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**GROUND-WATER/SURFACE-WATER
INVESTIGATION PLAN**

**PHASE 2 REMEDIAL INVESTIGATION
DRAFT REPORT**

VOLUME I of III

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Prepared for:

**Industri-Plex Site Remedial Trust
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**GROUND-WATER/SURFACE-WATER INVESTIGATION PLAN
PHASE 2 REMEDIAL INVESTIGATION DRAFT REPORT**

EXECUTIVE SUMMARY

Phase 2 of the Ground-Water/Surface-Water Investigation Plan (GSIP) Remedial Investigation (RI) was performed by Roux Associates, Inc., Environmental Science and Engineering, Inc. and PTI Environmental Services for the Industri-Plex Site Remedial Trust (ISRT) from September 1991 through May 1992. The GSIP Phase 2 RI was performed according to the procedures outlined in the July 1, 1991 work plan titled "Work Plan for the Ground-Water/Surface-Water Investigation, Phase 2 Remedial Investigation" (Roux Associates, Inc., July 1, 1991).

Phase 2 of the GSIP RI is designed to fill data gaps identified during the performance of the GSIP Phase 1 RI. The GSIP Phase 2 RI objectives are to:

- further characterize ground-water flow conditions and ground-water quality in selected areas of the Site;
- test the geochemical paradigm developed during the Phase 1 metals mobility study;
- collect additional data for purposes of characterizing the geochemical nature and extent of sediments within the Hall's Brook Holding Area (HBHA) pond; and
- evaluate ecological risks associated with the sediments within the HBHA.

Results of the GSIP Phase 2 RI are provided below.

Ground Water

Task G-1. Extent of Benzene at the West Hide Pile

Five piezometer well points (i.e., WP-1 through WP-5) were installed around the perimeter of the West Hide Pile to better define the extent of benzene previously identified as Observation Well OW-31 (Plate 1). Ground-water quality data developed from these new piezometers and existing observation wells show that benzene concentrations in ground water immediately around the West Hide Pile are limited to a small area along the northeastern perimeter of the West Hide Pile in the vicinity of Observation Well OW-31.

This localized area of ground water containing benzene concentrations appears to discharge into the adjoining surface-water body (Lower South Pond), based on ground-water flow patterns which show ground water flowing eastward from the West Hide Pile into the Lower South Pond. Additionally, benzene concentrations are not found immediately downgradient (southward) from the West Hide Pile, with the exception of 2 µg/L of benzene detected at Piezometer WP-5. It is noted that benzene was detected at OW-43 (518 µg/L), located 500 feet southeastward from the West Hide Pile. However, due to the absence of benzene immediately downgradient of the West Hide Pile, this hide pile does not appear to be the source of this detection.

Task G-2. Evaluation of Underflow at the HBHA

Two additional observation well clusters were installed and monitored (i.e., collection of ground-water samples and water-level measurements) to determine if ground water is flowing beneath (underflow) the HBHA. The results of the GSIP Phase 2 RI indicate that ground-water flow beneath the northern end of the HBHA pond is not occurring. Rather, shallow and deeper ground water is shown to be flowing toward the HBHA and discharging into the HBHA. This conclusion is based on:

- ground-water flow patterns in the shallow and deep unconsolidated deposits around the northern end of HBHA (on the east and west sides) which show ground water flowing laterally and vertically toward the HBHA;
- seepage meter data collected during the HBHA pond geochemical investigation which demonstrate that ground water beneath the base of both the southern and northern end of HBHA pond is flowing upward and discharging into the pond; and
- ground-water samples collected during the GSIP Phase 2 RI which reveal that arsenic was not present (not detected) in OW-30A and OW-30B, located on the western side of the HBHA pond.

Although ground water is not flowing beneath the northern end of the HBHA pond, underflow/dispersion may be occurring further southward in the central portion of the HBHA, where the unconsolidated aquifer thickens and widens. This conclusion is consistent with the results of the HBHA pond sediment geochemical investigation, which indicate that the axis of the arsenic plume intersects the HBHA in the central portion of the pond.

It is important to note that the lateral extent of the unconsolidated aquifer on the west side of the HBHA is limited, due to the presence of the adjoining bedrock high. Therefore, any arsenic-impacted ground water on the western side of the HBHA will be directed eastward/southeastward back toward the HBHA and will discharge into the HBHA.

Task G-3. Unconsolidated Deposits/Bedrock Interaction

The objective of this task was to evaluate the potential interaction of ground water between the unconsolidated deposits and the underlying crystalline bedrock. The results of Task G-3 indicate that due to the low hydraulic conductivity of the crystalline bedrock observed at three of the four bedrock observation well locations investigated during the GSIP Phase 2 RI, the crystalline bedrock does not appear to be a pathway for the transport of organic and inorganic constituents, except at Observation Well OW-55.

At two locations (i.e., OW-37 and OW-9 well clusters) ground-water recharge into bedrock pilot boreholes was extremely slow. This information indicates that the bedrock at these two locations exhibits an extremely low hydraulic conductivity. Also, no appreciable secondary porosity appears to be present. Due to this condition, the United States Environmental Protection Agency (USEPA) agreed to discontinue the bedrock investigations at these locations. Therefore, observation wells were not installed and ground-water sampling was not performed. Pilot bedrock boreholes were sealed in February 1991 according to Massachusetts guidelines.

Similar hydraulic conditions were observed at bedrock Observation Well OW-57, installed as part of Task G-2. The extremely slow recharge of ground water into OW-57 precluded the collection of a representative ground-water sample from this bedrock well.

The only bedrock well installed during the GSIP Phase 2 RI that recharged sufficiently enough to enable the collection of ground-water quality data and water-level information over time was at Observation Well OW-55, installed as part of Task G-2. At this location, a consistent downward flow gradient was observed between the bedrock and the overlying basal and unconsolidated deposits. Vertical gradients ranged between 0.0084 ft/ft and 0.0334 ft/ft.

Volatile organic compounds (VOCs) were detected in the ground-water samples collected from OW-55. Dissolved arsenic and dissolved chromium were also detected at concentrations of 193 mg/L and 122 µg/L, respectively.

A comparison of ground-water quality data between the bedrock well (OW-55) and the three adjacent overburden wells yields the following observations:

- Similar VOCs were detected in the adjoining basal unconsolidated deposits observation well (OW-54C). Concentrations of these VOCs were lower in OW-54C than in bedrock well OW-55.
- More VOCs were encountered at depth (i.e., in bedrock well OW-55 and basal unconsolidated deposits well OW-54C) than in shallower ground water (i.e., OW-54A and OW-54B).
- Concentrations of dissolved arsenic increased with depth in the unconsolidated deposits (from not detected [OW-54A] to 949 µg/L [OW-54C], but were lower in the bedrock (193 µg/L at OW-55).
- Concentrations of dissolved chromium also increased with depth in the unconsolidated (from not detected [OW-54A] to 145 µg/L [OW-54C], but were lower in the bedrock (122 µg/L at OW-55).

Surface Water/Stream Sediments

Surface-Water Quality

Six new sampling locations (i.e., SW-18, SW-19, SW-21, SW-22, SW-23 and SW-24) were established and sampled to supplement data collected from the 17 locations sampled during the GSIP Phase 1 RI.

GSIP Phase 2 RI surface-water sampling results indicate that VOCs were detected at the two upstream/off-site surface-water sampling locations (i.e., SW-18 and SW-19), and at three surface-water sampling locations downstream of the HBHA pond (i.e., SW-21, SW-22 and SW-23). These components and their ranges are:

- toluene (not detected to 130 µg/L);
- trichloroethene (1 µg/L to 11 µg/L);
- 1,2-dichloroethene (not detected to 11 µg/L);
- xylenes (not detected to 7 µg/L);

- 1,1-dichloroethane (not detected to 2 $\mu\text{g/L}$);
- 4-methyl-2-pentanone (not detected to 2 $\mu\text{g/L}$); and
- ethylbenzene (not detected to 1 $\mu\text{g/L}$).

Surface water collected at SW-18, located upstream/off-site in the New Boston Street Drainway contained the most VOCs detected, as well as the highest concentrations. Downstream of the HBHA pond in Hall's Brook only very low concentrations of a few VOCs were detected.

The distribution of arsenic, chromium, and lead detected during the GSIP Phase 2 RI sampling round indicate that:

- total arsenic concentrations ranged from not detected (SW-19) to 14.6 $\mu\text{g/L}$ (SW-21), with generally higher concentrations of arsenic detected in Hall's Brook downstream of the HBHA pond;
- total chromium concentrations ranged from 8.6 $\mu\text{g/L}$ (SW-24) to 195 $\mu\text{g/L}$ (SW-18), with the highest concentrations detected in the off-site/upstream surface water sample (SW-18) collected from the New Boston Street Drainway; and
- total lead was not detected in any of the surface-water samples.

Stream-Sediment Quality

VOCs and semi-volatile organic compounds (SVOCs) were detected in all six sediment samples collected during the GSIP Phase 2 RI sampling round. SVOCs detected were principally polycyclic aromatic hydrocarbons (PAHs).

VOCs detected included acetone, 2-butanone, chlorobenzene, 1,2-dichloroethene, ethylbenzene, toluene and vinyl chloride. Two of the seven VOCs detected in stream sediments were detected in both upstream/off-site samples as well as in sediment samples collected downstream of the HBHA pond. These components and their detected ranges are acetone (110 $\mu\text{g/kg}$ to 2,200 $\mu\text{g/kg}$) and 2-butanone (31 $\mu\text{g/kg}$ to 550 $\mu\text{g/kg}$). There appears to be no correlation between VOCs detected in surface water and VOCs detected in sediment at each respective sampling location.

SVOCs were detected at the upstream/off-site locations (i.e., SED-18 and SED-19 collected at SW-18 and SW-19, respectively) as well as sediment samples collected downstream of the HBHA pond. It is noted that the highest concentration of the SVOCs detected was 2,200,000 $\mu\text{g}/\text{kg}$ detected in SED-18 (upstream/off-site location SW-18).

The distribution of arsenic, chromium, and lead detected in stream sediment during the GSIP Phase 2 RI sampling round indicate that:

- the distribution of chromium in stream sediment shows no pattern, with the concentrations ranging from 116 mg/kg in SED-24, to 2,180 mg/kg in SED-23 (collected at SW-24 and SW-23, respectively);
- arsenic concentrations ranged from 4.1 mg/kg in SED-19, to 1,380 mg/kg in SED-22 (collected at SW-19 and SW-22, respectively), with the greatest concentrations of arsenic detected in Hall's Brook downstream of the HBHA pond; and
- lead concentrations ranged from 25.3 mg/kg in SED-19, to 452 mg/kg in SED-22, with the highest concentrations of lead detected in stream sediment in Hall's Brook downstream of the HBHA pond (SED-22).

Normalization of the stream-sediment quality data developed during the GSIP Phase 2 RI to account for variability in sediment grain size indicates that higher concentrations of arsenic, chromium and lead were seen in finer-grained sediments. The exception is SED-23 (collected at SW-23), a coarser-grained sample that yielded anomalously higher concentrations of these constituents.

Task S-2. Sediment Volume and Geochemical Investigation Within the HBHA Pond

The objectives of the HBHA pond sediment geochemical investigation were to determine the volume of affected sediment in the HBHA pond, determine the rate of ground-water recharge in the HBHA pond, and examine the geochemistry of the HBHA pond sediment-pore water system.

Physical characteristics of the HBHA pond are:

- the maximum water depth was 13.7 feet;
- total volume of water in the pond is approximately 1,400,000 cubic feet (39,000 cubic meters);

- two distinct types of sediment were encountered: an upper layer of black, fine-grained ooze consisting of water, silt and clay, and an underlying well-sorted tan sand;
- total volume of sediment (ooze and sand) is approximately 29,000 cubic yards (22,000 cubic meters); and
- the volume of black ooze is approximately 9,700 cubic yards (7,400 cubic meters).

Ground-water discharge was estimated by placing one seepage meter in three areas of the HBHA pond. Based on the seepage meter data, the calculated average total ground-water discharge rate is approximately 720 cubic feet per day. The retention time of ground water in the upper 1.4 feet of sediment (ooze) ranges between 170 and 1,800 days.

The geochemical conditions in the ooze and sand are pH neutral and moderately reducing as evidence by the presence of aqueous sulfide, As(III), Cr(III) and Fe(II). As previously discussed, arsenic and chromium in ground water are discharging to the Central Area of the HBHA pond. These data also indicate that benzene in ground water is discharging into the northern portion of the HBHA pond. The HBHA pond sediments act as a sink for these constituents by filtering metals out of recharging ground water, based on the high sorptive capacity (Kd) values for arsenic, chromium and lead, and the precipitation of lead sulfides. Pore water benzene concentrations are reduced by partitioning into organic carbon and perhaps also by biodegradation by the viable microbial community.

Metals Mobility Study

The results of the GSIP Phase 2 RI metals mobility study support the Industri-Plex geochemical paradigm, which was developed to explain metal distribution in soils, ground water and surface water at the Site. As the paradigm proposed, methylated arsenic was found in the reduced ground waters downgradient from the East-Central Hide Pile. However, the paradigm should be modified to reflect that the zone of arsenic methylation was limited to the area where sulfide was present above 1 mg/L in the ground water. Similarly, the hypothesis that dissolved chromium in the ground water was present as organically complexed Cr(III) was verified at the Industri-Plex Site by analyzing the ground waters for Cr(VI) and organically complexed Cr(III) separately. Analysis of the dissolved organic material, however, demonstrated that the majority of the aqueous ligands were

complex organic acids with more than five carbons, rather than acetate or other simple organic acids originally theorized. In addition, two important additions should be made to the paradigm: 1) the presence of ground-water zones with over 1 mg/L sulfide downgradient from the hide piles are keeping metals such as iron, zinc, and lead from migrating due to precipitation of sulfides (i.e., FeS, ZnS, and PbS); and 2) the ground-water redox conditions may be divided into three distinct zones—extremely reducing, reducing, and oxidizing—with arsenic most mobile in the extremely reducing zones due to methylation, less mobile in the reducing zone due to adsorption to minerals, and highly attenuated in the oxidizing zone due to adsorption to iron oxide precipitates.

Ground water downgradient from the East, West and East-Central Hide Piles is strongly reducing due to decomposition of remnant hide pile material. Consequently, ground waters interacting with these piles contain DO concentrations of less than 1 mg/L, aqueous sulfide above 1 mg/L (Figure 32), and DOC above 700 mg/L (Figure 37). In contrast, more oxidizing conditions exist across the remainder of the Site, with Eh potentials above zero (Figure 34) and dissolved oxygen above 1 mg/L. As ground water flows from reducing to oxidizing zones, geochemical reactions occur that limit the mobility of dissolved metals leached as precipitation infiltrates through impacted soils and hide material.

The presence of volatile, reduced sulfur compounds directly beneath the hide piles is indicative of anaerobic, reducing conditions. For example, in the East-Central Hide Pile, hydrogen sulfide (H₂S) and methylmercaptan (CH₃HS) gas were measured at up to 21,000 parts per million (ppm) and 500 ppm, respectively, with 250 ppm H₂S in the West Hide Pile and a sulfide odor recorded in the East Hide Pile (Roux Associates, Inc., 1984). The fact that the highest sulfide concentrations are found in the East-Central Hide Pile may be due to the water-table mound beneath the hide pile limiting oxygen transfer, as this hide pile has been interred the longest.

Breakdown of the hides has also resulted in the generation of organic acids. Ground water intersecting the East-Central Hide Pile has been affected by these conditions, resulting in the transport of reducing, high-DOC (i.e., > 100 mg/L) waters downgradient of the hide pile. The presence of dissolved organic acid anions may be important, because they form aqueous complexes with metal cations, thereby increasing metal solubility and mobility. In

addition, DOC may act as a source of nutrients for facultative bacteria, which are capable of biochemically methylating inorganic arsenic compounds (Rai et al., 1984) and in aerobic environments, degrade benzene (Chiang et al., 1989).

Based on the chromium ground-water speciation data, the anoxic conditions also result in reduction of remnant Cr(VI) to Cr(III), which should co-precipitate with iron to form the sparingly soluble $\text{Cr}_{0.25}\text{Fe}_{0.75}(\text{OH})_3$ or, in the absence of iron, amorphous $\text{Cr}(\text{OH})_3$. Once reduced, Cr(III) is unlikely to re-oxidize to Cr(VI), even when oxygen is present, due to kinetic limitations (Bartlett and Kimble, 1976a and 1976b; Bartlett and James, 1979). Iron hydroxide also provides a source of surface sites for sorption of metal cations, following the selectivity sequence $\text{Cr}(\text{III}) > \text{Pb} > \text{Cu} > \text{Zn} > \text{Cd} > \text{Mg}$ (Kinniburgh et al., 1976; Leckie et al., 1980).

However, despite theoretical solubility constraints, chromium is migrating in ground water (Figure 46). For example, based on the transport of chloride, a conservative tracer in ground water, there appears to be negligible attenuation of chromium between wells OW-16 and OW-12 as the Cl:Cr ration remains constant (≈ 0.24) in both wells. The migration of chromium is thus postulated to be a result of aqueous organic complexation of Cr(III) by carboxylate anions, which is consistent with the geochemical paradigm. The general absence of base metals (e.g., lead) in ground water is attributed to sorption of these metals in the oxidized vadose zone or to precipitation by sulfide in reducing environments.

Ecological Assessment

The purpose of the GSIP Phase 2 ecological assessment was to qualitatively and/or quantitatively appraise the actual or potential hazard that the Site might present to wildlife.

Sediment Bioassay

The purpose of the bioassay was to sample sediment from locations upstream and downstream of the Site, observe the response of laboratory reared macroinvertebrates to each individual sample under constant environmental conditions, and evaluate if an impact may exist. The results of this sediment bioassay show that the most severe affect was seen in SED-18, a background (upstream sample) in which 100 percent mortality was observed for both of the test organism populations. Also of interest were affects seen in the tests

conducted on SED-19, another upstream sample. Test end points for this sediment were also relatively low for both *H. azteca* (62 percent survival; measurable decrease in reproduction) and *C. tentans* (77 percent survival). Of the samples collected in the HBHA (Wetland 5), and behind the Woburn Mall (Wetland 4B), only SED-21 showed a measurable effect (a significant decrease in reproduction of *H. azteca*). Because adverse effects were seen with samples taken from the upstream reference stations (SED-18 and SED-19), it is impossible to conclude if the response to sample SED-21 is a direct result of Site-related constituents.

Fish Sampling Survey

Fish were sampled in Phillips Pond (PP) and the HBHA for the purpose of comparing tissue concentrations of metals and SVOCs. An attempt was made to collect individuals from three trophic levels: forager, bottom feeder, and predator.

There appear to be no differences in fillet metal concentrations when comparing samples taken from the HBHA and PP. Positive detections for arsenic and lead were within "normal" ranges cited in the literature for muscle tissue. Mercury was detected twice in the HBHA and four times in PP. Metal concentrations in offal, with the exception of BF/005 in the HBHA and BF/001 in PP, were also within normal tissue concentration ranges (the excursions seen with the latter two samples may be a result of the presence of sediment in the gut, as gut contents were not irrigated prior to processing).

It appears that the concentration of arsenic in the tissue samples taken from the HBHA may be greater than PP. Arsenic in fish tissue, however: 1) usually complexes as an organic species (e.g., arsenobetaine), which is known to be significantly less toxic than the inorganic form (ATSDR, 1987); and 2) is widely recognized that the metalloid does not biomagnify through the food chain. Arsenic, therefore, is not considered a threat to local wildlife.

The concentrations of chromium and lead generally appear to be comparable between the two ponds.

Assessment of Hazards to Semiaquatic Receptors

The purpose of this task was to evaluate the real or potential hazard that constituents of concern (COC) in surface water and sediment may pose to wetland dependant birds (e.g., ducks and geese). The assessment of hazards to semiaquatic receptors adopted the mallard duck as the representative indicator species, and evaluates the potential impact of arsenic, chromium, and lead following the ingestion of Site-related sediments.

Using exposure and toxicity information derived from the available literature, it appears that the Site-related sediments pose no significant hazard to the mallard duck which is considered to be the most representative indicator species. The exposure scenario, the ingestion of sediment during feeding or to obtain grit, was highly conservative in that it assumed that:

1. the duck(s) reside at the Site for 3 months/year;
2. each duck consumes sediment at the highest rate observed in the wild; and
3. the availability of these metals in the gut is much higher than solubility limits observed in previous tests of soils taken from the Site.

Despite the conservatism built into the exposure scenario, hazard quotients never exceeded one. Additive affects, which would not be anticipated given the mechanism of toxicity for each COC, were also less than one.

1.0 INTRODUCTION

Phase 2 of the Ground-Water/Surface-Water Investigation Plan (GSIP) Remedial Investigation (RI) was initiated by Roux Associates, Inc. (Roux Associates), Environmental Science and Engineering, Inc. (ESE), and PTI Environmental Services (PTI) for the Industri-Plex Site Remedial Trust (ISRT) in September 1991 and completed during May 1992. The GSIP RI was performed according to the procedures outlined in the July 1, 1991 GSIP Phase 2 RI Work Plan titled "Work Plan for the Ground-Water/Surface-Water Investigation Plan, Phase 2 Remedial Investigation" (Roux Associates, Inc., 1991b) and amended in the August 14, 1991 letter from Roux Associates to W. Smull (Roux Associates, Inc., 1991c). The August 14, 1991 letter addressed to United States Environmental Protection Agency (USEPA) comments on the GSIP Phase 2 RI Work Plan and modified the Work Plan to include the installation and sampling of additional bedrock wells.

The GSIP RI fulfills a major requirement of the Consent Decree (CD) between the USEPA and the ISRT. The CD was negotiated and executed by the parties involved (USEPA, the Commonwealth of Massachusetts, and the Settlers) in order to avoid protracted litigation (United States District Court, 1989). The work to be implemented under the CD will provide for containment and/or treatment of hazardous substances in the soils, air, and ground water at the Industri-Plex Site in a manner consistent with the Record of Decision (ROD). The Consent Decree provides for the responsible parties to assume the costs of the present remedial activities, and also provides for the financing of any necessary future remedial activities.

