements were made using either a pygmy vertical-axis current meter or a Marsh-McBirney Inc. (MMI) Model 201 analog meter. Prior to flow measurements of Prickly Pear Creek and Wilson Ditch, field comparisons of the two current meters were conducted by Hydrometrics and the U.S. Geologic Survey. Agreement between the two types of current meters was excellent.

Streamflow measurement procedures used are described in the project QAPP and are in accordance with U.S. Geological Survey (1968 and 1977) methods. Stream width was divided into subsectors and in each subsector the width, depth and water velocity was measured. Total streamflow was determined by summing the flows of all subsectors.

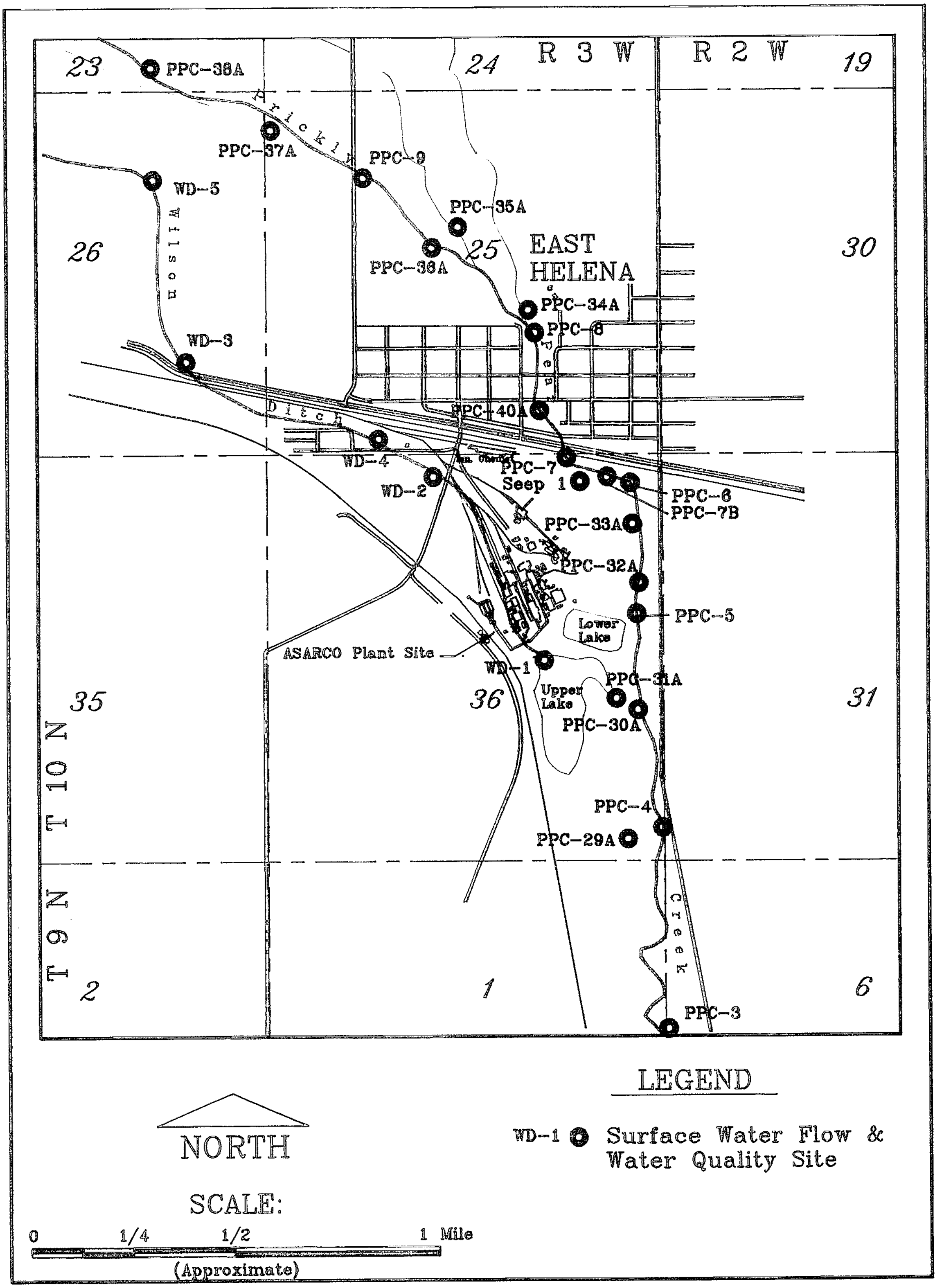


Figure 2-3-1: Surface Water Flow and Water Quality Monitoring Sites

2.3.2.2 Surface Water Sampling And Analysis of Prickly Pear Creek, Upper Lake and Irrigation Ditches

Surface water quality samples were collected in accordance with techniques outlined in the project QAPP and the Phase I and the Phase II WRM Work Plans. As part of the Phase I WRM investigation, water samples were collected at seven sites on Prickly Pear Creek (PPC-3 through PPC-9), three sites on Wilson ditch (WD-1, WD-2, and WD-3), Upper Lake, and a seep (Seep-1) at the toe of the north side of the slag pile (see Figure 2-3-1 and Exhibit 1). As part of the Phase II WRI investigation, water samples were obtained at 13 sites on Prickly Pear Creek (PPC-3 through PPC-9; PPC-30A, PPC-32A, PPC-33A, PPC-36A, PPC-38A and PPC-40A), the diversion from Prickly Pear Creek to Upper Lake (PPC-29A), a diversion culvert from Upper Lake to Prickly Pear Creek (PPC-31A), three irrigation ditches, (PPC-34A, PPC-35A, and PPC 37A) and the seep (Seep-1).

Eight additional sites (A, B, C, D, E, F, G, H, Exhibit 1) were sampled for overland runoff following two short, intense precipitation events. Sites A, B, C, and D were sampled during a thunderstorm on June 29, 1985, and sites A, E, F, G, and H were sampled shortly after a rain shower on July 2, 1987.

Table 2-3-1 summarizes surface water sampling conducted from fall 1984 through spring 1988 and includes analytical schedules and sample collection dates. The analytical parameter list for surface water sampling is on Table 2-3-2.

2.3.2.3 Bottom Sediment Sampling From Prickly Pear Creek, Wilson Ditch And Upper Lake

Bottom sediment samples were collected at seven sites on Prickly Pear Creek (PPC-3 through PPC-9), two sites on Wilson Ditch (WD-2 and WD-3), and from Upper Lake as part of Phase I WRM activities. In accordance with the WRM Work Plan, bottom samples were collected concurrently with the first water quality sampling event in November 1984 and during spring runoff in May 1985.

Bottom sediment samples were collected using procedures described in the project QAPP. Samples from streams were collected at several cross-section intervals and combined in a sample container.

Table 2-3-1 SUMMARY OF SURFACE WATER SAMPLING

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE
PPC-3	11-07-84	S+BS	DOES	NO
PPC-3	11-07-84	S+SP+BS	CAL	NO
PPC-3	01-14-85	P	DOES	NO
PPC-3	04-03-85	S	DOES	NO
PPC-3	05-08-85	P+BS	DOES	NO
PPC-3	05-08-85	S+SP+BS	JTC	NO
PPC-3	06-05-85	S	DOES	NO
PPC-3	07-02-85	P	DOES	NO
PPC-3	08-06-85	S	DOES	YES
PPC-3	09-12-85	P	DOES	YES
PPC-3	10-16-86	P	DOES	YES
PPC-3	10-16-86	S	RMA	YES
PPC-3	05-08-87	S	CHMTC	NO
PPC-3	05-08-87	P	DOES	NO
PPC-3	08-18-87	S	WYRHR	NO
PPC-3	08-18-87	P	DOES	NO
PPC-3	08-19-87	*	DOES	NO
PPC-4	11-06-84	S+SP	DOES	NO
PPC-4	11-06-84	S+SP+BS	CAL	NO
PPC-4	01-14-85	P	DOES	NO
PPC-4	04-03-85	P	DOES	NO
PPC-4	04-03-85	S+SP	JTC	NO
PPC-4	05-07-85	P+BS	DOES	NO
PPC-4	06-05-85	P	DOES	NO
PPC-4	07-02-85	P	DOES	YES
PPC-4	08-05-85	P	DOES	NO
PPC-4	09-13-85	P	DOES	YES
PPC-4	10-15-86	P	DOES	NO
PPC-4	05-08-87	P	DOES	NO
PPC-4	08-18-87	P	DOES	NO
PPC-4	08-18-87	S	WYRHR	NO
PPC-5	11-06-84	S+BS	DOES	YES
PPC-5	11-06-84	S+SP+BS	CAL	YES
PPC-5	01-11-85	P	DOES	NO
PPC-5	04-03-85	S	DOES	NO
PPC-5	04-03-85	S+SP	JTC	YES
PPC-5	05-07-85	P+BS	DOES	NO
PPC-5	06-05-85	S	DOES	NO
PPC-5	07-02-85	P	DOES	NO
PPC-5	07-02-85	S+SP	JTC	NO
PPC-5	08-05-85	S	DOES	NO
PPC-5	08-05-85	S+SP	JTC	NO
PPC-5	09-13-85	P	DOES	NO

Table 2-3-1
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE
PPC-5	10-15-86	P	DOES	
PPC-5	10-16-86	S	RMA	
PPC-5	05-07-87	P ***	CHMTC	NO
PPC-5	05-07-87	P	DOES	NO
PPC-5	08-18-87	P	DOES	NO
PPC-5	08-18-87	S	WYRHR	
PPC-6	11-06-84	S+BS	DOES	NO
PPC-6	11-06-84	S+SP+BS	CAL	NO
PPC-6	01-11-85	P	DOES	NO
PPC-6	01-11-85	S+SP	CAL	YES
PPC-6	04-02-85	P	DOES	NO
PPC-6	05-07-85	P+BS	DOES	NO
PPC-6	06-05-85	P	DOES	YES
PPC-6	07-01-85	P	DOES	NO
PPC-6	07-01-85	S+SP	JTC	NO
PPC-6	08-05-85	P	DOES	YES
PPC-6	08-05-85	S+SP	JTC	NO
PPC-6	09-13-85	P	DOES	NO
PPC-6	09-13-85	S+SP	JTC	NO
PPC-6	10-15-86	P	DOES	NO
PPC-6	05-07-87	P	DOES	NO
PPC-6	08-18-87	P	DOES	NO
PPC-6	08-18-87	S	WYRHR	NO
PPC-7	11-05-84	S+BS	DOES	NO
PPC-7	11-05-84	S+SP+BS	CAL	NO
PPC-7	01-10-85	P	DOES	NO
PPC-7	04-02-85	P	DOES	NO
PPC-7	05-07-85	P+BS	DOES	NO
PPC-7	06-04-85	P	DOES	YES
PPC-7	06-04-85	S+SP	JTC	YES
PPC-7	07-01-85	P	DOES	YES
PPC-7	07-01-85	S+SP	JTC	YES
PPC-7	08-06-85	P	DOES	NO
PPC-7	09-12-85	P	DOES	NO
PPC-7	10-15-86	P	DOES	NO
PPC-7	10-15-86	S	RMA	NO
PPC-7	05-07-87	P	DOES	NO
PPC-7	05-07-87	P ***	CHMTC	NO
PPC-7	08-18-87	P	DOES	NO
PPC-8	11-05-84	S+BS	DOES	NO
PPC-8	11-05-84	S+SP+BS	CAL	NO
PPC-8	01-10-85	P	DOES	NO
PPC-8	01-10-85	S+SP	CAL	NO
PPC-8	04-02-85	S	DOES	NO
PPC-8	05-07-85	P+BS	DOES	YES
PPC-8	06-04-85	P	DOES	NO
PPC-8	06-04-85	S+SP	JTC	NO

Table 2-3-1
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE
PPC-8	07-02-85	P	DOES	NO
PPC-8	08-06-85	S	DOES	NO
PPC-8	09-12-85	P	DOES	NO
PPC-8	10-16-86	P	DOES	NO
PPC-8	05-07-87	P	DOES	NO
PPC-8	08-18-87	P	DOES	YES
PPC-9	11-05-84	S+BS	DOES	
PPC-9	11-05-84	S+SP+BS	CAL	
PPC-9	01-10-85	P	DOES	NO
PPC-9	04-02-85	P	DOES	NO
PPC-9	05-07-85	P+BS	DOES	NO
PPC-9	06-04-85	P	DOES	NO
PPC-9	06-04-85	S+SP	JTC	NO
PPC-9	07-02-85	P	DOES	NO
PPC-9	08-06-85	P	DOES	NO
PPC-9	09-12-85	P	DOES	NO
PPC-9	10-16-86	P	DOES	YES
PPC-9	10-16-86	S	RMA	YES
PPC-9	05-07-87	P ***	CHMTC	YES
PPC-9	05-07-87	P	DOES	YES
PPC-9	08-18-87	P	DOES	NO
PPC-29A	10-15-86	P	DOES	NO
PPC-29A	10-16-86	S	RMA	NO
PPC-29A	05-08-87	P	DOES	NO
PPC-29A	05-08-87	P ***	CHMTC	NO
PPC-29A	08-18-87	P	DOES	NO
PPC-29A	08-18-87	S	WYRHR	NO
PPC-30A	10-15-86	P	DOES	NO
PPC-30A	10-16-86	S	RMA	NO
PPC-30A	05-08-87	P	DOES	NO
PPC-30A	05-08-87	P ***	CHMTC	NO
PPC-30A	08-18-87	P	DOES	NO
PPC-31A	10-15-86	P	DOES	NO
PPC-31A	05-08-87	P	DOES	YES
PPC-31A	05-08-87	S	CHMTC	YES
PPC-31A	08-18-87	P	DOES	NO
PPC-32A	10-15-86	P	DOES	NO
PPC-32A	05-07-87	P	DOES	NO
PPC-32A	08-18-87	P	DOES	NO
PPC-33A	10-15-86	P	DOES	NO
PPC-33A	10-15-86	P ***	RMA	NO
PPC-33A	05-07-87	P	DOES	NO
PPC-33A	05-07-87	S	CHMTC	NO
PPC-33A	08-18-87	P	DOES	NO

Table 2-3-1
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE
PPC-34A	05-07-87	P	DOES	NO
PPC-35A	10-16-86	P	DOES	NO
PPC-35A	10-16-86	S	RMA	NO
PPC-35A	05-07-87	P	DOES	NO
PPC-35A	05-07-87	P ***	CHMTC	NO
PPC-35A	08-18-87	P	DOES	NO
PPC-36A	10-16-86	P	DOES	NO
PPC-36A	05-07-87	P	DOES	NO
PPC-36A	08-18-87	P	DOES	NO
PPC-37A	05-07-87	P	DOES	NO
PPC-37A	08-18-87	P	DOES	NO
PPC-38A	10-16-86	P	DOES	NO
PPC-38A	05-07-87	P	DOES	NO
PPC-38A	08-18-87	P	DOES	NO
PPC-38A	08-18-87	S	WYRHR	NO
PPC-40A	05-07-87	P	DOES	NO
PPC-40A	08-18-87	P	DOES	NO
Upper Lake	11-07-84	S+BS	DOES	YES
Upper Lake	11-07-84	S+SP+BS	CAL	YES
Upper Lake	04-04-85	S	DOES	NO
Upper Lake	06-06-85	S+BS	DOES	YES
Upper Lake	08-06-85	S	DOES	NO
Upper Lake	11-08-84	S+BS	DOES	NO
Upper Lake	11-08-84	S+SP+BS	CAL	NO
Upper Lake	04-04-85	S	DOES	NO
Upper Lake	06-06-85	S+BS	DOES	NO
Upper Lake	08-06-85	S	DOES	NO
WD-1	05-08-85	S	DOES	NO
WD-1	05-08-85	S+SP	JTC	NO
WD-2	11-07-84	BS	DOES	NO
WD-2	11-07-84	BS	CAL	
WD-2	04-26-85	P	DOES	YES
WD-2	05-03-85	P	DOES	YES
WD-2	05-08-85	S+BS	DOES	YES
WD-2	05-08-85	S+SP+BS	JTC	NO
WD-2	05-17-85	P	DOES	NO
WD-2	05-24-85	P	DOES	YES
WD-2	05-31-85	P	DOES	YES
WD-2	06-05-85	S	DOES	NO
WD-2	06-14-85	P	DOES	YES
WD-2	06-21-85	P	DOES	YES

Table 2-3-1
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE
WD-2	07-01-85	P	DOES	NO
WD-2	07-05-85	P	DOES	YES
WD-2	07-12-85	P	DOES	YES
WD-2	07-19-85	P	DOES	YES
WD-2	07-26-85	P	DOES	YES
WD-2	08-02-85	P	DOES	YES
WD-2	08-12-85	P	DOES	YES
WD-2	08-15-85	P	DOES	YES
WD-2	08-29-85	P	DOES	YES
WD-2	09-04-85	P	DOES	YES
WD-2	09-10-85	P	DOES	YES
WD-3	11-07-84	BS	CAL	NO
WD-3	05-08-85	S+BS	DOES	NO
WD-3	05-08-85	S+SP+BS	JTC	NO
Seep-1	05-07-85	S(3)	DOES	NO
Seep-1	06-05-85	P(3)	DOES	NO
Seep-1	06-05-85	S+SP (3)	JTC	NO
Seep-1	07-01-85	P (3)	DOES	NO
Seep-1	07-01-85	S+SP	JTC	NO
Seep-1	08-06-85	P (3)	DOES	NO
Seep-1	09-12-85	P	DOES	NO
Seep-1	05-08-87	P	DOES	NO
Site A	05-29-85	S	DOES	NO
Site A	05-29-85	S+SP	JTC	NO
Site A	07-02-87	P	DOES	
Site B	05-29-85	S	DOES	YES
Site B	05-29-85	S+SP	JTC	NO
Site C	05-29-85	S	DOES	NO
Site C	05-29-85	S+SP	JTC	NO
Site D	05-29-85	S	DOES	NO
Site D	05-29-85	S+SP	JTC	NO
Site E	07-02-87	P	DOES	
Site F	07-02-87	P	DOES	
Site G	07-02-87	P	DOES	
Site H	07-02-87	P	DOES	

Table 2-3-1
(continued)

SAMPLE SITE	SAMPLE DATE	ANALYTICAL SCHEDULE(1)	LABORATORY(2)	SAMPLE REPLICATE

Notes

(1) S = Standard Analysis; P = Partial Analysis; SP= Special Analysis;
BS = Bottom Sediment Analysis; (see Table 2-3-1 for list of parameters for surface water analysis)

(2) DOES = Asarco's Department of Environmental Services Lab, Salt Lake
CAL = California Analytical Lab
JTC = JTC Environmental Consultants
RMA = Rocky Mountain Analytical Laboratory
CHMTC = Chem Tech Laboratory
WYRHR = Weyerhauser Laboratory

(3) See Table 2-3-2 for list of parameters. The ASARCO QAPP specifies the groundwater parameter list for seeps.

Table 2-3-2

SURFACE WATER SAMPLE PARAMETER LIST

STANDARD ANALYSES

Specific Electrical Conductivity (field and lab)
pH (field and lab)
Total Dissolved Solids (TDS)
Total Suspended Solids (TSS)
Static Water Level
Dissolved Oxygen ***
Temperature
Eh **
Calcium (Ca)
Magnesium (Mg)
Potassium (K)
Bicarbonate (HCO3)
Carbonate (CO3)
Sulfate (SO4)
Chloride (Cl)
Arsenic (As)*
Cadmium (Cd)*
Copper (Cu)*
Lead (Pb)*
Iron (Fe)*
Manganese (Mn) *
Zinc (Zn)*

PARTIAL ANALYSES

Specific Electrical Conductivity (field and lab)
pH (field and lab)
Total Dissolved Solids (TDS)
Total Suspended Solids (TSS)
Static Water Level
Dissolved Oxygen ***
Temperature
Eh **
Bicarbonate (HCO3)
Sulfate (SO4)
Arsenic (As)*
Cadmium (Cd)*
Lead (Pb)*
Iron (Fe)*
Zinc (Zn)*

SPECIAL METALS ANALYSES

Aluminum (Al) *
Antimony (Sb) *
Arsenic (As) *
Barium (Ba) *
Beryllium (Be) *
Cadmium (Cd) *
Calcium (Ca) *
Chromium (Cr) *
Cobalt (Co) *
Copper (Cu) *
Iron (Fe) *
Lead (Pb) *
Magnesium (Mg) *
Manganese (Mn) *
Mercury (Hg) *
Nickel (Ni) *
Potassium (K) *
Selenium (Se) *
Silver (Ag) *
Sodium (Na) *
Thallium (Tl) *
Tin (Sn) *
Vanadium (V) *
Zinc (Zn) *

* All metals measured as total and dissolved.

** Parameter measured as part of WRM Phase II and Comprehensive Remedial Investigation activities. Not measured during WRM Phase I activities. Not measured by EPA CLP laboratories.

*** Parameter measured as part of Phase I water resources monitoring only. Not measured during Phase II WRM or as part of Comprehensive Remedial Investigation activities.

Bottom samples from Upper Lake were obtained from random locations using a small boat and a manually-operated BMH-53 piston-type core sampler. At some Prickly Pear sampling sites, core samples could not be obtained using procedures in the QAPP because of the coarse, rocky character of stream bottom sediments. Sediment at these sites was sampled with a shovel.

As part of the Comprehensive RI activities, additional samples of bottom sediment and underlying strata at four Wilson Ditch sites (WD-2, WD-3, WD-4 and WD-5) were collected from backhoe test pits in December 1987. The additional samples were collected in accordance with procedures outlined in the Comprehensive RI/FS Work Plan. Samples were collected at the following increments; 0-4 inches, 4-12 inches (1 foot), 1-2 feet, 3-4 feet and 4-5 feet.

Bottom sediment samples were shipped to the DOES laboratory for analysis. Sample splits were obtained by EPA oversight personnel for shipment to an EPA contract laboratory for analysis. Analytical parameters included arsenic, cadmium, copper, lead, iron, manganese, and zinc. A portion of the samples were also analyzed for antimony, mercury, selenium, silver, tin, and thallium.

2.3.2.4 Evaluation of Surface Water And Groundwater Interrelationships

Three monitoring well pairs (DH-6 and DH-15, DH-12 and DH-13, and EH-51 and EH-101) and one station on Prickly Pear Creek (PPC-7B) were instrumented with continuous water level recorders to help evaluate the interaction of surface water and groundwater in the study area. The instrumented monitoring well pairs consisted of one well in the shallow aquifer and one well in the intermediate aquifer. Well pairs were selected to include one site near Prickly Pear Creek (DH-6 and DH-15), one site near the center of the plant site (DH-12 and DH-13), and one site in East Helena north of Highway 12. Continuous water level records from the three well pairs and Prickly Pear Creek station 7B are in Appendix 4-8.

2.3.2.5 Examination Of Surface Water Drainage Of the East Helena Plant Site

Surface water drainage of the Plant site was examined to determine if runoff leaves the plant site and to delineate on-site ponding of runoff in catchment basins. A drainage map was developed from field elevation measurements and runoff observations (Exhibit 2).

Catchment areas and potential off-site runoff areas were observed to determine how frequently they contain water, and to assess the fate of water that enters the basins and off-site areas.

An assessment of infiltration in these areas was made using Double Ring Infiltrometer (DRI) tests to provide information on the potential percolation of surface water to groundwater. The DRI tests measure macro-infiltration rate effects of a soil surface directly in the field and are typically more representative than laboratory tests because they include macroscopic features such as cracks, roots or higher permeability zones.

The infiltration rate is defined as the maximum rate at which water enters the soil under a specified hydraulic head. A double ring infiltrometer was used to prevent divergent flow in layered soils by providing an outer water barrier that allows only vertical flow in the inner ring.

Fifteen tests were performed at six drainage catchment or potential off-site runoff locations shown on Exhibit 2. The DRI tests were conducted in strict accordance with ASTM standard designation D3385-75 (ASTM, 1981). Two open cast iron cylinder rings were driven vertically into the ground to a depth of two inches. The inside diameter of the outer ring was 48.6 centimeters (cm) and the inside diameter of the inside ring was 25.2 cm. Measured volumes of water were added to the inside of the rings and infiltration rates were calculated in accordance with ASTM standard D3385-75. Graphical plots of DRI test results are in Appendix 5-1 and results are discussed in detail in Section 5.2.2.5.

2.3.3 Vegetation

The vegetation investigation has two major components: surveys to determine production and consumption patterns of food crops grown in the Helena Valley, and chemical analyses of food crops to determine the degree of elemental enrichment.

2.3.3.1 Vegetation Surveys

Separate surveys were conducted to define production and consumption patterns of commercial vs. non-commercial (garden vegetable) crops. Copies of both survey questionnaires are provided in Appendix 5-3. The commercial crop survey encompassed the entire Helena Valley study area, and the garden vegetable crop survey covered the area within a two mile radius of the East Helena plant, including the city limits of East Helena.

Commercial Crop Survey Methods. The commercial crop questionnaire (Appendix 5-3-2) was mailed in conjunction with the beef consumer and producer surveys (Section 2.3.4.1). The names of grain producers were compiled from a rancher/farmer list developed during the Phase I Soils RI in 1985, discussions with residents during grain sampling field work in 1987, and land use maps with landowner names published by Lewis & Clark and Broadwater Counties.

In addition to the written survey, a telephone survey was conducted to determine if any food retailers in the area buy or sell locally grown grain. All food stores, bakeries, and restaurants listed in the Helena Telephone Directory were contacted. The telephone survey did not identify anyone who sells or buys locally-grown grain products.

Non-Commercial Crop Survey Methods. A questionnaire with seven questions about the use of home-grown vegetables (Appendix 5-3) was sent to all residents within a two-mile radius of the plant. The most important information which the questionnaire sought was whether the households have a garden or not, how many people eat from it, and what fraction of their diet it constitutes. Owners of gardens that were sampled filled out a more detailed questionnaire (Appendix 5-3) which provided more information regarding crops grown and cultural methods used.

In order to examine the appropriate population, the garden survey was sent to all addresses with the East Helena zip code, and recipients were asked to record whether they live in the two-mile zone. The addresses of recipients who did not know or did not respond to that question were checked on maps to assess their proximity to the plant. Thus the entire population of interest was surveyed.

A one hundred percent response rate was not expected for this mailing. Furthermore, there was a suspicion that the survey results might be biased by unequal response rates among gardeners and non-gardeners. Therefore a "post-enumeration survey" (Raj, 1968) was conducted for a smaller population for which a 100% response rate could be achieved via a combination of mail and telephone calls. Therefore, an accurate determination of the fraction of East Helena households that have vegetable gardens was achieved.

There are only two possible outcomes for the primary question on the vegetable use survey, i.e. residents either do or do not have a vegetable garden. Therefore the answers form a binomial distribution (Roussas, 1973). A table of binomial confidence limits was used to determine the confidence interval for populations of specified size at a confidence level of 95% (Roussas, 1973). Based on that table and our initial survey results, a sample size of 150 was selected for the post-enumeration survey. Increases in the sample size above 150 narrow the confidence interval for our population by only a small margin, and were not considered as significant.

Results from the survey were recorded and summarized using DataBase III Plus, a computerized data base management system. Summaries of the responses to questions 2-7, (non yes-no data) encompassed information from the entire responding population. They were not restricted to the smaller post-enumeration survey population.

2.3.3.2 Vegetable Sampling and Analysis Methods

The sampling network of 14 gardens was designed to provide a thorough geographic coverage of East Helena and other nearby residential areas within two miles of the plant. Control samples were harvested from a single garden in Townsend, Montana. All samples were collected from healthy, edible portions of mature plants. Sampling personnel used new plastic gloves and a clean stainless steel knife for each collection. Different plant organs are known to vary in their uptake of elements, therefore, species were chosen to provide root, fruit, and leafy vegetable samples. Tomato fruits were sampled whole, as were potato and carrot roots. Leafy vegetable samples included young, fully expanded leaves from beet greens, lettuce, swiss chard, and parsley. People typically eat both the stem and flowers of broccoli, which was also sampled. All samples were collected from within rows or blocks, avoiding end or border plants. Samples were packaged in paper bags and placed in coolers with blue ice until the end of the day when they were transferred to secured cold storage. Within two days of harvest, all samples were sent under chain-of-custody to the DOES laboratory. Complete details of sampling procedures are provided in the vegetable sampling SOP, which is included in the Comprehensive RI/FS Work Plan (Hydrometrics Inc., 1987).

In the laboratory, samples were rinsed with deionized water to remove any surface soil, patted dry with paper towels and weighed to the nearest 0.1 gram. They were then dried at 150 degrees Fahrenheit until they reached constant weight. Samples were then reweighed and ground in a Wiley Mill.

For digestion, one gram of finely chopped vegetation was placed into 20 milliliters of a nitric/perchloric acid mixture and heated. After cooling, the samples were brought to volume (50 mls.) by adding deionized water. Samples were subsequently analyzed by flame AAS, hydride generation AAS, or graphite furnace AAS.

The general methods for sample preparation, digestion, and analysis are provided in the Contract Laboratory Program (CLP) Statement of Work (U.S. EPA, 1984g). The exact analytical procedures used by the Asarco laboratory are detailed in the laboratory analytical protocol developed through a series of correspondence between Asarco and EPA RI project team members (Neuman, 1987; Robbins, 1987; and Stanga, 1987).

2.3.3.3 Grain Head Sampling and Analysis Methods

Results from the Phase I Soils RI indicated that lead enrichment of grains within approximately three miles of the plant was high enough to be a potential health risk to people who obtain more than half of their wheat intake from these fields. Fields farther out were not as intensively sampled and showed little if any enrichment, therefore, one Comprehensive RI sampling objective was to more precisely define the "boundary zone" where grain lead levels drop from "potentially hazardous" to "safe" levels. Comprehensive RI sample locations were chosen to obtain a 1/2-mile sampling grid in the area where there may be a potential hazard (boundary zone). Several section corners within one mile of the boundary zone were also sampled. Sampling sites in and out of the boundary zone were established along three transects radiating from the plant in the northwest, northeast, and east-southeast directions. These sites minimize variance due to local factors and maximize the correlation between grainhead contamination and distance from the smelter stack. The transect directions were chosen to fill data gaps and clarify ambiguous results from the 1984 data set. Grid and transect sampling sites were sometimes moved if grain was being grown near but not on the predetermined site.

Three control samples of wheat grains were taken east of Canyon Ferry Reservoir. These were located as close as possible to the 1984 Phase I RI background sample sites.

The grain samples were taken as close to the predetermined sites as possible but at least 100 feet from the nearest road. At the sampling site, a stake was driven to mark the center of the site. Additional stakes were placed 20 meters north, south, and west of the central stake to form a triangle. Grain heads were sampled from three areas within the triangle. The grain heads were clipped from the plant with stainless steel scissors, composited, and packed into 32 ounce I-Chem jars. Detailed sampling procedures are contained in the Grain Sampling SOP, which is included in the Comprehensive RI/FS Work Plan (Hydrometrics Inc., 1987).

All samples were transferred to Bozeman (under custody) for drying, threshing, and milling. Samples were dried at 150 degrees Fahrenheit until they reached constant weight. They were put into plastic bags and the grain heads were crushed by hand to free the kernals. The grain was separated from the rachis and glumes by rolling on a plastic tray and using compressed air to blow out the finer chaff. A stainless steel blender was used to mill the grain, and the flour was put into clean jars and sent to the DOES laboratory under chain-of-custody. Digestion and analysis of the wheat samples was identical to the procedures used for garden vegetable tissue and is explained above in Section 2.3.3.2.

2.3.4 Cattle Investigation

The cattle investigation has two major components: surveys to determine the production and consumption patterns of locally grown beef, and tissue sampling and analysis to determine the degree of elemental enrichment.

2.3.4.1 Beef Consumption and Production Survey

To ensure as comprehensive a listing of consumers of local beef as possible, the survey encompassed producers, processors, retailers and buyers.

Producers: A list of beef producers in the study area was assembled from several sources. These include: (1) a list of ranchers that were questioned by personnel from the Montana State University Reclamation Research Unit in preparation for sampling of cattle blood and hair in 1985; (2) discussions with local residents during grain sampling field work for the Phase II Remedial Investigation; (3) land use maps with landowner names published by Lewis & Clark and Broadwater Counties; and (4) customer lists obtained from Helena-area custom meat processors.

No single public or private organization was able to provide a current list of cattle growers in the study area. A list was sought from the Montana Livestock Bureau, the County Extension Office, the Montana Stockmens' Association, the 4-H Council, and the local Brand Inspector.

Questionnaires were sent to all of the known or plausible cattle growers in the study area to gather information on the marketing and basic management practices of the producers. This mailing was combined with questionnaires for beef consumer and grain growers because ranchers commonly belong to more than one of these categories.

Processors: A telephone survey of all local meat processors that are listed in the Helena Telephone Directory was conducted as an auxiliary source of information about local producers. Written requests for customer lists were sent to those processors who deal with local ranchers. Questionnaires were sent to the processors to explain the nature of the cattle study, and to gather information if the processors were also consumers of locally-grown beef.

Retailers: A telephone survey of all food retailers in the Helena/East Helena area--food stores and restaurants, that are listed in the Helena Telephone Directory was conducted. Respondents were asked whether they sold any locally-grown beef. Further questioning of those who said yes identified specific beef sources.

Consumers: A list of consumers was compiled from the information gathered from producers, processors and retailers as described above. In addition, recipients of the vegetable garden questionnaire, i.e., all residents with the East Helena zip code, approximately 2000 people, were asked whether they consume locally-grown beef. The more detailed beef questionnaire was then sent to all those who responded yes.

A secondary post-card questionnaire was sent to all recipients of the beef questionnaire who did not return responses after a few months. Although much abbreviated, this mailing did yield many additional responses, and it covered the questions about local beef consumption rate which are most critical for the endangerment assessment.

2.3.4.2 Cattle Tissue Sampling

Six adult cattle were chosen for study from each of three herds. Two herds were from within three miles of the the plant, and one herd was from a ranch near Townsend, Montana, approximately 24 miles southeast of the plant. Appropriate animals within two miles of the plant, the distance specified by the Comprehensive RI/FS Work Plan (Hydrometrics, 1987) were not available. The Townsend herd provided a control sample; the climatic and feeding conditions are similar to those of the East Helena herds, but the ranch is outside the zone that is influenced by smelter emissions according to Phase 1 of the Soils Remedial Investigation (U.S.EPA, 1987).

The sample size was determined based on the requirements for executing a standard two-sample t-test (Sokal and Rohlf, 1981) with a confidence level of 90% and the power of the test at 80%. Coefficients of variation and acceptable percent errors were estimated from the literature as discussed in the work plan (Hydrometrics, 1987).

The 18 cattle were transported to Ranchland Packing, a slaughterhouse in Butte, Montana. They were given no food or water after leaving the home ranches.

Personnel at Ranchland Packing slaughtered the animals using a captive bolt and butchered the carcasses using routine procedures. Dr. Scott Carter, DVM, removed a lobe of the liver, the entire left kidney, and a portion of the hanging tenderloin muscle. Numerous steps to prevent sample contamination and to provide representative samples were executed as specified in the work plan (Hydrometrics, 1987).

The hanging tenderloin, rather than the quadriceps femoris, was sampled as the muscle tissue. This modification of the work plan was required because the quadriceps were inaccessible once the carcass was hung. The tenderloin was easily accessible, is a commonly-eaten cut of meat, and does not take up trace metals differently from other major muscle groups, so the procedural change was inconsequential for this study. The EPA oversight contractor approved the change at the sampling site.

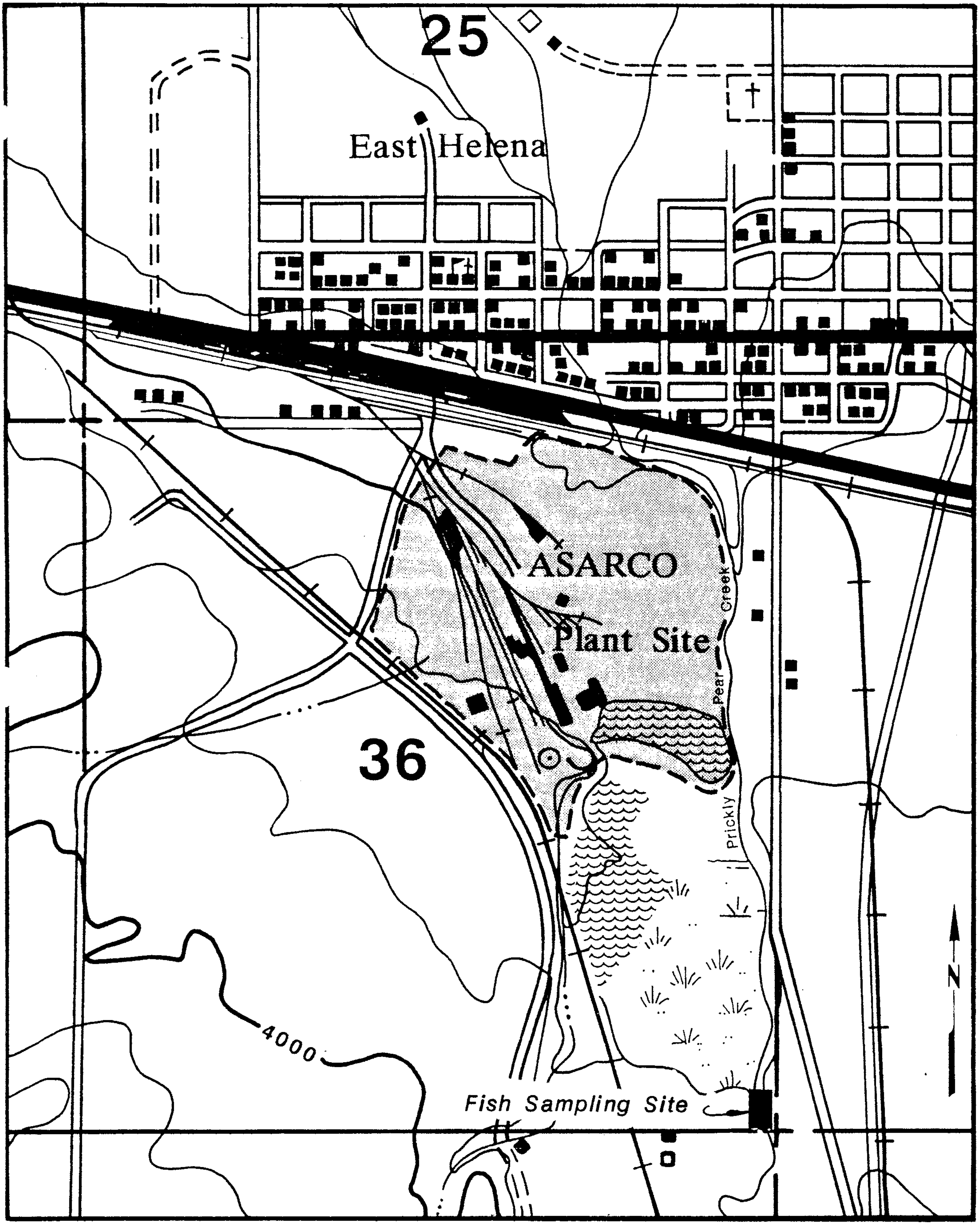
The samples were frozen at the slaughterhouse and shipped via air freight two days later to the DOES laboratory for analysis.

The tissue samples were homogenized while frozen and digested in nitric acid and nitric/perchloric acid mixture. Samples were subsequently analyzed by flame atomic absorption (FAA), graphite furnace atomic absorption (GFAA), or hydride generation (Arsenic only) methods. The methods for sample preparation, digestion and analysis are detailed in the laboratory analytical protocol developed through a series of correspondence between Asarco and EPA (Neuman, 1987; Robbins, 1987; and Stanga, 1987).

2.3.5 Fish and Waterfowl

2.3.5.1 Fish Sampling and Analysis

The fish collection program was designed to determine if elevated metals are present in fish flesh which could potentially be consumed by humans. Sampling was scheduled at four locations, shown in Figures 2-3-2 and 2-3-3: 1) station PP-1 was located on Prickly Pear Creek above the Upper Lake Diversion, in the southeast corner of Section 36, T10N, R3W and the



SCALE: 1" = 1000 feet (approx.)

Figure 2-3-2: Prickly Pear Creek Fish Sampling Site

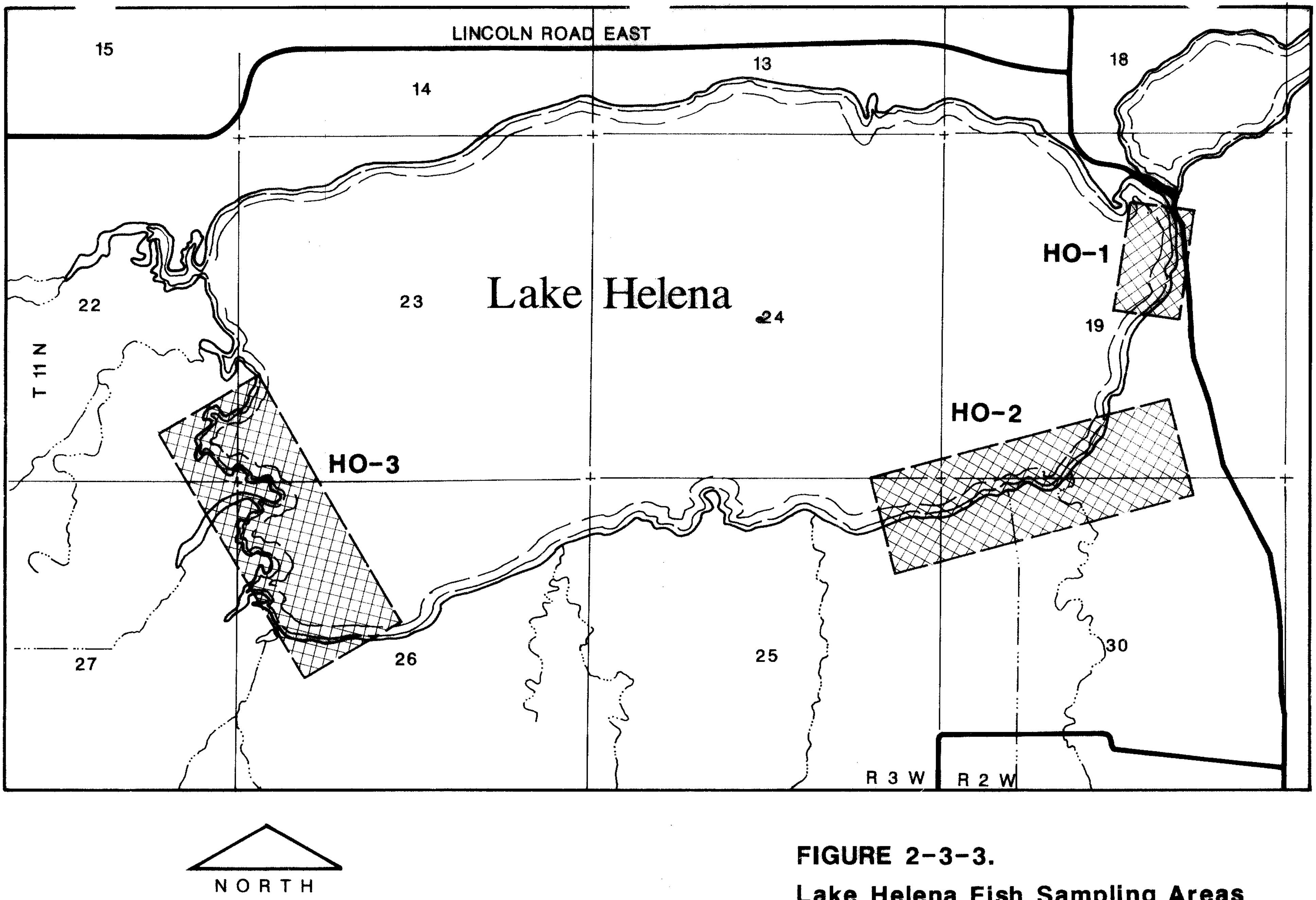


FIGURE 2-3-3.
Lake Helena Fish Sampling Areas

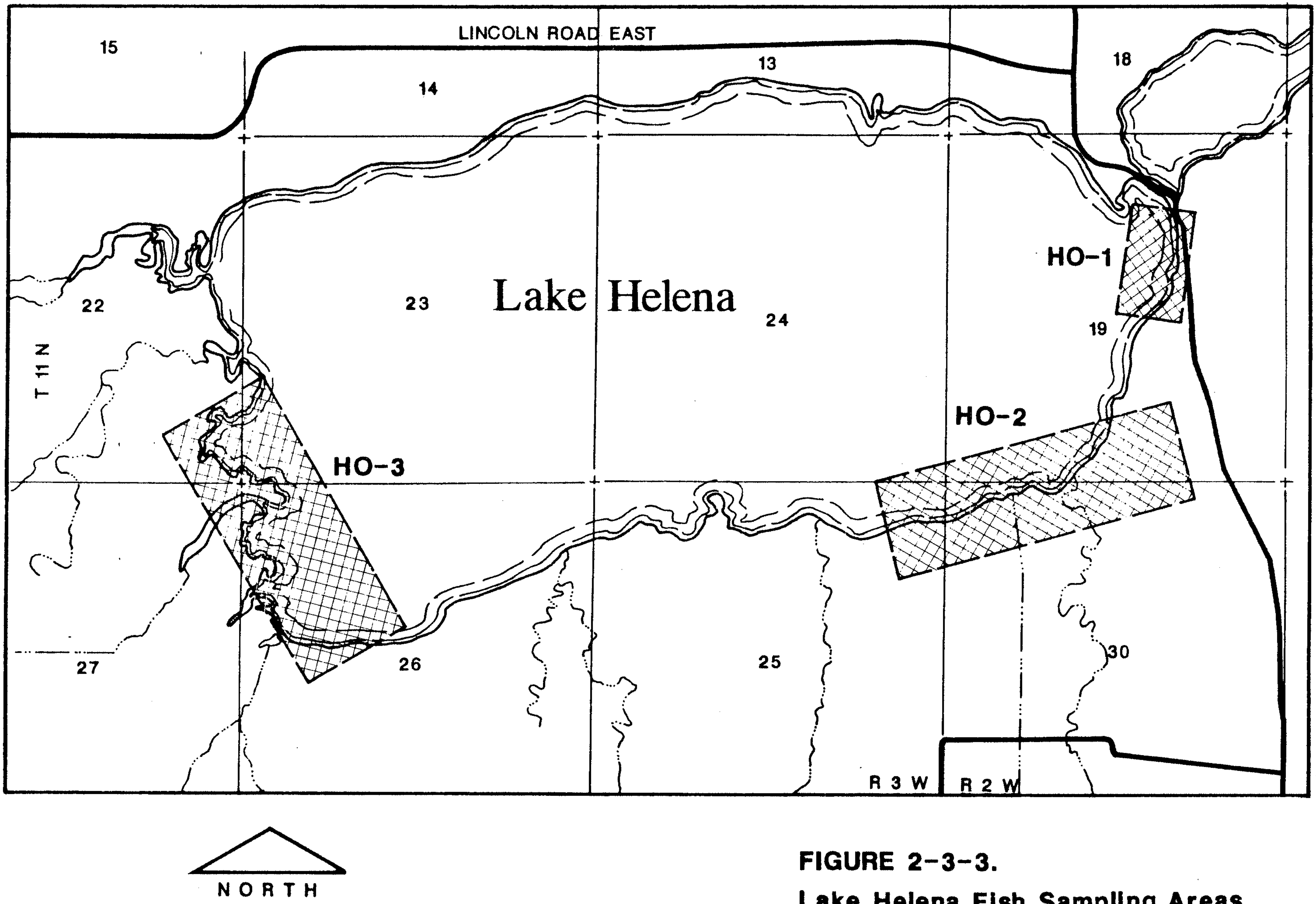


FIGURE 2-3-3.
Lake Helena Fish Sampling Areas

northeast corner of Section 1, T9N R3W; 2) station HO-1 was on the east shore of Lake Helena near the causeway to Hauser Lake in Section 19, T11N R2W; 3) station HO-2 was at the southeast corner of Lake Helena at the inlet of an irrigation system in Section 30, T11N, R2W; and 4) station HO-3 was in Lake Helena at the inlet of Prickly Pear Creek in Section 26, T11N, R3W.

At Lake Helena, five samples (one whole fish per sample) of carp (*Cyprinus carpio*) and five samples (one whole fish per sample) of brown trout (*Salmo trutta*) were to be collected at each station. Brown trout were selected because, as predators, they occupy an upper niche of the food chain. If five brown trout could not be captured, rainbow trout (*Oncorhynchus mykiss*) were to be substituted.

It was assumed that the Prickly Pear Creek station (PP-1) would support brook trout (*Salvelinus fontinalis*) and possibly rainbow trout, rather than brown trout. The sampling program was to collect five samples (one whole fish per sample) of each species. Brown trout, if caught, were also to be kept.

Field sampling was conducted by the Montana Department of Fish, Wildlife and Parks (MDFWP). MDFWP provided all personnel and equipment needed to electroshock (in Prickly Pear Creek) or gill net (in Lake Helena), weigh and measure fish. Hydrometrics' Document Control Officer (DCO) coordinated sampling dates and times with MDFWP and EPA, provided packaging and preservation equipment, and was responsible for all documentation. Documentation included: 1) Daily Work Forms, 2) Fish Description Forms, 3) Sample Identification Matrix, 4) EPA Sample Tags, 5) Chain-of-Custody Records, 6) Custody Seals and 7) Shipping Bills. All documentation was completed either in the field or immediately afterward, as appropriate.

Sampling was conducted on November 18, 1987 under an overcast sky. The air temperature was -2°C (+29°F), with little wind. Prickly Pear Creek was clear and low. Water temperature was +1°C (+34°F), with ice on exposed rocks and along the shoreline. Lake Helena was not sampled because the surface froze during the preceding 24 hours.

A two-person MDFWP crew, equipped with a Coffelt backpack electroshocker, caught seven brown trout at station PP-1. No other species were captured. All trout were dipnetted and carried to shore, where they were placed in a clean plastic bucket. The fish were handled only by the DCO; due to the cold temperature, he wore surgeon's gloves (as required by the Comprehensive RI/FS Work Plan) overlain by neoprene gloves. Each fish was measured to the nearest millimeter and weighed to the nearest 0.01 lb (these weights were later converted to grams). Each fish was placed in a large zip-loc polybag, accompanied by a completed EPA sample tag in a smaller zip-lock polybag. Each sample was sealed with a completed custody seal. Two samples were given to EPA. The five remaining samples were placed in a cooler containing a layer of vermiculite on the bottom. Blue ice was placed over the samples, and the remaining space in the cooler was filled with vermiculite. A Blind Field Standard (BFS) sample, obtained earlier from the EPA, was also placed in the cooler. The cooler was transported to a freezer, where it was placed with the lid slightly ajar until the samples were completely frozen. The cooler was then sealed with four completed custody seals (two in front and in back), and covered by strapping tape. The cooler was then shipped to the DOES laboratory.

Lake Helena stations were sampled on June 1, 1988 by a two-person MDFWP crew who set gill nets at stations HO-1 and HO-2. Station HO-3 could not be sampled because the water was too shallow (about two feet deep for more than one mile in this sampling reach). Nets were set between 0830 and 1000 hours, and were retrieved at 1500 hours; thus, nets were in the water 5 to 6 hours. Air temperature at 0830 hours was 9°C (48°F) and at 1615 hours (completion of field work) was 16°C (60°F). Water temperature, under an overcast sky, remained constant all day at 14°C (58°F). Winds were calm at 0830 but blew 11 to 16 km/hr (7 to 10 mph) from the southeast for most of the day, with occasional gusts to 25 km/hr (15 mph).

No carp were captured, although crew members reported seeing carp in shallow water and attempted to drive carp toward the nets. One brook trout and one brown trout were caught at station HO-1; no other trout were captured. All remaining fish caught were white suckers (*Catostomus commersoni*) and longnose suckers (*Catostomus catostomus*).

Lake Helena fish samples were prepared the same as Prickly Pear Creek fish. To prevent contamination, the DCO wore surgeon's gloves while the fish were handled. Nine fish were preserved: one brown trout, one brook trout, four white suckers and five longnose suckers. Both trout, one white sucker and one longnose sucker were given to EPA. Three longnose suckers and two white suckers were shipped to the DOES laboratory. No BFS (Blind Field Standard) was available for inclusion with the Lake Helena fish samples.

2.3.5.2 Waterfowl Assessment for Potential Exposure Pathways of Metals Contaminants

An assessment of potential exposure pathways of metals contaminants to humans from Upper Lake waterfowl was conducted in accordance with the Comprehensive Remedial Investigation/Feasibility Study (RI/FS) Work Plan. This assessment consisted of:

1) A literature search to determine if a correlation exists between metals concentration in migratory waterfowl and metals concentration in surface waters and bottom sediment.

   The literature review was conducted by examining journals, books and reprints on file in WESTECH's and Hydrometrics' in-house libraries; by visiting the libraries at the University of Montana (Missoula) and Montana State University (Bozeman), the Montana State Library in Helena; as well as computerized literature searches. These searches were through the Fish and Wildlife Reference Service (which includes many citations from government agencies and university research), the DIALOG

Information Retrieval Service of Biosis Previews (citations from Biological Abstracts) and EMBASE (which searches biomedical literature), and the U.S. Department of Commerce National Technical Information Service (NTIS). Additional publications were requested from the U.S. Environmental Protection Agency and the U.S. Fish and Wildlife Service.

Several hundred titles were examined. The most relevant were selected for more detailed review, and these were further reduced to the citations included in the assessment (Appendix 5-5). Whenever possible, sources were used that summarized or annotated previously published literature.

2) A comparison was conducted with sediment and water quality data collected during the Warm Springs Ponds contaminants assessment (Multitech, 1984) with Upper Lake sediment water quality data.

A result of the literature search was the discovery of the Warm Springs ponds waterfowl assessment. The conclusion of the Warm Springs ponds study was that metals concentrations in waterfowl were at low levels and posed little risk to human receptors. A comparison of Warm Springs ponds and Upper Lake water and bottom sediment quality was conducted to provide insight on the potential metals exposure pathways from waterfowl.

2.4 UPPER LAKE BIOLOGICAL INVENTORY

A qualitative inventory of wildlife species using habitats at Upper Lake was conducted February through June, 1989. Wetlands in the Upper Lake vicinity were mapped according to USFWS methodology and wildlife use was qualitatively assessed. The biological inventory methodology is described in detail in Appendix 5-6.

2.5 SLAG PILE REMEDIAL INVESTIGATION

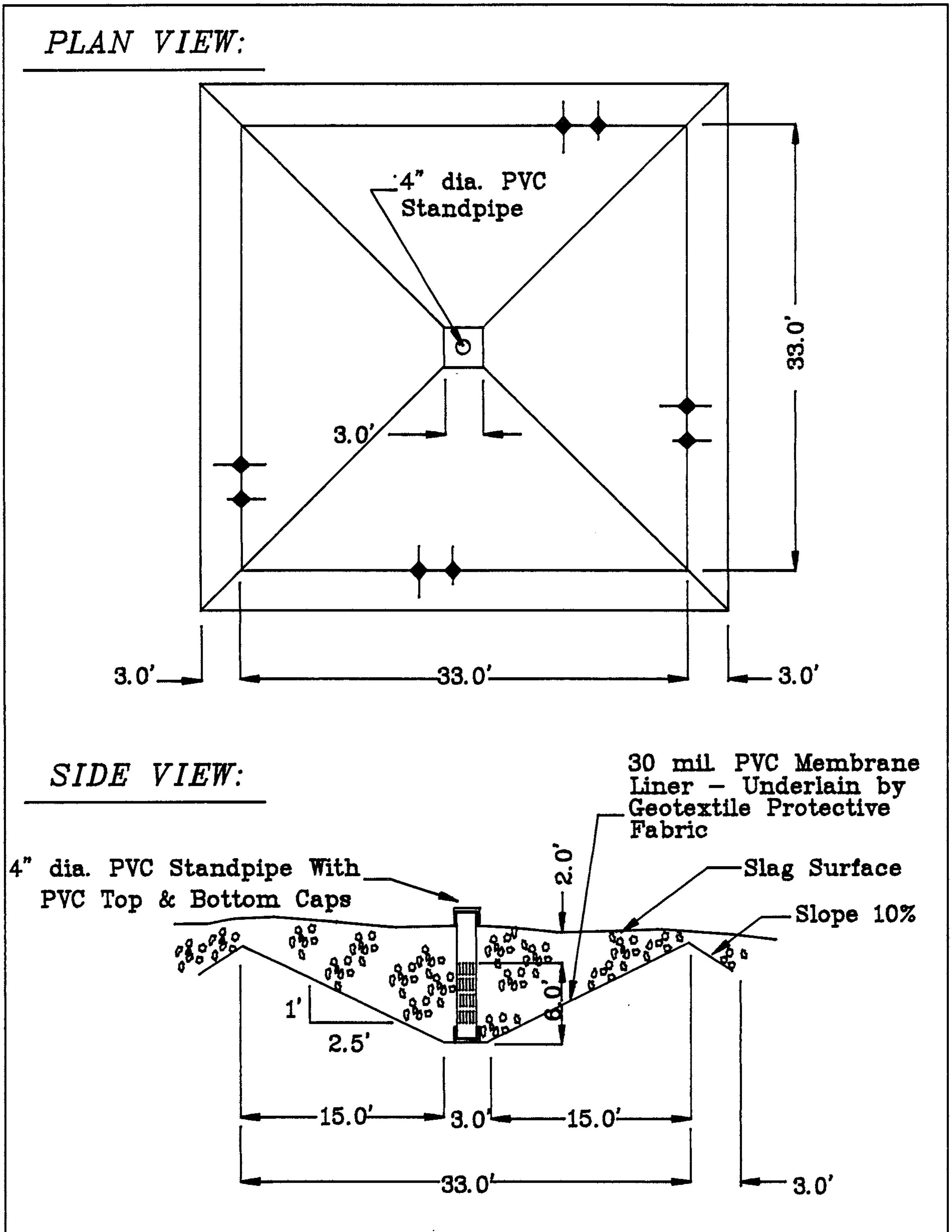
The remedial investigation procedures for the slag pile operable unit was conducted in accordance with procedures outlined in the Comprehensive RI/FS Work Plan and the WRI Phase II Work Plan. These work plans contain procedures for the investigation of the slag pile to determine potential impacts to groundwater and surface water. The Comprehensive RI/FS Work Plan also addressed the procedures used to assess potential slag pile impacts to air quality.

2.5.1 Slag Infiltration Test Basin Construction, Sampling And Analysis

Infiltration and percolation of precipitation into the slag pile was directly measured in slag test basins constructed in fumed and unfumed slag. Fumed slag is a by-product of the zinc recovery process, which consisted of air injection into molten slag to recover zinc oxide. The zinc recovery process was suspended in 1982 and zinc is no longer recovered from the slag. Since 1982, unfumed slag has been placed in an area segregated from fumed slag.

Two slag infiltration catchment test basins were constructed; one in a typical location in the fumed slag, and one in a typical location in the unfumed slag. Slag test basin construction was in accordance with the Phase II WRI Work Plan. Construction of the test basins included removal of a 2 to 3 meter layer of slag, placement of an impervious 36-mil reinforced hypalon liner in the excavation, installation of a collection sump, and replacement of the slag. Figure 2-5-1 shows the slag test basin design.

Water elevations in the collection sumps were measured periodically and after rainfall or snowmelt events to determine the actual accumulation of water in the slag basins. Collected water was pumped from the sump, sent to the DOES laboratory, and tested for the parameters on the groundwater standard analytical list (Table 2-2-4). Analytical results of water collected in the test basins are in Appendix 6-1.



NOTE: PVC Standpipe is schedule 40, capped on both ends and perforated with saw-cut slots from 2.0' to 8.0' beneath the slag surface.

Figure 2-5-1: Slag Test Basin Design

2.5.2 Slag Material Sampling And Analysis

To supplement slag information collected from the test basins, samples of slag were collected from the test basin sites and sent to the DOES laboratory for "bottle roll" tests. Bottle roll tests were conducted in accordance with procedures described in the QAPP addendum in the Phase II WRI Work Plan. Analytical results of the bottle roll tests are in Appendix 6-1.

In addition to the slag sampling and bottle roll tests performed as part of the East Helena RI activities, additional slag samples were collected and analyzed using the EP Toxicity Test procedure. Results of these analyses are also in Appendix 6-1.

2.5.3 Air Quality Sampling And Analysis

Air quality monitoring has been conducted jointly by Asarco and the Air Quality Bureau (AQB) of the Montana Department of Health and Environmental Sciences at two sites in the City of East Helena: the Fire Hall site and the Hadfield site (see Figure 2-5-2). Data for air quality impacts from the slag pile have been collected since 1985 as part of the Chemical Mass Balance/Source Apportionment Study being conducted in accordance with the State of Montana State Implemented Plan (SIP). The evaluation includes a determination of quantity of mass species, direction of metals migration, deposition locations, and principal receptors. The results of this study and the impacts to air quality from slag are discussed in detail in Section 6.0.

2.6 ORE STORAGE REMEDIAL INVESTIGATION

The remedial investigation for the ore storage operable unit was conducted in accordance with procedures outlined in the Comprehensive RI/FS Work Plan. The work plan outlines procedures for the investigation of potential impacts to groundwater, surface water, and air quality from the plant ore storage areas.

2.6.1 Stratigraphic Sampling

Soil core samples were collected in and adjacent to the ore storage areas as part of the groundwater remedial investigation and are discussed in Section 2.2.1. Soil cores from monitoring wells and drill holes associated with the ore storage areas are shown in Figure 2-6-1.

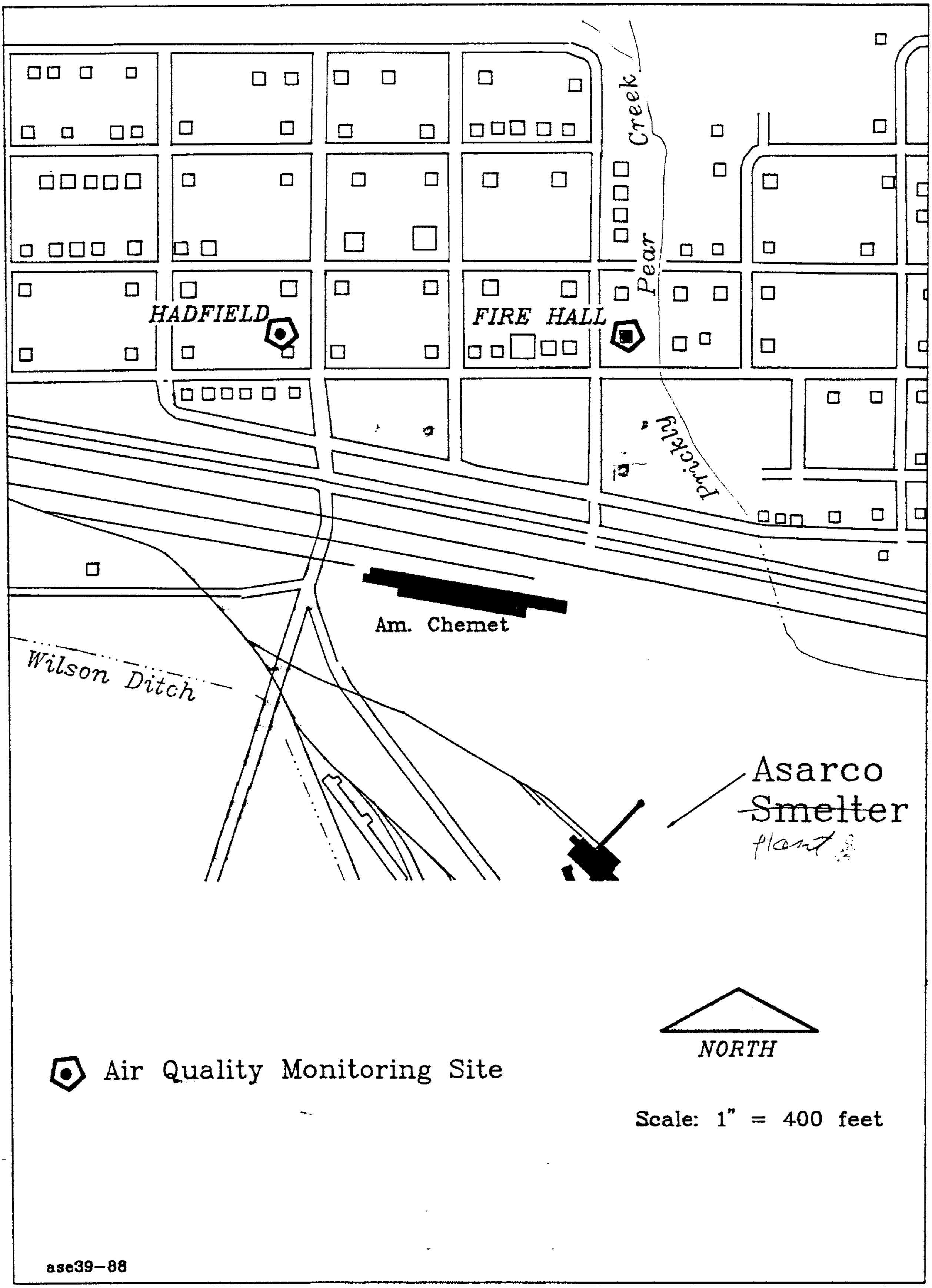


Figure 2-5-2: Location of East Helena Air Quality Monitoring Sites

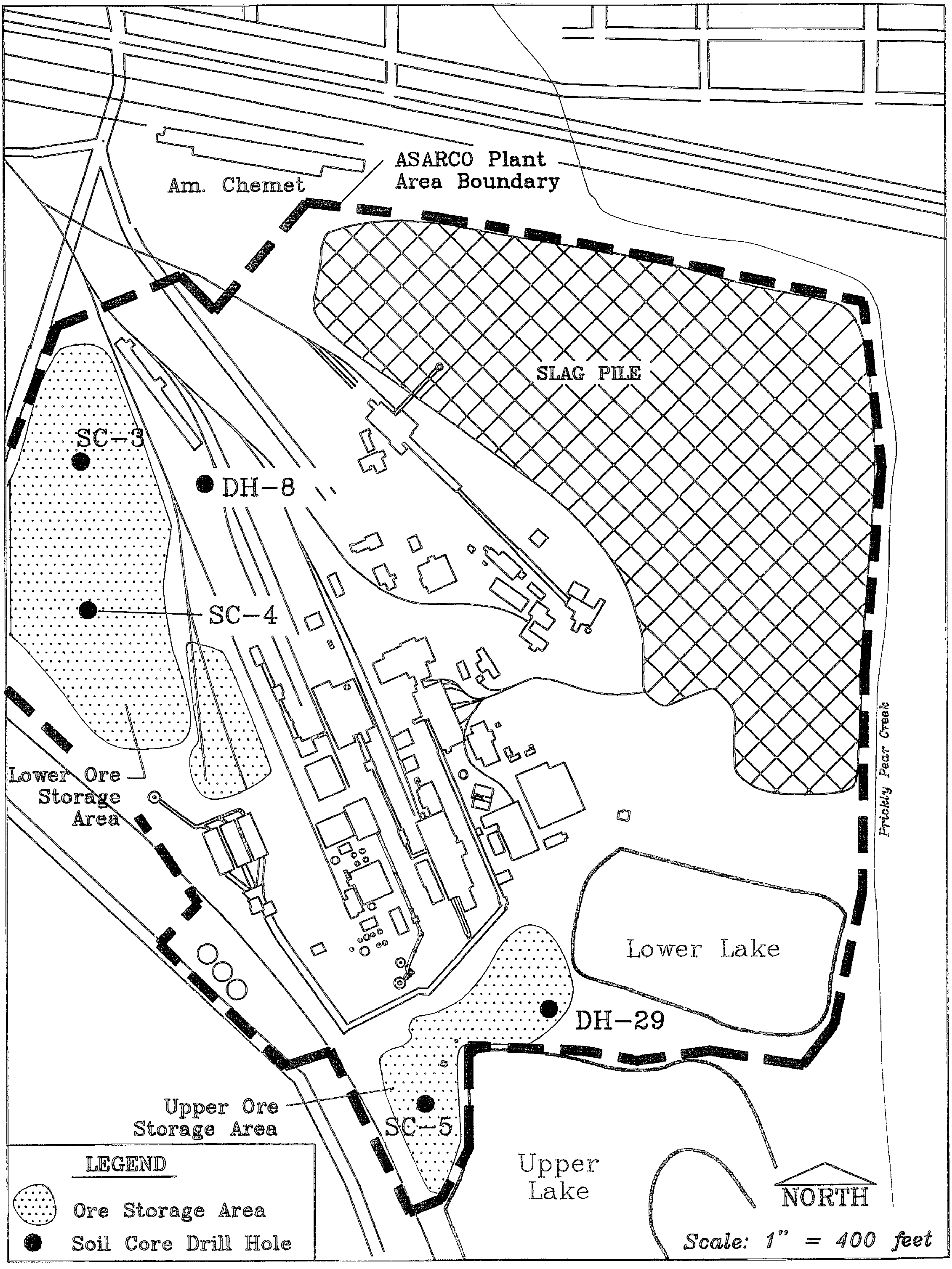


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Figure 2-6-1. Ore Storage Areas and Soil Core Drill Hole Sampling Sites

2.6.2 Surface Soils And Surface Water Runoff

Surface soil samples were collected in the ore storage areas as part of the surface soils investigation as described in Section 2.3.1. Surface water runoff in the ore storage areas was investigated as part of the surface water investigation activities described in Section 2.3.2.

2.6.3 Air Quality Sampling And Analysis

Air quality impacts from the ore storage area were investigated as part of the Chemical Mass Balance/Source Apportionment Study as described in Section 2.5.3. The results of this investigation are discussed in detail in Section 7.1.

Impacts from the ore storage areas and other locations were assessed by air quality monitoring at two sites in the City of East Helena; the Fire Hall site and the Hadfield site (see Figure 2-6-2). These sites in East Helena are part of the SLAMS (State and Local Air Monitoring System) network and have been monitored since 1983. Air quality monitoring was conducted jointly by Asarco and the Air Quality Bureau (AQB) of the Montana Department of Health and Environmental Sciences. Each monitoring site consists of one compliance High Volume (Hi Vol) air particulate sampler. The Hadfield site also has one collocated Hi Vol and two PM-10 type air particulate samplers. Air filter samples have been collected from these two monitoring sites by Asarco environmental personnel.

Samples collected by Asarco were submitted to the AQB for filter examination and processing. After processing and inspection, the filters were cut into 3/4-inch wide by eight-inch long strips for laboratory analysis. The AQB retained one strip for analysis of lead and other selected metals.

In the fall of 1988, Asarco and the U.S. Environmental Protection Agency (EPA) agreed to use the air quality data collected during the second half of 1987 and the first half of 1988 for the East Helena Remedial Investigation because this time period was most representative of existing conditions at the Fire hall site. Sample strips collected during the third and fourth quarters of 1988 were not considered representative because data from these strips reflect a unique condition

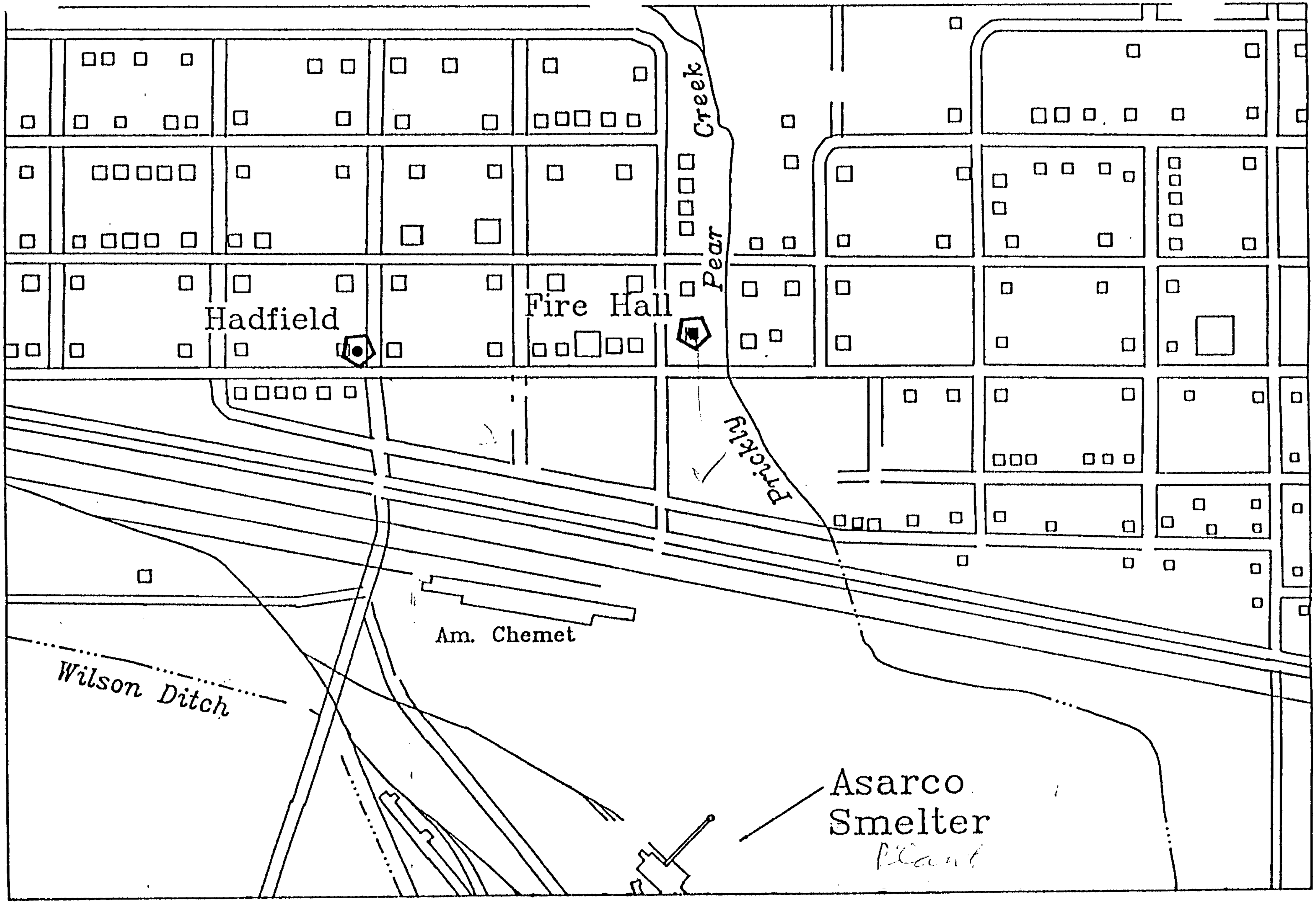


FIGURE 2-6-2. *Location of East Helena Air Quality Monitoring Sites*

associated with a fire at the plant which resulted in the loss of an ore storage building.

Air quality filters collected in 1987 and 1988 have been analyzed by the AQB and at the DOES laboratory. The parameters analyzed by the AQB included Lead (Pb), Total Suspended Particulate (TSP), Copper (Cu), and Zinc (Zn). Sample splits were also analyzed for lead by DOES. A total of 36 air filter sample strips collected from the Fire Hall monitoring site were also analyzed for Arsenic (As), Cadmium (Cd), Beryllium (Be), Chromium (Cr), Nickel (Ni), Iron (Fe), Barium (Ba), Mercury (Hg), Selenium (Se) and Manganese (Mn). Analyses of these parameters were conducted by the DOES laboratory.

Five splits of the selected 36 samples were also analyzed by the Montana AQB. The analytical schedule for these five sample splits was the same as the DOES laboratory analytical schedule.

2.7 QUALITY ASSURANCE AND QUALITY CONTROL

2.7.1 QA/QC for Water, Sediment and Stratigraphic Samples

The QAPP for the Asarco East Helena Plant - Water Resources Investigation was submitted by Hydrometrics in September of 1984 and approved by the EPA. This QAPP was incorporated by reference in the Comprehensive Remedial Investigation/Feasibility Study Plan - ASARCO Incorporated East Helena Plant (Hydrometrics, 1987b) and addendums to the QAPP were included in the Phase II WRI (Hydrometrics, 1986b) and the Comprehensive RI/FS plan.

Quality assurance in field investigation activities was ensured through the use of standard field operating procedures, sample chain-of-custody documentation, and submission of field QC samples including blanks, replicates, splits and blind field standards. Quality assurance in laboratory analyses was ensured through the use of Standard Laboratory Procedures and analysis of laboratory QC samples including laboratory control samples (standards), preparation blanks, duplicates, sample spikes and calibration verification standards and blanks. Precision and accuracies for all parameters analyzed in water, sediment, and stratigraphic samples are in the various data validation reports (Hydrometrics, 1988b, 1989c, 1989d and 1989e).

2.7.2 QA/QC for Air Quality Samples

Quality assurance/quality control procedures for collection and analyses of air filter strips were described in the EPA approved QAPP for Air Quality Monitoring (Hydrometrics, 1989f). Laboratory analytical procedures followed the LAP for the Phase I RI (Asarco, 1984).

Representativeness and comparability of data was assured through the use of samples collected jointly by MDHES Air Quality Bureau and Asarco as part of the SLAMS (State and Local Air Monitoring System) network. Sample site selection, sampling methodology, and instrument calibration procedures followed Air Quality Bureau standard operating procedures and are consistent with EPA protocol. Precision and accuracy in data were assured through the use of field and laboratory replicates, standards and blanks. Target QA objectives for lead and zinc analyses were established and met by the Montana Air Quality Bureau, as established in the Air Quality QA manual. QA target objectives for the remaining parameter analyses were detailed in the project air quality QAPP (Hydrometrics, 1989f).

Target QA objectives for air quality data analyzed by DOES were 90% completeness, accuracy of 90 to 110% for blind field standards and 75 to 125% for laboratory spikes, and precision of 0 to 35% average relative percent difference for field replicates and laboratory duplicates. Target completeness was met as the data set was 100% complete. Target precision was met for all parameters. Target accuracy based on standards was met for all parameters analyzed in filter media (arsenic, beryllium, cadmium, lead, manganese, selenium and zinc).

Standards for metals in filter media could not be found for the metals barium, chromium, iron and nickel. In coordination with the EPA, solid standard reference materials were used for these metals. However, the approved digestion and analytical procedures for filter media were found to be inappropriate for the solid standards. As a result, accuracies for barium, chromium, iron and nickel based on standards probably were not accurately indicative of filter analytical accuracy.

2.7.3 QA/QC for Surface Soils, Vegetation, Cattle, and Fish

The objective of the quality assurance/quality control program for surface soils, vegetation, cattle and fish sampling for the Comprehensive Remedial Investigation was to ensure that data of known and acceptable quality were collected. The general field and laboratory QA/QC objectives, methods and guidelines followed those of the Phase I Soils RI Quality Assurance Project Plan (U.S. EPA, 1985i). Specific QA/QC information for the Comprehensive RI/FS sampling tasks are presented as a series of QAPP addendums in the Comprehensive RI/FS Study Plan (Hydrometrics, 1987b). Internal laboratory QA/QC procedures are presented within a series of letters and memorandums between Asarco and EPA project team members (Neuman, 1987; Robbins, 1987; Stanga, 1987).

Sampling protocols for the soil, vegetation and cattle investigations included complete document control; chain-of-custody handling; and the collection of field duplicates, bottle blanks, cross-contamination blanks and blind field standards; as specified in the Comprehensive RI/FS Work Plan (Hydrometrics, 1987b). Bottle blanks and cross-contamination blanks were not required by the fish sampling protocol. Numerous measures to prevent contamination during sampling and to ensure preservation during handling and storage, were executed as specified in the work plan.

2.8 DATA VALIDATION

The purpose of data validation was to identify any unreliable or questionable laboratory data. Data validation procedures followed Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analyses (EPA, undated) and Laboratory Data Validation Functional Guidelines for Evaluating Organic Analyses (EPA, 1985j). Where applicable, validation also included statistical treatment of data to determine precision and accuracy of sample results.

2.8.1 Water, Sediment and Stratigraphic Sample Data

Methodology and results of validation of water, sediment, and stratigraphic sample data were presented in several Data Validation Summary reports (Hydrometrics, 1989b, 1989c, 1989d and 1989e).

Sample data associated with out of control laboratory situations are flagged in the data tabulations (Appendices 3-1, 4-3, 4-4, 4-5, 5-2-1, 5-2-2, and 6-1). Appendix 2-2 is a listing of flagged data and their associated data validation codes. Where applicable, biases in the data are also identified in Appendix 2-2.

Precision and accuracy statements for the data were calculated based on laboratory performance on QC samples for each analytical parameter and for each sample matrix using the methodology described in the Phase I Soils RI and previously used by the EPA in the Silver Bow Creek RI. In general, the method consisted of identifying and removing outliers from the data and then applying a t-distribution to estimate precision and accuracy at the 90% confidence level. Precision and accuracy statements for all parameters and matrices are presented and discussed in the Data Validation Summaries (Hydrometrics, 1989b, 1989c, 1989d and 1989e).

In addition to the validation procedures described in the EPA Guidance Document (EPA, undated), a statistical analysis of the water quality data was done for each sampling site to identify outlier results. Analyses containing outlier results were then examined in detail to identify problems in the analyses and field notes were checked to identify variations in sampling techniques or site conditions which may have been responsible for the anomalous results.

As a final check on the validity of data, calculated cation-anion balances and total dissolved solids (TDS) versus specific conductivity (SC) comparisons were made for each water sample. Analyses which exceeded control limits were examined in detail to identify any problems.

2.8.2 Surface Soils, Vegetation, Cattle, and Fish

The primary purpose of data validation was to identify any unreliable or questionable field sample data. The first step in validating the soils, vegetation, cattle and fish data entailed a review of the laboratory quality control data to verify that that the laboratory was operating within required control limits, that analytical results were correctly transcribed from instrument readouts and which, if any, field samples were related to any out-of-control quality control samples. Laboratory and sampling equipment biases were also identified during data validation. An EPA data validation guidance manual (U.S. EPA, 1984b) and various letters regarding Asarco laboratory protocol (Neuman, 1987; Robbins, 1987; Stanga, 1987) provided the procedure for the data validation.

The second step in validating the soils, vegetation, cattle and fish data involved the statistical treatment of laboratory and field duplicate results, natural matrix and digestant/extractant spikes, and blind field standards to determine the precision and accuracy of sample results. Statements describing analytical representativeness and completeness were also prepared. Data validation methods, results and discussion including statements on precision, accuracy, representativeness and completeness for soils, vegetation, cattle and fish analyses are presented in separate reports (Roy F. Weston Inc., 1988a, 1988b, 1989a, 1989b).

2.8.3 Air Quality Data

Air quality data validation methods and results are described in the Validation Summary of Air Quality Data (Hydrometrics, 1989g). As previously described in Section 2.7.2, lead and zinc analyses were conducted by the Montana AQB while analyses of 10 additional metals parameters were analyzed by DOES. Lead and zinc air quality data were validated by the Montana AQB in accordance with the AQB QA manual. The remaining 10 metals parameters analyzed by DOES were validated in accordance with procedures in the Air Quality QAPP (Hydrometrics 1989a).

Validation methods, including statements on accuracy, precision, representativeness, and completeness were similar to those used for other media and are presented in the Air Quality Validation Summary (Hydrometrics, 1989f).

3.0 PLANT PROCESS FLUIDS

3.1 PROCESS PONDS

The final Process Ponds RI/FS report submitted to the EPA on September 8, 1989 contains all the data and information obtained during the remedial investigation of this operable sub-unit. General conclusions of the process ponds remedial investigation were:

1) The four process ponds (Lower Lake, the speiss granulating pond and pit, the acid plant water treatment facility, and former Thornock Lake) are apparent sources of contaminants to the hydrologic system.

2) Lower Lake collects and stores water utilized in the main plant process water circuit as well as stormwater runoff. The speiss granulating pond and pit stores water that is used to cool the hot speiss from the dross plant as part of a granulation process. The acid plant water treatment facility removes particulates from the scrubber fluid. Former Thornock Lake was used to settle suspended solids from the main process water circuit. In October 1986, the lake was replaced by a tank (TT-1, Figure 2-2-1).

3) Water quality sampling results showed that Lower Lake is a sodium-sulfate type water, with moderately high concentrations of TDS, metals, arsenic and a slightly alkaline pH. Speiss granulation process fluids are very alkaline with high concentrations of TDS, carbonate and arsenic. The acid plant water treatment fluids, prior to treatment, are acidic with high concentrations of TDS, sulfate and arsenic.

   The main process fluid circuit inflows to Lower Lake are 50 to 70 gallons per minute higher than the outflows from Lower Lake. The gains in the main process fluid circuit are from groundwater, wastewater from the change house and water used to prevent pipes from freezing. The process fluids in the speiss granulation circuit and the acid plant water treatment circuit are closed loops.

4) The physical and chemical characteristics of the pond bottom sediments and underlying or adjacent strata depend on the pond location. The stratigraphy underlying Lower Lake consists of one to three feet of soft silt and clay, underlain by 13 to 15 feet of fine-grained sediments. Concentrations of arsenic and metals in Lower Lake sediments are highest in the upper one to three feet of the loose silt and clay and generally decrease with depth.

5) Strata near the speiss granulating pond and pit consist predominantly of gravels and cobbles in a sandy silt matrix. Arsenic and metals concentrations are higher near the surface and generally decrease with depth with some increase in the saturated zone.

6) Strata near the acid plant water treatment facility are similar to the sediments near the speiss granulating pond, although one area is more similar in physical and chemical profiles to the sediments near Lower Lake.

7) Former Thornock Lake bottom sediments generally consist of fine-grained, plastic, organic clay with elevated concentrations of arsenic and metals. These sediments are underlain by coarse-grained sand, gravel and cobbles. Arsenic and metals concentrations decrease with depth.

Results of water quality, bottom sediment and stratigraphy data from the Process Ponds RI/FS report are also included in Appendices 3-1, 4-2, 4-3, and 4-4. Where relevant to other operable units or sub-units, these data are discussed in this report; however, the detailed assessment of the Process Ponds operable sub-unit is in the Process Ponds RI/FS report.

3.2 PROCESS CIRCUITS

As described in Section 2.1.2, there are four major process fluid circuits at the plant site: the main process fluids circuit; the acid plant and sinter plant circuit; the blast furnace and dross plant circuit; and the City of East Helena water supply. Investigation activities focused primarily on the main plant process water circuit and the acid plant/sinter plant circuit. Elements of these circuits, (Lower Lake and the acid plant water treatment facility) were addressed as part of the process ponds investigation (see Section 3.1 and the Process Ponds RI/FS report).

3.2.1 Process Circuit Leakage Assessment

3.2.1.1 Main Plant Process Water Circuit

Pressure Lines

Results of the main process water circuit pressure line tests conducted in 1985 as part of the plant water balance investigation are summarized in Table 3-2-1. These tests indicate leakage in some of the pipes; however, quantification of leakage estimates was not possible with the information obtained. Also, non-functioning valves complicated the assessment. The assessment of the condition of the various sections of the process fluid line network are summarized in Figure 3-2-1.

Results of pressure testing conducted in March 1988 and March 1989 are in Tables 3-2-2 and 3-2-3, respectively. The assessment of the condition of pressure line segments from pressure testing in 1988 and 1989 are shown in Figures 3-2-2 and 3-2-3. Theoretical calculation of leakage rates suggest that fluid losses from the tested pressure lines range from 0.2 gpm to 4.3 gpm, or 105,120 gallons per year to 2,260,000 gallons per year, respectively.

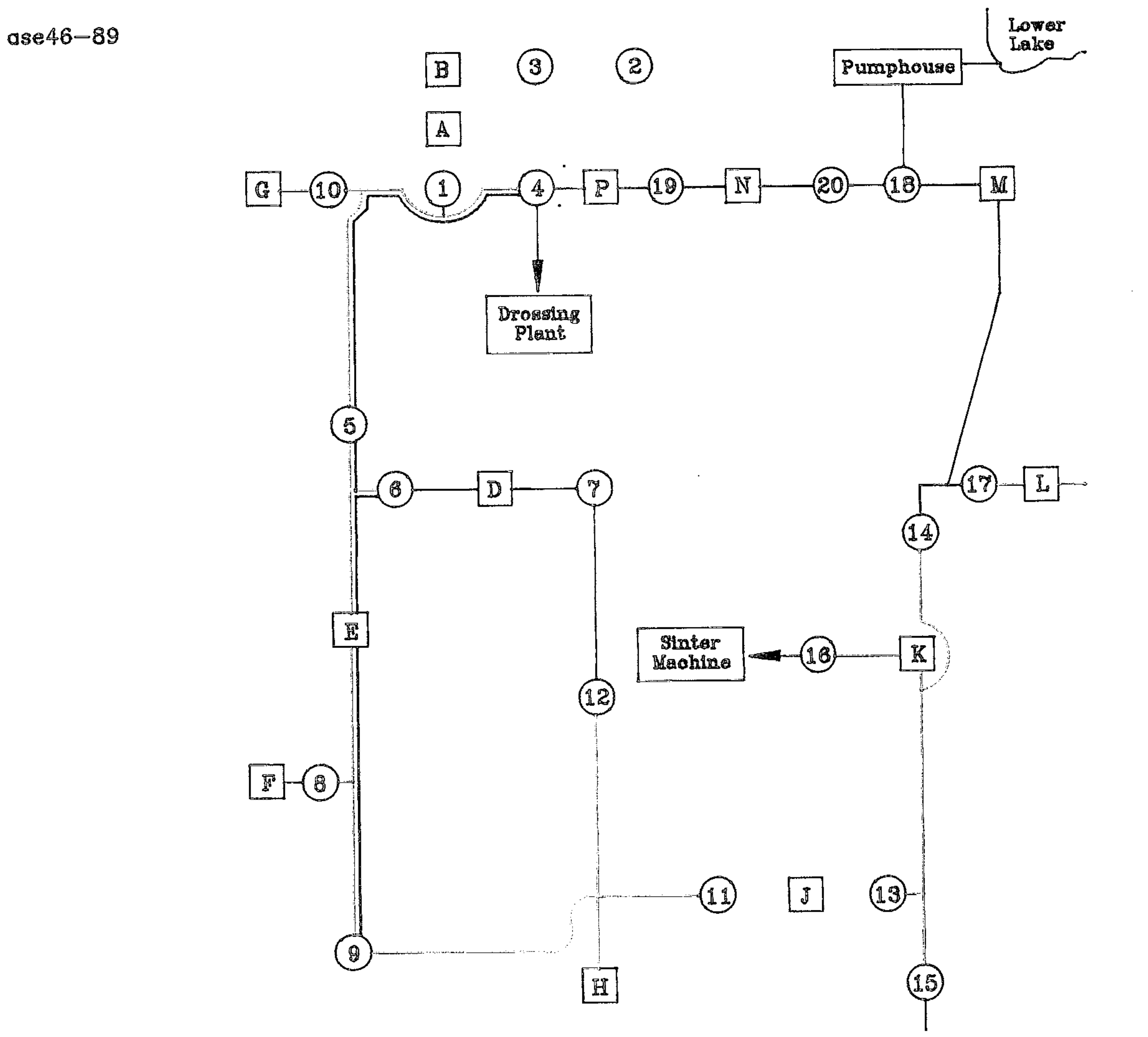
Drains and Sumps

Many of the drain lines present beneath buildings have extremely limited access for flow measurements or are not in a condition that reasonably accurate flow measurements could be obtained. In these cases, only a history of the construction, approximate age and overall conditions through visual inspection could be used to assess leakage possibilities. Visual examination of sumps revealed no obvious problems; however, only the dry portions of sumps could be examined. In addition, histories of

TABLE 3-2-1. PRESSURE TEST RESULTS OF THE PROCESS FLUID CIRCUIT NETWORK CONDUCTED 10/2/85

Valves Closed	Measuring Point	Initial Press PSI	Final Press PSI	Time (seconds)	Conclusions
1,2,4	A	67	0	Within 30	Pipe leaks.
1,2,3,4	B	69	0	Within 30	Pipe leaks.
1,4,5	C	147	90		Pipe leaks. Valve 5 leaks.
6,7	D	152	147	Greater than 2 min.	Pipe leaks. Valve(s) leak.
4,5,6,8,9	E	147	90		Pipe leaks. Valve(s) leak.
8	F	130	0	Within 30	Pipe leaks.
10	G	145	145		Pipe okay if valve 10 okay.
4,6,8,11,12	H	152	152		Pipe okay if valves okay. Contradicts test E.
11,13	J	148	0	Within 30	Pipe leaks.
13,14,15,16	K	70	70	Within 30	Pipe good if valves are good.
17	L	69	69		Pipe good if valve 17 is good.
14,17,18	M	150	20		Leaky pipe and valve.
19,20	N	155 0	25 25		Leaky pipe and valve.
4,19	P	75	135		No conclusion.