The GSIP RI was performed in response to Sections 106 and 107 of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 42 U.S.C. ss 9606, 9607, and Section 7003 of the Solid Waste Disposal Act (SWDA) 42 U.S.C. ss 6937; and the Massachusetts Oil and Hazardous Material Release Prevention and Response Act, G.L. c. 21C, the Massachusetts Clean Water Act, Massachusetts G.L. c. ss 27 (14), and the Massachusetts Solid Waste Management Act, G.L. c. 21H. The USEPA, the Commonwealth of Massachusetts, and the ISRT entered into the CD under the requirements of Section 122 (d) (2) of CERCLA and 28 C.F.R. ss 50.7.

The GSIP RI Study Area is located approximately 10 miles north of Boston, Massachusetts. The Study Area encompasses the 245-acre Industri-Plex Site (Site) and contiguous areas shown in Figure 1.

1.1 Purpose of the GSIP Phase 2 RI Report

The purpose of this report is to present the results of the GSIP Phase 2 RI. The GSIP Phase 2 RI report is organized in a similar format to the GSIP Phase 2 RI Work Plan. Results of the additional ground-water and surface-water/stream-sediment investigations are presented in Sections 2.1 and 2.2, respectively. The Halls Brook Holding Area (HBHA) sediment geochemical investigation is provided in Section 2.3. The metals mobility study is provided in Section 2.4, and the ecological assessment is provided in Section 2.5. A summary of the GSIP Phase 2 RI results and conclusions relative to the objectives of the GSIP RI are provided in Section 3.0.

All field activities were performed in accordance with the requirements of the GSIP Phase 2 RI Work Plan and Roux Associates' Standard Operating Procedures (SOPs). The SOPs are provided in Appendix A. All supporting documentation is provided in Appendices B through D. In addition, data are summarized in tables, figures and plates to further the understanding of hydrogeologic conditions and the extent of inorganic and organic constituents in the media studied.

1.2 Summary of the GSIP Phase 1 RI Final Report

The objectives of the GSIP Phase 1 RI were to:

- define the ground-water, surface-water, and sediment quality coming onto and leaving the Site;
- determine the potential impacts on downgradient water use based on ground-water, surface-water, and sediment quality results; and
- determine if metals could become mobile in the future and, if so, what risk do they represent to human health and the environment, including aquatic organisms and consumers of aquatic organisms.

The major findings and conclusions of the GSIP Phase 1 RI are provided below.

Ground Water

The following areas of impacted ground water were identified during the GSIP Phase 1 RI:

- benzene-impacted ground water at the east flank of the West Hide Pile (OW-31) and in the area just south of Atlantic Avenue;
- toluene-impacted ground water downgradient of the East-Central Hide Pile and south of Atlantic Avenue;
- dissolved arsenic-impacted ground water downgradient from the West, East-Central, and South Hide Piles, with discharges of dissolved arsenic from the South Hide Pile into the HBHA pond; and
- dissolved chromium-impacted ground water downgradient of the West Hide Pile and the East-Central Hide Pile.

Ground-water flow patterns and the orientation of the plumes are controlled by subsurface geology; i.e., west and east branches of the minor, on-site buried valleys merge into a single, more deeply incised main buried valley near Observation Wells OW-18A/OW-18 and OW-17, and the HBHA.

Sewers

Concentrations of organic and inorganic compounds detected in samples collected from the Town of Reading and City of Woburn trunk sewers are not higher in the downstream samples than in the upstream samples.

Surface Water

Surface-water stations on the east side of the Site are located on drainage areas that flow into or are within the Aberjona River. These stations include the upstream Site boundary (SW-1 and SW-3), on-site (SW-2, SW-4, SW-8 and SW-17), and downstream (SW-5, SW-12 and SW-14) stations. Surface-water stations on the west side of the Site are located in drainage areas that flow into or are within the HBHA. These stations have been divided up into the upstream Site boundary (SW-6), on-site (SW-7, SW-15, SW-10 and SW-16), and downstream (SW-9, SW-11, SW-13 and SW-14) stations. A summary of the surface-water sampling results is provided below.

- Organic compounds detected in surface-water samples consisted of only a few volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs). No polychlorinated biphenyls (PCB) or pesticide compounds were detected in surface water during the GSIP Phase 1 RI sampling.

- Organic compounds were detected at generally low concentrations, with the highest concentration being 20 micrograms per liter ($\mu\text{g/L}$) of acetone (SW-2). Moreover, many of the organic compounds detected were at method detection limits and/or are considered common laboratory contaminants (i.e., acetone, methylene chloride, and common phthalate esters). No benzene or toluene was detected in surface water on Site.
- Arsenic, chromium, and lead were the most widely distributed and frequently detected inorganic constituents. Arsenic was detected in either the dissolved or total analyses at 13 of the 15 sample locations, with concentrations of total arsenic ranging from 2.0 $\mu\text{g/L}$ (SW-8) to 40.6 $\mu\text{g/L}$ (SW-2), and dissolved arsenic from 2.7 $\mu\text{g/L}$ (SW-7) to 24.5 $\mu\text{g/L}$ (SW-2). Chromium and lead were only detected as total metals. Samples collected in the New Boston Street Drainway/Hall's Brook Drainage in the western portion of the Study Area exhibited the highest total chromium levels, ranging from 20.5 $\mu\text{g/L}$ (SW-10) to 62.6 $\mu\text{g/L}$ (SW-7). Total lead was detected in 13 of the 15 samples collected, at concentrations of 2.2 $\mu\text{g/L}$ (SW-1 and SW-6) to 8.6 $\mu\text{g/L}$ (SW-10).

Stream Sediments

The stream-sediment analytical data, collected from the 17 surface-water monitoring stations within the Study Area, were used to determine the extent, types and amounts of constituents detected. Key findings and conclusions are summarized below.

- No pesticides or PCBs were detected in sediment samples collected during the GSIP Phase 1 RI. However, sediment samples collected during the Pre-Design Investigation (PDI) did result in the detection of the pesticide 4,4-DDE (48 micrograms per kilogram $\mu\text{g/kg}$) from the chromium lagoons at SW-1 and PCB Aroclor 1248 (400 $\mu\text{g/kg}$) from the South Pond between the East and West Hide Piles.
- VOCs and SVOCs (i.e., phthalates and polynuclear aromatic hydrocarbons) were detected in the stream-sediment samples. VOCs detected in stream-sediment samples included:
 - methylene chloride
 - trichloroethene
 - trans-1,2-dichloroethene
 - acetone
 - benzene
 - chlorobenzene
 - 1,2-dichloroethane
 - ethylbenzene
 - toluene
 - xylenes
- Target Analyte List (TAL) metals detected in all of the 17 samples included:
 - aluminum
 - arsenic
 - iron
 - lead

- barium
- calcium
- chromium
- cobalt
- copper
- magnesium
- manganese
- potassium
- vanadium
- zinc

- Stream-sediment samples collected in the Aberjona River drainage area showed fewer detected analytes and lower concentrations upstream, increased with proximity to the Site, and while present in sediments downstream, were seen in decreasing concentrations with distance from the Site. Toluene was detected in sediment samples from the upstream boundary of the Site and on Site, but not in downstream samples. Benzene was detected in pond sediments located downstream of the Site (the HBHA pond), and on Site (Lower South Pond), but not in stream sediments. Total SVOCs were detected at higher concentrations in downstream samples than in samples collected within the Site boundary. Arsenic, chromium and lead were the metals most frequently detected upstream, on Site, and downstream of the Site. Analytical results of sediment from the farthest downstream surface-water sampling stations (i.e., SW-14, located just south of Mishawum Road) suggest that organic and inorganic compounds are not migrating off the Study Area.
- An order of magnitude decrease in organic and inorganic constituent concentrations occurs from the north end of the HBHA pond (SW-9) to the south end of the HBHA pond (SW-13) and then again to the confluence of Hall's Brook with the Aberjona River (SW-14). This indicates that the HBHA pond and associated wetland is effective in trapping organic and inorganic compounds transported on fine-grained sediment, and is preventing downstream migration of this sediment. Also, sediment within the HBHA pond and associated wetland filter out metals from ground water by sorption to sediment, resulting in decreased concentrations in surface waters.

Metals Mobility

A conceptual geochemical model explaining the mobility of arsenic and chromium was derived from published literature regarding the geochemical behavior of these compounds, and a thorough evaluation of Site-specific geochemical data. In summary, the juxtaposition of anaerobically decaying hide residues and metals-containing soils, resulting in the placement of the hide piles in the late 1970s, created the conditions that enhanced metal mobility.

Ground-water conditions below the hide piles are strongly reducing. Under reducing conditions, infiltration of precipitation through metal-containing soils and hide residues leaches arsenic and chromium. Through microbial activity, these metals form organic complexes which are even more mobile in ground water than their ionic forms. As these complexes move from reducing to oxidizing zones with ground-water flow, geochemical reactions occur that decrease the mobility of these metals, primarily by precipitation/sorption reactions. Chromium is less mobile than arsenic because it more readily complexes with iron hydroxides. However, arsenic precipitates and becomes immobilized as evidenced by the fact that, in areas of the Site where ground-water conditions are oxidizing, arsenic concentrations are less than 50 µg/L.

Human Health Evaluation

Five exposure scenarios were analyzed that may apply to present or potential future use of the property. Of the analyses, only one, ingestion and household use of drinking water from a domestic source, produced estimated risks of greater than 1 in 100,000. The estimated risks for this improbable exposure scenario ranged from 10^{-4} to 10^{-5} for average constituent concentrations and 10^{-2} to 10^{-3} for maximum constituent concentrations. Analyses of risks for a more reasonable exposure, such as consumption by industrial worker, yielded a lower range of risk. As municipal water is available from other sources, both scenarios are considered a potential future use.

Estimated risk levels for uses of surface waters such as fishing, swimming and sediment contact, range from 10^{-5} for swimming, wading, and ingestion of sediment, to 10^{-6} for fish ingestion. The probability of such exposures occurring are, at present, very low.

The results of this human health risk analysis revealed that, while several chemicals were observed in the various media, and these chemicals contributed to the overall potential risk of the Site, arsenic is the primary constituent of concern for the scenarios investigated.

Ecological Evaluation

All stations evaluated showed signs of environmental stress, a combined result of both destruction of habitat and non-point impacts associated with development of the area. Based on the results of the physical, chemical and biological data, acute Site-related effects

were confined to the New Boston Street Drainway and West Branch (East and East-Central Hide Pile) of the Aberjona River. Depauperate communities within the HBHA cannot be attributed solely to chemical impacts of the Site, as benthic conditions were anoxic. Internal and external examination of individual fish showed no gross abnormalities.

1.3 Objectives and Scope of the GSIP Phase 2 RI

The GSIP Phase 2 RI was designed to fill the data gaps identified during the performance of the GSIP Phase 1 RI. Specifically, GSIP Phase 2 objectives were to:

- further characterize ground-water flow conditions and ground-water quality at selected areas of the Site;
- test the geochemical paradigm developed during the GSIP Phase 1 metals mobility study;
- collect additional data for purposes of characterizing the geochemical nature and extent of sediments within the HBHA pond; and
- evaluate ecological risks associated with the sediments within the HBHA.

1.3.1 Ground Water

The objectives of the GSIP Phase 2 ground-water investigation were to:

- further define the areal extent of benzene along the eastern side of the West Hide Pile (Task G-1);
- evaluate the potential for ground-water flow beneath (underflow) the HBHA (Task G-2); and
- evaluate the potential for vertical flow between the unconsolidated aquifer and the underlying bedrock (Task G-3).

To accomplish this, 18 additional observation wells/piezometers were installed in the unconsolidated deposits and bedrock at the Site. Geologic logs and well construction logs are provided in Appendix B. A summary of well construction details is provided in Table 1.

Water-level data were obtained during three comprehensive measurement rounds performed during January 13 to 14, 1992, February 18 to 21, 1992 and March 19 to 21, 1992. Water-level data are summarized in Table 2.

Ground-water samples were collected from all newly installed wells, and selected existing wells (in accordance with the GSIP Phase 2 RI Work Plan), from December 16 to 19, 1992. Ground-water samples were analyzed for Target Compound List (TCL) VOCs and TAL metals. All data were validated according to the USEPA Region I Data Validation Criteria outlined in the USEPA documents titled "Functional Guidelines for Evaluating Organic Analyses" (USEPA, 1988) and "Functional Guidelines for Evaluating Inorganic Analyses" (USEPA, 1989f). Analytical results are provided in Appendix C and summarized in Tables 3 and 4. Data validation results are provided in Appendix D.

1.3.1.1 Task G-1. Extent of Benzene at the West Hide Pile

To further define the areal extent of benzene previously detected at OW-31 (48,000 $\mu\text{g/L}$ detected during the Phase 2 PDI program) along the eastern side of the West Hide Pile, five piezometers were installed around the perimeter of the West Hide Pile. All piezometers were hand-driven well points, with the exception of WP-1, which was installed using a truck mounted drill rig (due to difficulty in advancing the well point by hand). One piezometer was installed on the west side of the West Hide Pile (i.e., WP-1), and four piezometers were installed adjacent to Observation Well OW-31 (WP-2, WP-3, WP-4 and WP-5, Plate 1).

1.3.1.2 Task G-2. Evaluation of Potential Underflow at HBHA

Based on the presence of arsenic detected in Observation Wells OW-30A and OW-30B located along the western flank of the HBHA, Task G-2 was undertaken to determine the potential of ground-water flow beneath (underflow) the HBHA. To accomplish this, two observation well clusters, consisting of four wells per cluster, were installed at existing wells OW-17 (i.e., OW-56A, OW-56B, OW-56C and OW-57) and OW-12 (i.e., OW-54A, OW-54B, OW-54C and OW-55).

At the OW-17 well cluster, wells were installed to straddle the water table (i.e., OW-56A), screen the middle of the aquifer (i.e., OW-56B) and screen the base of the unconsolidated sand and gravel aquifer (i.e., OW-56C). In addition, one bedrock observation well (OW-57) was installed to screen the upper bedrock immediately underlying the unconsolidated sand and gravel aquifer.

The wells installed at the OW-12 cluster were installed in a similar fashion and at similar horizons as the OW-17 cluster (Table 1). Specifically, wells were installed to screen the top (OW-54A), middle (OW-54B) and basal (OW-54C) portions of the unconsolidated aquifer. In addition, a bedrock well (OW-55) was installed to screen the upper bedrock zone.

All newly installed wells were surveyed for horizontal and vertical coordinates (horizontally to 0.1 feet and vertically to 0.01 feet). Survey data are provided in Appendix B.

Water-level measurements were collected from these newly installed wells and all other existing observation wells in the HBHA during the January, February and March, 1992 water-level measuring rounds. Ground-water samples were collected from the OW-17 and OW-12 well clusters, as well as OW-30A and OW-30B. These ground-water samples were analyzed for TAL metals (dissolved) and TCL VOCs.

Additionally, one surface-water staff gauge (SW-56) was installed in the northern end of the HBHA pond and surveyed. However, the staff gauge was destroyed twice by heaving ice during January and February 1992. The staff gauge was reinstalled a third time and resurveyed in March 1992. Consequently, surface-water elevation data could only be obtained from this staff gauge during the March 1992 comprehensive water-level measuring round (Table 5).

1.3.1.3 Task G-3. Unconsolidated Deposits/Bedrock Interaction

The objective of this task was to evaluate the potential interaction of ground water between the unconsolidated deposits and the underlying crystalline bedrock. To accomplish this, bedrock observation wells and unconsolidated aquifer observation wells were to be installed at the locations of Observation Well OW-37 and Observation Well OW-9.

To accomplish this, two 2-inch diameter wells were installed adjacent to former Observation Well OW-9. The shallow well (OW-52A) was installed to straddle the water table and the deeper well (OW-52B) screened the base of the unconsolidated aquifer. One 2-inch diameter well (OW-37A) was installed adjacent to the existing water table Observation Well OW-37. OW-37A was installed to screen the base of the unconsolidated aquifer. Vertical

gradients between the unconsolidated and bedrock aquifers were calculated for select well clusters at the Site, and are summarized in Table 6.

The USEPA requested that the bedrock drilling program at these locations proposed in the GSIP Phase 2 RI Work Plan be modified to include multiple bedrock wells being installed at each location. Each individual bedrock well would be screened at horizons selected based on the results of discrete-horizon sampling of a pilot bedrock borehole.

To accomplish this, and as outlined in an October 28, 1991 letter from the ISRT to USEPA (ISRT, 1991), the bedrock wells were to be installed using the following procedure:

- drill and grout casing into unconsolidated sediments;
- advance a 6-inch diameter borehole 50 feet into bedrock;
- collect in-situ ground-water samples every 10 feet with a straddle packer/pump;
- analyze ground-water samples for VOCs and arsenic at an off-site laboratory and select the screened interval based on the sample interval exhibiting the highest constituent concentrations;
- backfill the borehole with bentonite grout to the required depth and install well screen casing to selected horizon(s);
- backfill the screen with the sand or gravel packing and grout the remain annulus;
- drill and install additional bedrock observation well(s) with well screens installed at additional horizons (determined from results of packer sampling);
- develop the wells and collect ground-water quality samples.

The drilling of these bedrock wells began on November 15, 1991. However, following the completion of the pilot borehole 50 feet into bedrock at both the OW-37 (OW-51B) and OW-9 (OW-53B) clusters, ground-water recharge into these pilot bedrock boreholes was found to be extremely slow (i.e., approximately 0.2 feet per day for OW-51B and 2 feet per day for OW-53B); thereby precluding packer testing or ground-water sampling from being performed. In view of the fact that the bedrock was relatively impermeable at these locations, the USEPA agreed to discontinue the bedrock investigation at these locations. This information was documented in a January 28, 1992 letter from Roux Associates to the USEPA (Roux Associates, Inc., 1992). The pilot bedrock boreholes were sealed on February 20, 1992 following Massachusetts guidelines.

In addition to the installation of observation wells at the OW-37 and OW-9 locations, Observation Well OW-9 was abandoned, as specified in the GSIP Phase 2 RI Work Plan, due to suspected problems with well construction. Following the installation of piezometers at the OW-37 and OW-9 locations, ground-water samples were collected and analyzed for TCL VOCs and TAL metals. In addition, water-level measurements were collected during comprehensive January, February and March 1992 water-level measuring rounds.

1.3.2 Surface Water/Stream Sediments

The objective of the GSIP Phase 2 surface-water/stream-sediment investigation was to further define the nature and extent of migration of organic and inorganic constituents via the surface-water pathways in the Study Area.

1.3.2.1 Task S-1. Surface-Water/Stream-Sediment Sampling and Analysis

To further define the migration of organic and inorganic constituents in surface water and stream sediment in the Study Area, six new sampling locations were established and sampled to supplement data collected at the 17 existing surface-water/stream-sediment locations sampled during the GSIP Phase 1 RI. The six new locations sampled are:

- SW-18, located to define upstream/off-site conditions in the New Boston Street Drainway;
- SW-19, located to determine upstream/off-site conditions in Hall's Brook;
- stations SW-21, SW-22, and SW-23, located to define conditions in the wetland downstream of the HBHA pond; and
- SW-24, located to define conditions in the wetland of the Aberjona River upstream of the confluence of Hall's Brook.

These six sampling locations were selected in conjunction with USEPA during a Site visit performed on April 30, 1991. Sampling locations are shown in Plate 2.

Surface-water and stream-sediment samples were collected at each location and analyzed for the following parameters:

- TCL VOCs;
- TCL SVOCs;
- total TAL metals;

- dissolved TAL metals (surface-water samples only);
- pH and Eh;
- total organic carbon (TOC);
- total suspended solids (TSS) (surface-water sample only);
- grain size (sediment sample only), sulfide (sediment sample only), and ammonia (sediment sample only); and
- dissolved oxygen (surface-water sample only), temperature (surface-water sample only), and conductivity (surface-water sample only).

Stream-sediment samples were collected with a Ponar dredge, according to the procedures in the GSIP Phase 2 RI Work Plan.

Surface-water/stream-sediment samples were collected on October 2 and 3, 1991. Analytical data are provided in Appendix C and are summarized in Tables 7 through 10. In addition, to establish flow conditions at the time of sampling, stream-flow measurements were collected at surface-water stations SW-5, SW-10, SW-12, SW-13, SW-14 and SW-17. Stream-flow measurements are provided in Table 11.

1.3.2.2 Task S-2. Sediment Volume and Geochemical Investigation Within the HBHA Pond

Previous samples collected from the HBHA pond during the GSIP Phase 1 RI indicated that arsenic, benzene, and toluene are present in the sediments. However, neither the distribution of these analytes between particulate materials (the solid phase) and interstitial pore waters (aqueous phase) nor the geochemical conditions controlling the spatial distribution of metals or organic compounds had been investigated.

The objectives of the HBHA pond geochemical investigation were to 1) determine the depth and volume of sediments in the HBHA pond; 2) evaluate interstitial water chemistry, focusing on the analytes (e.g., arsenic, benzene and toluene) previously identified in the GSIP Phase 1 RI Final Report (Roux Associates, Inc., 1991a) as Constituents of Concern (COC); 3) determine sorbed sediment concentrations for the same constituents; and 4) measure flux and water quality recharging the HBHA pond. The results of this investigation

were also used to determine the form and bioavailability of metals in the HBHA risk assessment.

1.3.3. Tasks M-1 and M-2. Objectives and Scope of the Metals Mobility Study

The primary focus of the metals mobility study was to collect data to support or refute the elements of the geochemical paradigm presented in the GSIP Phase I RI metals mobility study to explain metal migration in Site ground waters. To meet this objective, 18 wells were sampled at selected locations during November 1991, for parameters that would explain the migration of the previously identified COC (Roux Associates, Inc., 1991a). Chemical analyses (e.g., arsenic, chromium, benzene) were conducted to define the spatial extent of these constituents downgradient from the hide piles, and geochemical parameters (e.g., pH, Eh, sulfide, dissolved oxygen, ferrous iron, and major ion chemistry) were measured to help interpret migration of the analytes away from source locations. In addition, aquifer materials were collected and subjected to geotechnical measurements (e.g., bulk density and particle size analysis).

1.3.4 Tasks E-1, E-2 and E-3. Ecological Assessment

The results of the GSIP Phase 1 RI (Roux Associates, Inc., 1991a) identified, based on both biological data and the extent of COC, that the HBHA (Wetland 5) may require further ecological investigation. In particular, the hydrologic regime of Wetland 5, in addition to that of Wetland 4B (located behind the Woburn Mall), was considered favorable for the sedimentation of particulates from influent received from Hall's Brook and the Aberjona River, respectively. The consequence of this potential increase in water quality may be a decrease in sediment quality as COC accumulate within the benthos.

The objective of the GSIP Phase 2 ecological assessment (EA) was to further investigate the issues highlighted during the GSIP Phase 1 and define the degree of hazard that the sediment/surface waters may pose to aquatic receptors.

Sediment Bioassay

Although the GSIP Phase 1 EA provided insight into the nature of the relative impacts of potentially toxic constituents, it was limited in that it could only define the toxicity and concentration of each individual constituent, and not of the total mixture. Other

uncertainties, including the contribution of non-point source impacts and the variability of habitat between sampling stations, also affected the interpretation of the assessment (Roux Associates, Inc., 1991a). These factors may be reduced or eliminated by "standardizing" the environmental parameters in the form of a "bioassay", i.e. moving the media in question to a controlled laboratory setting and observing the effect each sample has on test organisms that are known to provide a reproducible response. Sediment bioassays were thus conducted during the GSIP Phase 2 EA to provide a direct measure of the toxicity of each sediment sample to benthic macroinvertebrates.

Sediment bioassays were performed on samples taken from SW-18 and SW-19 (upstream or west of the Site boundaries, and SW-21, SW-22, SW-23, and SW-24 (downstream or south of the Site boundaries (Plate 2). Each sample was tested in duplicate with two different types of freshwater test organisms, *Chironomus tentans* (a midge) and *Hyallela azteca* (an amphipod). Both would be considered typical of genera found within the Study Area. Test endpoints included survival, growth and reproduction.

Fish Sampling Survey

Some COC (e.g., mercury, selenium) have the potential to biomagnify. Although the uptake of these metals generally do not threaten fish populations, they may pose a hazard to predators that feed on them. A sampling survey was performed to identify concentrations of metals and SVOC in fish tissue to determine if a hazard may exist.

Fish taken from the ponded portion of HBHA (downstream of the Site) and Phillip's Pond (PP, reference area) were compared. Residues in fish were examined by capturing fish that were considered to be representative of three trophic levels (forager, bottom feeder and predator) and separating and analyzing fillet (muscle) and offal (entrails).

Assessment of Hazard to Semi-Aquatic Receptors

One concern that was not addressed in the GSIP Phase 1 EA was the potential adverse effect of COC on wetland dependent birds, such as ducks and geese. The GSIP Phase 2 EA chose the mallard duck as an "indicator species" as it is abundant and a common inhabitant of wetlands throughout the Northeast. The potential for adverse effect was evaluated by developing a conservative exposure model for the duck and comparing the predicted average

daily exposure (to arsenic, chromium, and lead) to a toxicity endpoint (reference dose, in milligrams per kilogram per day [mg/kg/day]) derived from the scientific literature.

2.0 RESULTS OF THE GSIP PHASE 2 RI

Phase 2 of the GSIP RI field investigation was performed from September 1991 through May 1992. The results of the field investigation were evaluated to fill the data gaps identified during the performance of the GSIP Phase 1 RI to further characterize the nature and extent of inorganic and organic compounds in ground water, surface water and stream sediments. Additionally, these data were used to further evaluate the mobility of metals within the Study Area, to test the geochemical paradigm developed during the GSIP Phase 1 metals mobility study, to characterize the geochemical nature and extent of sediments within the HBHA pond, and to evaluate ecological risks associated with these sediments.

The results of the GSIP Phase 2 ground-water, surface-water and stream-sediment investigations are summarized in Sections 2.1 and 2.2. The summary of the HBHA pond sediment geochemical investigation is provided in Section 2.3. The GSIP Phase 2 metals mobility study and GSIP Phase 2 EA are provided in Sections 2.4 and 2.5.

Hydrogeologic, and ground-water, surface-water and stream-sediment quality data developed during the GSIP Phase 2 RI were integrated with GSIP Phase 1 RI and PDI data in map form to illustrate environmental conditions in the Study Area. To further define ground-water flow patterns at the Site, available information on the bottom of the unconsolidated aquifer was compared with ground-water elevation measurements (Plates 3 and 4). Representative ground-water flow patterns are illustrated in Plate 3, utilizing water-level data collected on March 19-21, 1992. These data were consistent with water-level data collected during January and March 1992, and with ground-water flow patterns shown in the GSIP Phase 1 RI Final Report.

To illustrate ground-water quality conditions, several COC identified in the GSIP Phase 1 RI Final Report (i.e., benzene, toluene, arsenic) were used. Utilizing the historical database, the distribution of benzene (Plate 5), toluene (Plate 6) and arsenic (Plate 7) are shown using maximum/minimum concentrations detected at each well location.

Surface-water and stream-sediment quality data developed during the GSIP Phase 2 RI are illustrated in Plates 2 and 8 through 11. These plates were updated from the GSIP Phase 1 RI Final Report and illustrate all historical data developed to date during the GSIP and PDI investigations.

2.1 Ground Water

Phase 2 of the GSIP ground-water investigation was performed to further characterize ground-water flow conditions and ground-water quality at selected areas of the Site. Specifically, the GSIP Phase 2 ground-water investigation was performed to:

- further define the areal extent of benzene along the eastern side of the West Hide Pile (Task G-1);
- evaluate the potential for ground-water flow beneath (underflow) the HBHA (Task G-2); and
- evaluate the potential of vertical flow between the unconsolidated aquifer and the underlying bedrock (Task G-3).

Data developed during the GSIP Phase 2 ground-water investigation included the installation of unconsolidated and bedrock observation wells, collection of three comprehensive rounds of water-level data (i.e., January, February and March 1992), and the collection (i.e., December 1992) and analysis of ground-water samples. These data were evaluated together with data developed during the GSIP Phase 1 RI Final Report and the PDI to further define hydrogeologic and ground-water quality conditions in the selected areas of the Site identified above.

2.1.1 Task G-1. Extent of Benzene at the West Hide Pile

As discussed in Section 1.3.1, five piezometer well points (i.e., WP-1 through WP-5) were installed around the perimeter of the West Hide Pile, which is located along the northern edge of the Site (Plate 1). The objective of the installation and sampling of these well points was to further define the areal extent of benzene previously detected at Observation Well OW-31 (48,000 $\mu\text{g}/\text{L}$ detected during the GSIP Phase 2 PDI program).

Four of the five well points encountered saturated unconsolidated deposits. The fifth well point, Piezometer WP-2 did not encounter saturated deposits (i.e., was dry) and was not sampled. As shown in Plate 4, bedrock and/or till extend above the water table along the

northwestern side of the West Hide Pile. Consequently, the unconsolidated aquifer is not present in this area.

The results of the ground-water sampling around the West Hide Pile indicate that concentrations of benzene were detected at OW-31 (63,000 $\mu\text{g/L}$), WP-3 (12,000 $\mu\text{g/L}$) and WP-5 (2 $\mu\text{g/L}$). Benzene was not detected (ND) in Piezometers WP-1 and WP-4.

Other VOCs detected in these wells are listed below.

<u>Compound</u>	<u>Minimum Concentration Detected</u>	<u>Maximum Concentration Detected</u>
toluene	ND	440 $\mu\text{g/L}$ (WP-3)
xylenes	ND	320 $\mu\text{g/L}$ (OW-31)
ethylbenzene	ND	62 $\mu\text{g/L}$ (OW-31)
4-methyl-2-pentanone	ND	62 $\mu\text{g/L}$ (OW-31)
carbon disulfide	ND	2 $\mu\text{g/L}$ (OW-31)

The distribution of benzene in ground water around the West Hide Pile was illustrated utilizing all ground-water quality data developed since 1989 (the historical database) and is shown in Plate 5 (maximum and minimum concentrations of benzene in ground water). As shown in Plate 5, benzene concentrations near the West Hide Pile are limited to a small area along the northeastern perimeter of the West Hide Pile in the vicinity of Observation Well OW-31, with the exception of 2 $\mu\text{g/L}$ of benzene detected at Piezometer WP-5.

This localized area of ground water containing benzene concentrations appears to discharge into the adjoining surface-water body (Lower South Pond). This is based on ground-water flow patterns beneath the West Hide Pile (Plate 3), which show ground water flowing eastward into the Lower South Pond. Additionally, benzene concentrations are not found immediately downgradient (southward) from the West Hide Pile, with the exception of 2 $\mu\text{g/L}$ of benzene detected at WP-5.

It is noted that benzene was also detected in ground water further away from the West Hide Pile at OW-43, collected during the metals mobility study, at a concentration of 518 $\mu\text{g/L}$. OW-43 is located approximately 500 feet southeastward from the West Hide Pile. However, the absence of benzene immediately south of the West Hide Pile suggests that the West Hide Pile is not the source of this detection.

2.1.2 Task G-2. Evaluation of Underflow at HBHA

As discussed in the GSIP Phase 1 RI Final Report (Roux Associates, Inc., 1991a) arsenic was detected in Observation Wells OW-30A and OW-30B located along the western flank of the HBHA. Maximum concentrations of dissolved arsenic in OW-30A was 47 $\mu\text{g/L}$ and OW-30B was 16.4 $\mu\text{g/L}$ (Plate 7). Although ground-water flow data presented in the GSIP Phase 1 RI Final Report suggested that underflow from the east side of the HBHA is unlikely, the presence of dissolved arsenic in this well cluster suggested that arsenic may be from the plume along the eastern flank of the HBHA. If this were the case, the presence of arsenic at this location could be attributed to either the underflow of ground water from the east to the west side of the HBHA or to the lateral dispersion within the plume of the buried valley aquifer.

The results of the GSIP Phase 2 RI indicate that ground-water flow beneath the northern end of HBHA pond is not occurring. Rather, shallow and deeper ground water is shown to be flowing toward and discharging into the HBHA. This conclusion is based on:

- ground-water flow patterns in the shallow and deep unconsolidated deposits around the northern end of HBHA (on the east and west sides) which show ground water flowing laterally and vertically toward the HBHA (Figure 2);
- seepage meter data collected during the HBHA pond geochemical investigation which demonstrate that ground water beneath the base of the northern end of HBHA pond and is flowing upward and discharging into the pond; and
- ground-water samples collected during the GSIP Phase 2 RI which reveal that arsenic was not present (not detected) in OW-30A and OW-30B, located on the western side of the HBHA pond.

A detailed discussion is provided below.

As discussed in Section 1.3.1, additional observation well clusters were installed and monitored (i.e., collection of ground-water samples and water-level measurements) in the vicinity of the HBHA to determine if underflow is occurring. Specifically, two well clusters, consisting of four wells per cluster were installed at existing at Observation Well OW-17 (i.e., OW-56A, OW-56B, OW-56C and OW-57) and OW-12 (i.e., OW-54A, OW-54B, OW-54C and OW-55). At each well cluster, wells were installed to straddle the water table, screen the middle of the unconsolidated deposits, screen the base of the unconsolidated deposits and screen the upper bedrock immediately below the unconsolidated deposits.

Geologic logs and well construction logs are provided in Appendix B. Summary of well construction details are provided in Table 1. Water-level data obtained from the wells during the three comprehensive measurement rounds performed during January, February and March 1992 are summarized in Table 2. In addition, ground-water quality data developed from these wells (i.e., VOCs and metals) are provided in Appendix C and summarized in Tables 3 and 4. These data, coupled with data developed during the GSIP Phase 1 RI as well as the PDI, were evaluated to further define ground-water quality conditions, the vertical and lateral ground-water flow, and the configuration of the buried valley aquifer in the vicinity of the HBHA. This information was used, in turn, to determine if underflow is occurring.

Ground-water elevation data developed on March 19 to 21, 1992 were used to illustrate ground-water flow patterns in the Study Area. As shown in Plate 3, shallow ground water surrounding the HBHA flows radially inward and discharges to the surface-water body. The HBHA is therefore acting as a discharge boundary for shallow ground water, confirming the results of the GSIP Phase 1 RI.

Additionally, ground-water discharge data collected from seepage meters during the HBHA pond geochemical investigation (Section 2.3.1.4.2) confirms that ground water is discharging into the HBHA pond. To evaluate the vertical component of ground-water flow in the vicinity of the HBHA, a generalized hydrogeologic cross section (Figure 2) was prepared and oriented in a north-south direction (parallel with ground-water flow) extending through the OW-52 well cluster, the OW-54 well cluster, the OW-56 well cluster, beneath the HBHA pond and through the OW-30 well cluster (Plate 1). As shown in Figure 2, the area furthest

away from the HBHA (i.e., in the vicinity of the OW-52 well cluster) is acting as a recharge zone for ground water. As the northern end of HBHA pond is approached, the vertical component of ground-water flow in the unconsolidated deposits changes to an upward direction (e.g., at the OW-56 well cluster). This condition was generally observed during the January, February and March 1992 water-level measuring rounds. Specifically, as shown in Table 6, an upward flow gradient representing a discharge zone was observed in two of the three measuring rounds for well clusters located near the HBHA (i.e., OW-18 well cluster and OW-56 well cluster). The vertical gradient observed during the third measuring round was only very slightly downward (0.001 feet/foot [ft/ft] measured during January 1992 at the OW-56 well cluster) or horizontal (0.0 ft/ft measured during March 1992 at the OW-18 well cluster).

Finally, ground-water quality data collected during the GSIP Phase 2 RI shows that arsenic was not detected at Observation Wells OW-30A or OW-30B (located along the western side of the HBHA) during the December 1991 sampling round. It is noted that arsenic was detected at these locations during the two previous sampling rounds (June 1990 and October 1990). However, the highest concentration of arsenic detected was only 47 $\mu\text{g/L}$ (OW-30A).

This information indicates that in the northern portion of the HBHA pond ground-water underflow is not occurring, however underflow/dispersion may be occurring further southward in the HBHA where the unconsolidated aquifer thickens and widens (Plate 4). As discussed in the GSIP Phase 1 RI Final Report, ground-water flow in the unconsolidated aquifer is controlled by the geometry of the buried valley. The elevation of the bottom of the unconsolidated aquifer in the vicinity of the HBHA is shown in Plate 4. This interpretation of the bottom of the aquifer is based on Golder Associates' interpretation presented in the December 1991 report titled "Aquifer Pumping Test, Industri-Plex Site, Woburn, Massachusetts". As shown in Plate 4, the unconsolidated aquifer in the northern portion of the HBHA is thin and narrow, with the axis of the aquifer extending southward along the eastern side of the HBHA. Further to the south the bottom of the aquifer widens and deepens beneath the HBHA pond in the vicinity of the OW-30 well cluster. This localized widening of the buried valley could allow underflow to occur beneath the middle portion of the HBHA pond. This conclusion is consistent with the results of the HBHA

pond sediment geochemical investigation, which indicate that the axis of the arsenic plume intersects the HBHA in the central portion of the HBHA pond (Section 2.3.2.2).

It is important to note that the occurrence of arsenic in ground water at the OW-30 well cluster is discontinuous. Arsenic was not detected during the GSIP Phase 2 sampling round (December 1991). Moreover, the lateral extent of the unconsolidated aquifer on the western side of the HBHA ends approximately 300 feet west of the OW-30 well cluster due to the presence of the adjoining bedrock high which defines the westward boundary of the aquifer (Plate 4). Therefore, ground water on the western side of the HBHA will be directed eastward/southeastward back toward the HBHA, and will discharge into the HBHA.

2.1.3 Task G-3. Unconsolidated Deposits/Bedrock Interaction

As discussed in Section 1.3.1.3, the potential interaction of ground water between the unconsolidated deposits and the underlying crystalline bedrock was to be investigated through the installation of bedrock observation well clusters at two locations at the Site. Specifically, bedrock observation well clusters were to be installed at the location of Observation Well OW-37 (located downgradient of the West Hide Pile) and OW-9 (located near the western end of Atlantic Avenue).

However, pilot bedrock boreholes drilled fifty feet into bedrock at both the OW-37 (OW-51B) and OW-9 (OW-53B) clusters were dry immediately following their completion. Water levels within these pilot bedrock boreholes were monitored over a several week period and revealed that ground-water recharge into these boreholes was extremely slow (i.e., approximately 0.2 feet per day for OW-51B and approximately 2 feet per day for OW-53B).

Based on the low permeability of the bedrock at these locations, USEPA agreed to discontinue the bedrock investigation at these locations. Therefore, observation wells were not installed and ground-water sampling was not performed. Pilot bedrock boreholes were sealed on February 20, 1992 following Massachusetts guidelines. This information indicates that the bedrock at these two locations exhibits an extremely low hydraulic conductivity. Moreover, the bedrock at these locations also exhibits no appreciable secondary porosity.

Due to this low hydraulic conductivity, the bedrock at these locations will not act as a flow pathway for constituent-impacted ground water.

It is noted that the bedrock in the vicinity of the HBHA (i.e., at Observation Well OW-57) also exhibits an apparent low transmissivity. As shown in Table 2, water-level measurements collected from OW-57 during January, February and March 1992 show that water levels within this observation well required over two months to recover following its installation on December 10, 1991. Consequently, the extremely slow recharge of ground water into OW-57 precluded the collection of a representative ground-water sample from this well.

The only bedrock well installed during the GSIP Phase 2 RI that recharged sufficiently enough to enable the collection of a representative ground-water sample and the collection of representative water-level information over time was Observation Well OW-55. This bedrock well was installed directly downgradient of the South Hide Pile (Plate 1). As shown in Table 6, vertical gradient data developed from the January, February, and March water-level measuring rounds show a consistent downward gradient between Observation Well OW-55 (screened in the bedrock) and Observation Well OW-54C (screened in the basal unconsolidated deposits). Vertical gradients ranged between 0.0084 feet per foot (ft/ft) to 0.0334 ft/ft.

The following VOCs were detected in the ground-water sample collected from OW-55.

<u>VOC</u>	<u>Concentration (in $\mu\text{g/L}$)</u>
toluene	2,100
benzene	1,800
acetone	1,800
2-butanone	110
4-methyl-2-pentanone	83
total xylenes	49
ethylbenzene	8
2-hexanone	2

In addition, dissolved arsenic and dissolved chromium were detected at a concentration of 193 $\mu\text{g/L}$ and 122 $\mu\text{g/L}$, respectively.

A comparison of ground-water quality data between the bedrock well (OW-55) and the three adjacent overburden wells yields the following observations:

- Similar VOCs were detected in the adjoining basal unconsolidated deposits observation well (OW-54C). Concentrations of these VOCs were lower in OW-54C than in bedrock well OW-55.
- More VOCs were encountered at depth (i.e., in bedrock well OW-55 and basal unconsolidated deposits well OW-54C) than in shallower ground water (i.e., OW-54A and OW-54B).
- Concentrations of dissolved arsenic increased with depth in the unconsolidated deposits (from not detected [OW-54A] to 949 $\mu\text{g/L}$ [OW-54C], but were lower in the bedrock (193 $\mu\text{g/L}$ at OW-55).
- Concentrations of dissolved chromium also increased with depth in the unconsolidated (from not detected [OW-54A] to 145 $\mu\text{g/L}$ [OW-54C], but were lower in the bedrock (122 $\mu\text{g/L}$ at OW-55).

In summary, the results of Task G-3 indicate that, due to the low hydraulic conductivity the crystalline bedrock observed at three of the four bedrock observation well locations investigated during the GSIP Phase 2 RI, the crystalline bedrock does not appear to be a pathway for the transport of organic and inorganic constituents, except at Observation Well OW-55.

2.2 Task S-1. Surface-Water/Stream-Sediment Quality

To further define the extent of organic and inorganic constituents in surface water and stream sediment in the Study Area, six new sampling locations (i.e., SW-18, SW-19, SW-21, SW-22, SW-23 and SW-24) were established and sampled to supplement data collected from 17 existing surface-water/stream-sediment locations sampled during the GSIP Phase 1 RI. The Phase 2 sampling locations are shown in Plate 2.

Surface-water and stream-sediment samples were collected on October 2, 1991 and October 3, 1991. Analytical data collected during the GSIP Phase 2 RI are summarized in Tables 7 through 10.

Surface-water and stream-sediment quality data developed during the GSIP Phase 2 RI are illustrated in Plates 2 and 8 through 11. These plates were updated from the GSIP Phase 1 RI Final Report and illustrate historical surface-water and stream-sediment quality data developed to date during the GSIP and PDI investigations.

Stream-flow measurements were collected on October 4, 1991 at six locations (SW-5, SW-10, SW-12, SW-13, SW-14 and SW-17) to provide information on flow conditions at the time of sampling. No rainfall events occurred during the October 2, 1991 through October 4, 1991 when samples and flow measurements were collected. Flow measurements are presented in Table 11.

2.2.1 Surface-Water Quality

VOCs were detected at the two upstream/off-site surface-water sampling locations (i.e., SW-18 and SW-19), and at the three surface-water sampling locations downstream of the HBHA pond (i.e., SW-21, SW-22 and SW-23). No VOCs were detected at Station SW-24 located in the wetland of the Aberjona River upstream of the confluence of Hall's Brook. VOCs detected are listed as follows.