NOTE: Test performed by Lee Kitchen and Penn Breland.



	TEST RESULT	CONCLUSIONS
——	Pressure rises.	a) Line is not isolated from a pump. b) Velocity head at first reading was converted to pressure head for second reading.
	Rapid or slow pressure loss to zero.	a) Valves good, leak in pipe. b) Valves leak but pipe leaks faster.
······	Pressure holds constant.	a) Valves and pipe good. b) Valves do not work and pipes are unknown.
━━	Pressure drops but not to zero.	a) Valves and pipe leak eventually reaching a point of equilibrium.
——	Untested Line	
H	Pressure Measurement Nodes	
⑨	Valve	

NOTE: Where two results are indicated for one line segment, separate tests were conducted with two different results.

Figure 3-2-1: Process Fluid Pressure Line Network Testing Result Conducted 10/2/85

TABLE 3-2-2

MAIN PROCESS FLUID CIRCUIT LINE PRESSURE TESTING SUMMARY
CONDUCTED 3/8/88

VALVE NO.	MEASURING POINT	LINE LENGTH (ft)	LINE I.D. (in)	LINE TYPE	INITIAL PRESSURE (psi)	FINAL PRESSURE (psi)	TEST DURATION (min)	COMMENTS	THEORETICAL LEAKAGE RATE (GPM)
1									
	A	606	4	CI	140	0	1.58		3.6
3									
1									
	C	323	4	CI	100	0	0.25	Includes line 10 to G.	3.4
5		560	6	CI					
6									
	D	283	4	CI	90	0	0.85		1.8
7									
5									
	E	280	6	CI	98	90		Valve leak(s) measured 5 gpm.	
9					0	90	1.333	Reran pressure test from 0 to 90 psi.	0.2
9									
	H	281	6	CI	0	125	1.3	Valve leak measured at 1.07 gpm. Ran	0.4
11		67	4		25	125	1.333	pressure tests 0-125 psi and 25-125 psi.	0.2
11									
	J	308	6	CI	144	78	0.483	Valve leak measured at 8.6 gpm. Re-ran	0.3
13		202	4		0	90	0.083	pressure test 0-90 psi. Apparent leak.	4.3
13									
	K	388	4	ST	143	15	2.333	Apparently one or more leaky valves.	0.7
14,15,16		1167	6	CI	15	75	0.333		2.0
17	L	360	4	CI	87	0	2.0	Slow pressure drop. Relatively new	0.2
		191	6	CI				line: installed in 1976.	

TABLE 3-2-3 PRESSURE TEST OF PROCESS/FIREFLOW NETWORK CONDUCTED 3/89

VALVES CLOSED	MEASURING POINT	INITIAL PRESSURE (psi)	FINAL PRESSURE (psi)	TIME (sec)	COMMENTS
10	G	138	138		Tried to bleed off pessure but could not. Valve 10 does not work.
11,13	J	74	0	140	Estimated leak = 0.13 gpm. Water leaking at valve 11.
13,14, 15,16	K				Valve 14 bent, could not close.
4,19	P				Could not do test. Box containing valve was full of water and frozen solid.

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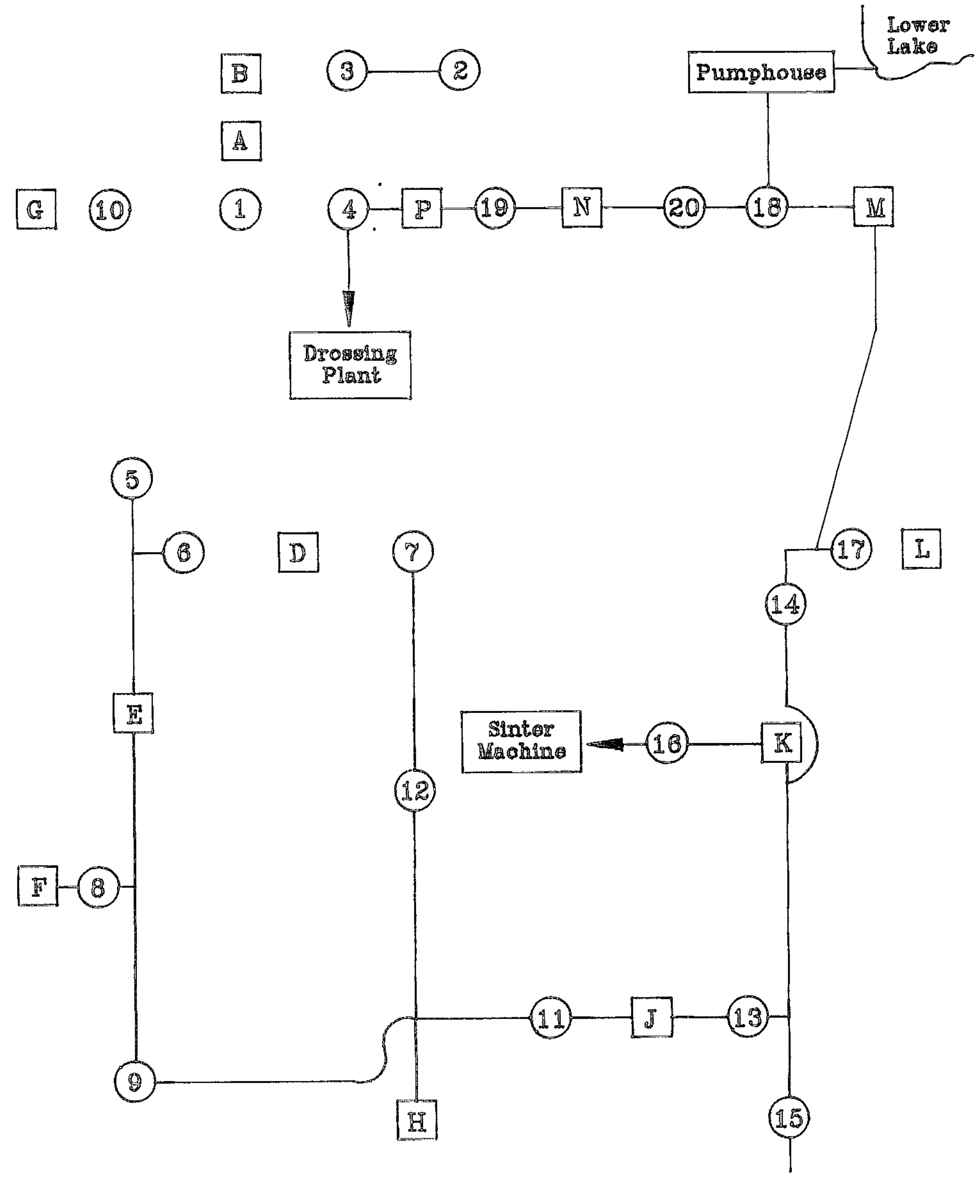
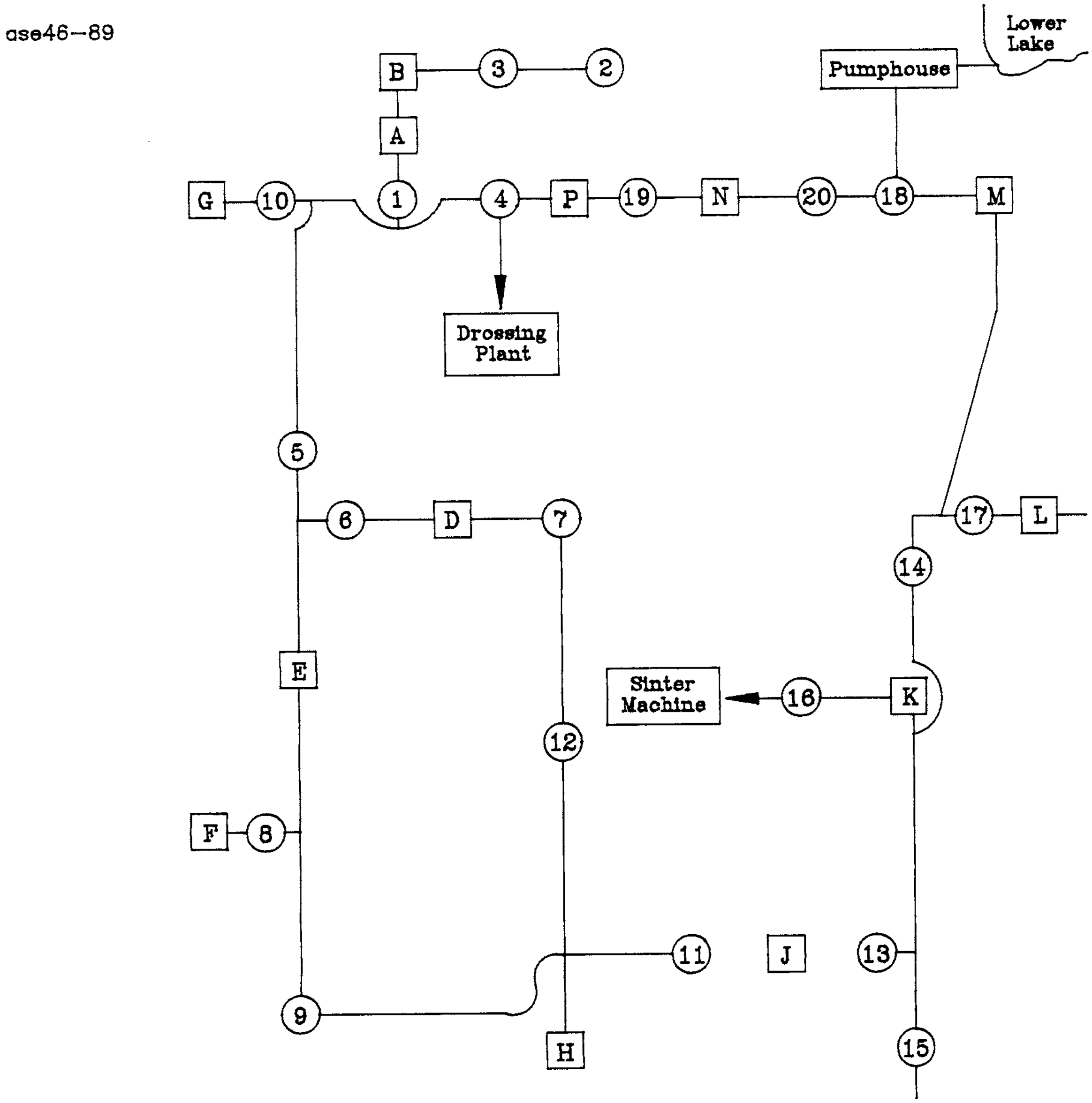


	TEST RESULT	CONCLUSIONS
	Rapid or slow pressure loss to zero.	a) Valves good, leak in pipe. b) Valves leak but pipe leaks faster.
—	Pressure drops but not to zero.	a) Valves and pipe leak eventually reaching a point of equillibrium.
—	Untested Line	
H	Pressure Measurement Nodes	
⑨	Valve	

Figure 3-2-2: Process Fluid Pressure Line Network Testing Result Conducted 3/8/88



	TEST RESULT	CONCLUSIONS
	Slow pressure loss to zero.	a) Valves good, small leak in pipe. b) Valves leak but pipe leaks faster.
———	Pressure holds constant.	a) Valves do not work, pipes are unknown.
———	Untested Line	
H	Pressure Measurement Nodes	
⑨	Valve	

Figure 3-2-3: Process Fluid Pressure Line Network Testing Result Conducted 3/8/88

only part of the drain line system were available. This history is based on engineering drawings of sumps including installation dates. Dates of known sump and line construction or replacement are shown on Exhibit 11.

Lines and sumps not shown with a date on Exhibit 11 probably were installed prior to 1975, the oldest dated record located. The drain line system was built as a standard storm drain system and these systems were generally not built to be watertight. It is reasonable to assume the plant drainage system also is not watertight. Standard methods of construction for this plant drain system and comments on those methods are as follows:

		Comments
1.	Concrete lined ditches were poured as one unit.	Lack of joints promotes watertightness in ditches.
2.	Some sumps were poured around incoming and outgoing pipes. If a sump was already built, the pipe seal was made with grout.	Pipe seals made with wet concrete or grout may not be watertight.
3.	Bottom of sumps poured and left to set, then walls poured.	No means of making sump joints watertight were employed.
4.	Connections between pipes and concrete ditches sealed with grout.	Ditch and pipe seals made with wet grout may not be watertight.
5.	Pipes are buried 10 to 32 inches below ground surface in sand-lined trenches and often under pavement.	Lines are protected from damage by heavy equipment.

Sump S-2 near the pumphouse is part of the process fluid drain system. This sump is reportedly 25 feet deep, brick-lined and an apparent input source to the groundwater system (see Section 4.0).

Where possible, flow measurements were taken at the beginning and end points of the drains. Flows were measured using a variety of methods including 1) bucket and stopwatch, 2) installation of a weir or flume in flow conduits, or 3) a Marsh/McBirney flowmeter. Measurement points are shown in Exhibit 10 with results and explanations given in Table 3-2-4.

TABLE 3-2-4. EAST HELENA DRAIN FLOW MEASUREMENTS

MEASUREMENT POINT	FLOW RATE (GPM)	METHOD OF MEASUREMENT	ACCURACY (GPM)	DIFFERENCE (GPM)	SITE DESCRIPTION	COMMENTS
DL-2 (ST-2)	331	MARSH/ McBIRNEY	± 50		MEASURED AS 8 INCH PIPE FLOWED INTO SUMP.	With the accuracy of 50 GPM on both DL-2 and DL-1 it is possible that there is no loss, but with a 25% difference it is likely that there is leakage. Visual inspection of the two flows seemed to indicate an obvious loss of process fluids. Both sumps and the line between are scheduled to be replaced in early 1989.
				84 LOST		
DL-1	247	MARSH/ McBIRNEY	± 50		MEASURED AS 8 INCH PIPE FLOWED INTO SUMP.	
DL-3	12.8	90 V-NOTCH WEIR W/ RUBBER SEALS	± 2		11 inch square concrete ditch, 2-4 inches of sediment on bottom. Pool developed above the weir with negligible velocity. Water did not break free cleanly.	
				9.8 GAINED		Increase in flow of 72%. There was surface runoff this day and this line is exposed to the possibility of surface runoff gain. It is a concrete ditch with steel covers. No obvious addition of surface runoff existed.
DL-4	22.0	MARSH/ McBIRNEY	± 3		11 inch square concrete ditch, 4-6 inches of sediment, plastic bags and pieces of metal on bottom. Section of ditch cleaned prior to measurement.	
DL-8 A (AP-1)	14.3	MARSH/ McBIRNEY	± 3		Site consists of two concrete sumps. Flow enters the first sump via a 15 inch concrete pipe (pt. A). Flow travels to the second sump via a 15 inch concrete pipe (pt. B). Other pipes into the sumps were dry.	At the time of measurement surface runoff was disappearing into the ground near the first sump. This could account for the discrepancy in flows. If this is the case the sump could also leak under drier conditions. However, the difference in the two flows is well within the accuracy of measurement.
				1.6 GAINED		
B	15.9	MARSH/ McBIRNEY	± 3			
				5.6 LOST		
DL-7	10.3	6 INCH V-NOTCH FLUME	± 1		Flow measured in an unlined ditch. Flow changes from PVC pipe to an open ditch somewhere between DL-8 and DL-7. A permanent measurement station with flume, stilling well and F-1 recorder is located here.	The difference in flows here is reasonable since the lower section of the drain is unlined. It should be noted that flow recorded at DL-7 is nearly double normal flow.

3.2.1.2 Acid Plant and Sinter Plant Circuit

The major element of the acid plant/sinter plant circuit is the acid plant water treatment facility which is addressed as part of the process ponds operable sub-unit (see Section 3.1 and the Process Ponds RI/FS report). Another potential source of leakage in the acid plant/sinter plant circuit include the acid plant scrubber pad that underlies the scrubber towers (see Exhibit 10). Scrubber sludge and acidic fluids collect on the scrubber pad prior to flowing to the acid water treatment facility. Although the pad is constructed with acid-resistant, treated concrete, elevated concentrations of arsenic in downgradient monitoring well DH-22, suggests leakage may occur from the scrubber pad. Considerable evaporation takes place in the entire acid plant/sinter plant circuit (see Exhibit 10) particularly in the scrubber process. Consequently, accurate measurements for the purpose of determining losses from the circuit cannot be made.

3.2.1.3 Blast Furnace and Dross Plant

Because of inaccessible lines and branches, a quantitative leakage assessment of the Blast Furnace/Dross plant circuit was not possible. Water in this circuit is pumped from the main pumphouse to the blast and reverbatory furnace area. Return water is piped to the pumphouse and is cooled in an enclosed heat exchanger. A small amount of water is required from the process water circuit to make up evaporative losses during bearing and flue cooling. Visual inspection of the system, where possible, showed no evidence of fluid losses from the closed system.

3.2.1.4 City of East Helena Potable Water Supply

The City of East Helena water supply line is shown on Exhibit 10. Water flow into the plant is not monitored. Flow out of the plant is via the city sanitary sewer and is monitored for flow and metals. Although water quality in this circuit is good, losses from the circuit were an important consideration in the process ponds water balance; specifically, freeze prevention bleeders, which contribute water to the main process circuit.

Although leakage tests were not conducted, there is evidence the potable water supply line leaks in at least one location. Some groundwater samples obtained from monitoring well DH-5 (see Exhibit 1 and Section

4.0) had the best water quality of any samples obtained from the groundwater or surface water system in the study area. DH-5 is located where the potable water supply line enters the plant. The source of the water supply is McClellan Creek which is similar in quality to some water samples from DH-5. A leak of the potable water supply line has apparently been detected by the groundwater quality monitoring of well DH-5. A more detailed discussion is in the groundwater section (4.0) of this report.

3.2.2 Process Fluid Chemistry

Process fluids were sampled from eight drain, sump or settling tank sites (AP-1, S-1, S-2, S-3, ST-1, ST-2, TT-1 and ZP-1; see Table 2-1-1 and Appendix 3-1). With the exception of AP-1 and ZP-1, these process circuit sampling sites are components of the main process fluid circuit which are ultimately routed to Thornock Tank (TT-1) and from there to the Lower Lake replacement tanks (see Figure 2-1-1). Flow from AP-1 is routed directly to the Lower Lake replacement tanks. Flow in ZP-1 is very small (about 1 gpm), contained in an unlined ditch, and infiltrates into the ground prior to discharge to Lower Lake.

Generally, process waters from sites S-1, S-2, S-3, ST-1, ST-2, and TT-1 are sodium-sulfate type, have moderately high concentrations of TDS, metals and arsenic, and are similar to Lower Lake water chemistry. Concentrations of arsenic, metals and TDS are variable over time, reflecting variations in plant process circuit management, and variations from occasional runoff within the plant. Of the metals measured, concentrations of arsenic are the highest, with dissolved values generally only slightly less than total concentrations. Arsenic is the most mobile metal in the East Helena groundwater system (see Section 4.0), and is the parameter of primary concern in process fluids.

Concentrations of total and dissolved arsenic measured at drain sump S-1 range from a high of 60 mg/l and 41 mg/l, respectively, to a low of 18 mg/l and 15 mg/l, respectively. Total and dissolved arsenic concentrations for fluids from drain sump S-2 ranged from a high of 51 mg/l and 25 mg/l, respectively, to a low of 18 mg/l and 14 mg/l, respectively.

Concentrations of total and dissolved arsenic at sump S-3 were considerably more variable than at sites S-1 and S-2, reflecting the modifying influence of groundwater input to sumps S-1 and S-2 (see Section 3.1). Concentrations of total and dissolved arsenic at sump S-3 (which receives only inputs from surface water runoff from plant washdown or precipitation) range from a high of 75 mg/l and 69 mg/l, respectively, to a low of 1.3 mg/l and 0.005 mg/l, respectively.

The quality of water samples collected at drain sites ST-1 and ST-2, reflect inputs from the sinter operation to the main plant process circuit (see Figure 2-1-1). Total and dissolved concentrations of arsenic from water at ST-1 range from a high of 23 mg/l and 17 mg/l, respectively, to a total low concentration of 3.6 mg/l. These relatively low concentrations reflect occasional inputs from Upper Lake which is used for washdown purposes.

Concentrations of arsenic and other metals, particularly cadmium, lead and zinc, in water from site ST-2 are significantly higher than from other drain sump locations. These elevated arsenic and metals concentrations reflect the use of this water for cooling during the sintering process. Total and dissolved concentrations of arsenic ranged from a high of 104 mg/l and 102 mg/l, respectively, to a low of 28 mg/l and 14 mg/l, respectively. Total and dissolved concentrations for cadmium were as high as 11 mg/l and 10 mg/l, respectively, and as low as 0.8 mg/l and 0.1 mg/l, respectively. Total lead and zinc were also elevated, ranging from highs of 200 mg/l and 55 mg/l, respectively, to lows of 7 mg/l and 2 mg/l, respectively.

Samples were collected from former Thornock Lake prior to its replacement in 1986 and from fluids in the replacement tank (Site TT-1) after its installation. Comparison of data collected from former Thornock Lake and from the tank TT-1 (Appendix 3-1) shows the water quality from the two installations is very similar, generally with slightly higher concentrations of TDS from TT-1 samples. Concentrations of arsenic during samples collected from both former Thornock Lake and tank TT-1 ranged from a total and dissolved high of 40 mg/l and 35 mg/l, respectively, to a low of 9 mg/l and 6 mg/l, respectively.

The flow at drain sample site AP-1 consists of acid plant blowdown water that drained to Lower Lake. Water quality from samples at AP-1 consist of a calcium-bicarbonate or calcium-sulfate type with lower concentrations of arsenic, metals and TDS than typical waters from other process drain sites or Lower Lake. Total and dissolved arsenic values ranged from a high of 0.41 mg/l and 0.35 mg/l, respectively, to lows of 0.045 mg/l and 0.039 mg/l, respectively.

Samples collected at site ZP-1 show this water is a calcium-sulfate type with high concentrations of TDS, and moderately high concentrations of arsenic and metals. Total and dissolved concentrations of arsenic range from a high of 42 mg/l and 16 mg/l, respectively, to a low of 13 mg/l and 11 mg/l, respectively.

Samples were also collected from two sites (TW-1 [truck wash sump], and SP-2 [speiss granulation pit coolant water]) that were not part of the Comprehensive RI sampling program and were only sampled once. TW-1 is a sample of waste wash water that is collected in an outside truck wash sump prior to discharge to Thornock Tank (TT-1). This sump appears to be only partially lined with concrete. SP-2 is a sample of speiss granulation pit coolant water and is the same recirculated fluid stored in the speiss granulation pond (see Section 3.1).

Water from TW-1 is a sodium-sulfate type water with high concentrations of cadmium, manganese, zinc, TDS, and relatively low concentrations of arsenic. Total metals concentrations are slightly higher than dissolved concentrations. Dissolved concentrations of cadmium, manganese, zinc and arsenic are 94 mg/l, 50 mg/l, 290 mg/l, and 0.5 mg/l, respectively.

Speiss granulation process fluids as sampled from SP-1 (speiss granulation pond) and SP-2 (speiss granulation pit) are very alkaline with a pH in excess of 12, and very high concentrations of TDS, carbonate, and arsenic (see Section 3.1).

3.2.3 Plant Dust Suppression

Process water from Lower Lake is used to reduce airborne particulates in the plant area by watering roads and by using a system of irrigation-type sprinklers. These sprinklers are placed on the sides of buildings and are timed to run intermittently during the warm weather. A 3,000 gallon watering truck sprays about 10 loads of process water per 8 hour shift from April through September. In 1987, the water truck operated for one shift per day during April, May and September and for two shifts per day during June, July and August. Average daily flow at 10 and 20 loads per day is 21 and 42 gpm, respectively. Most areas sprinkled or watered are paved with asphalt or concrete and visual inspection indicates the majority of this water evaporates. However, in unpaved areas, some process waters from either sprinkling or road watering may percolate downward to the groundwater system.

Airborne particulates from the ore storage area are controlled by process water applied with irrigation-type sprinklers. The majority of the ore storage area is underlain by concrete or asphalt. However, some areas are not paved and groundwater could potentially be impacted from percolation of excess process or runoff water that crosses or accumulates in these unpaved areas. In addition, areas presently paved may have historically impacted groundwater by infiltration of runoff water into the underlying soils when these areas were unpaved. Total quantity of water used in the combined plant and ore storage areas for dust suppression ranges from 87 to 108 gpm daily depending on whether watering trucks run one or two shifts per day, respectively.

An assessment of plant area runoff and potential for downward percolation associated with dust suppression or precipitation events is included in Section 5.2.4.

4.0 GROUNDWATER

The major pathway for movement of contaminants from process fluid sources in the East Helena study area is the groundwater system. Knowledge of hydrogeologic characteristics is essential in an evaluation of contaminant transport.

4.1 HYDROSTRATIGRAPHIC UNITS

Delineation of hydrostratigraphic units is based on data from drilling and analyses of 63 soil core drill holes and monitoring wells in the study area. These data are augmented by information from drillers' logs of private wells, and from existing hydrological and geological literature.

Surficial materials in the study area consist of unconsolidated outwash deposits of Quaternary age that are underlain by unconsolidated to semi-consolidated deposits of Tertiary age. Figure 1-1-3 shows the surficial geology of the East Helena area. Subsurface information collected during drilling shows a complex system of layers and lenses composed of a mixture of cobbles, gravel, sand, silt, clay and volcanic ash/tuff. Most of these geologic units provide a good medium for groundwater movement.

Tertiary deposits in the study area consist primarily of yellow-white to light gray compact siliceous ash/tuff. Samples from this Tertiary unit generally consists of 90 percent siliceous ash (Dr. Dick Berg, Montana College of Mineral Science, personal communication, June, 1987). The unit commonly contains clasts of angular basalt, ranging in size from sand to cobbles. The ash unit is partially to totally altered to clay in the City of East Helena. Drill logs (Appendix 4-2) show the ash unit is 20 to 25 feet thick in the study area. The Tertiary ash deposits are well exposed in a road cut along U.S. Highway 12, about one-half mile west of East Helena (Schmidt 1986) and are also exposed in an outcrop near the Helena airport southeastern boundary, about 2 miles west of East Helena. The ash unit is underlain by Tertiary age gravels and is overlain by gravels of probable Tertiary and Quaternary age.

Geologic cross-sections (Exhibit 3) were constructed from logs of the monitoring wells and soil core drill holes. They show the Tertiary ash/tuff unit lies at depths as shallow as 24 feet beneath the ground surface in the plant site area and as deep as 68 feet in off-plant areas in the City of East Helena. The top of the ash unit was mapped and contoured (Figure 4-1-1) using drill log information. Figure 4-1-1 shows that the ash unit generally dips to the northeast, with an apparent ridge underlying the ore storage area within the plant site. Exhibit 3B, Cross-section E-E′, shows that the unconsolidated sediments overlying the ash unit ridge are unsaturated. However, the water table intersects sand and gravel to the northeast.

Sand and gravel of probable Tertiary and Quaternary age overlie the ash unit within and to the west of the plant site. Since age determination of the sand and gravel was sometimes difficult, no contacts between Tertiary and Quaternary gravels are shown on the geologic cross-sections (Exhibit 3).

In some areas underlying the plant, and immediately east and north of the plant, Tertiary gravel deposits have been partially eroded and the erosion surface subsequently covered by more recent alluvium deposited by ancestral Prickly Pear Creek. These unconsolidated deposits consist predominately of cobbles and gravel with varying mixtures, lenses and layers of silt, sand and clay.

In the plant site area and off-site in East Helena, shallow and intermediate gravel layers overlying the ash/clay unit are often separated by thin (2 to 9 feet) clay and silt lenses. Exhibit 3 shows that these fine-grained layers are generally discontinuous, lenticular and pinch out.

Organic clay and silt overlie coarse-grained Quaternary alluvium in some locations in the plant site area. Geological cross-sections (Exhibit 3, cross-sections D-D′, F-F′ and G-G′) show about 13 to 15 feet of organic fine-grained sediments in the Lower Lake area. These sediments generally consist of organic clay and silt, which is soft, has a low density, and resembles peat. On portions of the plant site, these fine-grained sediments have been covered by slag (a siliceous smelting by-product) and

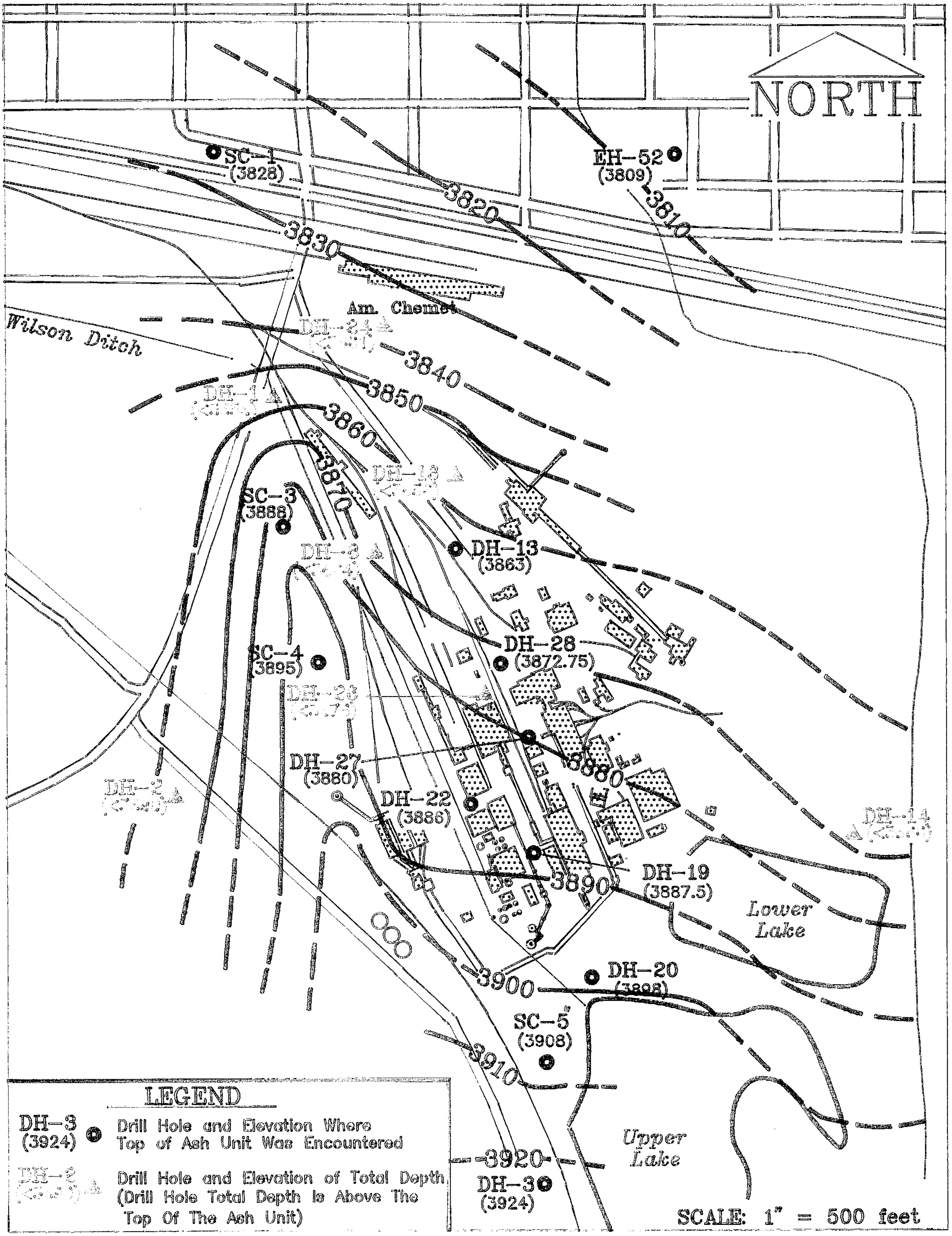


Figure 4-1-1: Top of Tertiary Ash Unit

other fill from the plant operation, including cobbles, gravel, silt, and clay. An old photograph (circa 1920) and early plant blue prints show that Quaternary flood-plain deposits from Prickly Pear Creek underlie the large slag piles.

Cross-sections C-C′ and I-I′ (Exhibit 3) and monitoring well logs (DH-5 and DH-23, Appendix 4) show that the slag is partially saturated at some locations within the plant site. This suggests that groundwater is perched where the underlying organic, fine-grained layer inhibits downward percolation. This conclusion is supported by the anomalously high water elevation in DH-23 and geologic log of DH-9. After five feet of drilling into slag, the water level observed in drill hole DH-9 was four feet below the ground surface. Additional drilling advanced the hole through a two foot thick organic clay layer. Water levels measured in DH-9 after well completion were six to seven feet deeper. As shown on Exhibit 3, well DH-23 is completed in slag overlying the fine-grained organic clay. The contrasting water levels in DH-23 and DH-9 implies that perched conditions occur in the slag.

Three industrial wells owned by American Chemet (AM-2, AM-3, and AM-4) and a well drilled for the plant in 1975 provide additional subsurface information of the plant site area (see Exhibit 1 for well locations). Although the drilling logs (Appendix 4-7) are not sufficiently detailed to clearly distinguish various types of sediments, they indicate that the wells are completed in fractured shale underlying the ash/clay unit. Examination of Figure 1-1-3 and cross-section C-C′ (Exhibit 3) suggest the deep "shale" may be Precambrian meta-sedimentary rock of the Belt Supergroup. An abandoned water supply well for the City of East Helena (Well No 4, Exhibit 1) was drilled to a depth of 170 feet east of Prickly Pear Creek near the plant. The reported lithology is incomplete, however, and may be inaccurately described.

Most private wells in the East Helena area are completed in coarse sand and gravel that underlies one or more discontinuous clay layers of Quaternary or Tertiary age. These wells generally range in depth from 34 to 80 feet. One 160 foot deep well (Jensen A-2, Appendix 11) is completed in bedrock underlying the ash unit and other Tertiary unconsolidated sediments. Three private wells outside of East Helena and west of the plant (D. Hulst, K. Hulst and L. Hulst; Appendix 11) are also completed in bedrock aquifers. The ash unit which underlies much of the plant site and the City of East Helena is exposed at ground surface near the three Hulst wells.

4.2 AQUIFER HYDRAULIC CHARACTERISTICS

In general, Quaternary and Tertiary age sand and gravel units in the Helena Valley are very permeable and yield considerable amounts of groundwater to wells. Numerous wells completed in these deposits are pumped at rates of 500 gallons per minute (gpm) or more. Transmissivities estimated from pumping tests at two water supply production wells ranged from 90,000 to 250,000 gallons per day per foot (gpd/ft) (Hydrometrics 1983). Permeability (hydraulic conductivities) of finer-grained sediments and bedrock materials are relatively low.

Aquifer tests were conducted on 38 of the 42 monitoring wells completed in the East Helena study site area. Details of aquifer testing are summarized in Table 2-2-5 and graphical plots of hydraulic testing data are in Appendix 4-6. Monitoring wells tested in the study area are completed in both the shallow and intermediate saturated zone. One deep unit well (DH-18) was also monitored for water level response during testing of adjacent shallower monitoring wells (see Table 2-2-5). Resulting estimates of transmissivity are representative only of the strata penetrated by the tested wells.

Drilling and testing show the unconsolidated deposits underlying the study area are heterogeneous and anisotropic due to the depositional processes that resulted in mixtures of cobbles, gravel, sand, silt, and clay. The stratified nature of alluvial deposits characteristically results in a very high ratio of vertical to horizontal hydraulic conductivity commonly on the order of 1:100 or even larger (Freeze and Cherry, 1979).

Transmissivity values estimated from aquifer tests ranged from a low of 35 gpd/ft at well EH-54 to a high of about 73,000 gpd/ft at well EH-62. As shown on Table 2-2-5, transmissivity values were calculated using both drawdown and recovery data. Transmissivity value estimates from one tested well DH-23 were not possible because no measurable drawdown occurred during pumping. The lithological log for well DH-23 (Appendix 4-2) shows this well was completed in cavernous slag with a zone of saturation perched above the true groundwater table (see Section 4.1).

The areal distribution of the average calculated permeabilities using monitoring wells and piezometers completed in the shallow and intermediate saturated zones are shown on Exhibit 4. Permeabilities were calculated by dividing the measured transmissivity by the thickness of aquifer penetrated by the well. In the shallow zone of saturation, the highest permeabilities generally are from wells north and east of the plant site. Shallow wells near Prickly Pear Creek have relatively high permeability reflecting the coarse-grained alluvium deposited by the stream in these areas. However, monitoring well EH-54 located near Prickly Pear Creek north of East Helena (see Exhibit 4) has a very low permeability reflecting shallow fine-grained materials.

With the exception of EH-54, shallow well permeabilities are lowest south and west of the plant site, and are associated with fine-grained Tertiary ash and clay deposits or partially indurated gravels of probable Tertiary age.

Average permeabilities from monitoring wells in the intermediate zone of saturation were lower than adjacent shallow aquifer wells. The lower permeability may reflect the partial cementing or induration of the intermediate sand and gravels observed during drilling (see Appendix 4-2). An exception is intermediate well EH-100 where calculated permeability was higher than the adjacent shallow well EH-50. The permeabilities in the intermediate aquifer are higher north of the plant in East Helena than on or near the plant site itself.

Reported values of transmissivity and permeability for the upper and intermediated saturated zones must be considered approximations since the heterogeneous-anisotropic strata and partial penetrating well completions did not provide ideal conditions for aquifer testing.

Recharge, leakage or barrier boundaries were detected during most of the aquifer pumping tests (see Table 2-2-5 and graphical plots in Appendix 4-6). These boundaries, in part, reflect changes in aquifer permeability within the zone of influence. Such variations in permeability are expected in a heterogeneous and anisotropic groundwater system.

Several pumping tests were conducted to assess aquifer storage characteristics of the shallow saturated unit and to assess the vertical hydraulic connection between the shallow saturated zone, the underlying intermediate zone and water-bearing zones underlying the ash/clay unit. Values of storativity or specific yield were estimated from aquifer test drawdown data collected from piezometers installed adjacent to pumping wells (see Table 2-2-5 and Appendix 7). Calculated storage coefficients range from 0.000001 to 0.05, respectively, and reflect both confined and unconfined conditions of the shallow unit.

The variability in calculated storage partly reflects the heterogeneous stratigraphy observed during monitoring well drilling. The water bearing zones of wells DH-13 and EH-51, which have low calculated storage coefficients (0.001 and 0.000001, respectively), characteristic of confined aquifer conditions, are overlain by finer grained materials that yielded little or no water during drilling. Confined conditions of well DH-13 are also obvious from continuous water level records of this well Appendix 4-8). Frequently recorded short-duration water level rises and declines in this well were correlated with the nearby passage of a railroad engine, indicating pressure effects from loading. Wells DH-17 and EH-52, which are not overlain by fine-grained materials that inhibit water movement, have relatively high storage coefficients (0.05 and 0.03, respectively), indicative of unconfined conditions.

Aquifer interconnection between the shallow and intermediate units was investigated during multiple well pumping tests at DH-14, DH-15, EH-101 and EH-102 (see Table 2-2-5). Water levels of shallow monitoring wells paired with intermediate monitoring wells were measured during intermediate monitoring well pumping tests. With the exception of the test of EH-102, water levels in shallow monitoring wells showed instant response to pumping of intermediate monitoring wells and had measurable water level declines. Water levels in shallow monitoring wells and piezometers did not respond to the pumping of intermediate well EH-102.

Two piezometers, P-8 and P-9, were installed in fine grained layers separating shallow and intermediate water bearing zones to help assess vertical leakage. Few analytical techniques exist to determine vertical water movement rates in confining layers. One of these, the Witherspoon and Neuman Ratio Method, can theoretically assess vertical movement rates (Javandel, No Date). A basic assumption of this technique is that there is some delay in water level declines in the confining unit after pumping begins. However, water levels in P-8 responded immediately to pumping of the underlying intermediate well, and P-9 did not respond at all (see Table 2-2-5). Therefore, calculation of vertical leakage through the aquifer was not possible from aquifer test data.

While pumping monitoring well DH-13, the water level in adjacent deep well DH-18 was monitored to provide information on the interconnection between water bearing zones overlying and underlying the ash/clay fine-grained unit. As shown in Table 2-2-5, the water level in DH-18 did not respond to the pumping of DH-13.

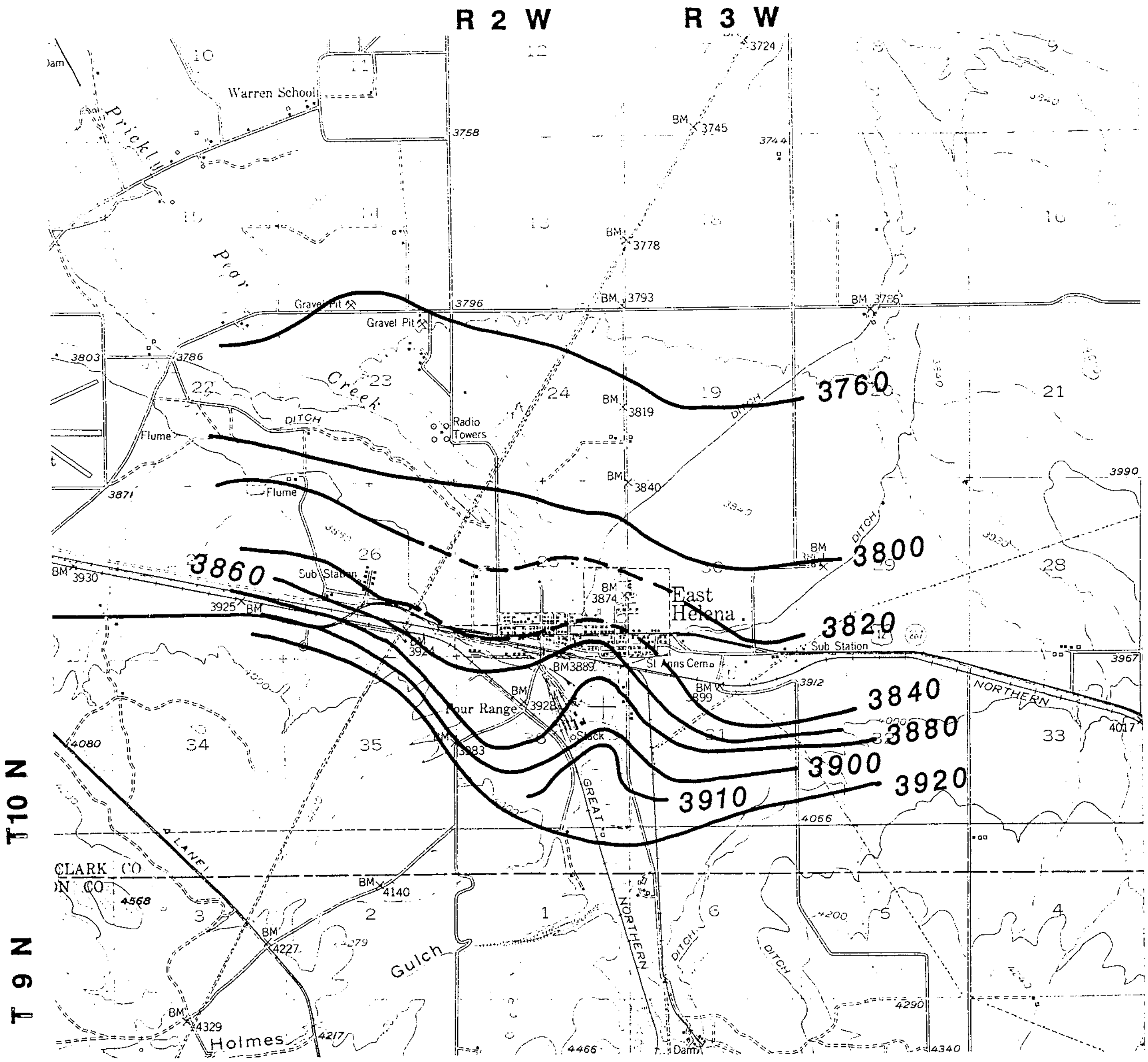
4.3 GROUNDWATER RECHARGE, DISCHARGE AND MOVEMENT

Regional potentiometric contours in the study area are shown in Figure 4-1-2 and a detailed potentiometric surface map of the plant site and East Helena is given as Exhibit 4. The regional contour map was constructed using a combination of sources including 1983 USGS water level data primarily for the area north of East Helena, and water level data from monitoring wells and private wells in the study area. All of the wells used for control in the regional potentiometric map (Figure 4-1-2) are not perforated in the same stratigraphic interval. Therefore, the potentiometric contours as shown do not necessarily represent groundwater movement in a single continuous aquifer. Instead, they generalize groundwater movement in several aquifers that may be poorly connected, hydraulically. Figure 4-1-2 shows regional groundwater movement in the study area is northward toward Lake Helena, which is a natural groundwater discharge point (Wilke and Coffin, 1973).

Recharge to groundwater in the Helena Valley comes from infiltration of precipitation on the valley floor and surrounding mountains, and particularly from water losses from streams and irrigation canals that cross the valley floor. Streams and springs, evapotranspiration, and numerous domestic, stock, and irrigation wells are important points of groundwater discharge in the valley. Depth to groundwater in the Helena Valley varies seasonally and usually ranges from about 10 to 50 feet below ground surface. The regional shallow groundwater hydraulic gradient in the East Helena area, as shown on Figure 4-1-2, averages about 85 feet per mile or 0.0162 feet per foot.

Groundwater in unconsolidated Quaternary outwash deposits from Prickly Pear Creek and in the underlying Tertiary deposits flows to the northwest beneath the plant site and East Helena (Exhibit 4). Groundwater at the plant site receives additional recharge from Upper Lake, Lower Lake, and Prickly Pear Creek. Groundwater off the plant site in the East Helena area also receives some recharge from Prickly Pear Creek. Wilson Ditch, which runs across the plant site, originates at Upper Lake (see WD-1, Exhibit 1) and is lined with concrete beneath the plant site. This lined segment of Wilson Ditch is above the water table and is not considered a significant recharge source in the plant site area. West of the plant site, this ditch is unlined and is an apparent groundwater recharge source in the Helena Valley west and northwest of the plant area. Flow in Wilson Ditch measured at two sites, WD-2 and WD-3 (see Exhibit 1), on May 5, 1985 showed a loss of over 2 cfs in about one-half mile of ditch.

Water from Prickly Pear Creek is diverted into Upper Lake just upstream of surface water monitoring station PPC-4 (see Figure 2-3-1). Streamflow downstream of Station PPC-4 increases, and about 0.5 miles downstream, the streamflow is similar to that at PPC-3. This additional streamflow primarily comes from Upper Lake via underground seepage and from overflow through several culverts. Some streamflow losses between surface water stations PPC-5 and PPC-8 probably occur, however, any losses were small enough to be within the measurement error range of the streamflow gaging conditions and techniques (see Prickly Pear Creek Section 5.2.1).



NORTH

LEGEND

3900 —— **Potentiometric Contour and Elevation (ft.) - Dashed Where Inferred**

Source Of Base: (a) 1983 USGS Unpublished Water Level Data Primarily For The Area North Of East Helena, (b) 1985 ASARCO Plant Monitoring Well Water Level Data, And (c) 1985 Water Level Data From Selected Private Wells In East Helena

Scale: 1" = 1 mile (approx.)

Figure 4-1-2: Regional Potentiometric Contours For East Helena Area

The configuration of the groundwater potentiometric surface at the plant site is shown on Exhibit 4. The following summarizes the sources of groundwater recharge and discharge as shown on the potentiometric contour maps of the plant site and East Helena.

1) The difference in elevation between the water surface in Upper Lake, Lower Lake, and the groundwater table suggests groundwater recharge occurs from the surface water bodies. Although the regional groundwater flow is to the northeast toward Lake Helena (see Figure 4-1-2), groundwater flow in the plant site area and the western portion of East Helena is to the northwest and appears to be significantly influenced by these two ponds.

2) Water table contours near Lower Lake indicate a contribution of flow or seepage to Prickly Pear Creek immediately east of the pond.

3) Water table contours considering both groundwater and surface water elevations suggest little recharge from Prickly Pear Creek to the groundwater system east of the slag pile. However, groundwater contours indicate a contribution of flow to the groundwater system north of the plant in East Helena.

4) Potentiometric contours within the plant site show a process fluid circuit sump (S-2, see Section 3.2.1) is a point source of recharge to the groundwater system at this location (see Exhibit 4). As described in Section 3.2.1, this sump is unlined and acts as a recharge source to the groundwater system within the plant.

Exhibit 4 shows that permeability varies within the plant site and study area. Aquifer permeability values were calculated by dividing the measured transmissisvity by the thickness of the aquifer penetrated by the well. As shown on Exhibit 4, the highest permeability values are generally north to northwest of the plant site in the shallow alluvium deposits. Shallow aquifer permeability values within the main plant site are generally lower than the majority of the values north and northwest of the plant and are associated with the steeper gradients shown on Exhibit 4. One well, DH-23, has a permeability that was too high to measure (water from the 4 inch well could not be pumped at a large enough rate for measurable drawdown). However, this well is completed in cavernous saturated slag that is perched on organic clay above the shallow aquifer water table. Therefore, it is not considered to be representative of shallow aquifer conditions (see Sections 4.1 and 4.2).

Permeability values from shallow aquifer wells located north and northeast of Lower Lake are generally higher than plant site wells and reflect the more permeable alluvium deposited by Prickly Pear Creek in this area. The lowest permeability values generally were measured from wells west and south of the plant site and are associated with fine-grained Tertiary sediments.

Several distinct zones of different aquifer permeability exist in the study area. These are shown in Figure 4-3-1 and listed in Table 4-3-1. The differences in permeability of strata in the plant and East Helena areas have important implications. To better understand these differences, a quantitative evaluation of groundwater flow in the plant site and East Helena area was completed.

Because complex geology and variable permeabilities severely restricted the applicability and usefulness of detailed techniques such as flow net analyses, a more generalized approach was used to calculate shallow groundwater flow using the following form of the Darcy flow equation:

$$Q = TIL$$

Where: Q = groundwater flow, gallons per day (gpd)
T = transmissivity, gpd/ft
I = Aquifer hydraulic gradient, ft/ft
L = Width of flow field, ft

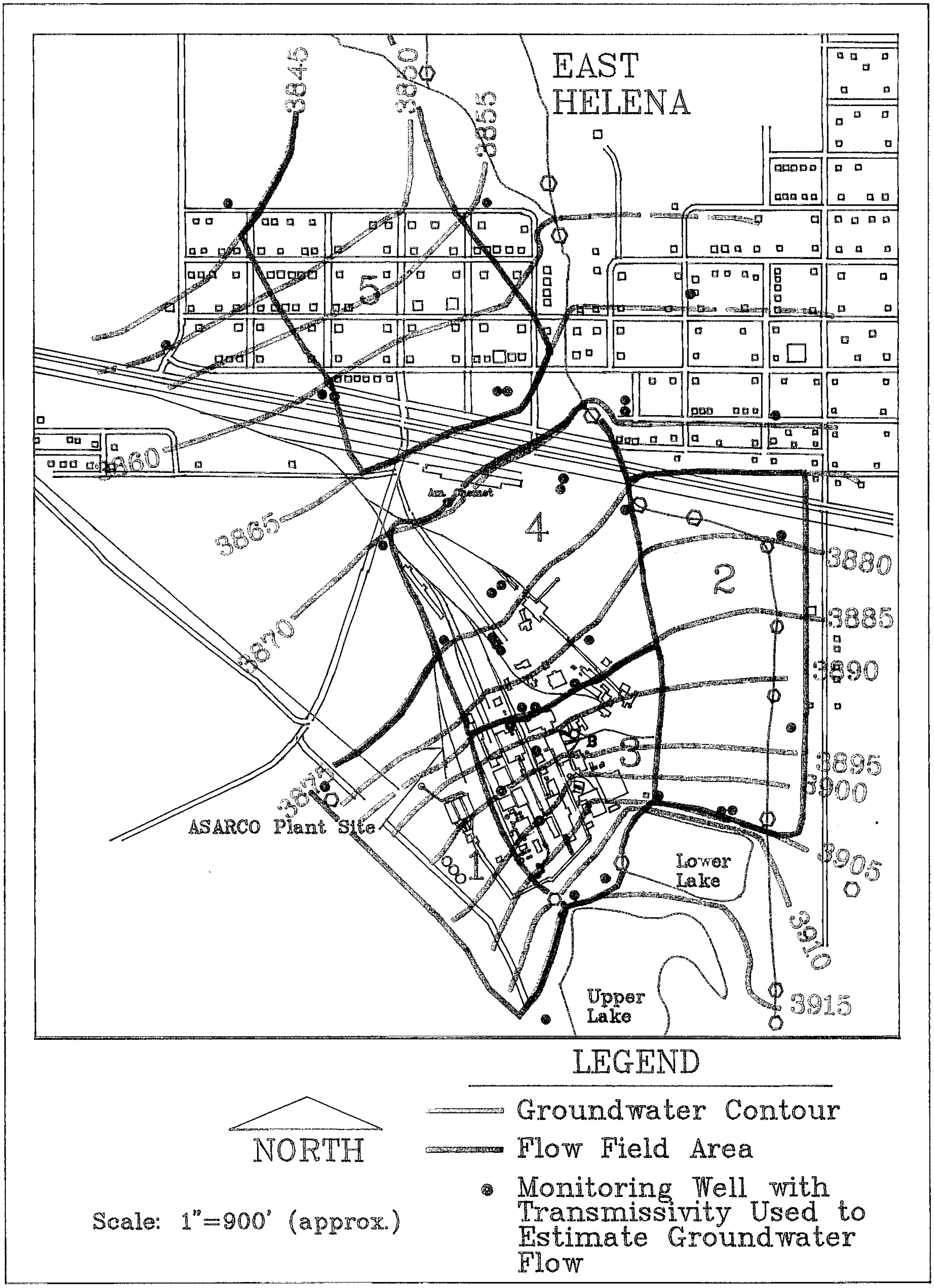


Figure 4-3-1: Flow Field Areas Used For Calculation of Groundwater Flow and Velocity Estimates

Table 4-3-1 AVERAGE PERMEABILITY AND TRANSMISSIVITY IN VARIOUS AREAS AND STRATA IN THE EAST HELENA STUDY AREA

FLOW FIELD 1 Monitoring Well	K (gpd/ft2)	T (gpd)
DH-1	30	300
DH-2	11	320
DH-3	39	45
Average	27	222

FLOW FIELD 2 Monitoring Well	K (gpd/ft2)	T (gpd)
DH-4	1345	8055
DH-7	1700	17100
DH-10	500	2190
DH-11	1350	13500
Average	1224	10211

FLOW FIELD 3 Monitoring Well	K (gpd/ft2)	T (gpd)
DH-19	305	3040
DH-20	985	9860
DH-21	132	1190
DH-22	434	3470
DH-26	750	6385
DH-27	420	4230
DH-28	795	5590
DH-29	500	4200
Average	540	4746

FLOW FIELD 4 Monitoring Well	K (gpd/ft2)	T (gpd)
DH-6	5250	52150
DH-13	1065	10630
P-1	2690	26870
P-2	1780	17795
DH-17	1890	18860
P-3	2280	22755
P-4	2150	21565
DH-8	1825	18250
DH-24	2010	11290
Average	2327	22241

FLOW FIELD 5 Monitoring Well	K (gpd/ft2)	T* (gpd)
EH-51	2160	21600
P-6	1830	18290
DH-60	2800	14870
EH-62	3820	73370
Average	2653	32033

INTERMED. WELLS Monitoring Well	K (gpd/ft2)	T (gpd)
DH-14	60	740
DH-15	67	570
EH-61	450	4525
EH-100	950	7580
EH-101	136	1360
EH-102	910	9090

* = Transmissivity calculated by multiplying the aquifer thickness by permeability K.

Flow field areas are shown on Figure 4-3-1.

Transmissivity is a function of the aquifer permeability (K) and the aquifer thickness (m).

Velocity of groundwater movement can be estimated using the following equation:

$$V = KI/p$$

Where: $K = T/m$, I is as previously defined, and p is effective porosity.

Using the above equations, the flow rates and velocities were calculated for the flow fields shown on Figure 4-3-1 and are summarized in Table 4-3-2.

Calculated groundwater flow in the main plant complex area (flow field 3) is similar to flow estimates for the area immediately northwest of the plant site (flow field 4). Although aquifer transmissivity increases north of the plant complex, the gradient is lower, resulting in a calculated flow rate that is roughly equivalent to that in the plant.

Accurate flow estimates in the shallow aquifer are more difficult in the City of East Helena area as the shallow alluvium becomes more heterogeneous and anisotropic. As Exhibit 4 shows, the average permeability values for monitoring wells and piezometers in East Helena are quite variable ranging from a low of 35 gpd/ft2 at EH-54 to a high of 2950 gpd/ft2 at P-5. Accurate flow estimates in much of East Helena are precluded by the increasing thickness and the untested permeabilities of alluvium deeper than monitoring well completion.

The high permeability value from well EH-62 (3820 gpd/ft2), in comparison with those of nearby wells EH-53 (100 gpd/ft2) and EH-54 (35 gpd/ft2) (see Exhibit 4), suggests that the majority of groundwater flow in the northern East Helena area may occur in high permeability strata that underlies some of the monitoring well locations. Well EH-62 was advanced about 10 feet deeper than wells EH-53 and EH-54 because the presence of water bearing strata could not be confirmed in shallower depths during drilling. The depth of the water bearing zone for the Flage well located

Table 4-3-2 FLOW AND VELOCITY ESTIMATES FOR SHALLOW GROUNDWATER IN THE PLANT SITE AND EAST HELENA AREAS

Flow Field 1

T * I * L = Q
222 * 0.019 * 767 = 3235 gpd
= 2.2 gpm

T = 222 gpd/ft
L = 767 ft
I = 0.019

V = KI/p = 0.9 ft/day
= 316 ft/yr

K = 3.6 ft/day
p = 0.25

Flow Field 2

T * I * L = Q
10211 * 0.01 * 988 = 100,890 gpd
= 70 gpm

T = 10211 gpd/ft
L = 988 ft
I = 0.01

V = KI/p = 6.5 ft/day
= 2,390 ft/yr

K = 164 ft/day
p = 0.25

Flow Field 3

T * I * L = Q
4746 * 0.06 * 1083 = 308,400 gpd
= 214 gpm

T = 4746 gpd/ft
L = 1083 ft
I = 0.06

V = KI/p = 17 ft/day
= 6320 ft/yr

K = 72 ft/day
p = 0.25

Flow Field 4

T * I * L = Q
22240 * 0.009 * 1388 = 277,822 gpd
= 193 gpm

T = 22240 gpd/ft
L = 1388 ft
I = 0.009

V = KI/p = 11 ft/day
= 4090 ft/yr

K = 311 ft/day
p = 0.25

Flow Field 5

T * I * L = Q
32033 * 0.01 * 1200 = 384,396 gpd
= 266 gpm

T = 32033 gpd/ft
L = 1200 ft
I = 0.01

V = KI/p = 14 ft/day
= 5180 ft/yr

K = 355 ft/day
p = 0.25

Note: Flow field areas are shown on Figure 4-3-1.

near EH-54 (see Exhibit 1) is an estimated 12-15 feet below the bottom of EH-54, which also supports the above observation.

The depth to groundwater in the study area ranges from about 6 feet to 60 feet below the ground surface. Appendix 4-8 contains hydrographs from monitoring wells located throughout the study area. Water level hydrographs for Upper Lake, Lower Lake and a variety of ponds and sumps are also in Appendix 4-8. In general, the hydrographs show minor changes in water levels throughout the period of record. Water level changes in several of the wells mirror water level fluctuations in Prickly Pear Creek. Continuous hydrograph records from six monitoring wells (DH-12, DH-13, DH-4, DH-14, EH-51, and EH-101) correlate with creek levels and show there is little lag time between groundwater and creek level fluctuation. A tabulation of water level data used to construct the hydrographs is also in Appendix 4-8.

A computer simulation of groundwater flow was used to provide additional information on the groundwater system in the study area. Groundwater flow was modeled using PLASM (Prickett-Lonnquist Aquifer Simulation Model) developed by Prickett and Lonnquist (1971). Plasm is a two dimensional finite difference model, which can be used to simulate flow in a variety of aquifer conditions. Model operational tasks, assumptions and results are described in detail in the Contaminant Fate and Transport Section, 8.0. Using assumptions that simplified actual groundwater conditions, the model provided a good approximation to field-observed responses of the groundwater system. Information from flow modeling was useful in simulating aquifer responses to various remediation scenarios explored during the feasibility study (Section 11.0).

4.4 QUALITY OF GROUNDWATER AND SUBSURFACE STRATA

To investigate hydrochemistry of the groundwater system, a total of 43 monitoring wells were completed in the study area. Monitoring wells were completed both on and off the plant site including the City of East Helena area north of the plant. During drilling of the monitoring wells, geologic strata were sampled to determine chemical and physical characteristics. A total of 41 monitoring wells (two wells were dry) were sampled for groundwater quality during several sampling campaigns from fall 1984 through spring 1988. All monitoring wells were analyzed for the inorganic parameters shown in Table 2-2-4. Based on observed evidence of organic contaminants during monitoring well drilling, the strata and groundwater of some monitoring wells were also analyzed for organic parameters (see Table 2-2-4). Additionally, 33 privately-owned wells in and outside the community of East Helena were sampled. The locations of all monitoring wells and private wells are shown in Exhibit 1. Results of all groundwater analyses are in Appendix 4-5, and results of chemical and physical analyses of stratigraphic samples are in Appendix 4-3. In addition to the data collected as part of the remedial investigation, there are water quality data for private wells obtained by Asarco in 1983 (Appendix 4-9).

4.4.1 Groundwater Quality - Inorganics

A total of 28 monitoring wells (DH-1 through DH-29) were completed within and adjacent to the plant site for groundwater quality sampling. Stratigraphic samples were collected during well drilling and from 10 additional soil core drill holes (SC-3 through SC-5, LH-1 through LH-6, and TH-2). Additional stratigraphic samples from shallow horizons (0-5 feet) were collected from 10 backhoe test pits (DH-1, DH-2, DH-3, DH-6, DH-7, DH-10, DH-11, DH-13, DH-17 and TH-1). The locations of all plant stratigraphic sampling sites are shown on Exhibit 1.

A total of 15 monitoring wells (EH-50 through EH-54, EH-57 through EH-62, and EH-100 through EH-102; see Exhibit 1) were completed for groundwater sampling in the city of East Helena north of the plant site. Stratigraphic samples were collected during well drilling and from 2 additional soil core drill holes (SC-1 and SC-2). In addition to monitoring well samples, groundwater samples were also collected from private wells in East Helena and from three private wells about 0.75 miles west of the plant site area.

4.4.1.1 Plant Site

Groundwater quality in monitoring wells in and adjacent to the plant site is highly variable in concentrations of major ions, arsenic and some metals, reflecting various impact sources from within the plant site (see Table 4-4-1). Generally, groundwater from observation wells completed in

TABLE 4-4-1. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR PLANT SITE SHALLOW AQUIFER MONITORING WELLS

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	4.5-20	11.2	2.49	94
SPEC. COND. (UMHOS/CM) FIELD	164-10537	2033	2156	126
SPEC. COND. (UMHOS/CM) LAB	161-10300	2117	2183	148
PH FIELD	4.08-11.3	6.77	1.291	97
PH LAB	3.02-11.32	7.24	1.386	148
TOTAL SUSP. SOLIDS	<1-5540	465.0	921.44	45
TDS MEAS. @ 180 DEG. C	125-8490	1636	1739.8	148
OXYGEN (O) DISS	0.35-9.1	2.79	1.93	94
DEPTH TO SWL BELOW MP (FT)	6.15-61.34	23.28	11.57	96
COMMON IONS				
CALCIUM (CA)	4-482	98.6	80.9	109
MAGNESIUM (MG)	0.1-160	27.8	27.2	109
SODIUM (NA)	6-2580	421.2	596.6	109
POTASSIUM (K)	1.13-122	24.7	22.4	109
ALKALINITY AS CACO3 (LAB)	51.8-2500	374.8	593.0	27
BICARBONATE (HCO3) (LAB)	<1-1135	208.7	163.0	120
CARBONATE AS CO3 (LAB)	<1-2064	74.0	307.1	87
HYDROXIDE (OH)	24	24.0	0.0	1
SULFATE (SO4)	<2-4150	594.8	761.7	121
CHLORIDE (CL)	<1-575	96.8	128.0	109
TRACE ELEMENTS				
ARSENIC (AS) DISS	<0.004-750	46.039	106.0	150
ARSENIC (AS) +3	<0.008-468	61.9404	94.3	87
ARSENIC (AS) +5	0.008-492	17.480	73.9	77
CADMIUM (CD) DISS	<0.001-7.55	0.3806	1.3	149
COPPER (CU) DISS	<0.008-0.065	0.011	0.011	86
IRON (FE) DISS	<0.02-62.3	9.015	16.276	120
IRON (FE II)	<0.01-87.5	15.351	25.516	92
LEAD (PB) DISS	<0.001-0.102	0.012	0.020	153
MANGANESE (MN) DISS	<0.003-36.8	4.931	7.483	86
ZINC (ZN) DISS	<0.008-48.1	3.864	9.632	149

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS. IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WASD USED FOR THE MEAN.

the shallow alluvial aquifer within or immediately north and northwest of the plant site have elevated levels of arsenic and some major ions, including sulfate, chloride, sodium and total dissolved solids (TDS) (see Table 4-4-2). Of the metals examined in this remedial investigation, arsenic is the most mobile in the groundwater system. Concentrations of major ions in groundwater are shown by Stiff diagrams on Exhibit 5. Groundwater from monitoring wells within the plant site are alkaline, sodium-sulfate types with high concentrations of TDS, sodium and arsenic.

On the plant site, groundwater from intermediate monitoring wells (DH-14 and DH-15, Table 4-4-3) is of similar quality to groundwater from shallow unit monitoring wells, but is significantly lower in arsenic and metals. However, similar to shallow wells within the plant site, these intermediate wells have elevated concentrations of sulfate, TDS and chloride.

Groundwater from monitoring wells south (upgradient) and east of the plant site (DH-2, DH-3, DH-7 and DH-11, Table 4-4-4) are apparently unaffected by potential contaminant sources and reflect ambient water quality of the Helena Valley area. Waters from these wells are very hard, alkaline, calcium-bicarbonate types with low to moderate concentrations of TDS, arsenic and metals.

A contour map of arsenic concentrations (Exhibit 6) in the shallow groundwater system shows a distinct relatively high concentration arsenic plume that extends from the plant site to the northwest, in the same general direction of shallow groundwater flow. This arsenic plume is bounded to the west by an unsaturated ridge of low permeability ash/clay (see geological cross-sections -- Exhibit 3B and Figure 4-1-1). The major sources of arsenic in groundwater appear to be the speiss granulating pond and pit. The acid plant water treatment facility and its associated sediment drying area also contribute arsenic to a lesser extent. This multi-source concentration plume with higher arsenic concentrations is superimposed over a relatively lower concentration plume that is apparently associated with Lower Lake. The lower concentration arsenic plume also extends to the north and northwest, in the general direction of groundwater flow. Exhibit 6 shows arsenic in groundwater from Lower

TABLE 4-4-2. TYPICAL GROUNDWATER QUALITY IN PLANT SITE SHALLOW UNIT WELLS

SITE NAME	DH-21	DH-19	DH-22	DH-13	DH-12	DH-4	DH-10
SAMPLE DATE	11/30/87	11/30/87	11/23/87	11/25/87	11/25/87	11/19/87	11/19/87
LAB	ASARCO	ASARCO	ASARCO	ASARCO	ASARCO	ASARCO	ASARCO
SAMPLE NUMBER	8711-236	8711-234	8711-237	8711-228	8711-227	8711-219	8711-225
PHYSICAL PARAMETERS							
WATER TEMPERATURE (C)	16	10.2	12.5	10.4	10.4	10.6	10.5
SPEC. COND. (UMHOS/CM) FIELD	10537	1893	1213	4389	5092	602.5	506.6
SPEC. COND. (UMHOS/CM) LAB	10000	2030	1270	4210	4880	680	550
PH FIELD	11.2	4.7	5.62	6.61	6.77	6.69	6.60
PH LAB	10.96	3.12	6.95	7.05	7.23	8.12	8.24
TOTAL SUSP. SOLIDS	17.3	51		38.7	8.0	44.5	<1.0
TDS MEAS. @ 180 DEG. C	8490	1760	900	3678	4234	461	345.2
OXYGEN (O) DISS	1.3	2.5	1.1	1.6	2.2	1.40	1.8
DEPTH TO SWL BELOW MP (FT)	22.83	16.05	26.76	29.60	30.00	11.53	8.00
COMMON IONS							
CALCIUM (CA)	9.0	94	72	63	56	40	26.5
MAGNESIUM (MG)	1.9	34	27.8	22	19.1	7.0	3.8
SODIUM (NA)	2500	138	122	860	1030	74.5	49.1
POTASSIUM (K)	28.5	28.3	10.3	34.4	32	5.4	47.8
ALKALINITY AS CACO3 (LAB)	2500						
BICARBONATE (HCO3) (LAB)	37	<1.0	55	281	167	210	140
CARBONATE AS CO3 (LAB)	1482	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
SULFATE (SO4)	3100	920	490	1930	2130	73	95
CHLORIDE (CL)	568	64	62	160	174	24	4.9
TRACE ELEMENTS							
ARSENIC (AS) DISS	750	99.0	8.0	185	198	4.38	5.25
ARSENIC (AS) +3	432.000	96.000	<0.008	160.000	206.400	4.000	0.560
ARSENIC (AS) +5	360.000	1.100	7.520	4.000	1.680	0.460	4.680
CADMIUM (CD) DISS	0.010	7.38	3.75	0.003	0.003	0.003	0.001
COPPER (CU) DISS	0.065	<0.008	0.025	<0.008	<0.008	<0.008	<0.008
IRON (FE) DISS	0.570	40.1	0.026	8.75	1.56	11.5	0.069
IRON (FE II)	0.30	59.8	0.04	17.2	2.25	16.8	0.04
LEAD (PB) DISS	0.075	0.096	<0.005	<0.005	<0.005	<0.005	<0.005
MANGANESE (MN) DISS	0.028	7.55	9.0	3.76	2.93	4.66	1.58
ZINC (ZN) DISS	0.018	34.0	2.20	6.28	0.850	<0.008	0.024

All quantities in milligrams per liter unless otherwise noted. Blank line indicates parameter not tested.

Output Date: 03-05-1989
HWQ-6/86-R1

ABLE 4-4-3. TYPICAL GROUNDWATER QUALITY IN EAST HELENA INTERMEDIATE UNIT SITE WELLS

SITE NAME	DH-14	DH-15	EH-61	EH-100	EH-101	EH-102
SAMPLE DATE	11/19/87	11/19/87	12/02/87	11/17/87	11/16/87	11/16/87
LAB	ASARCO	ASARCO	ASARCO	ASARCO	ASARCO	ASARCO
SAMPLE NUMBER	8711-229	8711-230	8711-246	8711-206	8711-207	8711-208
PHYSICAL PARAMETERS						
WATER TEMPERATURE (C)	10.1	12.0	10.6	10.6	10.2	10.2
SPEC. COND. (UMHOS/CM) FIELD	420.9	1125	1498	2390	1187	570.5
SPEC. COND. (UMHOS/CM) LAB	426	1190	1360	2280	1150	590
PH FIELD	5.95	6.56	6.71	5.36	4.92	6.14
PH LAB	7.89	8.30	7.88	7.88	7.84	7.90
TOTAL SUSP. SOLIDS	30.4	28.8	448	17.5	30	29
TDS MEAS. @ 180 DEG. C	252	836	1183	1996	865	387
OXYGEN (O) DISS	1.2	1.4	1.2	1.6	2.0	1.8
DEPTH TO SWL BELOW MP (FT)	9.77	14.51	22.90	26.02	14.43	8.79
COMMON IONS						
CALCIUM (CA)	60	144	182.5			
MAGNESIUM (MG)	12.6	34.5	40			
SODIUM (NA)	16.2	48.5	95			
POTASSIUM (K)	5.0	7.1	13.5			
BICARBONATE (HCO3) (LAB)	256	171	211	165	192	139
CARBONATE AS CO3 (LAB)	<1.0	<1.0	<1.0			
SULFATE (SO4)	7.0	490	560	1030	430	153
CHLORIDE (CL)	8.3	35	60			
TRACE ELEMENTS						
ARSENIC (AS) DISS	<0.006	0.043	0.021	0.020	0.006	<0.006
ARSENIC (AS) +3	<0.008	0.014	0.012	<0.008	<0.008	0.009
ARSENIC (AS) +5	0.029	0.035	0.031	0.008	0.009	<0.008
CADMIUM (CD) DISS	0.001	<0.001	0.005	0.001	0.001	0.001
COPPER (CU) DISS	<0.008	<0.008	0.008	0.013	<0.008	<0.008
IRON (FE) DISS	0.455	0.850	0.043	0.183	0.029	<0.020
IRON (FE II)	0.56	1.20	<0.01	<0.01		<0.01
LEAD (PB) DISS	<0.005	0.0066	<0.005	<0.0125	<0.005	<0.005
MANGANESE (MN) DISS	0.396	0.401	5.26	3.940	0.005	0.023
ZINC (ZN) DISS	<0.008	<0.008	0.030	0.078	<0.008	<0.008

All quantities in milligrams per liter unless otherwise noted. Blank line indicates parameter not tested. Output Date: 03-12-1989

ABLE 4-4-4. TYPICAL GROUNDWATER QUALITY IN SHALLOW UNIT WELLS SOUTH, EAST, AND WEST OF PLANT SITE

SITE NAME	DH-2	DH-3	DH-7	DH-11
<u>SAMPLE DATE</u>	<u>11/24/87</u>	<u>11/19/87</u>	<u>11/20/87</u>	<u>11/19/87</u>
LAB	ASARCO	ASARCO	ASARCO	ASARCO
SAMPLE NUMBER	8711-217	8711-218	8711-222	8711-226
<u>PHYSICAL PARAMETERS</u>				
WATER TEMPERATURE (C)	9.0	8.6	10.1	10.3
SPEC. COND. (UMHOS/CM) FIELD	577.6	462.2	307.5	359.6
SPEC. COND. (UMHOS/CM) LAB	610	482	305	382
PH FIELD	6.60	6.23	6.76	6.65
PH LAB	8.31	8.15	8.31	8.40
TOTAL SUSP. SOLIDS	13.2	<1.0	2.0	4.8
TDS MEAS. @ 180 DEG. C	410.8	314	197.2	240
OXYGEN (O) DISS	4.1	2.7	2.1	2.2
DEPTH TO SWL BELOW MP (FT)	59.52	31.11	20.12	16.40
<u>COMMON IONS</u>				
CALCIUM (CA)	70	54	31	36.3
MAGNESIUM (MG)	17	12.7	7.6	11.3
SODIUM (NA)	24.1	22.6	13.5	14.9
POTASSIUM (K)	6.8	5.9	4.1	2.5
ALKALINITY AS CACO3 (LAB)	225			126
BICARBONATE (HCO3) (LAB)	255	183	143	137
CARBONATE AS CO3 (LAB)	9.6	<1.0	<1.0	8.4
SULFATE (SO4)	61	75	46	16
CHLORIDE (CL)	15	10	2.7	3.0
<u>TRACE ELEMENTS</u>				
ARSENIC (AS) DISS	0.009	0.014	<0.006	0.006
ARSENIC (AS) +3	<0.008	<0.008	<0.008	<0.008
ARSENIC (AS) +5	0.073	0.033	0.031	0.009
CADMIUM (CD) DISS	0.001	0.001	0.001	0.001
COPPER (CU) DISS	<0.008	<0.008	<0.008	<0.008
IRON (FE) DISS	0.026	0.028	<0.020	0.025
IRON (FE II)	<0.01	<0.01	<0.01	<0.01
LEAD (PB) DISS	<0.005	<0.005	<0.005	<0.005
MANGANESE (MN) DISS	0.008	0.005	0.110	0.026
ZINC (ZN) DISS	0.018	<0.008	0.010	<0.008

Lake probably impacts Prickly Pear Creek immediately northeast of the pond. Analytical results of surface water quality samples show a slight but measurable increase in creek water arsenic concentration at the sampling station (PPC-5) nearest Lower Lake (see Surface Water Quality, Section 5.2.2).

To better understand the distribution of other diagnostic parameters in the study area groundwater system, the concentration of sulfate, chloride, total dissolved solids, and cadmium were plotted on maps and contoured. Sulfate is a major constituent in plant process waters (see Section 3.2.2). It is also formed by the dissolution of sulfate minerals and oxidation of sulfide minerals in ores and ore concentrates used in the smelting process. Exhibits 7 and 8 show the distribution of sulfate in the plant area. These exhibits show the highest concentration of sulfate is within the plant site in the vicinity of well DH-21, near the speiss granulation pond. Elevated but somewhat lower sulfate concentrations appear to be associated with Lower Lake and the acid plant water treatment facility. The sulfate pattern is generally oriented to the northwest direction and parallels the arsenic plume and groundwater flow. Monitoring wells east of Prickly Pear Creek (DH-11 and DH-7) and those upgradient of the plant site (DH-2 and DH-3) have low concentrations of sulfate and arsenic. However, groundwater from wells DH-1 and DH-8 have elevated concentrations of sulfate, but relatively low concentrations of arsenic, a situation similar to that observed for intermediate monitoring wells DH-14 and DH-15.

Contour maps for chloride and TDS (Exhibit 8) are very similar to the sulfate contour map and generally show a close relationship between sulfate and these parameters. However, chloride appears to be anomalously high in well DH-8 compared to sulfate and TDS. Well DH-8 is located in the ore storage area. The anomalously high chloride concentration in this well is probably associated with the leaching of ore minerals and subsequent percolation into the groundwater. Because the shallow groundwater near DH-8 is overlain by fine grained materials (see Exhibit 3), downward migration of arsenic appears to be inhibited. A complete discussion of arsenic migration mechanisms is included in the Contaminant Fate and Transport Section 8.0.

Of the metal parameters other than arsenic, only cadmium concentrations were high enough to contour in the plant site area. The concentration of other metals, including dissolved copper, lead, and zinc were very low in the plant site area. The highest concentrations of cadmium are in groundwater from wells DH-19, DH-22, and DH-26. These elevated cadmium concentrations seem to be associated with the acid plant/sinter plant facilities and probably reflect process fluid losses associated with the acid plant water treatment facility.

Graphical plots of temporal variations for selected parameters are shown in Appendix 4-10. The plots for monitoring wells DH-4 and DH-6 show that the trend for arsenic and sulfate concentrations are generally downward from 1985 through 1989 and reflect the effects of improved water quality in Lower Lake; the primary source of arsenic and sulfate in these wells. The trend of other parameters in these wells indicates little significant changes.

The graphical plot of concentration fluctuations for well DH-13 shows a seasonal increase and decrease of most parameters. A comparison of the concentration plots with the water table hydrographs for DH-13 (Appendix 4-8) show the concentration trends at this well are the inverse of water table elevation trends; parameter concentration rises during periods of declining water table, and declines during rising water table periods. The improved water quality (lower concentrations of most parameters) during rising water table periods reflect the influence of upgradient recharge.

Temporal concentrations for downgradient well DH-24 showed only small fluctuations with no obvious pattern.

4.4.1.2 <u>Off Plant Site</u>

Groundwater quality from monitoring wells in the East Helena area is highly variable in concentrations of major ions and arsenic (see Tables 4-4-5 and 4-4-6), reflecting the northwest movement of elevated constituents from the plant area.. Groundwater from private wells also shows a large variability in groundwater quality. Concentrations of major ions in groundwater are shown by Stiff diagrams on Exhibit 5.

TABLE 4-4-5. STATISTICAL SUMMARY OF WATER QUALITY ANALYSES EAST HELENA SHALLOW AQUIFER WELLS

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	3.5-15	10.1	2.37	46
SPEC. COND. (UMHOS/CM) FIELD	239.2-2284	1074	662	36
SPEC. COND. (UMHOS/CM) LAB	235-2300	1037	729	49
PH FIELD	5.63-7.8	6.64	0.420	48
PH LAB	6.54-8.08	7.36	0.403	49
TOTAL SUSP. SOLIDS	4.4-72.5	20.7	21.89	10
TDS MEAS. @ 180 DEG. C	147-1963	833	641.6	49
OXYGEN (O) DISS	1.2-8.4	4.27	1.79	48
DEPTH TO SWL BELOW MP (FT)	3.58-39.47	17.25	8.98	47
COMMON IONS				
CALCIUM (CA)	26-376	128.7	103.7	41
MAGNESIUM (MG)	5.9-100.5	32.1	29.4	41
SODIUM (NA)	10.5-197	71.6	58.5	41
POTASSIUM (K)	2.4-37	11.6	9.1	41
BICARBONATE (HCO3) (LAB)	82-303	172.4	63.8	48
CARBONATE AS CO3 (LAB)	<1	<1	0	41
SULFATE (SO4)	31-1021	376.8	341.7	49
CHLORIDE (CL)	2-450	49.1	78.5	41
TRACE ELEMENTS				
ARSENIC (AS) DISS	<0.004-1.63	0.294	0.504	49
ARSENIC (AS) +3	<0.008-1.4	0.105	0.307	46
ARSENIC (AS) +5	<0.008-1.83	0.247	0.514	46
CADMIUM (CD) DISS	<0.001-0.014	0.0017	0.0025	48
COPPER (CU) DISS	<0.008-0.018	0.006	0.004	38
IRON (FE) DISS	<0.02-0.62	0.020	0.014	48
IRON (FE II)	<0.001-0.08	0.012	0.021	46
LEAD (PB) DISS	<0.005-0.026	0.005	0.005	47
MANGANESE (MN) DISS	0.003-43	1.184	6.968	38
ZINC (ZN) DISS	<0.008-0.25	0.017	0.038	48

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
R VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.

Generally, monitoring wells immediately northwest of the plant site area and west of Prickly Pear Creek (EH-50, EH-51, EH-52, and EH-60) are calcium or sodium-sulfate type waters and have elevated concentrations of sulfate, chloride and TDS. Groundwater from monitoring wells EH-51, EH-52 and EH-60 also has moderately elevated concentrations of arsenic.

Groundwater from wells east of Prickly Pear Creek are hard alkaline, calcium-bicarbonate type waters with low concentrations of TDS and sulfate. One well west of the creek (EH-52) has moderately elevated concentrations of arsenic.

With the exception of arsenic concentrations, results from intermediate unit monitoring wells are generally similar to the groundwater from adjacent shallow unit monitoring wells. However, elevated arsenic concentrations observed in shallow wells EH-51, EH-52 and EH-60 were not found in adjacent intermediate unit monitoring wells (EH-101, EH-102, EH-61, respectively). Arsenic concentrations in the East Helena intermediate monitoring wells were generally near or below analytical detection limits.

The quality of groundwater from private wells is also variable. As shown on Table 4-4-7 and Exhibit 5, private well groundwater generally ranges from a very hard, alkaline, calcium-sulfate type along the west edge of East Helena, to a hard, alkaline, calcium-bicarbonate type eastward nearer Prickly Pear Creek. Iron and manganese from some of the private wells exceed Primary Federal Drinking Water Standards, Maximum Contaminant Levels (MCLs) (Table 4-4-8). One well (St. Claire) had arsenic concentrations slightly above MCLs.

The groundwater quality from three private wells about 3/4 of a mile west of the plant site (D. Hulst, K. Hulst and L. Hulst) had detectable concentrations of arsenic, but values were generally below MCLs. As Table 4-4-8 and Exhibit 5 show, the groundwater quality of these wells is generally very good with low concentrations of sulfate, TDS and metals.

Contour maps of arsenic concentrations (Exhibit 6 and Exhibit 8) show the arsenic plume within the plant site area extends north into the City of East Helena where arsenic concentrations become significantly lower, with

TABLE 4-4-8

FEDERAL DRINKING WATER STANDARDS FOR PUBLIC WATER SUPPLIES

Parameter

Primary Standards(1)	Maximum Contaminant Levels for Inorganic Chemicals (mg/l)
Arsenic	0.05
Barium	1.
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate as N	10.
Selenium	0.01
Silver	0.05
Fluoride	1.4 - 2.4(2)

Secondary Standards(3)	Recommended Maximum Contaminant Levels (mg/l)
Chloride	250
Color	15 (color units)
Copper	1.0
Corrosivity	Non-corrosive
Iron	0.3
Manganese	0.05
Odor	Threshold odor number of 3
pH	6.5 - 8.5 Standard Units
Sulfate	250
Zinc	5.0
Total Dissolved Solids	500
Foaming agents	0.5

(1) 40 CFR Part 141 (Federal Register, Vol. 40, No. 248, December 24, 1975) and (Administrative Rules of Montana) ARM 16-2.14(10)-S14381.

(2) Maximum allowable concentration depends on annual average of maximum daily air temperatures at site of supply.

(3) 40 CFR Part 143 (Federal Register, Vol. 44, No. 140, July 19, 1979).

the highest arsenic values of about 1.6 mg/l recorded for wells EH-60 and EH-52. Monitoring well EH-60 is located immediately downgradient from the relatively high arsenic concentration plume, in the plant site area. The significantly lower arsenic concentration of well EH-60 indicates that the migration of arsenic is significantly attenuated in the City of East Helena.

Plume contour maps of other diagnostic parameters (Exhibits 7, 8, and 9) including arsenic species (As III and As V), sulfate, chloride, TDS, and cadmium show elevated concentrations of these parameters in East Helena northwest of the plant. Groundwater from several monitoring wells and private wells in East Helena have elevated concentrations of sulfate and TDS.

Table 4-4-9 summarizes available information on well depth, perforated or open casing intervals, and water quality of private wells and nearby monitoring wells in the East Helena area. Table 4-4-9 shows the private wells with high sulfate and TDS concentrations are generally completed in intermediate strata that underly the most shallow saturation zone but overly the volcanic ash/clay unit.

The distribution of groundwater with high concentrations of sulfate and TDS is restricted both laterally and vertically. The lateral distribution of sulfate in groundwater in East Helena private wells and monitoring wells is restricted to the west edge of the community down-gradient of plant site sources. Groundwater from monitoring wells and private wells east of the wells on the west edge of the community have much lower sulfate and TDS concentrations, and are of a quality similar to Prickly Pear Creek. Deep wells, which are completed in strata that underly the fine grained ash/clay unit (Jensen A2 and AM Chemet 2) have good quality calcium-bicarbonate type waters.

Of the metal parameters, only cadmium in one East Helena monitoring well (DH-60) is considered elevated (see Exhibit 7). The concentrations of other metal parameters in East Helena monitoring well groundwater were very low.

TABLE 4-4-9. EAST HELENA MONITORING AND PRIVATE WELL WATER QUALITY AND WELL COMPLETION COMPARISONS

Well Owner	Well Depth (ft)	Open Interval (ft)	Perforation Elevation[1] (MSL)	General Quality	Water[2] Type
AM Chemet 2	162	100 - 162	3796 - 3734	$CaHCO_3$	(L)
AM Chemet 3	140	31-33/45-50 65-70/91-140	3860 - 3858 3846 - 3841 3826 - 3821	$CaSO_4$	(H)
EH-53	35	25 - 35	3844 - 3834	$CaSO_4$[1]	(H)
Hoff	37	Open End	3834	$CaSO_4$	(H)
Manion	80	Open End	3788	$CaSO_4$	(H)
Jensen A-1	82	Open End	3789	$CaSO_4$	(H)[3]
Jensen A-2	160	120 - 160	3751	$CaSO_4$	(L)
EH-60	29	22 - 28	3862.5 - 3856.5	$CaSO_4$	(H)
Ernst	75	Open End		$CaSO_4$	(L)
Berry		60 - 65		$CaSO_4$	(L)
Vetch	76	Open End		$CaSO_4$	(L)
Romasko	61	Open End	3810	$CaSO_4$	(M)
Weston	54	Open End		$CaSO_4$	(L)
Lamping, R.	41	Open End	3824	$CaSO_4$-HCO_3	(L)
Nordstrom	46	Open End		$CaSO_4$	(L)
Wojcik	N/A	N/A		$CaHCO_3$	(L)
Flage	31	Open End		$CaHCO_3$	(L)
Walter	41	Open End		$CaHCO_3$	(L)
Duel	43	32 - 43	3836 - 3825	$CaHCO_3$	(L)
Burnham	119	Open End		$CaHCO_3$	(L)
Helfort	180	Open End		$CaHCO_3$	(L)
D. Hulst	137	100 - 137		$CaHCO_3$	(L)
K. Hulst	N/A			$CaHCO_3$	(L)
L. Hulst	170	110 - 170		$CaHCO_3$	(L)
Lamping, C.	110	Open End		$CaSO_4$	(M)
Lamping, F.	46	Open End		$CaHCO_3$	(L)

NOTES: (1) Elevation included at surveyed wells.