<u>Compound</u>	<u>Minimum Concentration Detected</u>	<u>Maximum Concentration Detected</u>
toluene	ND	130 µg/L (SW-18)
trichloroethene	1 µg/L (SW-23)	11 µg/L (SW-18)
1,2-dichloroethene	ND	11 µg/L (SW-18)
xylenes	ND	7 µg/L (SW-18)
1,1-dichloroethane	ND	2 µg/L (SW-21)
4-methyl-2-pentanone	ND	2 µg/L (SW-18)
ethylbenzene	ND	1 µg/L (SW-18)

Only one SVOC (2-methylphenol) was detected in one of the upstream surface-water samples (SW-18) collected during the GSIP Phase 2 RI. A summary of organic compounds detected in surface-water samples is shown in Table 7.

The distribution of the GSIP Phase 2 VOC sampling results, coupled with all historical VOCs detected in the Study Area are shown in Plate 2. As shown in Plate 2, surface water collected at SW-18, located upstream/offsite of the New Boston Street Drainway contained the most VOCs detected as well as the highest concentrations.

Downstream of the HBHA pond, only very low concentrations of a few VOCs were detected. At station SW-23, the furthest downstream surface-water sample collected during the GSIP Phase 2 RI, trichloroethene (1 µg/L) was the only VOC detected.

A summary of inorganic constituents detected in surface-water samples collected during the GSIP Phase 2 RI are provided in Table 8. The distribution of arsenic, chromium and lead detected during the GSIP Phase 2 sampling round are shown in Plate 8. Total arsenic concentrations range from not detected (SW-19) to 14.6 µg/L (SW-21). In general, the higher concentrations of arsenic were detected in Hall's Brook downstream of the HBHA pond.

Total chromium concentrations ranged from 8.5 µg/L (SW-24) to 195 µg/L (SW-18). The highest concentration was detected in the off-site/upstream surface-water sample (SW-18) collected from the New Boston Street Drainway.

Total lead was not detected in any of the surface-water samples.

2.2.2 Stream-Sediment Quality

VOCs and SVOCs were detected in all six sediment samples collected during the GSIP Phase 2 RI sampling round. VOCs detected are listed below.

<u>Compound</u>	<u>Minimum Concentration Detected</u>	<u>Maximum Concentration Detected</u>
acetone	110 µg/kg (SED-19)	2,220 µg/kg (SED-23)
2-butanone	31 µg/kg (SED-19)	550 µg/kg (SED-22)
chlorobenzene	ND	13 µg/kg (SED-21)
1,2-dichloroethene	ND	12 µg/kg (SED-21)
ethylbenzene	ND	15 µg/kg (SED-22)

<u>Compound</u>	<u>Minimum Concentration Detected</u>	<u>Maximum Concentration Detected</u>
toluene	ND	9 µg/kg (SED-19)
vinyl chloride	ND	52 µg/kg (SED-22)

The distribution of VOCs detected in stream sediment are shown in Plate 2. As illustrated, VOCs were detected in both upstream/off-site samples (i.e., SED-18 collected at SW-18, and SED-19 collected at SW-19) as well as in sediment samples collected downstream of the HBHA pond (i.e., SED-21 through SED-23 collected at SW-21 through SW-23). There appears to be no correlation between VOCs detected in surface water and VOCs detected in sediment at each respective sampling location.

The SVOCs detected were principally polycyclic aromatic hydrocarbons (PAHs) and bis(2-ethylhexyl)phthalate. SVOCs detected are listed below.

<u>Compound</u>	<u>Minimum Concentration Detected</u>	<u>Maximum Concentration Detected</u>
anthracene	ND	1,200 µg/kg (SED-24)
benzo (a) anthracene	ND	5,800 µg/kg (SED-24)
benzo (a) pyrene	ND	8,700 µg/kg (SED-24)
benzo (g,h,i) pyrene	ND	5,700 µg/kg (SED-24)
benzo (b) fluoranthene	ND	15,000 µg/kg (SED-24)
benzo (k) fluoranthene	ND	4,900 µg/kg (SED-24)
bis (2-ethylhexyl) phthalate	ND	2,200,000 µg/kg (SED-18)
carbazole	ND	1,500 µg/kg (SED-24)
chrysene	ND	8,900 µg/kg (SED-24)
dibenzo (a,h anthracene)	ND	2,100 µg/kg (SED-24)
fluoranthene	ND	19,000 µg/kg (SED-24)
indeno (1,2,3-cd) pyrene	ND	6,100 µg/kg (SED-24)
4-methylphenol	ND	220 µg/kg (SED-19)
N-nitrosodiphenylamine	ND	680 µg/kg (SED-23)

<u>Compound</u>	<u>Minimum Concentration Detected</u>	<u>Maximum Concentration Detected</u>
phenanthrene	ND	8,000 µg/kg (SED-24)
pyrene	ND	13,000 µg/kg (SED-24)

As shown in Table 9, SVOCs were detected at the upstream/off-site locations (i.e., SED-18 and SED-19 collected at SW-18 and SW-19, respectively), as well as sediment samples collected downstream of the HBHA pond. It is noted that the highest concentration of SVOCs detected was 2,200,000 µg/kg detected in SED-18 (upstream/off-site location SW-18).

The distribution of arsenic detected in stream sediment is shown in Plate 9. Of the GSIP Phase 2 RI samples, greater concentrations of arsenic were detected in Hall's Brook downstream of the HBHA pond (i.e., SED-21 through SED-23 collected at locations SW-21 through SW-23, respectively) than in the upstream off-site sampling locations (i.e., SED-18 and SED-19 collected from locations SW-18 and SW-19, respectively). Detected concentrations of arsenic ranged from 4.1 mg/kg (SED-19) to 1,380 mg/kg (SED-22).

The distribution of chromium detected in stream sediment is shown in Plate 10. As shown, the distribution of chromium in stream sediment during the GSIP Phase 2 RI shows no pattern, with concentrations ranging from 116 mg/kg (SED-24) to 2,180 mg/kg (SED-23).

The distribution of lead detected in stream sediment is shown in Plate 11. As shown, the highest concentrations of lead detected in stream sediment during the GSIP Phase 2 RI was in Hall's Brook downstream of the HBHA pond (i.e., SED-21 through SED-23 collected at locations SW-21 through SW-23, respectively). Lower concentrations are generally seen in the two upstream/off-site sediment sampling locations (i.e., SED-18 and SED-19 collected at locations SW-18 and SW-19, respectively). Detected concentrations of lead ranged from 25.3 mg/kg (SED-19) to 452 mg/kg (SED-22).

In an effort to better evaluate the distribution of constituents detected in stream sediments, sediment-quality data were normalized to take into consideration grain size variability among sediment samples. This normalization process was performed utilizing methods described in "A Primer on Sediment Trace Element Chemistry" by Arthur J. Horowitz. Arsenic, chromium and lead were chosen as indicator parameters. The analytical data for these three metals were normalized using the following procedure: 1) detected concentrations were normalized to iron; and 2) the iron-normalized concentrations were corrected with respect to background concentrations using the stream-sediment sample SED-19 data as background.

Based on these calculations, it appears that stream-sediment quality data are related to grain size (i.e., higher concentrations of constituents were generally detected in finer-grained sediment samples). As a result, iron-normalized (and background-corrected) concentrations of constituents were generally higher in the wetlands than in the HBHA pond, since the wetlands contain a higher percent of fine-grained sediments and a lower percent of oxidized iron. These concentrations were further normalized for grain size variation by dividing each metal concentration by the percent of sediment below 125 microns within that sample. This data indicates that as distance from the source area increases, the concentration of arsenic generally decreases (Figure 3). However, all three indicator parameters showed increased concentrations in sample SED-23. Of the sediment samples collected during the GSIP Phase 2 RI, SED-23 appears to be an anomalous result, as it had the highest concentration of chromium but the lowest percentage of fine-grained sediment.

2.3 Task S-2. Sediment Volume and Geochemical Investigation Within the HBHA Pond

The HBHA pond is a 4.2-acre (17,000-square meter [m²]) pond constructed in the 1970s for flood control along the Hall's Brook Floodway. It is located 600 feet (180 meters [m]) and 1,500 feet (460 m) south-southwest of the South Hide Pile and East-Central Hide Pile, respectively, and 2,700 feet (820 m) south of the East and West Hide Piles. The HBHA receives surface-water flow from three major inputs: Hall's Brook, the Atlantic Avenue Drainway, and an unnamed drainage approximately 20 feet north of OW-17 (Figure 4). The HBHA also may receive waters from several small conduits along the eastern edge of the pond (runoff from Digital Equipment Corporation).

The objectives of the HBHA pond sediment geochemistry task were to determine the volume of affected sediment in the HBHA pond, determine the rate of ground-water recharge into the HBHA pond, and to examine the geochemistry of the HBHA pond sediment-pore water system.

2.3.1 Physical Characteristics of the HBHA Pond

2.3.1.1 Bathymetry

The water depth was sounded at 19 locations on October 8, 1991, by lowering a tape measure weighted with a 1-foot diameter disk. Water depths were recorded when the disk would advance no farther and varied between 2.2 and 13.7 feet. (Figure 5). The area encompassed by each contour interval was planimetered to calculate the total volume of the pond, which is estimated to be approximately 1.4 million cubic feet (39,000 cubic meters).

2.3.1.2 Sediment Depth

Sediment depths were determined (Figure 6) by advancing a 3/8-inch, 20-foot section of rebar into the sediment to the point of refusal. The sediment thickness data were contoured, the area of each contour interval was integrated, and the midpoint of each contour interval was used to estimate the sediment volume, which is approximately 29,000 cubic yards (22,000 cubic meters).

Sediment cores were collected and inspected visually for evidence of sedimentation (Section 2.3.1.3). Two distinct types of sediments were observed. The upper 1.4 feet (0.43 meters) consisted of a black, fine-grained ooze of water, silt and clay. Subjacent to this layer was a well-sorted tan sand. The contact between these two layers was distinct; the upper layer grades into the lower layer over less than a 1-inch interval. If the true detrital sediment is the black ooze, the post-construction deposited sediment volume is approximately 9,700 cubic yards (7,400 cubic meters) (Appendix D).

2.3.1.3 Geotechnical Measurements

2.3.1.3.1 HBHA Pond Sediment Sample Collection

Sediment cores were collected by lowering a 4-inch by 6-foot polyvinyl chloride (PVC) sampler to the water/ooze interface. A diver then positioned the sampler and a PVC riser so that the riser could be used to advance the sampler. The sampler was driven to refusal from a boat using a PVC slide hammer on the riser tube, the riser removed from the sampler, and the top of the sampler closed with a PVC cap. The core barrel was pushed to one side to break the suction between the sampler and the sediment and the sampler extracted from the sediment by means of a rope connected to the boat. As soon as the core cleared the sediment, the diver placed a PVC cap on the bottom end of the sampler, and the apparatus was transported immediately to shore.

On shore, the bottom end cap was removed carefully and the bottom of the core was inspected for sample loss. No sample loss was apparent in any of the cores. A 4-inch diameter plunger was inserted into the bottom of the sampler, the top cap removed, and the sample core extruded from the top of the sampler. As the core was extruded in approximately 2-inch lifts, discrete samples were collected in 8-ounce jars using a decontaminated stainless steel spoon. The sample interval was measured using the gradations marked on the plunger shaft. Table 12 shows the number of samples submitted for each analysis.

2.3.1.3.2 HBHA Pond Sediment Physical Characteristics

Two distinct sediment morphologies were observed in the HBHA pond. From the water/sediment interface to approximately 1.4 feet below the interface, the material consisted of a black suspension of fine-grained sediments (black ooze) subjacent to which (from 1.4 - 3.25 feet) was a tan medium-grained well sorted sand (Table 13). Six HBHA pond sediment samples were submitted to Particle Data Laboratories (PDL) for determination of fine-grained sediment size distribution by the electrozone method, and for determination of sediment surface area by the nitrogen BET sorption method. However, after receipt and inspection of the samples, PDL determined that the morphology of the samples (i.e., high water content, Table 13) and high organic compound content precluded the use of either method.

Particle size distribution was instead determined by wet sieving representative samples of each of the two characteristic sediments collected (e.g., the black suspension and the underlying tan sand). The upper sediment layer (SC-1-8) contained 70 percent silt and clay, while the lower layer (SC-1-11) contained 82 percent coarse to very fine sand (Table 14).

2.3.1.3.3 HBHA Pond Pore Water Sample Collection

Pore water samples were collected by installing equilibrators in the sediments (Figure 4). Each equilibrator consisted of a 120-centimeter (cm) x 7-cm x 7-cm polycarbonate block, containing forty-four 50-milliliter (ml) cells, spaced at 2-cm intervals. Before placement in the sediment, each cell was filled with deoxygenated, deionized water and a sheet of 0.45-micrometer (μm) filter placed over the open side of each cell. The filter was then clamped into place. Six equilibrators (3 pairs) were emplaced in the HBHA pond sediment by gently intruding each sampler vertically into the sediment. Where possible, all but the upper 10 to 15 cm (5 to 7 cells) of the equilibrator was advanced into the sediment (Figure 7).

The equilibrators were installed in the HBHA pond sediments on October 10, 1991, and recovered between November 19 through 21, 1991. The four-week period has been demonstrated by Carignan et al., (1985), and Davis and Galloway (1992) to be adequate for equilibration between sediment pore water and the equilibrator cells.

Upon recovery, each pair of equilibrators were transported to the field laboratory for immediate sample processing. The 0.45- μm membrane covering each cell was punctured, and pore water was extracted using a 60-ml disposable syringe. Samples for benzene, toluene, ethylbenzene, and xylene (BTEX) analysis were transferred immediately to two 20-ml glass VOA vials under zero-head space conditions. The field parameters (pH, electromotive force [emf]), temperature and specific conductivity) for selected cells were determined directly in the cells. Field-measured samples (alkalinity, Fe(II), Fe(III) and sulfide) were transferred into the appropriate glassware for immediate analysis. The remaining samples were then transferred from the cells into sample containers, compositing adjacent cells to obtain the minimum required sample volume for metals, nutrient, and anion analysis.

2.3.1.4 Ground-Water Discharge into the HBHA Pond

2.3.1.4.1 Collection Method

Ground-water discharge was estimated at three points (South Area [all Area 1 samples], North Area [all Area 3 samples] and the Seepage Meter 4 Area) in the HBHA pond by placing one seepage meter in each area (Figure 4). The seepage meters consisted of 1.9 feet (0.58 meters) diameter x 1.5 feet (0.46 meters) high cylinders, open at the bottom and connected to a Tedlar bag on the top (Figure 8). Prior to emplacement, each seepage meter was decontaminated with Alconox and deionized water. The open end of each meter was gently pushed into the sediment by a SCUBA diver and left open to equilibrate with ground-water discharge for four weeks, during which time water was allowed to flow, uncollected, out of the top of each seepage meter. Following the equilibration period, evacuated Tedlar bags were placed on each seepage meter and left undisturbed for a collection period of five to seven days. Four seepage meters were installed, but the Tedlar bag on the meter from the Central Area of the HBHA pond (sample SM-2) became disconnected from the seepage meter during the collection period, rendering the sample non-representative of discharging ground water.

Upon collection, the bags were transported to the field laboratory for immediate sample processing. Where possible, the seepage meter effluent samples were submitted for the same suite of analyses as the ground-water samples (Section 2.4.1). However, the range of analyses that could be performed on the seepage meter samples were limited by the volume of sample collected.

2.3.1.4.2 Discharge Rate Calculation

The volume of material collected from each seepage meter was used to calculate the ground-water discharge rate at that point. These rates were then applied to the area surrounding the three data points to estimate the total ground-water discharge to the HBHA pond, and to determine the portion of the entire HBHA pond water budget represented by ground-water recharge.

The ground-water flux into the HBHA pond at the measured points ranged between 6.9×10^{-4} ft³/ft²/day (0.21 liter per square meter per day [l/m²/day]) and 7.3×10^{-3} ft³/ft²/day (2.2 l/m²/day) (calculation shown in Appendix D). Based on the measured recharge rates from the seepage meters, the calculated average ground-water discharge rate for the base of the pond is approximately 720 ft³/day (20,000 l/day). The measured discharge of Hall's Brook into the HBHA pond was 2.79 cubic feet per second (ft³/s) (241,000 ft³/day or 6,748,000 l/day) on October 4, 1991 (Table 11). Based on these data (three discrete points), the average ground-water discharge from the base of the pond is approximately 0.3 percent of the total discharge into the HBHA pond over this measurement period.

It is noted that this percentage is low when compared with the ground-water discharge rate calculated from stream gauging measurements performed during this same period. Based on the October 4, 1991 surface-water flow measurements (Table 11), ground water discharging to the HBHA pond comprises approximately 15 percent (the percent difference between SW-10 and SW-13 discharge rates) of the total discharge from the HBHA pond. The surface-water gauging data provide a more comprehensive discharge rate for ground water into the HBHA pond, since these data incorporate total discharge rates for Hall's Brook and the HBHA pond, rather than discharge rates for discrete points within the pond.

2.3.1.4.3 Ground-Water Retention Time In Sediments

Assuming a sediment density of 1.1 grams per cubic centimeter (g/cm³) and an average water content of 90 percent, the porosity of the upper 1.4 feet (43 cm) of sediments is approximately 93 percent (Appendix D). Using the discharge rates listed in Table 15, the retention time of ground water in the upper 1.4 feet of sediment ranges between 170 and 1,800 days.

2.3.2 Sediment Pore Water Geochemistry

2.3.2.1 Major Geochemical Parameters

2.3.2.1.1 Eh/pH

The pore water pH ranged from 6.2 to 7.2 (Figure 9). The highest pore water pH occurred at the sediment/water interface, decreasing with depth in the sediment to 40 to 50 cm,

where the pH remained constant at approximately 6.2. The stabilization of pH between 40 and 50 cm coincides with the observed depth of the sand/ooze interface. The pH of the overlying water column also decreased with distance above the sediment/water interface (Figure 9).

An inverse trend from pH was observed for pore water Eh and overlying bottom waters, with an Eh minimum at the sediment/water interface (Figure 10). Both the overlying bottom water and the pore water increased in Eh with increasing distance from the sediment/water interface.

The agreement in Eh/pH measurements between adjacent equilibrators (i.e., EQ-1A and EQ-1B) within the South Area and between equilibrators from adjacent areas (Figure 11) (i.e., EQ-1A [South Area], and EQ-2A [Central Area]), demonstrates that the Eh and pH profiles are aerially consistent and that the geochemical processes controlling metal and organic distribution across the HBHA pond are similar. However, because the bulk chemistry of the ground-water discharge (measured in seepage meter samples and uppermost equilibrators samples) is laterally variable, the Eh and pH of the sediment-pore water system are probably controlled by local geochemical reactions in the sediment rather than by discharging ground water.

2.3.2.1.2 Total Organic Carbon in HBHA Pond Sediment

Total organic carbon is an effective scavenger of metals (e.g., arsenic, chromium) and neutral hydrophobic organic compounds (e.g., benzene), because it acts to retard the migration of these compounds in aquifers and sediments. Consequently, the total organic carbon content was determined for six sediment samples, which ranged from 0.02 percent in the tan sand layer to 13.4 percent at the sediment/water interface (Table 16, Figure 12). These data are consistent with typical diagenetic profiles within pond sediments. As the age of the sediments increases (corresponding to increasing depth) the TOC content decreases, due to the biodegradation of organic matter over time.

2.3.2.1.3 Dissolved Organic Carbon in HBHA Pond Pore Water

The dissolved organic carbon (DOC) concentration in the pore waters ranged between 6.8 mg/L and 247.5 mg/L. DOC concentrations decreased with depth in Areas 1 and 3, and increased with depth in the Central Area (Table 17). DOC was further characterized by resolving the total DOC into six fractions based on the solubilities and acid dissociation constants (pKa's) of the constituents. First, the DOC was separated into hydrophilic and hydrophobic fractions, each of which was further separated into acid, base, and neutral fractions. An average of 40 percent of the detected DOC was eluted in the hydrophilic acid fraction, representing the carboxylic and light fulvic acids, the fraction most likely to increase metal solubility by organic complexation (Table 17).

2.3.2.1.4 Water Content

The water content of the sediments provides the clearest demarcation between the tan sand sediments and the overlying black suspended sediments (Figure 13). The water content of the upper 30 cm of the black ooze layer contained between 84 and 92 percent water by weight, consistent with other measurements of sediment material (Berner, 1980). Between 30 and 50 cm depth, the water content decreased to 20 percent by weight. The interface between the black suspended sediment and the tan sand occurred at 36 cm, 50 cm, and 38 cm for Areas 1 (South), 2 (Central), and 3 (North), respectively, suggesting that, consistent with the observations of Wetzel (1975), the trough in the center of the pond has accumulated a greater thickness of sediment.

2.3.2.1.5 Iron

Iron concentrations in the pore waters of the HBHA pond ranged between 25 and 340 mg/L (Figure 14). The concentration of total iron in the pore water was consistent with equilibrium between the predominant aqueous iron species (Fe^{+2} , FeOH^+) and precipitating amorphous ferric hydroxide [$\text{Fe}(\text{OH})_3(\text{am})$] (Figure 11). In addition to determination of total iron, a field analysis for Fe(II) was performed on selected samples. The total iron concentrations and the corresponding Fe(II) concentrations were compared (Figure 15) and demonstrated that, on average, 92 percent of the dissolved iron was present as Fe(II), supporting the hypothesis that Fe(III)/Fe(OH)₃ (am) equilibria control iron solubility in the HBHA pond sediments.

Total iron concentrations in the HBHA pond sediments ranged between 11,000 and 190,000 mg/kg, decreasing with depth through the sediment profile (Figure 16). Examination of HBHA pond sediments by electron microprobe analysis identified both iron oxide and iron sulfide phases (Figure 17). However, the microprobe failed to detect co-precipitated arsenic or chromium within the detected iron phases, probably because the amorphous nature of the precipitate precludes quantification of trace metals by this method.