(2) $CaHCO_3$ = Calcium-Bicarbonate Type Water
$CaSO_4$ = Calcium-Sulfate Type Water
$CaSO_4$-HCO_3 = Calcium-Sulfate-Bicarbonate Type Water
L = Low Concentrations of Dissolved Solids <500 mg/l
M = Moderate Concentrations of Dissolved Solids <1000 mg/l
H = High Concentrations of Dissolved Solids >1000 mg/l

(3) The Jensen A-1 well was not sampled but the groundwater quality is reported to be similar to the Manion well.

Graphical plots of concentrations for selected parameters at EH-51 and EH-52 (Appendix 4-10) show seasonal increases and decreases for most parameters. Concentrations for most parameters are generally lowest in late winter and spring and highest in late summer and fall. The fluctuation of arsenic concentration in groundwater from well EH-52 is particularly large, with high values near 1 mg/l and low values near 0.1 mg/l. Examination of the potentiometric surface in the East Helena area (Exhibit 4 and Exhibit 9), in addition to the water quality fluctuations, suggest arsenic concentrations in well EH-52 are significantly influenced by recharge from Prickly Pear Creek. A complete discussion of chemical interaction of various parameters, fate and transport of contaminants in the groundwater system is in Section 8.

4.4.2 Groundwater Quality - Organic Constituents

Groundwater in some plant site monitoring wells, particularly DH-12, DH-16, DH-17, DH-21, DH-27, DH-28, and DH-26, and offsite wells EH-60 and EH-61, showed evidence of containing organic constituents. Organic analyses of groundwater and strata from these wells included complete scans for priority volatile (EPA-624 or 8240) and semi-volatile organic (EPA-625 or 8270) pollutants, fuel identification scans (GC-FID) and total organic content analyses (oil and grease, or total petroleum hydrocarbons (TPH)).

Laboratory analytical results for organic parameters in groundwater are in Appendix 4-5. Most of the parameters analyzed were below analytical instrument detection limits. The parameters and concentrations that were detected are summarized on Table 4-4-10. Although the presence of organic compounds in groundwater was evident in the field, few compounds were detected using standard EPA methods. All groundwater samples submitted for organic parameter analysis contained concentrations of total hydrocarbons (oil and grease, or TPH). Of the analyses conducted, no volatile organic parameters were detected and only low concentrations of four semi-volatile base/neutral and acids compounds were detected.

The four semi-volatile compounds detected include chrysene, phenol, fluorine and bis(2-ethylhexyl) phthalate. Of these compounds, the source of bis(2-ethylhexyl) phthalate is probably from laboratory contamination (Barbara Gleason, Laucks Laboratory, personal communication). Bis(2-

TABLE 4-4-10. ANALYTICAL RESULTS FOR ORGANIC PARAMETERS ABOVE DETECTABLE LIMITS: GROUNDWATER AND DRILL HOLE SOILS

SITE	LAB	SAMPLE #	SAMPLE METHOD	OIL & GREASE or TPH (mg/l)	DETECTED VOLATILE OR SEMI-VOLATILE ORGANIC PARAMETERS (ug/l)	COMPOUND TENTATIVELY IDENTIFIED BY NON-STANDARD ANALYTICAL PROCESS (ug/L)	GC/FID (mg/Kg)
DH-2	LKS	AEH 8711-217	B	0.1			
DH-3	LKS	AEH 8711-218	B	1.2			
	ATI	AEH 8812-123	BP	0.1			
DH-6	LKS	AEH 8711-221	B	0.7			
DH-12	LKS	AEH 8706-12	B	5			
	LKS	AEH 8708-01	B	4.6			
DH-13	LKS	AEH 8708-71	B	2			
	ATI	AEH 8812-132E	BP			Benzo (b) Thiophene 30 Dihydrobenzo (b) Thiophene 10 Branched Napthalene 8 & 10 Dibenzothiophene 9	
DH-17	LKS	AEH 8708-05	B	32			
	ATI	AEH 8804-316	BP	0.13	Phenol 26	Benzo (b) Thiophene 30 Dihydrodimethyl Indene 10 Dihydrobenzo (b) Thiophene 9 Branched Napthalene 4 Ethylmethyl Benzo (b) Thiophene 5 Dibenzothiophene 5	
	ATI	AEH 8812-135D	BP	4.7			
DH-20	LKS	AEH 8711-235	B	1.3			
DH-21	LKS	AEH 8706-101	B	19			
	LKS	AEH 8708-51	B	1.4			
REPLICATE	LKS	AEH 8708-09	B	3.9			
	LKS	AEH 8711-236	B	20	Flourene 9 Bis (2 Ethylhexyl) Phthalate 46		
DH-24	LKS	AEH 8711-239	B	0.7			
	ATI	AEH 8804-323	BP	0.13			
	ATI	AEH 8812-142	BP	0.05			

NOTE: B - Bailer
BP- Bladder Pump

TABLE 4-4-10 cont.: ANALYTICAL RESULTS FOR ORGANIC PARAMETERS ABOVE DETECTABLE LIMITS: GROUNDWATER AND DRILL HOLE SOILS

SITE	LAB	SAMPLE #	SAMPLE METHOD	OIL & GREASE or TPH (mg/l)	DETECTED VOLATILE OR SEMI-VOLATILE ORGANIC PARAMETERS (ug/l)	COMPOUND TENTATIVELY IDENTIFIED BY NON-STANDARD ANALYTICAL PROCESS (ug/L)	GC/FID (mg/Kg)
DH-26	LKS	AEH 8706-100	B	22			
	LKS	AEH 8708-13	B	13			
REPLICATE	LKS	AEH 8708-49	B	15			
DH-27	LKS	AEH 8706-22	B	9			
	LKS	AEH 8708-14	B	6.9			
	LKS	AEH 8711-242	B	2.1	Bis (2 Ethylhexyl) Phthalate 5		
EH-51	LKS	AEH 8711-201	B	0.4			
EH-52	LKS	AEH 8711-202	B	0.4			
EH-54	LKS	AEH 8711-204	B	1.2			
EH-60	LKS	AEH 8711-245	B	60			
	ATI	AEH 8804-350	BP	0.08			
	ATI	AEH 8812-169D	BP	0.07			
	ATI	AEH 8904-240	BP	0.17			
EH-61	LKS	AEH 8711-246	B	110			
	ATI	AEH 8804-351	BP		Chrysene trace	Iodocyclohexane 10	
EH-62	ATI	AEH 8812-171E	BP	0.23			
Reagent Blank	ATI					Oxygenated Hydrocarbon C14 20 & 10	

NOTE: B - Bailer
BP - Bladder Pump

TABLE 4-4-10 cont: ANALYTICAL RESULTS FOR ORGANIC PARAMETERS ABOVE DETECTABLE LIMITS: GROUNDWATER AND DRILL HOLE SOILS

SAMPLE #	LAB	SAMPLE INTERVAL (FT.)	OIL & GREASE or TPH (mg/kg)	GC/FID (mg/kg)	DETECTED VOLATILE OR SEMI-VOLATILE ORGANIC PARAMETERS (ug/kg)
DH-13-4	LKS	25-25.5	350		
DH-26-0	LKS				Methylene Chloride trace
DH-27-6	LKS	15-16			Phenanthrene 490
DH-28-C	LKS	22-25		Diesel 9,400 Bunker C 1,700	
P-2-1	LKS	25-30		Diesel 14,000 Bunker C 2,400	
P-2-2	LKS	25-30			Benzoic Acid 1,700 Phenanthrene 240 Bis (2 Ethylhexyl) Phthalate 230

ethylhexyl) phthalate is common in plastics that are used in laboratory implements and containers. Chrysene, phenol and fluorine are commonly constituents of heavier fuel oils.

Efforts to identify organic compounds found in water on the plant site were more successful on soil samples from drill holes than groundwater samples (see Table 4-4-10). Analyses of drill hole soil samples using a gas chromatagraph fuel identification procedure (GC/FID) indicated the organic contaminant in the plant site area may be a combination of diesel fuel and Bunker C fuel oil.

In an attempt to further identify the organic compounds, modified GC/MS techniques were conducted on groundwater samples collected in December 1988. The results of this analysis are summarized in Table 4-4-10 and include several long chain hydrocarbon compounds. None of these compounds are considered pollutants under the EPA priority pollutants list (volatile and semi-volatile organic parameters analyzed using EPA methods 624 and 625, respectively; see organic analytical results, Appendix 4-3).

Although additional analyses were proposed in the Comprehensive RI/FS Work Plan for the identification of the organic compound(s) in plant site groundwater, there were inadequate sample materials to conduct these analyses. This proposed testing included sulfur and nitrogen content, specific gravity, and boiling point curves to determine if the organic compound had the characteristics associated with Bunker C-type fuels. However, as discussed above, GC/FID procedures identifies Bunker C fuel as a potential component of the organic compound.

A review of historical documents and photographs indicate the source of organic contaminant on the plant site is probably a fuel oil used for oil fired sintering machines. Fuel oil was used in the East Helena Smelter sintering operations in the 1920s (Engineering and Mining Journal Press, May 30, 1925) and is apparently the only operation in the smelter to ever use fuel oil. Fuel oil for firing of the sinter machines was eventually replaced by natural gas, probably during the mid-1930s.

Although there is no current evidence of buried fuel tanks in the sinter plant area, the likely location of a fuel storage facility near the sinter plant coincides with observed subsurface organic contaminants. It is estimated by plant engineering personnel that the oil-burning sinter machine probably consumed about 400 gallons of fuel oil daily (Francis White, Asarco, personal communication, November 1988). Therefore, a large storage reservoir or tank(s) would have been required. Based on the subsurface information and the historical information available, this fuel storage facility was probably located just east of the existing sinter plant location.

Concentrations of oil and grease from groundwater in plant area wells, upgradient wells, and downgradient wells from the plant area are shown in Exhibit 7. Monitoring wells with highest concentrations include DH-21 and DH-17. Plant site monitoring wells DH-21, DH-26, DH-28, DH-12, DH-13, and DH-17 have elevated concentrations of oil and grease. However, downgradient well DH-24 has concentrations that are at background levels of upgradient wells DH-2 and DH-3. This is also consistent with observations during the drilling of DH-24 (Appendix 4); no evidence of organic staining or odors were observed during drilling. However, the elevated oil and grease concentrations near off-site wells DH-60 and DH-61, downgradient of well DH-24, suggests there may be a downgradient source of organic contaminants.

Removal of fuel storage tanks on the American Chemet property was observed during drilling of monitoring well DH-6 (fall 1984). The location of this tank was adjacent to the southeast corner of the main American Chemet building (see Exhibit 1) and is upgradient of EH-60. It is not known if the tank or its associated underground lines had leaked. However, this is a potential source of the off-plant site fuel contaminants.

Drilling logs (Appendix 4-2) and soil analyses for organic parameters (Table 4-4-10) suggest the vadose zone above the water table contains the highest amounts of organic contaminants. Seasonal water table rises probably cause the release of small amounts of organic hydrocarbons from the vadose zone into groundwater. Since most organic fuel components are lighter than water, higher dissolved phase concentrations are likely to be near the top of the water table. Table 4-4-10 compares the concentrations of oil and grease in water samples collected using a stainless steel bailer to concentrations in water samples collected using a stainless steel and Teflon bladder pump. The bladder pump collects water quality samples at depth in the well water column while the bailer samples were collected near the water column/air interface. Oil and grease, or the near equivalent TPH, are significantly higher from samples collected by bailer, and may reflect higher dissolved concentrations near the water column-air interface.

A complete discussion of organic contaminant fate and transport mechanisms is included in Section 8.0.

4.4.3 Subsurface Strata Quality

Stratigraphic samples were collected from 63 monitoring well and soil core sample drill holes in the plant site area and in the East Helena area. Strata encountered during drilling were analyzed for chemical characteristics and selected strata of some wells were analyzed for physical parameters (see Section 2.2.1). Additional selected samples were analyzed using a sequential metal leach extraction technique as described by Sondag (1981) and Chao (1984). A summary of stratigraphic sampling is in Table 2-2-1. Analytical results for stratigraphic chemical and physical characteristics are in Appendix 4-3. Sequential extraction results are summarized in Appendix 4-4.

Physical testing was conducted primarily on fine-grained alluvial materials and on stratigraphic samples from the ash/clay unit in the plant area and in East Helena (see Section 4.1). Physical testing of alluvial materials showed these strata range in texture from silts and clay (DH-4 and DH-5), to clay, silt and sand (LH-1, LH-6, SC-3 and SC-4), to clay, sand and gravel (DH-14), to coarse sand and gravel (DH-1 and DH-8). Textural analyses of the ash/clay unit showed that this material generally ranges from clay to coarse sand.

Laboratory permeability analyses were also conducted on samples of fine-grained alluvial strata (DH14-12, LH1-2345, LH6-2A345, SC3-245, SC4-23 and TH1-123; Appendix 7). Results of these analyses generally ranged from 1.2 x 10^{-6} to 7 x 10^{-6} centimeters per second (cm/sec). The exception was samples of fine grained materials from drill hole LH-6, with permeability results of 8.1 x 10^{-8} cm/sec.

Laboratory permeability analyses of samples from the ash/clay unit (DH18-23, SC-1-123, SC2-567, and SC3-10/4-9) gave results that range from 5.9 x 10^{-7} to 1.2 x 10^{-8} cm/sec. This material varied from unweathered volcanic ash (SC3-10/4-9), to ash weathered to a fine-grained clay (SC2-567).

Chemical analyses (Appendix 4-3) of stratigraphic samples showed elevated concentrations of metals, particularly arsenic and lead. Elevated concentrations are highest within the plant area (DH-4, through DH-6, DH-8 through DH-10, DH-12 through DH-29, SC-3 through SC-5, and TH-1 through TH-2). Concentrations typically are highest in the shallow strata, decrease with depth, but increase again at the saturated zone. Figures 4-4-1 and 4-4-2 (DH-28) show typical plant site area soil/depth profiles for selected parameters.

Chemical analyses of drill hole samples collected beneath Lower Lake show metals concentrations for bottom sediments and underlying strata are highest in the upper 2 to 3 feet. The upper 2 to 3 feet consists of partially suspended silt and clay that has been artificially deposited in the Lower Lake pond bottom. Chemical profiles for selected parameters (Figure 4-4-3) show metals and arsenic concentrations in strata underlying Lower Lake are higher in finer-grained silts and clays than sands, and generally decrease with depth.

Chemical analyses of stratigraphic samples from outside the plant site in East Helena show elevated metals and arsenic concentrations in the most shallow strata (0-2 feet), but at significantly lower concentrations than most plant site shallow samples. Shallow surface sampling and analyses (see Section 5.1) show these elevated concentrations are generally at depths of 0 to 4 inches and then drop to background levels. Typical chemical/depth profiles of deeper East Helena stratigraphy is shown in Figure 4-4-2 (EH-57, EH-59, EH-60-61). Shallow soil chemistry is discussed in the surface soils Section (5.1).

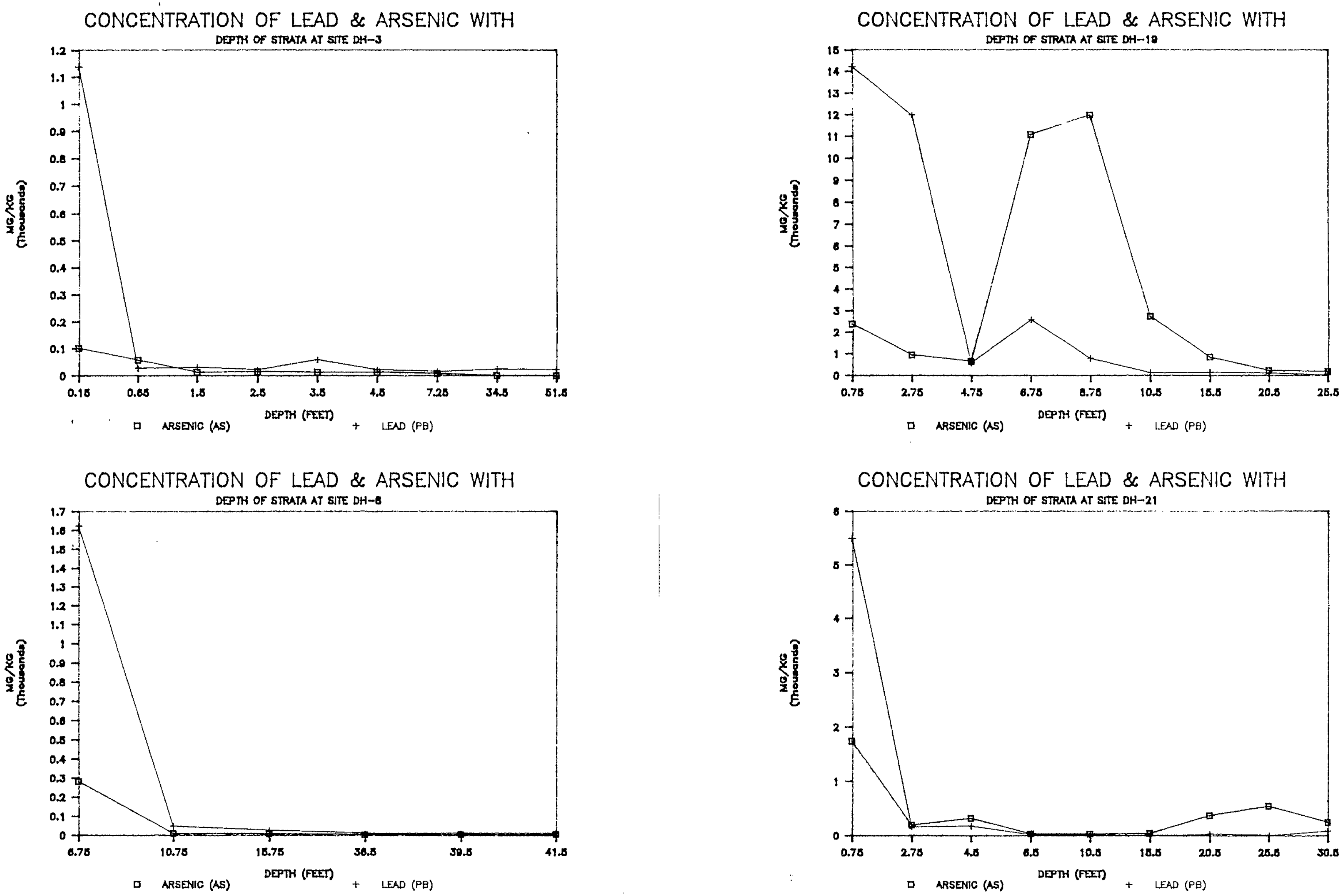


FIGURE 4-4-1. TYPICAL SOIL CHEMISTRY/DEPTH PROFILES FOR ARSENIC AND LEAD

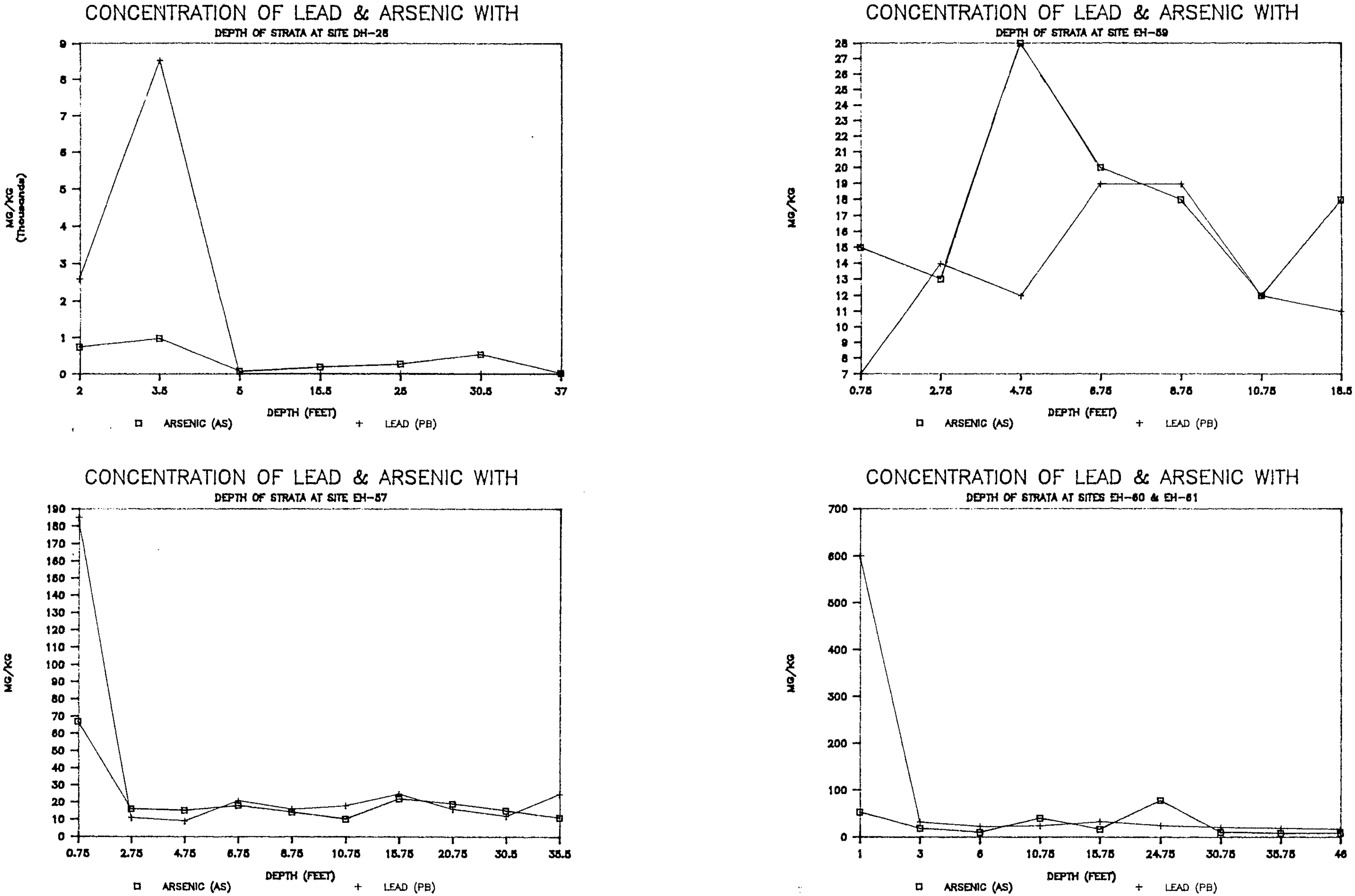


FIGURE 4-4-2. TYPICAL SOIL CHEMISTRY/DEPTH PROFILES FOR ARSENIC AND LEAD

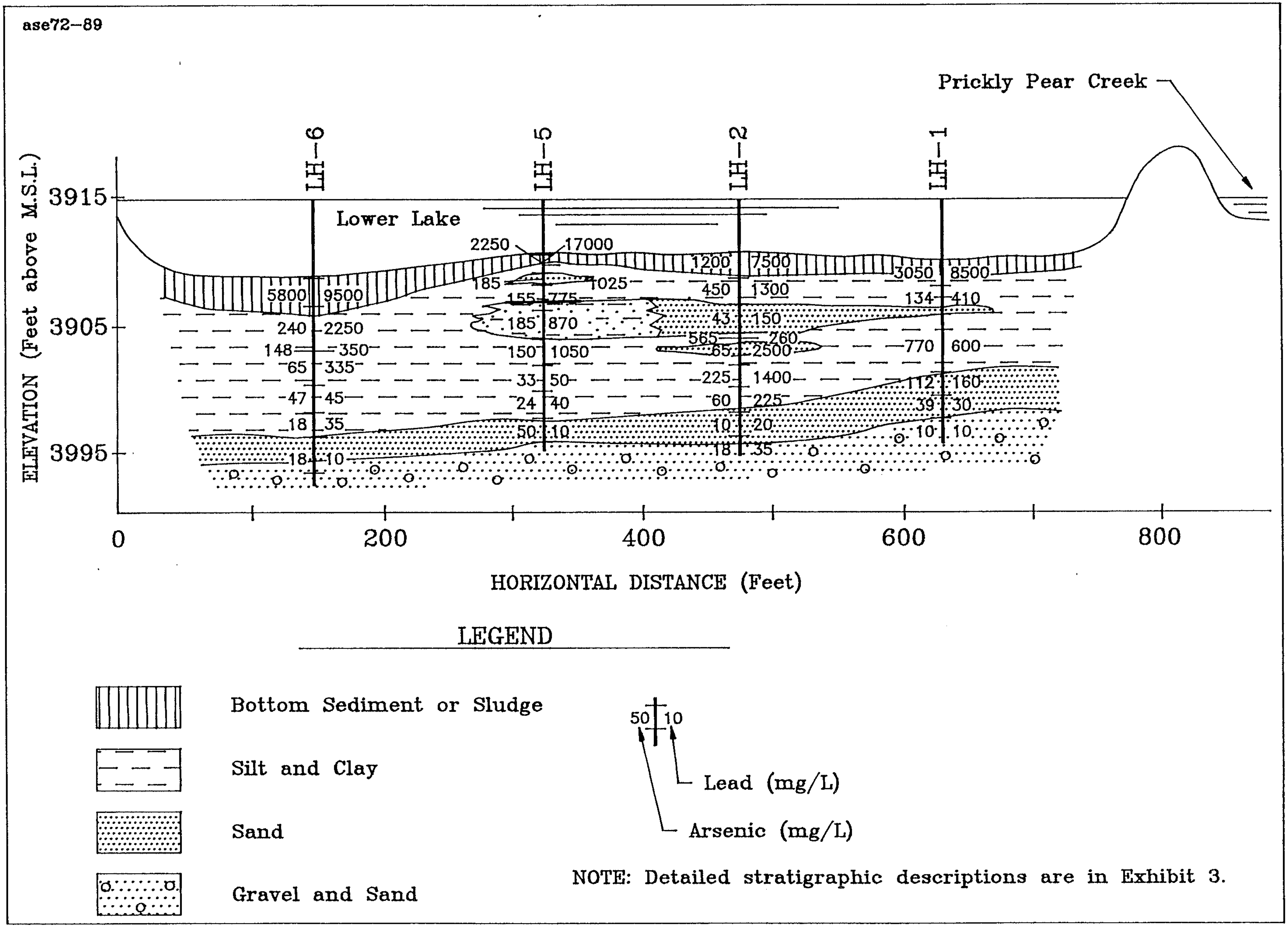


Figure 4–4–3: Chemical Profile and Stratigraphic Comparison For Lower Lake

Sequential extraction analyses (Appendix 4-4) provide information on various chemical attenuation mechanisms for arsenic and other metals. These analyses consisted of a sequential leaching of sediments to determine the materials reaction sites that may immobilize arsenic and metals within soils of the plant site area and in East Helena. The reaction sites examined included water soluble phases, ion exchange sites, manganese oxides, organic matter, amorphous iron oxides, and the residual crystalline fraction.

Based on these analyses, arsenic may be immobilized in plant and off-site sediments by a variety of chemical and physical mechanisms. Sequential extraction analyses of plant site samples (see analyses for DH-13 and DH-14, Appendix 4-4) suggest that coprecipitation with amorphous iron and manganese oxides are dominant reaction sites for arsenic. Ion exchange is also a mechanism that appears to be active in the plant site area.

Sequential extraction analyses of samples off plant site in East Helena (see analyses for EH-100 and EH-101, Appendix 4-4) show ion exchange and manganese oxide are the predominant reaction sites in soils that have relatively low concentrations of arsenic. Concentrations of arsenic in off-site samples generally were 10 to 100 times lower than plant site samples.

The sequential extraction analyses provided information on the chemical reaction sites associated with other metal parameters. Cadmium and lead, for example, are metals that do not appear to be mobile in the shallow groundwater system. The extraction analyses show that various reaction sites for cadmium and lead are at work at different sample depth intervals and locations.

In addition to the sequential extraction analyses, additional leach tests using standard EP toxicity tests were conducted on stratigraphic samples in the plant site area. Results of EP toxicity tests are also in Appendix 4-4. The EP toxicity test is commonly used as a standard analytical method to determine the potential to leach metals from sediments. EP toxicity analyses were conducted on stratigraphic samples from monitoring well DH-21 and DH-19, and from LH-2 and LH-4. These sites are near identified sources of groundwater contamination; the speiss granulation pond (DH-21), the acid plant water treatment facility (DH-19), and Lower Lake (LH-2 and LH-4).

Results of EP toxicity tests of stratigraphic samples from DH-21 show that shallow strata (0 to 4 feet) generally have the highest concentrations of arsenic and lead leachate. Of these, only the concentration of lead leachate from the most shallow sediment samples analysis (DH-21-1, 29 mg/l) is considered high enough to be EP toxic. Leachate concentrations for all parameters from samples at depths of 6 feet or greater were below MCLs.

Results of EP toxicity tests for strata from DH-19 show high metals concentrations in leachate for strata throughout the sampling profile. Leachate from the 0 to 4 foot sampling intervals (DH 19-1-1 and DH-19-2, Appendix 4-4) has concentrations of cadmium and lead in excess of levels considered to be EP toxic. EP toxic levels of cadmium are also in leachate from samples from the 4 to 8 foot intervals (DH-19-3 and DH-19-4). The leachate from deeper sampling intervals (10-11 feet, DH-19-6 and 15-16 feet, DH-19-7) exceeds EP toxicity limits for arsenic. At the bottom of the sampling profile, (25-26 feet, DH-19-9) leachate concentration for all metals were below MCLs.

EP toxicity test results of samples from LH-2 and LH-4 shows that the highest concentrations of arsenic and lead leachate are from the upper 2 to 3 feet of pond bottom sediment. These concentrations are higher than the MCLs but are significantly less than the levels which would classify these sediments as EP toxic. The concentrations of arsenic and metals in leachate from underlying sediment 8.5 feet (below pond surface) or deeper (see Appendix 4-4) are generally below MCLs.

A complete assessment and discussion of the mobility of contaminants in the groundwater system is in the contaminant fate and transport section (Section 8.0) of this report.

5.0 SURFACE SOILS/SURFACE WATER

5.1 SURFACE SOILS INVESTIGATIONS

5.1.1 Quality of Soils Within East Helena

5.1.1.1 Purpose and Scope of East Helena Soils Study

The purpose of the Comprehensive (Phase II) Remedial Investigation for East Helena soils was to ensure that sufficient data of acceptable quality exists for the site characterization, endangerment assessment, and any future remedial planning. Currently, there are three different East Helena soil data sets available for the Comprehensive (Phase II) RI report: 1) the 1983 MDHES/CDC Child Lead Study; 2) the 1984 EPA Phase I RI; and, 3) the data collected in 1987 by Asarco for the Comprehensive (Phase II) RI.

In 1983, the Montana Department of Health and Environmental Sciences (MDHES) in cooperation with the Centers for Disease Control (CDC) conducted a comprehensive epidemiologic study in the Helena Valley to assess children's blood lead levels and the relationship of these levels to different environmental media, including soil (MDHES, 1986). The MDHES/CDC Child Lead Study involved the collection of 674 soil samples from the yards of 296 residences in and around the City of East Helena. Soil samples were collected from the 0-1 inch zone and analyzed by x-ray fluorescence for total silver (Ag), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), manganese (Mn), lead (Pb), antimony (Sb), selenium (Se) and zinc (Zn). A biased sampling scheme was followed, focusing on households with children between the ages of 1 and 5 who have lived in the study area for 3 or more months.

In 1984, the EPA and their contractors (CH2M HILL and Montana State University) collected a total of 157 soil samples throughout the 100 square mile Helena Valley using a geometric grid sampling plan. In addition, three "background" surface soil samples were collected from an area approximately 26.7 miles southeast of the East Helena Site. All samples were collected from the 0-4 inch zone and analyzed for total Ag, As, Cd, Cr, Cu, Hg, Mn, Pb, Se, Zn as well as aluminum (Al), barium (Ba), beryllium (Be), cobalt (Co), iron (Fe), nickel (Ni), tin (Sn), thallium (Tl), and vanadium (V). These data were used to calculate elemental enrichment and to generate spatial distribution maps using geostatistical techniques (U.S. EPA, 1987a). Of the 157 sample sites, only five fell within the city limits of East Helena; however, an additional 13 sites lie sufficiently in and around the greater East Helena area to be used for residential soil characterization.

In 1987, Asarco and their contractors collected 24 soil samples from within the city limits of East Helena in accordance with the approved Comprehensive (Phase II) RI/FS study plan (Hydrometrics, 1987b). Of these, 20 samples were collected from the same locations sampled by the MDHES/CDC in 1983 in order to assess the quality of the larger 1983 data base. The statistical comparability of the 1983 MDHES/CDC data base and the 1987 Asarco data base is summarized below in Section 5.1.1.4. The other four 1987 samples were collected from public schools and parks that had never been sampled. The 24 samples were collected from the 0-1 inch zone and analyzed for total Ag, As, Cd, Cr, Cu, Hg, Mn, Pb, Sb, Se, Tl and Zn. A description of the sampling methods and laboratory analysis procedures for this Soils Phase II RI task are presented in Section 2.3.1.1. Quality assurance/quality control protocols and data validation methods were presented in Sections 2.7.3 and 2.8.2, respectively.

The scope of this Soils Phase II RI task is to make as much use as possible of the three data bases described above in the characterization of chemical element concentrations in East Helena residential surface soils. Therefore, the discussions below focus on background levels for elements in Helena Valley soils, interpretation of the 1984 Phase I RI and the 1987 Phase II RI soils data for East Helena, interpretation of the large 1983 MDHES/CDC soil lead data base, and the development of areal distribution maps for surface soil lead, cadmium and arsenic within the greater East Helena residential area.

5.1.1.2 Background Levels for Helena Valley Soils

In accordance with the approved Comprehensive RI/FS study plan (Hydrometrics, 1987), the background metal levels in soils, established in the Phase I RI report (U.S. EPA, 1987a) for the Helena Valley, will be used to evaluate metal enrichment in soils in East Helena. Table 5-1-1 presents summary statistics for the three background soil samples collected 26.7 miles southeast of the East Helena Site.

Table 5-1-1. Total element concentrations (ug/g dry weight) in background soils (N=3) for the Helena Valley Area of Montana (from U.S. EPA, 1987a).

Element	Geometric Mean	Range
Ag	0.20	0.09 - 0.45
As	16.5	15.0 - 18.0
Cd	0.24	0.17 - 0.30
Cr	15.3	14.0 - 17.0
Cu	16.3	16.0 - 17.0
Hg	0.08	0.09 - 0.12
Mn	336.0	270.0 - 410.0
Pb	11.6	10.0 - 13.0
Sb	0.27	0.27 - 0.27
Se	0.07	0.07 - 0.07
Tl	0.09	0.09 - 0.09
Zn	46.9	39.9 - 53.9

Enrichment factors for elements analyzed from East Helena soil samples will be calculated as the ratio of the geometric mean concentration of all samples within the study area to the geometric mean concentration of the soil background sites. Site specific enrichment will also be calculated as the ratio of the actual metal concentration at each study area sample site to the geometric mean concentration of the background sites. Enrichment factors substantially greater than one indicate significant surface soil enrichment whereas factors near or slightly less than or slightly greater than unity (one) suggest little, if any, increased enrichment/concentration in surface soils.

5.1.1.3 Results of the Phase I and II Soil Investigations

Element concentrations in the surface soils of the greater East Helena residential area will be characterized by combining the analytical results for the 24 samples collected by Asarco in 1987 (Phase II Soils RI) with the data from 18 sites sampled by the EPA in 1984 (Phase I Soils RI). A map of the East Helena area showing the locations of the 1987 soil sample sites and the sites selected from the 1984 EPA data set is shown in Figure 5-1-1.

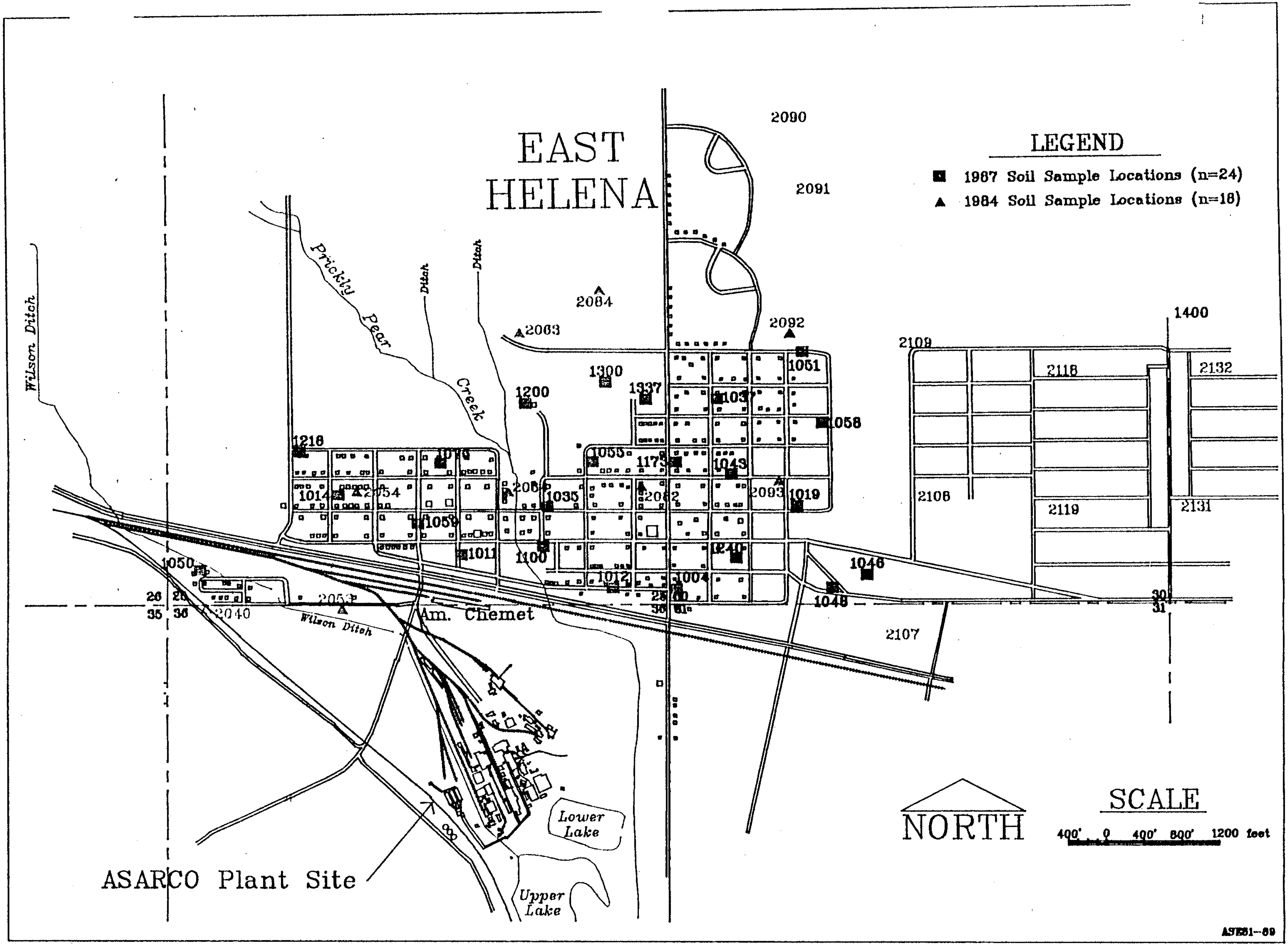


Figure 5–1–1: Map Of The East Helena Residential Area Showing The 1984

Two interpretive problems arose regarding the combined use of the 1984 and 1987 data sets. First, the reported analytical detection limits for three analytes (Sb, Se and Tl) were substantially different between the two sets. This is a problem because the majority of reported values for these three elements are at or near their respective detection limits. For example, the reported detection limit for selenium is 13.0 ug/g and 0.10 ug/g for the 1987 and the 1984 data sets, respectively. Selenium concentrations were reported at or near detection for the majority of samples in each data set. One data set with the majority of its values reported at <13.0 ug/g cannot be statistically combined with another if the majority of its values are reported at <.10 ug/g. Therefore, the combined 1984/87 data base will exclude the 1987 Sb, Se and Tl data and include only the 1984 data for these elements so that representative enrichment factors can be calculated.

The second potential problem associated with combining these two data sets relates to the different soil sampling depths. The 1984 EPA samples were collected from the 0-4 inch zone whereas the 1987 Asarco samples were collected from the 0-1 inch zone. Since aerial deposition is the primary mode of soil element enrichment, it is expected that the 0-1 inch soil depth has a higher element content than the 0-4 inch increment. The effect of sampling the 0-4 inch soil increment versus the 0-1 inch depth was investigated during the Phase I RI (U.S. EPA, 1987a). Ten project sites were sampled at 0-1 and 0-4 inches to compare their levels of As, Cd, Pb, Hg, Ag and Zn. A paired statistical t- test indicated there was no significant difference (P = .05) between the 0-1 and 0-4 inch increments regarding their chemical element concentrations. Therefore, for the purposes of this study, it has been assumed that the 1984 and the 1987 soil data sets are compatible with respect to sampling depth.

Table 5-1-2 presents the arithmetic mean, standard deviation, and the minimum and maximum values for the 12 elements of the combined 1984/87 data set. The data were transformed to log base 10 values to obtain a normal distribution and to compute geometric means for each element. Area-wide enrichment factors representing the magnitude of increased element burden over background concentrations have been calculated for each element. A complete listing of the combined 1984/87 soil data base is presented in Appendix 5-1. All values are presented on a dry soil

Table 5-1-2. Statistical summary of total element concentrations (ug/g dry weight) in surface soil samples collected within the East Helena residential area during 1984 and 1987, and the calculated enrichment factors.

Element	N[1]	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Geometric Mean	Geo. Mean Background	Enrichment Factor[2]
Ag	42	4.51	5.2	0.65	24.0	2.68	0.20	13.4
As	38	57.1	45.0	8.8	218.0	45.6	16.5	2.8
Cd	42	24.8	25.2	4.2	112.0	17.3	0.24	72
Cr	42	19.1	7.9	9.0	39.0	17.5	15.3	1.1
Cu	42	347.2	964.1	34.0	6200.0	129.1	16.3	7.9
Hg	38	2.54	3.6	0.2	16.0	1.43	0.08	17.9
Mn	42	532.8	162.6	321.0	1175.0	512.9	336.0	1.5
Pb	42	1121.0	1407.0	126.0	7225.0	635.3	11.6	55
Sb	18	0.35	0.22	0.27	1.10	0.32	0.27	1.2
Se	18	0.21	0.19	0.07	0.70	0.15	0.07	2.1
Tl	18	0.41	0.33	0.09	1.10	0.28	0.09	3.1
Zn	42	595.8	854.5	108.0	5200.0	354.0	46.9	7.6

1/ Note As and Hg sample sizes have been reduced due to rejection of some data during data validation; Sb, Se and Tl results are from 1984 EPA study only.

2/ Enrichment factor = geometric mean of study area / geometric mean background.

weight basis. All of the 12 elements presented in Table 5-1-2 exhibited area-wide enrichment in East Helena surface soils.

It should be noted that the maximum value for Pb (7225.0 ug/g from Station No. 76) was 3275.0 ug/g higher than the next highest value of 3950.0 ug/g. Furthermore, the 11 other elements measured in the same sample did not exhibit excessive enrichment comparable to the Pb value nor was this sample collected from an area within East Helena that exhibits substantial soil element enrichment. While the Pb value measured in sample no. 76 was not rejected during data validation, it is treated as suspect for the reasons noted above.

Simple correlation coefficients (r) were calculated between nine elements from the combined 1984/87 data base (Table 5-1-3). The distribution of the elements analyzed in East Helena soils were, except for Mn, well correlated and in most cases the correlations were significant at the 0.05 probability level. The distributions of Cd and Pb were significantly correlated to the distributions of the other elements with the exception of Mn. These findings are consistent with those discussed in the Phase I RI report for statistical correlations between elements in Helena Valley soils (U.S. EPA, 1987a). Site specific enrichment of total element concentrations in soils was investigated to calculate the percentage of samples exhibiting enrichment in East Helena (Table 5-1-4). All 42 samples within the combined 1984/87 East Helena data set were above background for Ag, Cd, Cu, Pb and Zn. Total concentrations for As, Hg and Mn were elevated above background in 88, 90 and 95 percent of the samples, respectively. Chromium, Se and Tl concentrations were above background in 60, 50 and 61 percent of the surface soil samples, respectively. Antimony levels were above background in only 17 percent of the samples.

Four samples taken from two public schools (play areas) and two public parks were included in the 24 surface (0-1 inch) soil samples collected within East Helena by Asarco during 1987. Generally, these samples were collected by sampling at the ends and in the center of two 30 meter (approx.) long transects that cross forming an X. The five subsamples were composited for shipping and analysis. Total element concentrations and enrichment factors for each of the four samples are presented in Table 5-1-5.

Table 5-1-3. Simple correlation coefficients between total element concentrations in surface soils collected within the East Helena residential area during 1984 and 1987.

	Correlation Coefficient(r)[1] (N = 42)[2]								
Element	Ag	As	Cd	Cr	Cu	Hg	Mn	Pb	Zn
Ag	1.00	0.70x	0.92x	0.50x	0.95x	0.76x	0.27	0.78x	0.96x
As		1.00	0.78x	-0.06	0.65x	0.74x	0.17	0.61x	0.66x
Cd			1.00	0.33x	0.88x	0.89x	0.17	0.83x	0.91x
Cr				1.00	0.51	0.11	0.15	0.37x	0.44x
Cu					1.00	0.64x	0.23	0.77x	0.95x
Hg						1.00	-0.02	0.67x	0.73x
Mn							1.00	0.10	0.22
Pb								1.00	0.78x
Zn									1.00

1/ x denotes significance @ P=0.05.

2/ Sample size (N) = 38 for As and Hg calculations.

Table 5-1-4. Number and percentage of surface soil samples above and below background levels within the East Helena residential area (1984 and 1987 data set).

Soil Concentrations	(Number) (Percent)	Elements (N=42)[1]											
		Ag	As	Cd	Cr	Cu	Hg	Mn	Pb	Sb	Se	Tl	Zn
Below background	(N)	0	5	0	17	0	4	2	0	15	9	7	0
	(%)	0	12	0	40	0	10	5	0	83	50	39	0
Above background	(N)	42	37	42	25	42	38	40	42	3	9	11	42
	(%)	100	88	100	60	100	90	95	100	17	50	61	100

1/ Sample size = 18 for Sb, Se and Tl calculations.

Table 5-1-5. Total element concentrations (ug/g dry weight) in surface (0-1 inch) soil samples collected from East Helena public schools and parks in 1987, and calculated enrichment factors (E.F.).

Element	Geometric Mean Background	Main St. Park		Kennedy Park		Radly School		East Gate School	
		Value	/ E.F.	Value	/ E.F.	Value	/ E.F.	Value	/ E.F.
Ag	0.20	12.0	60	8.40	42	5.90	30	1.25	6.3
As	16.5	140.0	8.5	R	--	75.0	4.6	23.0	1.4
Cd	0.24	50.0	208	44.0	183	20.0	83	4.20	18
Cr	15.3	18.0	1.2	19.0	1.2	16.0	1.1	21.0	1.4
Cu	16.3	830.0	51	460.0	28	298.0	18	58.0	3.6
Hg	0.08	2.20	28	R	--	1.40	18	0.27	3.4
Mn	336.0	885.0	2.6	775.0	2.3	473.0	1.4	438.0	1.3
Pb	11.6	1993.0	172	2118.0	182	1160.0	100	152.0	13
Zn	46.9	1470.0	31	960.0	20	888.0	19	108.0	2.3

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[1] E.F. = enrichment factor = Value in single soil sample / geometric mean background value.

R = value rejected during data validation process.

Total concentrations for all elements, except for Cr and Mn, appear to be elevated in both parks. Cadmium and Pb exhibited the highest level of enrichment in the Main Street Park with factors of 208 and 172, respectively. Cadmium and Pb were similarly enriched in the Kennedy park with factors of 183 and 182, respectively. At the Radley School, Cd was about 83 times background and Pb was about 100 times background. Enrichment factors for Ag, As, Cr, Cu, Hg, Mn and Zn at the Radley School play area ranged from 1.1 to 30. The Eastgate Elementary School exhibited substantially lower soil element concentrations compared to the two city parks and Radley School. Enrichment of Cd and Pb in the single sample collected at the Eastgate School playing field was about 18 and 13 times background, respectively. Enrichment factors for Ag, As, Cr, Cu, Hg, Mn and Zn were relatively low compared to enrichment factors for these elements from the two parks and the Radley School.

5.1.1.4 <u>Results of 1983 MDHES/CDC Soil Investigations</u>

The main objective behind reporting the 1983 MDHES/CDC results for total soil element concentrations is to make as much use as possible all available data of acceptable quality for the characterization of elemental enrichment in East Helena residential soils.

During the summer of 1983, the MDHES/CDC project team gathered 674 surface soil samples from the yards and nearby play areas of 246 residences within a 2.25 mile radius of the East Helena Site. Surface (0-1 inch) soil samples were collected from four different locations surrounding eligible households; 1) front and back yard composites, 2) side yards, 3) gardens, and 4) adjacent play areas. Eligible households were defined as those with children ages one through five who had lived in the study area for three months or more. Site selection, sampling and laboratory analysis procedures are presented in the East Helena, Montana - Child Health Study Protocol (MDHES, 1983).

In 1987, Asarco and its contractor collected 20 surface soil samples from nearly identical locations as were sampled in 1983 (see Section 5.1.1.3 above). A comparison of the 1983 and 1987 data sets using a paired t-test and simple correlation coefficients was conducted (Roy F. Weston

Inc., 1988c) so that a decision could be made on the usability of the large 1983 East Helena soil data set for the Comprehensive (Phase II Soils) RI. The technical approach used in the comparability analysis was reviewed by EPA and its contractors (Neuman and Dollhopf, 1988). Data for As, Cd, Cr, Mn and Sb exhibited significant differences between the 1983 and the 1987 data sets. Data for Hg and Se, although not significantly different between data sets, revealed low correlation coefficients. The Pb, Cu and Zn data, however, indicated no significant differences and their respective correlation coefficients were high indicating that the 1983 and 1987 subsets describe the same population. Therefore, EPA recommended (Brown, 1988) Asarco utilize 1983 data for Pb, Cu and Zn for characterization of East Helena surface soils in the Phase II Soil Remedial Investigation.

Only the 1983 data for total soil Pb is presented here. Compared to Cu and Zn, the Pb concentrations in East Helena soils are the most enriched (see Section 5.1.1.3 above). In addition, because of the strong correlations between concentrations of analytes in East Helena surface soils, any action regarding Pb in soil will also address the less-elevated Cu and Zn, and other key enriched elements. For a complete treatment of the 1983 Child Lead Study results, refer to the Final Report prepared by the Montana Department of Health and Environmental Sciences (1986).

The MDHES/CDC study team divided the project area into two zones based on distance from the center of the plant; Area 1 included all eligible households between 0 and 1 mile of the plant and Area 2 included all eligible households between 1 and 2.25 miles. For the purposes of the Phase II Soil Remedial Investigation, these data have been delineated for statistical analysis by sample type, distance from the plant, and city block. All of the 1983 Pb data were transformed to the log base 10 value prior to statistical analyses. Results of these statistical analyses are presented below. A complete listing of the surface (0-1 inch) soil lead data base for the samples collected during the 1983 Child Lead Study are presented in Appendix 5.1.2.

Lead concentrations measured in soils sampled during the 1983 study were first analyzed to determine if statistical differences existed between the four sample location types (Table 5-1-6). The overall average geometric mean for all types combined was 264 ug/g, resulting in an enrichment factor of 23 times background. The different sample types had averages ranging from 335 ug/g in the side yards to 172 ug/g in the play areas. An analysis of variance (ANOV) indicated that only the play areas had significantly (P = 0.1) different lead concentrations. Although this ANOV suggested that sample location may be a factor in the quantification of Pb in East Helena soils, the types were not separated in the following analyses so that a more general relationship between soil Pb distribution and distance could be examined.

Table 5-1-7 presents the combined Pb concentrations partitioned into four categories based on distance from the center of the plant area. Lead levels were highest near the plant (0 to 0.5 mile zone) with a geometric mean concentration of 1213 ug/g (enrichment factor = 105). Lead concentrations decreased significantly as distance from the plant increased with each quarter mile increment. Lead levels in the 0.5 to 0.75 mile interval measured an average of 420 ug/g, 308 ug/g in the 0.75 to 1.0 mile zone, and 158 ug/g in the final group, 1.0 to 2.25 miles from the plant complex. Figure 5-1-2 illustrates the area encompassed by each distance group.

Table 5-1-8 partitions the combined 1983 soil Pb data into eight different categories based on the location of the sample relative to a city block. Each group was delineated in the north-south direction by the northern bounding street and in the east-west direction by the East Helena city limits (Figure 5-1-3). The groups are designated by the name of the northern bounding street. Surface soil Pb concentrations followed a similar pattern as reported previously, decreasing as distance from the plant increased.

5.1.1.5 Areal Distribution of Elements in East Helena Soils

Isoline maps of total As, Cd, and Pb concentrations were prepared to spatially represent soils data collected within the East Helena residential area. Lead and Cd were chosen for mapping because they appear to be key elements with respect to levels of enrichment. Arsenic concentrations were contoured because As is a carcinogen.

Table 5-1-6. Statistical summary of total lead (Pb) concentrations (ug/g dry weight) in surface (0-1 inch) soil samples collected during the 1983 Child Lead Study within the East Helena area, and the calculated enrichment factors.

Soil Sample Type	N	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Geometric Mean	Enrichment Factor[1]
Front/Backyard	249	513.0	665	31.4	3415	307.6 a[2]	27
Sideyard	165	771.1	1293	3.4	7965	335.0 a	29
Play Area	183	481.8	862	3.1	6031	172.2 b	15
Garden	77	372.2	332	50.3	2038	266.7 a	23
Combined[3]	674	551.6	895	3.1	7965	264.2	23

1/ Enrichment Factor = geometric mean divided by geometric mean background for total Pb in soil (11.6 ug/g).

2/ Letters indicate significant differences determined by LSD. Soil Sample Type with a different letter is significantly different at P = 0.10.

3/ Combined soil sample type represents the four soil sample types grouped together.

Table 5-1-7. Statistical summary of total lead (Pb) concentrations (ug/g dry weight) in surface (0-1 inch) soil samples collected during the 1983 Child Lead Study within the East Helena area, grouped by distance from the Plant Site.

Distance[1] (miles)	N	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Geometric Mean	Enrichment Factor[2]
0 to 0.5	112	1792.0	1372	7.7	6462	1213.4 a[3]	105
0.5 to 0.75	140	811.7	1126	3.2	7965	420.7 b	36
0.75 to 1.0	124	409.7	294	3.1	1411	308.3 c	27
1.0 to 2.25	620	234.4	364	3.2	6031	158.9 d	14

1/ Distance measured from the geographic center of the smelter area.

2/ Enrichment Factor = geometric mean divided by geometric mean background for total Pb in soil (11.6 ug/g).

3/ Letters indicate significant differences determined by LSD. Distance groups with a different letter are significantly different at P = 0.10.

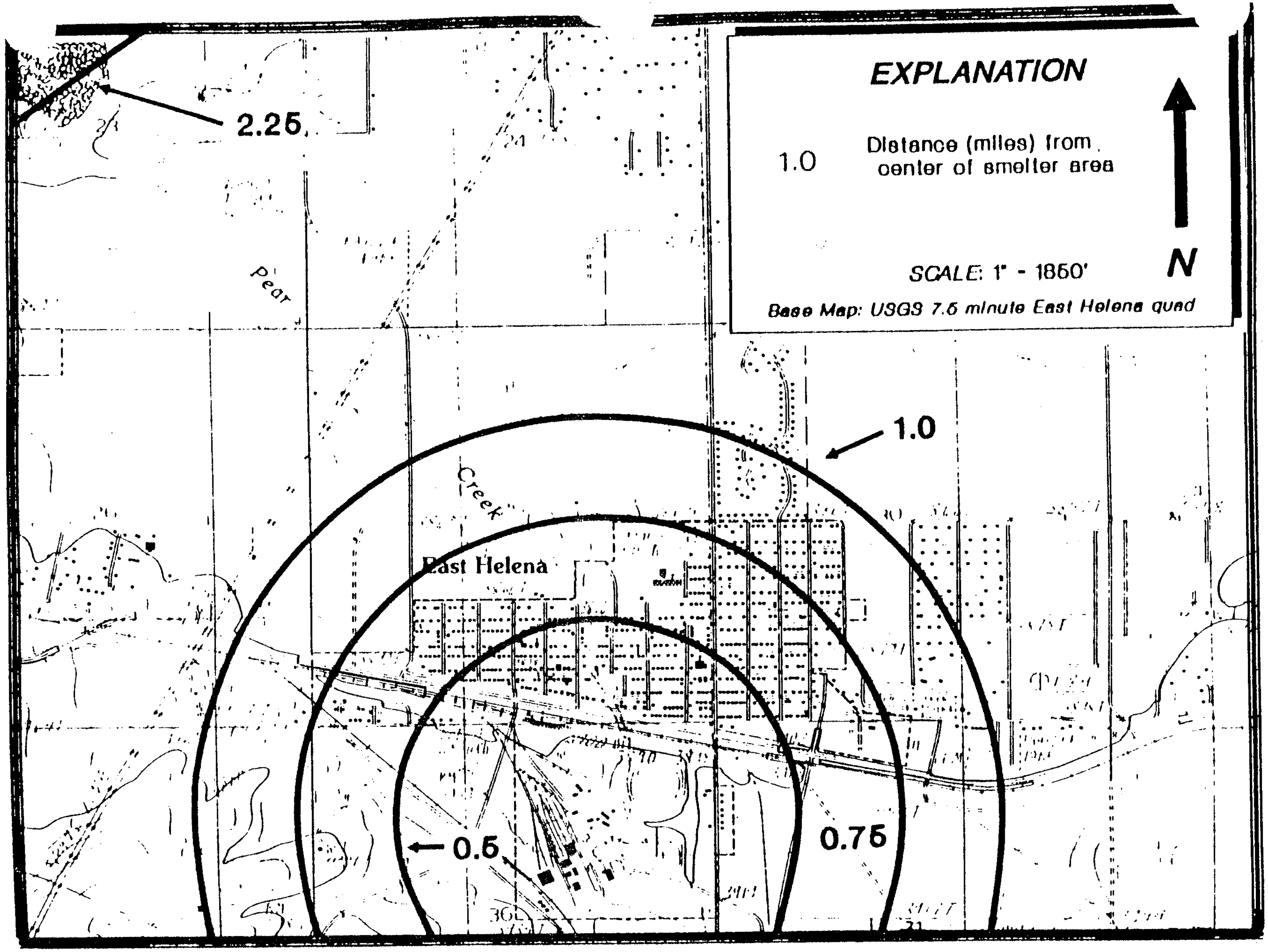


Figure 5-1-2. Map showing radial distances around the center of the Plant Site.

Table 5-1-8. Statistical summary of total lead (Pb) concentrations (ug/g dry weight) in surface (0-1 inch) soil samples collected during the 1983 Child Lead Study within the East Helena area, grouped by city block.

Block[1]	N	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Geometric Mean	Enrichment Factor[2]
Clark	32	2133.0	1283	401.8	5770	1807.2 a[3]	156
Main	32	2474.0	1812	121.7	7965	1870.7 a	161
Riggs	48	1193.0	1079	7.7	5076	755.0 b	65
Groschell	44	852.2	791	10.4	3705	572.8 b	49
Clinton	40	673.2	1327	8.7	6537	247.2 c	21
King	28	798.7	606	207.8	2518	631.0 b	54
Dudley	20	362.1	205	3.1	798	255.9 c	22
Lewis	28	437.0	380	98.0	1411	338.8 c	29

1/ Blocks are designated by the name of the northern bounding street and consist of one city block long in the north-south direction by all blocks in an east-west direction within the city limits of East Helena (see Figure 5.1.3).

2/ Enrichment Factor = geometric mean divided by geometric mean background for total Pb in soil (11.6 ug/g).

3/ Letters indicate significant differences determined by LSD. Block names with a different letter are significantly different at P = 0.10.

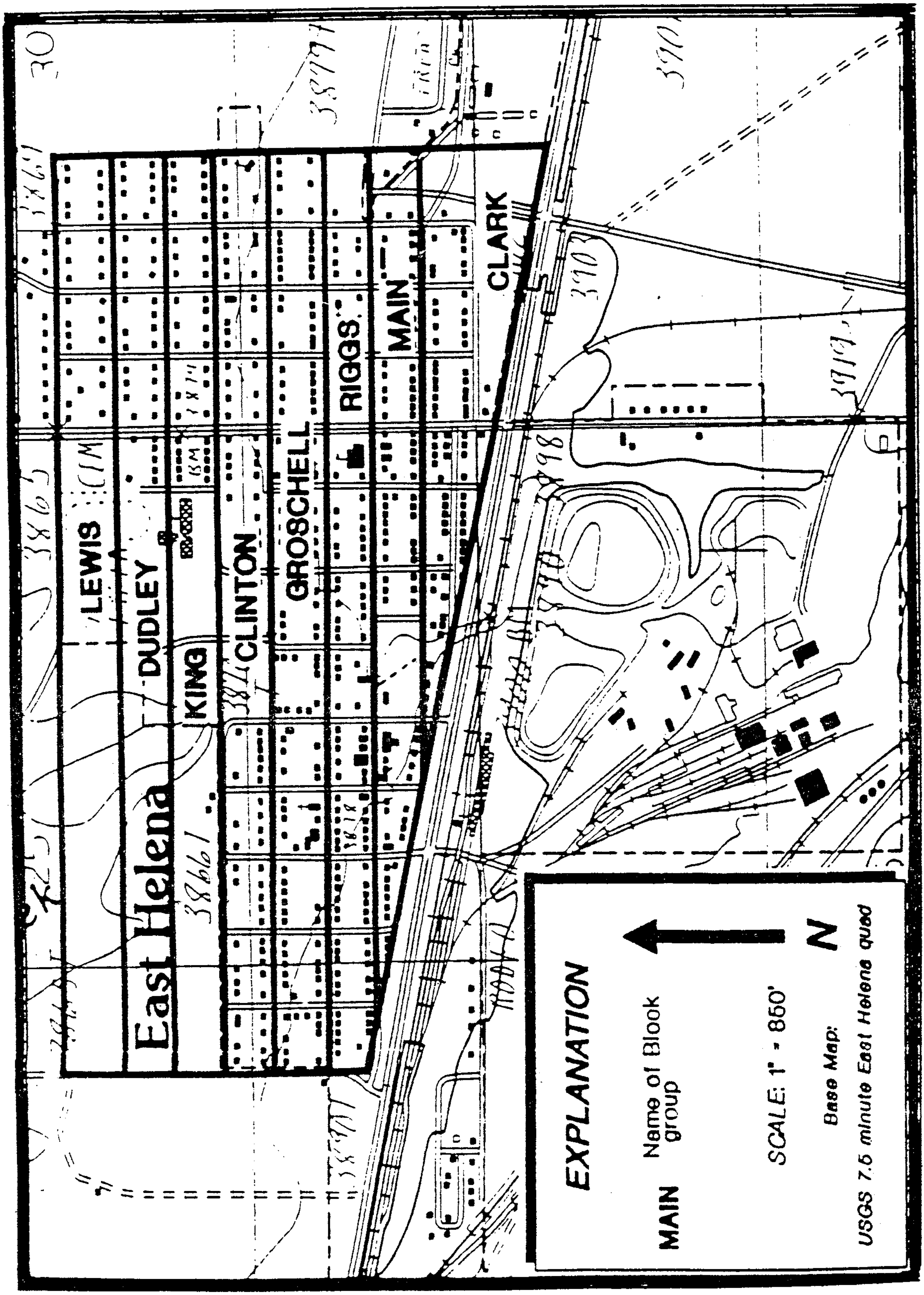


Figure 5-1-3. Map showing blocks used for grouping surface soil lead concentrations from 1983 Child Lead Study.

All three maps were produced using a portion of the 1984 Phase I soils data to supplement data collected in 1987 (N = 24) for the Phase II Soil RI.

Additional 1984 soil sample sites were added to the combined 1984/87 data set (N = 42) described above in Section 5.1.1.3 so that the 4.2 square mile zone encompassing the greater East Helena residential area would be adequately covered. A total of 85 samples from a 4.2 square mile area around East Helena were used to produce maps for Cd. Sample station number 76 was not used in the interpretation of the Pb data because it was thought to be an outlier (see Section 5.1.1.3 above), reducing the number of sample sites for the Pb map to 84. Four values of As in the 1987 data set were rejected in the data validation process, therefore, the total number of sample sites used to generate this map was 81. Lead values were transformed to $\log_{10}$ for contouring while nontransformed values are presented for As and Cd. The (x,y) coordinate system for all maps originates at the Sinter Plant Stack on the Plant premises. The original objective of contouring elemental concentrations was to provide isolines with associated confidence intervals to qualify the interpretation of the data. An attempt was made to model the spatial distribution of lead in East Helena soils using a geostatistical technique called kriging. Kriging models the spatial distribution of a parameter by using the principle of weighted local averaging. Kriging produces estimates of soil properties at nonsampled locations by minimizing the variance associated with each predicted value. This provides the best linear unbiased estimate of a value with an associated error variance (Journel and Huijbregts, 1978).

Kriging is based on the semi-variogram, a basic tool of geostatistics. The semi-variogram plots the semi-variance, a measure of the similarity between points a given distance apart, versus the average distance of those points (Burgess and Webster, 1980). Once the semi-variogram is generated, it is validated by meeting a number of statistical conditions. If these conditions are not met then the model parameters must be revised. Kriging should not be used unless a valid semi-variogram that satisfactorily models the data is produced.

An initial run of the East Helena lead data resulted in a semi-variogram with a large component of random variation and a small spatial component (semi-variance). To reduce the amount of random variation, an attempt was made to fit a quadratic equation to the data, subtract this equation from the values measured, and apply the semi-variogram to the residuals, i.e. the difference between the predicted value using the equation and the actual value measured. This procedure is known as universal kriging (Journel and Huijbregts, 1978) and is used when a trend is present in the data. The trend present in the East Helena data is a result of the distribution of surface soil lead from a point source.

Two different equations were fit to the data resulting in coefficient's of determination (r^2) of 0.46 and 0.32. Semi-variograms of the residuals, however, were not improved by removing the trend described by either equation. This result is primarily due to the high level of variation between samples situated in close proximity to each other. Since a good model could not be validated, the objective of providing confidence intervals on the contoured data could not be achieved.

Therefore, the three maps presented in Figures 5-1-4, 5-1-5, and 5-1-6 using a computer contouring program which applies an "estimated best-fit" model to the data (Golden Software Inc., 1987) were generated. It should be noted that while a statistical model was used to contour the data, confidence intervals around the contour lines cannot be drawn. This procedure does however produce a more realistic presentation of the data compared to other estimation procedures such as inverse distance, inverse distance squared or a subjective approach followed by an individual contouring the data by hand.

Figure 5-1-4 illustrates the distribution of the $\log_{10}$ Pb in the East Helena area. The highest concentrations of Pb (> 3000 ug/g) are located along the ellipse centered approximately 2000 feet north and 1000 feet east of the origin with the major axis of the ellipse oriented north-south. The 1000 ug/g concentration line (isoline 3.0) encircles the portions of East Helena located generally south of Clinton Avenue and east of First Street. This contour line was generated using a total of 10 soil sampling sites with concentrations of Pb ranging from 1035 to

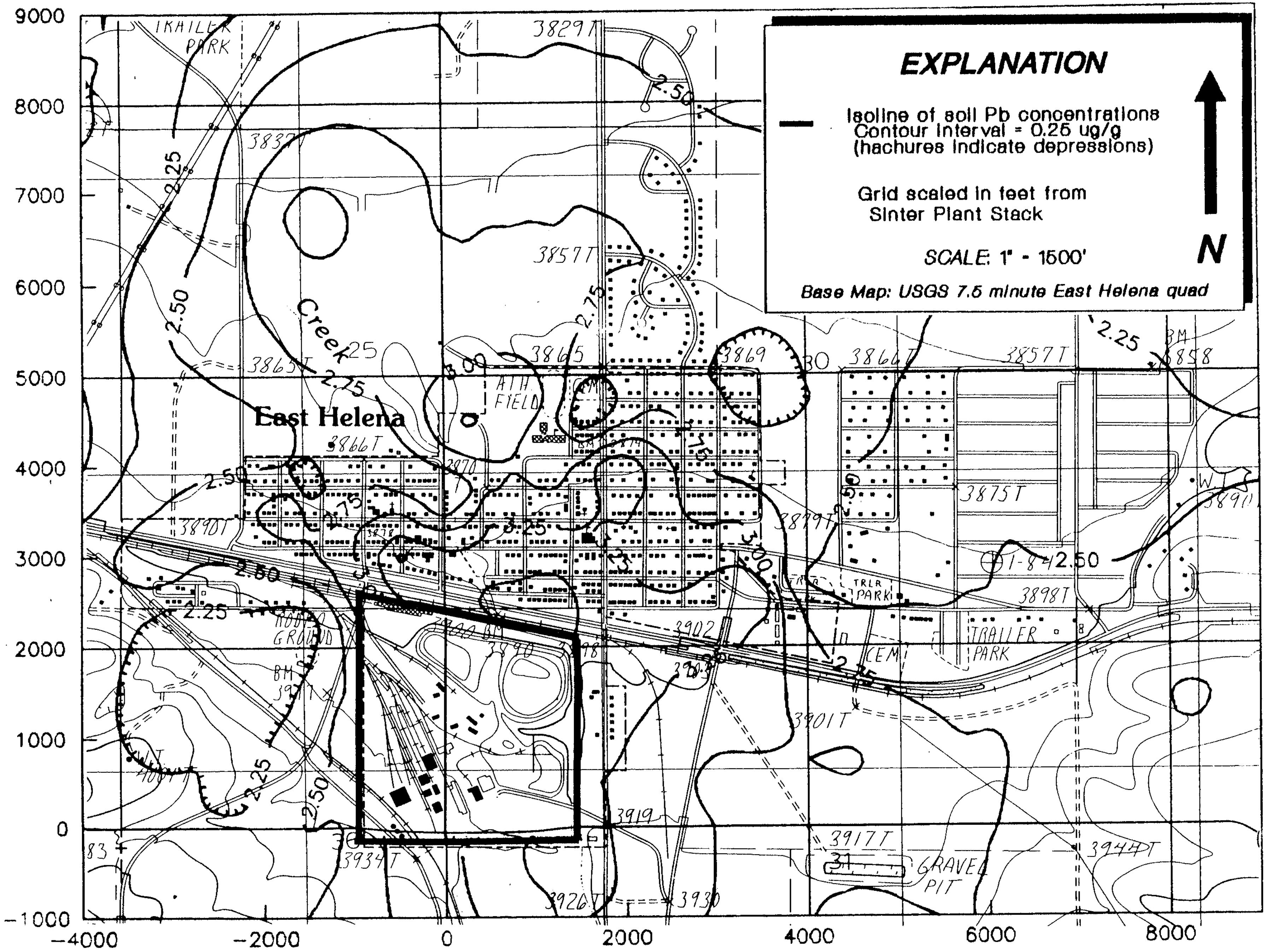


Figure 5-1-4. Isoline map of $\log_{10}$ total surface soil lead (ug/g) in the East Helena Area.

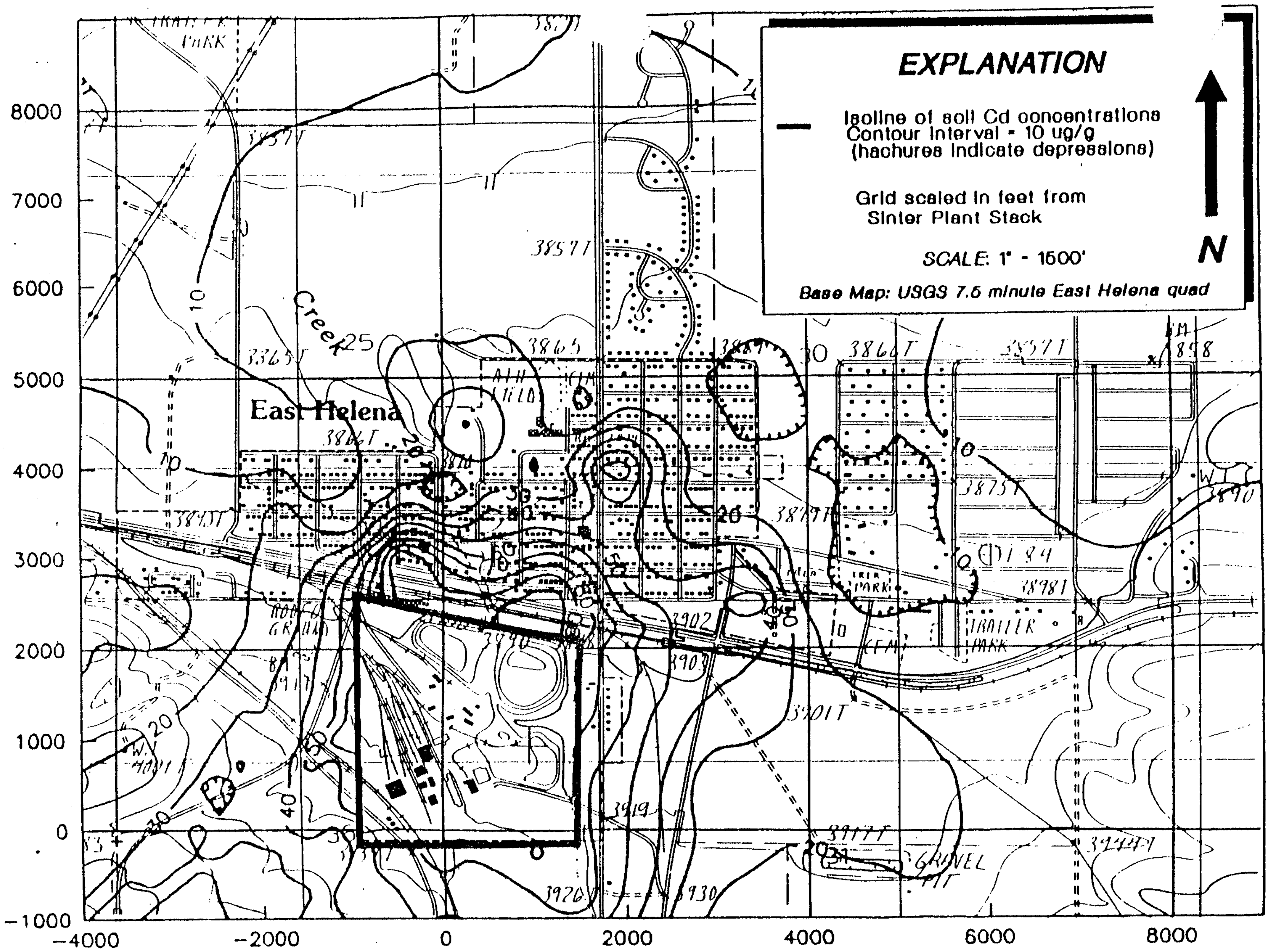


Figure 5-1-5. Isoline map of total surface soil cadmium (ug/g) in the East Helena Area.

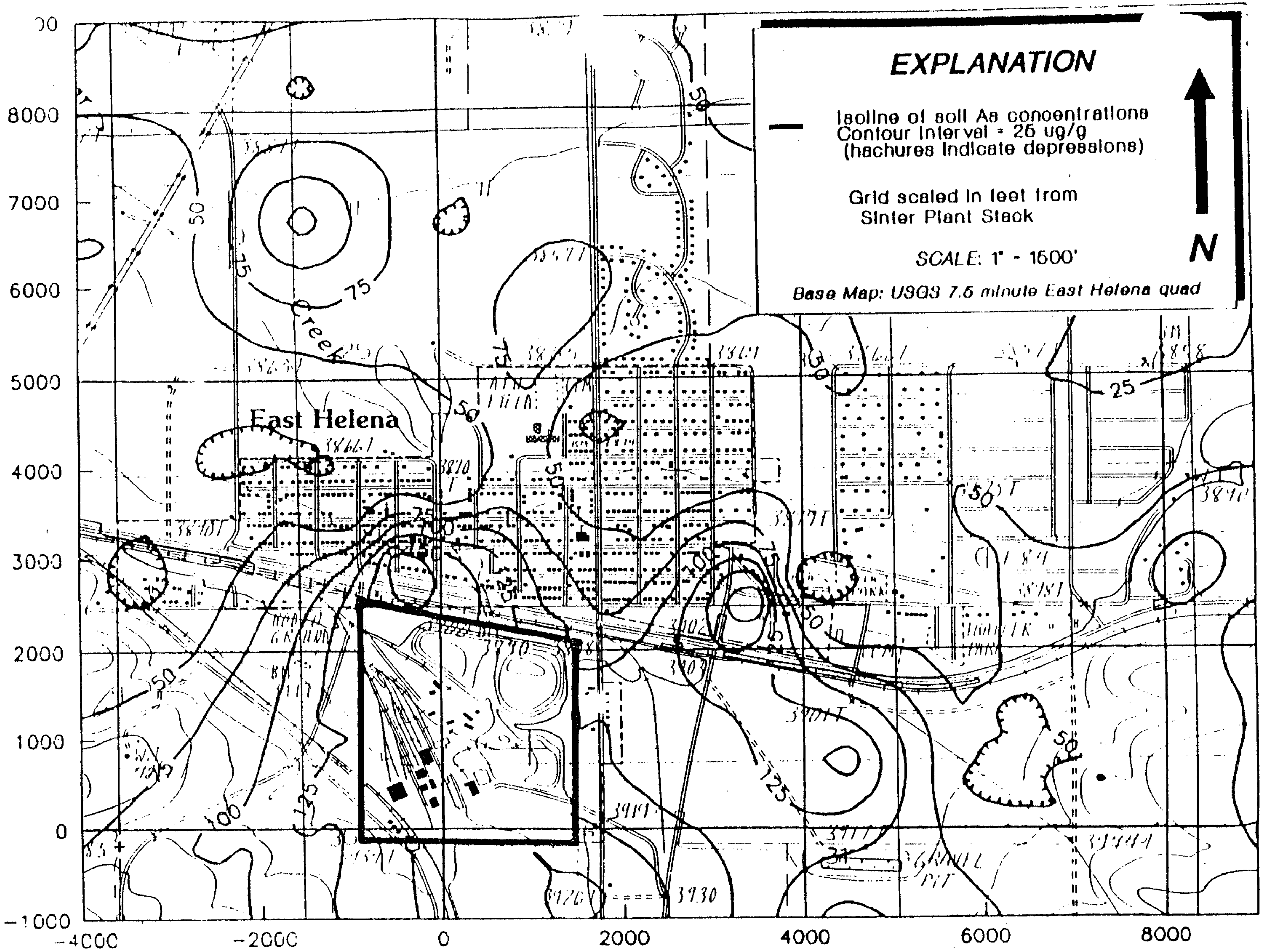


Figure 5-1-6. Isoline map of total surface soil arsenic (ug/g) in the East Helena Area.

3950 ug/g. Two other areas exceeded 1000 ug/g lead, one being located near the Radley School athletic field and another located 0.5 miles north of the city limits. A large portion of the mapped area has concentrations of Pb in excess of 316 ug/g, as indicated by the 2.5 isoline. It should be noted that, in general, Pb concentrations decrease as distance from the plant site reference point increases.

This analysis corresponds closely with the 1983 MDHES/CDC Pb data presented in the previous section. The 1983 data indicated that the area within a 0.5 mile radius from the center of the plant was enriched with Pb concentrations greater than 1000 ug/g and that these concentrations decreased significantly with distance from the reference point. An arc with a 0.5 mile radius from the center of the plant (see Figure 5-1-2) generally delineates an area similar to the area enclosed by the 1000 ug/g isoline (isoline 3.0 - Figure 5-1-4).

Figure 5-1-5 illustrates the distribution of Cd in the East Helena area. Cadmium distribution closely follows the pattern exhibited by Pb with the center of the highest Cd level (100 ug/g) located approximately 2000 feet north and 1000 feet east of the origin. The Cd isolines are more concentrically oriented than the Pb isolines although the 30 ug/g Cd isoline closely follows the 1000 ug/g isoline of Pb (isoline 3.0 - Figure 5-1-4). This relationship graphically confirms the simple correlation coefficient reported for the two elements in Section 5.1.1.3 ($r = 0.83$).

Figure 5-1-6 illustrates the distribution of As in the East Helena area. The highest As concentration isoline lies along the center of an ellipse oriented north by north-west. The concentrations of As are distributed in a more random pattern than the Pb and Cd data. This observation agrees with the lower simple correlation coefficients for each element ($r = 0.61$ and 0.78, respectively) reported in Section 5.1.1.3. Arsenic concentrations are less than 50 for most of the East Helena townsite with the highest concentration (218 ug/g) centered on one sample taken near the intersection of Cleveland Avenue and Pacific Street.

5.1.1.6 Summary and Conclusions of the East Helena Soils Study 1984 and 1987 Soil Investigations

- For 42 surface soil samples collected during 1984 and 1987, total concentrations of Cd ranged from 4.2 to 112.0 ug/g, Pb ranged from 126.0 to 7225.0 ug/g, and As ranged from 8.8 to 218.0 ug/g.

- Simple correlation coefficients (r) were calculated between nine elements analyzed in East Helena surface soils. Total concentrations for the elements were, except for Mn, well correlated and in most cases the correlations were significant at the P = 0.05 level.

- Of the 42 surface soil sampling sites distributed across the East Helena residential area, 90 to 100% had Ag, Cd, Cu, Hg, Mn, Pb and Zn concentrations above background. Seventeen to 88% of these sites were above background for As, Cr, Sb, Se and Tl.

1983 MDHES/CDC Soil Pb Investigations

- 674 surface (0-1 inch) soil samples were collected from the yards of 249 homes within a 2.25 mile radius of the plant site. Total Pb concentrations in these samples ranged from 3.1 to 7965.0 ug/g.

- The 674 soil sample sites were divided into four concentric zones radiating outward from the center of the Plant site. Statistical comparison of the geometric mean Pb levels for each zone (0-.5 mi., .5-.75 mi., .75-1.0 mi., and 1.0-2.25 mi.) indicated soil Pb levels decrease significantly (P = 0.10) with each increasing distance zone centered around the Plant. A concentric zone extending one half mile from the center of the Plant site exhibited a geometric mean surface soil Pb concentration of 1213.4 ug/g.

- To further characterize the spatial distribution of surface soil Pb in East Helena, the data were partitioned into 8 categories based on the location of the sample relative to a city block. Each group was delineated in the north-south direction by the northern bounding street and in the east-west direction by the East Helena city limits. Surface soil Pb concentrations generally decreased as distance from the plant increased. The highest soil Pb concentrations by city block were found in the first two groups north of the plant, Clark and Main, with geometric mean values of 1807 and 1870 ug/g, respectively.

Areal Distribution of Elements in East Helena Soils

- Isoline concentration maps of total surface soil As, Cd and Pb were prepared to spatially represent soils data collected within the East Helena residential area. A computer contouring program that applies an "estimated best-fit" statistical approach to the data was used to generate the maps.

- A 1000 ug/g isoline for Pb is located along an arc with a 0.5 mile radius from the center of the plant which encircles the portions of East Helena located generally south of Clinton Avenue and east of First Street.

- The isolines delineating the highest concentrations for Cd follow the same general trends as those for Pb. The As concentrations are distributed in a more random pattern than the Pb and Cd data. Arsenic concentrations are generally less than 50 ug/g for most of the East Helena townsite.

5.1.2 Quality of Surface Soils Within the Plant Site

5.1.2.1 Purpose and Scope of Plant Site Soils Study

The Phase I Soils RI (U.S. EPA, 1987a) addressed the potential environmental problem associated with metals in soils in the Helena Valley outside the East Helena Plant site. One of the objectives of the Phase II Soils RI (Hydrometrics, 1987b) was to characterize metal concentrations in surface soils (0-1 inch depth) within the Plant site that may be potential sources of wind-borne particulates. Data assembled from the analyses of these samples were used during the endangerment assessment process to address potential human risk due to fugitive dust originating from the Plant site.

The sampling locations for the plant area soils are presented in Figure 5-1-7. The 26 samples collected within the 111 acre Plant site have been grouped into six land-use area catagories in order to examine the possibility of spatial trends. These six use areas are:

- Upper Ore Storage Area
- Lower Ore Storage Area
- Railroad Tracks East and South of Thawhouse
- Perimeter of Slag Pile
- Miscellaneous Bare Areas Within Main Facility
- Miscellaneous Bare Areas Outside of Main Facility

Methods of sampling and laboratory analysis are presented above in Section 2.3.1.2. Quality assurance/quality control protocols and data validation methods for the onsite soils were presented in Sections 2.7.3 and 2.8.2, respectively.

5.1.2.2 Results of Plant Site Surface Soils Study

The 26 surface soil samples collected throughout the Plant site were analyzed for total levels of 12 elements. Complete analytical results for the surface soils are presented in Appendix 5.1.3. A statistical summary of these data showing the arithmetic means, standard deviations, minimum and maximum values, geometric means and calculated enrichment factors for the 12 analytes is presented in Table 5-1-9. All values are presented on a dry soil weight basis. All data points were converted to log base 10 values to obtain a normal distribution; the geometric mean represents the antilog of the converted mean. An enrichment factor for each element was calculated as the ratio of the geometric mean concentration of all 26 sites to the geometric mean concentration of the Helena Valley soil background sites discussed above in Section 5.1.1.2.

Enrichment factors substantially greater than one indicate significant surface soil enrichment within the Plant site. Enrichment factors near or slightly greater than unity suggest little, if any, increased element burden in the surface soils. All of the 12 elements analyzed exhibited enrichment; however, ten elements (Ag, As, Cd, Cu, Hg, Pb, Sb, Se, Tl and Zn) exhibited substantial area-wide enrichment above background, with Cd and Pb having the highest factors of 4697 and 1168, respectively. Enrichment factors for Cr and Mn were deemed insignificant compared to enrichment of the other ten elements which for the most part are several orders of magnitude greater.

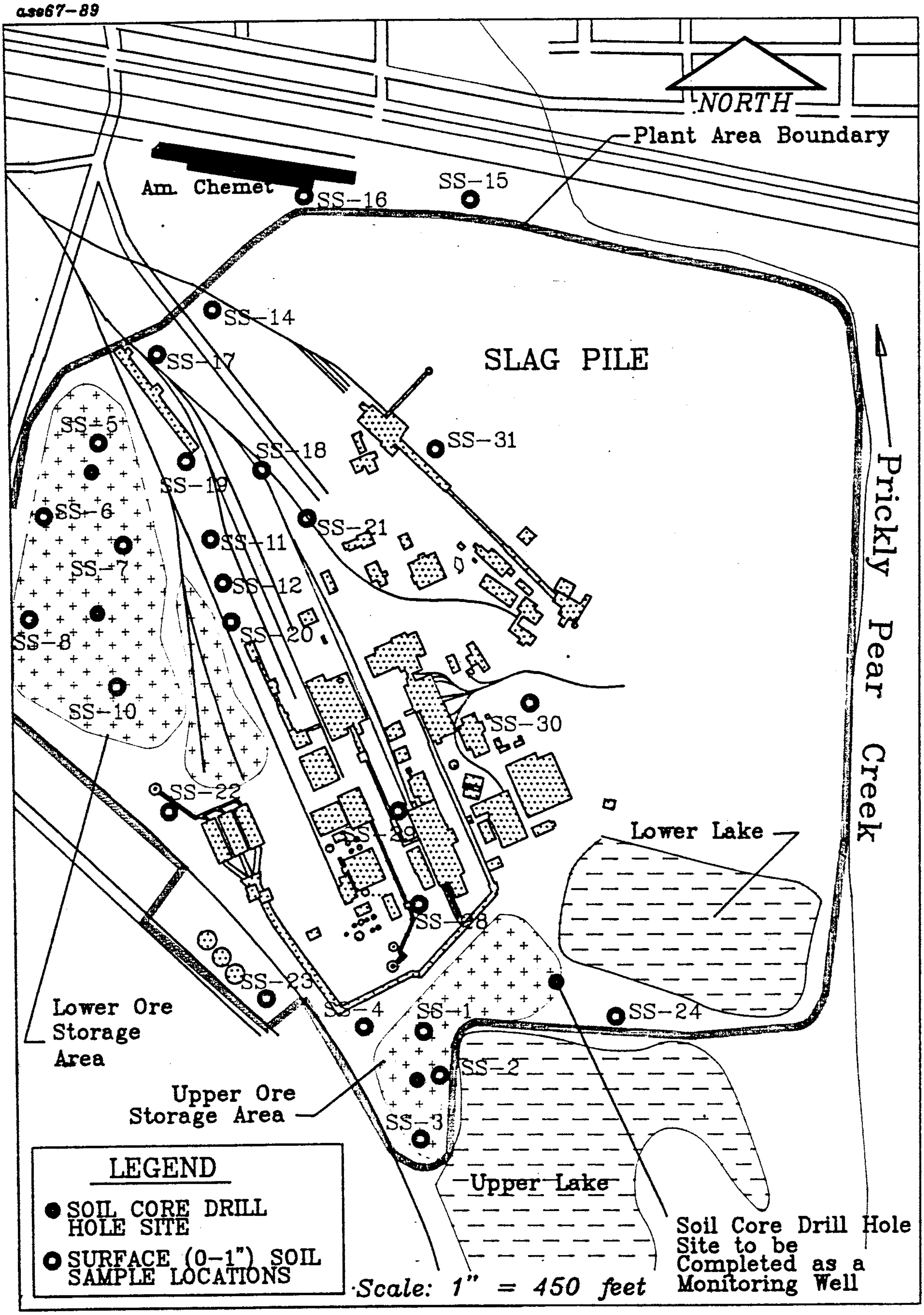


Figure 5-1-7: Surface (0-1") Soil Sample Locations Within The Plant Site - 1987 Phase II Sampling Program

Table 5-1-9. Statistical summary of total element concentrations (ug/g dry weight) in surface (0-1 inch) soil samples collected within the Plant Site.

Element	N[1]	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Geometric Mean	Geo. Mean Background	Enrichment Factor[2]
Ag	26	150.5	65.85	12.0	214.0	122.2	0.20	611
As	26	6228.0	7978.0	121.0	35500.0	2985.0	16.5	181
Cd	26	2986.0	5176.0	92.0	23400.0	1127.0	0.24	4696
Cr	26	27.58	18.34	12.0	86.0	23.77	15.3	1.6
Cu	26	13090.0	9954.0	320.0	35350.0	8492.0	16.3	521
Hg	21	56.84	100.0	0.60	360.0	9.94	0.08	124
Mn	24	1610.0	2284.0	195.0	11700.0	968.3	336.0	2.9
Pb	26	16550.0	7213.0	1368.0	24980.0	13552.0	11.6	1168
Sb	25	998.0	1365.0	5.0	4950.0	193.6	0.27	717
Se	26	115.3	155.2	13.0	518.0	49.09	0.07	701
Tl	26	94.33	116.0	9.90	515.0	52.97	0.09	589
Zn	26	27600.0	23890.0	1093.0	84650.0	16033.0	46.9	342

1/ Note unequal sample sizes due to rejection of some data during data validation process.