2.3.2.1.6 Lead

Lead has been detected at concentrations in excess of 10,000 mg/kg (Roux Associates, Inc., 1990) in the surface soils of the Site. However, ground-water concentrations of lead are low, ranging from <1 µg/L in OW-17, to 9 µg/L in OW-47 (Section 2.4). Similarly, pore water concentrations of lead ranged from < 1 µg/L to 3 µg/L, although the sediment concentrations of lead were as high as 1,200 mg/kg (dry weight) in the south end of the pond (Figures 18 and 19). These data are consistent with those of Davis and Galloway (1992), who demonstrated a high affinity ($K_{d_{pb}} = 6.7 \times 10^4$ to 6.7×10^5) of lead for organic-rich sediments.

2.3.2.2 Arsenic

Arsenic concentrations in the pore waters of the HBHA pond ranged from <0.01 mg/L to 5.4 mg/L (Figure 20). Sediment concentrations ranged from 9 mg/kg to 2,990 mg/kg (dry weight) (Figure 21). Assuming that equilibrium exists between analytes sorbed to sediment and interstitial water, and that metal sorption to sediments may be approximated by a linear isotherm passing through the intercept, data from both solid and aqueous phases may be used to determine a distribution coefficient for the constituent (Kd). The Kd is operationally defined as:

$$Kd = \frac{\text{sediment concentration}}{\text{equilibrium interstitial water concentration}} = \frac{(x/m)}{C_{iw}} \quad (\text{Eq.1})$$

where x/m is the mass [$\mu\text{g}/\text{mass of sediment (g)}$], and C_{iw} is the concentration in the pore water ($\mu\text{g}/\text{ml}$). The Kd value is indicative of the sorptive capacity of the sediment; the higher the Kd, the lower the aqueous concentration and the slower the migration of the constituent of interest.

A Site-specific distribution coefficient can be calculated from the total analyte concentration in the slurry ($C_{anal,tot}$), the analyte concentration in the interstitial water (C_{iw}), and the moisture content of the slurry (mc). The mass of interstitial water (m_{iw}) in the slurry sample may be computed (Eq. 2) from the moisture content and the total mass of the slurry sample (m_{slurry}), and the mass of the solid phase (sediment less interstitial water, m_{sed}), calculated by difference (Eq. 3).

$$m_{iw} = m_{slurry} * mc \quad (\text{Eq. 2})$$

$$m_{sed} = m_{slurry} - m_{iw} \quad (\text{Eq. 3})$$

The total mass of analyte in the interstitial water ($m_{anal,iw}$) is:

$$m_{anal,iw} = C_{anal,iw} * m_{iw} \quad (\text{Eq. 4})$$

assuming that the density of the interstitial water is 1 g/cm³. The mass of analyte sorbed to the solid phase ($m_{anal,sed}$) is equal to the total mass ($m_{anal,tot}$), less the mass of analyte in interstitial water, i.e.:

$$m_{anal,sed} = m_{anal,tot} - m_{anal,iw} \quad (\text{Eq. 5})$$

where:

$$m_{anal,tot} = C_{anal,tot} * m_{slurry} \quad (\text{Eq. 6})$$

The concentration sorbed (on a dry weight basis) is then:

$$(x/m) = \frac{m_{anal,sed}}{m_{sed}} \quad (\text{Eq. 7})$$

so the distribution coefficient (ml/g or l/kg) is therefore:

$$Kd = \frac{(x/m)}{C_{iw}} \quad (\text{Eq. 8})$$

Pore water concentrations were plotted, and a curve was fitted to the data. The pore water concentrations corresponding to the depths at which sediment data were collected were interpolated from the curve, and used in conjunction with the directly determined sediment data to calculate the Kd_{As} values (Figure 22). Kd_{As} ranged from 45 l/kg in the sand to nearly 8,000 l/kg in the ooze and were generally highest at the north end of the pond, where iron concentrations were greatest. While arsenic concentrations in the sediments were similar in the North, Central and South Areas of the pond (Figure 21), the pore water concentrations in the North Area were an order of magnitude lower (Figure 20) than in the Central and South Areas, indicating that the axis of the arsenic plume is intersecting the HBHA pond near the Central Area.

The concentration of arsenic in the sediments decreased with depth. The highest concentrations (2,990 mg/kg, 3.2 cm depth, Central Area) were detected in the upper 25 cm of the sediment, and the lowest concentrations (9 mg/kg, 72 cm depth, Central Area) were detected in the sand below 50 cm (Figure 21).

The arsenic speciation data (Table 18) indicate that except for the seepage meter sample collected at the South Area (SM-1), arsenic is present as As(III). However, the seepage meter samples were not filtered and may have contained some suspended sediments. No methylated species of arsenic (i.e., DMA and MMA) were detected in the pore waters of the HBHA pond.

2.3.2.3 Chromium

Chromium concentrations in the pore waters ranged from <0.003 mg/L to 0.2 mg/L (Figure 23). Sediment chromium concentrations ranged between 9 mg/kg to 1,400 mg/kg (dry weight) (Figure 24). The distribution coefficient for chromium, Kd_{Cr} , was calculated as described in Section 2.3.2.3. Above -40 cm, the Kd_{Cr} exceeded 10,000 l/kg, reaching a maximum of 55,000 l/kg, between -35 cm and -20 cm (Figure 25).

Because each equilibrator cell contained only 50 ml of sample, adjacent cells were combined for total chromium analysis and determination of Cr(VI), inorganic Cr(III) and organically-bound Cr(III) species (Appendix D). No Cr(VI) was detected in the pore waters (detection

limit of 10 $\mu\text{g/L}$), so all the total chromium detected was Cr(III), primarily organically bound (Table 19, Figure 26).

The vertical distribution of chromium in both the pore waters and the sediment was similar at all three sample locations. The highest concentrations occurred at the sediment/water interface and decreased with depth to between -40 and -50 cm. The high concentration of metals in the bulk sediment at the sediment-water interface are probably due to adsorption of chromium to amorphous ferric hydroxide consistent with the high concentration of iron (147,000 mg/kg, SC-2-1) at this depth. While the highest pore water concentration of chromium was observed in the North Area (202 $\mu\text{g/L}$, EQ-3B-10, 14, collected at -10 cm), the pore concentrations of chromium were generally higher in the Central Area (<3 $\mu\text{g/L}$ - 143 $\mu\text{g/L}$) than in the South and North Areas (11.6 $\mu\text{g/L}$ to 64.7 $\mu\text{g/L}$ and 7.1 $\mu\text{g/L}$ to 202 $\mu\text{g/L}$, respectively), indicating that the axis of the chromium plume is intersecting the HBHA pond near the Central Area.

2.3.2.4 Benzene

The benzene concentrations in both the pore water and sediment of the North Area were over an order of magnitude higher than in the South and Central Areas (Figures 27 and 28). Benzene concentrations in the seepage meters (Table 20) were slightly higher in the South Area (0.15 mg/L) than in the North Area (up to 0.12 mg/L). No seepage meter sample was collected from the Central Area due to equipment failure. The seepage meter sample collected from the North Area was 100 times less concentrated than the pore water sample collected at the same location at the sediment/water interface, suggesting that remnant surface water in the seepage meter may not have fully flushed prior to installation of the Tedlar collection bag. The vertical distribution of benzene in the North Area pore water demonstrated the same profile as the other target analytes, i.e., the highest benzene concentrations occurred at the sediment/water interface, consistent with the TOC data, and that both benzene (Figures 27 and 28) and TOC concentrations decreased with depth. The vertical distribution of benzene in the Central and South Areas showed a similar profile but at lower concentrations, demonstrating that the axis of the benzene plume is intersecting the HBHA at the Northern end of the pond.

The benzene distribution coefficient Kd_{benzene} was calculated as described in Section 2.3.2.4. Kd_{benzene} ranged between 10 and 900 (Figure 29). The Northern HBHA pond sediments exhibited the highest Kd_{benzene} values, even though pore water benzene concentrations were highest in this area.

Biodegradation of benzene in the sediments may result in decreases in sediment and pore water concentrations. To test if biodegradation of benzene is occurring in the HBHA pond sediments, cultures of bacteria from the HBHA pond sediments were exposed to nutrient media spiked with benzene at 100 mg/L. Following a four day incubation period, cell counts were made on both the spiked and unspiked nutrient media.

The results indicate that cell counts in the benzene spiked media were consistently higher than in the unspiked media (Figure 30) and that the ooze contains bacteria capable of thriving at high concentrations of benzene. At least six different species were observed on the tryptic soy agar (TSA) plates (based on colony size, color and surface structure). Approximately 3 percent of the cells in the North sediment sample at 50 cm below the sediment/water interface which were counted on TSA were also able to grow on benzene agar. In the sample from 32 cm, 5 percent of the cells, and in the sample from 7 cm below the interface, 24 percent of the cells were capable of living in a benzene atmosphere, demonstrating an increased capacity for benzene utilization with increased benzene concentration (Figure 30). The specificity for benzene as a primary substrate of at least 60 percent of the cells is apparent because only 40 percent of the total cells grew on mineral salts agar in the absence of benzene. The few cells on the control plates seemed to live on agar impurities. The fact that the number of colonies on benzene agar is higher than on mineral salts agar indicates that bacterial species in the sediment have the specificity and the capability to degrade benzene, that the microbiota has adjusted to the ambient benzene levels, and that the consortium can utilize benzene as a primary substrate. In addition, the increase in microbial counts in the upper portion of the sediment profile indicates that biodegradation may be occurring at a greater rate in the near surface sediments.

2.3.2.5 Acid Volatile Sulfides (AVS)

AVS is a measurement of sulfide bound in the sediment in monosulfide minerals such as FeS and PbS, but does not account for any sulfide bound into disulfide minerals such as pyrite FeS₂. The presence of AVS was both measured analytically and observed visually in the sediment during microprobe work. Assuming that all the AVS occurs as FeS, up to 27 percent of the total iron in the sediment could be incorporated into AVSs. The amount of chromium, arsenic and lead that were coevolved with AVS, were also measured (Tables 21 and 22) and accounted for between 18 percent to 48 percent of chromium, and 25 percent to 57 percent of the lead in the sediment. By contrast, only 1 to 7 percent of the arsenic in the sediment was to evolve with the AVS.

The presence of AVS is important in understanding controls on metal solubility in the sediment. Geochemical modeling using the program MINTEQA2 has demonstrated that AVS appears to be controlling lead, zinc and iron solubility, at least in the Central Area sediment (Table 23). In addition, the presence of PbS and FeS₂ has been verified in microprobe observations of the sediment (Figure 17). Consequently, the generation of diagenetic sulfide in the sediment may be an important reservoir of immobile lead and chromium in the sediment. Because aqueous sulfide was also measured in the sediment pore waters, a reservoir of excess sulfide is available to precipitate additional AVS minerals, as chromium, iron and lead migrate from ground water discharging through the sediments of the HBHA pond. Consequently, the low solubility of these metals will be maintained as long as reducing conditions prevail in the HBHA pond sediments.

2.3.2.6 Geochemical Modeling in the HBHA Pond Sediments

Pore water analytical results were entered into the MINTEQA2 geochemical model to determine if metal solubility may be constrained by precipitating solid phases in the HBHA pond sediments the potential precipitates that may control target metal solubility. MINTEQA2 is a geochemical equilibrium speciation model capable of computing equilibria among dissolved, adsorbed, solid, and gas phases in environmental settings. The model calculates ion speciation, activity coefficients, mineral precipitation and dissolution, adsorption, and mass transfer. The calculations are based on an extensive, well-documented, thermodynamic database of equilibrium binding constants, redox reactions, adsorption reactions, and mineral solubility. The model uses a Newton-Raphson approximation method

to successively approximate the solution to the set of mass balance equations. The program is written in FORTRAN 77 and is compiled using a Ryan MacFarland FORTRAN compiler (version 2.45).

MINTEQA2 performs speciation calculations by simultaneously solving equations that represent formation of ion pairs, complex ions, and solids, using an extensive database of internally consistent values that includes most complexes and solids for which thermodynamic data are reported in the literature. The potential for mineral precipitation or dissolution is assessed using the saturation index (SI) which is based on the relation between analyte activities (the ion activity product, IAP) and the thermodynamic calculation of the solubility product (K_{sp}). The SI of a mineral is determined using the equation:

$$SI = \log_{10} \frac{[IAP]}{[K_{sp}]}$$

If the SI is greater than zero, the solution is theoretically oversaturated with respect to the solid, and may precipitate. If the SI is less than zero, the solid is undersaturated with respect to the solution, and, if present in the system, will dissolve. At $SI = 0$, the solid and solution are in equilibrium and neither dissolution nor precipitation is predicted to occur.

Not all solids with an SI greater than zero can be realistically expected to precipitate from every system. Some solids are known to occur only in high pressure and/or high temperature environments and should not be considered in systems where near-surface conditions exist. Solid phases that may control iron concentrations in the HBHA pond sediments include ferrihydrite $[FeO(OH)]$ and pyrite (FeS_2) . Aluminum concentrations may be controlled by the solubility of gibbsite $[Al(OH)_3]$, while chromium solubility may be controlled by $Cr_{0.25}Fe_{0.75}(OH)_3$.

Uncertainties in the MINTEQA2 calculations are related to five factors: 1) the quality of the thermodynamic data; 2) calculation of activities from concentrations; 3) inclusion of all relevant aqueous species in the model; 4) the quality of the water analyses used in the calculations; and 5) kinetic limitations on attainment of equilibrium. The thermodynamic database used was distributed with the USEPA-approved MINTEQA2 model, has been successfully applied to a variety of geochemical problems, and has been thoroughly

examined by the USEPA for internal consistency (Allison et al., 1991). In these calculations, a modified Debye-Hückel expression was used to calculate the activity coefficients for each species that is reliable up to ionic strengths of 0.5 molar (Allison et al., 1991). All the ionic strengths of the waters in these calculations are less than 0.1 molar, with the exception of well OW-12, which has an ionic strength of 0.4 molar. Therefore, all calculations are within the range of ionic strength over which it is appropriate to calculate equilibrium activities using the modified Debye-Hückel expression.

In modeling HBHA pond sediments, the SI's of selected solid phases were calculated and used to determine whether these solids could be controlling metal solubility. The partial pressure of $O_{2(g)}$ was fixed based on the DO measurements and alkalinity data used to specify the partial pressure of $CO_{2(g)}$. All dissolved iron was entered as Fe(II), the dominant form in the pore waters. Manganese was entered as Mn (II) and chromium as Cr(III).

A useful rule of thumb is that extreme over-saturation, i.e., SI values $> +5$, may indicate that solid phase precipitation has not occurred due to kinetic inhibition. Actual mineral precipitation is generally indicated by SI values that are within ± 1 of zero.

Three samples were modeled for which speciated charge imbalances were < 10 percent to ensure that only reliable analytical data was employed in data interpretation. Two were pore waters in the ooze at the South and Central Areas, and one pore water from the tan sand layer (composited from pore-water samples collected below 45 cm in the North and Central Areas). The model indicates that these waters were saturated with respect to ferrihydrite, gibbsite, amorphous chromium hydroxide, and additionally in the Central Area, pyrite (FeS_2) and pyrrhotite (FeS) (Table 23). No obvious differences between the SI's of the pore waters in the ooze and sand were apparent.

2.3.2.7 Conclusions

This investigation of sediment geochemistry in the HBHA pond has demonstrated that two distinct layers of sediment are present in the pond consisting of approximately 0.4 meters of black, gelatinous, organic ooze overlying a tan medium-grained sand. The geochemical conditions of the ooze and sand are pH neutral and moderately reducing as evidenced by the presence of aqueous sulfide, As(III), Cr(III) and Fe(II). As previously discussed, arsenic

and chromium in ground water are discharging into the HBHA pond in the Central Area. These data also indicate that benzene in ground water is discharging into the northern end of the pond (Figures 27 and 28). The HBHA pond sediments act as a sink for these constituents by filtering metals out of recharging ground water, based on the high K_d values for arsenic, chromium and lead and the precipitation of lead sulfide. Pore water benzene concentrations are reduced by partitioning into organic carbon and perhaps also by biodegradation by a viable microbial community.

2.4 Tasks M-1 and M-2. Metals Mobility Study

The objectives of the GSIP Phase 2 RI Metals Mobility Study were to collect data to support or refute the geochemical paradigm described in the GSIP Phase 1 RI Final Report. These data include physical parameters (e.g., Eh, pH), ground-water geochemistry, and speciation of metals of concern (e.g., arsenic and chromium). These objectives were achieved by: 1) obtaining additional metals speciation data in ground water; 2) validation of the geochemical paradigm and the mechanism controlling metals mobility; and 3) analyses of aquifer materials for metal attenuation properties.

2.4.1 Ground-Water Geochemistry

The following sections describe the data collected to verify the Geochemical Paradigm (Figure 31). Each parameter is described in terms of its significance relative to the metals mobility study, and the results in terms of metal mobility are discussed. Interpretations are supported by geochemical modeling using MINTEQA2 (Felmy et al., 1984; Allison et al., 1991), aqueous speciation of selected analytes, and electron microprobe analysis of aquifer materials.

Fe(II)/Fe(III)

The Fe(II)/Fe(III) ratio is useful in assessing the redox state of the Site ground water. Under reducing conditions, iron exists in the ferrous state [Fe(II)]. Upon exposure to oxygen, Fe(II) is oxidized to Fe(III), and may precipitate to rapidly form insoluble ferric hydroxide (Sung and Morgan, 1980). Ferric iron, [Fe(III)] is insoluble unless the pH of the water is less than 3.5, or unless complex formation with anionic species increases solubility.

The distribution of Fe(II) in the Study Area (Figure 32) confirms the geochemical paradigm that reducing conditions exist downgradient of the hide piles. Specifically, the presence of Fe(II) > 1 mg/L is indicative of anoxic ground water. This zone corresponds to the region that can be considered "moderately reducing" and lies between the extremely reducing zone (characterized by Fe(II) > 5 mg/L and dissolved sulfide over 1 mg/L) and the oxygenated zone away from the hide piles (characterized by Fe(II) < 0.1 mg/L and dissolved oxygen above 1 mg/L).

In oxygenated zones, the distribution of dissolved iron controls the solubility and mobility of metals because Fe(II) will oxidize rapidly and precipitate as Fe(OH)_{3(s)} (Sung and Morgan, 1980). Precipitation of Fe(III) from solution has been shown to be an effective method of removing arsenic from solution, particularly at the near-neutral pH values typical of ground water within the Study Area (Pierce and Moore, 1980; Pierce and Moore, 1982; Robins and Huang, 1988). The oxidation and subsequent precipitation of ferrous iron in the aquifer will remove arsenic from solution via adsorption and coprecipitation, as illustrated by comparing the distribution of dissolved Fe(II) (Figure 32) and dissolved arsenic (Figure 33).

Sulfide

Sulfide is often present in ground water, usually a result of the bacterial decomposition of organic matter and/or the reduction of sulfate. The presence of dissolved sulfide species (S⁻², HS⁻ and H₂S) in ground water downgradient of the hide piles is consistent with the paradigm, which postulated that aqueous sulfides would be present within the aquifer (Figure 31). The reducing environment within the hide piles, coupled with the presence of hydrogen sulfide gas, is also consistent with the presence of aqueous sulfide species in ground water. Sulfide controls metal solubility by forming sparingly soluble precipitates with Zn⁺², Pb⁺², Fe(II) and Cu⁺².

Dissolved Oxygen

Dissolved oxygen (DO) sometimes provides useful information when characterizing ground-water oxidation-reduction (redox) potentials (Eh). For the dissolved oxygen concentration to serve as an accurate indicator of the redox conditions of the aquifer, other dissolved multivalent constituents must be present in negligible concentrations, and the system must

be at or near equilibrium (Freeze and Cherry, 1979). Measurable oxygen in the ground water indicates an oxidizing environment in which multivalent metal species should occur predominantly in the oxidized form.

Although all DO measurements were taken under zero headspace conditions in a flow-through cell, measurable oxygen was detected in all wells despite high levels of sulfide and Fe(II), suggesting that the low measurable DO concentrations in these wells resulted from oxygen that was entrained in ground water during well purging. The low oxygen concentrations measured in background wells OW-15 (0.7 mg/L) and OW-1A (1.2 mg/L), also indicate that the regional aquifer may have naturally low DO concentrations.

Although the low DO concentrations measured in the reduced ground-water plume are consistent with the other redox indicators (e.g., the presence of Fe(II) and sulfide above 1 mg/L), the low regional DO and the apparent introduction of DO during pumping render this parameter of limited utility in predicting redox trends at the Site.

Eh/pH

Low Eh values (e.g., < 0 mV) are indicative of reducing conditions and a high availability of electrons for chemical reactions, while low pH is representative of the high availability of protons for reaction. Both parameters are critical to precise geochemical interpretation of an aqueous system, because metal solubility is controlled by the ground water Eh and pH conditions.

The background Eh values measured in wells OW-1A (410 mV) and OW-15 (380 mV) are indicative of moderately reducing conditions (Figure 34). The only negative Eh values were measured in OW-41 (-89 mV) and OW-12 (-72 mV), and are representative of the extremely reducing conditions resulting from decomposition of organic material (hide piles) at these locations.

Generally, pH is elevated in the more reducing zone (Figure 35). The highest pH (8.4) was detected in well OW-36, immediately downgradient from the West Hide Pile, while the lowest pH (5.6) was measured in OW-33A, much further downgradient from this source.

In addition, the pH measurements from background wells OW-1A (6.6) and OW-15 (5.9) suggest that the background pH of the Site ground water is slightly acidic.

Dissolved Organic Carbon

Figure 36 illustrates the relative distribution of DOC in the Site ground water. The dominant organic carbon fraction was hydrophilic acids, which accounted for approximately half of the total DOC in the water, with hydrophobic acids accounting for another 25 percent (Figure 37). Both of these organic acid components are characterized by the presence of carboxyl groups in their structure. At neutral pH, these negatively charged groups have the potential to attract and bind positively charged groups, and thus may solubilize metal cations.

Alkalinity

Alkalinity is a measure of the acid-neutralizing capacity of a water sample. Because alkalinity is generally the result of carbonate species, it is typically reported as mg/L CaCO₃. To evaluate alkalinity, a sample of ground water from OW-16 was titrated by a stepwise acid titration, and the resultant curve evaluated by a Gran's plot (Stumm and Morgan, 1970). Gran's plots transform the titration data so that linear plots are generated, with endpoints indicated by the intercepts with the X-axis. The initial titration yielded only a single inflection point at a pH of 4.5, indicating that bicarbonate alkalinity was the dominant component (alkalinity of 11,250 mg/L CaCO₃). The Gran's plots supported this interpretation because linear plots indicated a single component system (i.e., carbonate), and the intercept confirmed the bicarbonate endpoint (Figure 38). This demonstrates that carboxylic and hydroxylic acids were not contributing to the total alkalinity in the Site ground water (Figure 39).

Nitrogen

The nitrogen chemistry of the aquifer was evaluated by measuring ammonia, nitrate and nitrite concentrations in ground water. Ammonia is generally present in ground water from deamination of organic nitrogen-containing compounds, or from the reduction of nitrate under anaerobic conditions (APHA, 1989).

The high concentration of ammonia present in the ground water below and immediately downgradient from the hide piles (e.g., 2,300 mg/L in OW-16, 400 mg/L in OW-31 and 7,900 mg/L in OW-12, Figure 40) are consistent with the deamination of organic compounds (e.g., hide proteins) under anoxic conditions (APHA, 1989).

Nitrate was measured above the 0.1 mg/L detection limit only in well OW-41 (0.31 mg/L). Nitrate was found at 0.66 mg/L and 0.15 mg/L in background wells OW-1A and OW-15, respectively (Appendix D), and never exceeded 1.88 mg/L (OW-31).

2.4.2 Metals Speciation

One objective of the GSIP Phase 2 RI Metals Mobility Study was to measure the parameters that are most important in controlling the aqueous migration of metals in Site ground water. Previous sections have described the Eh, pH and general aqueous chemistry of the Site ground water. The following section describes the results of the speciation analysis for the metals of concern (i.e., arsenic and chromium) and evaluates their actual and potential mobility in terms of the geochemical conditions of the Site ground water. Direct analytical methods were used to measure the chromium species Cr(VI), labile Cr(III), organically complexed Cr(III), and the arsenic species As(III), As(V), MMA, and DMA. These data have resulted in a validation of the original Site paradigm for metals mobility (reviewed in Section 2.4.1).

Arсенic

In accordance with the GSIP Phase 2 RI Work Plan, preliminary analyses of ground water from Observation Well OW-16 were conducted to determine whether arsenic was present as arsenate [As(V)], arsenite [As(III)], monomethylarsonic acid (MMA), or dimethylarsinic acid (DMA). These analyses demonstrated that 25 percent of the total arsenic in OW-16 was present in the methylated form. As a result, all ground-water samples were analyzed for both inorganic and methylated species at Battelle Laboratories, Northwest. Sample collection, handling, and preservation for the arsenic speciation analysis are detailed in Appendix A.

Acidification of the samples was not recommended for the As(III)/As(V) analysis. However, even under zero headspace conditions, iron precipitated rapidly, and in some cases, removed arsenic from solution. Consequently, the arsenic speciation data have been used qualitatively to determine the important arsenic species, and the total arsenic data (Figure 33), determined following CLP protocol, were used for quantitative interpretation.

The highest concentrations of total arsenic were detected immediately downgradient of the hide piles (2,800 $\mu\text{g/L}$ in OW-43, and 2,300 $\mu\text{g/L}$ in OW-16), decreasing with distance from the latter (Figure 33).

MMA was the only organic arsenic form detected above the 1.9- $\mu\text{g/L}$ detection limit probably due to microbial reduction of inorganic arsenic. A maximum value of 417 $\mu\text{g/L}$ MMA was detected in OW-16 (Figure 41). Comparisons of the distribution of MMA and sulfide (Figure 32) in ground water indicates that the generation of sulfide and methylated arsenic aqueous species are related. However, where MMA is present, it never represents more than 20 percent of the total arsenic concentration. Measurements of arsenic adsorption to sediments have indicated that MMA is more mobile than either of the inorganic forms of As(III) or As(V) (Holm et al., 1980) (Figure 42).

The less extensive distribution of MMA compared to total arsenic, despite the greater mobility of MMA, suggests that MMA is demethylated once it leaves the sulfidic ground waters. This interpretation is consistent with the Site paradigm, which hypothesized that methylated arsenic was formed in the reduced zone but was later oxidized in the higher-Eh zones away from the hide piles. These data are important to metals mobility considerations, because they demonstrate that outside the ground-water zone containing more than 1 mg/L sulfide: 1) the most mobile form of arsenic, DMA, is not present at measurable concentrations; and 2) MMA is not a stable form of arsenic.

Chromium

The investigation of chromium in ground water was designed to identify the form of aqueous chromium at the Site. This characterization focused on two types of analysis: 1) valence-state-specific analysis to determine whether Cr(VI) was present in solution; and 2) speciation analysis to measure the labile (e.g., Cr(III) hydroxide complexes) and organically complexed

concentrations of Cr(III). Samples for Cr(VI) analysis were analyzed on a daily basis to meet the 24-hour holding time requirement and the organic/ionic Cr(III) samples fractionated in the field (Appendix A). An important component of the Cr(III) analysis was the DOC fractionation analysis described in Section 2.4.1. In particular, the hydrophilic and hydrophobic acids have negatively charged sites at neutral pH that form strong aqueous complexes with metal cations such as Cr(III).

An aliquot of each filtered ground-water sample was passed through a Chelex-100 column that removed cationic Cr(III) from the solution but allowed passage of both anionic Cr(VI) and organically complexed Cr(III). The concentration of aqueous organic-Cr(III) complexes was then determined from the difference between the total chromium eluted from the Chelex-100 column and the Cr(VI) analyzed in the original sample. Because Cr(VI) was not detected in any column effluent samples ($< 1 \mu\text{g/L}$), only organic Cr(III) is present in Site ground water (Figure 43).

Although Cr(III) is generally insoluble in natural waters (approximately $1 \mu\text{g/L}$), its solubility is higher in the presence of dissolved organic acids (Figure 44) which were detected in the Site ground water at concentrations several times higher than chromium. Finally, field separations of ionic and organic Cr(III) demonstrated that virtually all of the dissolved chromium was present as organically complexed Cr(III) (Figure 43).

2.4.3 Analysis of Aquifer Materials

In this task, TOC content and cation exchange capacity data were collected to assess the attenuation capacity of the soil, and microprobe analyses were undertaken on soil samples to identify specific solid phases that may control metal mobility. Microprobe analysis provides mineralogic information to support the geochemical computations describing mineral precipitation reactions and metal solubility controls.

Samples were collected from two locations in the saturated zone downgradient from the East-Central Hide Pile. Sample SM-53B was collected during installation of Observation Well OW-53B located on the geochemical perimeter of the ground-water plume originating at the East-Central Hide Pile. Sample SM-12 was collected during drilling of the OW-54

cluster (near OW-12), and near the center of the same plume. All samples were obtained from drilling cuttings.

Cation Exchange Capacity

Metal migration in ground water is attenuated by ion exchange reactions within the saturated aquifer material. Thus, the migration rate of cations (e.g., Cr^{3+} , Pb^{2+}) may be related to the cation exchange capacity (CEC), which approximates the upper limit of readily exchangeable ion concentrations in the soil. Consequently, spatial variability in CEC along the ground-water flow path may indicate if retardation varies along the axis of a plume.

The values observed in the Industri-Plex materials, 2.0 milliequivalents (meq)/100 g (OW-12) and 5.59 meq/100 g (OW-53B), are consistent with the actual clay content of the soils (Table 24). As the clay content increases by a factor of 7 (i.e., from 2 to 14 percent) between soils OW-12 and OW-53B, the CEC values increase by a factor of 2.8 (i.e., from 2.0 to 5.59 meq/100 g). However, the low CEC in both samples of aquifer material suggests that ion exchange reactions in these soils will not control metal migration in the shallow aquifer (Table 24).

Total Organic Carbon

The adsorption and retardation of metals and organic compounds in aquifers are frequently controlled by the amount of total organic carbon (TOC) in the aquifer (USEPA, 1985 and Karickhoff, 1984). At the Industri-Plex Site, the hide piles are a significant localized source of organic carbon. Retardation of both metal and organic solutes may be affected by the fraction of organic carbon in the soil.

The samples of aquifer material collected from the Industri-Plex Site contained TOC of 0.12 percent (SM-12) and 6.71 percent (SM-53B), indicating that TOC varies widely in the aquifer (Table 25). The high TOC (6.71 percent) measured in SM-53B is either due to organic carbon in the adjacent hide pile or to the presence of high DOC concentrations (100 to 200 mg/L). Based on these data, retardation could vary by more than a factor of 50 between these two soils.

Mineralogy

The two samples of aquifer material collected from below the water table at OW-12 and OW-53B were analyzed using a JEOL 8600 wavelength-dispersive electron microprobe (Appendix A) to identify the major mineral phases and their paragenetic relationships. The microprobe analysis was used to: 1) directly identify mineral phases that may be affecting metal mobility; 2) support the results predicted by the aqueous geochemical modeling by identifying authigenic (i.e., formed in place) phases that the modeling predicts to be supersaturated; and 3) identifying spatial paragenetic relationships between the various phases that may relate to metal transport inferred from geochemical modeling.

Figure 45 is a photomicrograph of the sample from OW-53B showing a primary mineral grain of CaCO_3 surrounded by precipitated CaSO_4 , and a non-stoichiometric iron oxide (indicated as Fe(O) on the photomicrograph). The large black circle on the left half of the picture labeled CH_2O is a particle of natural organic carbon, possible coal or decaying plant matter. Scans of additional grains in this material also identified CaCO_3 and iron oxide rinding iron silicates. Figure 45 also shows a mixed metallic sulfate phase ($\text{Fe, Cu, As, Ag, Zn, SO}_4$) that may be acting as a potential solubility constraint phase for arsenic. Stoichiometric arsenic precipitates were not observed, suggesting that arsenic is attenuated primarily by adsorption to iron phases in the aquifer.

The microprobe analyses clearly demonstrate that several minerals, including CaCO_3 , $\text{CaSO}_4 \cdot \text{H}_2\text{O}$, and iron oxides are precipitating in the aquifer. These phases are important, because they are capable of removing metal from solution by coprecipitation (solid solution) and adsorption. This is particularly true of the iron oxides, which are effective at removing both anions and cations from solution. Consequently, precipitation reactions are likely to be partially responsible for the rapid attenuation of arsenic (Figure 33) and chromium (Figure 46) downgradient from the hide piles.

2.4.4 Results

The most important factors controlling metals mobility are the aqueous concentrations of dissolved organic carbon (DOC), dissolved sulfide, and dissolved Fe(II) . The DOC primarily contributes to metal mobility by forming aqueous complexes that enhance the solubility of Cr(III) . The dominant organic carbon fraction was hydrophilic acids, which accounted for

approximately half of the total DOC in the water, with hydrophobic acids accounting for another 25 percent. Both of these organic acid components are characterized by the presence of carboxyl groups in their structure. At neutral pH, these negatively charged groups have the potential to attract and bind positively charged ions, and thus may solubilize metal cations.

Dissolved sulfide controls metal solubility by forming sparingly soluble precipitates with Zn^{+2} , Pb^{+2} , $Fe(II)$ and Cu^{+2} . Arsenic transport is enhanced by methylation reactions occurring in the water with sulfide above $1 \mu g/L$, but is retarded where sulfide concentrations are below $1 mg/L$ (i.e., oxidizing conditions).

$Fe(II)$ limits metals mobility through oxidation of dissolved $Fe(II)$ and subsequent precipitation as $Fe(OH)_{3(s)}$ in the ground-water plumes downgradient from the hide piles, which removes arsenic and chromium as adsorbed or coprecipitated phases.

Data collected during the GSIP Phase 2 RI and the results of MINTEQA2 modeling demonstrate that arsenic mobility is largely controlled by the redox conditions of the ground water beneath and downgradient of the hide piles. Detailed analysis of redox parameters conducted in the metals mobility study indicated three distinct ground-water redox zones exist downgradient of the hide piles; extremely reducing, reducing, and oxidizing. In the highly reducing ground waters downgradient from the hide piles, arsenic is most mobile due to the presence of methylated arsenic and the decrease in iron hydroxide adsorption sites due to the formation of FeS precipitates. However, farther downgradient, arsenic will be removed from solution by coprecipitation or sorption as iron oxides precipitate.

The geochemical model MINTEQA2 was used to model the solubility and distribution of species in Site ground water. The pH and Eh values and Site ground-water chemistry data in conjunction with the measured concentrations of redox couples, e.g., $Fe(II)/Fe(III)$, SO_4^{-2}/S^{-2} , NH_4^+/NO_3^- and $Cr(OH)_2^+/CrO_4^{-2}$ for 11 different ground waters along transects A-A' and B-B' (Figure 47) were used as input for the model. In these calculations, only waters with special charge balances less than 10 percent were included to ensure that only reliable analytical data were employed in data interpretation. Redox pairs were decoupled in these simulations because each parameter was measured, obviating the necessity to force

internal equilibrium. In addition, no minerals were allowed to precipitate, and no sorption routines were incorporated in the computations to allow an evaluation of minerals and solid phases that may control metal solubility in the subsurface. Saturation indices (SI's) were calculated for selected solids that may control metal solubility in Site ground waters. The SI's were evaluated to assess dissolution/precipitation controls on metal mobility in the aquifer.

Saturation indices of ferrihydrite, dolomite, calcite, gibbsite, FeS, FeS₂, ZnS, PbS, CaSO₄, amorphous Cr(OH)₃, Cr(OH)₃, FeCr₂O₄ and As₂S₃ for all wells are shown in Table 25. Metals of interest were not detected in some wells, so SIs were not calculated for those samples. Cross sections showing SI variation for selected solids along the two transects are shown in Figure 48 through 53.

Where sulfide was detected (e.g., Observation Wells OW-12, OW-16, OW-17, OW-32 and OW-41) FeS, ZnS, and FeS₂ (pyrite) are in equilibrium with the ground water, and control the solubility of these metals (Figures 48 and 49). The solution is highly oversaturated with respect to pyrite where sulfide is present (SI > 15), indicating that FeS, not pyrite, is controlling iron solubility (Figures 48 and 49), because FeS is closest to an apparent equilibrium condition (Table 25). In the strongly reducing zone, the high alkalinity results in oversaturation of carbonate minerals (e.g., calcite). The hide piles are also a likely source of Mg⁺² (due to MgCO₃ used in tanning), resulting in coincident dolomite [(CaMg)(CO₃)₂] over saturation (Figures 50 and 51). Gypsum and calcite are at, or close to saturation in OW-47 (Transect A-A', in good agreement with the microprobe analysis of OW-53B aquifer materials).

In wells with no detectable sulfide, ferrihydrite saturation controls iron solubility (Figures 50 and 51). Carbonate minerals are undersaturated due to the lower alkalinity. Iron concentrations are higher in sulfide-free zones due to the lack of precipitation of highly insoluble sulfide minerals (Figure 49).

Arsenic mobility is theoretically constrained by precipitation of orpiment (As₂S₃) in sulfide-containing wells (SI > 15.0); however, orpiment probably does not precipitate, because this solid is typically associated with geothermal environments. In sulfide-free waters, no arsenic-

bearing minerals are supersaturated, suggesting that arsenic attenuation is through sorption rather than precipitation reactions.

The effect of organic carbon on metal solubilities was also modeled with MINTEQA2 for one set of well ground-water data (OW-16), which contained 230 mg/L DOC. Some of the stability constants for low molecular weight fulvic-acid/metal aqueous complexes have been measured (Martell and Smith, 1982) and were used in an attempt to predict the effect of organometallic complexing on metal solubility. Metal complexation by DOC was estimated using the constants for metal binding, based on Suwannee River fulvic acid association constants (Thurman and Malcolm, 1981). For this simulation, 4 μ moles of binding sites per milligram of metal were assumed, based on studies of copper-humic acid complexation (Thurman and Malcolm, 1981).

The inclusion of dissolved fulvic acid in the modeling simulation of the waters from well OW-16 did not change any saturation indices. The lack of effect on chromium speciation may be explained by the absence of pertinent thermodynamic data for relevant complexes of chromium with C1 through C5 organic acids.

Chromium hydroxide is near saturation in most wells regardless of the presence of sulfides. Amorphous $\text{Cr}(\text{OH})_3$ [e.g., $\text{Cr}(\text{OH})_3(\text{am})$] is generally supersaturated, while crystalline $\text{Cr}(\text{OH})_3$ is undersaturated. This degree of supersaturation, regardless of the concentration of chromium, indicates that chromium may not only be strongly complexed in these solutions, possibly by organic substances, but also that excess chromium may be precipitating from solution as an amorphous hydroxide.

2.4.5 Validation and Refinement of the Geochemical Paradigm

The geochemical paradigm presented in the Work Plan (Figure 31) has been evaluated for consistency with the data collected in the GSIP Phase 2 RI. As the paradigm proposed, methylated arsenic was found in the reduced ground waters downgradient from the East-Central Hide Pile. However, the paradigm should be modified to reflect that the zone of arsenic methylation was limited to the area where sulfide was present above 1 mg/L in the ground water. Similarly, the hypothesis that dissolved chromium in the ground water was present as organically complexed Cr(III) was verified at the Industri-Plex Site by analyzing

the ground waters for Cr(VI) and organically complexed Cr(III) separately. Analysis of the dissolved organic material, however, demonstrated that the majority of the aqueous ligands were complex organic acids with more than five carbons, rather than acetate or other simple organic acids originally theorized. In addition, two important additions should be made to the paradigm: 1) the presence of ground-water zones with over 1 mg/L sulfide downgradient from the hide piles are keeping metals such as iron, zinc, and lead from migrating due to precipitation of sulfides (i.e., FeS, ZnS, and PbS); and 2) the ground-water redox conditions may be divided into three distinct zones—extremely reducing, reducing, and oxidizing—with arsenic most mobile in the extremely reducing zones due to methylation, less mobile in the reducing zone due to adsorption to minerals, and highly attenuated in the oxidizing zone due to adsorption to iron oxide precipitates.

Ground water downgradient from the East, West and East-Central Hide Piles is strongly reducing due to decomposition of remnant hide pile material. Consequently, ground waters interacting with these piles contain DO concentrations of less than 1 mg/L, aqueous sulfide above 1 mg/L (Figure 32), and DOC above 700 mg/L (Figure 37). In contrast, more oxidizing conditions exist across the remainder of the Site, with Eh potentials above zero (Figure 34) and dissolved oxygen above 1 mg/L. As ground water flows from reducing to oxidizing zones, geochemical reactions occur that limit the mobility of dissolved metals leached as precipitation infiltrates through impacted soils and hide material.

The presence of volatile, reduced sulfur compounds directly beneath the hide piles is indicative of anaerobic, reducing conditions. For example, in the East-Central Hide Pile, hydrogen sulfide (H₂S) and methylmercaptan (CH₃HS) gas were measured at up to 21,000 parts per million (ppm) and 500 ppm, respectively, with 250 ppm H₂S in the West Hide Pile and a sulfide odor recorded in the East Hide Pile (Roux Associates, Inc., 1984). The fact that the highest sulfide concentrations are found in the East-Central Hide Pile may be due to the water-table mound beneath the hide pile limiting oxygen transfer, as this hide pile has been interred the longest.

Breakdown of the hides has also resulted in the generation of organic acids. Ground water intersecting the East-Central Hide Pile has been affected by these conditions, resulting in the transport of reducing, high-DOC (i.e., > 100 mg/L) waters downgradient of the hide

pile. The presence of dissolved organic acid anions may be important, because they form aqueous complexes with metal cations, thereby increasing metal solubility and mobility. In addition, DOC may act as a source of nutrients for facultative bacteria, which are capable of biochemically methylating inorganic arsenic compounds (Rai et al., 1984) and, in aerobic environments, degrade benzene (Chiang et al., 1989).

Based on the chromium ground-water speciation data, the anoxic conditions also result in reduction of remnant Cr(VI) to Cr(III), which should co-precipitate with iron to form the sparingly soluble $\text{Cr}_{0.25}\text{Fe}_{0.75}(\text{OH})_3$ or, in the absence of iron, amorphous $\text{Cr}(\text{OH})_3$. Once reduced, Cr(III) is unlikely to re-oxidize to Cr(VI), even when oxygen is present, due to kinetic limitations (Bartlett and Kimble, 1976a and 1976b; Bartlett and James, 1979). Iron hydroxide also provides a source of surface sites for sorption of metal cations, following the selectivity sequence $\text{Cr}(\text{III}) > \text{Pb} > \text{Cu} > \text{Zn} > \text{Cd} > \text{Mg}$ (Kinniburgh et al., 1976; Leckie et al., 1980).

However, despite theoretical solubility constraints, chromium is migrating in ground water (Figure 46). For example, based on the transport of chloride, a conservative tracer in ground water, there appears to be negligible attenuation of chromium between wells OW-16 and OW-12 as the Cl:Cr ratio remains constant (≈ 0.24) in both wells. The migration of chromium is thus postulated to be a result of aqueous organic complexation of Cr(III) by carboxylate anions, which is consistent with the geochemical paradigm. The general absence of base metals (e.g., lead) in ground water is attributed to sorption of these metals in the oxidized vadose zone or to precipitation by sulfide in reducing environments.

As an example of the general applicability of the geochemical paradigm in explaining the ground-water chemistry downgradient from a source area, the transport of chromium, and the migration and transition of arsenic species may be followed along a flow path downgradient from the South Hide Pile to well OW-12 to OW-17 and into the HBHA pond. Although the South Hide Pile has been selected as an example to demonstrate the utility of the paradigm, the same factors control transport of arsenic and chromium from the other hide piles (Figures 54 through 58).