2/ Enrichment factor = geometric mean Plant Site soils / geometric mean background.

The primary mode of soil element enrichment within the Plant site is most likely related to ore storage, ore handling and other plant-related activities which tend to concentrate metal ore materials on the soil surface. Analysis for total element concentrations in soil samples accounts for all forms of an element within the soil matrix which includes: 1) the mineral/solid phase; 2) the cation exchange capacity; and, 3) the amount in soil solution. Therefore, surface soil samples collected within the Plant site which have particles of mineral ore in them will likely exhibit unnaturally high total element concentrations compared to soils enriched by aerial deposition only.

5.1.2.3 Spatial Trends in Plant Area Soils

Analysis of variance (ANOV) was calculated to test differences between geometric mean element concentrations for each of the use areas. The least significant difference (LSD) method of multiple comparisons was then used to separate the means. Table 5-1-10 presents results of the LSD test for the 26 plant area surface soils data grouped into the six use area categories. The samples associated with each of the six use area catagories (see Figure 5-1-7) are:

Upper Ore Storage Area (Area 1) - Sample Nos. 1,2,3,4;

Lower Ore Storage Area (Area 2) - Sample Nos. 5,6,7,8,10;

Railroad Tracks East and South of Thawhouse (Area 3) -
Sample Nos. 11,12,17,18,19,20,21;

Perimeter of Slag Pile (Area 4) - Sample Nos. 14,15,16,31;

Miscellaneous Bare Areas Within Main Facility (Area 5) -
Sample Nos. 22,28,29,30;

Miscellaneous Bare Areas Outside Main Facility (Area 6) -
Sample Nos. 23,24.

Table 5-1-10. Geometric means of total element concentrations (ug/g dry weight) for 26 surface (0-1 inch) soil samples grouped into six use area types within the Plant Site.

	Area Type[1]					
Element[2]	1	2	3	4	5	6
Ag	137.1 B	169.8 B	162.9 B	45.8 A	196.3 B	45.1 A
As	3365.0 BC	3013.0 B	9057.0 C	605.3 A	4519.0 BC	505.8 A
Cd	2851.0 C	699.8 AB	2710.0 C	228.6 A	1521.0 BC	360.6 AB
Cr	20.9 A	22.0 AB	38.4 B	19.1 A	16.7 A	21.6 AB
Cu	5000.0 A	8670.0 BC	17219.0 C	6776.0 BC	13709.0 C	1169.0 A
Hg	180.7 B	6.96 A	4.99 A	1.62 A	18.3 A	19.0 AB
Mn	601.2 A	674.5 A	1726.0 A	598.4 A	1641.0 A	410.2 A
Pb	18750.0 BC	21727.0 C	17298.0 BC	4898.0 A	9661.0 AB	13868.0 BC
Sb	142.2 B	87.1 B	1556.0 C	25.4 AB	1459.0 C	5.00 A
Se	230.1 C	20.8 A	90.2 BC	18.5 A	54.6 AB	13.0 A
Tl	120.5 D	44.2 BC	75.0 CD	12.7 A	103.8 CD	21.5 AB
Zn	13397.0 A	20370.0 A	24831.0 A	11722.0 A	21577.0 A	2831.0 A

1/ 1 = Upper ore storage area; 2 = Lower ore storage area; 3 = R.R. tracks east and south of Thawhouse; 4 = Perimeter of slag pile; 5 = Misc. bare areas within main facility; 6 = Misc. bare areas outside main facility.

2/ Values within same element (rows) followed by same letter not signficantly different at P = 0.10.

The results of the ANOV and LSD multiple comparison test show significant variation (P = 0.10) across the six use area categories for all elements except Mn and Zn. Total geometric mean concentrations for six out of the 12 elements (As, Cr, Cu, Mn, Sb and Zn) were found to be highest around the Railroad Tracks East and South of the Thawhouse (Area 3). Four out of the 12 elements (Cd, Hg, Se and Tl) were highest in the Upper Ore Storage Area (Area 1). The highest mean concentration for Pb was in the Lower Ore Storage Area (Area 2).

The highest geometric mean values for Cd exhibited no significant differences (P = 0.10) in Areas 1, 3, and 5. Geometric mean concentrations for As were also statistically similar in Areas 1, 3 and 5. The highest non-significant Pb concentrations were in Areas 1, 2, 3 and 6.

In summary, the data indicate that the surface soil samples collected within Areas 1 (Upper Ore Storage Area) and 3 (Railroad Tracks East and South of Thawhouse) show the highest concentrations of As, Cd and Pb, collectively. Generally, Area 4 (Perimeter of Slag Pile) and Area 6 (Miscellaneous Bare Areas Outside Main Facility) exhibit the lowest concentrations of all 12 analytes. Overall, Areas 1, 2, 3 and 5 appear to have the highest potential to produce fugitive dust emissions with elevated metals.

5.1.2.4 Plant Site Fugitive Dust Control Programs

Fugitive dust emissions originating from enriched surface soils within the Plant Site result from wind erosion, spillage and subsequent vehicle re-entrainment, and from numerous ore handling activities. Asarco employs an ongoing comprehensive dust management program designed to reduce dust on-site as well as keep dust from migrating off-site (Nickel, 1989). This program consists of several dust control systems: 1) a water truck dedicated to dust control; 2) an automatically controlled aerial spraying network; 3) selective use of chemical soil sealers; and 4) pad roadway sweepers and vacuum equipment.

Roadway sweepers remove dust throughout the plant and reclaim metals for processing. In addition, a vacuum truck is also available to clean and contain product spillage, should it occur.

A dedicated water truck and operator are used to wet key dust producing areas throughout the plant complex such as high traffic zones. These key areas are wetted down approximately 12 times per day during non-freezing weather.

The aerial spraying system consists of an automatically timed network of single large "rainbird" type sprinklers, groups of small "rainbird" type sprinklers, and "DELTA" type misters. The large and small rainbird sprinklers have been installed at strategic locations throughout the plant to control dust across large open areas. The DELTA misters are used atop 15 foot poles within the ore storage areas to control dust levels there. Misters are more effective than sprinklers within the ore storage areas since they do not cause leaching and run-off of concentrated metal ores.

Chemical dust suppressants are applied to localized areas manually with a pump truck. A mineral latex binder (DOW Chemical M167.2) diluted with water is being used to "seal" ore piles. When applied, this product sets up as a crust on the surface of the ore pile, thus sealing the ore material from the wind. A petroleum based product (Witco Manufacturing Company COHEREX) is mixed with water and applied to smaller bare areas throughout the Plant such as dirt patches between buildings. This product sets up as a tacky surface, thus sealing the soil from the wind.

In addition to the dust control measures discussed above, Asarco is planning to reduce fugitive dust emisssions directly by constructing a 650′ L x 102′ W x 65′ H "Concentrate Storage and Handling Building". This facility is designed to enclose and ventilate the unloading, storage, mixing, blending and conveying of nearly all lead-bearing ore materials to be smelted. Compared to current open ore storage and processing methods, operation of this facility will result in a substantial reduction in fugitive airborne emissions eminating from the Plant Site. Asarco estimates that the building enclosure alone will reduce airborne emissions by approximately 50 percent. The building enclosure, in conjunction with the proposed ventilation system, will result in a total reduction of approximately 95 percent.

5.1.2.5 Summary and Conclusions of Plant Site Soils Investigation

- All of the 12 elements analyzed in plant area surface (0-1 inch) soil samples exhibited enrichment. The calculated mean enrichment factors for ten elements (Ag, As, Cd, Cu, Hg, Pb, Sb, Se, Tl and Zn) ranged from 124 to 4697 times background. Cadmium, Sb and Pb exhibited the highest enrichment with factors of 4697, 3696 and 1168, respectively. Chromium and Mn enrichment was markedly lower than the other ten elements with factors of 1.6 and 2.9, respectively.

- The data for the 26 samples when grouped into six land-use area catagories show significant spatial differences for particular elements. The highest concentrations of As, Cd and Pb appear to be from surface soil samples collected around the railroad tracks east and west of the Thawhouse, and from the upper and lower ore storage yards. Generally, the lowest values for all elements come from the perimeter of the slag pile and from miscellaneous bare areas outside the main facility. These data indicate that the highest total surface soil element concentrations, and thus the areas with the highest dust producing potential, are associated with ore unloading and storage, as well as ore processing which takes place amongst the various operational facilities.

- Asarco employs an ongoing dust management program designed to reduce dust on-site as well as keep dust from migrating off-site. This program consists of various dust control systems: 1) a water truck dedicated to dust control; 2) an automated aerial spraying network; 3) selective use of chemical soil sealers; and 4) roadway sweepers for dust reclamation.

5.2 SURFACE WATER

5.2.1 Flow in Prickly Pear Creek

Streamflow measurements of Prickly Pear Creek were made by the U.S. Geological Survey, the Montana Water Quality Bureau (WQB) and Hydrometrics. Prickly Pear Creek has been a source of water for agriculture, mining and industrial use for more than a century. The stream has been impacted by highway and railroad construction, subdivision developments, agricultural dewatering, acid-mine drainage from inactive mines in headwaters areas, and municipal and industrial discharges. Maximum streamflow in Prickly Pear Creek usually occurs in response to spring snowmelt, spring rainfall events and intense early summer rainstorms. Minimum streamflow occurs in mid-winter except for lower Prickly Pear Creek where severe summer stream dewatering occurs. Demand for irrigation water typically exceeds the available streamflow during the peak water demand period of July through September. During this time, Prickly Pear Creek often is dry or nearly dry downstream of East Helena. Nearly all agricultural water use occurs in the valley north of East Helena and nearly all points of diversion from the stream are just north of East Helena and upstream to the community of Clancy. Table 5-2-1 shows the diversions from Prickly Pear Creek for the year 1988.

Industries that consume water from Prickly Pear Creek include the Kaiser Cement Company at Montana City and the Asarco Plant. The Pegasus Gold Montana Tunnels mine uses about two cubic feet per second (cfs) from Spring Creek (a tributary of Prickly Pear Creek) near Jefferson City for mining and ore processing operations. In accordance with provisions of permits issued by the Montana Water Quality Bureau under the Montana Pollutant Discharge Elimination System (MPDES) regulations, Hillbrook Nursing Home at Alhambra, Kaiser Cement Company at Montana City, National Cylinder and Gas at East Helena, East Helena's sewage treatment plant, and Helena's sewage treatment plant all are permitted to discharge effluent to Prickly Pear Creek.

Since 1978, the USGS has maintained a continuous streamflow gaging station approximately five miles upstream from the Asarco Plant.

TABLE 5-2-1. DIVERSIONS FROM PRICKLY PEAR CREEK NEAR EAST HELENA, 1988

Source: Bill Wegner, Prickly Pear Creek Water Commissioner

Ditch or Diversion	User	Use *	Amount (cfs)			
			Apr-May	June	July	Aug
Kleffner Ditch	Paul Kleffner	PN	3.3	1.6	--	--
	City of East Helena	MC	3.1	3.1	3.1	2.5
TOTAL			6.4	4.7	3.1	2.5
Main (A)	Olson Ranch	LG,IR	--	--	--	--
	John Oitzinger	ST,IR	3.0	--	--	--
	Donald Espelin	IR	3.2	--	0.9	0.2
	Ike Lanning	ST,IR	--	5.1	1.6	0.2
	Laura Monson	IR	2.0	--	2.1	0.4
	Don Didrikson	IR	--	0.2	--	--
	Doug Porter	IR	0.2	--	--	--
TOTAL			8.4	5.3	4.6	0.8
Main (B)	Herrin Ranch	IR	9.2	5.5	1.8	0.6
	Beverly Donaldson	ST,IR	--	4.3	1.0	0.5
	Gene Helberg	IR	2.2	4.9	2.4	0.5
	Douglas Ashton	ST,IR	--	--	--	0.2
	Mike McCauley	IR	--	3.3	1.7	--
	Cella Merritt	IR	--	0.4	--	--
TOTAL			11.4	18.4	6.9	1.8
Main (C)	Victor Vincent	IR	4.6	2.5	--	--
Main (D)	Leonard Frank	IR	2.4	1.7	--	--
	Douglas Moore	IR	2.4	1.7	--	--
	William Anders	IR	--	1.0	0.6	0.2
TOTAL			4.8	4.4	0.6	0.2
Main Ditch (Total)			35.6	35.3	15.2	5.3

* ST = Stock   IR = Irrigation   IN = Industrial
LG = Lawn & Garden   MC = Municipal   PN = Power Generation

TABLE 5-2-1. DIVERSIONS FROM PRICKLY PEAR CREEK NEAR EAST HELENA, 1988 (continued)

Ditch or Diversion	User	Use *	Amount (cfs)			
			Apr-May	June	July	Aug
Brown Ditch	Don Burnham	ST,IR	--	--	--	--
	Virginia Bompart	IR	3.6	0.3	0.8	0.4
TOTAL			3.6	0.3	0.8	0.4
Ash Grove Diversion	Ash Grove	IN	0.4	0.4	0.4	0.4
ASARCO Diversion	Wilson Ditch **					
	Don Burnham	ST,IR	0.7	2.1	1.6	1.6
	Cliff Lamping	SI	--	--	--	--
	ASARCO Smelter	IN,IR	5.8	5.9	5.9	5.9
TOTAL			10.5	8.0	8.7	8.3
Mt. Tunnels		MN	0.1	3.0	3.4	--
Bob Marks			--	1.6	--	--
TOTAL DIVERSIONS IN 1988			10.6	12.6	12.1	8.3

* ST = Stock IR = Irrigation IN = Industrial
LG = Lawn & Garden MC = Municipal PN = Power Generation

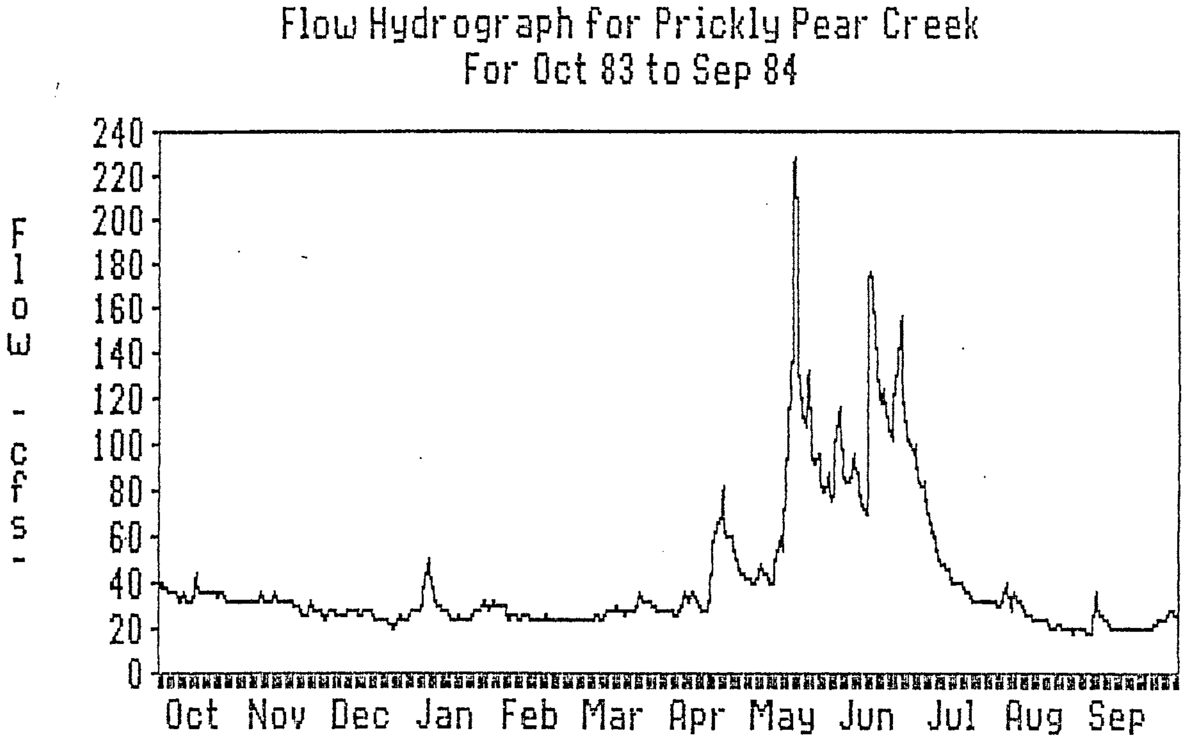
** Wilson Ditch diversion is included in diversion.

Streamflow also was recorded by the USGS at this station for selected years between 1908 and 1969. The drainage area above the gaging station is 192 square miles. Average flow at this station for the 49 years of record is 50.6 cfs. Maximum and minimum flows recorded at this station were about 2300 cfs in May 1981 and 0.5 cfs in January 1958, respectively. Typical streamflow hydrographs for Prickly Pear Creek for October 1983 through September 1988 at the USGS station are on Figures 5-2-1, 5-2-2 and 5-2-3.

The Montana WQB (1981) conducted a study of Prickly Pear Creek in 1979 and early 1980, including periodic streamflow measurements at eight stations on the mainstem of Prickly Pear Creek and four major tributaries. Results of these flow measurements (Table 5-2-2) show mean streamflow generally increases downstream along the mainstem of Prickly Pear Creek due to inputs from tributary streams. The increase in streamflow in Prickly Pear Creek downstream of East Helena is due primarily to effluent discharge from the Helena wastewater treatment plant (Montana WQB, 1981). The mean flow of Prickly Pear Creek at East Helena measured by the Montana WQB in 1979 and 1980 was 49.4 cfs, with measured maximum and minimum flows of 170 and 16 cfs, respectively.

Hydrometrics measured Prickly Pear Creek streamflows in the vicinity of Jefferson City during 1984 and 1985 as part of the hydrology baseline monitoring for the Montana Tunnels ore processing project (Montana DSL, 1985). Streamflow measurements of Prickly Pear Creek and selected tributaries made on October 23, 1985 and September 29, 1988 (Table 5-2-3) show that streamflow increases downstream as a result of inflow from tributary streams. Apparently, groundwater inflow to Prickly Pear Creek also occurs in the upper portion of the stream between Spring Creek and Warm Springs Creek.

Hydrometrics conducted surface water monitoring as part of the Phase I WRM (1984-1985) and the Phase II WRI (1986-1988). Seven surface water monitoring stations were established by Hydrometrics on Prickly Pear Creek in the vicinity of East Helena during 1984. These seven stations, identified as PPC-3 through PPC-9, are shown on Figure 5-2-4. Streamflow was regularly measured at each station from November 1984 through September 1985 and is tabulated in Table 5-2-4.


Flow Hydrograph for Prickly Pear Creek
For Oct 83 to Sep 84

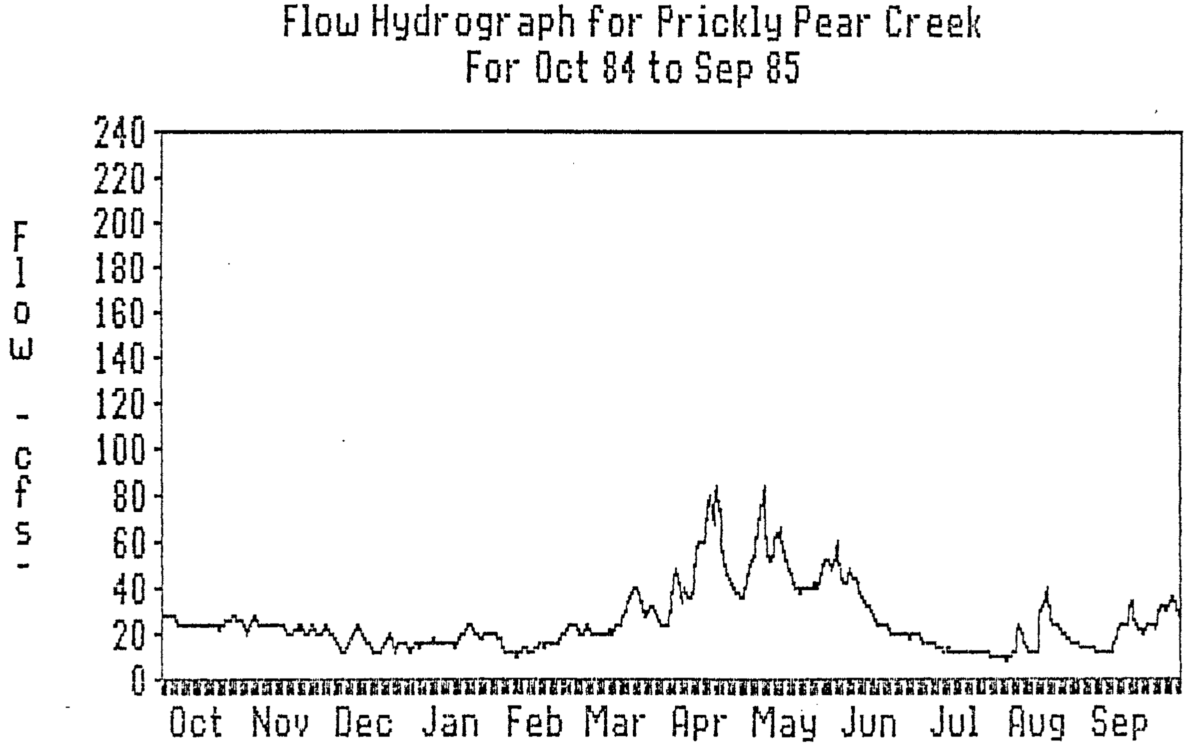
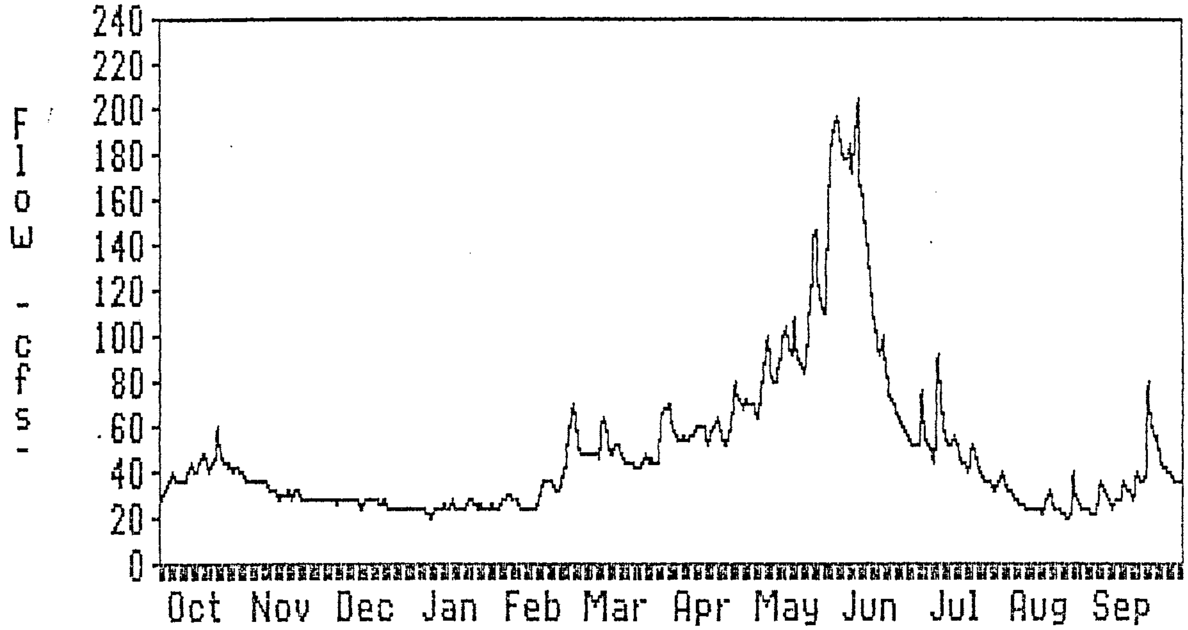

Flow Hydrograph for Prickly Pear Creek
For Oct 84 to Sep 85

Figure 5-2-1: Hydrographs of Prickly Pear Creek for October 1983 through September 1985

Flow Hydrograph for Prickly Pear Creek
For Oct 85 to Sep 86



Flow Hydrograph for Prickly Pear Creek
For Oct 86 to Sep 87

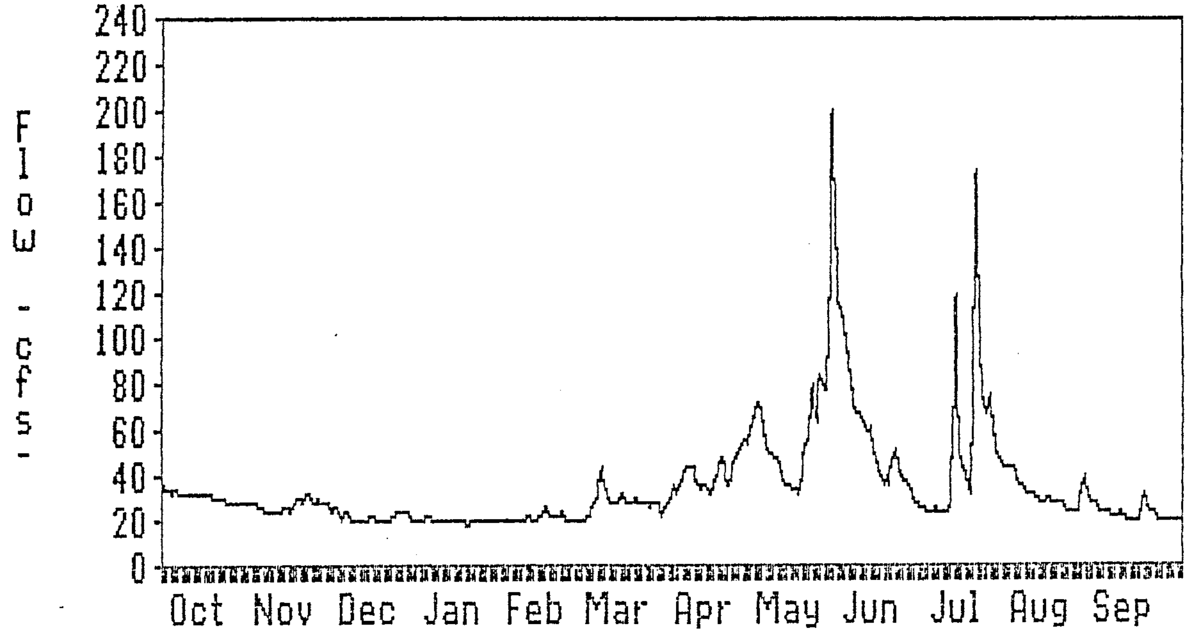


Figure 5-2-2: Flow Hydrographs of Prickly Pear Creek for October 1985 Through September 1987

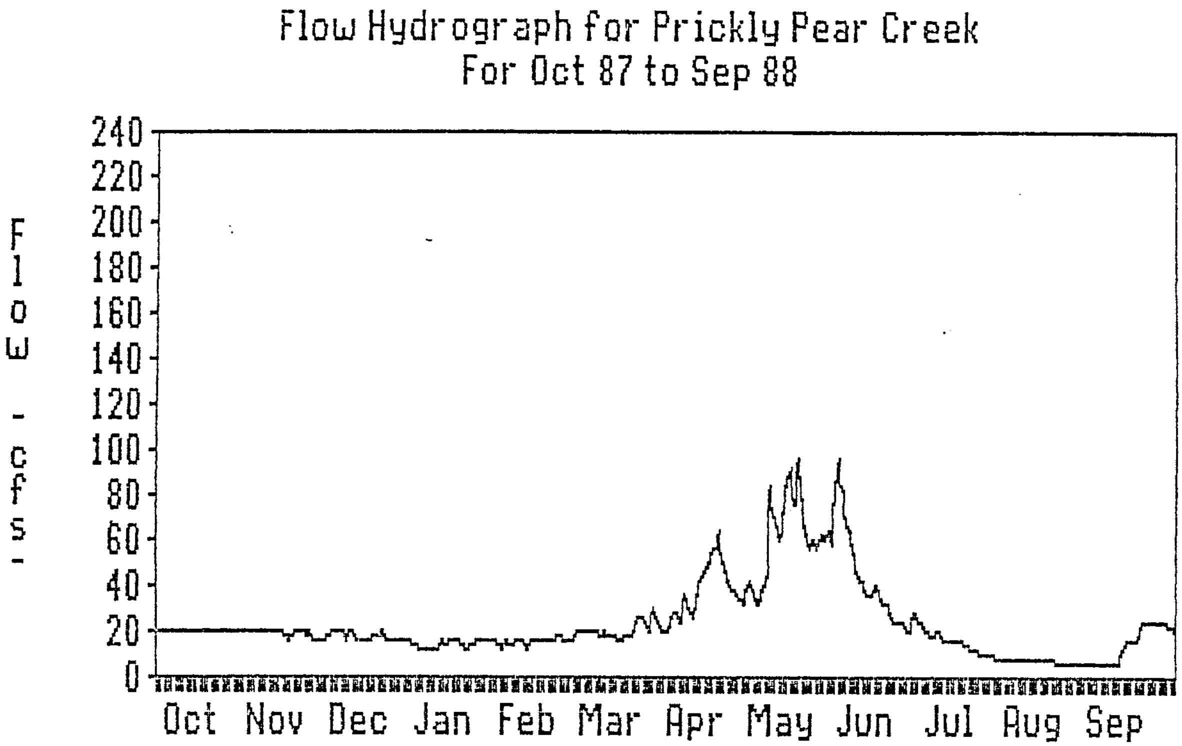


Figure 5-2-3: Flow Hydrographs of Prickly Pear Creek for October 1987 Through September 1988

TABLE 5-2-2. STREAMFLOW MEASUREMENTS OF PRICKLY PEAR CREEK, 1979-1980

		Streamflow in cfs		
Location	No. of Measurements	Minimum Value	Mean	Maximum Value
Prickly Pear Creek above Spring Creek	6	3.0	13.8	35.6
Spring Creek near Mouth	6	2.0	3.6	5.1
Prickly Pear Creek below Spring Creek	6	7.1	19.1	14.2
Warm Springs Creek near Mouth	5	0.8	5.5	19.4
Prickly Pear Creek below Warm Springs Creek	5	17.5	59.6	95.0
Clancy Creek near Mouth	5	1.9	8.8	21.2
Prickly Pear Creek below Clancy Creek	5	20.5	49.7	91.2
Lump Gulch Creek near Mouth	5	0.4	10.1	29.9
Prickly Pear Creek below Lump Gulch	5	19.0	60.8	136.0
Prickly Pear Creek at Montana City	5	13.9	61.7	141.7
Prickly Pear Creek at East Helena	10	15.9	49.4	169.6
Prickly Pear Creek at Mountain View School	12	24.9	55.7	153.0

Source: Montana Water Quality Bureau, 1981.

TABLE 5-2-3. STREAMFLOW MEASUREMENTS OF PRICKLY PEAR CREEK ON OCTOBER 23, 1985 AND SEPTEMBER 29, 1988

Location	10/23/85 Flow (cfs)	09/29/88 Flow (cfs)
Prickly Pear Creek above Spring Creek	3.6	1.6
Spring Creek at Mouth	1.3	DRY
Dutchman Creek at Mouth	1.5 - 2.0 (est.)	NM
Prickly Pear Creek between Dutchman and Warm Spring Creeks	22	21.0
Warm Springs Creek at Mouth	4 - 5 (est.)	NM
Clancy Creek at Mouth	4.5	0.9
Prickly Pear Creek between Clancy Creek and Lump Gulch	35	NM
Lump Gulch at Mouth	3 - 4 (est.)	NM
Prickly Pear Creek below Lump Gulch	40	26.43
Prickly Pear Creek at USGS Station	47	20.

* NM = flows not measured during this synoptic run.

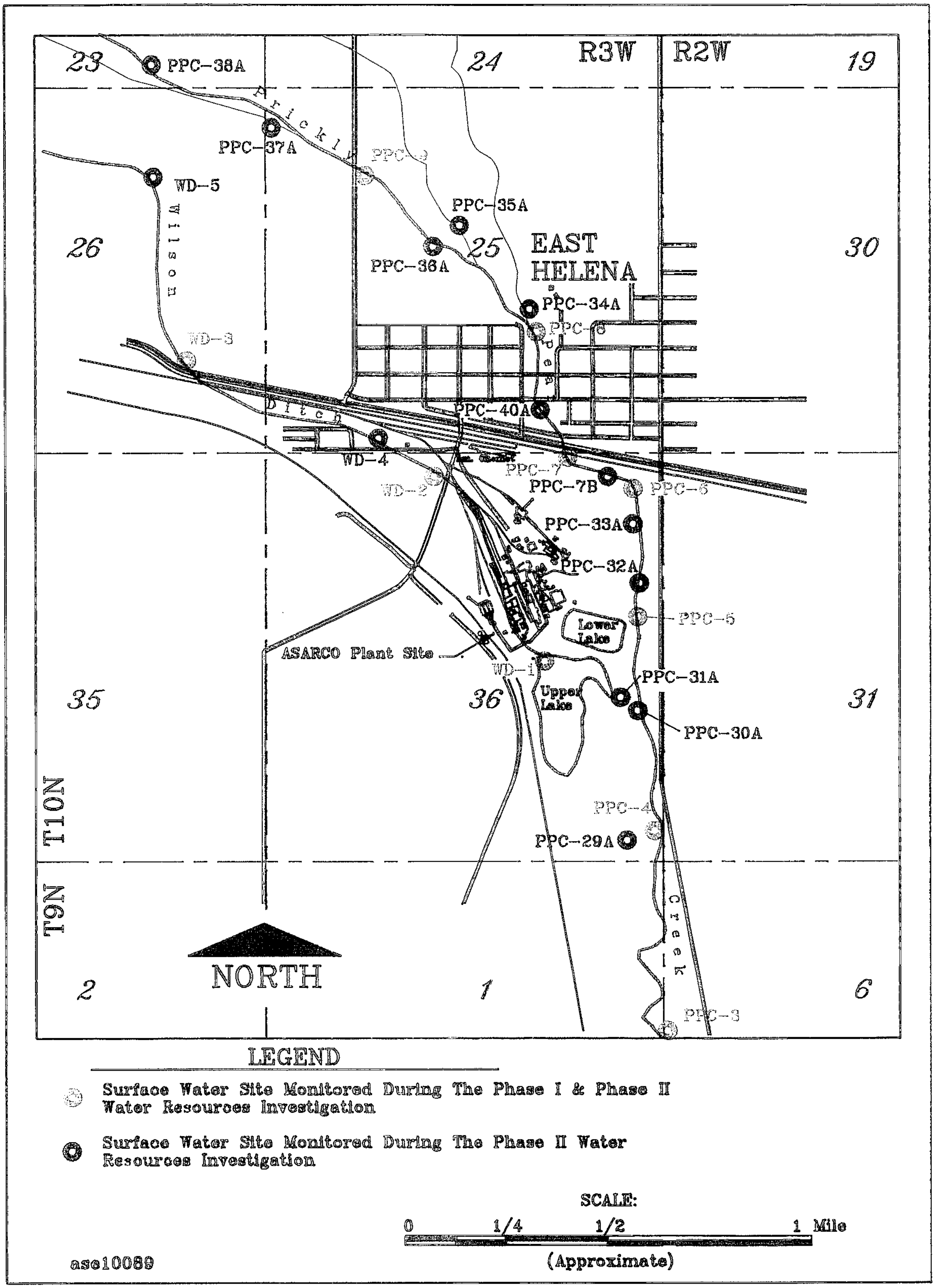


Figure 5-2-4: Surface Water Flow and Water Quality Monitoring Sites

TABLE 5-2-4. SUMMARY OF PRICKLY PEAR CREEK STREAMFLOW MEASUREMENTS NEAR THE ASARCO EAST HELENA PLANT 1984-1985

	STREAMFLOW (cfs)						
Date	Kleffner Ranch	Below Asarco Divers.	Below Plant Dam	Above North Seep	Below North Seep	No.Edge East Helena	Highway 443
Site No.:	PPC-3	PPC-4	PPC-5	PPC-6	PPC-7	PPC-8	PPC-9
11/5-11/7/84	28.6	32.1	33.1	30.7	29.1	28.2	31.7
1/10-1/14/85	Frozen	Frozen	23.7	21.4	Frozen	Frozen	Frozen
4/2-4/3/85	55.8	42.3	63.0	39.1	37.8	37.7	37.9
5/7-5/8/85	81.3	25.7	73.7	62.3	67.5	64.7	40.1
6/4-6/5/85	55.3	12.5	57.1	48.6	46.5	46.0	3.0
7/1-7/2/85	17.3	1.9	16.2	14.3	13.9	12.4	1.8
8/5-8/6/85	14.8	0.2	14.5	11.8	9.8	9.7	2.4
9/12-9/13/85	32.7	15.0	38.2	27.5	25.7	24.9	10.3
AVERAGE (excluding January)	40.8	18.5	42.3	33.5	32.9	31.9	18.2

The spring and early summer of 1985 were exceptionally dry in western Montana including the Prickly Pear Creek drainage. As shown on Figure 5-2-1 streamflow in Prickly Pear Creek was significantly lower from May through July of 1985 than in 1984. Based on streamflow measurements obtained at monitoring stations PPC-3 through PPC-9, during the Phase I investigation, the following conclusions were made.

1) Average flow at PPC-3 located 1.2 miles above the plant is about 41 cfs; the average flow at PPC-9 located about 2.3 miles downstream (about 1.0 miles downstream of the plant) is about 18.2 cfs. This loss reflects both large diversions for irrigation and seepage of surface water into the groundwater system.

2) The Prickly Pear Creek diversion into Upper Lake is located just above station PPC-4; therefore large streamflow decreases usually were observed at station PPC-4. Streamflow lost at station PPC-4 was regained within one-half mile downstream at PPC-5; this additional streamflow primarily comes from Upper Lake via underground seepage and overflow through several culverts.

3) An average streamflow decrease of approximately 8.8 cfs (or 21 percent) was observed between stations PPC-5 and PPC-6 along the east side of the plant area. No surface diversions exist between these stations; therefore, the observed stream decrease was assumed to be due to seepage into the underlying groundwater system. However, the apparent flow difference could be due to relatively poor measurement conditions associated with site PPC-5.

4) Measured streamflow at stations PPC-6, PPC-7 and PPC-8 are similar indicating little gain or loss of water to the groundwater system.

5) Significant decreases in streamflow occur between stations PPC-8 and PPC-9 due to a major irrigation diversion located just downstream of PPC-8.

Wilson Ditch transports irrigation water from Upper Lake to fields northwest of the East Helena Plant (see Exhibit I and Figure 5-2-4). Hydrometrics measured flows in Wilson Ditch from November 1984 through September 1985. The primary measurement site was WD-2 located just west of the plant site. One measurement (3.5 cfs on May 8, 1985) was taken at site WD-3 located approximately one-half mile downstream from WD-2. Wilson Ditch flows only during the irrigation season and averaged 3.5 cfs at WD-2 during the period of record (Table 5-2-5).

Ten additional surface water monitoring sites, PPC-29A through PPC-38A, were established in the vicinity of East Helena during the period 1986 to 1988 as part of the Phase II WRI activities. Additionally, a stilling well and continuous recorder (PPC-7B) were installed at site PPC-7B near monitoring site PPC-7 in order to help assess the interrelationship of Prickly Pear Creek with the groundwater system in the East Helena area. Section 4.0 (Groundwater) provides a discussion on the results from PPC-7B. All Phase I and Phase II surface water monitoring stations are shown on Figure 5-2-4. Streamflows were measured at the 18 measuring stations between PPC-3 and PPC-38A during three synoptic runs conducted during October 1986, May 1987 and August 1987. All streamflow data obtained during the 1986 to 1988 Phase II WRI Water Resources Investigation are tabulated in Table 5-2-6.

Average flows for the three Phase II synoptic runs were calculated in Table 5-2-6 in order to again determine overall trends related to losses or gains to Prickly Pear Creek within the study area. Significant streamflow diverted from Prickly Pear Creek to Upper Lake was again observed during the Phase II streamflow measurements. Monitoring site PPC-29A is located in a diversion canal to Upper Lake, while monitoring site PPC-4 is located on Prickly Pear Creek just downstream from the diversion to Upper Lake.

Using the streamflow data in Table 5-2-6, the approximate percentage of flow diverted from Prickly Pear Creek to Upper Lake for October 1986, May 1987 and August 1987 was 60%, 56% and 43%, respectively.

TABLE 5-2-5. FLOW MEASUREMENTS FOR WILSON DITCH

	Flow (cfs)			Flow (cfs)
Date	WD-2	WD-3	Date	WD-2
11-5-84	Dry		7-5-85	3.2
4-19-85	3.9		7-12-85	3.2
4-26-85	3.5		7-19-85	3.2
5-3-85	6.5		7-26-85	2.6
5-8-85	5.6	3.5	8-2-85	1.3
5-17-85	6.4		8-12-85	2.1
5-31-85	4.8		8-15-85	1.8
6-5-85	5.8		8-29-85	1.7
6-14-85	2.6		9-4-85	2.4
6-21-85	2.8		9-10-85	2.5
7-1-85	3.6			

TABLE 5-2-6. SUMMARY OF PRICKLY PEAR CREEK STREAMFLOW MEASUREMENTS NEAR THE EAST HELENA STUDY AREA 1986-1988

DATE	STREAMFLOW (cfs)									
SITE NO.	PPC-3	PPC-4	PPC-5	PPC-6	PPC-7	PPC-8	PPC-9	PPC-29A	PPC-30A	PPC-31A
10/15/86	40.6	17.0	43.2	41.9	41.8	41.0	39.2	26.0	15.2	24.0
5/7/87	67.8	31.4	66.3	65.7	74.9	69.9	19.9	40.7	24.3	54.5
8/18/87	34.5	22.0	40.4	39.5	36.9	40.4	15.4	16.8	22.6	10.2
11/29/88					13.8					
AVERAGE (Excluding November)	47.6	23.5	50.0	49.0	51.2	50.4	24.8	27.8	20.7	
MEASUREMENT <u>ERROR (+/-)</u>										
10/15/86	4.9	2.0	5.2	5.0	3.3	4.9	3.1	2.1	1.2	--
5/7/87	5.4	3.8	8.0	5.3	6.0	5.6	1.6	2.0	1.2	--
8/18/87	2.8	1.8	4.9	4.7	3.0	4.8	1.2	0.8	1.1	--

DATE	STREAMFLOW (cfs)						
SITE NO.	PPC-32A	PPC-33A	PPC-34A	PPC-35A	PPC-36A	PPC-37A	PPC-38A
10/15/86	41.1	41.7	Dry	2.2	37.4	Dry	37.0
5/7/87	69.5	65.2	0.01	47.8	19.9	9.6	9.3
8/18/87	34.9	37.9	Dry	22.5	15.9	9.0	5.9
11/29/88							
AVERAGE (Excluding November)	48.5	48.3	1.7	24.2	24.4	6.2	17.4
MEASUREMENT <u>ERROR (+/-)</u>							
10/15/86	4.9	5.0	--	--	1.9	--	3.0
5/7/87	5.6	7.8	--	--	2.4	0.8	0.7
8/18/87	4.2	4.6	--	--	1.9	0.5	0.5

It was also confirmed during the 1986-1988 measurements that Prickly Pear Creek regains most or all of its lost streamflow, due to rediversion to Upper Lake, within a one-half mile distance between the Upper Lake diversion (PPC-29A) and PPC-5. Other major diversions include irrigation ditches that were monitored at sites PPC-35A and PPC-37A. During summer irrigation usage, measured in May and August (1987), the average percentage of streamflow diverted by these two irrigation ditches was 68% and 18%, respectively.

The average streamflow decrease between PPC-5 and PPC-6 was observed to be much lower during the Phase II 1986 to 1988 monitoring than during the Phase I (1984-1985) monitoring. The observed average streamflow decrease between PPC-5 and PPC-6 was 8.8 cfs during 1984-1985 while the observed average streamflow decrease for 1986-1988 was only 1.0 cfs.

Table 5-2-6 shows the probable measurement error margin reflecting streamflow channel conditions at the various measurement sites. Since differences in measured flows between stations PPC-5 and PPC-8 are well within the error for flow measurement, gains and loss between these sites cannot accurately be quantified. Examination of groundwater potentiometric contours (Exhibit 4), shows no indications of stream gains or losses below stations PPC-5 through PPC-6. However some loss apparently occurs in the City of East Helena (see Section 4.3).

This conclusion is supported by significant groundwater quality fluctuations in response to streamflow fluctuation (see Section 4.3). However, these losses are apparently too small to accurately measure.

5.2.2 Quality of Surface Water and Bottom Sediment

As part of the November 1984 through September 1985 (Phase I WRM) surface water monitoring program, considerable data were obtained on the quality of waters in Prickly Pear Creek, Upper Lake, Wilson Ditch and Seep-1 (Appendix 5-2-1). Water quality data from overland runoff during an intense precipitation event also were obtained. Analytical results (Appendix 5-2-1) show a wide variation in the quality of various surface waters and show seasonal variations in quality. Chemical analysis of bottom sediment samples from Upper Lake, Prickly Pear Creek and Wilson Ditch (Appendix 5-2-2) show large quality variations between these sampling sites.

Generally, water in Prickly Pear Creek is a hard, alkaline, calcium-bicarbonate type with a moderate concentration of total dissolved solids (TDS) and low to moderate concentrations of arsenic and metals (Tables 5-2-7 and 5-2-8). The stream has moderate to low concentrations of total suspended solids (TSS) except during periods of very high flow. The stream supports a trout fishery upstream of East Helena, but summer dewatering from irrigation diversions and effluent from sewage treatment plants severely limits the fishery downstream of East Helena.

5.2.2.1 Prickly Pear Creek

Prickly Pear Creek is the most important surface water feature in the vicinity of the East Helena Plant. The water resources monitoring program examined the relationship of the East Helena Plant to this stream. Examination of the water quality record for Prickly Pear Creek shows arsenic, copper, iron, lead, manganese and zinc are of interest. Other metals are present only in very low concentrations or at concentrations less than laboratory detection limits. Based on concentration, mobility and environmental sensitivity, arsenic is the parameter of primary interest. An examination of dissolved arsenic provides important information on the relationship between the plant site and Prickly Pear Creek.

Results from 1984-1985 monitoring showed the concentration of both total and dissolved arsenic increases in Prickly Pear Creek between the upstream station PPC-3 and downstream stations PPC-6 through PPC-9. Water quality upstream of PPC-3 has been shown to be impacted by arsenic and metals from old upstream mining disturbances as described by Traynor (1969), Pedersen (1977) and Montana WQB (1981). During the study period of November 1984 to September 1985, the average dissolved arsenic concentration at PPC-3 ranged from <0.004 to 0.010 mg/l and averaged about 0.006 mg/l. Seasonal variations in dissolved arsenic concentrations at PPC-3 are shown in Figure 5-2-4.

Surface water monitoring during 1984 and 1985 included the collection of samples at seven sites (PPC-3 through PPC-9). Surface water monitoring during 1986 to 1988 included the collection of water samples at 13 sites (PPC-3 through PPC-9; PPC-30A, PPC-32A, PPC-33A, PPC-36A, PPC-38A and PPC-40A), the diversion from Prickly Pear Creek to Upper Lake (PPC-29A),

TABLE 5-2-7. TYPICAL WATER QUALITY IN PRICKLY PEAR CREEK, UPPER LAKE AND WILSON DITCH

SITE NAME	PPC-3	PPC-7	UPPER LAKE	WD-2
SAMPLE DATE	06/05/85	06/04/85	06/06/85	06/05/85
LAB	ASARCO	JTC	ASARCO	ASARCO
PHYSICAL PARAMETERS				
SPEC. COND. (UMHOS/CM) FIELD	218.0	223.6	228.4	227.0
PH LAB	7.8	8.00	7.7	7.6
TOTAL SUSP. SOLIDS	4.5	6	9.9	6.8
TDS MEAS. @ 180 DEG. C	152	128	165	161
COMMON IONS				
CALCIUM (CA)	25	28.70	25	25
MAGNESIUM (MG)	6.1	5.95	6.2	6.3
SODIUM (NA)	13.4	10.20	12.8	14
POTASSIUM (K)	2.3	<1.166	2.4	2.6
ALKALINITY AS CACO3 (LAB)	64.9	70.0	70.6	68.9
BICARBONATE (HCO3) (LAB)	79	85	86	84
SULFATE (SO4)	36.2	34.7	36.7	35.9
CHLORIDE (CL)	2.3	2.5	<2	<2
TRACE ELEMENTS				
ARSENIC (AS) TOTAL	0.007	0.0244	0.013	0.018
ARSENIC (AS) DISS	<0.004	0.0097	0.007	0.012
CADMIUM (CD) TOTAL	0.003	<0.0036	0.003	0.004
CADMIUM (CD) DISS	0.001	<0.0036	0.001	0.001
COPPER (CU) TOTAL	0.011	<0.015	0.024	0.016
COPPER (CU) DISS	0.009	<0.015	0.013	0.009
IRON (FE) TOTAL	0.188	0.356	0.263	0.388
IRON (FE) DISS	<0.020	<0.041	0.025	0.020
LEAD (PB) TOTAL	0.007	0.0183	0.088	0.075
LEAD (PB) DISS	<0.005	<0.0024	<0.005	0.016
MANGANESE (MN) TOTAL	0.053	0.119	0.074	0.123
MANGANESE (MN) DISS	0.028	0.079	0.066	0.096
ZINC (ZN) TOTAL	0.063	0.076	0.079	0.073
ZINC (ZN) DISS	0.035	0.049	0.041	0.038

Note: Values reported for 06/04/85 are from JTC lab; JTC values were used in lieu of ASARCO lab values because JTC tested for a more complete list of parameters. For the parameters tested by both JTC and ASARCO, reported values are comparable.

All quantities in milligrams per liter unless otherwise noted. Blank line indicates parameter not tested. Output Date: 01-03-1990

TABLE 5-2-8. STATISTICAL SUMMARY OF PRICKLY PEAR CREEK WATER QUALITY ANALYSES

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	5-17.5	15.8	25.86	48
SPEC. COND. (UMHOS/CM) FIELD	184-340.2	252	44	106
SPEC. COND. (UMHOS/CM) LAB	153-348	251	57	106
PH FIELD	6.72-8.86	7.88	0.497	50
PH LAB	6.4-8.4	7.79	0.298	105
TOTAL SUSP. SOLIDS	<1-45.4	9.0	22.61	66
TDS MEAS. @ 180 DEG. C	134-237	182	31.6	106
STAGE (FT)	0.54-5.4	1.49	1.03	34
COMMON IONS				
CALCIUM (CA)	25-35	31.1	2.7	15
MAGNESIUM (MG)	6.1-8.1	7.5	0.6	15
SODIUM (NA)	13-21	14.7	2.8	15
POTASSIUM (K)	2.3-4.3	3.1	0.7	15
ALKALINITY AS CACO3 (LAB)	60-104	80.5	14.4	16
BICARBONATE (HCO3) (LAB)	63-127	90.0	16.3	65
SULFATE (SO4)	0.036-87.9	40.5	10.1	64
CHLORIDE (CL)	<2-6.9	4.2	2.1	16
TRACE ELEMENTS				
ARSENIC (AS) TOTAL	<0.006-0.089	0.021	0.017	105
ARSENIC (AS) DISS	<0.004-0.079	0.016	0.015	106
CADMIUM (CD) TOTAL	<0.001-0.015	0.001	0.002	106
CADMIUM (CD) DISS	<0.001-0.011	0.005	0.043	105
COPPER (CU) TOTAL	<0.008-0.016	0.0146	0.0148	16
COPPER (CU) DISS	<0.008-0.009	0.007	0.005	17
IRON (FE) TOTAL	0.08-2.38	0.374	0.336	66
IRON (FE) DISS	0.006-0.13	0.067	0.024	66
LEAD (PB) TOTAL	<0.005-0.113	0.022	0.017	106
LEAD (PB) DISS	<0.005-0.2	0.006	0.019	105
MANGANESE (MN) TOTAL	0.053-0.303	0.112	0.074	16
MANGANESE (MN) DISS	0.028-0.279	0.072	0.057	17
ZINC (ZN) TOTAL	0.021-0.21	0.066	0.028	106
ZINC (ZN) DISS	0.011-0.082	0.036	0.013	105

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANAL
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.

a diversion culvert from Upper Lake to Prickly Pear Creek (PPC-31A), three irrigation ditches, (PPC-34A, PPC-35A, and PPC 37A) and the seep (Seep-1).

Downstream of PPC-3, arsenic concentrations increase and at PPC-7, dissolved arsenic averages 0.021 mg/l. Curves showing typical increases in concentrations of dissolved arsenic from the 1984 and 1985 results for PPC-3 to PPC-9 are in Figures 5-2-5, 5-2-6 and 5-2-7. These figures also illustrate the rapid increase in dissolved arsenic concentration between PPC-4 and PPC-6.

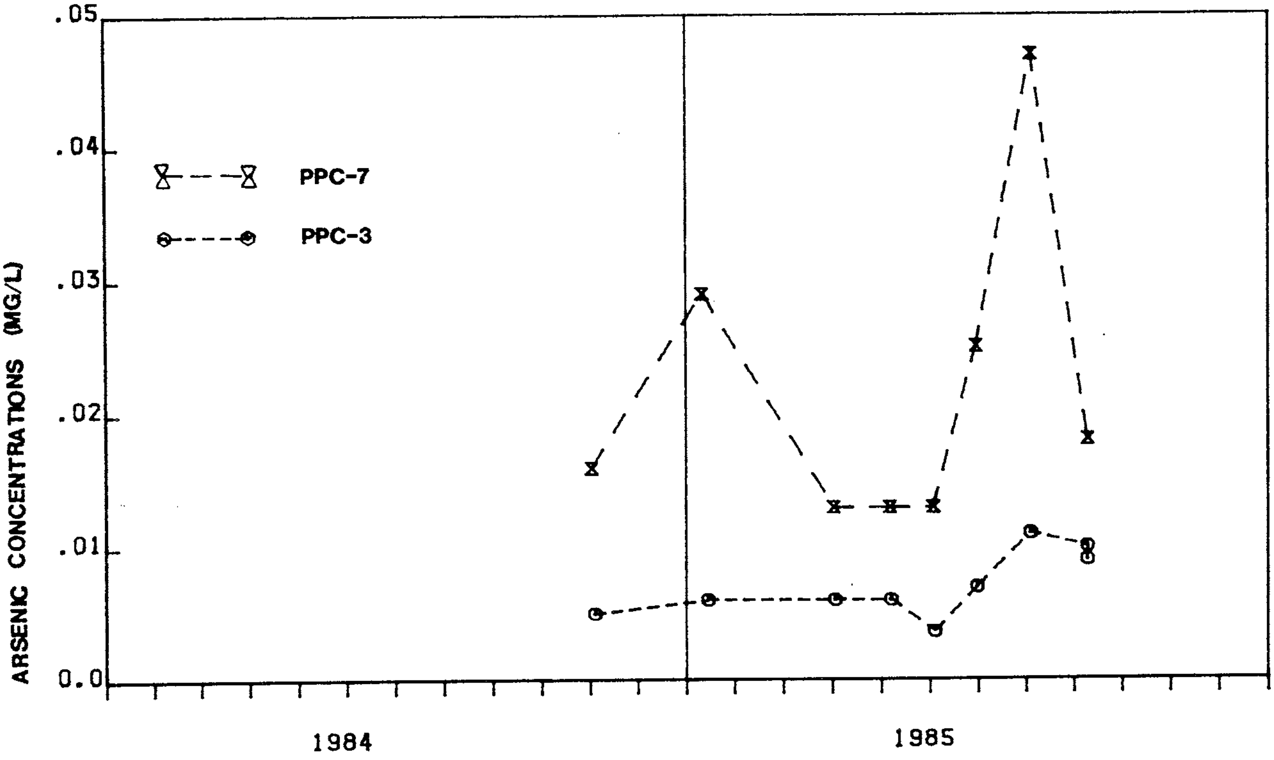
To further evaluate variations in arsenic concentration in Prickly Pear Creek, the loads of dissolved arsenic in the stream were calculated between PPC-3 and PPC-7. Transport of arsenic in the stream was assumed to be conservative; that is, arsenic was not lost or gained from the system by physical or chemical processes. Station PPC-3 is well upstream of the East Helena Plant and PPC-7 is downstream. Streamflows and dissolved arsenic concentrations are similar between PPC-3 and PPC-4 and between PPC-6, PPC-7 and PPC-8.

Loads were calculated using the following equation:

$$L = F \times C \times 2.44$$

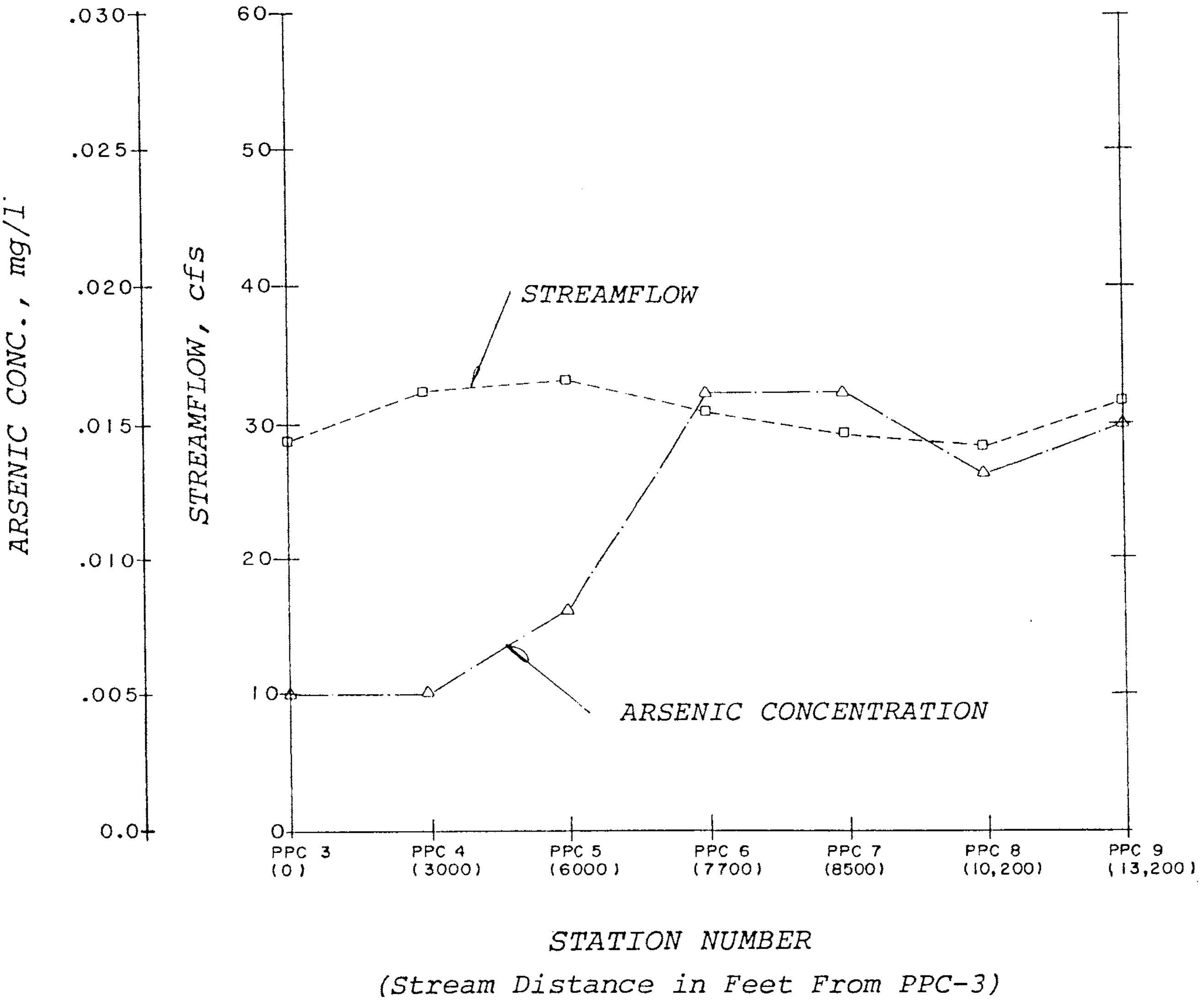
where: L = Load in kg/day (kilograms/day)
F = Streamflow in cfs (cubic feet per second)
C = Concentration in mg/l (milligrams/liter)

Results of load calculations are tabulated in Table 5-2-9 for the sampling period of November 1984 through September 1985. Load calculations for the period of October 1986 through August 1987 are tabulated in Table 5-2-10. Downstream increases in dissolved arsenic concentration between PPC-3 and PPC-7 range from 0.007 mg/l to 0.037 mg/l (1984-1985 results) or 0.004 mg/l to 0.013 mg/l (1986-1988 results) and average 0.014 mg/l (1984-1986 results) or 0.008 mg/l (1986-1988 results).



Hydrometrics, Inc.
Consulting Scientists & Engineers
Helena, Montana

Figure 5-2-5.
Seasonal Variations of Dissolved Arsenic Concentrations at Prickly Pear Creek Sites PPC-3 & PPC-7



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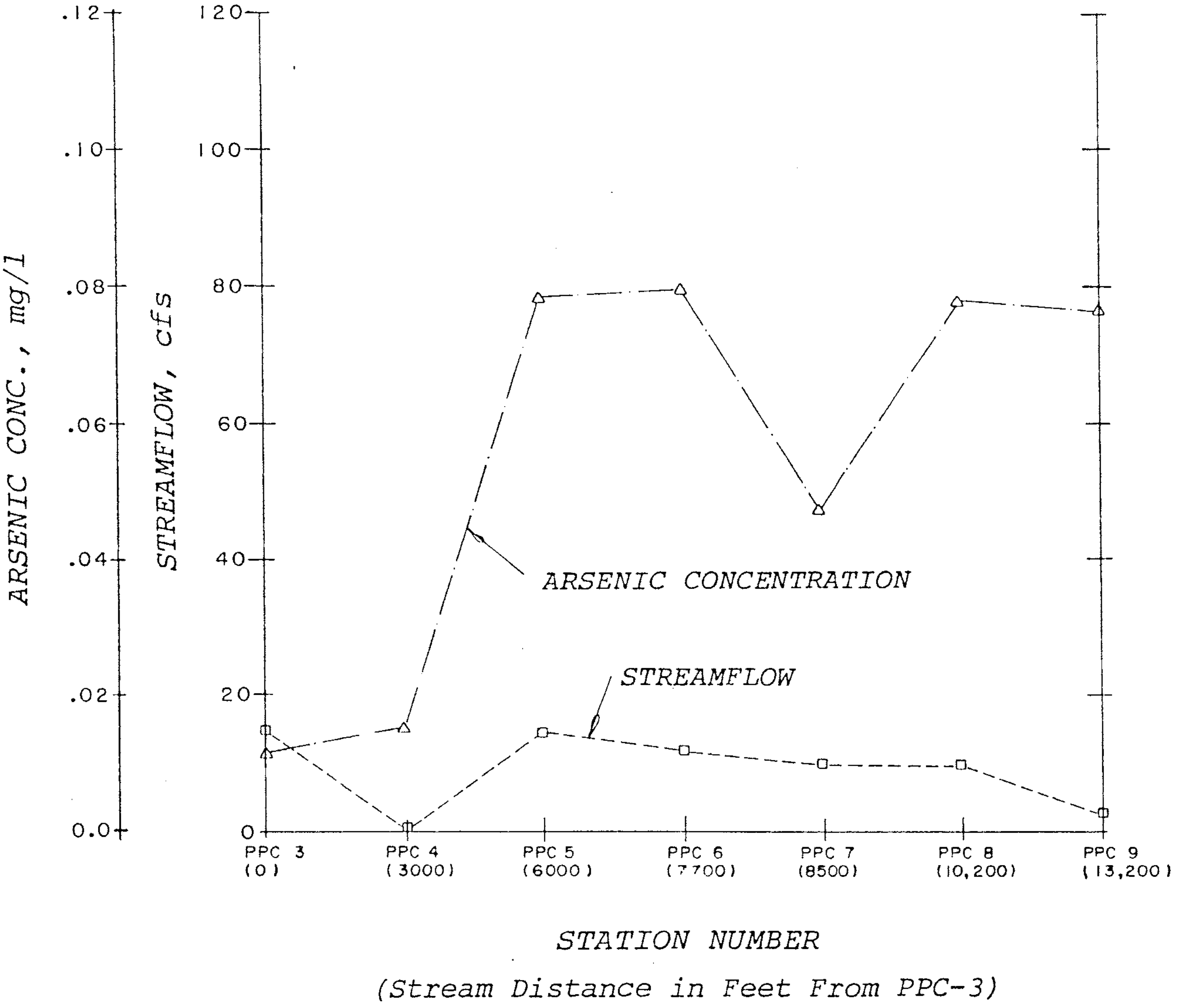
Helena, Montana

Figure 5-2-6.
Prickly Pear Creek Streamflow & Dissolved Arsenic Concentrations for November, 1984



Hydrometrics, Inc.
Consulting Scientists & Engineers
Helena, Montana

Figure 5-2-7
Prickly Pear Creek Streamflow & Dissolved Arsenic Concentrations for August, 1985

TABLE 5-2-9. DISSOLVED ARSENIC CONCENTRATIONS AND LOADS IN PRICKLY PEAR CREEK AT STATIONS PPC-3 AND PPC-7 (1984-1985)

Station	Streamflow (cfs)	Arsenic Concentration (mg/l)	Arsenic Load (kg/day)
November 1984			
PPC-3	28.6	0.005	0.349
PPC-7	29.1	0.016	1.137
Difference	0.5	0.011	0.787
April 1985			
PPC-3	55.8	0.006	0.817
PPC-7	37.8	0.013	1.199
Difference	-18.0	0.007	0.382
May 1985			
PPC-3	81.3	0.006	1.190
PPC-7	67.5	0.013	2.141
Difference	-13.8	0.007	0.951
June 1985			
PPC-3	55.3	<0.004*	0.540
PPC-7	46.5	0.013	1.475
Difference	- 8.8	0.009	0.935
July 1985			
PPC-3	17.3	0.007	0.295
PPC-7	13.9	0.025	0.848
Difference	- 3.4	0.018	0.553
August 1985			
PPC-3	14.8	0.010	0.361
PPC-7	9.8	0.047	1.124
Difference	- 5.0	0.037	0.763
September 1985			
PPC-3	32.7	0.010	0.798
PPC-7	25.7	0.018	1.129
Difference	- 7.0	0.008	0.331

*Assume for calculation purposes dissolved arsenic concentration is 0.004 mg/l.

TABLE 5-2-10. DISSOLVED ARSENIC CONCENTRATIONS AND LOADS IN PRICKLY PEAR CREEK AT STATIONS PPC-3 AND PPC-7 (1986-1988)

Station	Streamflow (cfs)	Arsenic Concentration (mg/l)	Arsenic Load (kg/day)
October 1986			
PPC-3	40.6	<0.006*	0.594
PPC-7	41.8	0.010	1.020
Difference	1.20	0.004	0.426
May 1987			
PPC-3	67.8	<0.006*	0.993
PPC-7	74.9	0.013	2.284
Difference	7.10	0.007	1.291
August 1987			
PPC-3	34.5	0.009	0.758
PPC-7	36.9	0.022	1.981
Difference	2.40	0.013	1.223

* Assume for calculation purposes dissolved arsenic concentration is 0.006 mg/L

Similarly, increases in loads of arsenic in the stream between stations PPC-3 and PPC-7 range from 0.33 to 0.95 kg/day (1984-1985 results) or 0.43 kg/day to 1.29 kg/day (1986-1988 results) and average 0.67 kg/day (1984-1985 results) or 0.98 kg/day (1986-1988 results). Streamflow in Prickly Pear Creek during the study period was exceptionally low in response to a near record low in precipitation during these periods (see Figure 5-2-1). Loads and concentrations of arsenic measured in Prickly Pear Creek during these periods of unusually low flow may have been higher than normal. Higher concentrations of arsenic generally occur during the periods of low streamflow. During years with normal spring and summer runoff, the loads and concentrations of arsenic in Prickly Pear Creek may be lower than measured during this study period.

If it is assumed that Lower Lake is the cause of arsenic concentration increases in Prickly Pear Creek, an approximation of the hypothetical quantity of seepage from Lower Lake into Prickly Pear Creek near station PPC-5 can be made using the following loading calculation:

$$L_3 + L_L = L_7$$

Where: L_3 = arsenic load in Prickly Pear Creek at station PPC-3.
L_L = hypothetical arsenic load in water seeping from Lower Lake into Prickly Pear Creek.
L_7 = arsenic load in Prickly Pear Creek at station PPC-7.

The above equation can also be written as follows:

$$F_3C_3 + F_LC_L = F_7C_7$$

Where: F = flow in cfs.
C = concentration of dissolved arsenic in mg/l.

This equation can be solved for F_L which is the hypothetical quantity of seepage from Lower Lake into Prickly Pear Creek. Assuming a mean flow of 35 cfs at stations PPC-3 and PPC-7, and dissolved arsenic concentrations of 0.0007 mg/l, 0.02 mg/l and 17 mg/l at PPC-3, PPC-7 and Lower Lake, respectively, F_L is calculated to equal about 13 gpm. Lower Lake is near

Prickly Pear Creek between stations PPC-4 and PPC-5 where the arsenic load and concentration increases and may be a source of arsenic.

The following conclusions are based on results for dissolved arsenic concentration and load data in Prickly Pear Creek.

1) Results for 1984-1985 and 1986-1988 show loads and concentrations of dissolved arsenic increase by a factor ranging from 0.3 to 2.3 and 0.7 to 3.7, respectively, between upstream station PPC-3 and downstream station PPC-7.

2) The most rapid increase in loads and concentrations of dissolved arsenic occurred at station PPC-5. Apparently, significant changes in loading do not occur between PPC-5 and PPC-8 which indicates the slag piles are not significant contributors to arsenic concentrations in Prickly Pear Creek.

3) Flows diverted from Prickly Pear Creek upstream of stations PPC-4 and PPC-9 severely affect loads but have little impact on dissolved arsenic concentrations.

4) Maximum increases in dissolved arsenic concentrations occurred during periods of lowest flow in Prickly Pear Creek. Exceptionally low rainfall during the study period and the resultant low streamflow probably caused higher than normal increases of arsenic loads and concentrations in Prickly Pear Creek.

5) The observed increase in dissolved arsenic concentration between PPC-3 and PPC-7 is related to an inflow of a small quantity of seepage water from Lower Lake into Prickly Pear Creek.

Concentrations of total arsenic at all stations on Prickly Pear Creek were slightly higher than for dissolved arsenic. Evaluation of total arsenic data shows loads and concentrations vary in a manner quite similar to that of dissolved arsenic.

Data for copper, lead, manganese and zinc also were examined for Prickly Pear Creek since these parameters may be good indicators of the relationship of the plant and the creek. Results of this examination show the following:

1) Copper. Surface water quality results show that dissolved copper concentrations commonly are less than laboratory detection limits and there are insufficient data to determine downstream trends in copper. Dissolved copper concentrations are sufficiently low, both upstream and downstream, and are of little significance in evaluating the effects of the plant. Total copper data have a pattern similar to dissolved copper with many analyses showing very low concentrations or concentrations less than laboratory detection limits.

2) Lead. Dissolved lead is present in low to undetectable concentrations in Prickly Pear Creek both upstream and downstream of the plant. No trends in dissolved lead concentrations are shown by the data. The results for 1984-1985 show a slight increase in total lead concentrations in the downstream direction with average total lead concentration increasing by about 0.012 mg/l between PPC-3 and PPC-7 for the study period. The results for 1986-1988 show an average total lead increase of .015 mg/l between PPC-3 and PPC-7 for the study period. Surface water quality results of total lead (loads) showed a very small average increase in the downstream direction (0.07 kg/day and .014 kg/day, respectively between PPC-3 and PPC-7).

3) Manganese. Once mobilized, dissolved manganese is not readily removed from natural waters. Surface water quality results show manganese is present in elevated concentrations in Lower Lake but is in low concentrations in Prickly Pear Creek. Dissolved and total manganese appear to be of little

significance in evaluating the relationship between the plant and Prickly Pear Creek.

4) Zinc. Dissolved zinc in Prickly Pear Creek was present both upstream and downstream of the plant during the sampling events. Concentration and load data for dissolved zinc show essentially no changes in concentration downstream in Prickly Pear Creek and 1984-1985 results showed a decrease of zinc loads of about 0.73 kg/day. This data indicates the plant has no measurable influence on zinc in stream water. Total zinc data show a pattern very similar to dissolved zinc.

5.2.2.2 Upper Lake

Water samples were collected from Upper Lake during 1984-1985 monitoring. Upper Lake receives water diverted from Prickly Pear Creek just above sampling site PPC-4. Quality of water in this pond is essentially the same as that of Prickly Pear Creek at sampling sites PPC-3 and PPC-4 (Table 5-2-7, and Appendix 5-2-1). Station PPC-3 is about 0.4 miles upstream of the Upper Lake diversion and PPC-4 is located about 150 feet downstream of the diversion. Seasonal variations in quality of water in Upper Lake are very similar to those observed in Prickly Pear Creek.

5.2.2.3 Wilson Ditch

Water is diverted from Upper Lake to the Wilson Ditch at a headgate located at sampling station WD-1 (Exhibit 1). Water quality (Appendix 5-2-1) is essentially the same as that of Upper Lake and Prickly Pear Creek at sample sites PPC-3 and PPC-4. Typical quality of water in Wilson Ditch is in Tables 5-2-7 and a statistical summary is in Table 5-2-11. Based on samples from stations WD-1, WD-2 and WD-3 taken during 1984-1985 the quality of water along Wilson Ditch is the same at all three stations. Seasonal variations of water quality in Wilson Ditch (Appendix 5-2-1) also are similar to those of Prickly Pear Creek and Upper Lake.

5.2.2.4 Seep-1

Seep-1 is located at the toe of the large fumed slag pile (Exhibit 1) and is primarily a ponded surface expression of the groundwater table. Seep-

1 was the only seep observed peripheral to the slag piles during this investigation.

Water at Seep-1 generally is a sodium-sulfate type water with concentrations of dissolved arsenic ranging from 3.31 mg/L to 13.75 mg/L. Typical quality of water data from Seep-1 are in Appendix 5-2-1. Water quality variations in this seep may have been caused by variable evaporation and precipitation. Concentrations of total dissolved solids and arsenic were highest during the August sampling period after several months of low rainfall and high evaporation rates. The 1984-1985 investigation indicated that the concentration of total dissolved solids and arsenic declined in September following a relatively high precipitation period in late August.

Comparison of 1984-1985 results for water in Seep-1 (Appendix 5-2-1) with groundwater in nearby monitoring wells DH-6 and DH-10 show the quality of these waters are similar. During this study, Seep-1 did not flow any measurable quantity of water and did not directly impact nearby Prickly Pear Creek. One sample of water from Seep-1 was collected during May, 1987, and the results confirm the conclusions from the 1984-1985 results.

5.2.2.5 <u>Overland Runoff</u>

Overland runoff samples were collected at four sites A, B, C and D during a short intense thunder shower on May 29, 1985. Additional overland runoff samples were collected at sites A, E, F, G and H after a rain shower on July 2, 1987. These sites were selected to determine quality of surface water runoff inside the plant boundary (Sites B, C, E, F, G and H) and immediately outside the plant (Sites A and D). Locations of these sites are shown on Exhibit 1. Analytical results (Appendix 5-2-1) show waters are basically two types: calcium-sulfate within the plant area and calcium-bicarbonate immediately outside the plant area. The runoff water collected contained elevated concentrations of total metals, particularly lead and arsenic. Results from samples collected in 1985 are shown in Table 5-2-12 and results for 1987 runoff samples are shown in Table 5-2-13. Dissolved metals are significantly lower than total metals. Suspended sediment concentrations were very high in the runoff waters which explains the higher concentrations of total metals. Samples from sites within confines of the plant (Sites B, C, E, F, G and H) had

TABLE 5-2-11. STATISTICAL SUMMARY OF WATER QUALITY ANALYSES FOR WILSON DITCH (WD-2)

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
SPEC. COND. (UMHOS/CM) FIELD	195-376.9	282	52.42	21
SPEC. COND. (UMHOS/CM) LAB	100-365	284	63.1	20
PH LAB	7-8.7	7.76	.421	21
TOTAL SUSP. SOLIDS	3.5-19.5	8.44	4.17	21
TDS MEAS. @ 180 DEG. C	<1-255	185	67.08	21
COMMON IONS				
CALCIUM (CA)	21.31-25	23.3	1.5	5
MAGNESIUM (MG)	4.79-6.3	5.43	.625	5
SODIUM (NA)	8.58-14	10.94	2.28	5
POTASSIUM (K)	1.82-2.6	2.15	.298	5
ALKALINITY AS CACO3 (LAB)	53-76	63.24	9.15	5
BICARBONATE (HCO3) (LAB)	65-93	77.2	11.19	5
SULFATE (SO4)	22.3-46.9	34.26	8.79	5
CHLORIDE (CL)	<2-4	2.2	1.25	5
TRACE ELEMENTS				
ALUMINUM (AL) TOTAL	.23-.36	.295	.092	2
ALUMINUM (AL) DISS	<.136	<.136	.0001	2
ANTIMONY (SB) TOTAL	<.052	<.052	0	2
ANTIMONY (SB) DISS	<.052	<.052	0	2
ARSENIC (AS) TOTAL	.007-.034	.019	.0079	25
ARSENIC (AS) DISS	.004-.03	.012	.0067	25
BARIUM (BA) TOTAL	.026-.036	.031	.0071	2
BARIUM (BA) DISS	.022-.024	.023	.0014	2
BERYLLIUM (BE) TOTAL	<.0049-.005	<.0049	.0018	2
BERYLLIUM (BE) DISS	<.0049	<.0049	0	2
CADMIUM (CD) TOTAL	<.001-.008	.0042	.0017	25
CADMIUM (CD) DISS	<.001-.006	.0016	.0015	25
CHROMIUM (CR) TOTAL	<.0079-.015	.0095	.0078	2
CHROMIUM (CR) DISS	<.0079	<.0079	0	2
COBALT (CO) TOTAL	<.02	<.02	0	2
COBALT (CO) DISS	<.015-<.02	<.015	.0018	2
COPPER (CU) TOTAL	.014-.05	.023	.015	6
COPPER (CU) DISS	<.008-<.02	<.008	.002	6
IRON (FE) TOTAL	.388-1.23	.792	.281	6
IRON (FE) DISS	.02-.125	.076	.054	6
LEAD (PB) TOTAL	.02-.163	.093	.041	25
LEAD (PB) DISS	<.0024-<.025	.0078	.0055	25
MANGANESE (MN) TOTAL	.123-.267	.186	.056	6
MANGANESE (MN) DISS	.096-.179	.137	.038	6
MERCURY (HG) TOTAL	.00025-<.00047	.00025	0	2
MERCURY (HG) DISS	.00019-<.00028	.0002	0	2

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 11-15-1989 HWQ-11/87R.ST.2

TABLE 5-2-11 (Continued) STATISTICAL SUMMARY OF WATER QUALITY ANALYSES FOR WILSON DITCH (WD-2)

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
TRACE ELEMENTS				
NICKEL (NI) TOTAL	<.018	<.018	0	2
NICKEL (NI) DISS	<.018	<.018	0	2
SELENIUM (SE) TOTAL	<.0039	<.0039	0	2
SELENIUM (SE) DISS	<.0039	<.0039	0	2
SILVER (AG) TOTAL	<.0096	<.0096	0	2
SILVER (AG) DISS	<.0096	<.0096	0	2
THALLIUM (TL) TOTAL	<.0026-<.026	.0072	.0083	2
THALLIUM (TL) DISS	<.026-<.1	.032	.026	2
TIN (SN) TOTAL	<.034-.061	.039	.031	2
TIN (SN) DISS	<.034-.048	<.034	.022	2
VANADIUM (V) TOTAL	<.033	<.033	0	2
VANADIUM (V) DISS	<.033	<.033	0	2
ZINC (ZN) TOTAL	.035-.204	.078	.039	25
ZINC (ZN) DISS	.008-.104	.029	.025	25

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 11-15-1989 HWQ-11/87R.ST.2

TABLE 5-2-12. WATER QUALITY OF OVERLAND RUNOFF 1985

SAMPLING SITE	SITE A	SITE B	SITE B	SITE C	SITE D
SAMPLE NUMBER	8505-A	8505-B	8505-E	8505-C	8505-D
SAMPLE DATE	05/29/85	05/29/85	05/29/85	05/29/85	05/29/85
LAB	ASARCO	ASARCO	ASARCO	ASARCO	ASARCO
REMARKS			REPLICATE		
PHYSICAL PARAMETERS					
SPEC. COND. (UMHOS/CM) FIELD	224.9	818.9		741.0	154.3
SPEC. COND. (UMHOS/CM) LAB	239	877		807	188
PH LAB	7.8	6.6		7.1	7.1
TOTAL SUSP. SOLIDS	4320	393		783	2210
TDS MEAS. @ 180 DEG. C	142	543		541	118
COMMON IONS					
CALCIUM (CA)	23	74		100	16.7
MAGNESIUM (MG)	4.7	6.8		4.2	1.8
SODIUM (NA)	7.0	74		39	4.3
POTASSIUM (K)	6.4	13.5		8.6	7.3
ALKALINITY AS CACO3 (LAB)	811	75.8		389	399
BICARBONATE (HCO3) (LAB)	989	92.5		475	487
CARBONATE AS CACO3 (LAB)	<2.0	<2.0		<2.0	<2.0
SULFATE (SO4)	37.6	1811		429	54.8
CHLORIDE (CL)	16.1	23		13.5	2.6
TRACE ELEMENTS					
ARSENIC (AS) TOTAL	1.63	8.0	7.5	5.88	1.75
ARSENIC (AS) DISS	0.137	1.75	1.75	0.040	0.155
CADMIUM (CD) TOTAL	0.975	1.09	1.08	2.41	0.525
CADMIUM (CD) DISS	0.006	0.344	0.331	0.85	0.039
COPPER (CU) TOTAL	3.99	8.75		14.0	2.85
COPPER (CU) DISS	0.060	0.129		0.035	0.073
IRON (FE) TOTAL	200	21.3		31.3	104.0
IRON (FE) DISS	0.1	<0.020		<0.020	0.263
LEAD (PB) TOTAL	30.1	36.4	34.5	92.5	24.6
LEAD (PB) DISS	0.063	0.063	0.063	0.388	0.075
MANGANESE (MN) TOTAL	4.75	1.23		2.36	2.3
MANGANESE (MN) DISS	0.019	0.553		0.838	0.409
ZINC (ZN) TOTAL	8.38	25.6	24.8	23.1	7.88
ZINC (ZN) DISS	0.020	6.5	6.25	3.0	0.213

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED
BLANK LINE INDICATES PARAMETER NOT TESTED
INCLUDES DATA FROM ASARCO LABORATORY ONLY. SAMPLE NUMBER PREFIX IS 'AEH'.
OUTPUT DATE: 02/04/86

TABLE 5-2-13. WATER QUALITY OF OVERLAND RUNOFF 1987

SITE NAME	SITE A	SITE E	SITE F	SITE G	SITE H
SAMPLE DATE	07/02/87	07/02/87	07/02/87	07/02/87	07/02/87
LAB	ASARCO	ASARCO	ASARCO	ASARCO	ASARCO
SAMPLE NUMBER	8707-1	8707-2	8707-3	8707-4	8707-5
PHYSICAL PARAMETERS					
SPEC. COND. (UMHOS/CM) LAB	750	980	4630	5000	14800
PH LAB	6.88	6.98	7.50	7.78	10.30
TOTAL SUSP. SOLIDS	1124	1524	4062	2564	2026
TDS MEAS. @ 180 DEG. C	562	888	2898	3595	11261
SETTLEABLE MATTER (ML/L)	3.0	0.9	7.5	25.0	4.5
COMMON IONS					
CALCIUM (CA)	49	74.5	125	335	10.8
MAGNESIUM (MG)	2.6	4.3	8.2	16.6	1.6
SODIUM (NA)	63	104	825	770	3850
POTASSIUM (K)	6.5	6.6	93	82	104
BICARBONATE (HCO3) (LAB)	59	87	172	84	3865
CARBONATE AS CO3 (LAB)	<1.0	<1.0	<1.0	<1.0	379
SULFATE (SO4)	340	258	1980	2220	2740
CHLORIDE (CL)	13	12	140	290	1950
TRACE ELEMENTS					
ARSENIC (AS) TOTAL	11.200	10.500	72.000	184.000	380.000
CADMIUM (CD) TOTAL	4.530	7.130	46.700	68.000	20.000
COPPER (CU) TOTAL	36.600	26.200	332.000	1200.000	800.000
IRON (FE) TOTAL	48.700	43.300	281.300	1093.000	364.000
LEAD (PB) TOTAL	76.000	68.700	520.000	1600.000	506.700
MANGANESE (MN) TOTAL	2.530	4.100	9.870	52.000	10.500
ZINC (ZN) TOTAL	76.000	48.700	221.000	544.000	180.000

All quantities in milligrams per liter unless otherwise noted. Blank line indicates parameter not tested. Output Date: 01-03-1990

the highest concentrations of total metals. Essentially all overland runoff from the plant is contained or routed by the plant drainage system and does not reach Prickly Pear Creek.

Site A is a shallow ephemeral drainage about 0.3 miles west of the plant and was flowing in excess of 100 gpm during the July 2, 1987 sampling. Site B, located in the plant complex near the zinc plant, was also flowing in excess of 100 gpm during the July 2, 1987 sampling. Site C is just northwest of Lower Lake and was a freshly formed pool of water. Site D is about 0.3 miles east of Lower Lake and was a small, freshly formed pool of water. Site E is just south of the change house and next to former Thornock Lake. Site F is east of the blast furnace and just south of site B. Site G is just east of the ore storage and handling building. Site H is northwest of the sinter plant in the ore storage area.

Estimates of storm surface water runoff resulting from precipitation is potentially a large contributor of excess water in the plant site. Estimates were calculated for the 10 year-24 hour and the 100 year-24 hour events using the SCS method (See Process Pond Remedial Investigation/Feasibility Study, Hydrometrics, Inc., 1989a). The plant was divided into 16 subdrainages as shown in Exhibit 2. Results of runoff computations are shown in Table 5-2-14. Of the 14 subdrainages, seven (P4, P5 and P8 through P11) are routed through the main plant process circuit drainage system and ultimately Lower Lake. The remaining subdrainages either do not contribute flow (primarily the slag pile) or flow off plant property. Total plant runoff estimated for the 100 year event is 4.5 acre-feet or about 1.5 million gallons. This volume would raise the elevation of Lower Lake about 0.7 feet. Runoff data for other potential configurations including paving all of the plant and routing all flow to one location are shown in Table 5-2-15.

Double Ring Infiltrometer (DRI) tests were conducted within the plant during May, 1987 in order to assess infiltration rates and potential percolation of surface water to groundwater.

Fifteen DRI tests were run at six different locations around the plant. The specific sites were chosen in the ore storage area and observed

TABLE 5-2-14. EAST HELENA PLANT RUNOFF CALCULATION SUMMARY

DRAINAGE	SURFACE DESCRIPTION	TOTAL AREA (acres)	PAVED AREA (acres)	10 YR/24 HR RUNOFF VOL. (acre-ft)	100 YR/24 HR RUNOFF VOL. (acre-ft)
P1	Slag	36.5	0	0	0
P1A	Slag	2.5	0	0	0
P2	Slag	7.2	0.2	0	0
P3	Lower Lake Slag	1.4	0	0	0
P4	Lower Lake Slag Upper Lake Storage Area	6.8	2.5	0.0	0.2
P5	South Warehouse	1.2	1.1	0.1	0.2
P6*	Upper Lake Storage Area	2.9	0.3	0.1	0.3
P7*	West Plant	4.7	0.2	0.2	0.5
P8	South Plant	11.8	8	0.8	1.5
P9	North Plant	5.6	1.5	0.4	0.7
P10	Zinc Plant and Parking Lot	14.4	7.8	0.4	1
P11	Northeast Storage	7.4	2.1	0.4	0.8
P12	North of Parking Lot	4.6	0	0.2	0.5
P13	Ore Storage	28.7	12.4	1.9	3.6
		-----	----	---	----
Total runoff from plant		135.7 acres	36.1 acres	4.5 ac-ft 1.5 M G	9.3 ac-ft 3.0 M G
Total runoff to Lower Lake (P5, P6, P8 - P12)		42.8 acres	20.9 acres	2.2 ac-ft 0.7 M G	4.5 ac-ft 1.5 M G

Note: Drainage areas used for calculation of runoff are shown in Exhibit 1.
M G = million gallons

*Flows from these subbasins do not flow into Lower Lake.

TABLE 5-2-15. EAST HELENA PLANT RUNOFF CALCULATION SUMMARY ASSUMING 95% PAVED CONDITIONS

DRAINAGE DESIGNATION	SURFACE DESCRIPTION	TOTAL AREA (acres)	10 YR/24 HR RUNOFF VOL. (acre-ft)	100 YR/24 HR RUNOFF VOL. (acre-ft)
P1	Slag	36.5	0	0
P1A	Slag	2.5	0	0
P2	Slag	7.2	0	0
P3	Lower Lake Slag	1.4	0	0
P4	Lower Lake Slag Upper Lake Storage Area	6.8	0.2	0.5
P5	South Warehouse	1.2	0.1	0.2
P6*	Upper Lake Storage Area	2.9	0.1	0.3
P7*	West Plant	4.7	0.1	0.5
P8	South Plant	11.8	1.1	2.3
P9	North Plant	5.6	0.5	1.1
P10	Zinc Plant and Parking Lot	14.4	1.3	2.8
P11	Northeast Storage	7.4	0.7	1.4
P12	North of Parking Lot	4.6	0.1	0.5
P13	Ore Storage	28.7	2.7	5.6
		----	----	---
Total runoff from plant		135.7 acres	6.9 ac-ft 2.2 M G	15.2 ac-ft 5.0 M G

Note: Plant drainage areas used for calculation of runoff are shown in Exhibit 1.
All area paved except slag pile
M G = Million Gallons

*Flows from these subbasins do not flow into Lower Lake.

runoff route or collection sites where infiltration of surface metals into the groundwater is possible. The specific locations of each individual test are shown in Figure 5-2-8.

At least two DRI tests were performed at each test site location. The areas for each DRI test were selected to present a range of expected infiltration rates. Typically, most of the site areas contained a lower area where water would drain to and/or pond during a precipitation event. These lower areas would naturally have a higher frequency of wet-dry cycles and therefore have higher relative densities than the surrounding soil. A similar soil type with a higher relative density will generally experience a lower infiltration rate. Because of these facts, the following results for the DRI tests show, in some instances, a ten-fold difference in infiltration rates at the same site.

These differences should not be averaged, but should be taken as the range of infiltration rates to be expected depending on the magnitude of a particular storm event.

DRI tests DR-1, DR-2, and DR-3 were conducted at Site 1, which is located just inside and west of the entrance gate, west of the thawhouse (Figure 5-2-8). Infiltration rates at Site 1 ranged from 0.85 cm/hr for DRI-1 to 5.0 cm/hr for DR-2. Plotted infiltration test data for all of the tests are in Appendix 5-2-2. A summary of the results is shown in Table 5-2-16.

DRI tests DR-4 through DR-7 were conducted at Site 2; however, the results for tests DR-5 and DR-7 were not retained because of suspected leaks between the inner and outer rings. The location of Site 2 is just inside of the northeast fence corner east of the thawhouse (Figure 5-2-8). Site 2 is located in an area where the ground surface is covered with coke fines. The results for DR-4 and DR-6 show the range of infiltration rates in this area to be between 0.5 to 1.0 cm/hr.

Site 3 was located approximately 50 feet west of the concrete lot containing the ore piles (Figure 5-2-8). The soil in this area is considered a silt-clay based on visual inspections. The infiltration rate for test DR-8 was 2.2 cm/hr and represented a relatively dry area

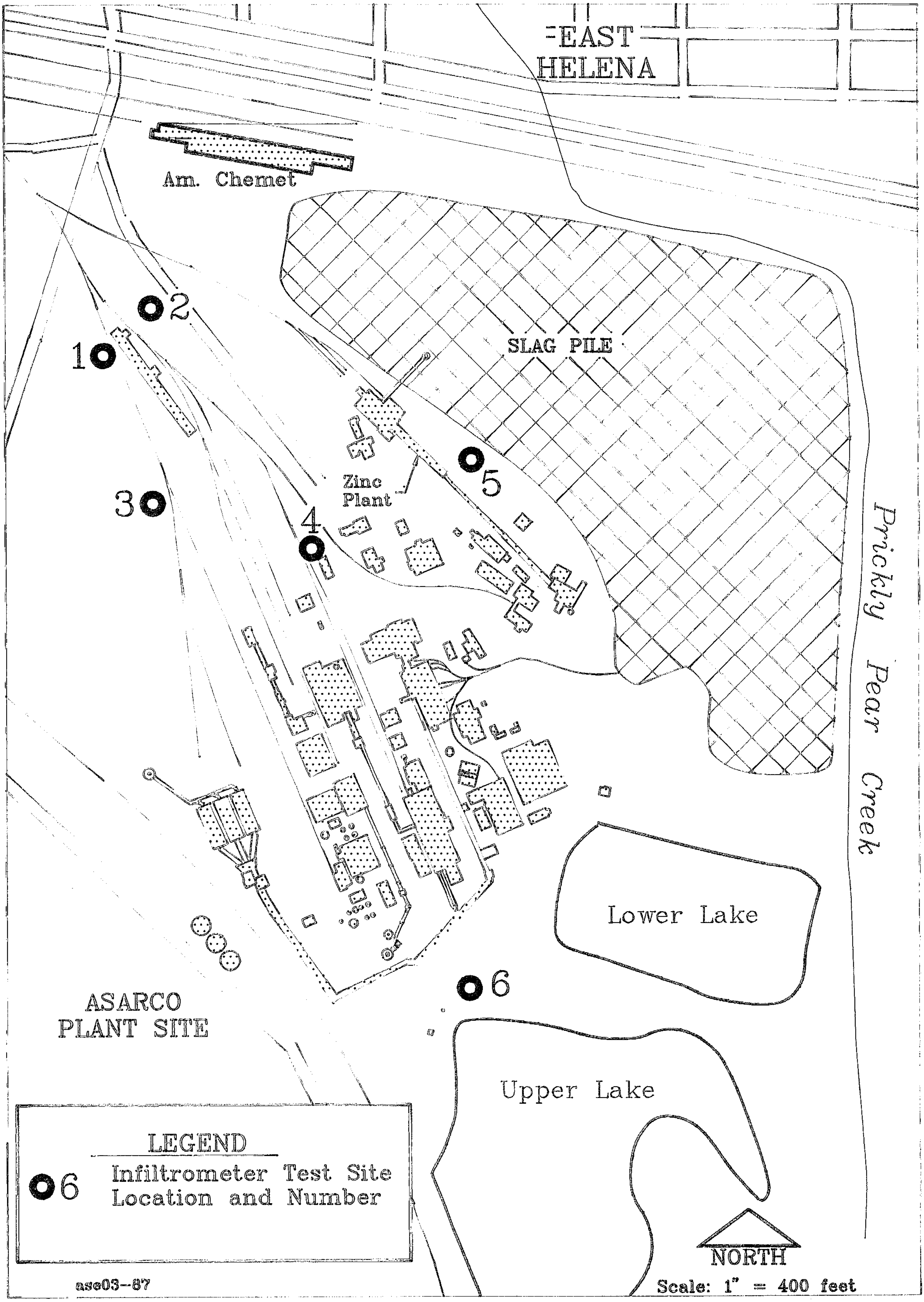


Figure 5-2-8: Location of Double Ring Infiltration Sites

TABLE 5-2-16. SUMMARY OF DRI TESTS

Test Site	Test No.	Soil Description	Infiltration Rate (cm/hr)
1	DR-1	Silty-clay	0.85
	DR-2	Silty-clay	5.0
	DR-3	Silty-clay	2.0
2	DR-4	Coke Fines	1.0
	DR-5	Coke Fines	Suspected Seal Leak
	DR-6	Coke Fines	0.5
	DR-7	Coke Fines	Suspected Seal Leak
3	DR-8	Silty-clay	2.2
	DR-9	Silty-clay	0.45
4	DR-10	Gravelly-clay	0.04
	DR-11	Gravelly-clay	0.03
5	DR-12	Gravelly-clay	1.5
	DR-13	Gravelly-clay	0.15
6	DR-14	Crushed Screenings with clay	0.25
	DR-15	Crushed Screenings with clay	0.06

within the site. Site 3 also contains numerous sprinkler systems which create definite drainage paths when discharging water. Test DR-9 was conducted next to one of the observed drainage paths. The results showed a relatively low infiltration rate of 0.45 cm/hr.

Site 4 was located just west of the main office in a depression between the railroad tracks and the main office (Figure 5-2-8). The soil at this site consists mostly of clay with some gravel. Site 4 testing results (DR-10 and DR-11), are 0.03 to 0.04 cm/hr, respectively.

Site 5 was located just east of the zinc plant flue (Figure 5-2-8). The soil in this area consists of clay with some gravel. Site 5 testing results, (DR-12 and DR-13) were 0.15 cm/hr and 1.5 cm/hr, respectively.

Site 6 was located approximately 120 feet north of the north end of a retaining wall near Upper Lake. This soil consisted of a mixture of crushed gravel with clay fines. Test results (DR-14 and DR-15), were 0.06 and 0.25 cm/hr, respectively.

5.2.3 Quality of Bottom Sediment

Bottom sediment was collected from Prickly Pear Creek at sites PPC-3 through PPC-9; from Wilson Ditch at sites WD-2, WD-3, WD-4 and WD-5; and from Upper Lake. Most bottom sediment samples were collected in November of 1984 and June of 1985. Analyses showed sediment chemical characteristics for most parameters varied little between the November 1984 and June 1985 sampling periods (Appendix 5-2-3). Additional sediment samples of Wilson Ditch were collected and analyzed as part of the Comprehensive RI activities in December 1987. The results of these analyses are in Appendix 4-3. Statistical summaries of bottom sediment analyses for Prickly Pear Creek, Upper Lake and Wilson Ditch are in Tables 5-2-17, 5-2-18 and 5-2-19, respectively.

5.2.3.1 Prickly Pear Creek and Upper Lake

Prickly Pear Creek sediment quality reflects two basic environments: 1) upstream physical and chemical conditions of Prickly Pear Creek, and 2) runoff transported (and deposited) sediment from the plant site including process waters.

TABLE 5-2-17. STATISTICAL SUMMARY OF BOTTOM SEDIMENT CHEMISTRY ANALYSES - PRICKLY PEAR CREEK

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
TRACE ELEMENTS				
ANTIMONY (SB) TOTAL	<10	<10	0	14
ARSENIC (AS) TOTAL	10-84	31.36	21.46	14
BARIUM (BA) TOTAL	35-150	88.57	35.05	14
CADMIUM (CD) TOTAL	1-19	6.61	6.68	14
CHROMIUM (CR) TOTAL	35-140	82.14	28.33	14
COBALT (CO) TOTAL	<10-14	<10	3.27	14
COPPER (CU) TOTAL	23-195	89.79	60.03	14
IRON (FE) TOTAL	15100-35000	24936	7355	14
LEAD (PB) TOTAL	60-1450	386	374	14
MANGANESE (MN) TOTAL	950-2850	1464	483	14
MERCURY (HG) TOTAL	.05-4.6	.937	1.33	14
SILVER (AG) TOTAL	<2.5-7.5	2.64	2.03	14
VANADIUM (V) TOTAL	<100	<100	0	14
ZINC (ZN) TOTAL	185-2650	896	717	14

ALL QUANTITIES IN MILLIGRAMS PER KILOGRAM UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.

TABLE 5-2-18. STATISTICAL SUMMARY OF UPPER LAKE BOTTOM SEDIMENT ANALYSES

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
TRACE ELEMENTS				
ANTIMONY (SB) TOTAL	<10	<10	0	2
ARSENIC (AS) TOTAL	83-264	174	128	2
BARIUM (BA) TOTAL	95-115	105	14.14	2
CADMIUM (CD) TOTAL	48-65	56.5	12.02	2
CHROMIUM (CR) TOTAL	45-75	60	21.21	2
COBALT (CO) TOTAL	16-18	17	1.41	2
COPPER (CU) TOTAL	280-330	305	35.36	2
IRON (FE) TOTAL	38750-40500	39625	1236	2
LEAD (PB) TOTAL	1350-4150	2750	1980	2
MANGANESE (MN) TOTAL	800-900	850	70.7	2
MERCURY (HG) TOTAL	2.5-15	8.75	8.84	2
SILVER (AG) TOTAL	7.5-9	8.25	1.06	2
VANADIUM (V) TOTAL	<100	<100	0	2
ZINC (ZN) TOTAL	2125-2550	2338	301	2

ALL QUANTITIES IN MILLIGRAMS PER KILOGRAM UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT,
WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE
WAS USED FOR THE MEAN.
OUTPUT DATE: 12-14-1989 HWQ-11/87R.ST.2

TABLE 5-2-19. STATISTICAL SUMMARY OF WILSON DITCH BOTTOM SEDIMENT (0-4" DEPTH) ANALYSES COLLECTED 12/22/87

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
PH LAB	7.3-8.5	7.83	.574	4
TRACE ELEMENTS				
ARSENIC (AS) TOTAL	169-2080	832	857	4
CADMIUM (CD) TOTAL	68-251	167	81.02	4
COPPER (CU) TOTAL	87-850	571	356	4
IRON (FE) TOTAL	18350-23550	20820	2480	4
LEAD (PB) TOTAL	889-6528	4277	2463	4
MANGANESE (MN) TOTAL	1879-2745	2363	410	4
ZINC (ZN) TOTAL	903-4865	3003	1695	4
OTHER PARAMETERS				
COARSE FRAGMENTS (%)	39.9-73.17	57.5	15.28	4

ALL QUANTITIES IN MILLIGRAMS PER KILOGRAM UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT,
WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE
WAS USED FOR THE MEAN.
OUTPUT DATE: 12-14-1989 HWQ-11/87R.ST.2

Figure 5-2-9 shows the average arsenic, cadmium, lead, and zinc concentration in mg/kg.

Prickly Pear Creek sites PPC-3 and PPC-4 probably reflect sediment conditions resulting from old upstream mining, milling and other disturbances. Sediment at sites PPC-5 through PPC-9 are noticeably higher in arsenic and other metals. Figure 5-2-9 shows metals concentrations in bottom sediments in Prickly Pear Creek increase downstream in Prickly Pear Creek.

Upper Lake, located upstream of the East Helena Plant, has bottom sediment that contains elevated concentrations of arsenic and metals (see Figure 5-2-9). This is probably a result of deposition of arsenic and metal-bearing sediment derived from old upstream mining disturbances and tailings in the Prickly Pear Creek drainage.

As Prickly Pear Creek is diverted to Upper Lake, the velocity of water movement slows considerably, and allows the settling and collection of suspended sediment. This results in higher metals concentrations in Upper Lake sediments than those found in Prickly Pear Creek bottom sediments.

Another potential source of elevated metals concentrations in Upper Lake bottom sediments is fallout from past air emissions. Examination of surface soils in areas outside the plant show areas of elevated metals concentration (see Section 5.1) that are probably the result of fallout from past air emissions. It is likely, therefore, that a portion of the elevated metals concentrations in Upper Lake sediments are attributable to this same source.

5.2.3.2 <u>Wilson Ditch</u>

Wilson Ditch bottom sediments were sampled in 1984 and 1985 as part of the Phase I WRM activities. Analytical results of these samples were variable but generally showed high concentrations of metals, particularly arsenic and lead. As shown in Appendix 5-2-3, concentrations of arsenic and lead were generally higher than those in Upper Lake.

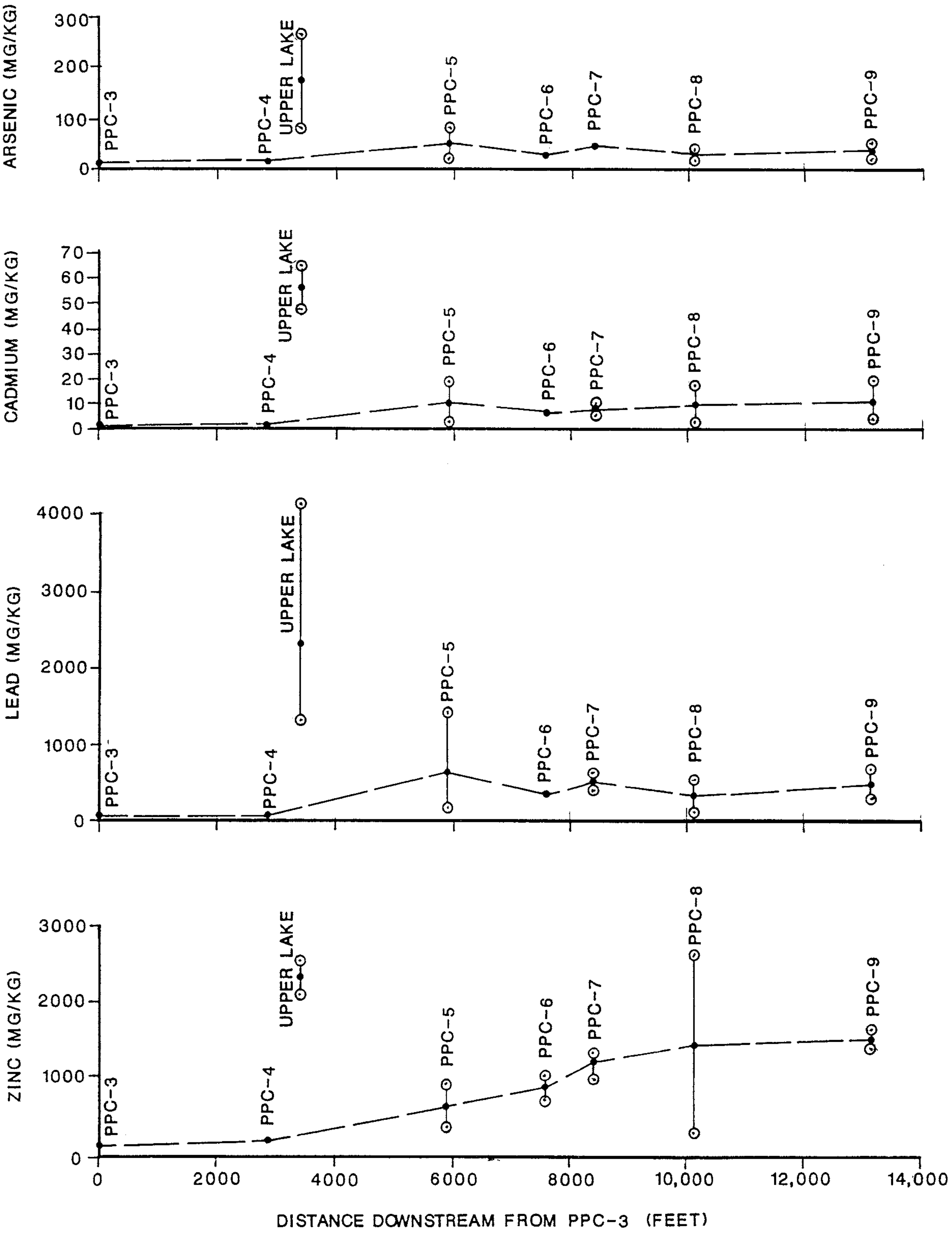


FIGURE 5-2-9.
Average Arsenic, Cadmium, Lead & Zinc Concentrations of Sediment Samples from Prickly Pear Creek & Upper Lake

As part of the Comprehensive RI activities, additional sediment samples were collected from the 0 to 30 inch interval from the bottom of the ditch. Four sites were sampled; WD-2, WD-3, WD-4 and WD-5 (see Figure 5-2-4). Results of these analyses are in Appendix 4-3 and are summarized in Table 5-2-9 and Figure 5-2-10.

Samples collected from the 0 to 30 inch interval showed the highest concentrations are typically within the 0 to 8 inch horizons, and that concentrations decrease with depth. Concentrations of arsenic and lead were highest at site WD-2 (2658 mg/kg and 6928 mg/kg, respectively), but decreased significantly with depth. Generally concentrations were less than 100 mg/kg in the 19 to 30 inch interval.

5.2.4 Prickly Pear Creek Soil Erosion and Transport Study

5.2.4.1 Purpose and Scope of Erosion and Transport Study

The purpose of this task was to estimate the mass of soil-bound metals that would be washed into Prickly Pear Creek from contaminated areas of the Helena Valley in the event of the 10- and 100-year storms. The metals selected for study were those which were found to be enriched in the upper soil layer (0-4") during the Phase I Soils RI (U.S. EPA, 1987a). These are: silver (Ag), arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), manganese (Mn), lead (Pb), selenium (Se), thallium (Tl), and zinc (Zn). The available data and methods used provide only general estimates of sediment transport. Their interpretation is accordingly limited.

5.2.4.2 Methods Used for Calculating Soil Erosion and Transport

The general strategy outlined in the Comprehensive RI/FS Work Plan (Hydrometrics, 1987b) was to define a study corridor along Prickly Pear Creek, divide it into blocks 1000 feet on a side (EW, NS), and calculate water erosion within each block based on the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The calculated soil losses for each block, multiplied by yield ratios and the soil metal levels measured in the Phase I Soils RI, provide an estimate of metal loadings to the creek. The sums of these values gave loading estimates from sub-watersheds in the study corridor (Figure 5-2-11), and total loading from the whole

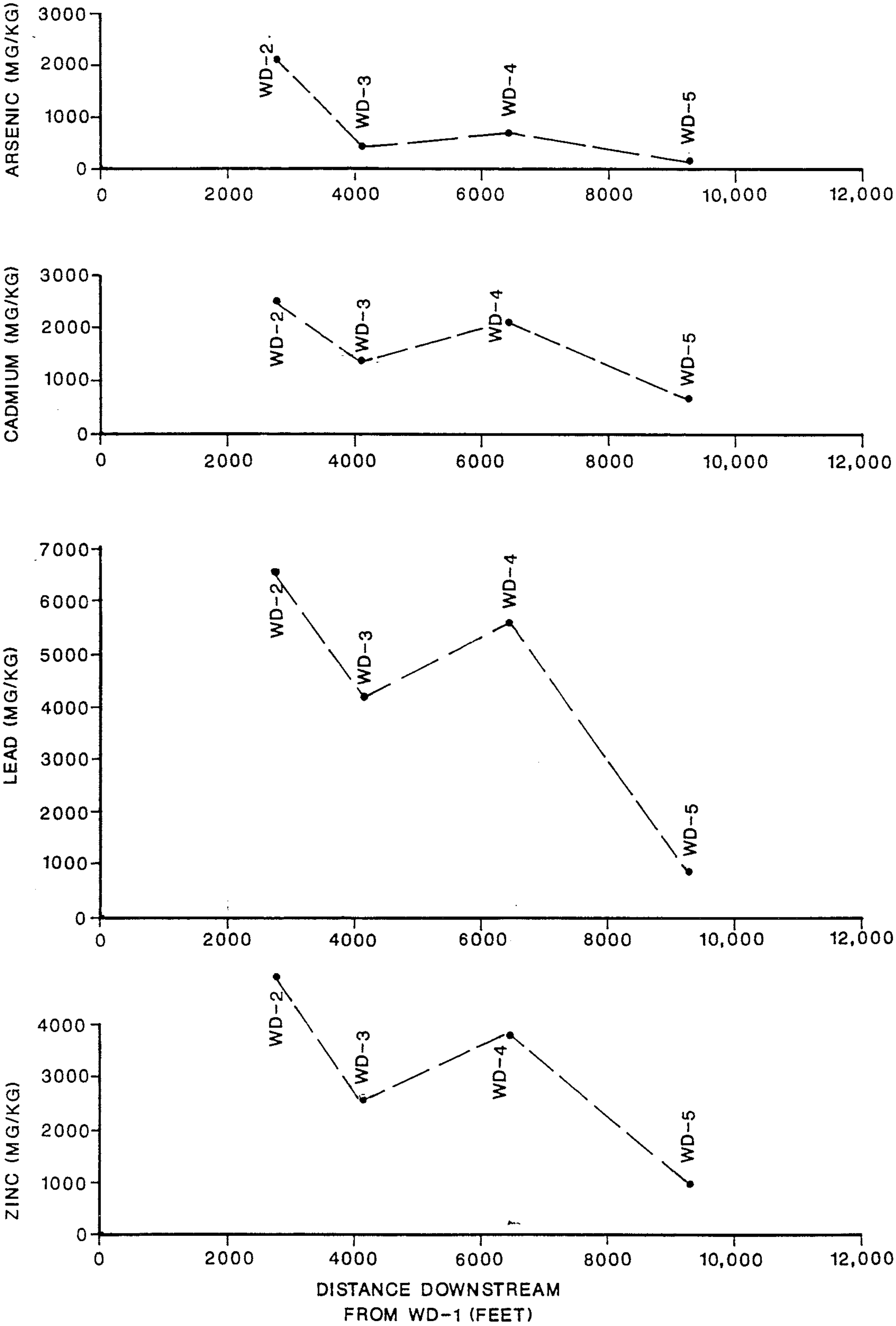


FIGURE 5-2-10.
Arsenic, Cadmium, Lead & Zinc Concentrations of Bottom Sediment Samples from Wilson Ditch

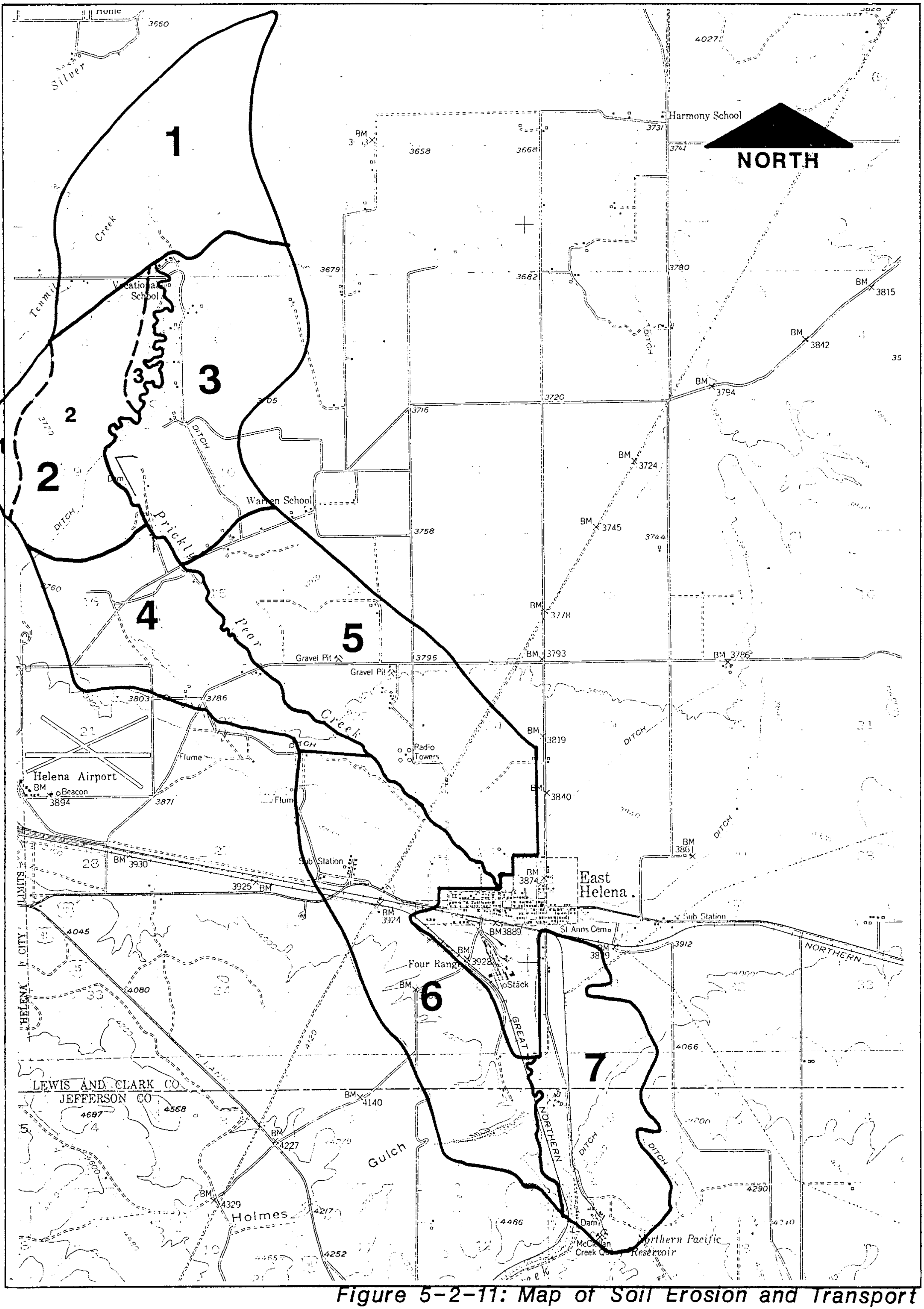


Figure 5-2-11: Map of Soil Erosion and Transport Study Area Showing Subwatersheds Along Prickly Pear Creek Based on Universal Soil Loss Equation

study area for the 10- and 100-year, 24-hour storms (2.1 and 3.1 inches of rain, respectively).

The study corridor includes a zone approximately one mile-wide along each side of Prickly Pear Creek within the Helena Valley RI study area (Figure 5-2-11). Areas within the one mile boundary that were judged unable to contribute soil to the creek by overland run-off were eliminated from consideration in these calculations, and the corridor boundary was adjusted accordingly. The eliminated portions include urban areas, a major gravel pit north of East Helena, Lake Helena, and lands upslope from major irrigation ditches which divert water away from the overland run-off route to Prickly Pear Creek. Some land along the creek has been designated 100-year flood plain (Federal Emergency Management Agency, 1985), and was therefore eliminated as a source of eroded soil for the 100-year storm soil loss calculation. Analogous data on the extent of the 10-year storm were unavailable and were assumed to be negligible for the purpose of this study.

The data on landscape characteristics required for the USLE and on soil metal levels required for the metal-loading estimates were tabulated and manipulated using Microsoft EXCEL, a spreadsheet program. Soil loss and eroded metal mass were estimated for each of 414 blocks defined by the 1000 foot-interval grid throughout the study area (Figure 5-2-11).

The Universal Soil Loss Equation is:

$SE = 169{,}524 * R * K * L * S * C * P$, where

SE = sediment eroded, expressed here in kg/block. The 169,524 multiplier combines appropriate conversion factors and constants to yield the correct units.

R = rainfall factor

K = erodibility factor

L = slope length effect

S = slope steepness factor

C = cover and management factor

P = support practice factor

Appendix 5-1-4 contains more detailed information on the measured, estimated and calculated values required for the USLE.

To determine the amount of soil delivered to the stream in each block, the eroded soil value was multiplied by a flood plain factor (fp) and a yield ratio. The floodplain factor eliminates the depositional flood plain zones from the soil loss calculation by assigning a value of 0 for all grid blocks in the 100-year flood plain. All non-flood plain grid blocks had fp=1.

Yield ratios for seven subwatersheds in the Prickly Pear study area were generated by executing SedCad, a computer model of sediment transport via overland run-off to a point in the drainage system (Hydrometrics, 1988c; and see Appendix 5-1-5). Subwatersheds (Figure 5-2-11) were defined by dividing the corridor along the creek into generally homogeneous zones with respect to slope, soil type and hydrologic group as mapped by the Soil Conservation Service. The SedCad estimates rely on Soil Conservation Service (SCS) "Curve Numbers" -- a function of antecedent moisture, relative permeability of the soil, vegetation cover and management factors (Tetratech, 1982). The estimates depend upon other physical parameters of the soils which are described together with the curve number selection method in Appendix 5-1-5.

The metals data for the transport calculation were derived from isopleth maps of metals concentrations (U.S. EPA, 1987a) overlain on the 1000′ grid. The average metal value for each block was estimated based on linear interpolation between isopleths to determine the metal value (expressed in log ppm) across the middle of each block. Those averages were then multiplied by the mass of delivered sediment from each block, yielding the amount of soil-bound metal (in kg) which would reach the creek.

It is essential to recognize the limitations of the USLE in order to interpret its results. It was originally designed to characterize annual erosion losses from fairly uniform agricultural land in the midwestern United States. The USLE parameters can be adjusted to reflect the characteristics of 10-year versus 100-year storms and/or the erodibility of forested versus plowed land, but there is unavoidable averaging of land and weather conditions, and dependence upon empirical factors which only partially describe transport processes. The more heterogeneous the study area, the more uncertain the USLE results.

One of the most important site-specific variables which can disrupt the USLE model is the nature of the eroding landscape in the immediate vicinity of streams. This study included an assessment of streambank erosion to supplement the USLE-based erosion estimates based on reconnaissance of the Prickly Pear creekbanks and review of previous investigations by Streamworks, Inc. (1984). Seven stream reaches were selected for rating and documentation of erosion susceptibility. A numerical rating scheme of 1-5 (1 = most erosive), and a standardized form for field notes were applied in accordance with the Streambank Stability Assessment SOP in the Comprehensive RI/FS Work Plan (Hydrometrics, 1987b and see Appendix 5-1-6). This approach documents the ways in which the Prickly Pear channel can influence the final outcome of regular downslope erosion, but it does not provide a quantitative assessment of near-stream soil inputs.

5.2.4.3 Results of Erosion and Transport Calculations

The soil transport study generated estimates of the amount of soil eroded (Table 5-2-20) and transported to Prickly Pear Creek and the amount of associated metals (in kg) in the event of 10- and 100-year storms. The most distinctive feature of the data (Table 5-2-21) is the wide variation of erosion and transport among the seven subwatersheds which make up the study area.

Table 5-2-21 shows three sets of yield ratios derived from the SedCad modeling of three sets of plausible soil/moisture conditions which are defined in Appendix 5-1-5. The transported soil mass ranges from 0.2 to 0.6 million kg for the 10-year storm, and from 0.5 to 1.2 million kg for the 100-year storm. The following discussion focuses on the "high moisture, good soil" results because:

1) the major storm events commonly occur during periods of frequent storm activity and associated high soil moisture, and

Table 5-2-20. Estimates of soil erosion within subwatersheds of Prickly Pear Creek for the 10 and 100 year storm--calculated using the USLE.

Sub-watershed	Area* (acres)	10-year Storm			100-year Storm		
		kg	tons	tons/acre	kg	tons	tons/acre
1	1480	94300	21.4	0.014	117600	26.7	0.018
2	129	36500	8.3	0.064	68200	15.5	0.120
3	977	35600	8.1	0.008	68500	15.6	0.016
4	121	35900	8.2	0.067	82800	18.8	0.156
5	1304	127000	28.9	0.022	273000	62.0	0.048
6	1121	2047700	465.4	0.415	4753000	1080	0.964
7	1990	190700	43.3	0.022	438800	99.7	0.050
1-7	7122	2567800	583.6	0.08	5801800	1319	0.19

* Area measured by planimeter off of topographic map.

Table 5-2-21. Estimates of eroded soil and soil transported to Prickly Pear Creek (kg), based on Universal Soil Loss Equation.

MODERATE ANTECEDENT MOISTURE, POOR SOIL CONDITION

Subwatershed	Eroded soil 10-yr storm	Eroded soil 100-yr storm	Yield ratio (%) 10-yr storm	Yield ratio (%) 100-yr storm	Soil delivered 10-yr storm	Soil delivered 100-yr storm
1	94,300	117,600	1.6	3.4	1,500	4,000
2	36,500	68,200	4	6.2	1,500	4,200
3	35,600	68,500	5.2	7.3	1,800	5,000
4	35,900	82,800	7.4	8.1	2,600	6,700
5	127,000	273,000	4	4.7	5,100	12,800
6	2,047,700	4,753,000	16	16	317,400	755,700
7	190,700	438,800	4.2	4.6	7,900	20,000
AVG1 =	419,700	950,600	6.2	7.3	56,500	135,000
AVG2 =	366,800	828,900	6	7.2	48,300	115,500
TOTAL (kg) =	2,567,800	5,801,800			337,900	808,400

MODERATE ANTECEDENT MOISTURE, GOOD SOIL CONDITION

Subwatershed	Eroded soil 10-yr storm	Eroded soil 100-yr storm	Yield ratio (%) 10-yr storm	Yield ratio (%) 100-yr storm	Soil delivered 10-yr storm	Soil delivered 100-yr storm
1	94,300	117,600	0.68	2	600	2,400
2	36,500	68,200	0.4	1.6	100	1,100
3	35,600	68,500	1.6	1.7	600	1,100
4	35,900	82,800	0.61	1.8	200	1,500
5	127,000	273,000	0.35	1.1	400	2,900
6	2,047,700	4,753,000	8.7	11	178,400	518,100
7	190,700	438,800	0.3	0.99	600	4,300
AVG1 =	419,700	950,600	1.8	3.1	30,500	89,500
AVG2 =	366,800	828,900	1.8	2.9	25,900	75,900
TOTAL (kg) =	2,567,800	5,801,800			181,000	531,400

HIGH ANTECEDENT MOISTURE, GOOD SOIL CONDITION

Subwatershed	Eroded soil 10-yr storm	Eroded soil 100-yr storm	Yield ratio (%) 10-yr storm	Yield ratio (%) 100-yr storm	Soil delivered 10-yr storm	Soil delivered 100-yr storm
1	94,300	117,600	3.2	5.5	3,000	6,400
2	36,500	68,200	6.2	8.3	2,300	5,600
3	35,600	68,500	9.6	11	3,400	7,500
4	35,900	82,800	8.1	8.6	2,900	7,100
5	127,000	273,000	4.4	5	5,600	13,600
6	2,047,700	4,753,000	29	24.2	593,900	1,150,200
7	190,700	438,800	4.6	4.8	8,700	21,200
AVG1 =	419,700	950,600	9.8	10	104,000	203,000
AVG2 =	366,800	828,900	9.5	9.8	88,500	173,100
TOTAL (kg) =	2,567,800	5,801,800			619,700	1,211,600

AVG1 = average, weighted according to areas of subwatersheds
AVG2 = average of subwatershed values

2) the average slopes, tillage, rotation, and range practices of the study area generally conform to the definitions of "good soil conditions" stipulated for the curve numbers (see Appendix 5-1-5).

The general relationships are the same for all three data sets in Table 5-2-21. However, the high antecedent moisture analyses provide the the most conservative results.

Subwatershed 6 (Figure 5-2-11) yields approximately 80% of the total transported soils, primarily because of its steep topography. Subwatershed 7 is the second most erodible zone, yielding approximately 7.5% of the transported soil for the 10- and 100-year storms. All of the other subwatersheds combined yield only 12.5% of the the soil transported to Prickly Pear Creek.

Soils from Subwatershed 6 contain relatively high concentrations of trace elements (Table 5-2-22). Thus Subwatershed 6 yields 96-98% of the Ag, As, Cd, Hg and Pb, 94-95% of the Cu, Mn, Se and Zn (Tables 5-2-23 and 5-2-24).

The eroded soil values in Table 5-2-21 correspond to erosion rates ranging from 0.008-0.4 tons/acre for the 10-year storm and 0.016-0.96 tons/acre for the 100-year storm. These rates are of the same order of magnitude as the rates measured during rainfall simulation tests (Marlow, 1988) which were run using a precipitation rate of 3 inches per hour. Marlow's (1988) rates ranged from 0.01-0.07 tons/acre for grass-dominated and weed-dominated fields. An alternative set of values (Branson, Gifford and Owen, 1972) based on 2.4 inches of rain per hour on subalpine rangeland includes 0.05 tons/acre for 60-70% groundcover, 0.5 tons/acre for 37% cover, and 5.5 tons/acre for 10% cover. These literature values represent more intense storms than the East Helena 100-year storm (3.1 inches per 24 hours). The fact that the estimates in the East Helena study are of comparable magnitude suggests that the USLE modeling in this report yields conservative results, i.e. relatively high erosion rates.

Table 5-2-22. Metal concentrations (ppm) in the surface soil of subwatersheds on Prickly Pear Creek.

subwatershed	Ag	As	Cd	Cu	Hg	Mn	Pb	Se	Tl	Zn
1	0.24	22.6	0.83	23.9	0.24	391	30.7	0.33	0.59	77.3
2	0.30	24.6	1.32	30.2	0.23	416	40.3	0.24	0.39	101
3	0.31	24.8	1.57	32.5	0.28	416	44.5	0.26	0.47	115
4	0.30	25.9	2.10	31.5	0.23	456	53.5	0.09	0.28	128
5	0.41	34.1	3.81	41.2	0.27	575	99.6	0.10	0.41	188
6	0.66	41.9	8.16	35.1	0.93	471	188	0.23	0.40	159
7	0.30	26	1.55	31.7	0.26	423	47.6	0.23	0.39	111
AVG1	0.41	32.2	2.89	34.3	0.39	462	81	0.21	0.43	130
AVG2	0.36	28.6	2.76	32.3	0.35	450	72	0.21	0.42	126
Range	0.1-3.2	22-224	.5-32	22-200	0.2-8	347-794	23-1585	.03-10	.25-.79	71-562

AVG1 = averages weighted according to areas of subwatersheds
AVG2 = average of subwatershed values

Table 5-2-23. Metals transported to Prickly Pear Creek in a 10-year, 24-hour storm, based on USLE estimates (kg).

MODERATE ANTECEDENT MOISTURE, POOR SOIL CONDITION

Subwatershed	Ag10	As10	Cd10	Cu10	Hg10	Mn10	Pb10	Se10	Tl10	Zn10
1	0.0003	0.036	0.0012	0.035	0.0004	0.59	0.0445	0.045	0.0009	0.11
2	0.0004	0.036	0.0019	0.043	0.0003	0.6	0.0559	0.0003	0.0005	0.14
3	0.0006	0.049	0.0029	0.064	0.0005	0.76	0.0873	0.0005	0.0007	0.21
4	0.0008	0.072	0.0048	0.083	0.0007	1.12	0.1359	0.0006	0.0007	0.31
5	0.0016	0.15	0.017	0.19	0.0012	2.7	0.4005	0.0003	0.0021	0.78
6	0.26	12.6	3.58	11.2	0.56	141	77.513	0.18	0.12	40
7	0.0066	0.38	0.11	0.52	0.01	4.17	2.1699	0.004	0.003	0.97
AVG1 =	0.05	2.23	0.62	2.02	0.10	25.2	13.5	0.04	0.02	7.12
AVG2 =	0.039	1.9	0.53	1.73	0.083	21.6	11.5	0.027	0.019	6.08
TOTAL (kg) =	0.27	13.3	3.72	12.1	0.58	151	80.41	0.19	0.13	42.6

MODERATE ANTECEDENT MOISTURE, GOOD SOIL CONDITION

Subwatershed	Ag10	As10	Cd10	Cu10	Hg10	Mn10	Pb10	Se10	Tl10	Zn10
1	0.0001	0.015	0.0005	0.015	0.0002	0.246	0.019	0.0002	0.0004	0.046
2	0.00004	0.0036	0.0002	0.0043	0.00003	0.06	0.0056	3E-05	5E-05	0.014
3	0.0002	0.015	0.0009	0.02	0.0002	0.232	0.027	0.0002	0.0002	0.064
4	0.00007	0.0015	0.0004	0.0069	0.00005	0.093	0.011	5E-05	6E-05	0.026
5	0.0001	0.0059	0.0014	0.017	0.0001	0.236	0.035	3E-05	0.0002	0.068
6	0.15	0.013	2.01	6.29	0.317	79.2	43.6	0.1	0.069	22.5
7	0.0005	7.06	0.0081	0.037	0.0007	0.3	0.157	0.0003	0.0002	0.07
AVG1 =	0.03	0.83	0.34	1.08	0.05	13.6	7.41	0.02	0.01	3.85
AVG2 =	0.021	1.02	0.29	0.912	0.046	11.5	6.26	0.015	0.01	3.26
TOTAL (kg) =	0.15	7.14	2.02	6.38	0.32	80.4	43.8	0.1	0.07	22.8

HIGH ANTECEDENT MOISTURE, GOOD SOIL CONDITION

Subwatershed	Ag10	As10	Cd10	Cu10	Hg10	Mn10	Pb10	Se10	Tl10	Zn10
1	0.0006	0.069	0.0023	0.068	0.0007	1.15	0.087	0.001	0.0017	0.215
2	0.0007	0.055	0.003	0.067	0.0005	0.93	0.086	0.0005	0.0008	0.214
3	0.0011	0.092	0.0055	0.119	0.001	1.42	0.162	0.001	0.0012	0.392
4	0.0009	0.079	0.0052	0.091	0.0007	1.23	0.149	0.0007	0.0008	0.344
5	0.0017	0.159	0.018	0.208	0.0013	2.96	0.439	0.0004	0.0023	0.849
6	0.487	23.5	6.7	20.9	1.06	264	145	0.342	0.23	75
7	0.0073	0.411	0.123	0.563	0.011	4.56	2.37	0.0045	0.0032	1.06
AVG1 =	0.08	4.09	1.15	3.68	0.18	46.4	24.9	0.06	0.04	13.1
AVG2 =	0.071	3.48	0.979	3.15	0.153	39.4	21.2	0.05	0.034	11.2
TOTAL (kg) =	0.5	24.4	6.85	22	1.07	276	148	0.35	0.24	78.1

AVG1 = average, weighted according to areas of subwatersheds
AVG2 = average of subwatershed values

Table 5-2-24. Metals transported to Prickly Pear Creek in a 100-year, 24-hour storm, based on USLE estimates (kg).

MODERATE ANTECEDENT MOISTURE, POOR SOIL CONDITION

Subwatershed	Ag100	As100	Cd100	Cu100	Hg100	Mn100	Pb100	Se100	Tl100	Zn100
1	0.0008	0.1	0.0032	0.091	0.001	1.55	0.13	0.0013	0.0023	0.29
2	0.0013	0.1	0.0054	0.12	0.0009	1.73	0.15	0.0009	0.0014	0.39
3	0.0016	0.14	0.0081	0.17	0.0015	2.05	0.24	0.0015	0.0016	0.58
4	0.002	0.18	0.012	0.21	0.0016	2.81	0.34	0.0016	0.0019	0.79
5	0.0036	0.36	0.04	0.46	0.0027	6.72	0.95	0.0007	0.0053	1.87
6	0.62	29.9	8.57	26.6	1.36	335	185	0.44	0.29	95.4
7	0.017	0.95	0.285	1.31	0.026	10.5	5.49	0.01	0.0075	2.43
AVG1 =	0.11	5.30	1.49	4.81	0.23	60.2	32.2	0.08	0.05	17
AVG2 =	0.093	4.53	1.28	4.14	0.199	51.5	27.5	0.065	0.04	14.5
TOTAL (kg) =	0.65	31.7	8.92	29	1.39	361	193	0.46	0.31	102

MODERATE ANTECEDENT MOISTURE, GOOD SOIL CONDITION

Subwatershed	Ag100	As100	Cd100	Cu100	Hg100	Mn100	Pb100	Se100	Tl100	Zn100
1	0.0005	0.056	0.0019	0.053	0.0006	0.905	0.074	0.0008	0.0013	0.168
2	0.0003	0.026	0.0014	0.031	0.0002	0.443	0.04	0.0002	0.0004	0.099
3	0.0004	0.031	0.0019	0.04	0.0003	0.47	0.055	0.0003	0.0004	0.132
4	0.0005	0.041	0.0027	0.047	0.0004	0.631	0.077	0.0004	0.0004	0.177
5	0.0008	0.082	0.0092	0.107	0.0006	1.55	0.219	0.0002	0.0012	0.43
6	0.427	20.5	5.88	18.2	0.93	230	127	0.302	0.2	65.4
7	0.0036	0.217	0.062	0.29	0.0057	2.29	1.19	0.0023	0.0016	0.53
AVG1 =	0.07	3.53	1.00	3.15	0.16	39.8	21.7	0.05	0.03	11.3
AVG2 =	0.062	2.99	0.851	2.69	0.134	33.7	18.4	0.029	0.029	9.57
TOTAL (kg) =	0.43	20.9	5.95	18.8	0.94	236	129	0.21	0.21	67

HIGH ANTECEDENT MOISTURE, GOOD SOIL CONDITION

Subwatershed	Ag100	As100	Cd100	Cu100	Hg100	Mn100	Pb100	Se100	Tl100	Zn100
1	0.0013	0.152	0.0051	0.145	0.0016	2.48	0.203	0.0021	0.0037	0.459
2	0.0018	0.136	0.0072	0.161	0.0012	2.31	0.206	0.0012	0.0018	0.517
3	0.0024	0.206	0.012	0.262	0.0023	3.09	0.362	0.0022	0.0025	0.865
4	0.0022	0.193	0.013	0.223	0.0018	2.99	0.362	0.0017	0.002	0.839
5	0.0038	0.378	0.043	0.493	0.0029	7.13	1.01	0.0008	0.0057	1.98
6	0.947	45.5	13	40.5	2.06	510	282	0.67	0.444	145
7	0.018	1.01	0.302	1.39	0.028	11.2	5.82	0.011	0.0079	2.58
AVG1 =	0.16	7.97	2.25	7.21	0.35	90.3	48.7	0.12	0.08	25.5
AVG2 =	0.14	6.79	1.92	6.17	0.3	77	41.4	0.099	0.067	21.8
TOTAL (kg) =	0.98	47.6	13.4	43.2	2.1	539	290	0.7	0.47	153

AVG1 = average, weighted according to areas of subwatersheds
AVG2 = average of subwatershed values

These USLE estimates of soil-borne metal in particulate form which reach Prickly Pear Creek do not lead to direct measures of human health or environmental risk. However, it is possible to put the USLE results in perspective by comparing them to (1) other forms of stream media (stream sediments), or (2) slag and other mine waste in the Prickly Pear drainage.

1) Comparisons of the metal concentrations in the local soils with those of the existing stream sediments provide one perspective on potential sources of metals to the stream. Table 5-2-25 shows the analyses of stream sediments collected by Hydrometrics, Inc. of Helena, Montana in 1985, along with the average soil metal levels measured during the Phase I RI.

   The geometric means of the stream sediments' concentrations are higher than the soil levels for all elements except As, Se and Tl. Therefore, assuming that resuspension of bottom sediments is significant during storm events, the sediment-derived contaminants will be more important than the soil-borne elements on a storm-by-storm basis. However the soils do represent a contaminant reservoir that could replenish the stream sediment metal supply. In that context, absolute concentrations are not critical. The relative importance of the soil and slag reservoirs (see (2) below) as contributors to the stream, is unknown.

2) The slag pile at the East Helena Plant site and mine waste rock and tailings in the upper Prickly Pear Creek drainage represent additional sources of metals which may dwarf the soil-borne metals considered in the USLE modeling. Analyses of two slag samples demonstrate high concentrations in that source (Table 5-2-25). However, water quality results from samples collected upstream, adjacent to and downstream of the slag pile, indicate slag contribution to Prickly Pear Creek arsenic and metals concentrates is apparently very minor (see Sections 6.2.3 and 7.0). Analyses of the miscellaneous waste rock and tailings piles to the north are unavailable, although it is reasonable

Table 5-2-25. Metal levels in Prickly Pear Creek sediments and slag vs. local soils.

Element	Surface soils in study area* (ug/g, data from isopleth maps)		Sediments in Prickly Pear Creek (ug/g for 8 locations 13 samples)**		Slag pile near Process Pond (ug/g for 2 analyses, depth = 6-7.5 ft**
	range	mean***	range	mean***	
Ag	0.1-3.2	.41	<0.13-8	2.4	32,47
As	22-224	32	0.44-84	29	783,900
Cd	0.5-.32	2.9	0.5-19	4.8	75,94
Cu	22-200	34	7.5-195	69	1350,1590
Hg	0.2-8	.39	<0.5-1.1	0.61	1.3,7.4
Mn	347-794	462	225-1800	1024	3920,4750
Pb	23-1585	81	22-1450	306	13100,15750
Se	.03-.10	0.21	<.12-.27	<.12	<25 (1 analysis)
Tl	.23-.79	0.43	<.1-.37	0.18	4.2 (1 analysis)
Zn	71-562	130	86-2920	746	31500,42750

* U.S. EPA, 1987. Remedial Investigation of Soils, Vegetation and Livestock for for East Helena Site (ASARCO), East Helena, Montana

** Hydrometrics, 1986. Water Resources Monitoring Report, Phase 1.

*** geometric mean

to assume that they are more metalliferous than the field soils. Similarly, the erosion rates of those mine wastes are unquantified, but their proximity to the creek and their unvegetated and irregular topography contribute to relatively rapid erosion which may exceed the overland runoff processes of the basin as a whole.

Simplistic interpretation of total suspended solids from soils, sediments, slag, or other waste materials with regard to water quality criteria is risky at best. The significance of the solids depends on their effect on dissolved constituents' concentrations, a function of the complex equilibria between adsorbed loads on particle surfaces and stream waters.

The stream sediment, upstream mine waste, and slag pile issues raised above are part of the more general consideration of bank erosion along Prickly Pear Creek. Initial investigations for this Phase II Soils RI showed that bank erosion may be just as important as the overall watershed erosion in the study area. Streamworks, Inc. (1984) assessed the sediment burden in Prickly Pear Creek in 1984 for the Jefferson and Lewis & Clark Conservation Districts based on aerial photographs, ground surveys and other data. They concluded:

> "The high concentrations of suspended sediment in Prickly Pear Creek comes mostly from bank erosion along the mainstem and tributaries. Abandoned mine dumps, eroding channel banks, breached settling ponds and periodic flushing of sediment from behind the Asarco dam in East Helena contribute to the problem."

Based on Phase II RI reconnaissance and the Streamworks report, seven potential "hot spots" for bank erosion were selected for more detailed documentation as specified in the Study Plan. The results, tabulated in Appendix 5-1-7, demonstrate that erodible features such as slag piles, gravel pits, irrigation works and localized bank grazing are common. However, with the exception of slag piles, those sites do not necessarily increase heavy metal contamination since much of the sloughing material is from subsurface, uncontaminated zones. The potential contribution of metals from the slag pile is discussed in more detail in Section 6.0.

5.2.4.4 Summary and Conclusions of the Erosion and Transport Study

The USLE calculations strongly suggest that most of the eroded soil (excluding the creek channel itself), is derived from subwatersheds 6 and 7, i.e., the steep, heavily dissected area south of East Helena. This relatively erodible zone also contains the soils with the highest amount of element enrichment. Therefore, if any future action regarding soil-erosion-related contamination takes place, it should probably concentrate on the erodible area south of the plant. This conclusion relies on major differences among the subwatersheds, and is probably not jeopardized by the uncertainties of absolute values derived by application of the USLE.

The results do demonstrate that the soils represent a potential reservoir for metals in Prickly Pear Creek water, but they do not quantify the soil reservoir relative to slag, tailings, or other waste rock in the same drainage area. Based on qualitative study of the erodible channel conditions and the proximity of metalliferous waste to the water, it is conceivable that the normal field erosion is relatively insignificant.

5.3 VEGETATION INVESTIGATIONS

5.3.1 Vegetation Surveys

5.3.1.1 Purpose and Scope of Vegetation Surveys

Vegetable and grain crop surveys were conducted to define the patterns of production and consumption of wheat in the Helena Valley and vegetables grown in the East Helena area. This information, in association with the chemical analyses of grains and vegetables (Section 5.3.3), is the basis for the vegetation portion of the endangerment assessment. The vegetable and grain surveys are discussed separately below.

5.3.1.2 Vegetable Garden Survey Results

Garden vegetable survey results are compiled from three different sources: 1) a garden questionnaire sent to all East Helena residents; 2) a smaller post-enumeration survey; and 3) a detailed questionnaire filled out by owners of sampled gardens. A complete explanation of these sources is provided in Section 2.3.3 (methods). Tabulated results of each survey and copies of the questionnaires are presented in Appendix 5.3.

Sixty three percent, or 259 of 409 responses to the larger mailing were affirmative (yes to having gardens). Results of this survey indicate the typical gardens are approximately 13 years old, approximately 1950 square feet in area, 60 feet away from the nearest road or alley, and provide less than 10% of the yearly food supply. The average age of the residents in households with gardens is 33.5 years. There are 97 children under 6 years, and 24 children 2 years or under in those households.

Results of the post-enumeration survey (Appendix 5-3) show that 43-59% of East Helena area households have gardens (95% confidence level). The actual number of affirmative responses (yes to having gardens) was 77 out of 150, or 51.3%.

Fourteen gardens within a two-mile radius of the plant site were sampled in August 1987 and the vegetables were analyzed for trace contaminants. A more detailed questionnaire with questions about vegetable use, family statistics, and garden management was completed by 12 out of the 14 owners of sampled gardens.

Forty-two residents live in the twelve households which were sampled and responded to the questionnaire. Seven percent (3) of the residents were less than six years old. Half of the gardens are fertilized with commercial fertilizers. Ten of the twelve respondents reported the use of pesticides, which can be a source of heavy metals. One garden was limed and one garden had added topsoil. Every respondent grows leafy vegetables and root crops. All families wash and scrub their produce and all but one peel their root crops. Only one family estimates that more than 25% of their annual food supply comes from their garden.

In summary, it appears that approximately half of the residents in East Helena grow gardens. Most of these families derive a significant portion (>5%) of their annual diet from their gardens, and about six percent of residents estimate that over half of their food is from their garden.

5.3.1.3 Grain Survey Results

The objective of the grain survey was to define the production, marketing and consumption patterns of cereal grains grown in the Helena Valley. Survey results indicate that wheat is the predominant cereal crop in the Helena Valley. Average production is approximately thirty bushels per acre for non-irrigated and forty to fifty bushels per acre for irrigated land. The average total production for surveyed wheat producers is 11-12 thousand bushels per year. Most harvested grain is sold to elevators in the towns of Townsend, Butte, and Great Falls, Montana. Each of these wholesalers market their grain regionally and nationally. All area elevators store their grain according to type and quality. Grain from any given geographic locality is therefore mixed with grain from other locations, probably several times, before processing.

Agricultural practices in the Helena Valley are typical for the region. About 80% of growers irrigate at least some of their land, most growers (92%) broadcast or inject commercial fertilizers, and a minority (17%) use at least some reduced till methods.

The survey identified one family that grinds and sells their own flour. This family grinds five to six hundred pounds of grain per year. The wheat is grown approximately five miles northeast of the plant site. Locally grown wheat flour provides about 75% of their total baked-goods consumption. Some of their flour is given away or sold to friends and family, who characterize their local grain consumption as a relatively minor part of their total wheat diet. A total of five households were identified that consume local wheat. No other retailers or processors of local grain were identified through survey, telephone or other contacts.

5.3.2 East Helena Garden Vegetable Investigation

5.3.2.1 Purpose and Scope of Vegetable Investigation

Sampling of 14 East Helena gardens (Figure 5-3-1) was undertaken to provide data for estimating the amount of metals ingested via vegetables by typical gardening residents near the plant site. Commonly-eaten varieties which could be compared to samples from a control site and/or to broader databases from non-local studies were collected. The analytical results permit evaluation of risks due to vegetable intake.

5.3.2.2 Background Trace Element Concentrations

Trace element levels in the control garden in Townsend, Montana are shown in Table 5-3-1. The concentrations are within the ranges of other background studies. Wolnik et al. (1985) and Wiersma et al. (1986), cited in Table 5-3-1, refer to additional vegetable studies on smaller sample groups which are not tabulated. Both sets of research generally corroborate the Townsend results. However, the tomato results in the U.S. and European background studies show markedly lower concentrations than the Townsend control sample for several elements.

Previous studies consistently demonstrate that different vegetables, and even different varieties of the same vegetable, accumulate trace elements at different rates (Wolnik et al., 1983a, 1983b, 1985; Chaney et al., 1987). In addition, trace element concentrations of Townsend tomatoes may reflect the generally higher metals environment associated with soils derived in mountainous regions in western Montana, compared to conditions of the U.S. and European background studies.

5.3.2.3 Results of East Helena Garden Vegetable Analyses

The trace element content of most of the East Helena samples is greater than that of the control garden. Table 5-3-2 records summary statistics for the seven vegetables, together with enrichment factors with respect to the corresponding control garden vegetable. All analytical results for the East Helena area garden vegetables are presented in Appendix 5-3-3.

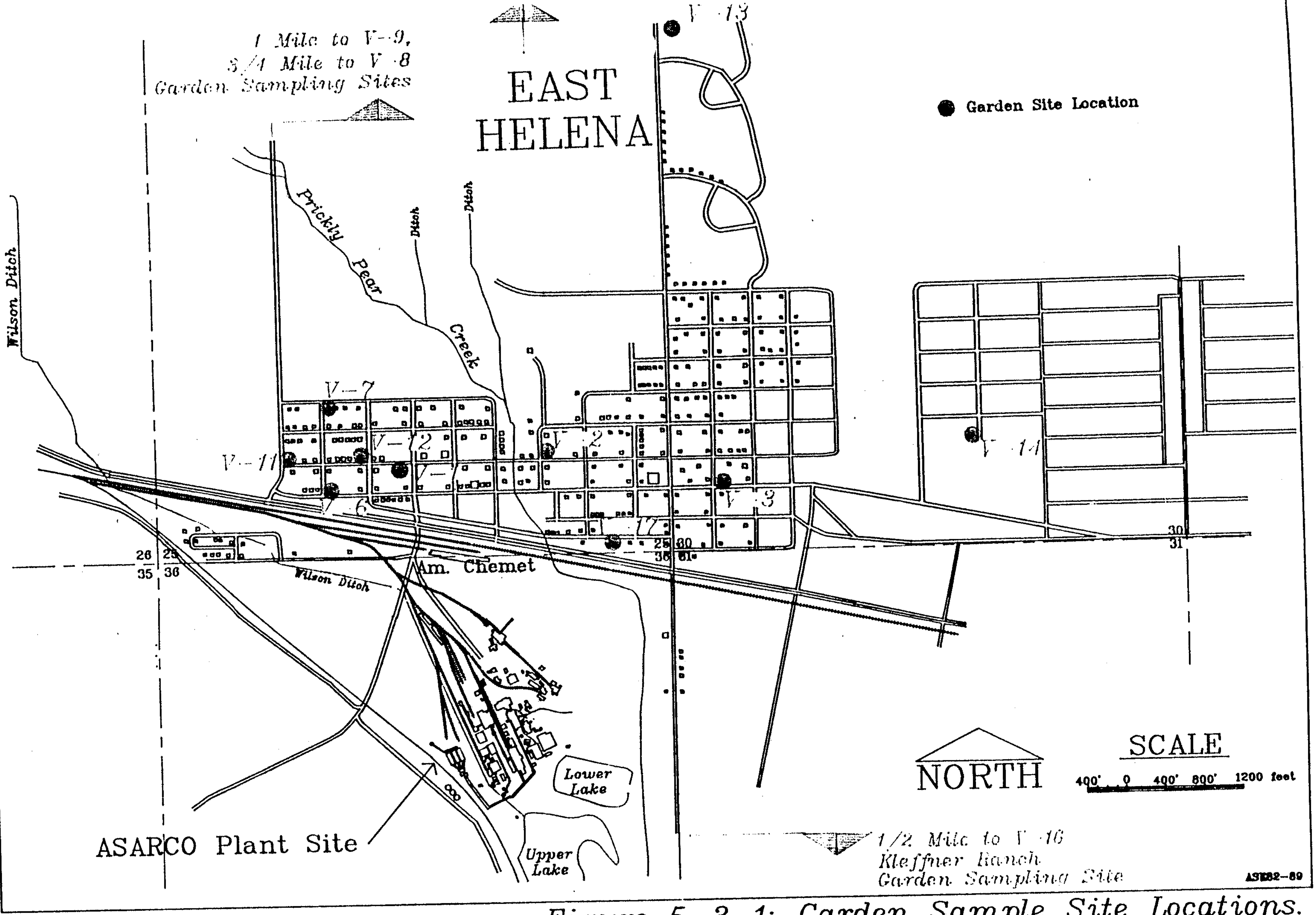


Figure 5–3–1: Garden Sample Site Locations.

Table 5-3-1. Trace element concentrations in local background garden vegetables (Townsend, Montana and in background studies in the literature (ug/g).

Vegetable	Location (reference in parentheses)	Ag	As	Cd	Cu	Hg	Mn	Pb	Sb	Se	Tl	Zn
CARROTS	Local	0.01	0.02	0.04	0.48	0.001	1.2	0.003	0.006	0.012	0.01	0.96
	US(2)			0.028	0.58		1.5	0.009				2.6
	US(4)		0.02									
	Neth(5)			0.04		0.002		0.05				
	Germany(7)										0.01	
LETTUCE	Local	0.001	0.006	r	0.34	0.008	0.8	0.01	0.44	0.002	r	1.27
	US(1)			0.026				0.013				1.9
	US(2)				0.26		1.8	0.075				
	US(3)			0.048								
	Neth(5)		0.01			0.002		0.14				
POTATOES	Local	0.02	0.08	0.17	1.6	0.002	1.6	0.18	0.06	0.02	0.02	6.5
	Neth(5)		0.013			0.003		0.03				
	US(1)			0.031				0.009				
	US(3)			0.037				0.038				
	US(2)				0.96					0.003		3.1
TOMATOES	Local	0.38	0.02	r	2.05	0.001	1.3	r	0.03	0.01	0.01	2.4
	Neth(5)		0.001	0.02		0.001		0.01				
	US(2)			0.017	0.65		1.1	0.002				1.4
BEET GREENS	Local	0.08	0.04	0.06	0.88	0.02	14.3	0.18	0.04	0.01	r	5.2
	Spain(6)			0.036				0.545				
CHARD	Spain(6)			0.012				0.19				
PARSLEY	Spain(6)			0.027				0.412				
	Germany(7)										0.28	

1 - Wolnik et al., 1983
2 - Wolnik et al., 1985
3 - Food and Drug Administration, 1980
4 - Jelinek and Braude, 1978
5 - Wiersma et al., 1986
6 - Zurera et al., 1987
7 - Adriano, 1986
= Data rejected during data validation (Roy F. West [illegible] 1988)

able 5-3-2. Statistical summary of trace element concentrations (ug/g) of garden vegetables collected in East Helena in 1987.

Vegetable	n		Ag	As	Cd	Cu	Hg	Mn	Pb	Sb	Se	Tl	Zn
CARROTS	10	mean*	0.05	0.1	0.2	0.74	0.002	1.16	0.33	0.05	0.01	0.04	2.9
		std.dev.	0.07	0.06	0.18	0.26	0.002	0.31	0.35	0.08	0.005	0.04	1.7
		minimum	0.01	0.04	0.05	0.5	0.001	0.75	0.05	0.006	0.003	0.008	1.2
		maximum	0.2	0.2	0.6	1.2	0.008	1.88	1.2	0.26	0.02	0.14	6.5
		e.f.**	5	5	5	1.5	2	0.97	110	8.3	0.83	4	3
LETTUCE	9	mean	0.09	0.34	0.64	1.54	0.01	4.66	2.91	0.12	0.01	0.02	6.2
		std.dev.	0.06	0.22	0.54	0.89	0.007	2.84	3.99	0.12	0.005	0.02	5.7
		minimum	0.01	0.08	0.2	0.34	0.003	1.48	0.29	0.02	0.002	0.005	1.79
		maximum	0.16	0.65	1.82	2.82	0.02	9.7	12.3	0.34	0.02	0.04	19.3
		e.f.	90	57	r	4.5	1.3	5.9	291	0.27	5	r	4.9
POTATOES	10	mean	0.04	0.16	0.19	2.4	0.01	2.4	0.54	0.08	0.03	0.05	7
		std.dev.	0.03	0.15	0.11	1.4	0.008	2.9	0.58	0.08	0.03	0.03	6.1
		minimum	0.02	0.07	0.1	1.2	0.004	1.1	0.04	0.01	0.02	0.02	3.1
		maximum	0.1	0.5	0.44	5.5	0.03	10.5	1.74	0.24	0.1	0.09	23
		e.f.	2	2	1.1	1.5	5	1.5	3	1.2	15	2.5	1.1
TOMATOES	10	mean	0.01	0.01	0.05	0.7	0.002	0.61	0.06	0.03	0.006	0.009	1.3
		std.dev.	0.004	0.008	0.03	0.22	0.002	0.11	0.07	0.04	0.14	0.01	0.35
		minimum	0.002	0.004	0.02	0.45	0.001	0.44	0.002	0.003	0.003	0.003	0.85
		maximum	0.01	0.03	0.1	1.15	0.006	0.83	0.23	0.13	0.008	0.03	1.98
		e.f.	0.21	0.5	r	0.34	2	0.47	r	1	0.6	1	0.56
ET REENS	8	mean	0.14	0.2	1.25	1.98	0.01	10.4	1.41	0.11	0.03	0.03	21.6
		std.dev.	0.1	0.17	0.98	0.97	0.008	3.69	1.51	0.1	0.01	0.03	19.4
		minimum	0.04	0.03	0.2	1.05	0.003	4.8	0.01	0.005	0.009	0.008	3.8
		maximum	0.26	0.47	2.8	3.8	0.02	16.2	4.7	0.28	0.04	0.08	52.8
		e.f.	1.6	5	21	2.3	0.5	0.73	7.8	2.8	3	r	4.2
SWISS CHARD	2	mean	0.03	0.44	1.12	1.25	0.02	24.1	0.54	0.02	0.03	0.01	11.5
		std.dev.	0.04	0.56	1.4	0.18	0.006	19.4	0.33	0.02	0.04	0	10.9
		minimum	0.009	0.05	0.14	1.13	0.01	10.4	0.31	0.013	0.009	0.01	3.8
		maximum	0.06	0.84	2.1	1.38	0.02	37.8	0.77	0.04	0.06	0.01	19.2
		e.f.		no swiss chard in control garden									
PARSLEY	1	mean	0	0.12	0.24	1.6	0.02	6.7	1.5	0.04	0.01	0.05	10.5
		e.f.		no parsley in control garden									

* mean = arithmetic mean

** e.f. = enrichment factor with respect to control garden in Townsend, Montana (arithmetic mean concentration in vegetable)/(arithmetic mean of background concentration in same vegetable type)

r = data rejected during data validation (Roy F. Weston, 1988)

Arithmetic means and associated statistics are used (as opposed to log-transformed expressions), primarily to maintain consistency with other vegetable studies (Wolnik et al., 1983a, 1985; Wiersma, 1986). Furthermore the distribution of the East Helena data suggests normality, although the small sample size for individual vegetable types hinders such characterization. The normal statistical treatment generates higher means than computations which assume log-normality, so this procedure is a conservative assessment of the data.

Standard deviations are approximately equivalent to the absolute concentrations for all elements except Cu, Mn and Zn. The standard deviations of those three elements are typically well below the measured concentrations but they range up to higher levels in several instances.

Arsenic, Cd, Hg and Pb are the most elevated and/or the elements of greatest toxicological concern. Subsequent discussion focuses on these four, although the data for all eleven elements portray a generally consistent condition, i.e., all the analytes are enriched to some extent. Figure 5-3-2 portrays mean As, Cd, Hg and Pb concentrations for all the vegetable groups. Mean Pb values range from 0.06 to 2.91 ug/g, and it is the most abundant trace element in all vegetables except swiss chard, in which Cd is the highest. Cd is typically the next most abundant trace element, ranging from 0.05 to 1.25 ug/g. Arsenic is generally approximately half the Cd level with a range of 0.01 to 0.44 ug/g among vegetable means. The Hg means are all low (<=0.01), and even the individual high values do not exceed the upper range of Hg concentrations measured in other background studies (Wiersma et al., 1986).

The leafy green vegetables, lettuce, swiss chard, beet greens and parsley, accumulate more metals than other crops. The Pb concentrations in lettuce (mean of 2.9 ug/g, maximum of 12.3 ug/g) are especially elevated. The root crops, carrots and potatoes, show the next highest trace element levels. Tomatoes have low concentrations of all the measured constituents. These rankings among vegetable types are consistent with literature data (Wolnik et al., 1983a; Chaney et al., 1987; Adriano, 1986).

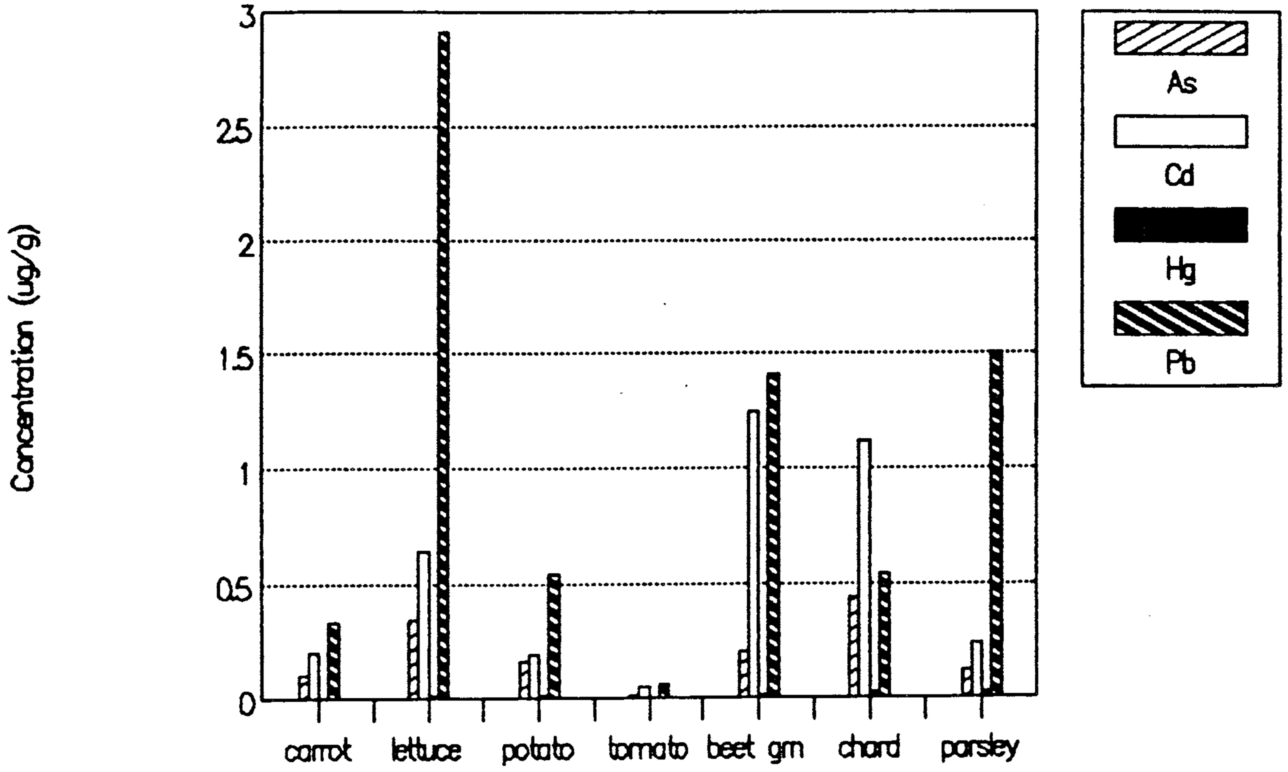


Figure 5-3-2. Mean concentrations of As, Cd, Hg, and Pb (ug/g, wet weight) in East Helena garden vegetables.

There is no apparent correlation between the distance from the gardens to the nearest road for Pb, Cd or other elements. The data are listed in order of decreasing Cd concentrations in Appendix 5-3-3.

Comparisons of the enrichment factors demonstrates the same general relationships among vegetables as for the absolute values. Virtually all of the enrichment factors are greater than one for all of the tested vegetables except tomatoes. The mean tomato trace element content is relatively low (Figure 5-3-1), and only Hg shows enrichment relative to the control (by a factor of 2). The Hg concentrations are so low, and the Hg analytical difficulties are so significant (Roy F. Weston Inc., 1988a), that the measured values and associated enrichment factors must be considered estimates at best.

The tomato enrichment factors in Table 5-3-2 are low, but the enrichment is quite similar to the that of the other vegetables if the larger background databases are considered in place of the Townsend results. The reason for the anomalously high Townsend "background" results is unknown, but the data suggest that the East Helena tomatoes should be considered enriched, albeit mildly, along with the rest of the test samples.

The enrichment factors are quite variable, and are not uniformly high for any single vegetable or element. Some distinct features underscore the atypical nature of East Helena vegetables compared to background crops however. For example, Pb enrichment in carrots and lettuce is very high, with factors of 110 and 291, respectively. Individual samples of these plants are much more enriched. Mean As and Cd enrichment factors, ranging up to 57 in lettuce and 21 in beet greens, are less severe than for Pb.

Further discussion of the details of the vegetables' enrichment factors and absolute concentrations is inappropriate because the variability of all results is high. There are numerous factors which can contribute to this variability. Factors that apply in the homes where vegetables are produced and consumed may be just as important, if not more so, than those which apply in the analytical laboratory. For example, if washing procedures are imperfect; if plants are partially dehydrated due to low precipitation or storage procedures; if uptake differences are introduced by selection of genetically different varieties; and if cultivation or fertilization practices are altered, the absolute and relative concentrations of vegetables' trace elements can change significantly. Studies of trace element introduction to the food chain through sludge application to cropland have documented these factors and have concluded that they can be of overriding importance (Chaney et al., 1987).

Trace constituents Ag, Sb, Se and Tl are quite low (typically well under 0.1 ug/g). In many cases these elements occur below detection limits, so accurate measures of enrichment are not possible. If half-detection limit is assumed, enrichment factors are greater than one and less than five in all but two cases: enrichment of Ag in lettuce is 90, and enrichment of Se in potatoes is 15.

Copper, Mn and Zn occur in higher concentrations than the other analytes, and is consistent with plants as well as soils and air emissions. Although these components are enriched over the control garden (factors ranging up to 38 in swiss chard but usually less than 5), they are probably less significant for their toxicity potential than for their interactions with other elements. Table 5-3-3 records correlations between all the analytes. Cadmium and Zn show the strongest correlation, with an r of 0.851. Cadmium commonly substitutes for Zn when present in elevated concentrations (Friberg, 1979). Most of the r-values do not indicate associations between elements for the vegetable samples as a group. All but seven coefficients (Ag-Cd, Ag-Zn, As-Cd, Cd-Zn, Sb-Cu, Se-Cu, Sb-Pb) are less than 0.7.

5.3.2.4 Summary and Conclusions of Vegetable Investigation

- All measured trace elements in the East Helena vegetable gardens are enriched relative to local and national background levels.

- Enrichment in East Helena area vegetable samples is largest for Pb, Cd and As.

Table 5-3-3. Correlation coefficients (r) for element pairs in East Helena garden vegetables.

	Ag	As	Cd	Cu	Hg	Mn	Pb	Sb	Se	Tl	Zn
Ag	1	.583x	0.716x	0.569x	0.413x	0.275	0.594x	0.500x	0.281x	0.162	0.761x
As		1	0.714x	0.619x	0.671x	0.630x	0.581x	0.666x	0.514x	0.056	0.522x
Cd			1	0.545x	0.470x	0.590x	0.387x	0.603x	0.425x	0.071	0.851x
Cu				1	0.552x	0.274x	0.396x	0.745x	0.738x	0.376x	0.648x
Hg					1	0.49x	0.464x	0.521x	0.461x	0.041	0.444x
Mn						1	0.203	0.192x	0.522x	0.050	0.435x
Pb							1	0.734x	0.090	-0.052	0.477x
Sb								1	0.430x	0.253x	0.660x
Se									1	0.458x	0.485x
Tl										1	0.266x
Zn											1

x = correlation significant to a 95% confidence level (n = 50)

- Enrichment of Ag, Hg, Sb, Se and Tl is typically low, and is difficult to quantify because of small concentrations and associated analytical uncertainties.

- The relatively abundant "trace" elements, Cu, Mn and Zn, are enriched, but generally less so than the other analytes.

- Variability among vegetable types and among individual samples from East Helena is consistent with variability documented elsewhere. The data demonstrate that leafy green vegetables are at greatest risk of excess metal accumulation, but that no vegetables are immune from elevated concentrations, because varietal differences, potential inconsistencies of food preparation techniques, and other factors can introduce significant amounts of trace elements.

5.3.3 Helena Valley Grain Investigation

5.3.3.1 Purpose and Scope of Grain Investigation

Locally grown grains are a potential source of As, Cd, Cu, Hg, Pb, and Zn intake by residents living in the Helena Valley. The objective of the grain head investigation is to determine levels of these elements in area crops, and how residents utilize locally grown grain. Sampling and elemental analyses of grains, in conjunction with a cropping survey (survey results in Section 5.3.2) were the primary tasks for this study.

Commercial crops grown in the Helena Valley for human consumption are almost entirely small grains (Montana Dept. of Agric., 1986). Wheat is the most important crop due to the large quantity grown and the concentrated form in which it is ingested (baked goods). Wheat is the only cereal grain for which metals data are reported. The crop survey covers all cereal grains grown by respondents.

The available analytical data for grain heads are from two separate studies conducted between 1984 and 1987. The 1984 grain head sampling was conducted as part of the Phase I RI (U.S. EPA, 1987a). Fourteen study area samples of wheat grain heads were analyzed for As, Ag, Ba, Cd, Co, Cr, Cu, Fe, Hg, K, Mn, N, P, Pb, V, and Zn. Study area sample results were compared to results of a background sample taken approximately 24 miles southeast of the plant site. Results of these analyses showed a zone of substantially elevated metal levels in grains grown near the plant site. Sampling, processing, analytical methods, QA/QC, data validation and a treatment of the results are presented in the Phase I RI Final Report (U.S. EPA, 1987a).

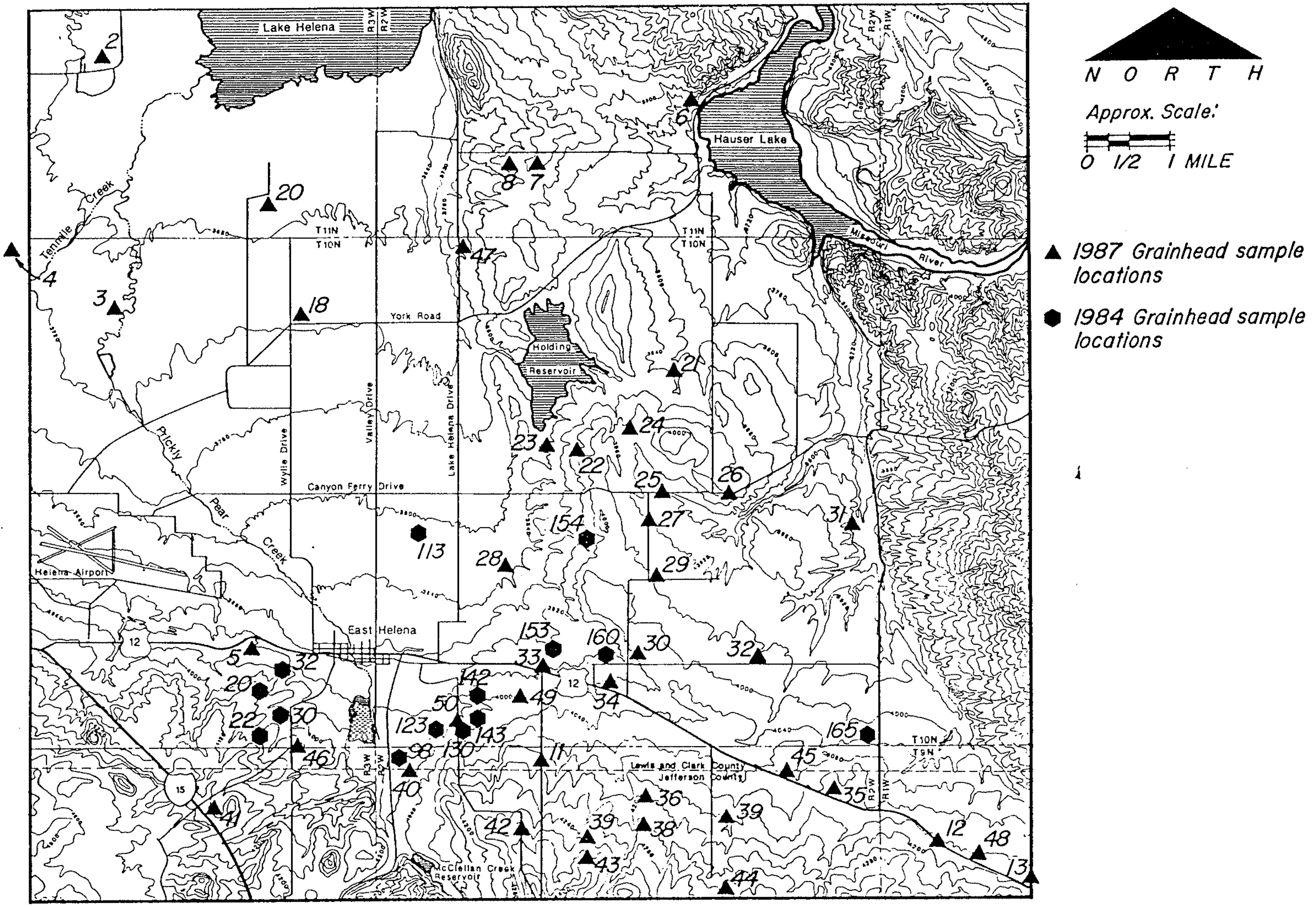
The 1987 grain head sampling was conducted by Asarco contractors as part of the Phase II RI. The purpose of the 1987 study was to obtain additional Helena Valley grain head data to fill spatial data gaps in the 1984 study. Forty-two study area grain head samples were collected to augment the 1984 data. Three background samples were collected east of Canyon Ferry Lake approximately 24 miles southeast of the plant site, near the 1984 background site. These samples were analyzed for the six elements found to be enriched in grain heads in 1984: As, Cd, Cu, Hg, Pb, and Zn. Sampling methods and analytical procedures are discussed above in Section 2.3.3.3. Quality assurance-quality control protocols and data validation methods are presented above in Section 2.7.3 and 2.8.3, respectively. Sample locations for both studies are presented in Figure 5-3-3.

Where possible, the two data sets have been combined to optimize the characterization of elements in study area grain heads. There are some instances where the data sets could not be combined due to various compatibility problems. In these cases, only the 1987 data are used. All 1987 analytical results for grain heads are in Appendix 5.3.4.

5.3.3.2 <u>Element Concentrations in Helena Valley Grain Heads</u>

Compatibility of 1984 and 1987 data is good for Cu, Pb, and Zn and combined data are used unless otherwise noted. The 1984 and 1987 data sets are not combined for the elements As, Cd, and Hg. Compatibility problems with As, Cd, and Hg are discussed below.

All 1984 results show no detectable concentrations (detection limit 0.1 ug/g) of As in any samples (U.S. EPA, 1987). Most of those samples were from within two miles of the plant site. Results of 1987 samples taken within a four mile radius of the plant site are all above 0.1 ug/g with a mean value of 2.9 ug/g. The 1987 results indicate detectable levels of



Hydrometrics, Inc.
Consulting Scientists & Engineers
Helena, Montana

FIGURE 5-3-3.
Helena Valley Wheat and Grainhead Sampling Locations for 1984 and 1987 Data.

arsenic throughout the area sampled in 1984, and also an enrichment over background levels. Interpretation of each As data set leads to different conclusions, precluding their combined use.

Cadmium results from each study were produced by different laboratories using different methods. The ICP analyses used in 1984 had detection limits of 0.5 ug/g. The 1987 graphite furnace results were reported to 0.05 ug/g. Seventy six percent of the 1987 results were below the 1984 detection limit, revealing differences between study area and background that exist below the 1984 detection limit. Interpretation of cadmium results is therefore based only on 1987 data.

Like Cd, comparability of the Hg data sets was impaired by order of magnitude differences in the reported detection limits for the two studies (0.001 for 1984 vs. 0.05 for 1987). Furthermore, the results of each study point towards different conclusions, much like the As results did.

Table 5-3-4 presents summary statistics and enrichment factors for each element in the combined 1984/1987 data set. Enrichment factors are calculated by dividing the arithmetic mean concentration of study area samples by the arithmetic mean concentration of the background samples. Enrichment factors substantially above unity (1) indicate significant elemental grain enrichment. Note that all 1984 data were transformed to log base 10 values for normalization. The larger sampling size of 1987 and combined data provides a more normally distributed range of values so that transformation is not necessary.

No enrichment was found for elements Cu, Hg, and Zn. No samples contained detectable levels of Hg (detection limit 0.05 ug/g). Quantities of Cu and Zn are within normal ranges for wheat (Wolnik, 1983b).

Results for As and Pb show low levels of enrichment (1.8 and 1.5 times background respectively) in the study area while Cd enrichment is 9.4 times background. Concentrations are generally higher with increasing proximity to the plant site for all three of the enriched elements. Both background and study area samples are high in As and Pb

Table 5-3-4. Statistical summary of total element concentrations (ug/g dry weight) in wheat grain head samples collected in the Helena Valley during 1984 and 1987[1], and the calculated enrichment factor.

Element	N	Arithmetic Mean	Standard Deviation	Minimum Value	Maximum Value	Background	Enrichment Factor
As	42	0.22	0.10	0.07	0.61	0.13	1.7
Cd	42	0.45	0.44	0.03	2.10	0.05	9.4
Cu	56	4.74	1.14	2.00	7.00	4.85	1.0
Hg	42	0.025	0.00	0.025	0.025	0.025	1.0
Pb	56	0.49	0.43	0.05	2.20	0.34	1.4
Zn	56	36.79	9.89	21.00	62.00	40.25	.9

1/ Datasets for As, Cd, and Hg are not compatible for summary statistics. 1987 data is used here. See text for explanation.

compared to background levels found in other studies (Satzger, 1982; Wiersma, 1986; Wolnik, 1983a, 1983b). Table 5-3-5 shows the number and percentage of study area samples that are above background for each element.

The mean As concentration in study area grain is 0.22 ug/g. This value is 1.8 times the background mean, indicating a moderate level of enrichment. Nine out of 42 area As values are at or below the background mean (Table 5-3-5).

Results from 1984 for Pb showed higher average values and much greater enrichment than the 1987 and combined results. The elevated mean was probably a result of sampling location bias. The 1987 sampling locations were designed to supplement the 1984 data and to provide better coverage of the entire Helena Valley study area. No attempt was made to duplicate 1984 sites. The average distance from the plant for 1987 sites is more than double the 1984 average. The change in the area wide enrichment factor for Pb between the 1984 and 1987 studies is primarily due to a higher background level in the more recent study (avg.= 0.05 for 1984 vs. 0.433 for 1987). The 1984 study used only one sample to quantify the background mean, whereas the 1987 study provides three additional background samples. Most Pb study area values are at or below the average background level for the combined data sets (Table 5-3-5).

The enrichment factor of 9.4 for Cd is relatively higher than for As or Pb. However, the average Cd content (0.45 ug/g) in the grain is only about three times the upper range for Montana wheat grain in areas minimally impacted by human activities (Wolnik, 1983a). Ninety percent of study area Cd values are above the background mean (Table 5-3-5). Each of these interpretations indicate that overall Helena Valley wheat grain Cd enrichment is higher than for the other five elements analyzed.

5.3.3.3 Distance/Concentration Trends for Elements in Grain Heads

Study area means and enrichment factors indicate area-wide trends but do not provide the resolution necessary for this investigation. Three additional techniques were used to more specifically determine areas of concern: 1) all elemental concentration data were plotted as a function

Table 5-3-5 Distribution of Helena Valley study area sample results as related to background values for grain heads

Project area grainhead results	Number Percent	Elements (ug/g dry weight)					
		As	Cd	Cu	Hg	Pb	Zn
At or below <u>background</u>							
Combined 1984/87 data	N	*	*	28	*	30	40
(56 samples)	%	*	*	50	*	54	71
1987 data only	N	9	4	15	42	26	28
(42 samples)	%	21	10	36	100	62	67
1984 data only	N	14	11	1	2	4	13
(14 samples)	%	100	79	7	14	29	93
<u>Above background</u>							
Combined 1984/87 data	N	*	*	28	*	26	16
(56 samples)	%	*	*	50	*	46	29
1987 data only	N	33	38	27	0	16	14
(42 samples)	%	79	90	64	0	38	33
1984 data only	N	0	3	13	12	10	1
(14 samples)	%	0	21	93	86	71	7

* Datasets are incompatible, see text for explanation.