In the immediate vicinity of the South Hide Pile (e.g., OW-12), conditions are reducing (<0 mV, sulfide > 1 mg/L, Fe(III) < 1 mg/L) and anaerobic (based on the genesis of arsine and mercaptan gas). Dissolution of metal salts (Figure 45) in conjunction with the microbially facilitated biodegradation of the hide pile material results in generation of more soluble and mobile methylated arsenic (Figure 42), and organically complexed chromium aqueous species (Figure 43) where the hide pile intersects the alluvial aquifer (Figures 41 and 43). As ground water moves downgradient, (e.g., OW-17), the oxygen deficit is reduced by entraining adjacent, unaffected ground water into the plume, resulting in demethylation of arsenic to arsenic(III) and arsenic(V) in well OW-17 (Figure 41) and in HBHA pond pore waters (Table 18). When the arsenic plume intersects HBHA pond sediments, amorphous ferric hydroxide sequesters the inorganic arsenic species in the sediments (Figure 22). Organic complexation (possibly by organic acid chelation) of chromium (III) maintains chromium in solution adjacent to and downgradient from the South Hide Pile (e.g., between OW-12 and OW-17). However, when chromium discharges to the HBHA pond, the sediment adsorbs most of the organically complexed chromium(III) by complexing with organic carbon, which constitutes up to 14 percent of the benthic substrate.

This organic component is most probably a result of the presence of saprophytic organisms, as evidenced by anaerobic conditions within the sediment matrix.

2.5 Ecological Assessment

This Phase 2 Ecological Assessment (EA) is a continuation of studies performed as a requirement of the GSIP Phase 1 (Roux Associates, Inc., 1991a), as presented in the GSIP Phase 2 Work Plan (Roux Associates, Inc., 1991b). The purpose of the EA is to qualitatively and/or quantitatively appraise the actual or potential hazard that the Site may present to wildlife.

2.5.1 Task E-1. Sediment Bioassay

The purpose the Sediment Bioassay (Roux Associates, Inc., 1991a, Task E-1) was to sample sediment from locations upstream and downstream of the Site ($N = 6$, Plate 2), observe the response of laboratory reared macroinvertebrates to each individual sample under constant environmental conditions, and evaluate if an impact may exist. Each sediment sample was originally split from a larger pooled sample taken for chemical and physical analyses

(Section 2.2). The sediment samples were shipped on ice to the ESE Midwest Aquatic Toxicology Laboratory in St. Louis, Missouri. Test species used for assessing toxicity were *Hyallela azteca* (*H. azteca*) and *Chironomus tentans* (*C. tentans*), both of which are representative of genera which have been observed within the Study Area. Toxicological endpoints were survival, growth (length) and reproduction for *H. azteca* and survival and growth (length and weight) for *C. tentans*. Raw data recorded during the study are presented in Appendix C.

2.5.1.2 Methods

2.5.1.2.1 Test Organisms

H. azteca (2-3 mm juveniles) were obtained from stock laboratory cultures maintained at ESE's Midwest Aquatic Toxicology Laboratory in St. Louis, Missouri. Cultures were originally obtained from the USFWS-CRC, Columbia, Missouri and cultured for several years in hard reconstituted water (USEPA, 1985). Specific age of the organisms were determined from offspring produced by gravid adults isolated before the test. Offspring were collected, assigned a lot number, and cultured in the same manner as stock cultures until time of testing. This procedure, when conducted on successive days, provided a continuous supply of test organisms at the required age on a daily basis. Cultures were fed a dried oak, ash and maple crushed leaf mixture at rates of 1.0 g/tank/day, and maintained at 20° C under a 16 hour:8 hour light:dark photoperiod.

C. tentans were also obtained for testing purposes from stock laboratory cultures. Cultures were originally obtained from Aqua Survey, Inc., and were cultured in moderately hard reconstituted water (USEPA, 1985). Homogenized paper towels were supplied to each stock culture tank as a substrate for larval tube development. Cultures were fed 0.5 ml per day of a 100 gram per liter (g/L) Tetra Min Flake homogenate, and maintained at 20° C under a 16 hour:8 hour light:dark photoperiod.

2.5.1.2.2 Test Sediment

Sediments were received on October 3 and 4, 1991. Receiving temperature ranged from 10-12° C. All sediments were stored at 4° C until October 8, 1991, at which time all sediments were processed. A control sediment, consisting of Meramec River sand, was

tested concurrently. The approximate ranges of composition of the test sediments were: detritus (63-78 percent); silt (10-25 percent); and brown to black fine sand (12-18 percent). A more detailed description of sediment quality is presented in Section 2.2.2.

2.5.1.2.3 Sediment Preparation

Homogenization of sediment was performed by placing each original sediment container in a polycarbonate anaerobic chamber equipped with gloves. Nitrogen gas was continuously pumped into the chamber (percent oxygen <0.1 percent, as measured with a Teledyne Model 999d Air Analyzer) while sediments were blended for 15 minutes with a stainless steel paddle. This procedure was repeated separately for each sediment sample. Following this, 500 ml volumes of sediment were removed and placed into two clean 3.5-L glass jars for conducting the tests. Reconstituted water (2.5 L) was then added to each test chamber.

Test chambers (each chamber constituting one replicate) were placed into a 20° C water bath. Sediments were allowed to settle for 24 hours before test organisms were added.

2.5.1.2.4 Test Initiation

Initial dissolved oxygen concentration was measured after the sediments were allowed to settle. All test chambers exhibited low dissolved oxygen concentrations (<40 percent saturation) and were gently aerated using a borosilicate glass pipette with air supplied from an aquarium pump. Aeration was continued for the remainder of the test period. Animals were placed into test chambers after the dissolved oxygen concentration reached acceptable levels. All test chamber solutions remained static for the test duration.

Half of the test chambers received *H. azteca* juveniles (N = 30/chamber, 2-3 mm organisms), while the remaining test chambers received second instar *C. tentans* (N = 30/chamber, 14 day old). Individuals were introduced into test chambers below the water surface and allowed to burrow into the sediment before introducing the next larvae. This procedure was continued until all chambers had received 30 organisms.

2.5.1.2.5 Feeding

The food suspensions used for stock cultures were also used to feed the test organisms. *C. tentans* were fed at a rate of 0.5 ml suspension/chamber/day (final concentration = 50 mg dry weight/chamber). *H. azteca* test chambers were fed at a rate of 0.2 g dried crushed leaves/chamber/day. Larvae were fed at the time they were placed into the test chambers and on each observation day thereafter.

2.5.1.2.6 Water Quality

Water bath temperature was measured hourly using a KM 1202 Temperature Recorder (Cole Parmer). Dissolved oxygen (Yellow Springs Instrument Co.) and pH (pHep/Ph meter, Cole Parmer) were measured biweekly. Ammonia was measured initially and weekly using an ion selective electrode (Baxter Scientific Products). Conductivity was measured using a HANNA Dissolved Solids meter. Alkalinity and hardness were also measured initially and weekly according to procedures outlined in Standard Methods (APHA, 1980).

2.5.1.2.7 Test Termination

At the end of the exposure period (21-day, *H. azteca*; 14-day, *C. tentans*) test chambers were removed from the water bath. The chamber contents were poured through an 80 micron sieve and the remaining solids rinsed from the screen. Organisms were then preserved in an isopropanol/Rose Bengal solution and collected in 10 ml scintillation vials. After removal of excess water, the organisms were measured with calipers and sorted into juveniles and adults (midges were weighed).

2.5.1.3 Statistical Analysis

Statistical analysis of test endpoints (survival, adult length and reproduction for *H. azteca*; length and weight for *C. tentans*) was performed using one-way analysis of variance. Bonferroni's T test was used to determine whether each treatment group was significantly different from the control sediment.

No significant test anomalies occurred which may have affected the final test results. Initially, the control chambers were inadvertently filled with deionized water instead of reconstituted freshwater. This error was discovered and corrected prior to the addition

of test organisms. The quick settling rate of the control sediment did not affect test initiation.

2.5.1.4 Results

Table 26 presents the results of the *H. azteca* 21-day exposure. Mean percent survival of the amphipods ranged from 0 (SED-18) to 88 percent (SED-22). With the exception of SED-18, all treatment groups exhibited greater than 60 percent survival. Mean adult length ranged from 5.07 mm (SED-19) to 5.64 mm (control). Mean number of offspring ranged from 15 (SED-21) to 44 (SED-22).

Table 27 presents the results of the *C. tentans* 14-day exposure. Mean survival of the midges ranged from 0 (SED-18) to 90 (SED-21 and SED-22). With the exception of SED-18, all treatment groups exhibited greater than 75 percent survival. Mean length ranged from 18.26 mm (SED-19) to 20.78 mm (SED-22). Mean wet weight ranged from 0.032 g (SED-24) to 0.039 g (SED-22).

No statistically significant differences were observed between sediment samples when comparing mean length of *H. azteca* or *C. tentans*. Compared to the control sediment, the mean number of offspring for *H. azteca* were significantly lower in sediments taken from SED-19 and SED-21 (Table 26). The small variance seen in the final weights of *C. tentans* for SED-24 resulted in a statistically significant difference when compared to the control sediment (Table 27).

Standard water quality parameters (temperature, pH, D.O., conductivity) remained within acceptable limits for sustaining the test populations for the entire test period (Tables 28 and 29).

2.5.1.5 Discussion

The most severe effect was seen in SED-18, a background (upstream) sample, in which 100 percent mortality was observed for both of the test organism populations. This is not surprising as the sample, based on field observation, had an oily sheen, a "greasy" texture, and exhibited a hydrophobic characteristic ("beading") typical of sediment containing petroleum hydrocarbons. Also of interest were effects seen in the test conducted on

SED-19, another upstream sample. Test endpoints for this sediment were relatively low for both *H. azteca* (62 percent survival; measurable decrease in reproduction) and *C. tentans* (77 percent survival).

Of the samples taken, only SED-21 showed a measurable effect (a significant decrease in reproduction of *H. azteca*). Because adverse effects were seen with samples taken from the upstream reference locations (SED-18 and SED-19), it is impossible to conclude if the response to Sample SED-21 is a direct result of Site-related constituents.

2.5.2 Task E-2. Fish Sampling Survey

Fish were sampled in Phillip's Pond (PP) and the HBHA for the purpose of comparing tissue concentrations of metals and SVOCs. An attempt was made to collect individuals from three trophic levels: forager, bottom-feeder and predator. Based on capture experience during the GSIP Phase 1 EA, the types of fish expected within these impoundments included Pumpkinseed (*Lepomis gibbosus*), White Sucker (*Catostomus commersoni*), Golden Shiner (*Notemigonus crysoleucas*) and Largemouth Bass (*Micropterus salmoides*).

2.5.2.1 Sampling Method

For larger fish, one hundred foot sinking gill nets (½", 1", 2", 4", and 5" stretch monofilament) were placed in an east-to-west direction near the outlet of each impoundment. Smaller fish were collected using minnow traps. All fish were collected at 24-hour intervals, logged, and photographed. Larger fish were then eviscerated, inspected for external and internal lesions, and rinsed with distilled water. Fillet was separated from offal and the tissue samples were bagged, tagged, and frozen on dry ice. Small fish were frozen and categorized as offal, as they were processed whole.

Table 30 presents descriptive data for each fish sampled. With the exception of a single catfish (*Ictalurus nebulosus*), the sampling survey captured the same types of fish caught during the GSIP Phase 1. Compared to PP, fish appeared to be less abundant within the HBHA as the field sampling time for the latter had to be increased to obtain a similar yield.

Foragers were also not recovered from the HBHA, although a large school was observed at SED-13 during the summer of 1991. Crayfish were abundant in both PP and the HBHA.

Excluding foragers, the average fish measured 21 cm in length and weighed approximately 65 grams (2 ounces). Fillet and offal contained approximately 3.4 and 8.9 percent lipid, respectively. A more in-depth statistical analysis comparing group means or location specific differences was not performed because of: a) age-dependent variables (e.g., length and weight); b) heterogeneous sample numbers within and between groups (N = 3 - 6) and c); the presence of outliers.

2.5.2.2 Analytical

Tissue samples were sent to ESE's St. Louis Analytical Laboratory and prepared in accordance with approved EPA methodology (600/8-80-038 and 600/4-79-0200). Samples were processed by blending in a food processor and subsampling a minimum of five grams of tissue. Prepared samples were analyzed for the presence of 23 CLP metals and 65 base/neutral/acid extractable organic compounds. A more complete tabulation of results for each analysis is presented in Appendix D.

2.5.2.3 Results

Metals

Table 31 presents concentrations of arsenic (As), chromium (Cr), and lead (Pb) in fillet tissue sampled from fish in the HBHA and PP. Concentrations of chromium were not observed above the detection limit. Lead was detected in one of eight samples taken from the HBHA (0.73 mg/kg [or ppm]) but was not detected in any sample taken from PP. Arsenic was detected in one of eight samples taken from the HBHA (1.19 mg/kg) and one of twelve samples taken from PP (1.18 mg/kg).

Table 32 presents concentrations of arsenic (As), chromium (Cr) and lead (Pb) in offal tissue sampled from fish taken from the HBHA and PP. Arsenic was detected in four of eight samples taken from the HBHA (1.3 - 3.8 mg/kg), while the frequency of detection within PP was five of sixteen (0.94 - 1.15 mg/kg). Chromium was detected in only one of eight samples within the HBHA (2.85 mg/kg) and two of sixteen in PP (0.16 and 8.87

mg/kg). Finally, lead was detected in three of eight samples taken from the HBHA (0.71 - 3.86 mg/kg) and eleven of sixteen (0.58 - 4.76 mg/kg) of those taken within PP.

Other metals known to bioconcentrate within aquatic organisms include cadmium, mercury and selenium (Eisler, 1988b;e;f). Cadmium and selenium were not observed above the detection limit in any sample of fillet (Appendix D). Mercury was detected in two fillet samples from the HBHA (mean = 0.163 mg/kg) and four from PP (mean = 0.160 mg/kg). In samples of offal, selenium was undetected, mercury was detected once in a sample from PP (0.107 mg/kg), and cadmium was detected once in a sample taken from each location (0.11 and 0.19 mg/kg in HBHA and PP, respectively).

Semi-Volatile Organic Compounds

SVOCs were not observed above the detection limit in any fish tissue sample. Limits of detection for each individual analyte are presented in Appendix D. These limits are higher for biological tissue than for solid media because of the presence of strongly interfering compounds (e.g., lipid, protein, nucleic acids).

2.5.2.4 Discussion

The U.S. Fish and Wildlife Containment Hazard Reviews (Eisler, 1988a-f) present some normal metal concentration ranges in freshwater fish (fresh weight) as follows:

MUSCLE (fillet):

Arsenic	0.03 - 1.30	mg/kg
Cadmium	0.20 - 0.60	mg/kg
Chromium	0.03 - 1.10	mg/kg
Lead	NA	
Mercury	0.09 - ~2.0	mg/kg
Selenium	0.04 - 1.3	mg/kg

WHOLE FISH:

Arsenic	0.02 - 1.90	mg/kg
Cadmium	0.01 - 1.07	mg/kg
Chromium	<0.01 - 5.70	mg/kg
Lead	0.10 - 1.40	mg/kg

Mercury	0.08 - 0.80	mg/kg
Selenium	0.20 - 6.00	mg/kg

Given the data presented in Table 31, there appear to be no differences in fillet metal concentrations when comparing samples taken from the HBHA and PP. Positive detections for arsenic and lead were within "normal" ranges cited in the literature for muscle tissue. Mercury, detected twice in the HBHA and four times in PP. Metal concentrations in offal, with the exception of BF/005 in the HBHA and BF/001 in PP, were also within normal tissue concentration ranges (the excursions seen with the latter two samples may be a result of the presence of sediment in the gut, as gut contents were not irrigated prior to processing).

It appears that the concentration of arsenic in the tissue samples taken from the HBHA may be greater than PP. Arsenic in fish tissue, however, is: a) usually complexed as an organic species (e.g., arsenobetaine), which is known to be significantly less toxic than the inorganic form (ATSDR, 1987); b) widely recognized that the metalloid does not biomagnify through the food chain. Arsenic, therefore, is not considered a threat to local wildlife.

The concentrations of chromium and lead generally appear to be comparable between the two ponds.

2.5.3 Task E-3. Assessment of Hazard to Semi-Aquatic Receptors

The GSIP Phase 1 EA addressed station-specific habitat and impacts to fish and macroinvertebrates, but did not address semi-aquatic receptors. The purpose of this task is to evaluate the real or potential hazard that COC in surface water and sediment may pose to wetland-dependent birds (e.g., ducks and geese). It is important to state at the outset of this task that the available literature addressing toxicity endpoints for birds is limited. In particular, the primary current source of information for ecological receptors is a series of monographs published by U.S. Fish and Wildlife (Eisler, 1985a-f). For the Industri-Plex Site, the only applicable COC which these publications cover in sufficient detail are arsenic, chromium, and lead. In addition, guidance addressing exposure factors is, at the time of this report, unavailable. Guidance that proved useful for this portion of the EA included the

following citations: ORNL, 1986; USEPA, 1989a; USEPA, 1989b; USEPA, 1989c; USEPA, 1989d.

Although ecological assessment methodology is generally patterned after human health risk assessment, an important distinction exists between the two. A human health risk assessment deals with only one species and assumes the presence of sensitive receptors. In contrast, a site that is being evaluated for potential environmental impact may harbor many populations of different species that interact with each other and with the physical environment. Presently, because no methodology has been developed that adequately integrates the complex parameters of an ecosystem, an ecological assessment generally evaluates a single "indicator" species.

This section of the GSIP Phase 2 EA addresses the potential impact of COC on wetland-dependent birds. As detailed in the following discussion, the scenario adopts the mallard duck (*Anas platyrhynchos*) as the representative indicator species, and evaluates the potential impact of arsenic, chromium and lead following the ingestion of Site-related sediments.

2.5.3.1 Hazard Evaluation

The purpose of the hazard evaluation is to identify COC that would have the highest probability to manifest a hazard to wildlife. Criteria typically used in this evaluation are the toxicity of the constituent, frequency of detection, concentration, environmental persistence, mobility, fate and transport, and the quality of the data base.

The lack of available information on toxic endpoints for volatile and semi-volatile organic compounds, as well as many of the metals, preclude the choice of any compound within these chemical classes as COC. U.S. Fish and Wildlife monographs are available for mercury, cadmium, and polycyclic aromatic hydrocarbons, but lacked definitive acute, subchronic or chronic data for adverse effects of these COC in wetland-dependent birds. The GSIP Phase 1 EA did, based on the preceding criteria, identify arsenic, chromium and lead as key COC in surface water and sediment. The aforementioned monographs (in addition to recent publications), did provide enough information on the effects of arsenic, chromium and lead to ducks. Consequently, these three metals remain the key COC for evaluation of hazard.

Table 33 and Table 34 present descriptive statistics for metal concentrations in surface water and sediment, respectively. As wetland-dependent birds primarily inhabit lentic environments, the database constructed for this hazard evaluation chose stations representative of deeper, open waters. For surface waters, this includes stations SW-1, SW-8, SW-9, SW-11 and SW-13 (from GSIP Phase 1); SW-18, SW-19, SW-21, SW-22, SW-23, and SW-24 (from GSIP Phase 2). For sediments, these environments include stations SED-1, SED-8, SED-9, SED-11, SED-13, and CORE (GSIP Phase 1); SED-18, SED-19, SED-21, SED-22, SED-23, and SED-24 (GSIP Phase 2); and SW1/001, SW1/030, SW1/032 through SW1/037, SW1/039 through SW1/050, SW1/055 through SW1/057, and SW1/059 (from the PDI).

With the exception of SW-18 (located upstream of the Site boundary, downstream of a confirmed Massachusetts Contingency Plan Disposal Site, and downstream of an active NPDES industrial effluent), trace metal concentrations in surface waters were below Federal Ambient Water Quality criteria and Maximum Concentration Limits for drinking water. Mean concentrations of total arsenic, chromium, and lead in surface water (Table 33) were 7.2, 23.7, and 2.4 $\mu\text{g/L}$, respectively (Table 34). Mean concentrations of dissolved arsenic, chromium, and lead were 5.0, 3.9, and 1.1 $\mu\text{g/L}$, respectively. These metal concentrations, and those of the remaining alkali-earth and transition metals, are within ranges typically observed in natural waters throughout the United States (USGS, 1989). As seen in the GSIP Phase 1, metals do not have a strong tendency to mobilize into surface water. Consequently, surface water is ruled out as a significant exposure source for wetland-dependent birds.

Mean sediment concentrations for arsenic, chromium, and lead were 459.7, 231.4, and 138.5 mg/kg, respectively (Table 34). The mean was strongly skewed by samples from the HBHA, which contains a high percentage of organic matter and fine-grained sediment (silts and clays). Bulk concentrations of metals are generally higher in this type of substrate as they have a much higher surface area, which increases metal binding capacity (Horowitz, 1991). This is evidenced by the observation that the maximum concentrations of other metals, which are not Site-related (e.g., calcium, selenium) were seen within the HBHA.

In summary, the availability of an adequate toxicity database for arsenic, chromium, and lead and the fulfillment of selective hazard identification criteria (e.g. toxicity, frequency of detection, location) obviates the choice of these metals as COC. Average concentrations of total and dissolved forms of these metals in surface water were judged to be within the range seen for natural waters. Thus, this media was eliminated as an effective exposure pathway. Maximum sediment concentrations of most metals were located in the HBHA. As wetland-dependent birds do ingest small amounts of sediment, the above COC within this medium will be evaluated as a significant exposure route.

2.5.3.2 Toxicity Assessment

Toxicity is a measure of the capacity of a chemical to cause injury or damage to an organism. A fundamental principle of toxicology is that the toxic effect of a chemical is dose-dependent. As the dose (exposure magnitude) of a chemical increases, the probability (or hazard) that the chemical will cause damage to an organism also increases.

For this assessment, it is assumed that a toxic threshold exists (i.e., a dose below which no adverse effects will be seen). Because the degree of hazard will be eventually be expressed as the ratio of a "safe" reference dose (RfD, represented as mg/kg body weight-day) to the exposure dose, the former must be derived from available literature using experimental dose-response data. Ultimately, the RfD will be used to calculate a hazard quotient. If the value of the hazard quotient is below one, then it is assumed that no risk is associated with the scenario. If the hazard quotient is above one, then an impact may be feasible. Hazard quotients for compounds that have *similar* toxic mechanisms and/or effects may be treated in an additive fashion, expressed as a cumulative hazard index.