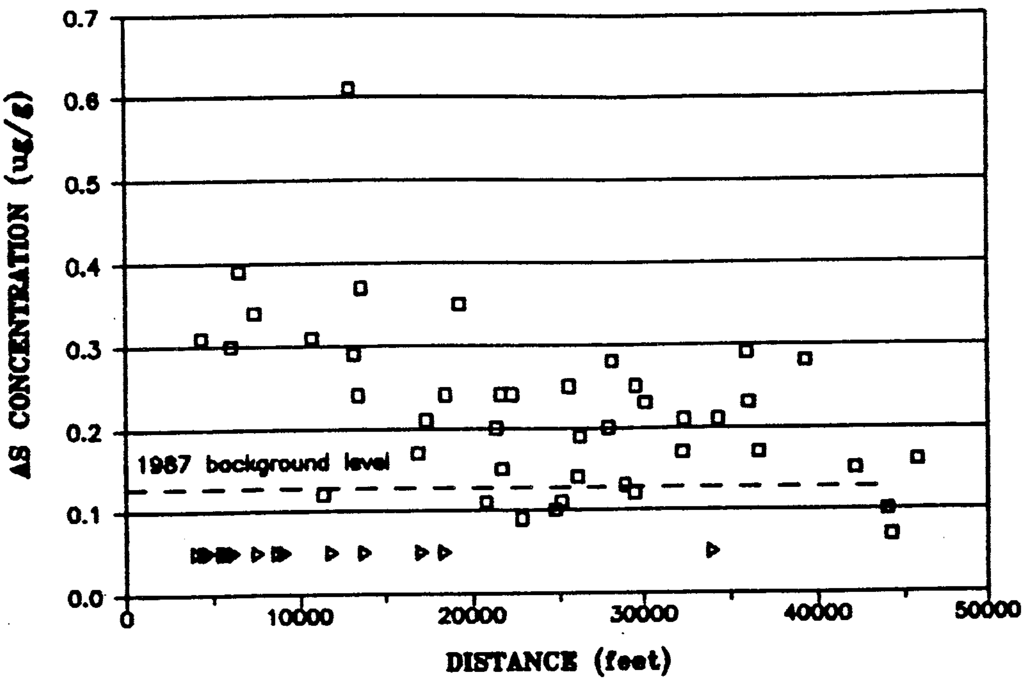
of distance from the plant site; 2) the study area was divided into concentric circles centered around the plant site and sample data were grouped and analyzed accordingly; and 3) data points along three transects radiating from the plant site were used to examine the relationship between distance from the plant and analyte concentrations in grain. Results of these tasks are presented below.

Figure 5-3-4 plots the elemental concentration in grain heads as a function of distance from the plant site for each element. The graphs illustrate a trend of increasing concentrations with decreasing distance from the plant site for As, Cd, and Pb. No trend is visually evident for Cu, Hg, or Zn. The apparent relationship of distance from the plant site and grain head concentrations of at least some elements led to the statistical analyses presented below.

Table 5-3-6 presents results of a one-way analysis of variance (ANOV) for unequal sample sizes (Lund, 1988) and a multiple comparison test based on least significant difference (LSD) for the grain head samples divided into six groups. The first group is from background sites and five more groups are based on distance from the plant site. Proximity to the plant site had no significant effect upon grain head levels of Cu or Hg. Results for Zn show the closest zone (within one mile of the plant site) was significantly different ($p = .10$) from the outermost zone (over four miles from the plant site); however, no zone is significantly different than the background mean.

Results for As, Cd, and Pb (Table 5-3-6) all show significantly ($p = .10$) higher grain head concentrations for inner zones as compared to outer zones. Arsenic values up to three miles from the stack are significantly higher than values for samples taken more than three miles out. Cadmium values tend to decline with distance, although the difference is not significant between every zone. Only the outermost zone (>4 miles) is significantly lower than the innermost zone (0 to 2 miles) for Cd. Lead values from zero to two miles from the plant site are higher than other zones and, like Cd, the general trend suggests an inverse relationship between elemental grain concentrations and distance from the plant site.

The 1987 sampling sites were chosen first to fill data gaps evident in the 1984 data set, and secondly to provide data along three transects



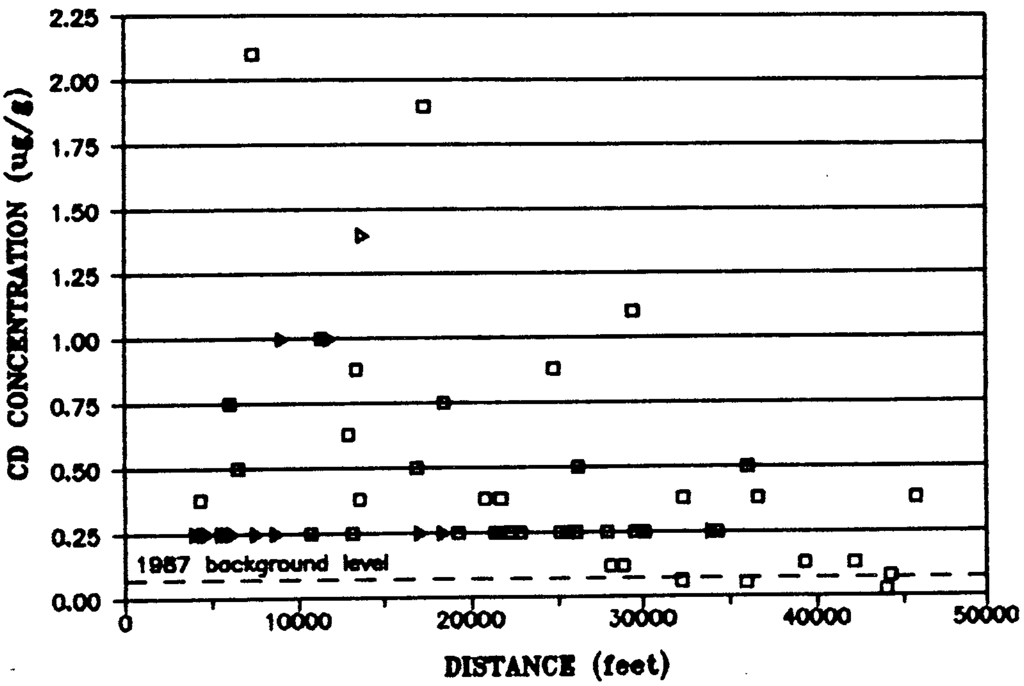
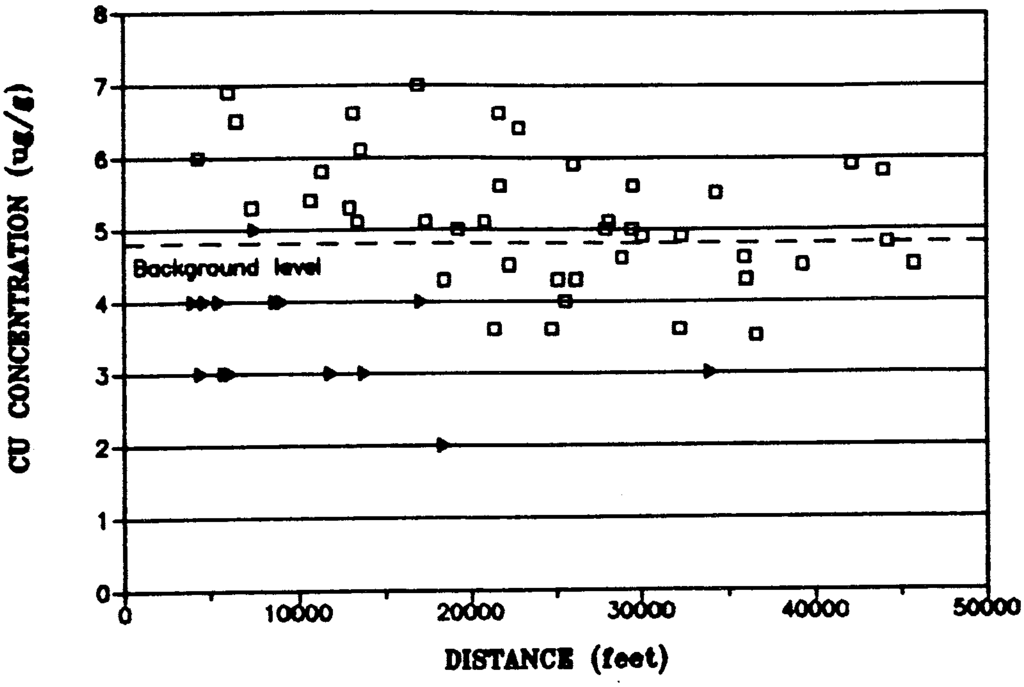


Figure 5-3-4. Elemental concentrations (ug/g) in Helena Valley wheat grain heads plotted as a function of distance from the Plant site for elements As, Cd, Cu, Hg, Pb, and Zn. Squares = 1987 data, triangles = 1984 data.



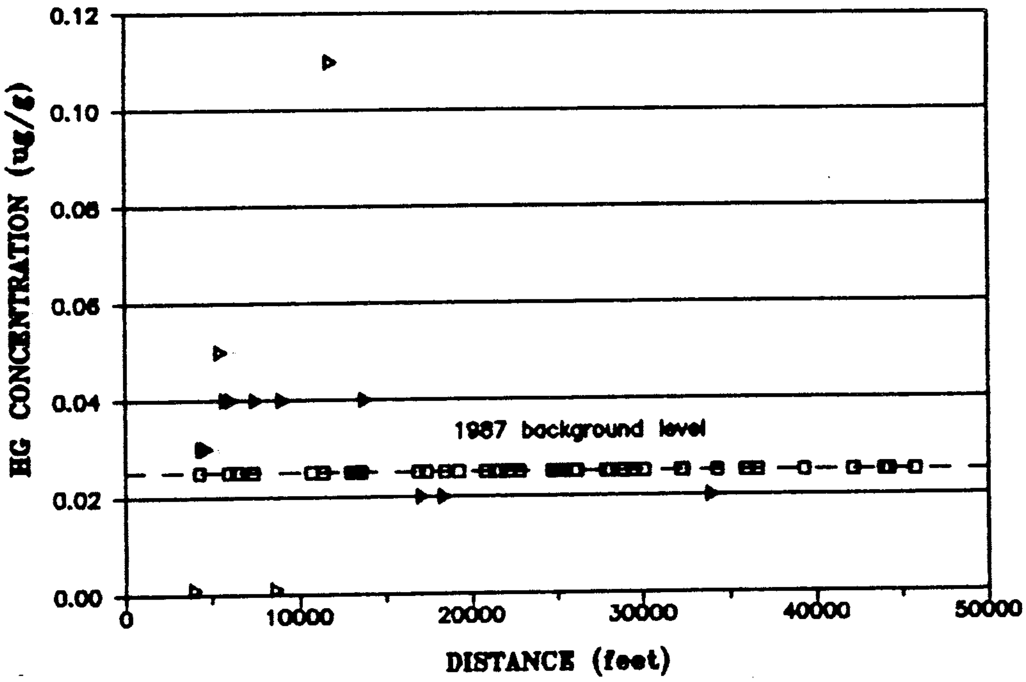


Figure 5-3-4. (continued).

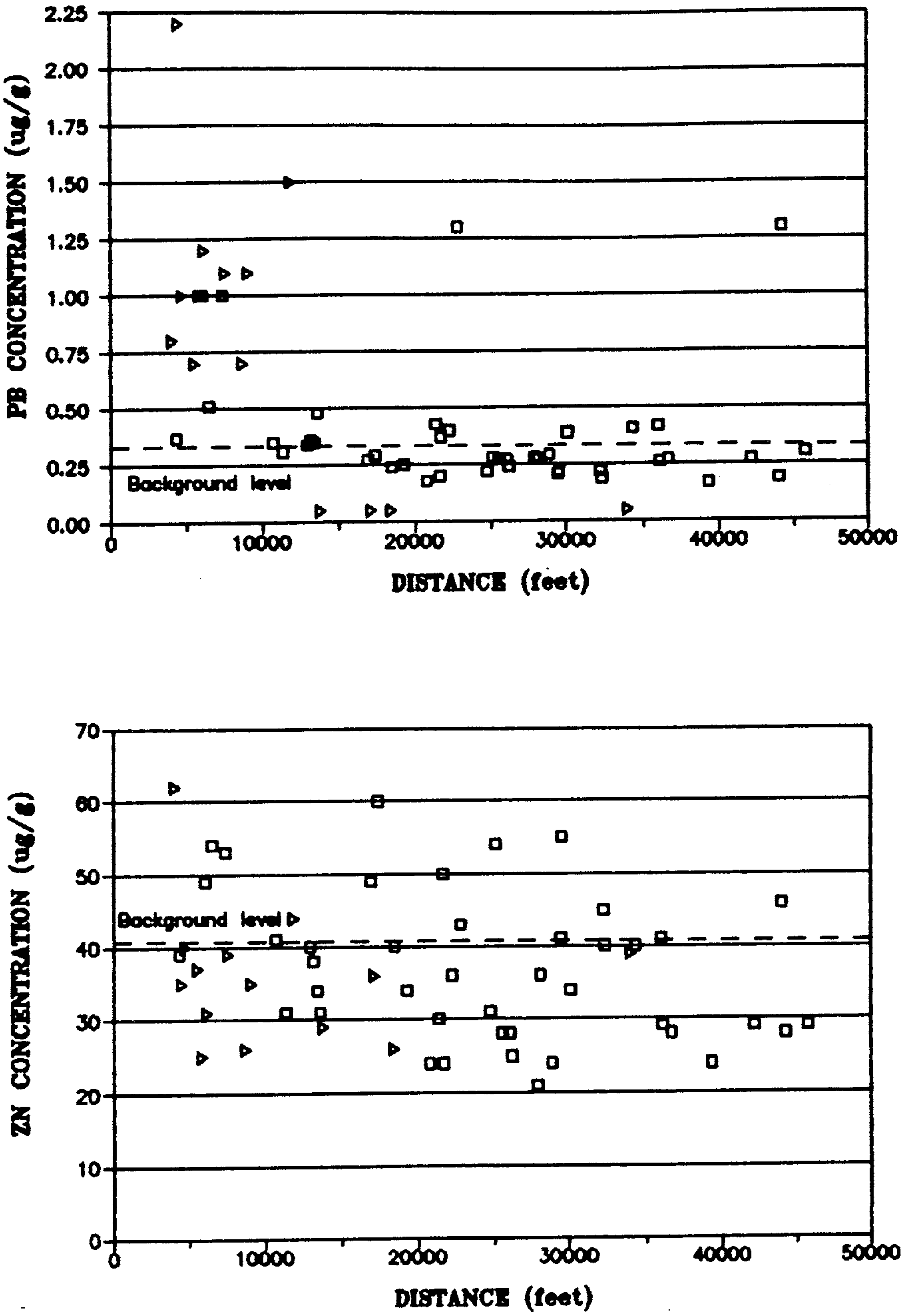


Figure 5-3-4. (continued).

Table 5-3-6. Statistical comparisons of Helena Valley grain head data grouped into zones based on distance from the Plant Site.

Element	Background Mean	Mean element concentrations based on radial distance from Plant Site (in miles)[2] 0-1	1-2	2-3	3-4	>4
As[1]	0.12 A		0.34 B	0.32 B	0.22 A	0.18 A
Cd[1]	0.06 A		0.93 C	0.57 BC	0.76 C	0.30 AB
Cu	4.85 A	4.25 A	4.63 A	5.03 A	4.64 A	4.78 A
Hg[1]	0.025		0.025 A	0.025 A	0.025 A	0.025 A
Pb	0.34 A	1.09 B	0.92 B	0.46 A	0.19 A	0.34 A
Zn	40.25 AB	44.00 B	38.78 AB	36.00 AB	38.43 AB	34.93 A

1/ As, Cd, and Hg statistics are based on 1987 data only (see text for explanation). The two nearest zones (0-1 and 1-2 miles) are combined to provide sufficient sample size for each zone.

2/ Same letter within rows (elements) indicates no significant difference at the 90% confidence level.

radiating outward from the plant site. The transects lie in the northwest, northeast, and east-southeast directions. The transect data were examined to determine what correlation, if any, exists between grain head element levels and distance from the plant site. In some instances, the transect sampling sites had to be moved from planned locations in order to find wheat. This resulted in fewer transect samples for the northwest vector. Sampling sites are also not as evenly distributed as planned along the northeast transect.

Elemental concentration data for As, Cd, and Pb were plotted as a function of distance from the plant site for each transect. Linear regression analyses showed poor correlation for all elements along all transects except for Cd and Pb in the northeast direction. To the northeast, correlation coefficients (r) were 0.87 and 0.94 for Cd and Pb, respectively. While no simple model adequately describes the distance/concentration relationship, highest concentrations were again found to be from samples close to the plant and lowest concentrations were relatively farther away. The results here generally agree with trends identified earlier by dividing the study area into concentric zones.

5.3.3.4 <u>Areal Distribution of Elements in Helena Valley Grains</u>

Isoline maps of total As, Cd, and Pb concentrations were prepared to spatially represent grain head data collected in the Helena Valley. Arsenic, Pb, and Cd were chosen for mapping because they appear to be key elements with respect to levels of enrichment. The Pb map was produced using the 1984 grain head data and the 1987 data, for a total of 56 samples. Maps for As and Cd were produced using only the 1987 data (see Section 5.3.3.2 above for explanation). The (x,y) coordinate system for each map originates at the sinter plant stack on the plant site premises. The sinter plant stack was used as a reference point because it is easily located on aerial photos and topographic maps.

The original objective of contouring elemental concentrations was to provide isolines with associated confidence intervals to qualify the interpretation of the data. An attempt was made to model the spatial distribution of As and Pb using a geostatistical technique called kriging. Kriging models the spatial distribution of a parameter by using the principle of weighted local averaging. Kriging produces estimates of elemental concentrations at nonsampled locations by minimizing the variance associated with each predicted value. This provides the best linear unbiased estimate of a value with an associated error variance (Journel and Huijbregts, 1978).

Kriging is based on the semi-variogram, a basic tool of geostatistics. The semi-variogram plots the semi-variance, a measure of the similarity between points a given distance apart, versus the average distance of those points (Burgess and Webster, 1980). Once the semi-variogram is generated, it is validated by meeting a number of statistical conditions. If these conditions are not met then the model parameters must be revised. Kriging should not be used unless a a valid semi-variogram that satisfactorily models the data is produced.

Semi-variograms produced for both As and Pb in Helena Valley grainheads had large components of random variation and small spatial components (semi-variance). This was a result of the irregular spacing of the grainhead samples and the high level of variation between samples situated in close proximity to each other. With this in mind, it was determined that a good model of the spatial distribution of the data could not be validated and the objective of providing confidence intervals on the contoured data could not be achieved.

This led to the production of the three maps presented in Figures 5-3-5, 5-3-6 and 5-3-7 using a computer contouring program which applies an "estimated best-fit" model to the data (Golden Software Inc. 1987). It should be noted that while a statistical model was used to contour the data, confidence intervals around the contour lines cannot be drawn. This procedure does however produce a more realistic presentation of the data compared to other estimation procedures such as inverse distance, inverse distance squared or a subjective approach followed by an individual contouring the data by hand.

The general trend for Cd and Pb is again one of decreasing concentrations as distance from the plant increases. Higher concentrations of Cd generally extend to the east and southeast of the plant site. The higher Pb levels are also, in general, more extensive to the east of the plant site. The greatest extent of elevated Pb concentrations being in the

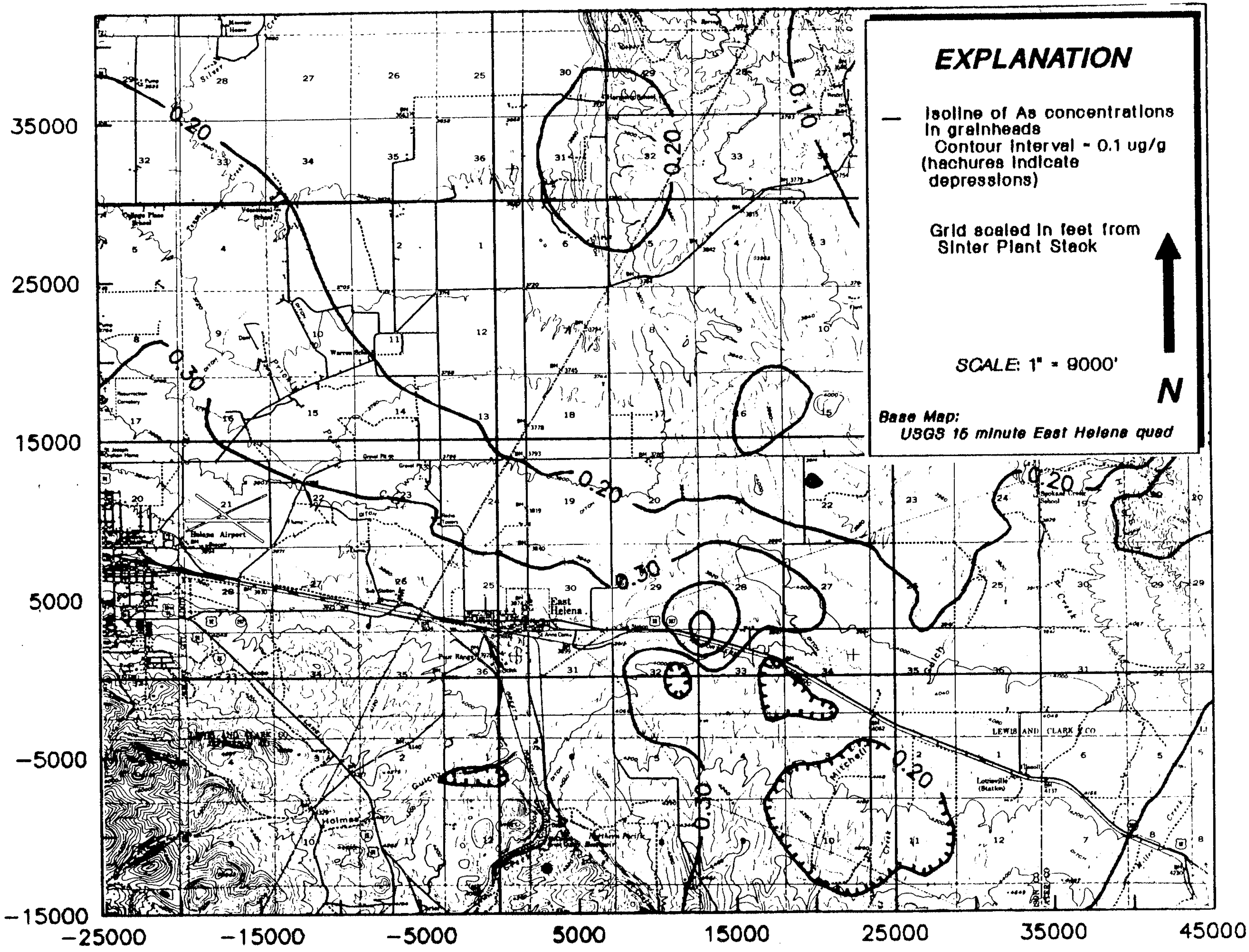


Figure 5-3-5. Isoline map of As concentrations in Helena Valley grain heads (based on 1987 data).

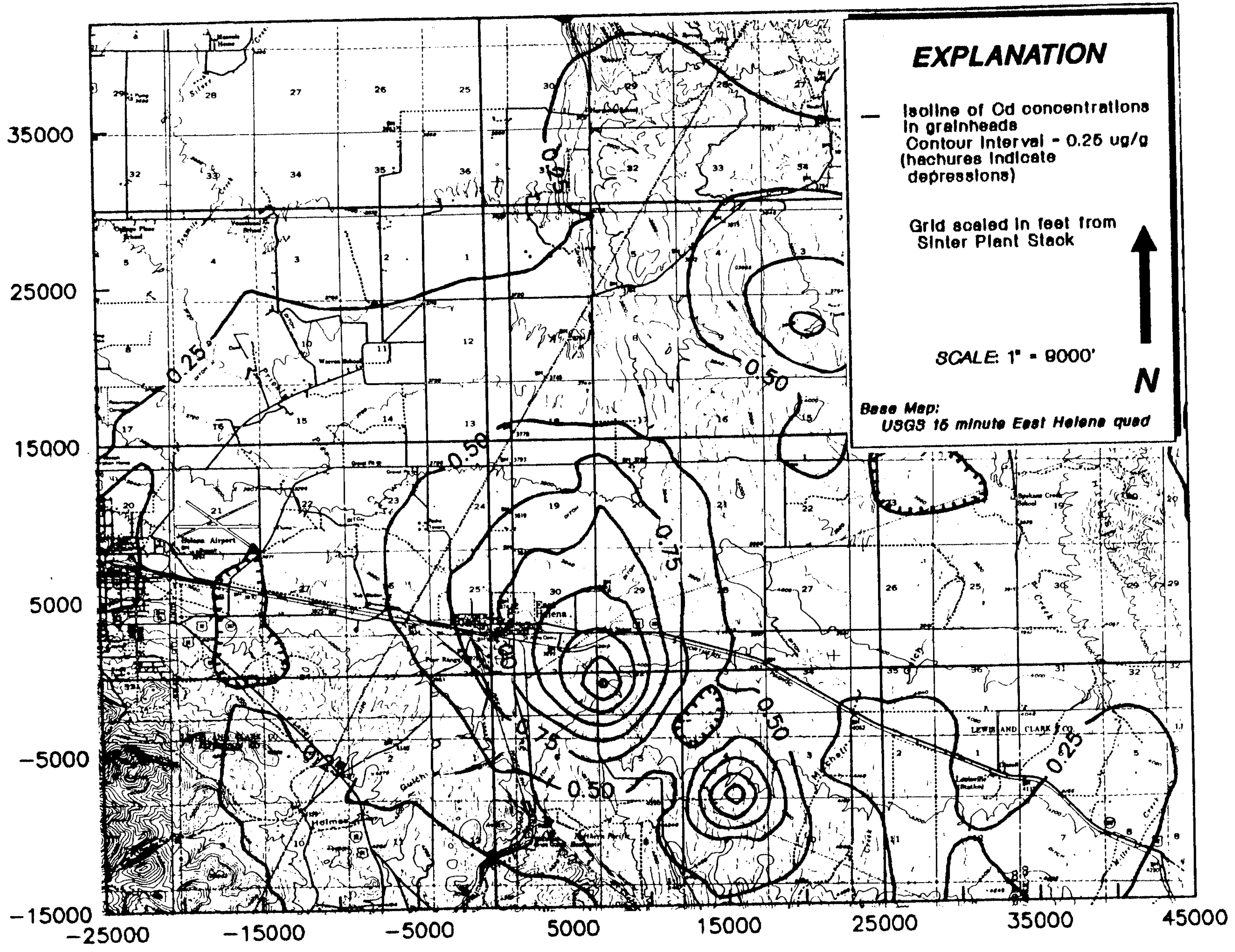


Figure 5-3-6. Isoline map of Cd concentrations in East Helena grain heads (based on 1987 data).

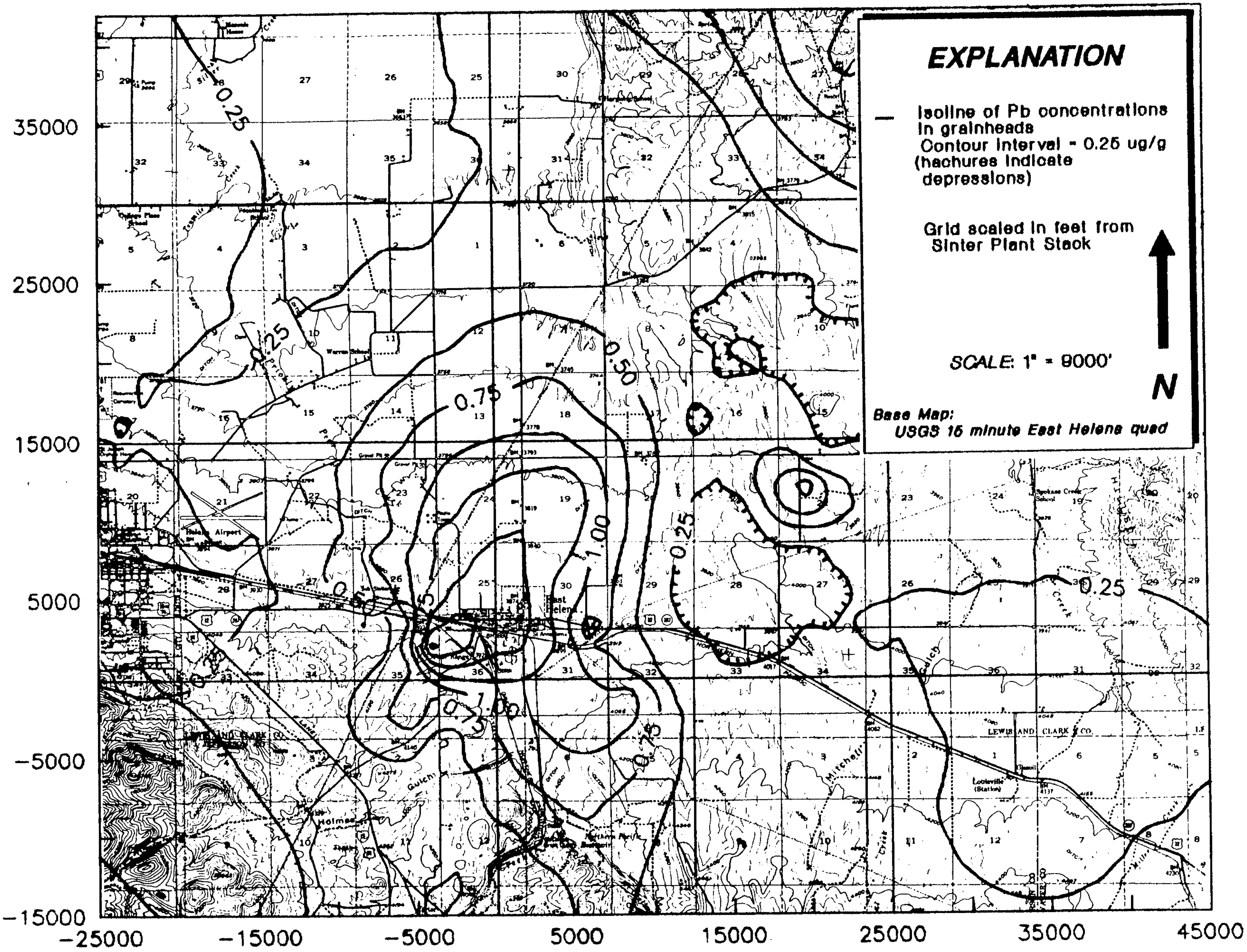


Figure 5-3-7. Isoline map of Pb concentrations in East Helena grain heads (based on 1987

northeast and southeast directions. The map for As is more ambiguous. This is apparently due to more random variation between samples than for Cd and Pb.

5.3.3.5 Effect of Sewage Sludge Application

The grain head investigation included a study of the application of Helena municipal sewage sludge onto agricultural land in the Helena Valley. The objective of this study was to determine if sewage sludge application is likely to significantly increase the heavy metal burden in affected soils or crops.

Municipal sewage sludge from the Helena wastewater treatment plant has been applied locally to agricultural lands within the study area since 1982. Data from the City of Helena (Ham, 1988) and a Montana State University study (Gavlak, 1985) were reviewed to assess the contribution of sludge to observed Pb and Cd levels in soils. These metals were chosen because they are the most enriched elements present at the sludge application site and are commonly present in sludge at significant levels. The sludge contribution of other metals is either insignificant or the site soils have a relatively large capacity to accept more of the element. No analytical data were found for As levels in Helena sludge.

All sludge has been applied to the Ken Diehl Ranch, located approximately 2.5 miles east of East Helena. The soils of this site are classified as Aridisols, are calcareous, and have pH values mostly above 8.0 with cation exchange capacities of greater than 15meq/100g. These conditions provide an optimum environment for metal immobilization. Investigation of heavy metals movement conducted during the Phase I RI showed that Cd is not migrating below surficial soils and that Pb migration to deeper soils is small in both quantity and distance of movement (U.S. EPA, 1987a).

Sludge analyses (1984-1987) provided by the City of Helena showed that average extractable metal levels were 0.26 mg/L and 4.7 mg/L for Cd and Pb respectively (Ham, 1988). The recommended application rate of 5,219 liters/hectare (biannually, 6" depth of incorporation) provides optimal nitrogen levels for maximum crop yield. There are no plans to increase this rate in the future. Seven soil samples were collected from the

Diehl ranch during the Phase I RI (U.S. EPA, 1987a). Average total Cd and Pb levels in these soil samples were 3.91 and 136.29 ug/g, respectively.

Total Cd and Pb sludge metal loading per year is calculated by multiplying the yearly application rate by the average sludge metal content. Assuming a conservative six inch zone of incorporation and an average soil bulk density of 1.25, a 100 year term of sludge injection at this rate would increase observed levels of Cd by 0.77% and of Pb by 0.40%. These values are smaller than the measured variance of metal levels in ranch soils. Sludge application rates of over 5 times the recommended rate have shown no significant short term enrichment of Pb or Cd in plant tissue or grain heads at this site (Gavlak, 1985).

5.3.3.6 <u>Summary and Conclusions of Helena Valley Grain Studies</u>

- The 1984 and 1987 grain studies both show that wheat grain head levels of Cd and Pb are elevated above background for the Helena Valley study area. The 1984 study found enrichment of Cu and Hg that was not confirmed in 1987. Grain head As was elevated in the 1987 study.
- Cadmium exhibits the highest enrichment factor (9.4) times background for wheat grain heads.
- Element concentrations in background samples are within global ranges for wheat grain heads.
- The frequency of elements exceeding background levels in Helena Valley wheat grain heads were As at 79%, Cd at 90%, Cu at 64%, Hg at 0%, Pb at 38% and Zn at 33%.
- Grain head As, Cd, and Pb concentrations within the Helena Valley are generally higher nearest the Plant.

In summary, it appears that some grain fields in the study area are producing a crop containing elevated concentrations of As, Cd, and Pb. These fields are likely to be relatively close to the plant site. Only Cd is significantly enriched above background for fields more than three miles from the plant. Fields greater than four miles from the plant do not show significantly ($p = .10$) elevated concentrations above background for any element.

5.4 HELENA VALLEY CATTLE INVESTIGATIONS

5.4.1 Purpose and Scope of Cattle Investigations

Ingestion of meat products raised in the Helena Valley is one potential pathway for metal intake by residents of the study area. The beef investigation was conducted to assess the human health risk of metal ingestion via cattle, the most commonly raised domestic livestock in the Helena Valley (U.S. EPA, 1987a). Principle tasks of the cattle investigation are: 1) Identification of potentially high-risk populations by tracing the fate of locally-grown beef with a beef consumption and production survey, and 2) analyses of edible beef tissues which are most likely to accumulate metals and/or are commonly eaten meat cuts.

The scope of the tissue study is to determine the concentration of Pb, Cd, As and Zn in liver, kidney and muscle tissues of beef cattle which have been raised in the vicinity of the plant site. These four analytes were selected for the tissue investigation because they were the principle trace elements detected in forage and in cattle blood and hair in the Phase I Soils Remedial Investigation (U.S. EPA, 1987a). The purpose of the analyses is to provide an indicator of the amount of heavy metals in beef which is consumed by humans. This investigation included only the highest risk population, i.e., cattle which had lived within a three-mile radius of the plant for a minimum of two years.

5.4.2 Beef Consumption and Production Survey

Complete results of the beef consumption and production survey are in Appendix 5.4.1, as is a copy of the survey that was sent to potential local beef producers and consumers. Many of the 117 repondents to the survey did not answer all of the questions, so different questions rely on different sample sizes. The principle findings with regard to locally-grown beef consumption are that 76 households either produce their own and eat, or buy and eat, locally-grown beef. For the 67 households which provided consumption data, average beef intake is 3.9 pounds per person per week, with a maximum of 20 pounds per person per week. The average household included four people, so the survey indicates that the diet of at least 304 people includes locally-grown beef.

All of the cattle producers market most of their animals through the Butte or other local livestock markets. The East Helena cattle are thereby typically distributed to feedlots in the Western and Midwestern United States, and mixed in with the general U.S. beef supply.

The management practices summarized in Appendix 5.4.1 demonstrate that local pasture (typically in use for 5-8 months per year), and locally-grown hay are the dominant feed sources for virtually all of the cattle herds in the East Helena vicinity.

5.4.3 Element Levels in Helena Valley Beef Tissue

Results of the muscle, liver and kidney tissue analyses for the control group (Herd 1) and test groups (Herds 2 and 3) are shown in Table 5-4-1. The principle features of the data are (1) muscle tissue with As, Cd, Pb and Zn levels that fall within the typical range of national data published by USDA; (2) high Cd levels in cattle kidney and liver; and (3) complication of the control herd/test herd comparison because of the older age of the control group. A summary of the relevant descriptive information on the herds and of the Pb, As, Cd and Zn results, together with more detailed discussion of the Cd issues follows. Appendix 5-4-2 contains additional animal information.

The three herds selected for cattle sampling include:

> <u>Herd 1</u>. The control herd, a commercial cow operation of several hundred head of grade Herefords, is from a ranch approximately eight miles northeast of Townsend, Montana. The sampled group stayed on home pasture throughout 1987 and ate ranch-grown alfalfa/grass hay during the winter. In preceding summers however, these cows had grazed on mountain pasture several miles east of the ranch. They stayed on the home place during the summer of 1987 only because they exceeded the age past which the rancher sends his cows to the mountains. Thus by selecting cows that had grazed only on pasture of approximately known metal content, the investigation was forced to select older cows, i.e., greater than ten years old. The impact of this choice is discussed below. All six cows were in good health at the time of slaughter, although it was clear from the quality of their teeth and muscling that they were older.

Table 5-4-1. As, Cd, Pb and Zn concentrations in Helena Valley and Townsend cattle muscle, liver and kidney tissue.

			MUSCLE				LIVER				KIDNEY			
Herd	Animal	Age	As	Cd	Pb	Zn	As	Cd	Pb	Zn	As	Cd	Pb	Zn
1	r-1	>10	<0.05	0.09	0.17	44.20	<0.05	0.67	0.14	28.20	<0.05	10.9	0.12	19.00
1	r-2	>10	<0.05	0.04	0.06	48.20	<0.05	0.29	0.36	26.70	<0.05	r	0.12	20.00
1	r-3	>10	<0.05	0.1	0.07	56.70	<0.05	0.6	0.18	23.70	<0.05	r	1.00	19.00
1	r-4	>10	<0.05	0.03	0.09	46.20	<0.05	0.73	0.16	56.00	<0.05	0.1	0.20	59.00
1	r-5	>10	<0.05	0.05	0.07	44.00	<0.05	0.5	0.15	28.00	<0.05	0.2	0.11	26.20
1	r-6	>10	<0.05	0.2	0.01	51.70	<0.05	0.38	0.16	32.00	0.09	10.05	0.08	19.30
2	b-1	4	0.07	0.06	0.08	46.50	0.15	0.5	0.49	*256	0.73	r	0.21	21.20
2	b-2	9	<0.05	0.03	0.08	57.50	0.06	0.44	0.16	31.20	0.1	16.1	0.21	24.2
2	b-3	5	<0.05	0.03	0.01	53.30	<0.05	r	0.26	33.00	0.12	2.69	0.53	21.20
2	b-4	12	0.06	0.05	0.14	48.50	0.12	r	0.32	33.70	0.74	13	r	22.50
2	b-5	2	0.03	0.07	0.10	92.40	0.03	0.25	0.20	52.10	0.06	1.61	0.22	24.00
2	b-6	2	0.06	0.2	0.19	94.40	0.02	0.3	0.38	68.20	0.08	0.43	0.58	35.00
3	j-1	4.5	<0.05	0.04	0.03	45.80	<0.05	0.57	0.12	32.70	0.09	5.2	0.47	19.50
3	j-2	2.5	<0.05	0.03	0.32	51.30	<0.05	1.6	0.38	32.50	0.10	r	0.89	18.70
3	j-3	4.5	0.06	0.02	0.01	49.50	<0.05	1.43	0.17	31.50	0.10	0.5	1.08	18.70
3	j-4	2.5	<0.05	0.04	0.02	49.70	<0.05	0.78	0.14	31.00	0.16	6.2	0.49	18.70
3	j-5	2.5	<0.05	0.11	0.78	61.50	0.07	1.06	0.16	33.00	0.16	8.3	0.50	18.70
3	j-6	5	<0.05	0.01	0.03	47.20	0.07	1.51	0.15	33.00	0.13	9.5	0.25	18.50

r = data rejected during data validation (Roy F. Weston, 1989)

* = This result is anomalously high; the result for the split sample, analyzed by a separate CLP lab, was 23.8 ug/gm. The lower value was used for statistical computations.

Herd 2. This test group is from a herd of several hundred head of registered Simmental cows whose home pasture extends from approximately three to five miles northwest of the plant. Sales from this herd are primarily for breedstock, and the animals are marketed nationally with the use of detailed performance and genetic records. The sample group included three cows, two heifers and a bull, all of which had grazed on home pasture in 1987, and grazed on mountain pasture south of Helena only in pre-1987 summers. Prickly Pear Creek was their water supply, and home-grown alfalfa/grass hay was their winter feed.

All six animals were in good health at the time of slaughter. There were some adhesions in the bull's chest cavity indicative of pneumonia during the previous spring or summer. Pneumonia is not a rare ailment among breeding bulls in Montana, and this particular animal showed no unusual side effects (Carter, 1987). The females ranged in age from two to twelve.

Herd 3. This test group represented all but one of a small herd which resided approximately three miles west of the plant. The six cows included three registered Herefords and three cross-breeds, ranging in age from 2.5 to 4.5 years. They grazed on the home ranch for their entire lives, and ate alfalfa/grass hay in the winter, most of which was purchased from Helena Valley ranches more than three miles away from the plant. During the fall preceding the sampling, the rancher was supplementing the home pasture with a small amount of feed: approximately ten pounds of ranch hay per day per cow, and a very small amount of home-grown barley. A spring in the pasture was the cows' water supply. All of the cows were in good health at the time of slaughter, and the veterinarian noted that the abscess on one cow's kidney was not unusual. Two of the cows had had their hair and blood sampled during Phase 1 of the Remedial Investigation (U.S. EPA, 1987a). Their eartag identification numbers from that study are noted in Appendix 5-4-2, together with a complete tabulation of all the herds' individual animal information.

Locations of the three herds selected for the beef tissue study are shown on Figure 5-4-1.

Results of the As, Cd, Pb and Zn analyses of muscle, liver and kidney tissue are shown in Table 5-4-1 and summarized statistically in Table 5-4-2. The statistical computations were performed on log-transformed results because the data are log-normally distributed. They are calculated for validated data only; thus one Pb and nine Cd results are not included. However splits of two of the rejected kidney samples and one of the rejected liver samples were also analyzed by a separate EPA-approved laboratory. Those results were incorporated into the data set for statistical treatment.

Although the trace element levels are quite variable, the data demonstrate some general patterns. Arsenic content is typically below or near the detection limit of 0.05 ug/g in all organs in all three herds. Exceptions include two liver samples from Herd 2 and seven kidney samples from Herd 2 and 3 which have 0.10-0.16 ug/g As. Two kidney samples from Herd 2 had the highest As levels at 0.73 and 0.74 ug/g As. According to t-test comparisons of the test herds with the control herd, the As levels are not significantly different between herds for all three organs at a 95% confidence level.

Cadmium levels in muscle were typically near-detection limit (0.05 ug/g Cd) for all three herds; the control herd was highest with a mean value of 0.07 ug/g. One cow from Herd 1 and one heifer from Herd 2 had 0.2 ug/g Cd, the highest reported level of that analyte in muscle. The muscle Cd levels are statistically indistinguishable.

Cadmium levels in liver range up to 1.6 ug/g. The t-test confirms that the test herds differ from the control at a 95% confidence level, but the Herd 2 mean is lower than the control. Similarly, mean kidney Cd levels in both test herds are lower than that of the control, although the range of Herd 2 starts at a relatively high concentration.

Direct comparison of herd means may not be useful for evaluating human health risks from typical edible beef, because all of the control herd

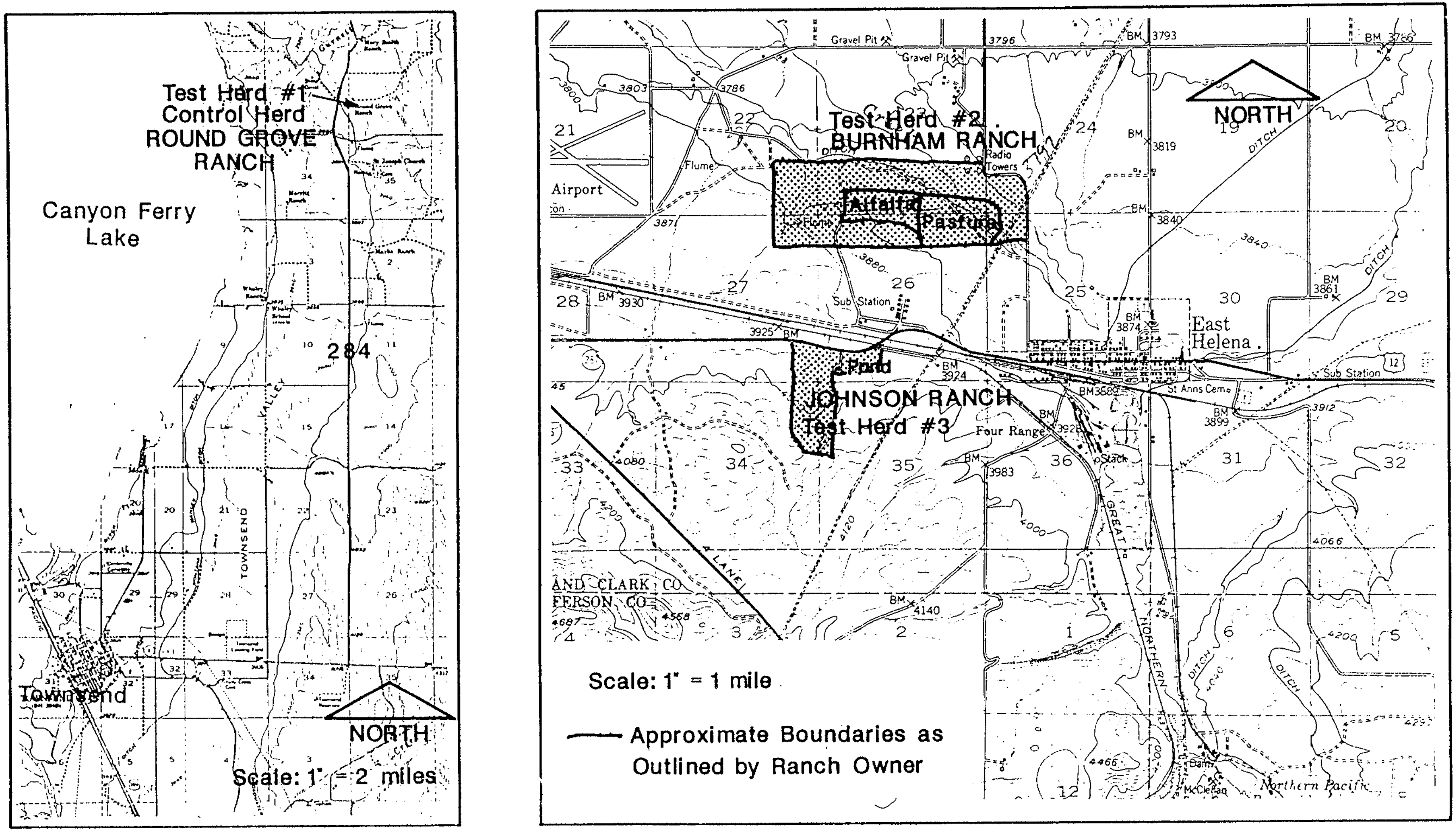


Figure 5-4-1. Ranch Locations for Beef Tissue Study

Table 5-4-2. Summary statistics and t-test results for Helena Valley cattle tissue study.

Organ	Herd	Statistics on log-transformed data* (ug/g)	As	Cd	Pb	Zn
MUSCLE	1	mean	0.025	0.07	0.06	48.3
	2	mean	0.04	0.05	0.07	62.7
	3	mean	0.03	0.03	0.06	50.6
	1:2	**t-test	same	same	same	same
	1:3	t-test	same	diff	same	same
LIVER	1	mean	0.025	0.5	0.18	31
	2	mean	0.05	0.36	0.29	56.2
	3	mean	0.04	1.09	0.17	32.3
	1:2	**t-test	same	diff	same	same
	1:3	t-test	same	diff	same	same
KIDNEY	1	mean	0.03	8.74	0.17	24.5
	2	mean	0.18	2.22	0.31	24.3
	3	mean	0.12	4.3	0.55	18.8
	1:2	**t-test	same	diff	same	same
	1:3	t-test	same	diff	same	diff

* The statistics are calculated using the log-transformed data, but the tabulated results are not expressed logarithmically

** The t-test was performed at 95% confidence level to compare the means of test herds with that of the control (1:2 and 1:3)

*** Arsenic results at the detection limit of 0.05 ug/g are treated as half-detection limit for computations cows are more than ten years old. Their high liver and kidney Cd concentrations are consistent with several reports of Cd accumulation by mammalian visceral organs with age (National Academy of Sciences, 1980b; Friberg, 1979). Such an aged control sample forces important constraints on the interpretation of the trace element data.

Mean Pb levels (Table 5-4-2) for all three organs are not significantly different among the herds (p=0.05), nor do any individual animals exhibit a consistent age-concentration relationship analogous to that for Cd. The means are 0.06-0.07 ug/g in muscle, 0.17-0.29 ug/g in liver, and 0.17-0.55 ug/g in kidney for the three herds.

Zinc concentrations are typically in the range of 40-60 ug/g in muscle, 30-50 ug/g in liver, and 20-30 ug/g in kidney. One anomalously high liver value of 256 ug/g in animal B-1, Herd 2, is not corroborated by the CLP split value of 23.8 ug/g, and is suspect. The mean calculated with the 23.8 (40.3 ug/g) value is much closer to the Herd 2 and 3 means (31 and 31 ug/g).

Excluding that outlier, Zn levels are generally lower in organs in which Cd is higher when the data are viewed collectively. This is consistent with replacement of Zn by Cd in many biological systems (Friberg, 1979).

Within-organ, between-herd comparisons of Zn means show that all three herds have indistinguishable muscle and liver Zn levels. However, Herd 3 may exhibit statistically significant Zn depletion (p=0.05) relative to background in kidney tissue (Table 5-4-2). Examination of the Cd:Zn ratio provides a more direct approach to this issue of Cd substitution for Zn. However, comparison of the Cd:Zn ratios is more meaningful when age is accounted than comparison of herd means of Cd:Zn. Figure 5-4-2 shows Cd:Zn plotted against age. In kidneys, the relationship is analogous to that for Cd concentrations; the test herds are higher than the control herd when age is accounted for. In liver and muscle tissue the Cd:Zn ratio does not increase with age.

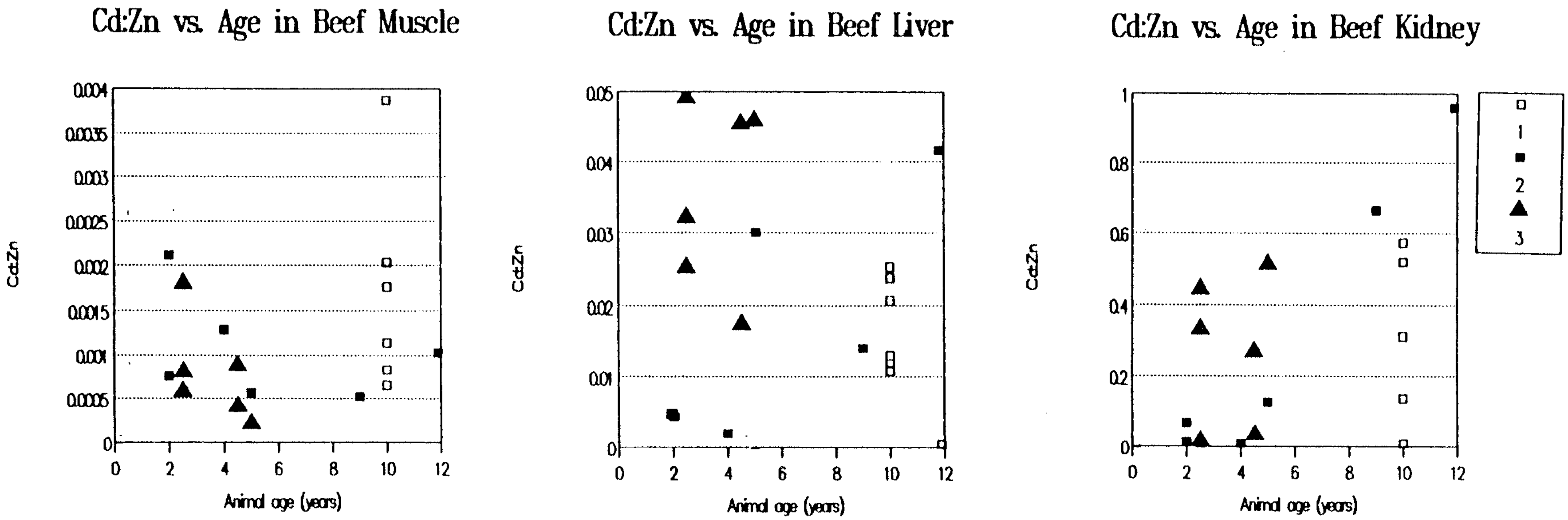


Figure 5-4-2. Cadmium-to-zinc ratios versus age in beef muscle, liver and kidney. Herd 1 = empty square; herd 2 = filled square; herd 3 = filled triangle.

If the Zn depletion is due to Cd activity, then the data suggest that the test herds contain a relatively high concentration of metabolically active Cd. Such partitioning of "active" versus "inactive" Cd is borne out by variable Cd levels in kidney structures with active metabolic versus storage functions (Friberg, 1979). This implies that Herd 2 and 3 animals had greater dietary Cd intake than Herd 1 at the time of slaughter, for cortical kidney Cd is proportional to Cd dose (Harokova, 1982). Therefore, Herd 1 cows would have had lower Cd levels than Herd 2 and 3 cows had they been slaughtered at equivalent ages.

Considerable scatter in the data underlies all discussion of the age-concentration relationships. Several factors could contribute to such scatter, including variable eating habits among individuals; analytical difficulties discussed in the Data Validation and Reduction Report (Roy F. Weston Inc., 1989b); non-uniform ratios of medullary and cortical kidney tissue in the analyzed samples (the cortex contains higher Cd than the medulla, Friberg, 1979); genetic differences, as well as proximity to the plant site. The resulting uncertainties associated with the control/test herd comparisons do not weaken the goal of the investigation, which was to examine trace element levels in typical beef for human consumption from 2-3 year old animals. Comparison of the test herds with a national data base provides an auxiliary approach to the evaluation of edible beef from East Helena cattle. Trace element data from the Residue Evaluation and Planning Division (REPD) of the Food Safety and Inspection Service of USDA provides such a reference for comparison.

Table 5-4-2 shows the mode and upper 90% confidence level of the REPD data for 1970-79 and for 1985. Means for animals of corresponding sex and age from test herds are tabulated where possible. Modes were not used for the Helena Valley and Townsend cattle tissue data because of the small number of test animals.

In muscle tissue, the cadmium level of test herds do not exceed the upper 90% limit of the REPD animals. If heifer data alone are considered, one animal from Herd 2 exceeds the 90% level by 0.05 ug/g.

Table 5.4.3. National data on Cd in beef* (ug/g, wet weight).

		1970-1979			1985			Test herd 2		Test herd 3	
Animal	Organ	n	mode	high**	n	mode	high***	n	values	n	values
Bull	MUSCLE		-		17	<0.1	<0.1	1	0.06		
	LIVER		-		17	0.15	0.5-1	1	0.5		
	KIDNEY		-		17	0.75	1-2.5	1	-		
Cow	MUSCLE	16	*	0.1	78	<0.1	0.1-2	3	.03, .03, .05	3	.04, .02, .01
	LIVER	16	0.3	0.7	78	0.15	0.5-1	1	0.44	3	.57, 1.43, 1.51
	KIDNEY	16	*	3.5	78	1.75	>5	3	16, 2.7, 13	3	5.2, 0.5, 9.5
Heifer	MUSCLE	154	0.1	0.15	97	<0.1	<0.1	2	0.2, .07	3	.03, .04, .11
	LIVER	155	0.2	0.4	98	<0.1	>5	2	0.25, .3	3	1.6, 0.7, 1.06
	KIDNEY	154	0.5	1.0	97	0.3	>5	2	1.61, .43	2	6.2, 8.3
Steer	MUSCLE	161	0.1	0.2	192	<0.1	0.1-0.2				
	LIVER	163	0.2	0.4	191	<0.1	0.2-0.3				
	KIDNEY	144	0.5	0.75	191	0.28	1-2.5				

* USDA, Residue Evaluation and Planning Division, Food Safety and Inspection Service, Trace Element Background Levels

** The upper limit of the 90% confidence level was reported by USDA

*** The highest values were within this range in the 1985 data (single analysis results were not reported)

In liver tissue the test herd means exceed the REPD mode by as much as 0.8 ug/g, but only the Herd 3 mean exceeds the REPD upper level. For heifers, all cases exceed the mode, and only the Herd 3 cases exceed the 90% confidence level (by up to 1.2 ug/g).

In kidney tissue the test herd means exceed the the REPD mode by up to 2.7 ug/g (Herd 3), and only the Herd 3 mean exceeds the 90% confidence level. Among heifers, one Herd 2 animal exceeds the mode by approximately 1 ug/g and the Herd 3 animals exceed the mode by 5.7 and 7.8 ug/g). Both herds have animals which exceed the 90% confidence level.

For all organs there is at least one animal which exceeds the upper 90% confidence level of the REPD cadmium data.

Table 5-4-4 shows analogous REPD data for As, Pb and Zn. The test herds show similar concentrations for all three organs. Zinc in East Helena muscle is somewhat higher (means of 48, 63 and 51) than the REPD modes of 35-40. All of the test herd Pb levels are lower than or equal to the REPD modes. Undetectable As is the mode value for all organs in the REPD animals, so the several occurrences of measurable As in the test herds must be considered above background. However all of the test herd As levels fall below the 90% confidence limits of 0.2 (cows) and 0.1 (heifers), except for animals B-1 and B-4 (See Table 5-4-1). Those cattle are 4 and 12 years old, and they contain 0.73 and 0.74 ug/g As in their kidneys.

5.4.4 Summary and Conclusions of Cattle Investigations

Summary of the cattle trace element concentrations must emphasize the following points:

o Cadmium is the most significant of the four trace elements analyzed in this study. Arsenic and Pb do not exhibit major deviations from local or national background data, although there are two cases of markedly elevated As in kidneys. The Zn concentrations may be significant primarily because of their relationship to Cd excess. Therefore Cd receives the principle emphasis in this report.

Table 5-4-4. National data on As, Pb and Zn in cattle tissues* (ug/g wet weight).

		As			Pb			Zn***		
Animal	Organ	n	mode	high**	n	mode	high	n	mode	high
Bull***	MUSCLE		-		17	ND	ND	17	>5	-
	LIVER		-		17	ND	ND	17	>5	-
	KIDNEY		-		16	ND	0.5-1	17	>5	-
Cow	MUSCLE	2194	ND	0.15	2192	0.3	0.9	78	>5	-
	LIVER	2194	ND	0.2	2192	0.4	0.9	78	>5	-
	KIDNEY	2194	ND	0.2	2192	0.4	1.0	78	>5	-
Heifer	MUSCLE	142	ND	0.01	133	0.3	0.6	97	>5	-
	LIVER	155	ND	0.2	155	0.4	0.8	98	>5	-
	KIDNEY	127	ND	0.1	134	0.4	0.9	97	>5	-
Steer	MUSCLE	140	ND	0.01	145	0.3	0.7	192	>5	-
	LIVER	164	ND	0.1	163	0.4	0.8	192	>5	-
	KIDNEY	128	ND	0.1	144	0.5	0.9	192	>5	-
Herd 2	MUSCLE	6	0.04	0.07	6	0.07	0.19	6	62.7	94.4
	LIVER	6	0.05	0.15	6	0.29	0.49	6	56.2	256
	KIDNEY	6	0.18	0.74	6	0.31	0.58	6	24.3	35.0
Herd 3	MUSCLE	6	0.03	0.06	6	0.06	0.78	6	50.6	61.5
	LIVER	6	0.04	0.07	6	0.17	0.38	6	32.3	33.0
	KIDNEY	6	0.12	0.16	6	0.55	1.08	6	18.8	19.5

* USDA, Residue Evaluation and Planning Division, Food Safety and Inspection Servic
Trace Element Background Levels

** The upper limit of the 90% confidence level was reported by USDA
For Herds 2 and 3, the highest individual value is shown

*** Bull data are 1985 background levels; there were no 1970-1979 bull results

- The absolute Cd levels in the test herds are commonly lower than the older, control herd Cd levels. This reflects longer accumulation by the older animals and does not directly aid the evaluation of typical candidates for slaughter (2-3 year olds).

- Typical slaughter-age cattle from the test herds would produce muscle tissue with Cd levels that fall within the typical range of national data published by USDA. However, their liver, and to an even greater extent their kidney tissue, commonly exceed the typical range of the national data.

- The occurrence of high Cd levels in a supposed control or "background" herd demonstrates that all liver and kidney tissue from old animals are at risk of containing high Cd concentrations. Whether the Townsend cows obtained their Cd from mineralized summer pasture in the mountains, or from metal levels in the home ranch pasture, similar Cd accumulation is likely to occur elsewhere, considering the diversity of ranch conditions throughout the country.

- The East Helena test herd tissue data was compared to a national data base developed by the Residue Evaluation and Planning Division of the Food Safety and Inspection Service of the USDA. This comparison clearly indicates that the measured As, Cd, Pb and Zn levels in the muscle tissue from East Helena test herds do not exceed typical ranges for cattle raised throughout the United States. This is a significant finding in that most individuals consume meat products from the muscle tissue of cattle.

5.5 FISH

Physical characteristics of fish sampled from Prickly Pear Creek and Lake Helena are summarized in Table 5-5-1.

Available sample species were limited during both Prickly Pear Creek and Lake Helena sampling efforts (see Section 2.3.5.1 - Methodology). A total of five brown trout fillet samples from Prickly Pear Creek, and two white sucker and three longnose sucker fillet samples from Lake Helena were analyzed for metals concentrations. The results are summarized in Table 5-5-2. In addition to the fish samples summarized on Table 5-5-1, six split samples were also collected by EPA (2 brown trout from Prickly Pear Creek; one brown trout, one brook trout, one white sucker, and one longnose sucker from Lake Helena.

Because of the limited number of samples, statistical analyses of length-weight or condition parameters could not be conducted. However, based on field observations, brown trout from Prickly Pear Creek seemed to be in poor condition (i.e., body size/depth appeared to be underproportioned to head size). Both species of trout and both species of suckers taken from Lake Helena, however, appeared to be in normal condition.

There were no obvious trends between body size and metals concentrations. In general, Zn concentrations in fish from Lake Helena were higher than those from Prickly Pear Creek, while Cd concentrations were lower. As, Hg and Pb concentrations were similar to those from fish in Prickly Pear Creek. It is not clear if any differences are due to environmental conditions or to differences among fish species. The white suckers show higher lead and zinc concentrations than longnose suckers, however, the sample size comparison is very small.

Table 5-5-3 shows the correlations for metal parameters measured in fish by both the DOES and EPA CLP laboratories, and by the EPA CLP laboratory alone. The correlation of various metals parameters appears to be poor for the entire fish sample set (both DOES and EPA CLP analyses). However, a strong correlation appears to exist for arsenic, cadmium and lead for fish analyzed by the CLP laboratory alone. Table 5-5-2 shows that, in general, metal analyses by the DOES laboratory (record numbers 95 through 99 and 100 through 104) were higher than the CLP laboratory analyses (99b, 99c and 104d through 104g).

TABLE 5-5-1. PHYSICAL CHARACTERISTICS OF FISH SAMPLES FROM PRICKLY PEAR CREEK, AND LAKE HELENA

Record No.	EPA Tag	Location	Date	Spp.[a]	Sex	Lgth. (mm)	Wgt. (gm)
95	8-60995	Prickly Pear Crk.	11/18/87	BT	F	331	789
96	8-60997	"	"	BT	unk	220	91
97	8-60996	"	"	BT	M	436	1116
98	8-60998	"	"	BT	F	361	413
99	8-60994	"	"	BT	F	359	494
---[b]	8-60999	"	"	BT	M	362	468
---[c]	8-61000	"	"	BT	F	310	272
100	8-60953	Lake Helena	6/1/88	WS	F	357	553
101	8-60954	"	"	WS	M	385	671
102	8-60956	"	"	LNS	F?	435	916
103	8-60957	"	"	LNS	F	445	1080
104	8-60958	"	"	LNS	M	368	499
---[d]	8-60959	"	"	WS	M?	378	599
---[e]	8-60960	"	"	LNS	F?	489	1189
---[f]	8-60990	"	"	BT	unk	237	141
---[g]	8-60961	"	"	BKT	F?	335	445

---

[a] BFS = Blind Field Standard
BT = Brown trout
BKT = Brook trout
WS = White sucker
LNS = Longnose sucker

[b] EPA sample, CLP No. 3438H-54
[c] EPA sample, CLP No. 3438H-55
[d] EPA sample, CLP No. 3856H-2
[e] EPA sample, CLP No. 3856H-1
[f] EPA sample, CLP No. 3856H-3
[g] EPA sample, CLP No. 3856H-4

TABLE 5-5-2. METAL CONCENTRATIONS IN FISH SAMPLES FROM PRICKLY PEAR CREEK AND LAKE HELENA [a]

Record		Fish tissue concentrations (ug/g)*					
No.	Spp.	As	Cd	Hg	Pb	Zn	Cu
95	BT	0.15	0.100	0.05	0.94	16.00	----
96	BT	0.84	0.120	0.05	0.46	19.00	----
97	BT	0.09	0.100	0.05	0.59	12.30	----
98	BT	0.09	0.090	0.07	0.11	9.80	----
99	BT	0.10	0.130	0.05	0.46	20.80	----
---[b]	BT	0.05	0.18	0.10	0.27	72.8	4.58
---[c]	BT	0.05	0.18	0.10	0.35	20.6	0.98
100	WS	0.12	0.026	0.09	0.72	90.00	----
101	WS	0.11	0.049	0.11	0.57	89.00	----
102	LNS	0.11	0.093	0.08	0.17	17.00	----
103	LNS	0.00	0.039	0.05	0.22	53.00	----
104	LNS	0.22	0.055	0.05	0.05	13.00	----
---[d]	WS	0.03	0.02	0.19	0.07	3.6	0.41
---[e]	LNS	0.03	0.02	0.41	0.08	7.6	0.61
---[f]	BT	0.03	0.02	0.51	0.07	5.8	0.41
---[g]	BKT	0.03	0.01	0.11	0.09	3.4	0.39

---

[a] Source: Weston (1989)
BFS = Blind Field Standard
BT = Brown trout
WS = White sucker
LNS = Longnose sucker

[b] EPA sample, CLP No. 3438H-54
[c] EPA sample, CLP No. 3438H-55
[d] EPA sample, CLP No. 3856H-2
[e] EPA sample, CLP No. 3856H-1
[f] EPA sample, CLP No. 3856H-3
[g] EPA sample, CLP No. 3856H-4

* Metals concentration data were flagged as J (estimated). See Data Validation and Reduction Report, Asarco East Helena Phase II RI Cattle and Fish Data (Weston, April 1989)

TABLE 5-5-3. CORRELATION COEFFICIENTS (r) FOR ELEMENT PAIRS IN FISH.

Fish analyzed by both DOES and EPA CLP laboratories (does not include copper)

	As	Cd	Hg	Pb	Zn
As	1.0	0.23	-0.28	0.23	0.06
Cd		1.0	-0.45	0.29	0.08
Hg			1.0	-0.43	-0.26
Pb				1.0	0.43
Zn					1.0

n=16

Split samples of fish analyzed by the EPA CLP laboratory (includes copper analyses)

	As	Cd	Hg	Pb	Zn	Cu
As	1.0	1.0	-0.59	0.98	0.79	0.72
Cd		1.0	-0.56	0.97	0.79	0.72
Hg			1.0	-0.60	-0.43	-0.41
Pb				1.0	0.65	0.57
Zn					1.0	0.99
Cu						1.0

n=6

Metals concentrations in fish tissue reported by other studies are compared in Table 5-5-4. Based on this comparison, mercury concentrations from the East Helena fish study were low; arsenic, cadmium and lead concentrations were similar, and zinc concentrations were higher than most values reported for the same species from other studies in Montana.

Arsenic is bioconcentrated by organisms but is not biomagnified in the food chain (Eisler, 1988a). According to Trout et al. (1986), neither the U.S. Department of Agriculture nor the U.S. Food and Drug Administration regulates arsenic in fish. The USDA's lowest standard for swine and poultry is 0.50 ug/g. With the exception of one brown trout from Prickly Pear Creek (Table 5-5-2), all fish collected during this study were well below this standard. The EPA quality criteria for water (Gold Book, U.S. EPA, 1986b and updates) lists a standard of 17.5 ug/l for fish consumption. Although concentrations per volume of consumable fish were not directly measured, it is intuitively apparent that arsenic in almost all fish in Montana and nationwide exceed the Gold Book Standard of 17.5 ug/l.

Cadmium tends to concentrate in the viscera, especially the liver and kidneys, rather than in muscle (Eisler, 1985). Trout et al. (1986) reported that the FDA does not regulate cadmium concentrations in fish; the Food and Agriculture Organization/World Health Organization (FAO/WHO) standard is 400-500 ug/week. Using this standard, and the highest cadmium value found during this study (0.130 ug/g, Table 5-5-2), 3846g (8.48 lbs) of fish would have to be consumed per week to reach the 500 ug/week cadmium. Eisler (1985) recommended a standard of 16 ug/kg diet/day.

Mercury bioconcentrates in organisms and biomagnifies through the food chain (Eisler, 1987). Its effects on fish and humans have been widely documented. Eisler (1987) reported a recommended criterion for a human adult of 500 ug Hg/week. Using this standard, and assuming that the only source of mercury to a human consumer was fish from the East Helena Site, a human would have to consume 4.5 kg (9.9 lbs) of fish with the highest mercury values (0.11 ug/g, see Table 5-5-2) per week. Similar to arsenic, the U.S. EPA Quality Criteria for Water (Gold Book, U.S. EPA,

TABLE 5-5-4. VALUES OF AS, CD, HG, PB AND ZN IN FISH SPECIES FOUND IN THE EAST HELENA STUDY REPORTED IN THE LITERATURE*

Location	Species[a]	As	Cd	Hg	Pb	Zn	Citation
		Range of concentrations (ug/g)					
Nationwide, USA (whole fish)		0.05-2.9 FW					Lima et al. (1984)
Nationwide, USA (whole fish)			0.01-1.04 FW				May and McKinney (1981)
Nationwide, USA (whole fish)				0.01-0.77 FW			Lowe et al. (1985)
Nationwide, USA (whole fish)					0.1-1.9 FW		Lowe er al. (1985)
Clark Fork River, MT	BT	ND-0.83	ND-1.48	0.02-0.47	ND-1.28	1.35-7.75	Phillips (1982)
Warm Springs Ponds, MT	RBT	ND-0.390	.010-.089			3.74-6.18	Trout et al. (1986)
Clark Fork River drainage, MT	trout ($\bar{X}$)		.19			6.3	Van Meter (1974)
Upper Clark Fork River, MT	3 spp.		0.2-0.6 FW				Hammons et al.(1978)
Laboratory	RBT	2.5 (max.)					Dabrowski (1976)
?	WS	0.03-0.13 FW					Jenkins (1980)
? (all tissues)	RBT	<0.4 FW					Jenkins (1980)
Alaska (whole fish)	RBT		<0.07 FW				Jenkins (1980)
New York (whole fish)	BRT			<1.0 FW			Sloan and Schofield (1983
Missouri (liver and muscle)	trout			0.1-0.3 FW			Lloyd et al. (1977)
Missouri (whole fish)	suckers				0.4-0.8 FW		Schmitt et al. (1984)

[a] RBT = rainbow trout
BT = brown trout
BRT = brook trout
WS = white sucker

* All values for muscle tissue unless otherwise noted.

1986b and updates) lists a mercury standard of 146.0 mg/L for fish consumption by humans. Based on Tables 5-5-2 and 5-5-3, it is apparent that mercury in almost all fish in Montana and Nationwide exceed the Gold Book standard for mercury. As stated earlier, necessary values from Prickly Pear Creek and Lake Helena fish were lower than reported values for fish in other locations in Montana.

Eisler (1988b) reported that lead concentrations are usually highest in algae and benthic organisms, and lowest in upper trophic level predators. No significant biomagnification of lead occurs in aquatic food chains. Lead concentrations in fish tend to increase with increasing age, and to localize in hard tissue such as bone and teeth rather than flesh (Eisler, 1988b). Eisler (1988b) also stated that proposed criteria for the protection of natural resources and human health are numerous and disparate, and listed values for fishery products from <0.3 to <10 mg/kg (ug/g). Using the lower standard, six of ten reported lead concentration values for East Helena fish would be considered elevated;. using the higher standard, all of the values would be considered low (Table 5-5-2).

Zinc values were the highest of all metals, but varied greatly between individual fish (Table 5-5-2). Lowe et al. (1985; cited in Trout et al., 1986) reported background levels of zinc in fish muscle of the United States to have a geometric mean of 23.82 ug/g wet weight in 1980-1981. The geometric mean from the 10 fish collected in the East Helena study is 24.29 ug/g, slightly higher than the national geometric mean, although seven of ten values were below the national geometric mean (Table 5-5-2). Trout et al. (1986) found that zinc appeared to show greater concentrations in livers than in fillets, suggesting that zinc values in the viscera of East Helena study fish might be even greater than those in muscle tissue.

Trout et al. (1986) stated that the USDA does not regulate zinc in cattle, swine or poultry and the FDA does not regulate zinc in fish; a Canadian Food and Drug Directorate standard of 100 ug/g was cited. All the Prickly Pear Creek and Lake Helena fish zinc values are below this standard (Table 5-2-2).

5.6 MIGRATORY WATERFOWL PATHWAY ASSESSMENT FOR METAL CONTAMINANTS AND POTENTIAL EXPOSURE TO HUMAN RECEPTORS

An assessment of potential exposure pathways of metal contaminants to humans from Upper Lake waterfowl was conducted in accordance with the Comprehensive Remedial Investigation/Feasibility Study (RI/FS) work plan. A discussion of the study methodology is in Section 2.3.5.2. The study results are in Appendix 5-5.

Upper Lake is a pond and associated marsh located southeast of the plant complex (Figure 5-6-1). Upper Lake receives flow from a diversion on Prickly Pear Creek located about 1/2-mile south of the plant. Upper Lake water is used in the smelter operations as make-up water and to supply irrigation water to Wilson Ditch. Flow into the ditch is controlled by a headgate at the pond.

Upper Lake is part of property owned by Asarco and there is no public access to the pond. Its shorelines are vegetated with a mix of mesic species and the pond supports a variety of emergent and submergent plants. A small number of waterfowl nest in or near the pond and it receives variable use during migration.

5.6.1 Bottom Sediment and Surface Water Quality for Upper Lake

Laboratory analyses show that Upper Lake bottom sediments have elevated concentrations of arsenic and metals. Possible causes of elevated metals concentrations in Upper Lake bottom sediment are: overland runoff of sediment containing high metals concentrations into Upper Lake; deposition of metals-bearing sediment derived from old upstream mining disturbances and tailings in the Prickly Pear Creek drainage; fallout of airborne particulates from past smelter emissions.

Results of Upper Lake water analyses indicated that water quality is essentially the same as Prickly Pear Creek upstream of the plant (Phase I WRM report, Hydrometrics, 1986a). Generally, Upper Lake water is a hard, alkaline, calcium-bicarbonate type with moderate concentrations of total dissolved solids (TDS) and low to moderate concentrations of arsenic and metals.

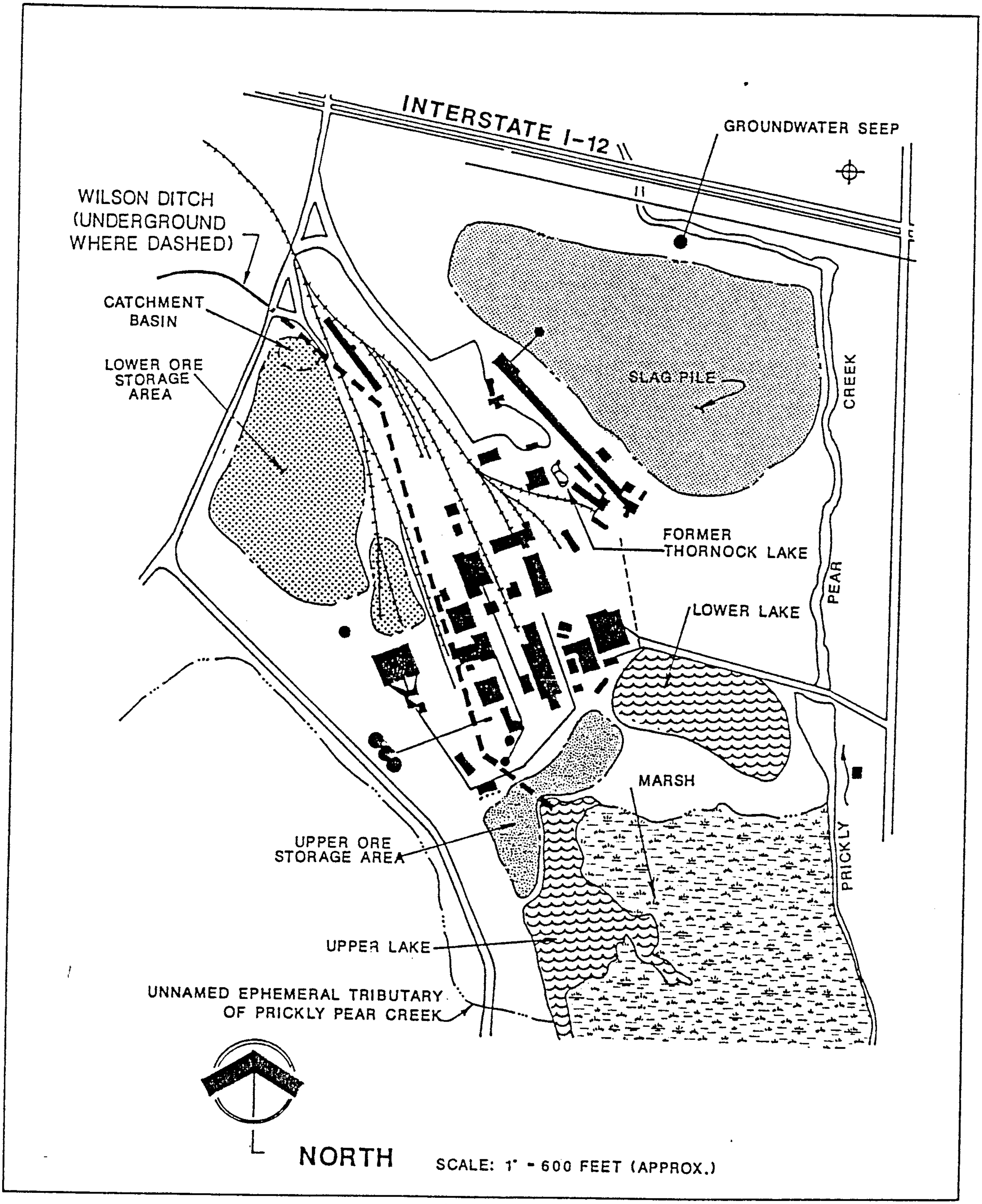


FIGURE 5-6-1. *Location Map of Asarco East Helena Plant Area Showing Upper Lake*

Detailed surface water bottom sediment and chemistry data from the Upper Lake area are in Appendices 5-2-1 and 5-2-3, respectively.

5.6.2 Warm Springs Ponds Bottom Sediment Data

Preliminary sediment data for the Warm Springs Ponds on Silver Bow Creek (Multitech, 1984) are in Table 5-6-1. The elements analyzed from the Warm Springs Ponds are arsenic, cadmium, copper and zinc. No data for lead or any other elements are available. These data provide some insight into a comparison of sediment data with the potential accumulation of metals in waterfowl, since waterfowl at the Warm Springs Ponds were also sampled. The results of the waterfowl sampling program are discussed in detail in Appendix 5-5.

5.6.3 Comparison of Upper Lake and Warm Springs Ponds Bottom Sediment Data

A comparison of the Warm Springs Ponds sediment data with the Upper Lake sediment data is in Table 5-6-1. This comparison shows:

1) The average metals concentrations between sediments from Warm Springs Ponds 1, 2 and 3 vary significantly between the ponds.

2) The average concentrations of arsenic, cadmium, copper and zinc for all the Warm Springs Ponds sediments is significantly higher than the average concentrations of these same parameters for Upper Lake sediments.

5.6.4 Literature Review

The appropriate reference citations for the information contained in the following subsections are in Appendix 5-5.

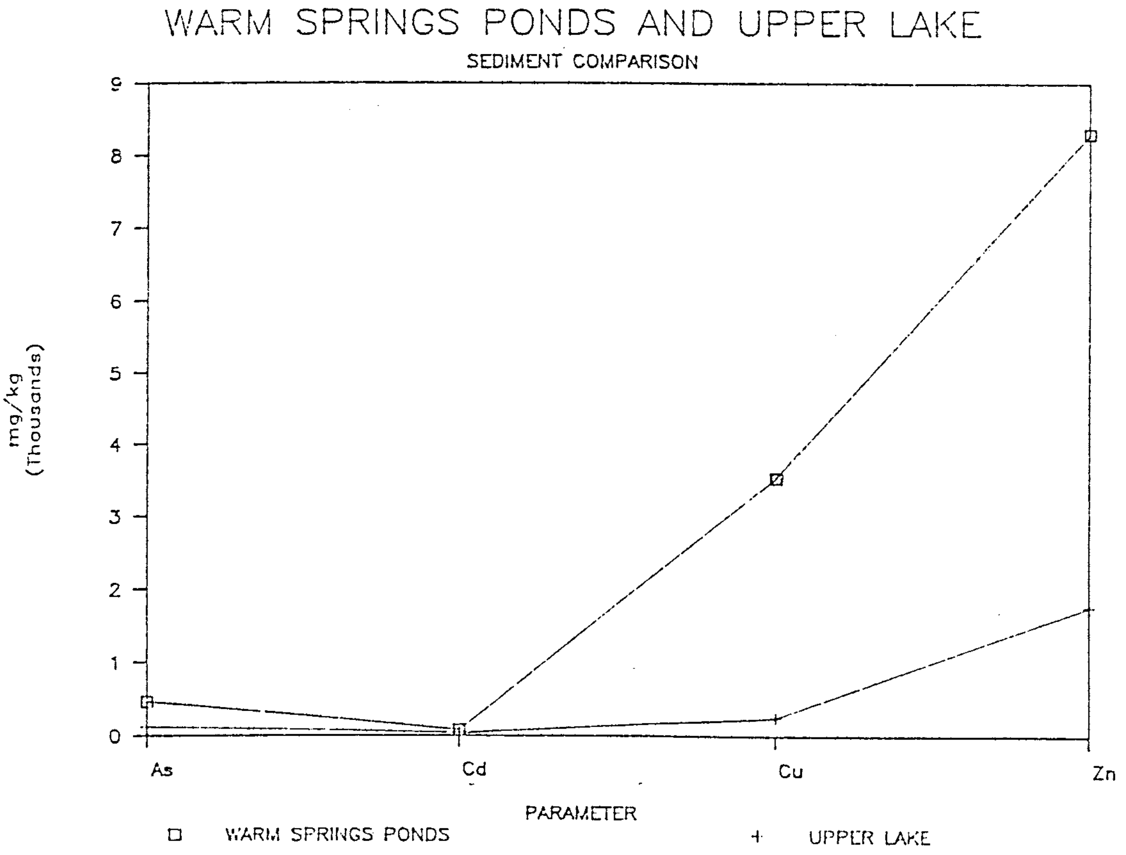
5.6.4.1 <u>Factors Influencing Heavy Metals Effects on Waterfowl and Human Receptors</u>

The literature review revealed that it is very difficult to predict whether or not heavy metals, when known to be present in an aquatic ecosystem, will affect waterfowl using that ecosystem. Factors which can influence effects on waterfowl were identified in the literature review and include:

TABLE 5-6-1. COMPARISON OF As, Cd, Cu, AND Zn IN SEDIMENTS AT WARM SPRINGS PONDS AND ASARCO UPPER LAKE SEDIMENTS

POND #	ELEMENT	WARM SPRINGS PONDS AVG. CONC. OF UPPER 5 ft. OF SEDIMENT IN mg/kg		UPPER LAKE AVG. CONC. OF UPPER 1 ft. OF SEDIMENT IN mg/kg
1	As	376		
	Cd	2.5		
	Cu	700		
	Zn	600		
2	As	645		
	Cd	25		
	Cu	3600		
	Zn	3900		
3	As	364		
	Cd	204		
	Cu	6300		
	Zn	20400		
POND AVG.	As	461	As	121.17
	Cd	77.1	Cd	38.17
	Cu	3533	Cu	255.3
	Zn	8300	Zn	1768.5

NOTE: Detailed individual element concentration data for Upper Lake are found in Appendix 5-2-2.



1) Biotic Factors: differences between species of waterfowl; differences between sexes and age classes within a particular species; differences between individuals of the same species, sex and age; differences in food habits between species; changes in food habits of a particular species, either seasonally or annually, based on food availability at the site and/or at other feeding sites; occurrence of other avian diseases that may exacerbate the effects of metals; the season of use of a contaminated site (e.g. breeding vs. wintering areas); exposure time (i.e., length of use of a contaminated site); diversity and abundance of plants; and microbial activity in sediments.

2) Abiotic Factors: water depth, temperature, pH, hardness, salinity, oxygen content, and amount and types of organic compounds; the presence of other metals; the amount of suspended sediment; the form of the metal present; the size of the metal particles present; and climatic factors that affect the use of the site by waterfowl.

The above factors interact to cause considerable variation in the number of birds affected at a given site from season to season, or from year to year. Consequently, some researchers have concluded lethal hazard cannot be predicted solely on the basis of chemical hazards, and that the specific compound more decisively influences the toxic effect of an element than its total concentration.

Since it is so difficult to predict the probability of passage of metals through the aquatic ecosystem to waterfowl, it is even more difficult to predict the likelihood of potential effects from waterfowl to humans. This difficulty is reflected by the paucity of literature references on the subject.

5.6.4.2 Lead, Mercury, Cadmium, and Arsenic

Detailed toxicity information obtained from the literature search are in Appendix 5-5.

Lead

Based upon the results of the literature review, lead poisoning in waterfowl at Upper Lake and consumption of these birds by humans is not considered to be a concern because:

1) Upper Lake does not have the physical and chemical characteristics (i.e., elevated temperature, low pH, soft water) conducive to mobilizing lead from sediments;

2) In general, forms of lead other than shot are unlikely to cause lead poisoning in waterfowl, further reducing the potential for effects to humans;

3) Birds must be exposed to considerable dosages of biologically incorporated lead for relatively long periods of time, suggesting that waterfowl that use Upper Lake only during the fall migration have not been present long enough to consume enough lead to be a hazard;

4) In general, humans do not consume the parts of waterfowl that concentrate lead;

5) There is no public access to Upper Lake, so that there should not be any hunting of birds at the pond itself; and

6) Assuming that waterfowl that reside at Upper Lake all summer are shot by hunters at other locations, these birds probably contain little lead and make up such a small proportion of the hunter's bag, that they do not represent a health hazard.

Mercury

Based on the literature review, mercury in waterfowl at Upper Lake does not pose a threat to human receptors because:

1) Mercury values in Upper Lake sediments are low and in water are very low (Appendices 5-2-1 and 5-2-3, respectively);

2) Upper Lake is slightly alkaline, which retards the methylation of mercury into its most toxic form;

3) Some studies indicate that waterfowl may not concentrate harmful levels of methyl mercury even if they have been consuming it in fish and invertebrates;

4) Birds in Upper Lake must have fed in the pond long enough to accumulate mercury in muscle tissues as well as organ tissues. This would probably preclude migrants that use the pond only during fall, when they might be potentially harvested by hunters;

5) Because public access to Upper Lake is prohibited, hunters cannot readily harvest these birds; and

6) A sufficient quantity of contaminated tissue must be consumed by human receptors.

The recommended criterion for mercury in waterfowl breast tissue is <1,000 ug/kg fresh weight. Of the papers examined for the literature review, only three reported values of more than 1,000 ug/kg in duck muscle tissue, suggesting that the incidence of such high values in waterfowl is quite low.

<u>Cadmium</u>

Based upon the information gathered during the literature review, it is remote that cadmium in Upper Lake represents a threat to either waterfowl or human receptors because:

1) Hunting is not allowed at Upper Lake, further reducing the likelihood of human exposure;

2) The number of waterfowl that feed in Upper Lake long enough (at least 90 days) to accumulate cadmium is very low;

3) Cadmium accumulates in parts of the waterfowl that are not generally eaten by human receptors;

4) Cadmium residues in waterfowl muscle are very low, indicating that human receptors would have to eat large quantities of these birds in order to ingest deleterious amounts of cadmium. There are not enough birds at Upper Lake to supply these quantities.

Arsenic

Very few publications were found that specifically addressed arsenic contamination in waterfowl. Based on the papers that were reviewed, however, it can be concluded that arsenic in Upper Lake does not pose a threat to human consumers of waterfowl because:

1) The form of arsenic being consumed by waterfowl (and therefore, by humans) may not be toxic;

2) Waterfowl metabolize and excrete arsenic relatively rapidly;

3) Arsenic generally does not differentially accumulate in muscle tissue of waterfowl; and

4) As in the discussion of other metals, it should be noted that waterfowl hunting is not allowed at Upper Lake, and the numbers of waterfowl that reside at Upper Lake long enough to accumulate arsenic are very low.

5.6.4.3 Conclusions

A literature review was conducted to examine the toxicity of lead, mercury, cadmium and arsenic in the sediments of Upper Lake to waterfowl using the lake, and to humans that might consume the waterfowl. The review found that:

1) There are so many biotic and abiotic variables influencing the pathway from sediments to waterfowl to humans that there are no general correlations between the concentrations of metals contaminants in sediments or water with those in waterfowl;

2) The physical and chemical properties of Upper Lake are not conducive to methylization of lead from sediments, reducing the potential for impact to waterfowl and/or humans;

3) Levels of mercury in Upper Lake sediments and water are so low that the potential for impact to waterfowl or humans is also low. In addition, the chemical properties of Upper Lake are not conducive to the methylation of mercury into its more toxic forms;

4) Waterfowl must be exposed to high concentrations of cadmium for long periods before deleterious effects become evident. Cadmium does not accumulate in parts of the waterfowl that are generally eaten by humans. Therefore, humans would have to eat large quantities of waterfowl to ingest deleterious amounts of cadmium, and Upper Lake does not support sufficient numbers of waterfowl to supply these amounts; and

5) Arsenic is metabolized and excreted by waterfowl rapidly and does not generally accumulate in muscle tissue, thereby reducing the threat to human receptors.

These factors, combined with the low numbers of waterfowl at Upper Lake and the fact that public access to Upper Lake is restricted so that hunters cannot harvest these waterfowl, indicate that there is little need for concern about the four contaminants examined.

5.7 QUALITATIVE BIOLOGICAL ASSESSMENT OF UPPER LAKE

Wildlife resources and habitats in the Upper Lake vicinity were qualitatively examined through seven site visits from mid-march to early June, 1989. The Qualitative Assessment Report is in Appendix 5-6 and report conclusions are summarized below.

The Upper Lake area, while comparatively small, provides a diverse mixture of habitats comprised of a variety of vertical structures and edge. In total, five wetland habitats and five upland habitats were recognized and mapped within approximately 176 acres of study area.

Because human use of the study area is restricted, most of these habitats (and the wildlife that use them) are little affected by human activities, particularly in comparison to the rest of the Prickly Pear Creek drainage.

In response to its habitat diversity, the Upper Lake site supports a good diversity of wildlife species. Qualitative reconnaissance observations yielded 79-82 species of birds, mammals and reptiles, or about 24 percent of the total number of species reported in the literature from the surrounding 3,000 square mile latilong.

Based on qualitative observations, wetland habitats that provided a mixture of vertical habitat structure (trees and shrubs) with wet sites supported more species and than any other habitats. Wetlands generally supported more species and a greater diversity of birds than uplands. As expected, upland habitats contributed a greater diversity of mammals than wetlands.

There were no sightings of Federally-listed endangered or threatened species during the reconnaissance period. Upper Lake did not contain a persistent prey base or suitable nest sites for either bald eagles or peregrine falcons, the two endangered species most likely to occur at the site.

There were no other ponds or impoundments in the Prickly Pear Creek drainage from Upper Lake to Interstate Highway 15 that were similar in habitat composition or wildlife use. The nearest similar habitat is probably at Lake Helena, about seven miles north.

6.0 SLAG PILE

The potential for contamination from the slag pile was evaluated according to the procedures described in the comprehensive RI/FS Study Plan and the Phase II WRM Work Plan.

6.1 AIR QUALITY IMPACTS

Air quality impacts from the slag pile and other potential sources were assessed by the collection of air quality samples at the Fire Hall site in the City of East Helena. The results of air quality monitoring are discussed in detail in Section 7.1.

In order to assess sources of lead impacts measured during air quality monitoring, a Chemical Mass Balance/Source Apportionment (CMB/SA) Study was conducted (NEA, Inc., May 11, 1989). Results of the CMB/SA study indicate that slag pouring contributed only 5 percent (mean concentration of 0.112 ug/m3) of the lead particulate concentrations measured during air quality monitoring and that other sources, including ore processing areas, were sources of the majority of lead particulates. The CMB/SA results are discussed in more detail in Section 7.1.

Since the CMB/SA study was conducted, Asarco has altered its slag pouring practices. Molten slag is no longer poured onto the piles, but instead is solidified into ingots prior to disposal. The new slag disposal procedure should significantly reduce air quality impacts from the slag pile.

6.2 GROUNDWATER IMPACTS

Slag infiltration test basins were constructed in the fumed and unfumed slag piles in order to measure infiltration, percolation, and changes in water quality. The slag basin test results are in Appendix 6-1.

In an effort to approximate infiltration rates, the volume of water retained in the slag test basins was calculated for 13 time intervals, beginning December 23, 1986 and ending February 10, 1988. These volumes were compared to the volumes of precipitation during the same periods and converted to percentages, as summarized in Table 6-2-1. The percentage of precipitation retained in the basins varied from -6.7% to 61.9% in the

TABLE 6-2-1. PRECIPITATION COLLECTED IN SLAG TEST BASINS

FUMED SLAG

Date	Precipitation (inches)	Amount of Precipitation* Retained (inches)	Percent of Precipitation* Retained
12/23/86			
1/22/86	0		
2/23/87	0		
3/26/87	0.75	0.01	1.4
4/21/87	0.23	-0.01	-5.8
5/18/87	0.51	0.32	61.9
6/18/87	2.46	0.49	19.8
7/14/87	0.88	0.25	28.7
8/11/87	1.70	0.36	21.2
9/11/87	0.37	not calculated	
10/14/87	0.65	0.25	38.4
12/7/87	0.45	-0.02	-3.9
1/20/88	0.34	-0.02	-6.7
2/10/88	0.49	-0.01	-1.1

Date	Precipitation (inches)	Amount of Precipitation* Retained (inches)	Percent of Precipitation* Retained
UNFUMED SLAG			
12/23/86			
1/22/87	0		
2/23/87	0		
3/26/87	0.75	0	
4/21/87	0.23	0.12	52.7
5/18/87	0.51	0.27	53.6
6/18/87	2.46	0.73	29.8
7/14/87	0.88	0.28	31.7
8/11/87	1.70	0.12	7.2
9/11/87	0.37	not calculated	
10/14/87	0.65	0.40	61.8
12/7/87	0.45	-0.05	-12.1
1/20/88	0.34	-0.15	-45.0
2/10/88	0.49	0.14	27.6

* Negative values indicate evaporation exceeds infiltration

fumed slag, and -45% to 61.8% in the unfumed slag (negative percentages indicate evaporation rates exceed precipitation collected in the test basins). Although there is a relationship of test basin water level fluctuations to precipitation (see Figures 6-2-1 and 6-2-2), the relationship is complicated by variable evaporation, and the infiltration rates are therefore variable.

Concentrations of arsenic and metals from test basin water samples were relatively low compared to plant area groundwater. Dissolved arsenic varied from 0.0198 mg/l to 0.075 mg/l in the fumed slag, and 0.353 to 0.590 mg/l in the unfumed slag during the study period. Dissolved cadmium varied from 0.003 to 0.075 mg/l in the fumed slag, and 0.003 to 0.0063 mg/l in the unfumed slag. Dissolved lead varied from 0.016 to 0.045 mg/l in the fumed slag, and 0.021 to 0.098 mg/l in the unfumed slag.

The concentrations of arsenic and metals from bottle roll testing were similar to the slag test basin water quality (see Appendix 6-1). For the fumed slag, dissolved arsenic was 0.19 mg/l, cadmium was 0.003 mg/l, and lead was less than 0.017 mg/l. For the unfumed slag, dissolved arsenic was 0.31 mg/l, cadmium was 0.003 mg/l and lead was 0.083 mg/l.

EP toxicity tests indicate that leachable trace element concentrations from the slag are variable. In some cases, the values for arsenic, cadmium, and lead exceed the maximum contaminant levels (MCLs). Results for 18 tests are: arsenic varied from below detection level to 1.2 ppm with an average of 0.16 ppm; cadmium varied from below detection level to 3.9 ppm, with an average of 0.26 ppm (only one cadmium value was greater than 0.25 ppm; if the 3.9 ppm value is dropped, the cadmium average is 0.04 ppm); lead values varied from below detection level to 30 ppm, with an average of 5.2 ppm.

The EP Toxicity tests were not conducted as part of the Comprehensive RI/FS activities, but have been included as supplementary data. When the EP Toxicity test results are compared to the results of the slag test basin and bottle roll tests, the EP Toxicity tests indicate a higher mobility of metals than may actually occur under site conditions. In particular, the values for lead appear to be much higher.

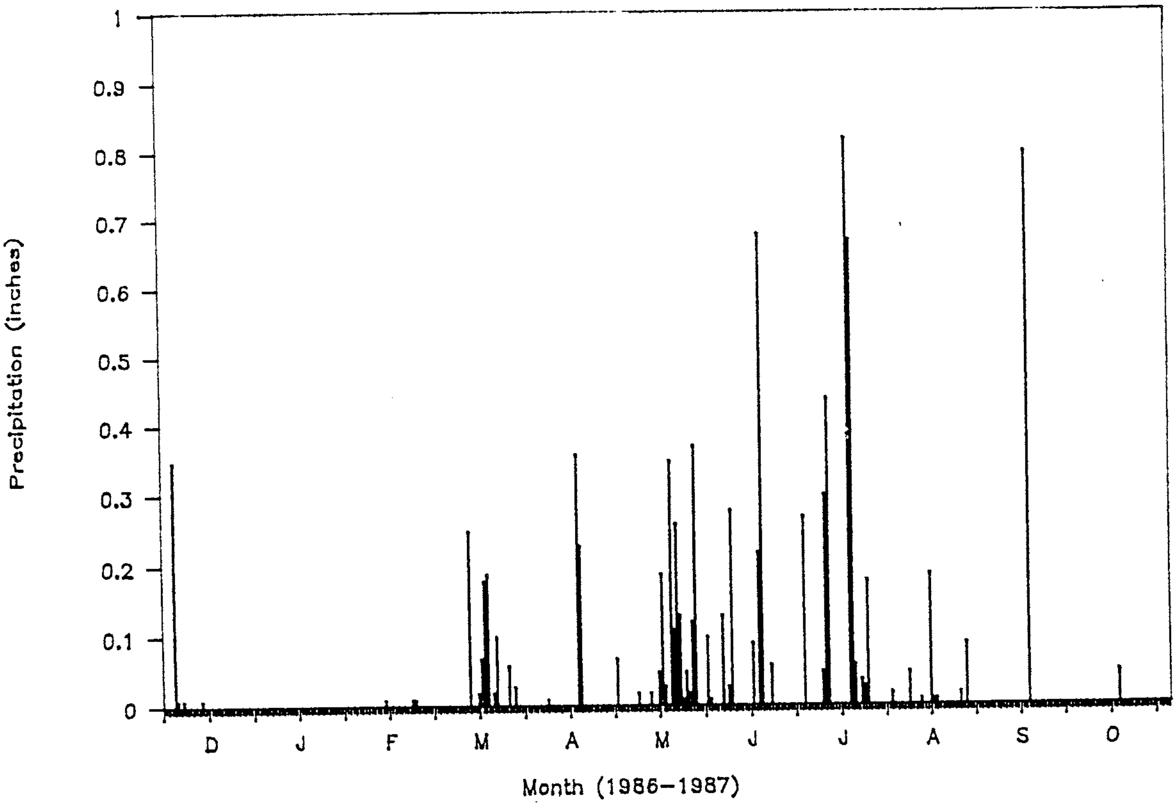


Figure 6-2-1. Daily Precipitation At Helena Airport

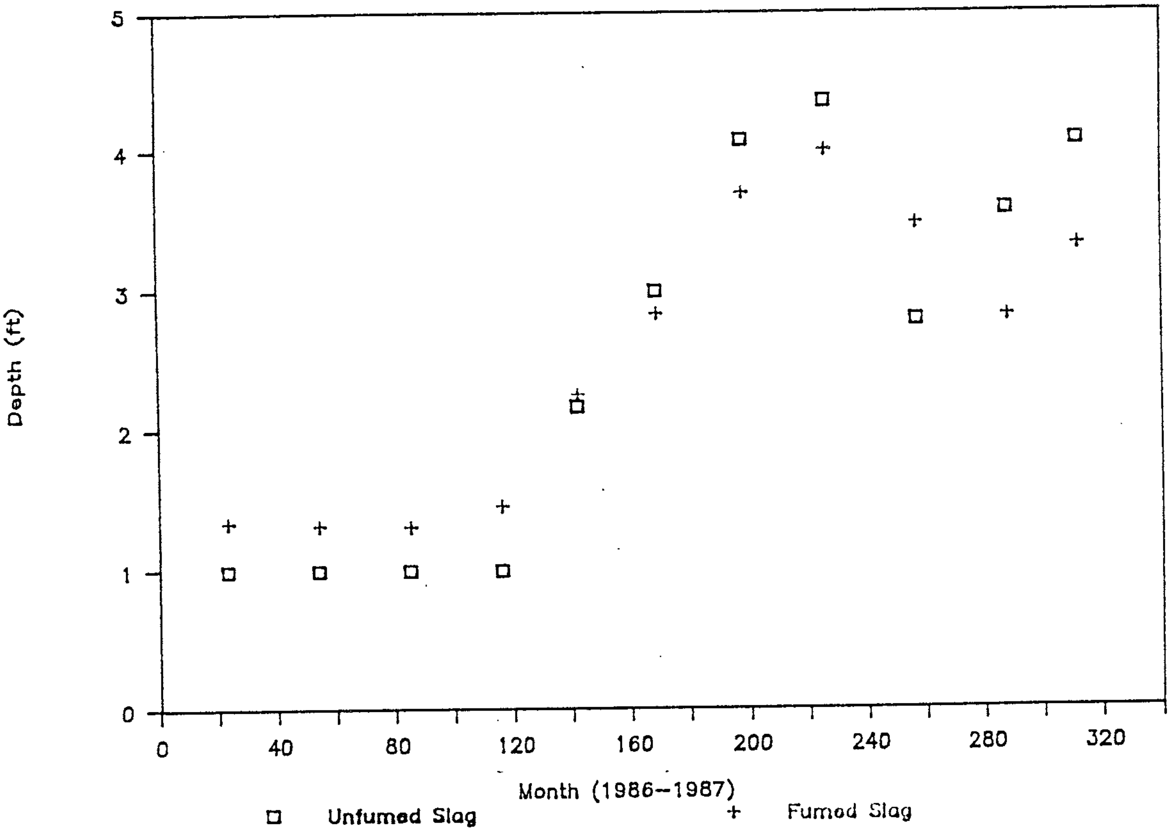


Figure 6-2-2. Depth Of Water In Slag Pile Basin

Concentrations of arsenic and other metals in the groundwater system has been discussed in Section 4.4. Results of water quality and bottle roll analyses indicate arsenic concentrations are significantly lower than concentrations observed in monitoring wells both upgradient and downgradient of the slag pile.

Since slag test basin water quality and laboratory bottle roll test result concentrations are so low, it seems apparent the slag pile is not responsible for elevated arsenic concentrations observed in monitoring wells DH-6 and DH-10 (see Section 4.4). Concentrations of arsenic in these wells are similar to arsenic concentration in DH-4, which is near Lower Lake, the apparent source of elevated arsenic in these wells.

Based on the results of test basin water quality analyses and bottle roll tests, it is unlikely that slag significantly impacts the groundwater system.

6.3 SURFACE WATER IMPACTS

The overland transport potential of particulates from the slag pile is essentially limited to erosion of steep sided banks adjacent to Prickly Pear Creek. The coarse, granular nature of the slag pile allows extremely rapid infiltration of precipitation and runoff potential is very low. The most significant transport mechanism for elevated metals probably occurs where Prickly Pear Creek is in immediate contact with the slag pile between stations PPC-5 and PPC-6. In order to assess the potential impact of the slag pile on Prickly Pear Creek, water quality data was compiled for measuring stations upstream and downstream of the slag pile.

Because of the inaccuracies inherent in streamflow measurement, no clear conclusions can be drawn for loading data between PPC-5 to PPC-6 adjacent to the slag pile. A measured increase of arsenic concentration occurs at station PPC-5, but is apparently caused by seepage from Lower Lake. Comparison of water quality data collected during high flow and low flow in 1985 and 1987 shows no clear trends. Arsenic concentrations during high flow in 1985 showed a slight increase in arsenic (0.02 mg/l total, 0.004 mg/l dissolved). A slight increase was also measured in 1987 (0.005 mg/l total and 0.0 mg/l dissolved).

Surface water flow and quality data (Appendix 5-2-1) were collected in 1985 and in 1987. Tables 6-2-2 (Phase I WRM data) and 6-2-3 (Phase II WRI data) summarize the flows, arsenic concentrations (expressed as total and dissolved arsenic in mg/l), and calculated arsenic loads (expressed as total and dissolved arsenic in kg/day) for stream measuring stations PPC-3 through PPC-9 along Prickly Pear Creek. The tables include data for dates of high and low flow.

The data indicate that the concentration of arsenic in Prickly Pear Creek increased downstream of PPC-3 at both high and low flow conditions. During higher flow periods, the concentration is apparently low, about 0.01 ppm at PPC-3, increasing slightly to 0.015-0.020 ppm at PPC-5 and PPC-6. During lower flow periods, the concentrations are similar at PPC-3, about 0.01 ppm, increasing to as much as 0.1 ppm at PPC-6.

Tables 6-2-2 and 6-2-3 show that the overwhelming majority of the increase in arsenic concentration in Prickly Pear Creek downstream of the Upper Lake diversion is contributed between PPC-4 and PPC-5, and is associated with Lower Lake. Slight increases may occur downstream of PPC-5, but the data show some scatter and it is difficult to draw conclusions. Although the data clearly show that most of the arsenic is in solution, the low flow data suggest that the total concentrations increase slightly between PPC-5 and PPC-6, possibly due to erosion of the slag pile.

Contribution of the slag pile to surface water arsenic and metals concentration is very minor. The majority of the increase of arsenic concentration in Prickly Pear Creek is clearly upstream of the slag pile near Lower Lake. The changes in water quality which take place in the vicinity of the slag pile do not show a consistent pattern; however, it is clear that the changes which do occur are extremely small.

TABLE 6-2-2. PHASE I WRM SURFACE WATER DATA

May 7, 1985 - High Flows

	Arsenic Concentration (ppm)			Arsenic Load (kg/day)	
SITE #	Total As	Dissolved As	Flow (cfs)	Total	Dissolved
PPC-3	.013	.006	81.3	2.58	1.19
PPC-4	.018	.006	25.7	1.13	0.38
PPC-5	.018	.014	73.7	3.24	2.52
PPC-6	.020	.018	62.3	3.04	2.74
PPC-7	.017	.013	67.5	2.80	2.14
PPC-8	.015	.011	64.7	2.37	1.74
PPC-9	.016	.013	40.1	1.57	1.27

August 5-6, 1985 - Low Flows

PPC-3	.011	.011	14.8	0.40	0.40
PPC-4	.016	.015	0.2	.008	.007
PPC-5	.079	.078	14.5	2.80	2.76
PPC-6	.103	.095	11.8	2.97	2.74
PPC-7	.083	.047	9.8	1.98	1.12
PPC-8	.088	.077	9.7	2.08	1.82
PPC-9	.082	.076	2.4	0.48	0.45

Arsenic concentrations and loads in Prickly Pear Creek - Phase I

TABLE 6-2-3. PHASE II WRI SURFACE WATER DATA

May 7, 1987

SITE #	Arsenic Concentration (ppm) Total As	Arsenic Concentration (ppm) Dissolved As	Flow (cfs)	Arsenic Load (kg/day) Total	Arsenic Load (kg/day) Dissolved
PPC-3	.01	<.006	67.8	1.65	0.99
PPC-4	.014	.0125	31.4	1.07	0.96
PPC-5	.015	.01	66.3	2.43	1.62
PPC-6	.0125	.010	65.7	2.0	1.62
PPC-7	.0125	.0125	74.9	2.28	2.28
PPC-8	.015	.010	69.9	2.56	1.71
PPC-9	.0125	.0125	19.9	0.61	0.61

August 18, 1985 - Low Flows

SITE #	Arsenic Concentration (ppm) Total As	Arsenic Concentration (ppm) Dissolved As	Flow (cfs)	Arsenic Load (kg/day) Total	Arsenic Load (kg/day) Dissolved
PPC-3	.009	.009	34.5	0.76	0.76
PPC-4	.0083	.0067	22.0	0.45	0.36
PPC-5	.021	.02	40.4	2.07	1.97
PPC-6	.025	.021	39.5	2.41	2.02
PPC-7	.028	.022	36.9	2.52	1.98
PPC-8	.023	.019	40.4	2.27	1.87
PPC-9	.024	.021	15.4	0.90	0.79

Arsenic concentrations and loads in Prickly Pear Creek - Phase II

7.0 ORE STORAGE AREA

7.1 AIR QUALITY IMPACTS

Air quality impacts from the ore storage areas and other potential sources were assessed by the collection of air quality samples at the Fire Hall site in the City of East Helena. The concentrations of metals collected on air filter samples are summarized in Appendix 7-1. Analytical results show filter samples had elevated concentrations of arsenic, cadmium, copper, lead, and zinc. Of the metals analyzed, a national ambient air quality standard exists only for lead. Monthly average lead concentrations from samples at the Fire Hall site ranged from 2.0 to 4.6 ug/m3 and are in excess of the national ambient air quality standard of 1.5 ug/m3.

In order to assess sources of lead impacts measured during air quality monitoring, a Chemical Mass Balance/Source Apportionment (CMB/SA) Study was conducted (NEA, Inc., May 11, 1989). Results of the study were submitted to EPA and the State of Montana DHES May 15, 1989. The CMB/SA study concluded that ore processing areas, which include the upper and lower ore storage areas, contribute 30 to 35 percent of the lead and 5 percent of the total mass particulates measured at the Fire Hall site in East Helena. Other major contributors of lead particulates include East Helena plant road dust (21 percent) and the American Chemet pyromet stack (13 percent). Tables 7-1-1, 7-1-2 and 7-1-3 summarizes the results of the CMB/SA study.

7.2 GROUNDWATER IMPACTS

Groundwater impacts from the ore storage area are addressed as part of Section 4.0 of this report. Data from drill holes SC-3, SC-4, SC-5 and monitoring well DH-8, provide subsurface and groundwater data in the ore storage areas.

General conclusions for the ore storage area are:

1) Results of stratigraphic sampling and analyses show that near surface strata have elevated arsenic and metals concentrations that gradually decrease with depth.

TABLE 7-1-1. AVERAGE SOURCE CONTRIBUTION ESTIMATES TO LOW VOLUME TSP LEAD

Source	Mean Source Contribution to Lead[a]	
	$\mu g/m^3$	Percent
Am. Chemet Pyromet Stack	0.341 ± 0.137	12.95 ± 3.23
Am. Chemet Mills and Rotohearth	0.004 ± 0.001	0.31 ± 0.10
Am. Chemet Zinox	0.000 ± 0.000	0.01 ± 0.01
Asarco Ore Processing	0.673 ± 0.129	29.54 ± 3.12
Asarco Blast Furnace	0.124 ± 0.036	6.65 ± 2.44
Asarco Matte Crushing	0.035 ± 0.022	2.91 ± 1.38
Asarco Matte Crushing (Sodium)	0.011 ± 0.007	0.62 ± 0.39
Asarco Dross Building	0.286 ± 0.102	6.52 ± 1.64
Asarco Speiss Pit	0.013 ± 0.006	1.07 ± 0.49
Asarco Slag Pouring	0.112 ± 0.050	5.09 ± 2.07
Asarco Lime Dust	0.007 ± 0.001	0.39 ± 0.07
Asarco Road Dust	0.127 ± 0.127	1.51 ± 1.51
East Helena Road Dust	0.387 ± 0.059	21.40 ± 2.94
Wood Smoke	0.001 ± 0.000	0.03 ± 0.01
Leaded Motor Vehicles	0.005 ± 0.003	0.31 ± 0.14
Unexplained	0.268 ± 0.073	10.68 ± 2.86

[a] Uncertainties listed are the standard deviation of the mean.

TABLE 7-1-2. AVERAGE SOURCE CONTRIBUTION ESTIMATES TO LOW VOLUME TSP MASS

Source	Mean Source Contribution to Mass[a] $\mu g/m^3$	Percent
Am. Chemet Pyromet Stack	1.48 ± 0.59	2.57 ± 0.72
Am. Chemet Mills and Rotohearth	1.52 ± 0.38	3.83 ± 1.00
Am. Chemet Zinox	0.01 ± 0.01	0.03 ± 0.03
Asarco Ore Processing	2.50 ± 0.48	5.05 ± 0.64
Asarco Blast Furnace	0.50 ± 0.14	1.31 ± 0.45
Asarco Matte Crushing	0.57 ± 0.36	1.22 ± 0.59
Asarco Matte Crushing (Sodium)	0.14 ± 0.09	0.37 ± 0.22
Asarco Dross Building	2.69 ± 0.96	3.83 ± 1.14
Asarco Speiss Pit	0.37 ± 0.17	1.42 ± 0.67
Asarco Slag Pouring	0.41 ± 0.18	1.09 ± 0.48
Asarco Lime Dust	1.97 ± 0.37	4.33 ± 0.73
Asarco Road Dust	1.29 ± 1.29	1.25 ± 1.25
East Helena Road Dust	15.83 ± 2.42	31.37 ± 2.09
Wood Smoke	5.96 ± 1.45	12.92 ± 2.20
Leaded Motor Vehicles	0.03 ± 0.02	0.09 ± 0.05
Secondary Sulfate	1.02 ± 0.27	3.30 ± 0.89
Unexplained	9.93 ± 1.37	26.03 ± 2.83

a. Uncertainties listed are the standard deviation of the mean.

TABLE 7-1-3. AVERAGE SOURCE CONTRIBUTIONS TO HIGH VOLUME TSP MASS AND LEAD*

Source	Mass $\mu g/m^3$	Lead $\mu g/m^3$	Lead* Percent
Asarco Slag Pouring	0.482	0.130	5.4
Asarco Speiss Pit	1.163	0.041	1.7
Asarco Dross Building	0.572	0.061	2.6
Asarco Matte Crushing (Sodium)	0.214	0.016	0.7
Asarco Matte Crushing	0.831	0.050	2.1
Asarco Blast Furnace	0.541	0.134	5.6
Asarco Ore Processing	3.748	0.847	35.4
Asarco Lime Dust	2.734	0.008	0.3
East Helena Road Dust	18.192	0.517	21.6
Wood Smoke	7.168	-	-
Am. Chemet Pyromet Stack	1.535	0.354	14.8
Unexplained	24.9	0.233	9.6

*Average total lead is 2.392 $\mu g/m^3$

2) Contaminant level plume plots of indicator parameters, particularly chloride, indicate probable downward migration of some contaminants. With the exception of monitoring well DH-21, which is located just down gradient of the speiss pond, groundwater from ore storage area well DH-8 had the highest concentrations of chloride of any of the sampled monitoring wells. Elevated chloride concentrations are probably associated with leaching from ore storage concentrates. Because finer grained strata overly the water bearing zone near well DH-8 (see Appendix 4-2 and Exhibit 3b), downward migration of arsenic and metals has apparently been inhibited, as these parameters are not elevated in DH-8 groundwater samples.

3) Migration of elevated chloride, sulfate and TDS concentrations is bounded by an unsaturated ridge of the low permeability ash unit west of monitoring well DH-8 (see Figure 4-1-1 and Exhibit 3b). This ridge extends northwest from the west end of the ore storage area and generally underlies unpaved areas.

7.3 SURFACE WATER IMPACTS

Potential surface water impacts from the ore storage areas are addressed as part of the process circuit operable sub-unit and Surface Soil/Surface Water operable unit.

General conclusions are:

1) Surface soils in the ore storage areas have elevated concentrations of metals; including arsenic, cadmium and lead from storage of ore concentrates.

2) The plant area drainage map shows that ore storage area surface water drainage during periods of runoff is generally toward the west end of the plant site. If runoff magnitude is sufficiently large, off-site transportation of metals in sediment and water is possible. Estimated runoff volumes from

drainage in the ore storage area (drainage areas P-11 and P-13, Exhibit 2) for the 10-year and 100-year precipitation events are 2.3 acre-ft and 4.4 acre-ft, respectively. It is likely that runoff of this magnitude would cause migration of metals off-site assuming the existing conditions continue.

3) Results of double ring infiltrometer tests (Section 5.2.2) show that, in much of the ore storage areas, infiltration rates of ponded surface waters are relatively slow due to the fine texture of ore dust in surface soils. However, infiltration test results were relatively high in areas intended as catchment basins on the west edge of the ore storage area within the plant boundary (see Section 5.2.2).

8.0 CONTAMINANT FATE AND TRANSPORT

As part of the Comprehensive RI (Phase II) activities, EPA identified four primary sources of potential contamination at the East Helena plant: smelter emissions; ore storage areas; slag pile; and process fluids including process ponds and process fluid transport circuits (EPA, 1987c). These sources were identified based on elevated metals concentrations found in various media in the plant site. In the aquatic environment, the contaminant of greatest concern is arsenic, due to its mobility and toxicity. Arsenic is the only contaminant that is present in East Helena waters at levels exceeding MCLs. Visual evidence of petroleum hydrocarbons were also observed in plant site area groundwaters, however, no organic compounds detected exceeded MCLs (see Section 4.0). In other environmental media (including air and surface soils), cadmium and lead as well as arsenic are of concern because of their high frequency of detection and their relatively higher potential for impacts to human health compared to all other metals in the study area.

8.1 POTENTIAL ROUTES OF MIGRATION

Primary contaminant pathways include air, surface soils, crops, groundwater, and surface water. Potential receptors of contaminants are humans, livestock, vegetation, fish, and wildlife. Figure 8-1-1 summarizes potential migration pathways and receptors of contaminants from the plant.

Contaminants from the plant site and process pond areas have migrated toward the downgradient receptor areas and other environmental media. Contaminants in the ore storage areas, slag pile, process ponds, and subsurface soils and sediments may leach into groundwater and then be transported downgradient to nearby surface waters. Air transport of contaminated materials can also occur. The following sections will summarize contaminant transport processes for the pathways: (1) subsurface soil/sediment-to-groundwater, (2) groundwater-to-surface water, 3) air transport, and 4) air to soil. The rate and extent of the migration of the metallic (includes arsenic and metals) contaminants to receptors are strongly influenced by the speciation of each metal and existing environmental conditions.

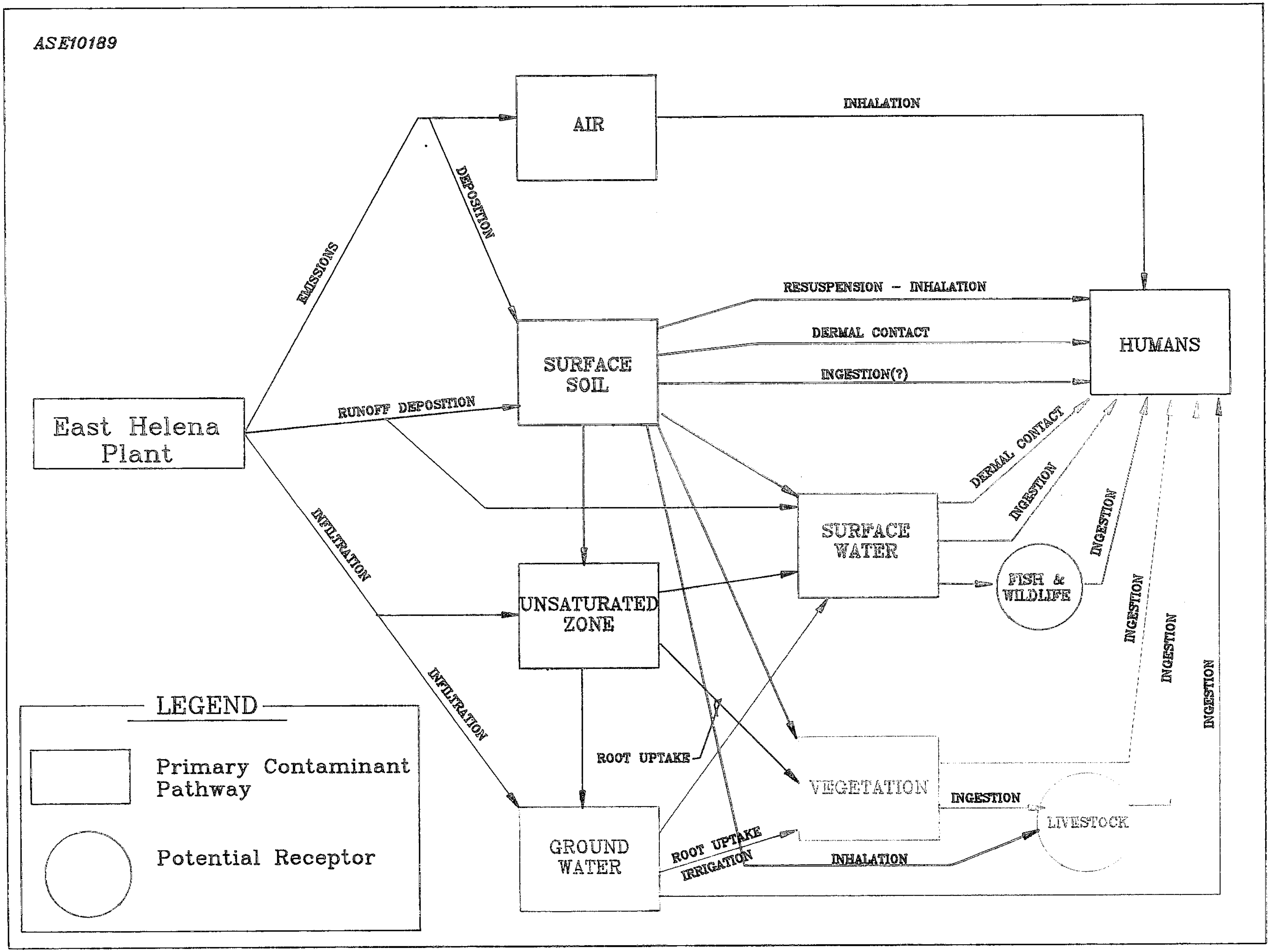


Figure 8-1-1. Potential Migration Pathways & Receptors

8.1.1 Process Ponds Potential Migration Routes

The primary migration route of metals and arsenic from the process ponds is groundwater, with surface water being a somewhat lesser route of migration. Of the metals examined in the process pond fluids and sediments, arsenic is the most mobile in the groundwater system. The major source of arsenic in groundwater is the speiss granulating pond and pit. The acid plant water treatment facility and its associated sediment drying area is a lesser source.

8.1.1.1 Subsurface Soil/Sediment-to-Groundwater Pathway

During storm events, water moves on land surface as runoff and infiltrates into the contaminated subsurface soil becoming leachate. As the leachate percolates through the subsurface environment, it carries soluble metallic species as well as compounds adsorbed to suspended matter in the aqueous solution. Those metallic species adsorbed to suspended matter most probably remain in the upper few centimeters of the surficial soil, whereas the dissolved forms can continue to migrate downward. However, only a fraction of the dissolved metallic species reach the groundwater due to retardation of the remaining fraction by the soil environment.

Upon reaching the groundwater, the concentrations and forms of the metallic contaminants can change significantly. Groundwater will generally have higher dissolved minerals and may have different pH and redox conditions than the soil environment. The change in pH and redox conditions could significantly alter the mobility of contaminant species in the groundwater.

8.1.1.2 Groundwater-to-Surface Water Pathway

Arsenic and metals present in subsurface soils and sediments of the process pond areas are assumed to have leached into the groundwater. Based on hydrogeologic information obtained during the water resource investigations, the direction of groundwater flow in the East Helena site is to the northwest. This flow path is significantly influenced by permeable alluvial deposits in the Prickly Pear Creek floodplain. Just northeast of Lower Lake, the equipotential lines show groundwater flows toward Prickly Pear Creek (Exhibit 4). This section of the groundwater flow system probably includes both groundwater underflow beneath, as well as seepage from Lower Lake. The seepage, however, is most likely restricted by the thick layer of fine-grained sediment deposited on the pond bottom and by fine-grained material underlying the pond.

The permeability of the shallow alluvium north and northwest of Lower Lake is significantly increased by the presence of ancestral stream channels of Prickly Pear Creek. These buried stream channels could serve as conduits which could increase the rate of groundwater transport of dissolved metallic contaminants from the process pond areas to nearby surface water bodies. However, data collected as part of the Comprehensive RI have not shown measureable migration of metals or arsenic by the groundwater to surface water pathways.

8.1.2 Ore Storage Areas Potential Migration Routes

The primary migration routes of metals from the ore storage areas are: air transport of airborne particulates resulting in direct inhalation, downward percolation from ore storage areas into groundwater, and off-plant surface runoff. Of these three pathways, air transport is the most significant.

8.1.2.1 Surface Soil to Air Pathway

As discussed in Section 7.1, the ore processing and ore storage areas contribute 30 to 35% of lead and 5% of the total mass particulates measured at an East Helena air quality monitoring site. Elevated levels of arsenic, cadmium, copper, lead and zinc are also transported as airborne dust. Air migration rates may be highest during winter months due to the dry conditions which result when freezing temperatures prevent the use of sprinklers for dust control. The ore storage enclosure building constructed in 1989 and 1990 will significantly reduce migration of metals from the ore storage area (see Section 11.5).

8.1.2.2 Subsurface Soil to Groundwater Pathway

As described in Section 8.1.1, arsenic and sulfate are the major ions found in groundwater which has been impacted by process fluids and sediments. However, groundwater samples from monitoring wells completed in the ore storage areas do not have elevated arsenic concentrations, but do have elevated concentrations of sulfate and chloride. As described in

Section 4.0, downward migration of arsenic is retarded by fine-grained sediment underlying the ore storage areas (see monitoring well logs for DH-8, Appendix 4-2). The fine-grained layers apparently do not impede the migration of sulfate or chloride. Since no serious health effects are associated with these two elements, no MCLs have been established.

8.1.2.3 Off-Plant-Site Surface Water Runoff to Groundwater Pathway

As described in Section 5.0, the potential for surface water runoff from the plant site exists (see Exhibit 2), particularly north west of the plant site; however, off-plant runoff has not been observed. However, if off-site runoff were to occur, surface infiltration and downward percolation of arsenic and metals into groundwater is a possible pathway.

8.1.3 Slag Pile Potential Migration Routes

Potential migration pathways of contaminants from the slag pile include air, groundwater and surface water. Based on the results of the air apportionment study, slag has been a known minor source of airborne particulates. Based on the CMB/SA study, slag pouring contributed only 5% (0.112 ug/m^3) of lead particulate concentrations measured during air quality monitoring (NEA, May 11, 1989). Since slag is no longer poured in a molten state, but is deposited in a solid state, migration of particulates from slag has been significantly reduced.

The potential pathway of rainfall percolation through the slag pile to groundwater was investigated using field and laboratory testing (see Section 6.2). Results of this investigation suggest this pathway could result in very small contributions of low concentration arsenic to groundwater. The apparent low percolation rate through the slag pile, and the low concentration of arsenic and metals collected from field and laboratory tests, indicate migration of metals and arsenic by this pathway is not significant.

A potential pathway of metals migration from the slag pile to Prickly Pear Creek was also investigated (see Section 6.3). Surface water sampling results indicate that during typical runoff conditions a very slight increase of metals to Prickly Pear Creek may occur. However, the sampling results were considered to be inconclusive. While migration of arsenic and metals from slag to the creek is minor or nonexistent during normal flow conditions, it could occur during very high flow conditions causing erosion of the slag pile where it is in contact with the creek.

8.1.4 Smelter Emissions Potential Migration Routes

Process fugitive dust emissions are the primary sources of air migrations pathways. Based on the CMB/SA study (May 1989), the primary sources of fugitive dust are the ore processing areas with the blast furnace, dross building, the slag pile, the speiss granulating pit. The matte crushing operations is a secondary source (see Table 7-1-3). The plant stacks, which historically were primary sources of metal particulate migration through air pathways, are currently sources of very minor amounts of particulates, and regulated amounts of SO_2 gasses. Other sources of air migration particulates include the City of East Helena road dust, and the American Chemet pyromet stack (see Table 7-7-3). As described above, implementation of new ore and slag processing procedures will reduce metal particulate migration along air pathways.

8.2 CONTAMINANT PERSISTENCE (Environmental Chemistry of Contaminants)

The fates of the metallic contaminants are determined by the properties of the metals and physiochemical changes taking place in the environment. In this section, the environmental chemistry of each metal is discussed and reviewed to evaluate how environmental fate processes influence the mobility and potential migration behavior of the contaminants. Parameters such as pH and Eh or pe are sometimes used to describe the behavior of some metals involved in the oxidation-reduction reactions in the environment. Eh is the redox potential of a reduction reaction relative to the standard hydrogen electrode reaction. pe is the negative logarithm of electron activity and is analogous to pH, the negative logarithm of the hydrogen ion activity. The relationship of the two redox parameters is Eh (millivolts) = 59.2 pE. Either Eh or pe along with pH is used as a tool in predicting whether a certain environmental condition is oxidizing (aerobic) or reducing (anaerobic). In aqueous environments, the most oxidized equilibrium condition corresponds to pe + pH = 20.78, when O_2 (g) is 1 atmosphere (atm). The most reduced equilibrium is represented by pe + pH = 0, when H_2 (g) is 1 atm. However, these highly oxidizing and reducing environments defined by indicated pe + pH values are not typically observed in nature. For

However, these highly oxidizing and reducing environments defined by indicated pe + pH values are not typically observed in nature. For example, groundwater environment at a depth of 35 ft with a pe + pH of 17.2 is considered oxidizing (DO = 8.5 mg/L). For the same groundwater at a depth of 104 ft, the condition becomes reducing because pe + pH = 9.7 (DO less than or equal to 0.2 mg/L). For the groundwater at the 35-ft depth, metals are expected in the oxidized states. Ferric iron (Fe^{+3}) will predominate under this condition. At the 104-ft depth, metals would exist in the reduced states in which ferrous iron (Fe^{+2}) will be the dominant form.

In this report, the above redox concept represented by pH, pe, or Eh is utilized in describing the environmental behavior of the metal contaminants. Emphasis will be placed on the physical and chemical transformation of arsenic.

8.2.1 Arsenic

Arsenic has complex chemistry in the aquatic and sediment environments. Several important physicochemical processes affect its fate and transport in the different environmental media such as soil, groundwater, and surface waters. These processes include chemical speciation, adsorption, biotransformation, and volatilization.

<u>Chemical</u> <u>Speciation</u>--Arsenic can exist in the natural environment in several oxidation states: +5, +3, +1, -3, and 0. The 0 (neutral) oxidation state, which corresponds to the elemental form, is rarely found in nature. Arsenic can form many inorganic and organic compounds with toxicities largely dependent on the oxidation states and presence of organic moieties. The toxicity of arsenic from greatest to least is as follows: arsine (-3), organo-arsine compounds, arsenites and oxides (+3), arsenates (+5), arsonium metals (+1) and native arsenic (0).

There are more than 320 minerals that have been identified as containing arsenic (Fleischer, 1983). Of these minerals, the commonly identified sulfide-bearing compounds are realgar (AsS), orpiment (As_2S_3), arsenopyrite (FeAsS) and the oxide-containing compounds such as claudetite (As_2O_3), arsenolite (As_4O_6), arsenic pentoside, and scorodite

($FeAsO_4 2H_2O$). Among these minerals, arsenopyrite probably is the most common (Mason and Berry, 1968). Arsenic has no aqueous cationic chemistry (Cotton and Wilkinson, 1972) and is generally present in groundwater as an anion in the form of arsenate(+5) or arsenite(+3) or both. In the absence of organic materials, the dominant aqueous species is determined by pH and redox conditions at equilibrium as shown in Figure 8-1. Due to limited or uncertain thermodynamic data, Figure 8-1 has been constructed without taking into account arsenic-sulfur complexes that may be important in reducing environments. According to this Eh- or pe-pH diagram, both the pentavalent As(V) and trivalent As(III), in the form of H_3AsO_4 and H_3AsO_3, respectively, are tripotic acids that sequentially ionize to form each respective anions as pH increases from 0 to 14. In oxidizing environments likely to exist in most surface waters, As^{+5} species predominate, with $H_2AsO_4^{-1}$ and $HAsO_4^{-2}$ being the most likely anions. At reducing conditions, the trivalent form is expected to be more stable at pH range normally encountered in natural waters (6.0 to 9.5).

At conditions that are neither strongly oxidizing nor reducing, both the pentavalent and trivalent arsenic species can coexist. The relative distribution of arsenite(+3) and arsenate(+5) will vary based on Eh or pe, pH, solution composition, and presence or absence of other compounds. The redox transformation from one species to the other can be slower than would be expected. While oxidation of As(III) to As(V) in oxic surface waters is thermodynamically favored, the kinetic rate of the oxidation process is not rapid. As(III) can remain in the reduced form for an extended period of time, possibly on the order of months (Tallman and Shaikh, 1980).

Even though the Eh- or pe-pH diagram serves as a useful geochemical tool in predicting which species of arsenic can predominate under a given condition, it is difficult to estimate with reasonable accuracy the ratio of arsenite to arsenate from Eh values derived from analytical data for other redox couples (Fe^{+3}/Fe^{+2}, for instance) or Eh values measured in the field. Values calculated using analytical data for the As(III) to

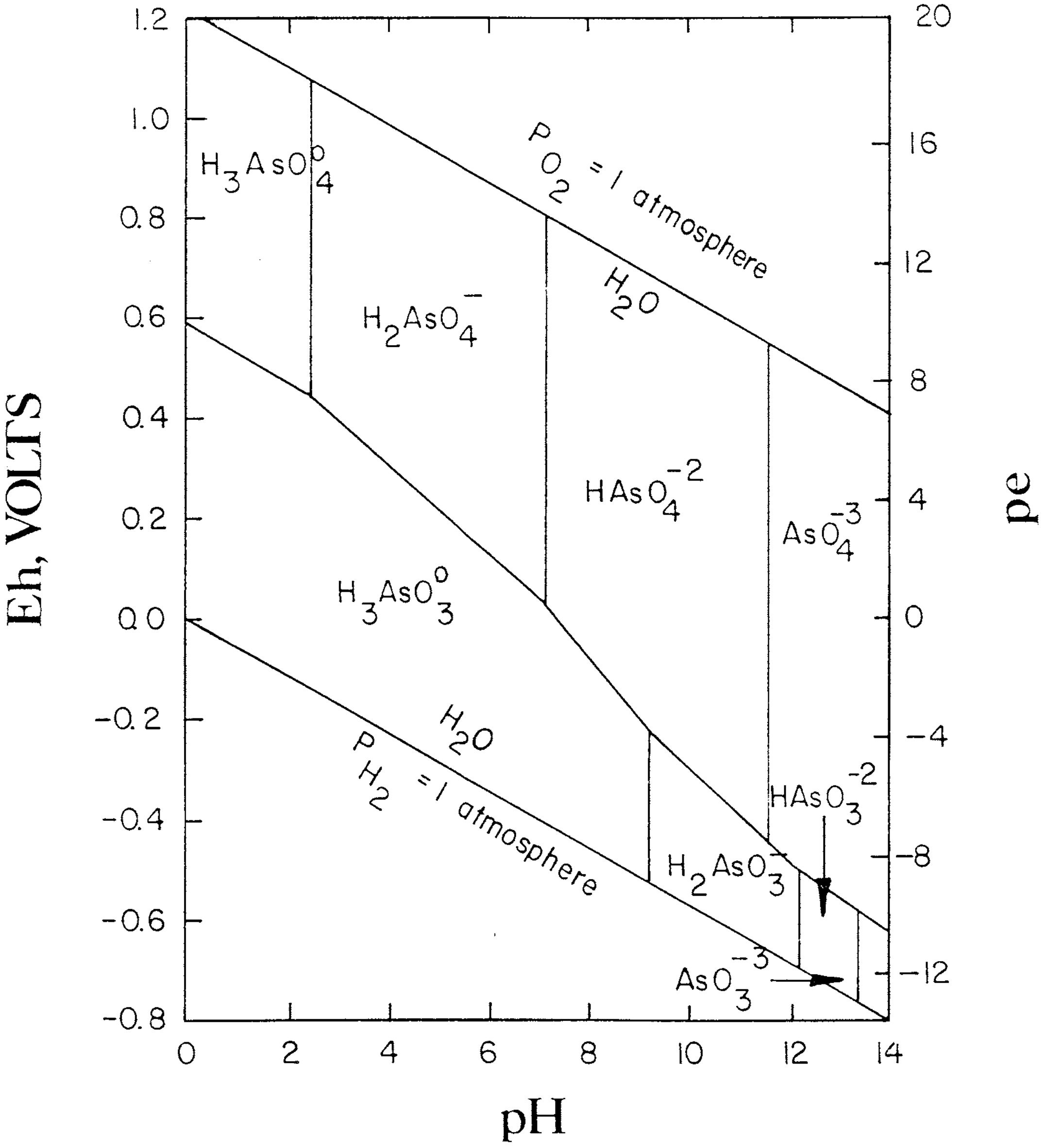


Figure 8-2-1. Eh - pH Diagram for Arsenic at 25°C

As(V) aqueous species are different than values measured in the field. The discrepancy is probably related to the lack of electrochemical equilibrium that may be a common feature in groundwater systems (Lindbury and Runnels, 1984).

Sorption and Coprecipitation--In soil and aquatic environments, the transport of arsenic is dominated by adsorption-desorption mechanisms. Both As(III) and As(V) species are expected to adsorb onto oxide and clay surfaces. As(V) has been demonstrated in the laboratory to have a greater adsorptive affinity for alumina, bauxite, and carbon. Adsorption decreases with increasing pH above pH 9.0 for As(III) and above pH 7 for As(V) (Gupta and Chen, 1978). Under various pH and salinity conditions, the rate of adsorption and extent of arsenic removal decrease with increasing salinity. These results tend to suggest that arsenic adsorption will be most important in aerobic, acidic, fresh waters. Under anoxic, alkaline, or saline conditions, arsenic is expected to be weakly adsorbed and will preferentially be in the dissolved form.

Under certain conditions, coprecipitation of arsenic with hydrous oxides of iron appears to be a dominant pathway for the removal of dissolved arsenic from aqueous systems. The oxyanions of both arsenic and arsenous acid have been reported to coprecipitate with hydrous iron and manganese oxides (Ferguson and Gavis, 1972). Sakata (1987) analyzed the linear adsorption isotherm for As(III) in 15 subsurface soils collected from different sites in Japan. The relationship between the distribution coefficients (Kd) and soil properties suggested that soil adsorption of As(III) is controlled mainly by levels of amorphous iron oxides and hydroxides. Agett and Roberts (1986) examined the mechanism of arsenate accumulation in lake sediments and concluded that arsenate, like phosphate, are incorporated in the sediments by coprecipitation at the time of formation of the hydrous iron oxyhydroxides rather than by adsorption on existing surfaces. In a study of arsenic discharges from a smelter to a lake, a certain fraction of arsenic in the sediments was found to be extractable with the iron-manganese compounds. This indicates that sorption or coprecipitation was the primary removal process of arsenic from the aqueous phase.

<u>Biotransformation</u>--Microbial metabolism is an important process that significantly affects the mobility of arsenic in the aquatic and flooded soil environments. Most of these biologically mediated transformations involve formation of methylarsenic and dimethylarsenic acids from arsenite, which results from bacterial oxidation of arsenate. The methylated arsenic acids formed are, in turn, transformed to methyl derivatives of arsine. In addition to bacteria, a number of yeasts and fungi have been reported to produce methylarsines (Ferguson and Gavis, 1972; Woolson, 1977; Cox and Alexander, 1973).

Interconversion of arsenate and arsenite mediated by microorganisms is known to take place. Arsenite can be oxidized to arsenate by a soil isolate of <u>Alcaligenes</u> (Osborne and Ehrlich, 1976; Phillips and Taylor, 1976). In other instances, the As(V) species are reduced to As(III) by some microbial species. This biological reduction can cause an increase in the ratio of arsenite to arsenate (Braman and Foreback, 1973) and, in turn, the toxicity of arsenic in natural waters. Arsenate reduction to arsenite is generally followed by a methylation process yielding methylated arsines (McBride and Wolfe, 1971; Cheng and Focht, 1979) and other organoarsenic compounds, which have been found in heavily contaminated watersheds (Faust <u>et</u> <u>al</u>., 1983), rivers (Fish <u>et</u> <u>al</u>., 1983) and soil polluted with arsenic (Takamatsu <u>et</u> <u>al</u>., 1982). These reduced arsenic compounds, which include arsine and methylated arsenic, are typically produced under very reduced conditions.

<u>Volatilization</u>--Since arsenic can undergo microbial transformations to produce volatile compounds, volatilization can be a significant fate process, especially in highly reducing environments where arsine (AsH_3) is formed. Arsine, however, may have only a short half-life because it is probably oxidized rapidly when it reaches aerobic waters or the atmosphere (Parris and Brinckman, 1975; 1976). Other methylated products such as trimethylarsine may leave an anoxic environment and eventually reach the atmosphere. Trimethylarsine has a high vapor pressure (322 torr) at room temperature (Callahan <u>et</u> <u>al</u>., 1979) and is reported to be oxidized very slowly by dissolved oxygen (Parris and Brinckman, 1976).

Volatilization of methylated forms of arsenic from groundwater is possible. However, the extent of loss may be negligible if nonporous soil and heavy vegetation cover are present to impede volatilization. In addition, oxygen present in the soil pore spaces has the potential to transform the volatile arsenic forms into nonvolatile species or other species that will be readily adsorbed by organic matter, clay, iron and aluminum complexes.

8.2.2 Cadmium

In the aqueous environment, cadmium exists only in the +2 oxidation state, regardless of the redox potential of the system. Under reducing conditions and in the presence of sulfur, cadmium may be precipitated as cadmium sulfide (CdS), which controls the level of Cd^{+2} ions. At other conditions, formation of solid cadmium hydroxide ($Cd(OH)_2$) or cadmium carbonate ($CdCO_3$) is favored especially at higher pH and carbonate concentrations. Formation of solid solutions of carbonate salt of calcium and cadmium is expected to be an important mechanism in controlling cadmium concentrations in calcareous soil (Baes and Mesmer, 1976). The upper limits of dissolved levels of cadmium in waters associated with abandoned lead and zinc mines and tailing piles have been reported to be controlled by $CdCO_3$ (Jenne et al., 1980).

Cadmium can be found in several chemical forms, ranging from simple aquated ions and metal-inorganic complexes to metal-organic forms. It has been shown to interact with ligands such as OH^-, Cl^-, CO_3^{-2}, and SO_4^{-2} and SO_4^{-2} in aqueous solutions (Long and Angino, 1977). Bingham et al. (1984) reported that cadmium complexes readily with chloride and sulfate in soil solutions in such a way that its availability is significantly influenced. Humic substances can also account for most of the complexation in natural waters. In a study of metal-organic interactions in aqueous phases, Guy and Chakrabarti (1976) found that fulvic acids and other natural complexing agents can maintain cadmium ions in a bound form at a pH as low as 3. Thus, the release of cadmium from sediments may be controlled by an ion exchange and complex formation in which the amount of dissolved metal is determined by the stability of the metal-organic complex.

Sorption processes are considered the most important factor in reducing the aquatic load and transport velocity of cadmium. Adsorption onto mineral surfaces and organic materials, in addition to coprecipitation with hydrous metal oxides and isomorphous substitution in carbonate minerals can decrease the aqueous concentrations of cadmium. During adsorption, competition between cations for adsorption sites strongly influences the behavior of cadmium. The presence of alkaline earth metal ions such as Ca^{+2} and Mg^{+2} reduces the adsorption of cadmium by soils, manganese and iron oxides, alumina, and clay minerals.

The sorbed cadmium may be released from soil by physicochemical changes in the soil environment induced by microbial activities. During metabolism, microorganisms can excrete metabolic products that can change the soil conditions or produce water soluble organic compounds or ligands that can form soluble metal complexes resulting in the solubilization of cadmium. Recently, Chanmugathas and Bollag (1987) conducted experiments on the microbial mobilization of cadmium in soil under aerobic and anaerobic conditions. The amount of cadmium released was found to be more rapid under anaerobic than aerobic incubation.

8.2.3 Lead

Lead is a heavy metal that exists in three oxidation states: 0, +2, and +4. Metallic lead and the common lead minerals are normally insoluble in water, but they can be solubilized by some acids. In contrast, some industrially produced lead compounds are water soluble (Callahan et al., 1979). Natural compounds of lead are sparingly mobile in normal groundwater or surface water because the lead leached from ores is adsorbed by ferric hydroxide or combines with carbonate or sulfate ions to form insoluble compounds. Throughout most of the natural environment, the divalent form, Pb^{+2}, is the stable ionic species of lead. The more oxidized solid, PbO_2, in which lead has a +4 charge, is stable only under highly oxidizing conditions and probably has little significance in the aquatic environment (Callahan et al., 1979). Although lead will exist mainly as the divalent cation in most unimpacted waters and become sorbed into particulate phases (i.e., sediments). The presence of suspended organic material in the water can greatly effect the chemical form in which lead will be present. Thus, lead can sorb to sediments as well as suspended organics. In addition, due to the low solubility of lead, it is readily adsorbed by soils.

In the presence of clay (kaolinite, illite, and montmorillonite) at pH ranging from 5.0 to 7.0, most lead ions are precipitated and sorbed probably as low solubility ions such as $PbOH^+$ and $Pb_4(OH)_4^{+4}$ (Demayo et al., 1982). The capacity of soils to adsorb lead increases with pH, cation exchange capacity, organic carbon content, and phosphorus levels. Of the total lead in soils, only a small percent is expected to be leachable. Thus, surface runoff transporting soil particles containing adsorbed lead is an unlikely pathway for lead migration from contaminated soils.

8.2.4 Copper

Copper exists in the lithosphere primarily as a sulfide mineral in the form of chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S) and bornite (Cu_5FeS_4). In aqueous solutions, copper is present in a +1 or +2 oxidation state. Cu(I) predominates in relatively reducing conditions while Cu(II) dominates in oxidizing conditions. Thus, the solubility of the solid phases of Cu(I) and Cu(II) is influenced by the redox potential of the system. Lindsay (1979) evaluated the relative stability of the different copper solids and discovered that cuprous ferrite ($Cu_2Fe_2O_4$) and cupric ferrite ($CuFe_2O_4$) are the stable phases under reducing and oxidizing conditions, respectively.

Several processes that affect the fate and transport of copper in the aquatic environment include complex formation, especially with humic substances; sorption to hydrous metal oxides, clays, and organic materials; and precipitation. Both organic and inorganic ligands can complex copper. In waters containing organic materials, Stiff (1971) showed that the predominant species of soluble copper are complexes with humic substances, amino acids, cyanide, carbonate and the hydrated Cu(II) ion. Lopez and Lee (1977) found that the predominant soluble copper species in a heavily copper-ladened, organic-depleted lake in Michigan were hydroxide and carbonate complexes in addition to the cupric ion.

Both complexation and ion exchange serve as two important mechanisms for the retention of copper by soils. Soil organic matter has been considered the dominant factor controlling copper adsorption in surface soils (Ramamoorthy and Rust, 1978). Aside from mercury, copper is known to have greater affinity for the soil organic fraction than all other cationic heavy metals. When the specific adsorption and complexation capacity of soil hydrous oxides and organic matter has been exceeded, ion exchange becomes an important adsorption mechanism especially in solution with higher copper concentrations.

During adsorption of copper by soil constituents, formation of solid phases is sometimes thermodynamically favored to the extent that the aqueous mobility of copper can be significantly retarded. Precipitation of copper hydroxide, oxide, and phosphate solid phases has been suggested as occurring during the adsorptive interaction of montmorillonite and kaolinite with copper (Bingham et al., 1971; Farrah and Pickering, 1976). Formation of copper solids ($Cu(OH)_2$ or $Cu_2(OH_2)CO_3$) can complicate the adsorption of copper (Dhillon et al., 1981) such that it is impossible to distinguish between precipitation and adsorption in alkaline soils. Irrespective of the actual mechanism taking place, however, the ultimate effect would reduce the copper concentration in the solution. In the subsurface or aquatic environments, either mechanism will decrease the aqueous phase concentration and retard the migration of copper.

8.2.5 Zinc

Zinc is found exclusively in the aqueous environment in the +2 oxidation state and is insensitive to redox conditions. It commonly exists in minerals such as sphalerite (ZnS), smithsonite ($ZnCO_3$), willemite (Zn_2SiO_4) and zincite (ZnO). Lindsay (1979) calculated the relative solubility of Zn compounds and showed that franklinite ($ZnFe_2O_4$) and willemite are the two least soluble compounds compared to the other minerals such as $Zn(OH)_2$, $ZnCO_3$, and ZnO. Thus, these two compounds may control the level of zinc ions in the aqueous solutions.

Humic acids and other natural complexing agents have the ability to maintain zinc in the dissolved forms through metal-organic interactions in natural waters (Guy and Chakrabarti, 1976). In addition to organic complexation, zinc can form complexes with inorganic ligands such as OH^-, Cl^-, $CO_3{}^{-2}$, $SO_4{}^{-2}$, and $HCO_3{}^{-3}$ at pH 3.5 to 11.0 at 25°C in aqueous solutions (Long and Angino, 1977). The relative importance of these various organic and inorganic complexes will depend on their stability to significantly influence the transport of zinc in the aquatic environment.

Generally, zinc remains as a Zn^{+2} ion in most unimpacted waters. In waters containing inorganic and organic chemical species, complexation reactions are favored.

Manganese and iron oxides are the predominant adsorbents controlling the adsorption behavior of zinc in soils (Kinniburgh and Jackson; 1982; Ballistrieri and Murray, 1982). Adsorption by soil organic matter and clay minerals can also take place; however, their contributions are expected to be less. Cation exchange capacity of the soil becomes important in environmental situations where the zinc concentration is high and adsorption is governed by coulombic interaction rather than specific adsorption. In some instances, adsorption can be reduced due to the presence of high concentrations of divalent alkaline metals (Mg^{+2}, Ca^{+2}) which can compete with zinc for the adsorption sites in soils. This can result in maintaining the Zn^{+2} ions in solution. These ions favor transport in the aqueous phase.

8.2.6 Manganese

Manganese is an element that can exist in several oxidation states: +2, +3, +4, and +7. Compounds of manganese with +3 and +4 oxidation states are more stable in oxidizing conditions, whereas those with +2 are dominant under reducing conditions. At pe + pH greater than 16.6 (oxidizing conditions), pyrolusite (P-MnO_2) appears to be the most stable compound. In the presence of CO_2 and under reducing conditions, Rhodochrosite ($MnCO_3$) is expected to be the stable species in soils. Although Mn(III) and Mn(VII) can exist in solution, Mn(II) is the most stable aqueous oxidation state.

Speciation, precipitation, and adsorption are important mechanisms affecting the fate of Mn in the environment. Manganese is known to form inorganic complexes such as $MnSO_4^+$ and $MnCl^+$ below pH values of about 9.3 in groundwater containing waste leachates. At pH greater than 10.0, $MnHCO^+_3$ and $MnOH^+$ tend to become dominant. In soil solution, $MnCO_3$ can precipitate and control Mn^{+2} levels at low redox potentials (pe + pH less than 15) (Schwab and Lindsay, 1983). At the higher redox potentials, manganese oxides may be the solubility-controlling solid. Either precipitation of $MnCO_3$ or manganese oxides can restrict the mobility of manganese in the aqueous phase because the precipitate can settle out of solution or deposit in the sediments of natural waters. In addition to precipitation, adsorption can limit the migration of dissolved manganese species. Mn(II) can be adsorbed by clay minerals (Reddy and Perkins, 1976) and iron oxides (Takamatsu, 1979; McKenzie, 1980). In calcareous soils, strong interaction with $CaCl_3$ occurs, which can lead to formation of $MnCO_3$ (McBride, 1979). Consequently, the potential migration of Mn(II) is offset by chemical precipitation, especially if the extent of precipitation is extensive.

8.2.7 Iron

Iron exists in the +2 and +3 oxidation states, which are stable over a broad range of pH and redox conditions. Fe(III) species are dominant under oxidizing conditions and Fe(II) species under reducing conditions. Both the oxides or hydroxides of Fe(III) and Fe(II) are known to exist in the environment depending on the redox conditions. Using available thermodynamic data, Lindsay (1979) showed that under oxidizing conditions (pe + pH greater than 11.5), ferric hydroxides ($Fe(OH)_3$) control iron solubility. At pe + pH less than 11.5, magnetite (Fe_3O_4) is the stable compound. Further decrease of pe + pH to 3.7 favors the stability of siderite ($FeCO_3$) under conditions in which gaseous carbon dioxide concentration is less than 0.032 atmosphere.

Aside from redox changes, other processes affect the fate and transport of iron in the environment. These processes include hydrolysis, complexation, precipitation, and adsorption. Fe(III) ions are known to react with water to yield different species of hydroxide complexes. Chlorides, nitrate, sulfate, and phosphate interact with Fe(III) ions to produce inorganic complexes. Water-soluble organic ligands such as fulvic acids can form strong aqueous complexes (Schnitzer, 1969) that are capable of maintaining solution concentrations at far higher levels than that predicted by solubility considerations alone. These complexes generally increase iron mobility through soil and subsurface environments. Under conditions where Fe(II) prevails, hydrolysis and complex ion formation are thermodynamically possible. Several hydroxylyated Fe(II) species and complexes of chloride, phosphate, and sulfate can be formed (Lindsay, 1979).

In groundwaters, iron concentrations are primarily controlled by precipitation and dissolution reactions. From the redox potential and pH data obtained from many groundwaters, ferrosic hydroxide ($Fe_3(OH)_8$) has been suggested as the compound controlling iron solubility (Back and Barnes, 1965). Other investigators also indicate that solid $Fe_3(OH)_8$ may control the levels of Fe^{+2} in natural waters (Schwab and Lindsay, 1983; Ponnamperuma et al., 1967). This compound is considered meta-stable and is expected to persist in changing redox environments (Schwab and Lindsay, 1983).

Both organic and inorganic sorbents have been reported to have strong affinity for Fe(III). Soil components which adsorb Fe(III) are silica, clay minerals, crystalline oxides, and hydrous oxides of manganese. It is possible that adsorption of Fe(II) can also take place. However, the extent of adsorption of this reduced species has not been studied in greater detail.

8.2.8 Petroleum Hydrocarbons

Hydrocarbons introduced into the subsurface environment are typically a mixture of organic compounds, each with unique physicochemical properties. Depending on the nature of the hydrocarbons introduced, transport in the subsurface environment can occur in several phases including bulk liquid, dissolved in groundwater, and vapor phases (Hinchee and Reisinger, 1985). Mechanisms that influence subsurface transport of individual compounds include density, vapor pressure, viscosity and hydrophobicity.

Volatilization of lighter hydrocarbons is largely a function of vapor pressure and relative solubility of a compound in the bulk hydrocarbon liquid. Following introduction into the subsurface environment, petroleum in the liquid phase moves vertically through the unsaturated zone. Typically, fuel products are immiscible, less dense than water and will spread over the water table via capillary spreading. This phenomenon may result in some apparent upgradient movement of free product liquid (Guswa and Lyman 1983).

Fuel hydrocarbon compounds that do not remain in the bulk liquid phase will partition into groundwater or soil vapor. In groundwater, compounds will migrate with groundwater flow and interact with the rock or soil medium. Adsorption to the subsurface medium results in a net retardation of the velocity of movement of the compound(s) relative to groundwater movement.

The relative mobility of dissolved fuel components in groundwater has been examined by a variety of investigators. Retardation factors of BTX (benzene, toluene and xylene) have been reported to range 1.2 to 1.4 for benzene and xylene, respectively (Patrick and Barker 1985).

In the subsurface environment, chemical aging and biological breakdown by natural bacteria result in the chemical alteration of fuel compounds, particularly the volatile and semi-volatile components. Fuel composed primarily of lighter components such as gasoline can be totally broken down by biological activity (enhanced biological breakdown is often implemented for remediation of aquifers contaminated by fuel hydrocarbons). Heavier fuels including diesel and fuel oils may lose volatile and semi-volatile compounds with heavier long chain hydrocarbon residuals remaining adsorbed to soils at or above the groundwater table. These long chain residuals can be periodically remobilized from vadose zone soils by seasonal rises in the groundwater table.

Introduction of petroleum hydrocarbons to the groundwater system often enhances anaerobic conditions of the aquifer. The resultant lower pe reducing environment can result in elevated concentrations of metals including iron, manganese and arsenic (Longmire, 1986).

8.3 GROUNDWATER TRANSPORT OF ARSENIC

An overview of the fate of arsenic in the natural environment and a description of possible mechanisms for attenuation of arsenic have been presented in the previous Section 8.2. The purpose of this site specific arsenic fate and pathway analysis is to identify specific arsenic attenuation mechanisms and factors controlling the mobility of arsenic in groundwater at the East Helena site. This information can then be used to predict the rate of movement of the arsenic contaminant plume and to help evaluate remedial alternatives for arsenic contaminants in groundwater.

8.3.1 Mechanisms of Arsenic Attenuation

Aquifer materials that remove arsenic from groundwater were identified by sequential extraction of monitoring well sediments. This identification was based on the assumption that material fractions attenuating or removing arsenic from groundwater should contain correspondingly higher amounts of arsenic. The sequential extraction followed the method of Chao (1984) and Sondag (1981) and has been described in detail in the WRM Phase II Work Plan. In general, the extraction procedure selectively dissolves and/or removes metals from the following six fractions: water soluble, exchangeable ions and carbonates, manganese oxides, organic material, amorphous iron oxides, and residual crystalline material (primarily silicate minerals and well crystallized oxides). Extracts from each of these fractions were then analyzed for arsenic, cadmium, copper, iron, lead, manganese and zinc.

Results of sequential extractions of twelve samples from eight drill holes are in Appendix 4-4. These results indicated that in every drill hole the largest percentage of the arsenic (40 to 80% of total arsenic) in sediments is contained in the residual crystalline phase. The second largest reservoir for arsenic in the sediment varies between exchangeable arsenic (in five samples), manganese oxides (in four samples), and amorphous iron oxides (in three samples). Water soluble and organically-bound arsenic was low in all samples. These extraction results indicate the dominant materials which are capable of removing arsenic from solution. However, it remains to be scientifically shown that arsenic enrichment in the sediments is the result of loading from the arsenic-bearing contaminant plume.

One test for arsenic loading onto sediment from groundwater is to test for correlations between the arsenic concentration in groundwater from monitoring wells and the amount of arsenic in the sediment from the monitoring wells. Because adsorption of arsenic onto solids occurs in proportion to the amount of arsenic in solution, positive correlations should exist if adsorption is occurring. Similarly, phases removing arsenic by coprecipitation should also positively correlate with arsenic concentrations in groundwater. Correlation coefficients for arsenic in groundwater and arsenic in extract fractions are shown in Table 8-3-1. Positive correlation coefficients exist between arsenic in water and arsenic in amorphous iron oxides, manganese oxides, exchangeable arsenic, and arsenic in the residual crystalline fraction. These positive correlations indicate that removal of arsenic from groundwater by these fractions is occurring.

As an additional test, the amount of arsenic recovered from the amorphous iron oxide and manganese oxide fractions of sediment were correlated with the amorphous iron oxide and manganese oxides content of the sediment in the plant site wells. If iron and manganese oxide are removing arsenic from groundwater, then sediment containing more iron and manganese oxides should contain proportionately more arsenic in these fractions. This relationship may not be linear if attenuation is controlled by surface reactions. However, sediments with higher bulk amounts of iron and manganese oxides should have correspondingly (throughout linearly) more surface areas for reactions.

The correlation with iron was positive though the correlation coefficient was low ($r < 0.48$) indicating a general positive correlation between the amount of iron oxide and the amount of arsenic removed by iron oxides. Surprisingly, the correlation with amounts of manganese oxide was negative ($r = -0.60$), indicating an inverse relationship between the amount of manganese oxide in the sediment and the amount of arsenic removed by manganese oxide. The positive correlation with iron oxide content may be explained by larger surface areas for adsorption in sediment of higher iron oxide content or by coprecipitation of arsenic with amorphous iron oxides. The negative correlation with manganese oxide content does not fit either adsorption or coprecipitation scenarios

TABLE 8-3-1. CORRELATION COEFFICIENTS BETWEEN ARSENIC CONCENTRATIONS IN GROUNDWATER AND ARSENIC CONTENT OF SEDIMENT FRACTIONS

Sediment Fraction	Correlation Coefficient (r)	Significance Level *	CI
Exchangeable ions	0.73	10%	80
Manganese oxides	0.81	5%	90
Amorphous iron oxides	0.72	10%	80
Residual crystalline	0.76	5%	90

* Based on t-test, where $t = \dfrac{r\,(f)^{\frac{1}{2}}}{(1 - r^2)^{\frac{1}{2}}}$ and

f = degrees of freedom 1 or N-2

but may be explained by replacement of manganese oxide by arsenic precipitates.

Results of sequential extraction analyses and correlation of these results with arsenic levels in monitoring wells indicate arsenic is being loaded onto sediment by several different mechanisms; adsorption onto ion exchange sites, adsorption or coprecipitation on amorphous iron, replacement of manganese oxides, and incorporation into the residual crystalline fraction of the sediment. Adsorption of arsenic onto exchange sites occurs due to electrostatic interactions between the negatively charged arsenic anions (primarily arsenate) and positively charged mineral surfaces. Adsorption of arsenic on ion exchange sites is strongly controlled by the concentrations of other ions in solution and by solution pH. Strongest arsenic adsorption will occur at low pH when mineral surfaces are most highly charged and at low anion concentrations when competition with other anions for exchange sites is lowest.

Removal of arsenic by amorphous iron oxides may be occurring by adsorption, coprecipitation, or a combination of both. Adsorption onto these oxides differs from adsorption onto exchange sites in that the adsorption is specific for arsenic so that other ions do not compete with arsenic for these sites. This is evidenced by the fact that arsenic in the iron oxide fractions was not released by the extraction for adsorbed exchangeable ions. Arsenic specifically adsorbed is much more firmly held than exchangeable arsenic and should be little affected by changes in the concentration of other ions in solution. Coprecipitation of arsenic with iron oxides may also occur, most probably in the form of ferric arsenate ($FeAsO_4$) or, alternatively, ferric hydroxy arsenate (Wagemann, 1978).

Coprecipitation of arsenic with manganese oxides is unlikely for two reasons. There is an inverse correlation between amounts of arsenic in the manganese oxides and the amount of manganese oxides in the sediment. In other words, the amount of manganese oxide decreases as the amount of arsenic in manganese oxides increases. This is exactly the opposite of what would be expected if arsenic and manganese were coprecipitating. Also, because manganese arsenate ($Mn_3O\ (AsO_4)_2$) is fairly soluble (dissolved arsenic > 1000 mg/L at pH of 8; Wagemann, 1978), precipitation of manganese arsenate is not likely. Removal of arsenic by manganese oxides is most probably by adsorption of arsenic.

The loading of arsenic onto the residual crystalline fraction most likely occurs by incorporation of arsenic into well crystallized oxides during the crystallization of amorphous oxides. This would occur in a stepwise fashion with arsenic initially being adsorbed on, or coprecipitated with amorphous oxides. As the amorphous oxides crystallize, arsenic would be incorporated into the oxide crystal lattice most probably as ferric arsenate or as a separate arsenic phase. Arsenic bound in the residual crystalline phase is likely to be very stable and would only be dissolved and remobilized by gross changes in solution composition.

8.3.2 Arsenic Mobility in Groundwater

Arsenic mobility in the groundwater system at the East Helena site was investigated by examination of the chemical changes occurring in the contaminant plume with downgradient distance from arsenic sources. Of particular interest were the differences in mobility and concentration between arsenic III and arsenic V; between arsenic, iron, and manganese; and between arsenic and the conservative, unretarded anions sulfate and chloride.

The speiss granulating pond and pit area has been identified as the most important source of arsenic to the groundwater system. For this reason, the arsenic contamination from the speiss area was chosen for examination. Lower Lake is a secondary source of arsenic contamination and was examined to verify conclusions based on the speiss granulating pond analysis. Chemical changes occurring as the contaminant plume moves away from the speiss area were determined by examining the water quality of the speiss granulating pond and downgradient monitoring wells (sites SP-1, DH-21, DH-13, DH-17, DH-24, EH-60, EH-62). Average values for selected water quality parameters for the speiss granulating pond and downgradient monitoring wells are shown in Tables 8-3-2 through 8-3-8. Cross-sections showing locations and well completion data for the downgradient monitoring wells are in Exhibits 3a, 3b and 3c.

TABLE 8-3-2. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE SP-1

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	7.2-37	18.96	10.98	5
SPEC. COND. (UMHOS/CM) FIELD	2898-117662	48011	45192	6
SPEC. COND. (UMHOS/CM) LAB	2800-150000	53283	58899	6
PH FIELD	12.21-13.51	12.93	.501	5
PH LAB	10.9-13.3	12.5	.885	6
TOTAL SUSP. SOLIDS	26-305	105	115	5
TDS MEAS. @ 180 DEG. C	2441-52051	22052	19607	6
SETTLEABLE MATTER (ML/L)	0	0	0	2
COMMON IONS				
CALCIUM (CA)	.3-37	13.9	16.86	6
MAGNESIUM (MG)	<.1-2.9	.533	1.16	6
SODIUM (NA)	625-23250	8175	9038	6
POTASSIUM (K)	38-197	109	66.1	6
CALCIUM (CA) TOTAL	5.4	5.4	0	1
MAGNESIUM (MG) TOTAL	.1	.1	0	1
SODIUM (NA) TOTAL	15100	15100	0	1
POTASSIUM (K) TOTAL	197	197	0	1
ALKALINITY AS CACO3 (LAB)	598-45900	14467	18803	6
BICARBONATE (HCO3) (LAB)	<1-7.3	1.63	2.78	6
CARBONATE AS CO3 (LAB)	355-116000	20923	46601	6
HYDROXIDE (OH)	335-12376	6806	5549	5
SULFATE (SO4)	660-2400	1236	657	6
CHLORIDE (CL)	131-3800	1233	1466	6
TRACE ELEMENTS				
ARSENIC (AS) TOTAL	55-3750	1609	1594	5
ARSENIC (AS) DISS	55-3733	1688	1551	5
CADMIUM (CD) TOTAL	.018-.4	.115	.164	5
CADMIUM (CD) DISS	.005-.093	.029	.037	5
COPPER (CU) TOTAL	.838-28.3	8.82	11.49	5
COPPER (CU) DISS	.009-.115	.057	.05	5
IRON (FE) TOTAL	.625-12.55	3.73	5.1	5
IRON (FE) DISS	.05-1.33	.685	.525	5
LEAD (PB) TOTAL	1.35-24	8.59	10.14	5
LEAD (PB) DISS	.008-.061	.03	.021	5
MANGANESE (MN) TOTAL	.015-.5	.148	.204	5
MANGANESE (MN) DISS	.003-.16	.039	.068	5
ZINC (ZN) TOTAL	.043-5.35	1.39	2.23	5
ZINC (ZN) DISS	.015-.173	.056	.066	5

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT
WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE
WAS USED FOR THE MEAN.
OUTPUT DATE: 04-20-1989 HWQ-6/86-R.ST.1

TABLE 8-3-3. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE DH-21

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	16-20	17.44	1.62	5
SPEC. COND. (UMHOS/CM) FIELD	8483-10537	9515	1060	4
SPEC. COND. (UMHOS/CM) LAB	8500-10300	9340	789	5
PH FIELD	10.66-11.3	10.99	.271	5
PH LAB	10.4-11.32	10.76	.381	5
TOTAL SUSP. SOLIDS	17.3	17.3	0	1
TDS MEAS. @ 180 DEG. C	6389-8490	7152	870	5
OXYGEN (O) DISS	.4-1.3	.70	.408	4
DEPTH TO SWL BELOW MP (FT)	21.83-25.02	23.18	1.17	5
COMMON IONS				
CALCIUM (CA)	4-11	8.08	2.56	5
MAGNESIUM (MG)	.1-4.3	1.56	1.67	5
SODIUM (NA)	2050-2580	2328	225	5
POTASSIUM (K)	12-37	20.98	11.19	5
ALKALINITY AS CACO3 (LAB)	2052-2500	2276	317	2
BICARBONATE (HCO3) (LAB)	<1-452	250	214	5
CARBONATE AS CO3 (LAB)	680-2064	1192	589	5
HYDROXIDE (OH)	24	24	0	1
SULFATE (SO4)	42-3100	2036	1170	5
CHLORIDE (CL)	400-575	495	85.73	5
TRACE ELEMENTS				
ARSENIC (AS) DISS	283-750	496	203	5
ARSENIC (AS) +3	276-468	392	102	3
ARSENIC (AS) +5	2.24-492	285	253	3
CADMIUM (CD) DISS	.001-.01	.0038	.0039	5
COPPER (CU) DISS	.012-.065	.036	.028	4
IRON (FE) DISS	.135-.855	.461	.269	5
IRON (FE II)	.3-1.33	.884	.395	5
LEAD (PB) DISS	.006-.082	.049	.032	5
MANGANESE (MN) DISS	.02-.071	.039	.022	4
ZINC (ZN) DISS	.01-.043	.026	.013	5

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 04-19-1989 HWQ-6/86-R.ST.1

TABLE 8-3-4. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE DH-13

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	9.7-13	11.62	1.42	6
SPEC. COND. (UMHOS/CM) FIELD	3291-6344	5031	1307	5
SPEC. COND. (UMHOS/CM) LAB	3250-6800	5093	1298	6
PH FIELD	5.6-6.79	6.49	.502	5
PH LAB	6.3-7.49	6.84	.471	6
TOTAL SUSP. SOLIDS	38.7	38.7	0	1
TDS MEAS. @ 180 DEG. C	2662-5454	4106	988	6
OXYGEN (O) DISS	.35-3	1.64	.888	6
DEPTH TO SWL BELOW MP (FT)	26.68-31.37	29.08	1.66	6
COMMON IONS				
CALCIUM (CA)	60-124	81	24.84	6
MAGNESIUM (MG)	20-35	26.08	5.75	6
SODIUM (NA)	547-1450	1065	344	6
POTASSIUM (K)	3.3-43	29.47	13.64	6
BICARBONATE (HCO3) (LAB)	227-695	391	174	6
CARBONATE AS CO3 (LAB)	<1	<1	0	6
SULFATE (SO4)	1476-2350	2004	303	6
CHLORIDE (CL)	134-300	203	73.24	6
TRACE ELEMENTS				
ARSENIC (AS) DISS	160-186	173	11.5	6
ARSENIC (AS) +3	153-250	181	35.38	6
ARSENIC (AS) +5	1.1-14.5	6.31	5.06	5
CADMIUM (CD) DISS	.001-.0075	.0028	.0027	6
COPPER (CU) DISS	<.008-.01	<.008	.0028	5
IRON (FE) DISS	7.3-45.6	17.89	14.85	6
IRON (FE II)	8.46-49.8	21.86	14.9	6
LEAD (PB) DISS	<.005-.037	.0087	.014	6
MANGANESE (MN) DISS	3.76-10	5.88	2.69	5
ZINC (ZN) DISS	3.7-27.5	10.33	8.96	6

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 04-19-1989 HWQ-6/86-R.ST.1

TABLE 8-3-5. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE DH-17

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	11.3-13.4	12.62	.832	5
SPEC. COND. (UMHOS/CM) FIELD	3546-4247	4007	329	4
SPEC. COND. (UMHOS/CM) LAB	3180-4550	4026	569	5
PH FIELD	5.63-6.75	6.25	.424	5
PH LAB	6.2-6.6	6.42	.148	5
TDS MEAS. @ 180 DEG. C	2896-3562	3272	301	5
OXYGEN (O) DISS	1.2-3.1	2.38	.753	5
DEPTH TO SWL BELOW MP (FT)	26.73-31.32	28.69	2.16	4
COMMON IONS				
CALCIUM (CA)	50.5-164	91.2	54.59	5
MAGNESIUM (MG)	18.5-39	26.3	9.15	5
SODIUM (NA)	533-1010	844	182	5
POTASSIUM (K)	25-33	29.34	3.42	5
BICARBONATE (HCO3) (LAB)	139-207	184	26.83	5
CARBONATE AS CO3 (LAB)	<1	<1	0	5
SULFATE (SO4)	1390-1800	1572	149	5
CHLORIDE (CL)	153-275	233	54.11	5
TRACE ELEMENTS				
ARSENIC (AS) DISS	80-111.3	95.16	13.71	5
ARSENIC (AS) +3	82-118	97.11	14.6	5
ARSENIC (AS) +5	.296-1.56	.724	.569	4
CADMIUM (CD) DISS	<.001-.005	.0016	.0019	5
COPPER (CU) DISS	<.008-.01	<.008	.0026	4
IRON (FE) DISS	5.38-41	22.34	16.63	5
IRON (FE II)	8.5-47.8	26.38	17.85	5
LEAD (PB) DISS	<.005-.03	.011	.012	5
MANGANESE (MN) DISS	6.23-15.9	10.5	4.85	4
ZINC (ZN) DISS	3-8.2	4.72	2.15	5

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT
WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE
WAS USED FOR THE MEAN.
OUTPUT DATE: 04-19-1989 HWQ-6/86-R.ST.1

TABLE 8-3-6. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE DH-24

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	10.5-12	11.18	.699	4
SPEC. COND. (UMHOS/CM) FIELD	2143-4807	3383	1342	3
SPEC. COND. (UMHOS/CM) LAB	3400-3560	3478	68.5	4
PH FIELD	5.24-5.88	5.57	.265	4
PH LAB	3.22-5.6	3.91	1.13	4
TOTAL SUSP. SOLIDS	80.7	80.7	0	1
TDS MEAS. @ 180 DEG. C	2881-2971	2906	43.77	4
OXYGEN (O) DISS	1.6-5.8	2.75	2.04	4
DEPTH TO SWL BELOW MP (FT)	16.33-30.29	25.86	6.41	4
COMMON IONS				
CALCIUM (CA)	188-205	196	9.54	4
MAGNESIUM (MG)	69-89	80.63	8.5	4
SODIUM (NA)	380-470	408	41.8	4
POTASSIUM (K)	26.4-34	30.33	3.18	4
BICARBONATE (HCO3) (LAB)	<1-70	37.38	29.74	4
CARBONATE AS CO3 (LAB)	<1	<1	0	4
SULFATE (SO4)	1550-1671	1633	57.01	4
CHLORIDE (CL)	150-200	182	21.97	4
TRACE ELEMENTS				
ARSENIC (AS) DISS	75-89	81.45	5.76	4
ARSENIC (AS) +3	68.1-100	83.22	15.23	4
ARSENIC (AS) +5	2.28-6.2	3.84	2.08	3
CADMIUM (CD) DISS	.272-.42	.337	.071	4
COPPER (CU) DISS	.015-.025	.02	.005	3
IRON (FE) DISS	40.3-57.6	50.1	7.26	4
IRON (FE II)	8.72-87.5	64.38	37.29	4
LEAD (PB) DISS	<.005-.035	.012	.016	4
MANGANESE (MN) DISS	30.9-36.8	33.43	3.04	3
ZINC (ZN) DISS	26.5-35.8	31.33	3.82	4

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 04-19-1989 HWQ-6/86-R.ST.1

TABLE 8-3-7. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE EH-60

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	9.7-12.5	11.1	1.98	2
SPEC. COND. (UMHOS/CM) FIELD	1987	1987	0	1
SPEC. COND. (UMHOS/CM) LAB	1600-1870	1735	191	2
PH FIELD	6.05-6.4	6.23	.247	2
PH LAB	6.54-7.82	7.18	.905	2
TOTAL SUSP. SOLIDS	4.4	4.4	0	1
TDS MEAS. @ 180 DEG. C	1312-1538	1425	160	2
OXYGEN (O) DISS	1.8-2	1.9	.141	2
DEPTH TO SWL BELOW MP (FT)	21.24-27.5	24.37	4.43	2
COMMON IONS				
CALCIUM (CA)	109-148.5	129	27.93	2
MAGNESIUM (MG)	32-41.5	36.75	6.72	2
SODIUM (NA)	195-197	196	1.41	2
POTASSIUM (K)	16.9-20.2	18.55	2.33	2
BICARBONATE (HCO3) (LAB)	148-208	178	42.43	2
CARBONATE AS CO3 (LAB)	<1	<1	0	2
SULFATE (SO4)	593-750	672	111	2
CHLORIDE (CL)	99-130	115	21.92	2
TRACE ELEMENTS				
ARSENIC (AS) DISS	1.23-1.63	1.43	.283	2
ARSENIC (AS) +3	.008	.008	.0028	2
ARSENIC (AS) +5	1.55-1.83	1.69	.198	2
CADMIUM (CD) DISS	.001-.01	.0055	.0064	2
COPPER (CU) DISS	.01	.01	0	1
IRON (FE) DISS	<.02-.041	.025	.022	2
IRON (FE II)	<.001-<.01	.0027	.0032	2
LEAD (PB) DISS	<.005-.022	.012	.014	2
MANGANESE (MN) DISS	43	43	0	1
ZINC (ZN) DISS	.019-.115	.067	.068	2

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 04-19-1989 HWQ-6/86-R.ST.1

TABLE 8-3-8. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE EH-62

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	10.7-10.8	10.75	.071	2
SPEC. COND. (UMHOS/CM) FIELD	974.5	974.5	0	1
SPEC. COND. (UMHOS/CM) LAB	650-940	795	205	2
PH FIELD	6.49-6.81	6.65	.226	2
PH LAB	7.05-7.9	7.48	.601	2
TOTAL SUSP. SOLIDS	13.5	13.5	0	1
TDS MEAS. @ 180 DEG. C	458-747.6	603	205	2
OXYGEN (O) DISS	4.2-4.8	4.5	.424	2
DEPTH TO SWL BELOW MP (FT)	28.3-28.33	28.31	.024	2
COMMON IONS				
CALCIUM (CA)	73-130	102	40.31	2
MAGNESIUM (MG)	18.4-30.5	24.45	8.56	2
SODIUM (NA)	36.5-46.7	41.6	7.21	2
POTASSIUM (K)	4.8-6.5	5.65	1.2	2
BICARBONATE (HCO3) (LAB)	132-199	166	47.38	2
CARBONATE AS CO3 (LAB)	<1	<1	0	2
SULFATE (SO4)	191-340	266	105	2
CHLORIDE (CL)	9-23	16	9.9	2
TRACE ELEMENTS				
ARSENIC (AS) DISS	<.006-.051	.027	.034	2
ARSENIC (AS) +3	<.008	<.008	.0028	2
ARSENIC (AS) +5	.01-.028	.019	.013	2
CADMIUM (CD) DISS	<.001-.014	.0073	.0095	2
COPPER (CU) DISS	<.008	<.008	0	1
IRON (FE) DISS	<.02-.036	.023	.018	2
IRON (FE II)	<.001-<.01	.0027	.0032	2
LEAD (PB) DISS	<.005	<.005	0	2
MANGANESE (MN) DISS	.02	.02	0	1
ZINC (ZN) DISS	<.008-.02	.012	.011	2

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT
WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE
WAS USED FOR THE MEAN.
OUTPUT DATE: 04-19-1989 HWQ-6/86-R.ST.1

Retardation

Retardation of arsenic can be estimated by comparing the concentrations of arsenic with concentrations of the unretarded or conservative species sulfate and chloride as a function of downgradient distance from the speiss granulating pond. Chloride, because of its very high solubility and low negative charge density is rarely precipitated or adsorbed by natural geologic material. Therefore, decreases in chloride concentration with downgradient distance are likely to be due solely to dilution and dispersion of the contaminant plume. Arsenic concentrations, however, will be affected by attenuation mechanisms, such as adsorption and coprecipitation, as well as by dilution and dispersion. Because dilution and dispersion are physical effects, dilution/dispersion of arsenic and chloride will be identical and any changes in the arsenic/chloride ratio with downgradient distance can be attributed to retardation of arsenic. Sulfate is also rarely attenuated by geologic material and was used to verify the arsenic to chloride comparison.

Figure 8-3-1 shows arsenic, chloride and sulfate concentrations (log mg/L) as a function of downgradient distance from the speiss granulating pond. In general, chloride and sulfate concentrations show similar decreases in concentration with distance.

Arsenic concentrations show a much greater decrease with downgradient distance than chloride and sulfate due to retardation of arsenic. Over the 3200 feet of transport, arsenic concentrations are reduced by a factor of 800 to 3,000 times more than chloride and sulfate, respectively.

Factors Controlling Arsenic Mobility

It is obvious from Figure 8-3-1 that arsenic attenuation does not occur at a constant rate in all areas of the aquifer and that the mobility of As III is much greater than As V. Arsenic V concentrations are reduced quickly to the 1 mg/L level within 600 feet of the speiss granulating pond. Arsenic III concentrations remain near the 100 mg/L level up to 1600 feet from the speiss granulating pond and appear to attenuate little over this distance. Between 1600 and 2000 feet downgradient, Arsenic III is very strongly attenuated with concentrations dropping from approximately 80 mg/L at 1600 feet to 0.005 mg/L at 2000 feet. This

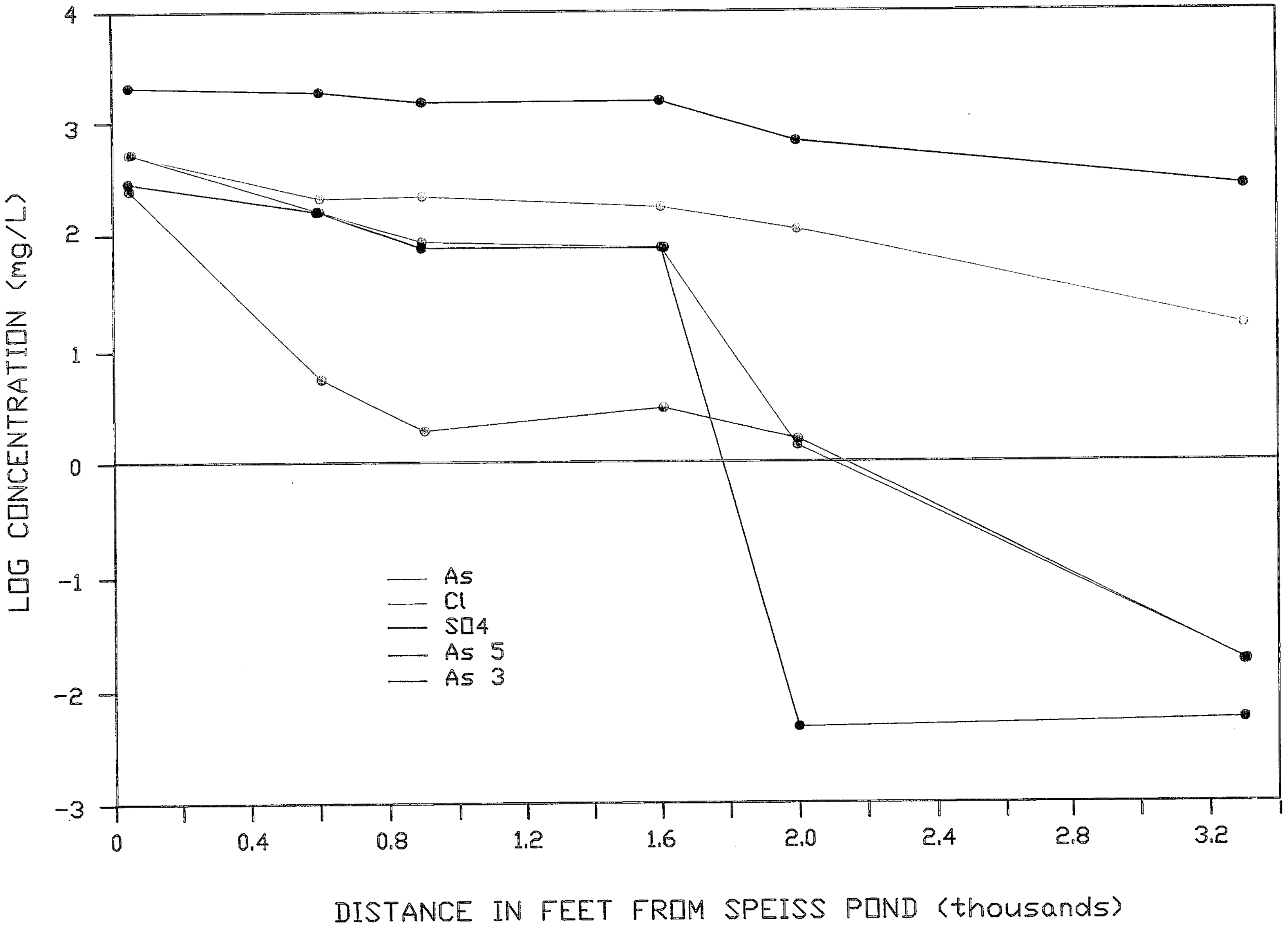


Figure 8–3–1. Arsenic, Chloride and Sulfate Concentration/ Distance Profiles

sudden decrease in As III concentration is accompanied by a change in the dominan from As III to As V. These changes in attenuation behavior of arsenic are indicative of geochemical variations in the groundwater system. By determining the geochemical changes in groundwater that correspond with the various attenuation behavior, it is possible to identify the geochemical factors controlling arsenic mobility.

pH

Concentrations of arsenic species and pH in groundwater from wells downgradient of the speiss granulating pond are shown in Figure 8-3-2. Solution pH appears to exert control primarily over the attenuation of As V. The large decrease in As V between 50 and 600 feet corresponds with a large decrease in the pH of groundwater from approximately 11 to 7. This increased attenuation is probably due to the increased adsorption of Arsenic V at lower pH. Because of the negative charge of the arsenate ion, adsorption of arsenate is low at high pH. Beyond 600 feet, pH is fairly constant in the pH 6 to 7 range (with the exception of DH-24) and appears to exert little control on arsenic attenuation. Groundwater samples from well DH-24 exhibited lower pH values of about 4 to 5. However, the resulting affect on arsenic mobility appears negligible.

Redox Conditions

Redox conditions in groundwater appear to be the primary factor controlling arsenic mobility. Evidence of redox conditions are dissolved oxygen (DO) content of well water, pe of water calculated from Arsenic III/V ratios, and indirectly from iron, and Arsenic III and V behavior in groundwater.

Redox conditions (pe) in wells downgradient of the speiss granulating pond were calculated based on As V/As III ratios assuming equilibrium conditions. As V/As III equilibria is described by the following reactions for the given pH ranges:

pH Range	Reaction
2.2 to 6.96	$H_3AsO_3^\circ + H_2O \rightleftharpoons H_2AsO_4^- + 3H^+ + 2e^-$
6.96 to 9.2	$H_3AsO_3^\circ + H_2O \rightleftharpoons HAsO_4^{2-} + 4H^+ + 2e^-$
9.2 to 11.5	$H_2AsO_3^- + H_2O \rightleftharpoons HA_2sO_4^{2-} + 3H^+ + 2e^-$

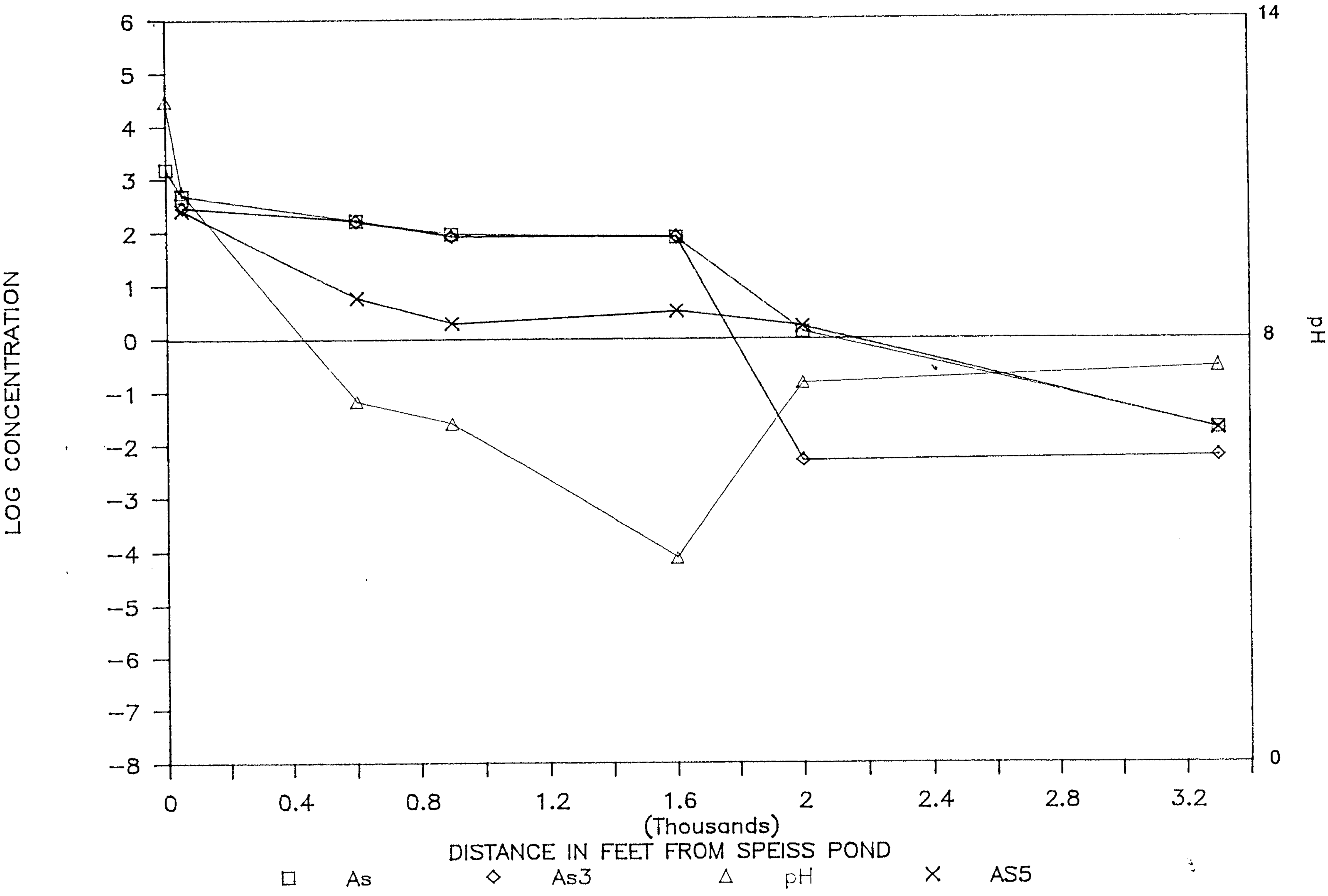


Figure 8-3-2: Arsenic Concentration and pH vs Distance Profiles From Speiss Pond

These reactions reflect the dominant As V and As III species for the given pH ranges. The ratio of the activities of As V to As III ((As V)/(As III)) of solution is related to solution pe and pH by the following relationships (Cherry et al, 1979):

pH Range	pe Equation*
2.2 to 6.96	$pe = 1/2 \log (H_2AsO_4^{-})/(H_3AsO_3^{\circ}) - 3/2\ pH + 11.03$
6.96 to 9.2	$pe = 1/2 \log (HAsO_4^{2-})/(H_3AsO_3^{\circ}) + 14.51 - 2\ pH$
9.2 to 11.5	$pe = 1/2 \log (HA_2sO_4^{2-})/(H_2AsO_3^{-}) + 9.89 - 3/2\ pH$

* (species) denotes activity of chemical species

The PHREEQE geochemical modeling program (Parkhurst et al, 1980) was used to calculate arsenic speciations and activity coefficients based on the Davies Equation. Arsenic V and arsenic III data were then corrected for speciation and the activities of the dominant species were calculated. Activities of the As V and As III species and solution pH were then used to calculate solution pe based on the above relationships.

Calculated pe values, dissolved oxygen concentrations and arsenic V and III concentrations are shown in Figure 8-3-3 for wells downgradient of the speiss granulating pond. As Figure 8-3-3 shows, there is an inverse relationship between pe and arsenic concentrations. This trend is paralleled by dissolved oxygen concentrations. That is, arsenic concentration decreases as dissolved oxygen concentrations and pe values increase.

Concentrations of Arsenic III and V in well water also provide indications of redox conditions in groundwater. Groundwater in which As III is dominant (As III/As V > 1) are indicative of pe-pH conditions above the As III/As V boundary while As III/As V < 1 is indicative of pe-pH conditions below the As III/As V boundary. Interpretation of As III/As V ratios is complicated by the strong adsorption of As V as described earlier. At moderate pH, As V is quickly attenuated so that even in oxidized waters As V concentration may be low.

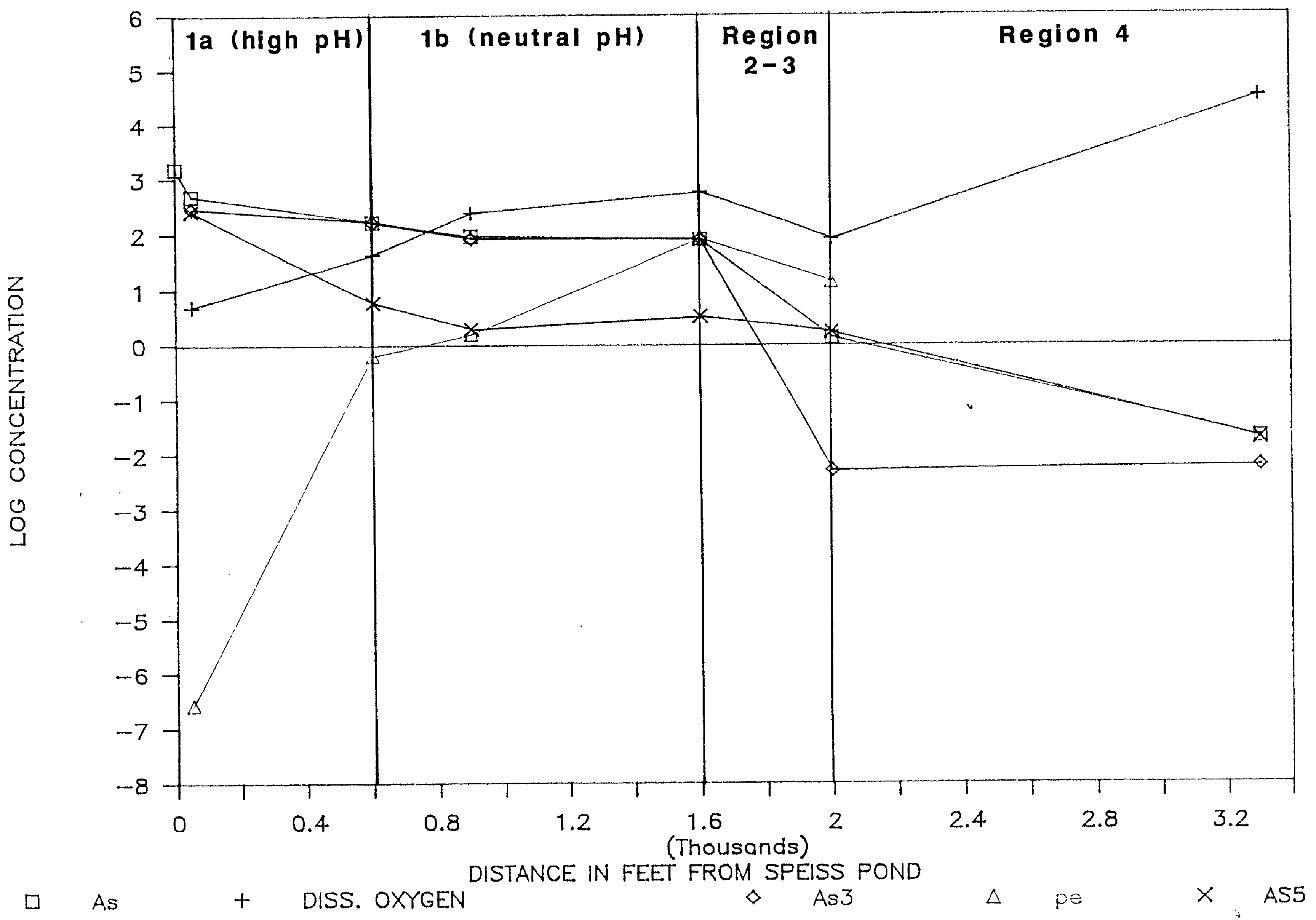


Figure 8-3-3: Arsenic, Dissolved Oxygen, pe vs Distance Profiles From Speiss Pond

Based on the relationships between pe and concentrations of Arsenic III and V, the contaminant plume can be divided into distinct redox regions as a function of downgradient distance from the speiss granulating pond. These regions are shown superimposed on the arsenic concentration profile in Figure 8-3-3. Figure 8-3-3 shows that 1) the geochemical environment near the speiss granulating pond is reducing and becomes increasingly more oxidizing with downgradient distance from the speiss granulating pond, and 2) changes in redox conditions correlate very well with changes in arsenic mobility and solubility. Dissolved oxygen concentrations also show a general increase with downgradient distance and confirm the conclusions based on metal mobilities.

Arsenic mobility in groundwater at the East Helena site can be explained very well by variations in the redox conditions of groundwater. In redox region 1 (0 to 1600 feet downgradient) arsenic III is dominant and arsenic solubility and mobility are high. Region I can also be subdivided based on groundwater pH and mobility of arsenic V as shown on Figure 8-3-3. In the high pH (ph 10 to 12) region 1a, (0 to 600 feet downgradient), adsorption of arsenic V is poor and arsenic V in solution is present in moderate quantities. In Region 1b (neutral pH), arsenic V is strongly adsorbed to the point that essentially all arsenic V is removed from solution.

An abrupt decrease in arsenic concentration occurs with the increase in oxidation state of groundwater from redox region 1 to 2 and 3. This switch from region 1 to 3 occurs very abruptly over a distance of only 400 feet and is accompanied by a decrease in arsenic concentration by a factor of 100. This reduction in arsenic and iron concentrations is believed to be due to oxidation of As III to As V and subsequent adsorption of As V and coprecipitation of As V with amorphous iron oxides.

The oxidation state of groundwater increases further in redox region 4 between 2,000 and 3,200 feet downgradient of the speiss granulating pond. This results in a further decrease in arsenic concentration by a factor of 100. At a distance of 3,200 feet from the speiss granulating pond, arsenic concentrations are at background levels for the Helena Valley.

In summary, migration of arsenic is controlled primarily by the redox state of groundwater. Under redox conditions present in ambient off-plant groundwater, arsenic is sparingly mobile and is present at very low concentrations, well below Federal Drinking Water Standards. One possible remedial alternative for groundwater at the site could be maintainance of the oxidation state of groundwater near natural background levels. To test these conclusions and to determine arsenic behavior in the Lower Lake contaminant plume, the migration of contaminants from Lower Lake was also examined.

Although these discussions have centered on transitions in oxidation state of metals, it is also possible that mobility of metals is controlled to some extent by other factors also related to the oxidation state of the environment. Evidence of petroleum hydrocarbon contamination has been noted in and downgradient of the speiss granulating pond area in sediments and groundwater (see Section 4.0). Although volatile and semi-volatile fractions of the petroleum hydrocarbon have apparently been biodegraded, heavy long chain residuals remain in soils at and just above the water table. It is possible that elevated concentrations of organic materials contribute to the reducing conditions in the area and thus exhibit control of metals mobility. This phenomena was observed at other sites where fuel contamination resulted in elevated mobility of arsenic and metals (Longmire, 1986). Alternatively, organic complexes may govern metals mobilities and changes in oxidation state may only be coincident with changes in organic concentrations and thus metals mobilities. It is also possible that oxidation of organic complexes causes precipitation and reduction in the mobilities of metals.

Average water quality of Lower Lake and the downgradient monitoring wells DH-4, EH-52, and EH-59 are listed in Tables 8-3-9 through 8-3-12. Groundwater concentrations of arsenic, dissolved oxygen, sulfate, chloride, pe and pH as a function of downgradient distance from Lower Lake is shown in Figures 8-3-4 and 8-3-5. The concentration profile of dissolved constituents in the Lower Lake plume is very similar to the concentration profile in the speiss granulating pond plume in that correlations exist between the mobilities of arsenic species and the oxidation state of groundwater with downgradient distance. The increase

TABLE 8-3-9. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR LOWER LAKE

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	5.1-21.5	13.3	11.6	2
SPEC. COND. (UMHOS/CM) FIELD	1371-2102	1595	271	6
SPEC. COND. (UMHOS/CM) LAB	1190-1900	1465	219	8
PH FIELD	6.75-6.93	6.84	.127	2
PH LAB	6.7-8.85	8.01	.738	8
TOTAL SUSP. SOLIDS	9.8-182	51.38	73.42	5
TDS MEAS. @ 180 DEG. C	959-1500	1200	189	8
STAGE (FT)	2.76	2.76	0	1
COMMON IONS				
CALCIUM (CA)	65.5-104	88.79	14.83	7
MAGNESIUM (MG)	11.1-15.2	13.94	1.4	7
SODIUM (NA)	88-320	220	70.56	7
POTASSIUM (K)	23-53	38.3	10.88	7
ALKALINITY AS CACO3 (LAB)	86-204	145	55.45	5
BICARBONATE (HCO3) (LAB)	98-249	155	61.5	8
CARBONATE AS CO3 (LAB)	<1	<1	0	2
SULFATE (SO4)	384-740	543	123	8
CHLORIDE (CL)	60-160	101	31.36	7
TRACE ELEMENTS				
ALUMINUM (AL) TOTAL	.175	.175	0	1
ALUMINUM (AL) DISS	<.161	<.161	0	1
ANTIMONY (SB) TOTAL	.288	.288	0	1
ANTIMONY (SB) DISS	.696	.696	0	1
ARSENIC (AS) TOTAL	10.5-36	19.89	8.36	8
ARSENIC (AS) DISS	8.25-29	17.05	7.57	7
BARIUM (BA) TOTAL	.037	.037	0	1
BARIUM (BA) DISS	.026	.026	0	1
BERYLLIUM (BE) TOTAL	<.0006	<.0006	0	1
BERYLLIUM (BE) DISS	<.0006	<.0006	0	1
CADMIUM (CD) TOTAL	.225-2.05	1.08	.521	8
CADMIUM (CD) DISS	.019-.75	.354	.244	7
CHROMIUM (CR) TOTAL	<.0021	<.0021	0	1
CHROMIUM (CR) DISS	<.0021	<.0021	0	1
COBALT (CO) TOTAL	.098	.098	0	1
COBALT (CO) DISS	.08	.08	0	1
COPPER (CU) TOTAL	.131-12	1.92	4.44	7
COPPER (CU) DISS	.016-.098	.038	.031	6
IRON (FE) TOTAL	.463-7.1	1.76	2.19	8
IRON (FE) DISS	.025-.226	.083	.07	7
LEAD (PB) TOTAL	<.003-24.7	4.96	8.09	8
LEAD (PB) DISS	<.003-.238	.058	.085	7

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 06-15-1989 HWQ-6/86-R.ST.1

TABLE 8-3-9. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR LOWER LAKE (Continued)

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
TRACE ELEMENTS				
MANGANESE (MN) TOTAL	1.14-3.48	2.07	.886	7
MANGANESE (MN) DISS	.548-2.63	1.5	.687	6
MERCURY (HG) TOTAL	.0036	.0036	0	1
MERCURY (HG) DISS	.0003	.0003	0	1
NICKEL (NI) TOTAL	.057	.057	0	1
NICKEL (NI) DISS	.051	.051	0	1
SELENIUM (SE) TOTAL	.0094	.0094	0	1
SELENIUM (SE) DISS	.012	.012	0	1
SILVER (AG) TOTAL	(.0026	(.0026	0	1
SILVER (AG) DISS	(.0026	(.0026	0	1
THALLIUM (TL) TOTAL	.233	.233	0	1
THALLIUM (TL) DISS	.22	.22	0	1
TIN (SN) TOTAL	(.036	(.036	0	1
TIN (SN) DISS	(.036	(.036	0	1
VANADIUM (V) TOTAL	(.0035	(.0035	0	1
VANADIUM (V) DISS	(.0035	(.0035	0	1
ZINC (ZN) TOTAL	.813-11	3.5	3.38	8
ZINC (ZN) DISS	.068-2.41	.796	.848	7

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 06-15-1989 HWQ-6/86-R.ST.1

TABLE 8-3-10. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE DH-4

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	9.2-11.7	10.4	1.04	4
SPEC. COND. (UMHOS/CM) FIELD	466-838.4	698	113	11
SPEC. COND. (UMHOS/CM) LAB	520-900	716	106	10
PH FIELD	5.96-7.06	6.64	.475	4
PH LAB	6.9-8.12	7.37	.422	10
TOTAL SUSP. SOLIDS	10-295	120	127	4
TDS MEAS. @ 180 DEG. C	353-686	516	96.97	10
OXYGEN (O) DISS	1.3-2.2	1.65	.404	4
DEPTH TO SWL BELOW MP (FT)	11.12-11.53	11.28	.179	4
COMMON IONS				
CALCIUM (CA)	35.5-46	40.75	3.74	6
MAGNESIUM (MG)	6.5-8.8	7.36	.941	6
SODIUM (NA)	71-142	96.25	27.91	6
POTASSIUM (K)	4.3-7.8	5.84	1.48	6
ALKALINITY AS CACO3 (LAB)	193-224	209	15.52	3
BICARBONATE (HCO3) (LAB)	184-273	237	30.42	7
CARBONATE AS CO3 (LAB)	<1	<1	0	3
SULFATE (SO4)	70-160	117	36.39	7
CHLORIDE (CL)	24-44	32	7.56	6
TRACE ELEMENTS				
ALUMINUM (AL) DISS	<.161	<.161	0	1
ANTIMONY (SB) DISS	<.014	<.014	0	1
ARSENIC (AS) DISS	4.3-11.4	8.18	3.06	11
ARSENIC (AS) +3	3.7-5.433	4.38	.756	4
ARSENIC (AS) +5	.045-.5	.282	.231	4
BARIUM (BA) DISS	.039	.039	0	1
BERYLLIUM (BE) DISS	<.0006	<.0006	0	1
CADMIUM (CD) DISS	<.001-<.004	.0011	.001	11
CHROMIUM (CR) DISS	.0078	.0078	0	1
COBALT (CO) DISS	<.0069	<.0069	0	1
COPPER (CU) DISS	.0059-<.008	.0059	.0008	5
IRON (FE) DISS	4.69-15.7	9.91	4.33	7
IRON (FE II)	14.8-17.2	16.35	1.06	4
LEAD (PB) DISS	<.003-<.005	<.003	.0003	11
MANGANESE (MN) DISS	3.38-5.01	4.33	.673	5
MERCURY (HG) DISS	<.00019	<.00019	0	1
NICKEL (NI) DISS	<.034	<.034	0	1
SELENIUM (SE) DISS	<.0024	<.0024	0	1
SILVER (AG) DISS	<.0026	<.0026	0	1
THALLIUM (TL) DISS	<.0021	<.0021	0	1
TIN (SN) DISS	<.036	<.036	0	1

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 06-15-1989 HWQ-6/86-R.ST.1

TABLE 8-3-10. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE DH-4
(Continued)

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
TRACE ELEMENTS				
VANADIUM (V) DISS	.01	.01	0	1
ZINC (ZN) DISS	<.008-.095	.025	.027	11

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 06-15-1989 HWQ-6/86-R.ST.1

TABLE 8-3-11. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE EH-52

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	4-15	8.77	3.44	7
SPEC. COND. (UMHOS/CM) FIELD	379.4-846	583	174	7
SPEC. COND. (UMHOS/CM) LAB	380-950	581	194	7
PH FIELD	6.27-7.05	6.71	.3	7
PH LAB	6.9-7.95	7.25	.366	7
TOTAL SUSP. SOLIDS	4.4	4.4	0	1
TDS MEAS. @ 180 DEG. C	302-638	429	132	7
OXYGEN (O) DISS	1.6-6.4	3.96	1.82	7
DEPTH TO SWL BELOW MP (FT)	3.58-8.64	7.19	1.72	7
COMMON IONS				
CALCIUM (CA)	39.3-78	56.13	15.7	6
MAGNESIUM (MG)	6.5-12	8.8	2.49	6
SODIUM (NA)	28-75	47.55	19.09	6
POTASSIUM (K)	16-37	25.65	8.36	6
BICARBONATE (HCO3) (LAB)	87-163	133	30.7	7
CARBONATE AS CO3 (LAB)	<1	<1	0	6
SULFATE (SO4)	74-250	151	67.15	7
CHLORIDE (CL)	5.5-16	9.98	4.05	6
TRACE ELEMENTS				
ARSENIC (AS) DISS	.963-1.45	1.2	.201	7
ARSENIC (AS) +3	<.008-1.4	.468	.624	6
ARSENIC (AS) +5	.04-1.75	.945	.716	6
CADMIUM (CD) DISS	<.001-.003	.0011	.0009	7
COPPER (CU) DISS	<.008-.016	<.008	.0049	6
IRON (FE) DISS	<.02-.062	.026	.02	7
IRON (FE II)	<.001-.02	.0092	.0085	6
LEAD (PB) DISS	<.005	<.005	0	7
MANGANESE (MN) DISS	.003-.048	.012	.018	6
ZINC (ZN) DISS	.01-.025	.016	.0057	7

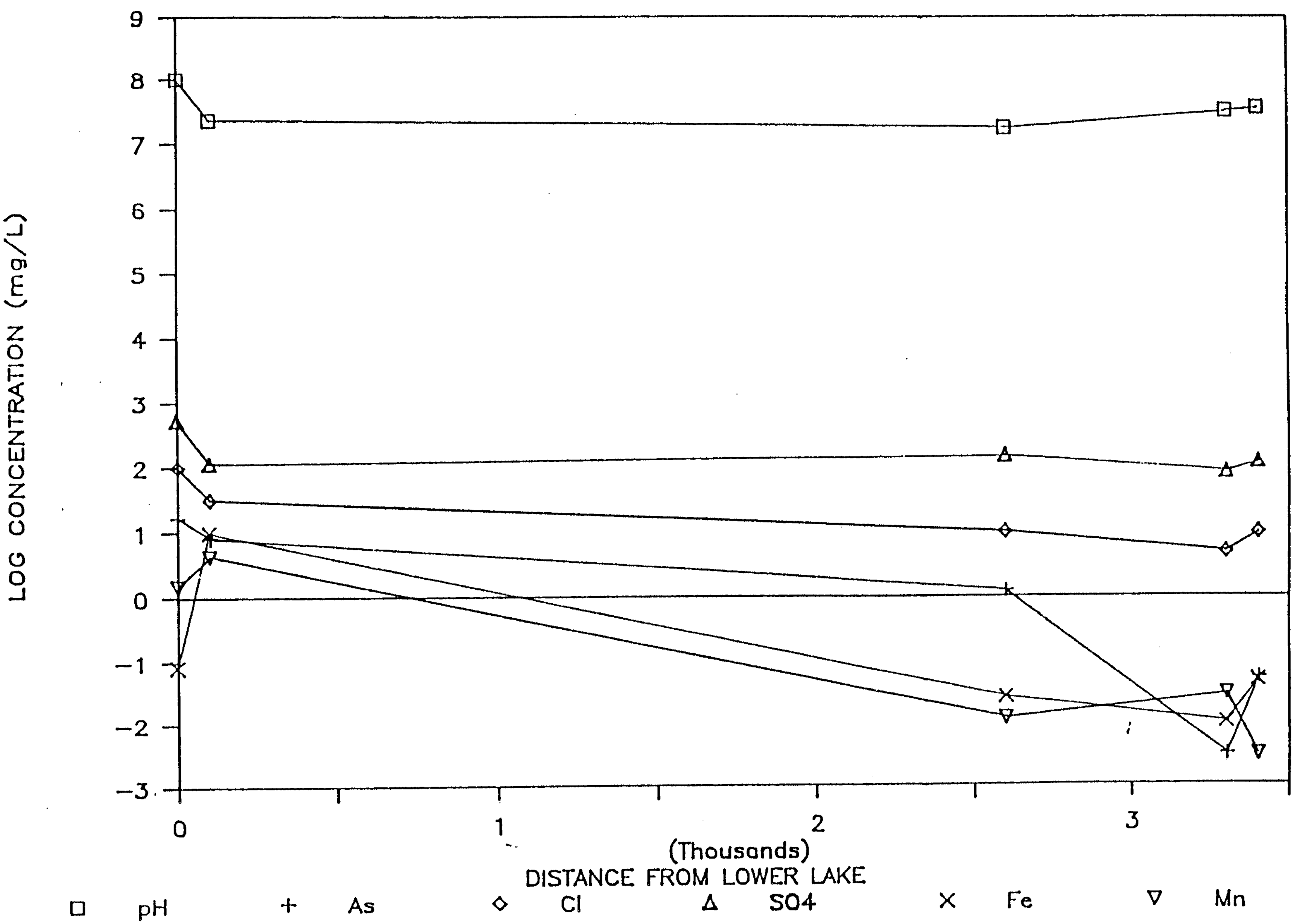
ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 06-15-1989 HWQ-6/86-R.ST.1

TABLE 8-3-12. STATISTICAL SUMMARY OF WATER QUALITY ANALYSIS FOR SITE EH-59

	RANGE	MEAN	STANDARD DEVIATION	NUMBER OF SAMPLES
PHYSICAL PARAMETERS				
WATER TEMPERATURE (C)	9.5-15	11.7	2.35	4
SPEC. COND. (UMHOS/CM) FIELD	345.5-448.4	408	54.87	3
SPEC. COND. (UMHOS/CM) LAB	344-422	388	36.52	5
PH FIELD	6.28-6.69	6.52	.171	4
PH LAB	7.05-7.8	7.5	.321	5
TOTAL SUSP. SOLIDS	12	12	0	1
TDS MEAS. @ 180 DEG. C	222-294	254	29.53	5
OXYGEN (O) DISS	2.8-7	4.68	2.15	4
DEPTH TO SWL BELOW MP (FT)	6.84-8.31	7.68	.615	4
COMMON IONS				
CALCIUM (CA)	29-42	37.2	7.14	3
MAGNESIUM (MG)	7.1-9.3	8.37	1.14	3
SODIUM (NA)	24.2-26.5	25.6	1.23	3
POTASSIUM (K)	9.4-13.4	11.4	2	3
BICARBONATE (HCO3) (LAB)	95-121	113	12.39	4
CARBONATE AS CO3 (LAB)	<1	<1	0	3
SULFATE (SO4)	66-108	85	20.3	5
CHLORIDE (CL)	3-6.5	4.83	1.76	3
TRACE ELEMENTS				
ARSENIC (AS) DISS	<.006	<.006	.0013	5
ARSENIC (AS) +3	<.008-.014	<.008	.0048	4
ARSENIC (AS) +5	.008-.036	.018	.013	4
CADMIUM (CD) DISS	<.001-.006	.0021	.0026	4
COPPER (CU) DISS	<.008	<.008	0	3
IRON (FE) DISS	<.02-.021	<.02	.0061	4
IRON (FE II)	<.001-<.01	.0039	.0022	4
LEAD (PB) DISS	<.005	<.005	0	4
MANGANESE (MN) DISS	.004-.076	.029	.041	3
ZINC (ZN) DISS	<.008-.019	<.008	.0075	4

ALL QUANTITIES IN MILLIGRAMS PER LITER UNLESS OTHERWISE NOTED.
FOR VALUES BELOW THE DETECTION LIMIT, ONE HALF THE DETECTION LIMIT WAS USED IN THE STATISTICAL ANALYSIS.
IF THE RESULTING MEAN WAS BELOW THE RANGE THEN THE LOW RANGE VALUE WAS USED FOR THE MEAN.
OUTPUT DATE: 06-15-1989 HWQ-6/86-R.ST.1

FIGURE 8-3-4. ARSENIC, CHLORIDE AND SULFATE CONCENTRATION/DISTANCE PROFILES FROM LOWER LAKE



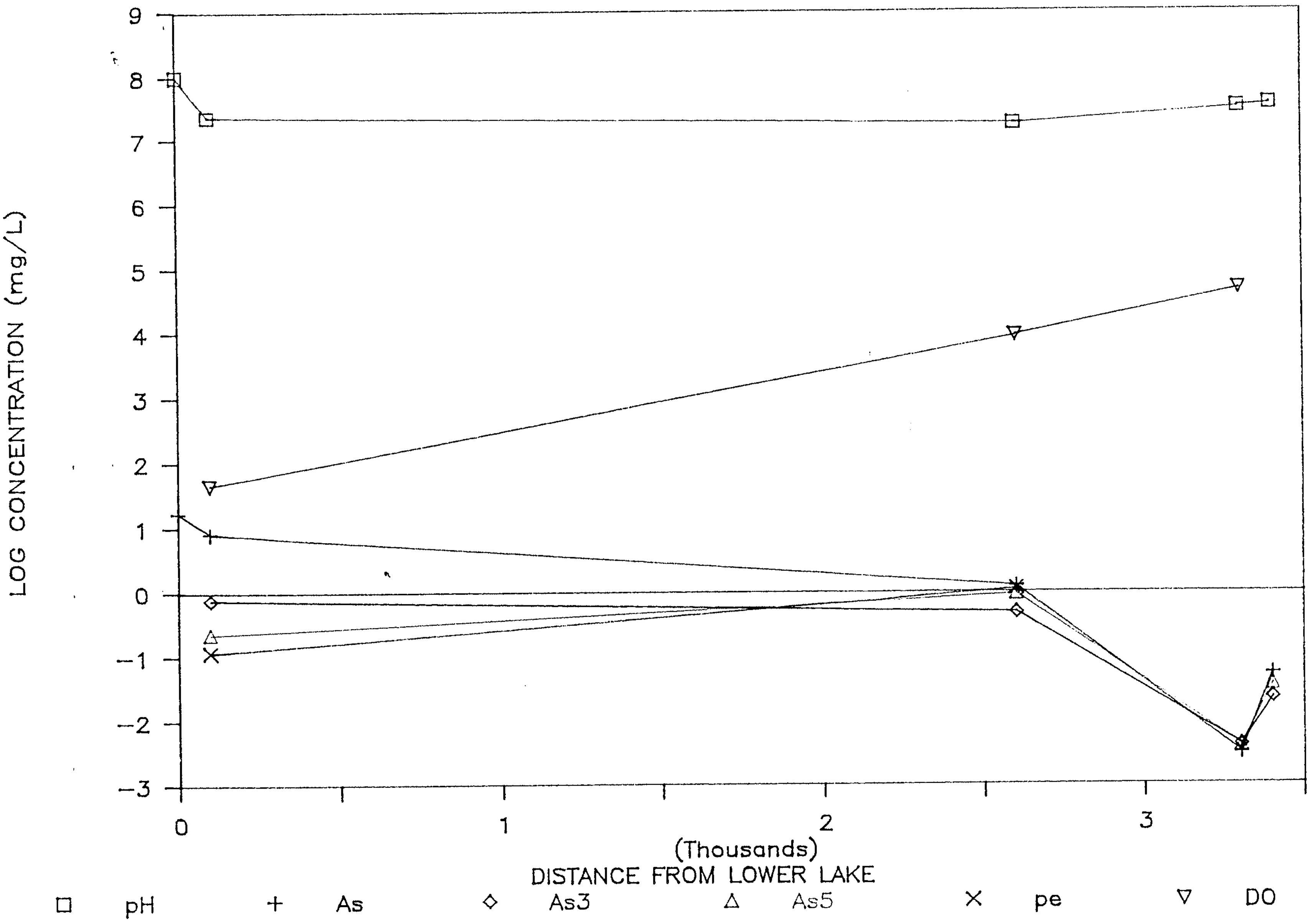


Figure 8-3-5: Arsenic, Dissolved Oxygen, pe and pH vs Distance Profiles From Lower Lake

in oxidation state with downgradient distance is confirmed by the increase in the average dissolved oxygen content of monitoring wells from 1.65 mg/L at DH-4 (100 feet downgradient) to 4.68 mg/L at EH-59 (3300 feet downgradient).

Arsenic contamination from Lower Lake appears to attenuate, by chemical processes over the initial 2,600 feet of transport. Arsenic concentrations in this initial 2,600 feet generally parallel concentrations of the conservative elements sulfate and chloride indicating that reductions in arsenic concentrations over this distance are primarily the result of dilution/dispersion processes. Dilution/dispersion reduce arsenic concentrations by a factor of 10 during 2,600 feet of transport. Between 2,600 and 3,300 feet downgradient, arsenic concentration is reduced by a factor of approximately 300. This decrease in arsenic concentration is accompanied by large decreases in iron and manganese concentrations and most likely is the result of a higher oxidation state of groundwater in this region.

The lack of attenuation of arsenic in the initial 2,600 feet of transport from Lower Lake is probably due to a variety of site factors. The subsurface strata in this region contains an abundance of organic-rich alluvial and lake sediments which are capable of maintaining a relatively reducing redox environment in groundwater. Moreover, these organic-rich sediments are overlain by a low permeability clay layer which impedes the influx of oxygen-rich rainwater to the shallow groundwater system. These factors combine to depress the redox state of groundwater and the attenuation of arsenic downgradient of Lower Lake.

8.3.3 Groundwater Flow and Solute Transport Modeling

8.3.3.1 Methodology

Groundwater flow and solute transport of As and SO_4 were simulated at the East Helena site. The purpose of modeling groundwater flow was to test the collected hydrogeologic data and surface water flow data. Modeling these data help characterize and confirm the existing groundwater flow conceptual model, surface water interaction and aquifer parameters. In addition, groundwater flow modeling was needed to provide a flow field to move contaminants in a solute transport model. The purpose of solute transport modeling was to attempt to estimate contaminant transport coefficients (such as dispersivity and retardation, timing of arsenic loading, future arsenic concentrations, and locating arsenic source areas).

The computer code used to model groundwater flow was PLASM (Prickett Lonnquist Aquifer Simulation Model) developed by Prickett and Lonnquist (1971). PLASM is a 2-dimensional finite difference model, which can be used to simulate transient and steady-state flow in a heterogeneous or homogeneous aquifer under unconfined, confined, and leaky-confined conditions with isotropic or anisotropic aquifer permeabilities. The area to be modeled is overlain by a grid system, the intersection of grid lines are referred to as nodes. Each node then represents a discrete portion of the aquifer (referred to as a cell), the area of which is determined by the nodal spacing. A unique set of aquifer characteristics can then be assigned to each node (cell). The hydraulic head at individual nodes is estimated using the ADI (alternating direction implicit) iterative numerical method which solves a set of finite difference equations. The model can account for variable pumping rates from wells, natural and artificial recharge rates, evapotranspiration, and provide a water balance.

The computer code used to model contaminant transport was Random-Walk (Prickett and others, 1981), which simulates solute transport through the groundwater flow system created with PLASM. The governing equation used in the model takes into account convection, dispersion, retardation, sources, and sinks. Contaminant migration is modeled by "particles" (representing the contaminant) that are moved in a velocity vector field (converted from PLASM nodal head values) from cell to cell. The model's basic premise is that dispersion is a random process which approaches a normal distribution. At the end of a simulation run (the desired length of time for contaminant transport), the model will generate areal maps of resultant solute concentration and/or the number of particles distributed to each cell.

The fall of 1987 data were simulated in the model runs. This low-flow period was chosen because contaminant concentrations, typically higher in the fall, were thought to approach worst case conditions.

8.3.3.2 Groundwater Flow Input Parameters

The following paragraphs detail model input parameters used to simulate groundwater flow. In addition, a discussion on the rationale used to choose these parameters, and assumptions used in the model, are presented.

The model's boundary conditions and node locations are shown on Exhibit 12 and numerically in a PLASM PLA output file in Appendix 8-1. Exhibit 12 shows a 20 by 30 variable grid system with most grid size intervals of 400 feet in the i and j directions (along the x and y axes, respectively). A variable grid spacing was desirable in this case because the number of nodes needed to cover a particular area could be reduced, thereby decreasing the amount of necessary computer memory and processing time. At one row location ({1,26} through {20,26}) a 400 foot (i direction) by 200 foot (j direction) variable grid was used to simulate runoff water that seeps into the shallow aquifer from sump S-2 located on the plant site at {15,26}. After several trial simulations, the effect of the sump seepage was determined to be negligible in the model, and was not used in the steady-state simulation. Variable grid spacing was also used at the north edge of the model. Row {1,29} through {20,30} used an 800 foot (i diameter) and 800 foot (j direction) spacing to extend the model northward.

Constant head boundaries shown on Exhibit 12 represent hydraulic head elevations assumed to be constant throughout a simulated time period. To maintain a constant head at these nodes, the storage coefficients were set at many orders of magnitude above the typical or representative storage values.

No-flow boundaries shown on Exhibit 12 represent locations where potentiometric lines are at right angles to the no-flow boundary (along flow lines within the aquifer). Where applicable, these were placed where very low permeability material (aquifer boundaries) inhibits normal groundwater flow. The no-flow boundary extending across the southwest corner of the model simulates the ridge of low permeability ash in this area (see Figure 4-1-1, Section 4.1). Potentiometric lines are generally at right angles along this zone. No-flow boundaries along the east and northwest edges of the model (see Exhibit 12) were placed parallel to actual groundwater flow lines.

Shallow and intermediate unconsolidated strata which overly the ash/clay unit were considered as one aquifer in the model. Aquifer thickness in the model varied from 10 feet thick at the southern edge of the model to a maximum aquifer thickness of 168.5 feet at the northern edge of the model. The aquifer thickness at the northern boundary was estimated from monitoring well logs which indicated a low angle slope of the aquifer bottom (10 feet of drop per 400 feet linear distance) dipping towards the valley center.

Hydraulic conductivity or permeability (K), is an important model parameter for simulating groundwater flow since it describes the ease at which water will move through an aquifer. In this model, K (assumed to be isotropic and homogeneous) was set at 500 gallons/day/ft^2 for all nodes. This was considered to be a conservative estimate (based on aquifer tests) for vertical and horizontal variations in the shallow and intermediate strata. Exhibit 4 shows the range of calculated permeabilities from aquifer testing results. Since PLASM is a two dimensional model it interprets K to be constant throughout the entire aquifer thickness.

In addition to K, specific yield also is an important model parameter. The greater the specific yield, the more water will be available for storage. Representative values of specific yield for sand and gravel range from 19% to 25% (Walton, 1970) while specific yield for fine grain materials (sand and clay) can range from 1 to 30%. Since the shallow aquifer consists of a heterogenous mixture of gravel, sand, silt and clay, a relatively low value of 15% (0.15) was selected for the model at all nodes except those nodes representing constant head boundaries.

An error tolerance is input into the model to limit the cumulative difference between previously calculated head values and present head values calculated for all node locations after each iteration. The model continues to iterate until the difference between the previous and present head values are equal to or less than the specified tolerance. For this model, a cumulative model error tolerance of one foot was chosen. This was within the recommended maximum value of six feet calculated by a subroutine in the PLASM code for a 20 by 30 grid.

During calibration, nodal head values were matched to within two feet of actual heads measured in area monitoring wells during the fall of 1987. This level of accuracy was thought to be appropriate when considering the many variables, including complex aquifer heterogeneities, which were simplified in the model.

Surface water often plays a key role in recharging an underlying aquifer. In this model, surface water leakage was modeled for Prickly Pear Creek, Wilson Ditch and Lower Lake. Seepage for Prickly Pear Creek (Exhibit 12) was assumed to have a maximum seepage rate of four cfs water loss over the modeled creek length (13,000 feet). As described in Section 5.2, streamflow gains and losses north of Lower Lake could not be accurately quantified because of gaging measurement error margins caused by bottom channel conditions. However, based on the results, and relative differences between the stream and groundwater levels, an assumed loss of 4 cfs is reasonable. Seepage was modeled by assigning a nodal seepage rate for each node representing the creek, all of which would have a total combined rate of about 4 cfs.

Wilson Ditch (Exhibit 12) was assumed to have a maximum seepage rate of approximately 0.75 cfs. One flow measurement at WD-3 conducted concurrently with a flow measurement at WD-2 on May 8, 1985 shows the ditch lost about 2 cfs (see Table 5-2-5). However, because ditch flow in the fall is significantly lower than flow in May (2 cfs and 6 cfs respectively), seepage losses in November 1987 are lower. Seepage was modeled in nodes representing the ditch by assigning a leakance rate for each node, averaging 0.75 cfs water loss over the 8,000 foot length of the unlined portion of the ditch. Unless seepage was simulated along Wilson Ditch, head at nodes near Wilson Ditch would have low values compared with the actual measured heads. A slight recharge factor was necessary to bring model heads within two feet of the measured values. Since other irrigation ditches located within the modeled area were dry in November 1987, seepage from these ditches were not simulated.

The location of Wilson Ditch in Exhibit 12 shows the actual ditch location is slightly to the southwest in comparison with the modeled position of Wilson Ditch. Since recharge from Wilson Ditch was modeled after the boundaries were selected, it was more appropriate to approximate the location of Wilson Ditch rather than move the southwestern no-flow boundary to accommodate the actual location of Wilson Ditch for surface recharge.

Small variations in leakage rates (Appendix 8-1) were modeled at a few creek and ditch nodes to more accurately simulate head in these areas.

Lower Lake and the northern half of Upper Lake were also modeled as surface water leakage areas. A leakance factor of 1 gallon/day /ft^3 was used at these node locations, for a total leakance rate of 3.7 cfs over the 800,000 ft^2 area representing the two lakes. This value is artificially high since the two lakes are in an area of both surface and groundwater recharge. The constant head boundary in this area of the model could not influence the local groundwater flow direction (Exhibit 4) resulting from Lower Lake and Upper Lake recharge unless a high leakance value was assumed.

Seven time steps over a simulated period of 10,000 days (27.4 years) were used to model steady-state heads. The PLASM water balance was used to determine the percentage of water lost or gained in the steady-state simulation.

In addition to modeling steady-state heads, an aquifer test was simulated at monitoring well DH-17 to compare drawdown measured in an actual field test (see Table 2-2-5) with drawdown in the model. Node (14,22) in the model was used to represent a shallow aquifer well similar to DH-17. This model node was stressed at the same pumping rate (18 gpm) and time schedule (.93 days) as the DH-17 aquifer test.

To compare the simulated and actual aquifer test results, the drawdown at DH-17 (3.4 feet) at the end of the field test was adjusted for well efficiency loss. This adjustment was accomplished by using the standard method of distance verses drawdown plotted on semi-log graph paper to estimate drawdown in a 100% efficient well. Estimated drawdown at DH-17 with 100% well efficiency was calculated to be 1.8 feet or 53% of the measured drawdown. Additionally, the simulated drawdown was adjusted for well diameter withdrawal instead of nodal area withdrawal. Nodal area drawdown is significantly less than well drawdown. This adjustment was accomplished with an equation in the PLASM documentation (Prickett and Lonnquist, 1971) that gave a simulated drawdown of 2.0 feet in the well.

Assumptions used in the groundwater flow modeling are:

1) The shallow-aquifer dimensions in the model are similar to actual aquifer dimensions.

2) The actual groundwater flow is not significantly affected by three-dimensional heterogeneities in the aquifer, can be simulated in two dimensions, and solute moves essentially perpendicular to potentiometric lines.

3) The groundwater flow simulations represent steady-state conditions (i.e. no change in head or flow direction) over a discrete time period.

4) Aquifer parameters used in the model represent average values for the shallow aquifer in the study area.

5) The underlying ash/clay unit is impermeable. Aquifer recharge only occurs along constant head boundaries and surface water leakance nodes.

8.3.3.3 Groundwater Flow Modeling Results

The following discussion presents the simulated steady-state head results. The first paragraph presents the simulated head data which is followed by a statistical analysis of the results.

The simulated steady-state groundwater flow field for fall 1987 (Figure 8-3-6) shows a close resemblance to the November 1987 flow field shown in Exhibit 4. Hydraulic conductivity, leakance and constant head data were

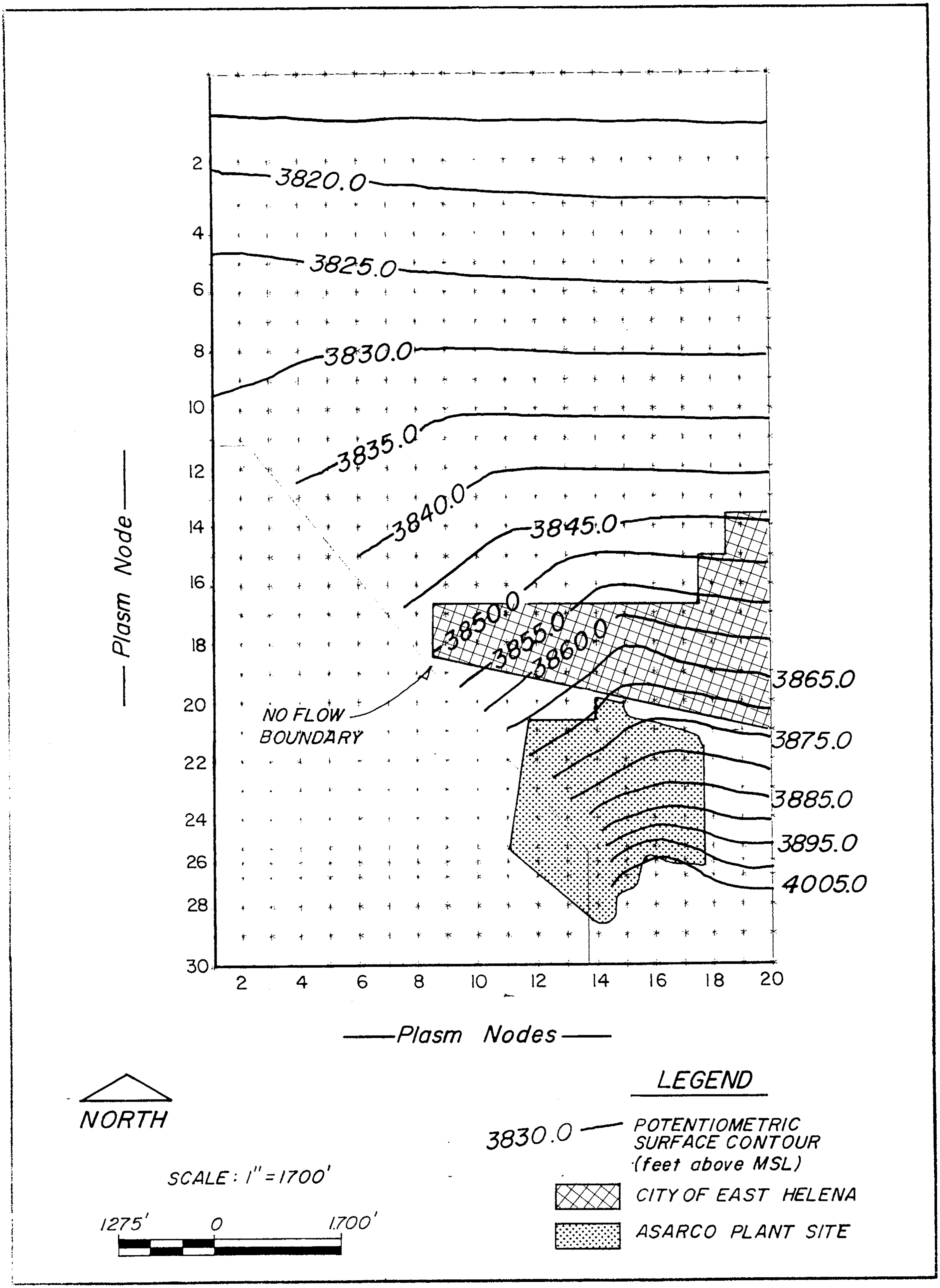


FIGURE 8-3-6. Simulated Steady State Groundwater Flow Field.

adjusted in a total of 13 model runs to produce the simulated results in Figure 8-3-6. A regression plot of actual verses simulated head (Figure 8-3-7) indicates there is a good correlation between the actual and simulated head data. A coefficient of determination (r^2) calculated for the regression plot (0.990214, Table 8-3-13) also indicates a good correlation exists between the actual and simulated head data.

A variance plot of the simulated head values (Figure 8-3-8) shows that 70% (or approximately two standard deviations) of the simulated heads are within two feet of the actual heads, and 95% of the simulated heads (or approximately one standard deviation) are within three feet of the actual heads. This indicates that the model was successful simulating heads within the anticipated two feet head accuracy threshold.

Comparison of the simulated aquifer test of well DH-17 with actual aquifer testing results helps determine the capability of the model to accurately simulate water level head data under transient conditions.

Results of the simulated drawdown at DH-17 were 2.02 feet in the pumping well (corrected for well drawdown) with no drawdown in adjacent nodes 400 feet away. These results are very similar to the actual DH-17 drawdown corrected for well inefficiency (1.8 feet) and a .02 foot drawdown approximately 400 feet away at DH-24. The simulated data indicate the model did an accurate job of simulating drawdown with the modeled input parameters and boundary conditions.

8.3.3.4 Solute Transport Modeling Goals, Input Parameters and Modeling Techniques

The goals of solute transport modeling were to approximate transport parameters, locate the contaminant source area(s), determine timing of intial arsenic loading, and predict future arsenic and sulfate transport if the source area is remediated. The initial step for solute transport modeling required that the simulated steady-state flow field was converted to a velocity vector field. This enabled simulated arsenic and sulfate concentrations to move in accordance to the modeled groundwater flow direction. Since a steady-state flow field was used for solute transport, change in head was assumed to be negligible during the simulation period.

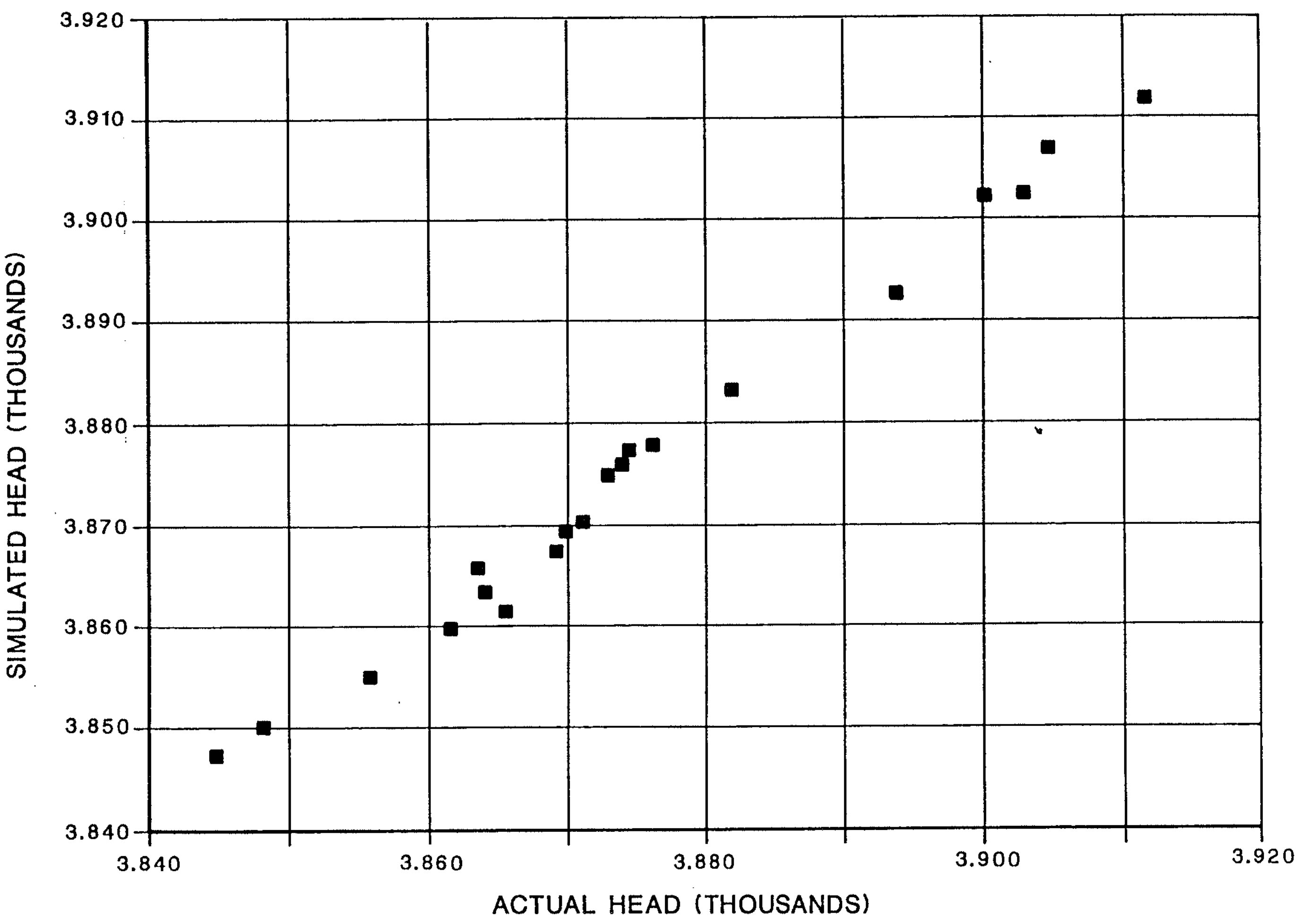


FIGURE 8-3-7.
Steady State Actual Versus Simulated Head Regression Plot

TABLE 8-3-13.

STEADY STATE MODEL STATISTICS

WELL SITE	ACTUAL HEAD	SIMULATED HEAD	DIFF.	NUM. OF POINTS
DH20	3911.73	3911.92	0.19	1
DH19	3900.11	3902.19	2.08	2
DH5	3904.68	3906.86	2.18	3
DH4	3902.96	3902.5	-0.46	4
DH11	3893.84	3892.68	-1.16	5
DH7	3876.14	3877.86	1.72	6
EH58	3869.17	3867.49	-1.68	7
DH9	3881.89	3883.23	1.34	8
DH8	3874.47	3877.39	2.92	9
DH17	3873.98	3875.89	1.91	10
DH6	3872.91	3874.96	2.05	11
EH52	3869.89	3869.5	-0.39	12
EH59	3865.54	3861.47	-4.07	13
DH1	3871.11	3870.36	-0.75	14
EH50	3861.57	3859.75	-1.82	15
EH60	3864.07	3863.4	-0.67	16
EH51	3863.55	3865.81	2.26	17
EH54	3855.8	3855.01	-0.79	18
EH57A	3848.22	3850.03	1.81	19
EH53	3844.82	3847.31	2.49	20

ACT. VS. SIM. HEAD

```
                 Regression Output:
Constant                                -23.0537
Std Err of Y Est                        1.921146
R Squared                               0.990214
No. of Observations                           20
Degrees of Freedom                            18

X Coefficient(s)   1.006067
Std Err of Coef.   0.023572
```

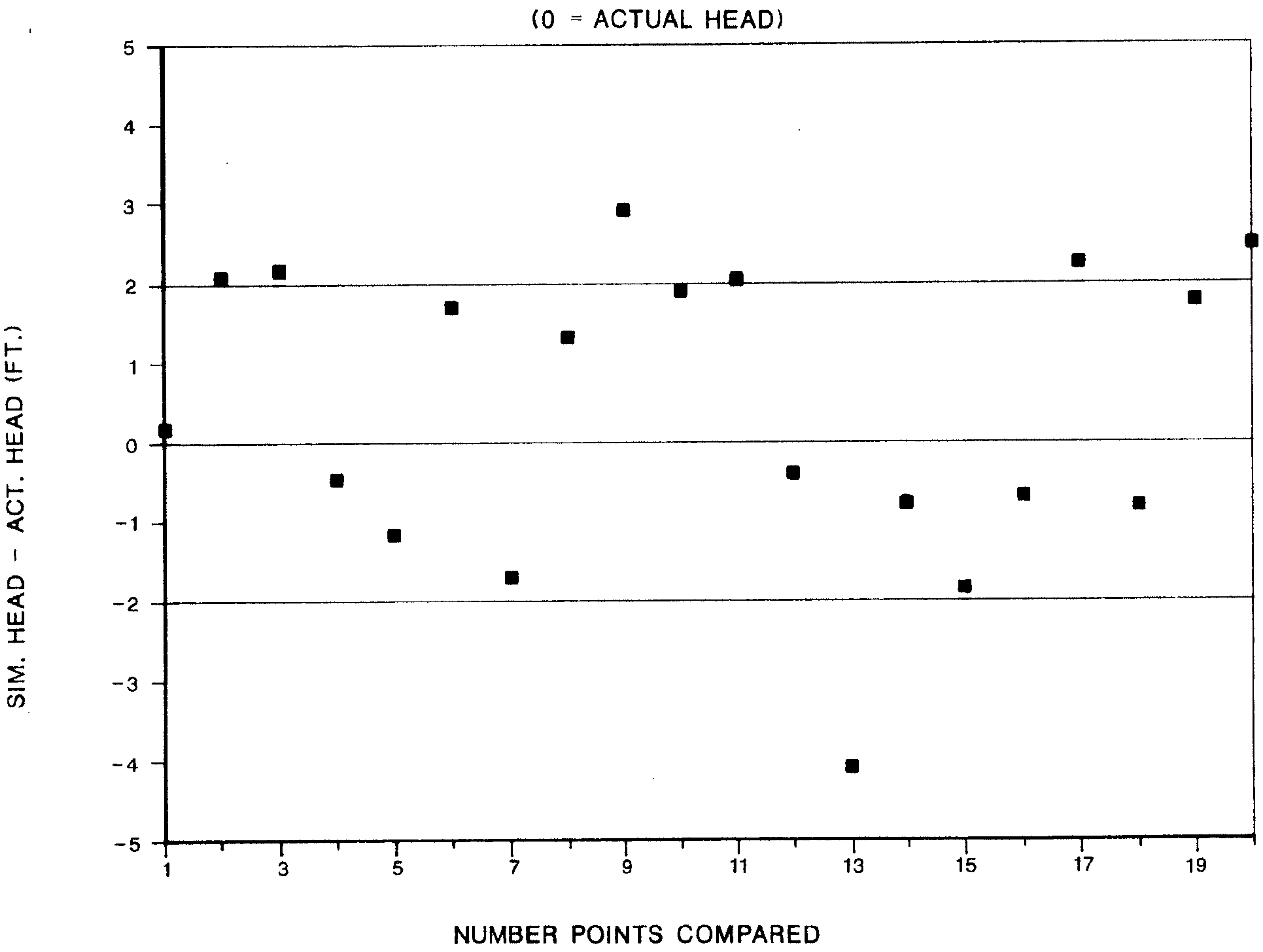


FIGURE 8-3-8.

Variance Plot of Simulated Head.

The purpose of simulating arsenic concentrations was to match the November 1987 plume shape and concentrations in the shallow aquifer (see Exhibit 6). The model was then used to predict movement of arsenic for 500 years after November 1987.

Chemical analyses indicate arsenic migrates at a slower rate compared to other constituents of groundwater degradation in the East Helena study area. As a comparison with arsenic, sulfate was modeled to simulate a dynamic constituent that migrates near the rate of groundwater flow velocity. Sulfate was chosen because it represents a constituent that is generally not retarded by chemical reactions, adsorption or other factors affecting arsenic concentration. Comparison of time required to simulate the November 1987 sulfate plume with the time needed to simulate the arsenic plume helps estimate arsenic retardation or apparent time differences of arsenic and sulfate migration rates.

The locations of simulated arsenic and sulfate loading were the plant site and Lower Lake. These source locations reflect actual contaminant loading areas that contribute arsenic and sulfate into the shallow aquifer. The plant site area (PLASM node {15,24}) is located at the drossing plant, and the speiss granulating pond and pit area. In the model, the speiss granulating pond and pit area were considered responsible for approximately 80% to 90% of the arsenic and sulfate concentrations in the shallow aquifer. The Lower Lake source area was modeled at PLASM nodes {15,27} through {17,27}.

The presence of arsenic and sulfate in the groundwater at the plant site is probably a result of contaminant loading into the shallow aquifer over an extended period of time. No data exist that indicate when loading began. It was assumed that contaminant loading could have occurred as recently as 15 years ago and as long ago as 100 years. Variability in annual arsenic (and sulfate) concentrations probably are a result, to some degree, of the amount of arsenic loaded into the groundwater. However, annual arsenic concentration changes were not modeled since initial simulations indicated that the different particle loading scenarios for arsenic and sulfate (including annual particle loading variability, yearly particle loading, or loading particles in five year increments) had no significant impacts on arsenic or sulfate concentrations for long-term simulations (25 to 75 years). Since short interval loading scenarios had no significant impact on the contaminant simulation, a particle loading scenario that input particles every 1000 days (2.74 years) was used in the arsenic solute transport simulation to decrease computer run time.

The number of particles representing plant site arsenic loading was modeled to be low, initially, and gradually increased to a maximum final arsenic load. The soil and aquifer capacity for absorbing arsenic were assumed to allow more arsenic into the aqueous system as time passed. Lower Lake arsenic loading was simulated to be the opposite of the plant site loading scenario, where more particles were loaded into the shallow aquifer in the initial loading period and less in the later part of the simulation. This scenario reflects higher arsenic concentration (200 mg/l vs. 20 mg/l) in Lower Lake prior to 1984 (see Process Pond RI/FS report). The number and timing of particles input into the model are presented in the solute transport modeling results section.

Model input parameters for the solute transport simulation describe how the contaminant will be disposed. Input parameters include: dispersivity (longitudinal and transverse), porosity (n), retardation and particle mass. No data were available on dispersivity values for the shallow aquifer. Values of dispersivity were estimated based on sediment type (sand and gravel) and on model scale. Dispersivity can be defined as "the measure of the number of aquifer hetrogeneites encountered by a contaminant moving through an aquifer". Since more aquifer hetrogeneites will be encountered by a contaminant moving a greater distance, a larger scale model uses a greater dispersivity values than a smaller scale model.

Based on spacial dependent dispersivity values and published dispersivity values for both modeled and calculated dispersivity in a sand and gravel aquifer (CRC Critical Review in Environmental Control, November 1979 pages 126 and 127), a dispersivity value of 300 feet in the longitudinal flow direction and five feet in the transverse flow direction were used. Other longitudinal dispersivity values, ranging from 20 to 350 feet, were simulated to cross check the selected values. The most accurate simulations were accomplished by using a longitudinal dispersivity of 300 feet and a transverse dispersivity of 5 feet.

A porosity value also was estimated. A value of 0.2 or 20% was selected which is a conservative estimate for a sand and gravel aquifer. A particle mass for the arsenic simulation (3000 lbs per particle) was selected so that the simulated concentrations approximated actual arsenic concentrations. Therefore, fewer particles would have to be input into the model, resulting in a reduction of model run time. A particle mass for the sulfate simulation (1500 lbs per particle) was selected so that the simulated concentrations approximated actual sulfate concentrations while limiting the number of particles to the capacity of available computer memory storage.

The model input parameters describe the physical aspects of the solute transport model. Timing of arsenic loading is the counterpart to these physical input parameters that dictate the fate and pathway of arsenic in the system.

The starting date of arsenic inputs to the groundwater system, and the rates of arsenic migration/retardation are unknown. The initiation of arsenic input to the groundwater system probably ranges from 15 years to 100 years ago. In addition, the arsenic (or sulfate) input rate(s) may be time dependent where variable shallow-aquifer loading occurred as a result of a varying source area(s) or arsenic capacity of the aquifer and soil.

Results of sequential extraction analyses (Sections 4.4.3 and 8.3.1) indicate several geochemical reactions, adsorption, ion exchange and other factors govern arsenic transport in the shallow aquifer. However, a combined retardation effect of the mechanisms affecting arsenic concentrations cannot be concluded from this data. Therefore, an RD factor (retardation) for Random-Walk could not be determined. For this reason, retardation and the time of initial contaminant input to the groundwater system was estimated to simulate a "worst case" scenario for potential arsenic transport.

A worst case scenario was defined for arsenic transport as a retardation parameter and initial timing of contaminant input that permits the most rapid movement of arsenic within constants of the known timing (15 to 100 years) and reasonable retardation rates (0 to 100 times slower than groundwater flow). This scenario assumes: 1) a more rapid moving arsenic plume will contaminate the shallow aquifer quicker than a slow moving plume, 2) arsenic in groundwater will not be as affected by retardation mechanisms which remove arsenic from the aqueous system and 3) arsenic, in the worst case scenario, will be more difficult to remediate since it is moving rapidly compared to a more retarded arsenic plume.

To determine the worst case arsenic transport scenario three different models were tested. A 15 year, 30 year and 55 year arsenic transport simulation was conducted using an appropriate RD factor to model the November 1987 arsenic plume. These three models indicate the likely initial contaminant input timing is approximately 25 to 35 years.

The 15 year simulation (RD = 16) matched the November 1987 plume. However, particles input into the model representing arsenic after 1987 moved too rapidly. This was inconsistant with water quality data collected in 1986 through 1989 which shows arsenic concentrations were relatively stable during these three years. The 15 year simulation suggested that RD must be larger in order to simulate the actual 1986 to 1989 arsenic concentrations.

Both a 25 to 35 year (RD = 30) simulation and 50 to 60 year (RD = 65) simulation yielded arsenic plumes that were similar to the November 1987 plume. However, the 50 to 60 year simulation was approximately 50% slower then the 25 to 35 year model. Both of the simulated plumes showed little variance in arsenic concentration in the last three to five years of the simulation, similar to the actual arsenic concentration data. An RD factor of 30 was selected since it 1) moved arsenic faster than the 50 to 60 year transport model, 2) simulated the actual plume shape/concentration, and 3) represented a worst case scenario of arsenic transport.

8.3.3.5 Solute Transport Modeling Results

The following discussion presents the simulated arsenic and sulfate results in addition to a 500 year arsenic transport simulation. Arsenic and sulfate were transported in accordance with the steady-state groundwater flow field to predict future transport characteristics.

Results of the 31 year "worst case scenario" arsenic transport simulation with a retardation factor of 30 is shown in Figure 8-3-9 (and Appendix 2). The simulated arsenic plot shows the same general shape as the November 1987 plume (Exhibit 6). The simulated arsenic concentrations compare well with the actual arsenic concentration data at some monitoring well locations, but concentrations compare less well at other monitoring well sites (Table 8-3-14). Differences in actual and simulated arsenic concentrations are attributed to the following:

1) Modeling a three dimensional problem in two dimensions. Random-Walk assumes arsenic concentration is evenly distributed throughout the entire aquifer thickness.

2) The flow field was calibrated within a two feet error tolerance of actual groundwater elevations which may be insufficient to accurately move particles through the solute transport model.

3) Nodal scale in the model may be too large to accurately simulate head without creating a "blocky" velocity vector field to move particles in Random-Walk.

4) The flow field model is simplistic in describing the geologic system. Actual aquifer geology is complicated with variable K in two and three dimensions.

5) Solute modeling input parameters may not adequately simulate actual complicated aquifer conditions.

6) Inability to model chemical reactions including arsenic precipitation, soil and aquifer arsenic sorbtion capacity, and other parameters that remove arsenic from the aqueous system.

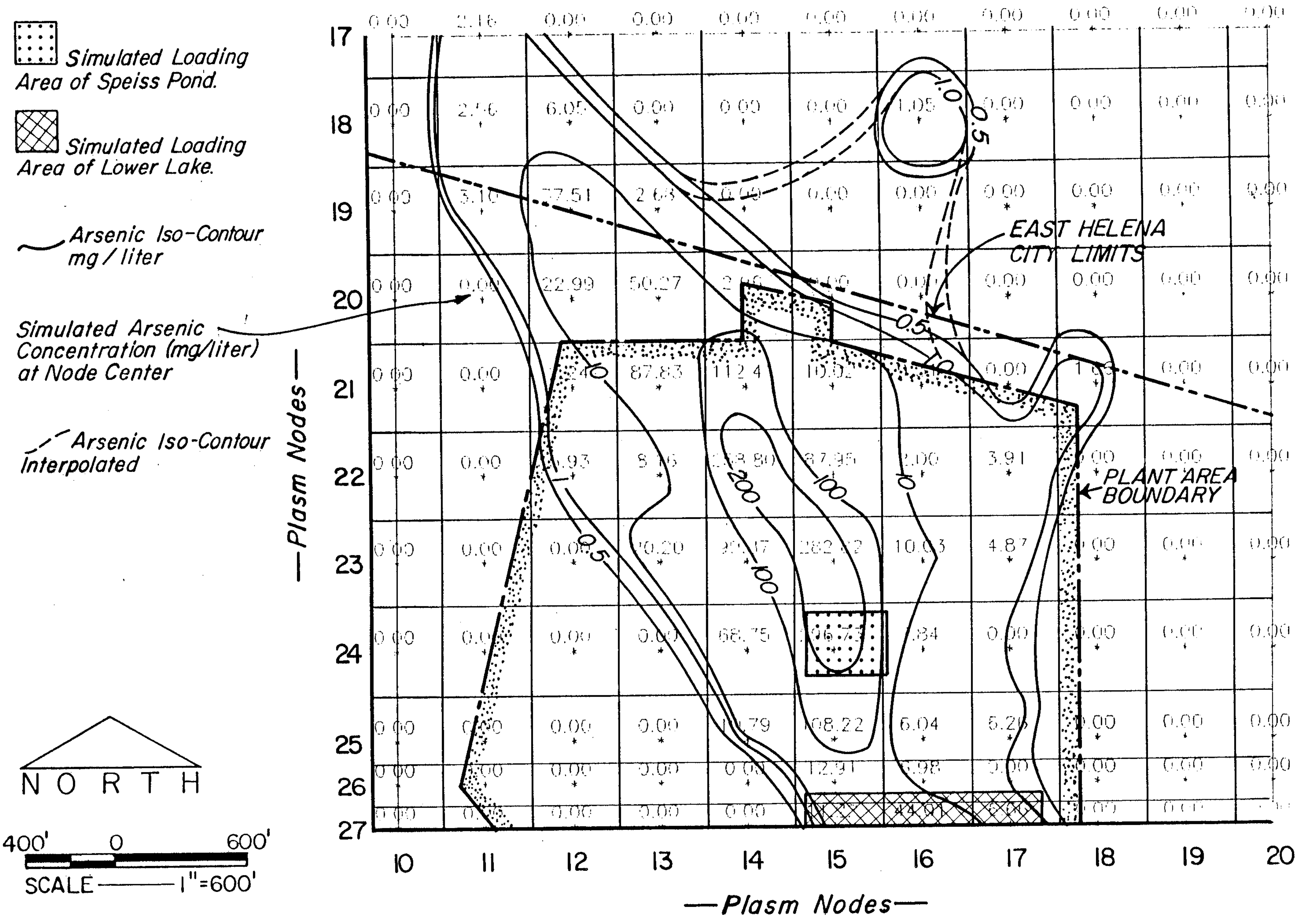


Figure 8-3-9. Simulation of Arsenic Transfer at 31 Years.

TABLE 8-3-14. ACTUAL ARSENIC CONCENTRATION VERSUS SIMULATED ARSENIC CONCENTRATION

(Arsenic is estimated if nodes are not located on a well site)

Well Site	Actual Arsenic (mg/l)	Simulated Arsenic (mg/l)
DH-20	0.12	6
DH-4	4.4	6
DH-29	19.0	19
DH-19	99.0	11
DH-8	8.0	0
DH-27	50.0	60
DH-26	72.5	40
DH-21	750.0	297
DH-12	185.0	100
DH-9	4.5	283
DH-23	3.0	297
DH-16	116.0	259
DH-1	0.01	6
DH-24	81.3	88
DH-10	5.25	9
DH-6	4.9	10
DH-7	<0.006	0
DH-8	0.035	20
DH-5	0.4	7
EH-60	1.3	2
EH-50	<0.006	1
EH-62	0.052	0
EH-53	0.023	0
EH-51	0.49	0
EH-52	1.5	0

The total of 660 particles were input to groundwater in the 31 year arsenic migration simulation (Table 8-3-15). Four particles were lost to Prickly Pear Creek. Each particle constitutes 3,000 pounds of arsenic which is equivalent to 1,980,000 pounds of arsenic loaded into the shallow aquifer over 31 years or 175 pounds of arsenic loaded into the aquifers per day.

TABLE 8-3-15. NUMBER AND TIMING OF PARTICLE INPUT

Time Accum.	Time Simulation	#Parcl. L. Lake	#Parcl. P. Site	Total Parcl.	Part.Lost In PPC
0 days	1000 days	15	20	35	0
1000	1000	10	20	30	0
2000	1000	10	40	50	0
3000	1000	12	40	52	0
4000	1000	12	40	52	1
5000	1000	8	60	68	1
6000	1000	3	60	63	0
7000	1000	8	60	68	0
8000	1125	8	70	78	0
9125	1000	3	70	73	1
10125	825	1	90	91	1
10900	365	-	-	-	0
11315	31 yrs	90	570	660	4

The actual poundage of arsenic loaded into the shallow aquifer can be estimated by assuming the contaminated aquifer is 1,500 feet wide at the plant site (Exhibit 6), 20 feet thick, has a porosity equal to 0.20, a groundwater velocity equal to 7.5 feet per day, and an average arsenic concentration of 35 mg/l. Using these data, a calculated 5.399×10^7 mg of arsenic is moving through the aquifer per day. The simulated arsenic load per day converted into mg of arsenic per day is equal to 1.89×10^7 mg. The model loads 1.4 times as much arsenic compared to the calculated arsenic load per day, indicating the model is a good representation of actual arsenic loading.

Assuming sources of arsenic to the groundwater system are remediated, and no additional loading occurs after 31 years, arsenic migration was simulated for an additional 500 year time period. Since sources were assumed to be remediated, no new particles were loaded into the model. Figure 8-3-10 shows simulated arsenic concentration changes for two monitoring well sites (DH-24 and EH-60), and for a node location on the northwest corner of East Helena. Appendix 8-1 shows arsenic concentration change at all model nodes in 100 year increments.

The 500 year simulation indicates arsenic concentration for wells DH-24 and EH-60 would peak at 90 to 110 mg/l 20 years from 1987. Concentrations in both wells are predicted to steadily decrease to less then one mg/l in 120 years for DH-24, and in 180 years for EH-60. The simulation predicts arsenic concentrations in groundwater in northwest East Helena peaks at 33 mg/l at 80 years after 1987, and steadily decreases to less than 1 mg/l 220 to 300 years after 1987.

The 500 year simulation is a worst case scenario only. There are no groundwater modeling mechanisms that can accurately simulate the removal of arsenic from the aqueous systems by coprecipitation and sorption and ion exchange which is apparently occurring in the East Helena groundwater system (see Section 8.3.1). If the sources of arsenic are remediated and the existing subsurface environment remains constant, it is unlikely that the arsenic plume will migrate beyond its current extent. Thus the model simulated increases in arsenic concentration in East Helena are not likely to occur.

A 1.25 year sulfate transport simulation was also modeled (Figure 8-3-11 and Appendix 4). The simulation was conducted assuming sulfate migration is essentially not retarded. Particle input for sulfate concentrations were modeled to match the 1987 sulfate plume concentrations and extent of 1987 arsenic migration. A comparison of the arsenic and sulfate simulation indicate that modeled arsenic migration is 25 times slower than migration of sulfate.

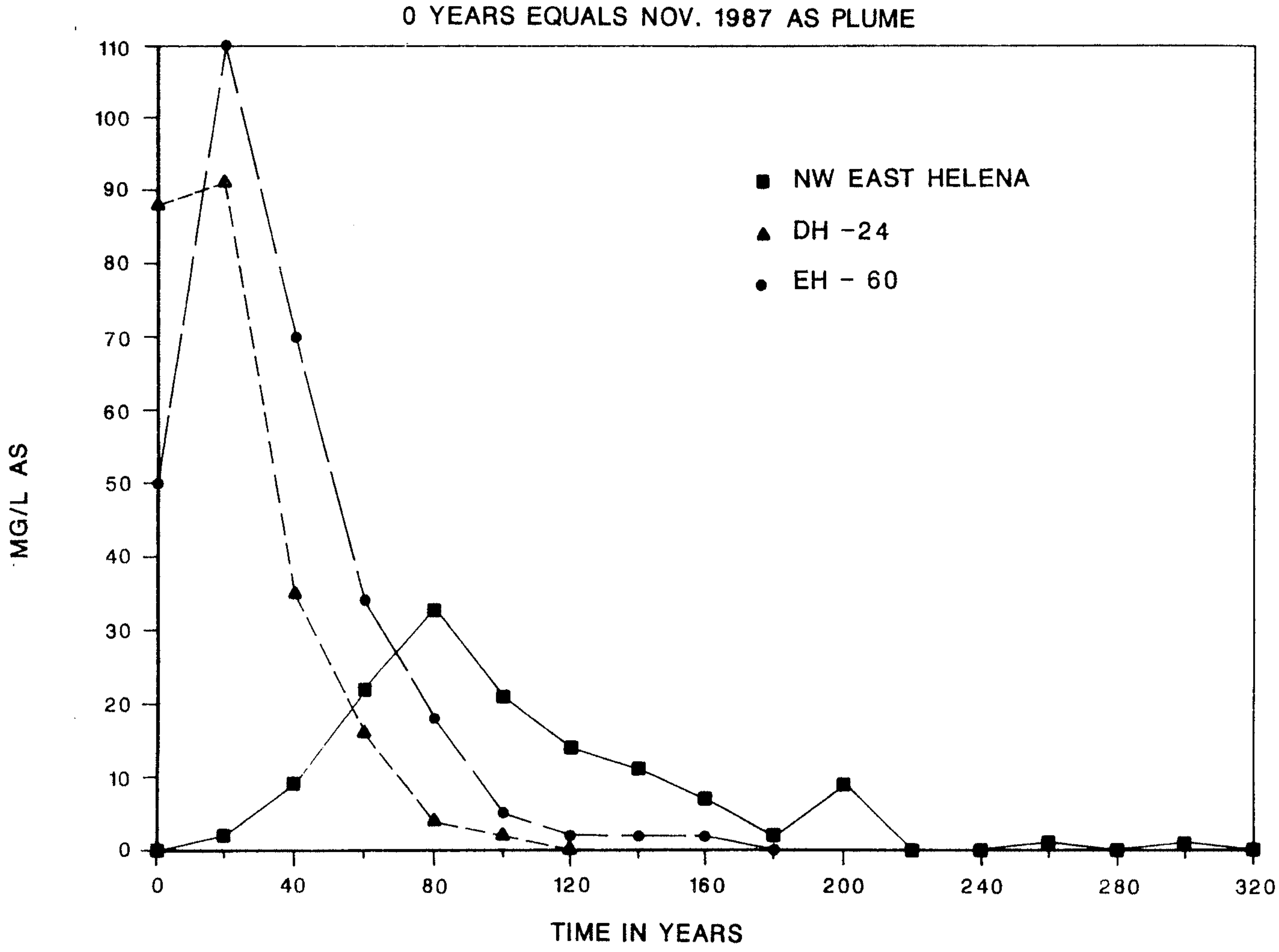


FIGURE 8-3-10.
Simulation of Arsenic Transport at 500 Years.

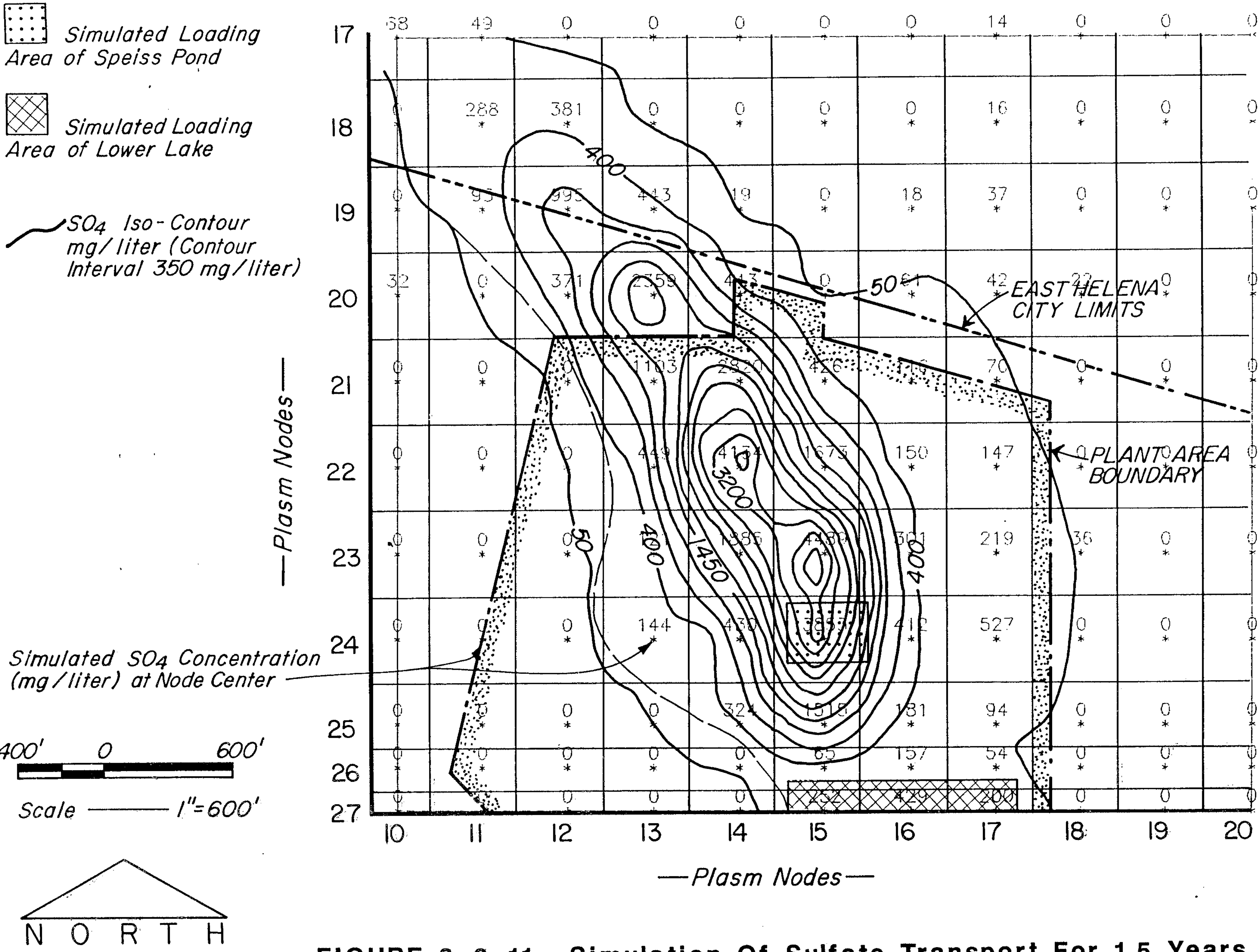


FIGURE 8-3-11. Simulation Of Sulfate Transport For 1.5 Years