Ecological toxicity profiles for the COC, which summarize the properties, sources, fate, and known toxic effects of each chemical in the environment, are presented in Appendix D. The reference doses for this evaluation (Table 35) were derived from available peer-reviewed literature of experimental results that reported a no observed effect level (NOEL) for chromium (Haseltine et al., 1985) and lead (Finley et al., 1976), and the lowest observed adverse effect level (LOAEL) for arsenic (Camardese et al., 1990). In human health risk assessment a NOEL is typically derived from a LOAEL by dividing the latter by a safety factor between 1 and 10. No comparable experimental data or safety factors, however, are

available for ecological assessments. For this assessment, arsenic was the only metal which did not have a NOEL available from the literature. The NOEL for arsenic at this Site was derived by dividing the LOAEL by a safety factor of 3. This factor was chosen, using best professional judgement, because: a) the effects seen in mallard ducklings at the lowest feed concentration (30 ppm; Camardese et al., 1990) were primarily biochemical in nature; b) the length of the study from which the NOEL was derived was in between that of a chronic and subchronic design, and; c) it is difficult to conclude that any of the effects seen in the group of ducklings receiving the lowest feed concentration were "adverse" (i.e., even at the highest feed concentration, no significant increase in mortality or histopathological lesions were observed).

2.5.3.3 Identification of Indicator Species

The selection of an indicator species included consideration of the following:

- wetland-dependent species with a high potential for exposure to sediments;
- prevalence in the Northeast;
- availability of information on the adverse effects of COC on the species, or related species.

Of the wetland-dependent fauna that have been observed on Site (Table 4.40, Roux Associates, Inc., 1991a), the mallard duck (*Anas platyrhynchos*) best satisfy these criteria. Canada geese populations have been sighted regularly at the Site and nest within the wetlands, but spend the majority of their time foraging on upland grasses (Beyer, 1992). Consequently, the latter was not considered as a potential indicator species.

2.5.3.4 Exposure Assessment

The potential for mallards to be exposed to sediment at the Industri-Plex Site was evaluated. Exposure is dependent on a number of physical and biological variables including the behavior patterns (influencing duration and frequency of exposure), seasonal and climatic variation, and the bioavailability of the various COC.

The chronic daily intake of COC was determined by adapting a formula used for soil ingestion for humans (Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual, USEPA, 1989g) for the mallard duck at this Site as follows:

Equation: Ingestion of Chemicals in Sediment.

$$\text{Chronic Daily Intake (mg/kg/day)} = \frac{(\text{CS}) (\text{IR}) (\text{CF}) (\text{FI}) (\text{EF}) (\text{ED}) (\text{AF})}{(\text{BW}) (\text{AT})}$$

where,

CS	=	Chemical Concentration in Soil (mg/kg)
IR	=	Ingestion Rate (mg sediment/day)
CF	=	Conversion Factor (10^{-6} kg/mg)
FI	=	Fraction Ingested from Contaminated Source (unitless)
EF	=	Exposure Frequency (days/years)
ED	=	Exposure Duration (years)
AF	=	Availability Factor (fraction available for uptake from intestine)
BW	=	Body Weight (kg)
AT	=	Averaging Time (period over which exposure is averaged -- days)

Table 35 presents the parameters used for each variable for each COC.

Mallards, once rare to the Northeast, now nest throughout Massachusetts and other New England States (Heusmann, 1991). The current population of mallards is partly due to their introduction by game farmers, who raise and release the ducks for hunting. Nesting activity begins in April and peaks in May. Ducks choose nesting sites in marsh or upland areas within 100 yards of water where the female forms a nest in moist earth or plant litter. The primary requirement for nesting appears to be the presence of dense vegetation, about two-feet tall (Bellrose, 1978). Unlike some waterfowl, mallards do not mate for life. Bonding between pairs weakens at the onset of incubation, and some individuals mate a second time during the season with a different partner.

Although mallards are migratory birds, some populations migrate the shortest possible distance to find sufficient food for winter. Because of their well-developed homing instinct, mallards tend to migrate to previously visited habitats during the fall migration. When winter conditions are favorable, some groups do not migrate at all; they remain in the same general vicinity throughout the year (Bellrose, 1978). On a day-to-day basis, most mallards remain within a relatively localized area (15 to 50 kilometer radius), moving from one wetland area to another (Heusmann, 1992). For this exposure assessment, both the daily

movement of ducks from one wetland area to another and their long-range migratory behavior was considered in determining the exposure frequency (EF), which was estimated to be 90 days per year.

Mallards are dabbling, or puddle ducks. In comparison to the feet of diving ducks, a mallard's feet are set further forward and lack the lobe of skin found between the toes of diving ducks. These structural features aid the bird's dabbling behavior. They often feed by tipping up in shallow water, usually within two feet of the shore, so that their heads are beneath the surface of the water and their tails stick up above it (Haramis, 1992). While in this position, they forage for food and grit in sediment (Heinz, 1992).

Adult mallards feed primarily on seeds of many different grasses and other plants, although these birds are somewhat opportunistic. They also eat stems and leaves of pondweeds, and feed in agricultural fields. Mallards also eat small vertebrates, such as frogs, and may opportunistically feed on invertebrates. Ingestion of COC via food was considered, but judged to an insignificant exposure pathway for several reasons. First, floating aquatic macrophytes would be predicted to have low concentrations of arsenic, chromium, and lead concentrations because surface water concentrations were typical of those observed for natural waters (Section 2.5.3.1). Second, low concentrations of arsenic, chromium, and lead are anticipated in tissues of rooted aquatic macrophytes as these metals are poorly translocated to edible portions of the plant (ORNL, 1984).

Studies of fecal material from the lower intestines of mallards revealed that they ingest small amounts of sediment in their diet (Beyer, 1992). Of 88 birds examined, most had little or no sediment in the gut and the overall consumption of sediment was estimated to be less than 2 percent of the dietary intake. Ingestion of sediment is thus an important consideration in this exposure assessment because of the concentrations of metals observed in sediment, relative to local surface waters. Sediment is considered the primary route of exposure for semi-aquatic receptors at this Site.

Experimental feeding studies have reported that adult mallards consume an average of 140 g of food (dry weight) per day (Camardese, 1990). The amount of food (wet weight) that a duck consumes in the wild was estimated to be 560 g per day, based on observations of

water consumption in the previous experiment (four times the weight of the mash, *op. cit.* and Hoffman, 1992). The daily sediment ingestion rate (IR) was determined by multiplying the average daily food intake (560 g) by the maximum amount of sediment (2 percent) determined in the diet (Beyer, 1992). The product equals 11.2 g of sediment per day. The daily fraction of sediment considered to be ingested from a Site-related source (FI) was estimated to be half of the total daily intake, based on the random movement of birds between wetlands.

The toxicity of a substance is also dependent on its bioavailability, which is the fraction of an ingested substance that is absorbed by the intestine into the blood stream. Bioavailability, in turn, is dependent on the degree to which an ingested substance is solubilized by parenteral secretions in the intestine. For this exposure assessment, availability factors (AF) reported from experimental studies of rabbits were used for arsenic (11 percent) and lead (5.6 percent) (Davis et al., 1992). For chromium, a bioavailability factor of 3 percent, based on experimental studies with rats, was used (Mertz, 1965). These percentages represent the highest reported for each metal and are therefore conservative.

2.5.3.5 Risk Characterization

Characterization of the potential impact was based on the "quotient method" (ORNL, 1986). As referenced in Section 2.5.3.2, the quotient method is the ratio of the estimated chronic daily intake of a chemical to a "safe" reference dose (threshold concentration). If the resulting quotient, called a hazard quotient, is one, or greater than one, then there may be concern for a potential ecological hazard. A hazard quotient less than one indicates that, although the potential for environmental impact may exist, adverse effects are likely to be insignificant. For this assessment, the chronic daily exposure concentration (mg/kg-day) of each metal was divided by the derived reference dose to obtain a hazard quotient (Table 36). Hazard quotients for all three COC were below one for both the mean and maximum sediment concentrations at the Site.

A further (and highly conservative) assessment of potential environmental impact can be made by assuming that the toxic effects due to arsenic, chromium, and lead are additive. An evaluation of additive effects can be made by summing together the individual hazard quotients to derive a hazard index. Like the hazard quotient, a hazard index of one or less

implies no risk, whereas a hazard quotient greater than one prompts further consideration. Table 36 presents the calculated hazard indices for the Site. The hazard index of the mean sediment concentrations of metals is below one. Because the toxic mechanisms are different for each metal, this exercise is also highly conservative. Even for the maximum concentrations, the hazard index is only slightly above one.

2.5.3.6 Discussion

Using exposure and toxicity information derived from the available literature, it appears that the Site-related sediments pose no significant hazard to the mallard duck, which is considered to be the most representative indicator species. The exposure scenario, the ingestion of sediment during feeding or to obtain grit, was highly conservative in that it assumed that: 1) the duck(s) reside at the Site for 3 months/year; 2) each duck consumes sediment at the highest rate observed in the wild; and 3) the availability of these metals in the gut is much higher than solubility limits observed in previous tests of soils taken from the Site (Roux Associates, Inc., 1984. Vol. I, Table 6.4). Despite the conservatism built into the exposure scenario, hazard quotients never exceeded one. Additive effects, which would not be anticipated given the mechanism of toxicity for each COC, could also be regarded to be insignificant.

3.0 SUMMARY AND CONCLUSIONS

The following sections summarize findings and conclusions of the GSIP Phase 2 RI. These conclusions are based on an evaluation of all hydrogeologic, and ground-water, surface-water and stream-sediment quality data developed during the GSIP Phase 2 RI, in conjunction with data developed during the GSIP Phase 1 RI and the PDI.

3.1 Tasks G-1, G-2 and G-3. Ground Water

Task G-1. Extent of Benzene at the West Hide Pile

Five piezometer well points (i.e., WP-1 through WP-5) were installed around the perimeter of the West Hide Pile, to better define the extent of benzene previously identified as Observation Well OW-31. Ground-water quality data developed from these new piezometers and existing observation wells show that benzene concentrations were limited to a small area along the northeastern perimeter of the West Hide Pile in the vicinity of Observation Well OW-31. This localized area of ground water containing benzene concentrations appears to discharge into the adjoining surface-water body (Lower South Pond), based on ground-water flow patterns which show ground water flowing eastward from the West Hide Pile into the Lower South Pond. Additionally, benzene concentrations are not found downgradient (southward) from the West Hide Pile, with the exception of 2 $\mu\text{g}/\text{L}$ of benzene detected at Piezometer WP-5.

Task G-2. Evaluation of Underflow at the HBHA

Two additional observation well clusters were installed and monitored (i.e., collection of ground-water samples and water-level measurements) to determine if ground-water is flowing beneath (underflow) the HBHA. The results of the GSIP Phase 2 RI indicate that ground-water flow beneath the northern end of the HBHA pond is not occurring. Rather, shallow and deeper ground water are shown to be flowing toward the HBHA and discharging into the HBHA. This conclusion is based on:

- ground-water flow patterns in the shallow and deep unconsolidated deposits around the northern end of the HBHA (on the east and west sides) which show ground water flowing laterally and vertically toward the HBHA;
- seepage meter data collected during the HBHA pond geochemical investigation which demonstrate that ground water beneath the base of both the southern and northern end of the HBHA pond is flowing upward and discharging into the pond; and

- ground-water samples collected during the GSIP Phase 2 RI which reveal that arsenic was not present (not detected) in OW-30A and OW-30B, located on the western side of the HBHA.

The presence of arsenic detected during previous sampling rounds in OW-30A and OW-30B is probably due to underflow/dispersion occurring further southward in the central portion of the HBHA pond where the unconsolidated aquifer thickens and widens. The unconsolidated aquifer in the northern portion of the HBHA pond is thin and narrow, with the axis of the aquifer extending southward along the eastern side of the HBHA pond. Further to the south, the bottom of the aquifer widens and deepens beneath the HBHA pond in the vicinity of the OW-30 well cluster. This localized widening and deepening of the buried valley could allow underflow to occur beneath the central portion of the HBHA pond. This conclusion is consistent with the results of the HBHA pond sediment geochemical investigation, which indicate that the axis of the arsenic plume intersects the HBHA in the central portion of the pond.

It is important to note that the occurrence of arsenic in ground water at the OW-30 well cluster is discontinuous. Arsenic was not detected during the GSIP Phase 2 RI sampling round. Moreover, the lateral extent of the unconsolidated aquifer on the west side of the HBHA is limited, due to the presence of the adjoining bedrock high which defines the westward boundary of the aquifer. Therefore, any arsenic impacted ground water on the western side of the HBHA will be directed eastward/southeastward back toward the HBHA and will discharge into the HBHA.

Task G-3. Unconsolidated Deposits/Bedrock Interaction

The results of Task G-3 indicate that due to the low hydraulic conductivity of the crystalline bedrock observed at three of the four bedrock observation well locations investigated during the GSIP Phase 2 RI, the crystalline bedrock does not appear to be a pathway for the transport of organic and inorganic constituents, except at Observation Well OW-55. At two locations (i.e., OW-37 and OW-9 well clusters) ground-water recharge into bedrock pilot boreholes was extremely slow. This information indicates that the bedrock at these two locations exhibits an extremely low hydraulic conductivity. Also, no appreciable secondary porosity appears to be present. Due to this condition, USEPA agreed to discontinue the bedrock investigations at these locations. Therefore, observation wells were not installed

and ground-water sampling was not performed. Pilot bedrock boreholes were sealed in February 1991 under Massachusetts guidelines.

Similar hydraulic conditions were observed at bedrock Observation Well OW-57, installed as part of Task G-2. The extremely slow recharge of ground water into OW-57 precluded the collection of a representative ground-water sample from this bedrock well.

The only bedrock well installed during the GSIP Phase 2 RI that recharged sufficiently enough to enable the collection of representative ground-water quality data and water-level information over time was at Observation Well OW-55, installed as part of Task G-2. At this location, a consistent downward flow gradient was observed between the bedrock and the overlying basal and unconsolidated deposits. Vertical gradients ranged between 0.0084 ft/ft and 0.0334 ft/ft.

VOCs were detected in the ground-water samples collected from OW-55. Dissolved arsenic and dissolved chromium were also detected at concentrations of 193 $\mu\text{g}/\text{L}$ and 122 $\mu\text{g}/\text{L}$, respectively.

A comparison of ground-water quality data between the bedrock well (OW-55) and the three adjacent overburden wells yields the following observations:

- Similar VOCs were detected in the adjoining basal unconsolidated deposits observation well (OW-54C). Concentrations of these VOCs were lower in OW-54C than in bedrock well OW-55.
- More VOCs were encountered at depth (i.e., in bedrock well OW-55 and basal unconsolidated deposits well OW-54C) than in shallower ground water (i.e., OW-54A and OW-54B).
- Concentrations of dissolved arsenic increased with depth in the unconsolidated deposits (from not detected [OW-54A] to 949 $\mu\text{g}/\text{L}$ [OW-54C]), but were lower in the bedrock (193 $\mu\text{g}/\text{L}$ at OW-55).
- Concentrations of dissolved chromium also increased with depth in the unconsolidated (from not detected [OW-54A] to 145 $\mu\text{g}/\text{L}$ [OW-54C]), but were lower in the bedrock (122 $\mu\text{g}/\text{L}$ at OW-55).

3.2 Task S-1. Surface-Water/Stream-Sediment Quality

Surface-Water Quality

Six new sampling locations (i.e., SW-18, SW-19, SW-21, SW-22, SW-23 and SW-24) were established and sampled to supplement data collected from the 17 locations sampled during the GSIP Phase 1 RI.

GSIP Phase 2 RI surface-water sampling results indicate that VOCs were detected at the two upstream/off-site surface-water sampling locations (i.e., SW-18 and SW-19), and at three surface-water sampling locations downstream of the HBHA pond (i.e., SW-21, SW-22 and SW-23). These compounds and their ranges are:

- toluene (not detected to 130 $\mu\text{g/L}$);
- trichloroethene (1 $\mu\text{g/L}$ to 11 $\mu\text{g/L}$);
- 1,2-dichloroethene (not detected to 11 $\mu\text{g/L}$);
- xylenes (not detected to 7 $\mu\text{g/L}$);
- 1,1-dichloroethane (not detected to 2 $\mu\text{g/L}$);
- 4-methyl-2-pentanone (not detected to 2 $\mu\text{g/L}$); and
- ethylbenzene (not detected to 1 $\mu\text{g/L}$).

Surface water collected at SW-18, located upstream/off-site in the New Boston Street Drainway contained the most VOCs detected, as well as the highest concentrations. Downstream of the HBHA pond only very low concentrations of a few VOCs were detected.

The distribution of arsenic, chromium, and lead detected during the GSIP Phase 2 RI sampling round indicate that:

- total arsenic concentrations ranged from not detected (SW-19) to 14.6 $\mu\text{g/L}$ (SW-21), with generally higher concentrations of arsenic detected in Hall's Brook downstream of the HBHA pond;
- total chromium concentrations ranged from 8.5 $\mu\text{g/L}$ (SW-24) to 195 $\mu\text{g/L}$ (SW-18), with the highest concentrations detected in the off-site/upstream surface-water sample (SW-18) collected from the New Boston Street Drainway; and
- total lead was not detected in any of the surface-water samples.

Stream-Sediment Quality

VOCs and SVOCs were detected in all six sediment samples collected during the GSIP Phase 2 RI sampling round. SVOCs detected were principally PAHs.

VOCs detected included: acetone, 2-butanone, chlorobenzene, 1,2-dichloroethene, ethylbenzene, toluene and vinyl chloride. Two of the seven VOCs detected in stream sediments were detected in both upstream/off-site samples as well as in sediment samples collected downstream of the HBHA pond. These two compounds and their detected ranges are acetone (110 $\mu\text{g}/\text{kg}$ to 2,200 $\mu\text{g}/\text{kg}$) and 2-butanone (31 $\mu\text{g}/\text{kg}$ to 550 $\mu\text{g}/\text{kg}$).

There appears to be no correlation between VOCs detected in surface water and VOCs detected in sediment at each respective sampling location.

As shown in Table 9, SVOCs were detected at the upstream off site locations (i.e. SED-18 and SED-14 collected at SW-18 and SW-19, respectively, as wells as sediment samples collected downstream of the HBHA pond. It is noted that the highest concentration of the SVOCs detected was 2,200,000 $\mu\text{g}/\text{kg}$ detected in SED-18 (upstream/off site location SW-18).

The distribution of arsenic, chromium, and lead detected in stream sediment during the GSIP Phase 2 RI sampling round indicate that:

- the distribution of chromium in stream sediment shows no pattern, with the concentrations ranging from 116 mg/kg in SED-24 to 2,180 mg/kg in SED-23 (collected at SW-24 and SW-23, respectively);
- arsenic concentrations ranged from 4.1 mg/kg (SED-19) to 1,380 mg/kg (SED-22) (collected at SW-19 and SW-22, respectively), with the greatest concentrations of arsenic detected in Hall's Brook downstream of the HBHA pond in SED-22 (collected at SW-22); and
- lead concentrations ranged from 25.3 mg/kg (SED-19) to 452 mg/kg (SED-22), with the highest concentrations of lead detected in stream sediment in Hall's Brook downstream of the HBHA pond in SED-22.

Normalization of the stream-sediment quality data developed during the GSIP Phase 2 RI to account for variability in sediment grain size indicates that higher concentrations of arsenic, chromium and lead were seen in finer-grained sediments. The exception is SED-23

(collected at SW-23), a coarser-grained sample that yielded anomalously higher concentrations of these constituents.

3.3 Task S-2. Sediment Volume and Geochemical Investigation Within the HBHA Pond

The objectives of the HBHA pond sediment geochemical investigation were to determine the volume of affected sediment in the HBHA pond, determine the rate of ground-water recharge in the HBHA pond, and examine the geochemistry of the HBHA pond sediment-pore water system.

Physical characteristics of the HBHA pond are:

- the maximum water depth was 13.7 feet;
- total volume of water in the pond is approximately 1,400,000 cubic feet (39,000 cubic meters);
- two distinct types of sediment were encountered; an upper layer of black, fine-grained ooze consisting of water, silt and clay, and an underlying well-sorted tan sand;
- total volume of sediment (ooze and sand) is approximately 29,000 cubic yards (22,000 cubic meters); and
- the volume of black ooze is approximately 9,700 cubic yards (7,400 cubic meters).

Ground-water discharge was estimated by placing one seepage meter in three areas of the HBHA pond. Based on the seepage meter data, the calculated average total ground-water discharge rate is approximately 720 cubic feet per day. The retention time of ground water in the upper 1.4 feet of sediment (ooze) ranges between 170 and 1,800 days.

The geochemical conditions in the ooze and sand are pH neutral and moderately reducing as evidenced by the presence of aqueous sulfide, As(III), Cr(III) and Fe(II). As previously discussed, arsenic and chromium in ground water are discharging to the Central Area of the HBHA pond. These data also indicate that benzene in ground water is discharging to the northern portion of the HBHA pond. The HBHA pond sediments act as a sink for these constituents by filtering metals out of recharging ground water, based on the high sorptive capacity (Kd) values for arsenic, chromium and lead, and the precipitation of lead sulfides. Pore water benzene concentrations are reduced by partitioning into organic carbon and perhaps also by biodegradation by the viable microbial community.

3.4 Tasks M-1 and M-2. Metals Mobility Study

The results of the GSIP Phase 2 RI metals mobility study support the Industri-Plex geochemical paradigm, which was developed to explain metal distribution in soils ground water and surface water at the Site. As the paradigm proposed, methylated arsenic was found in the reduced ground waters downgradient from the East-Central Hide Pile. However, the paradigm should be modified to reflect that the zone of arsenic methylation was limited to the area where sulfide was present above 1 mg/L in the ground water. Similarly, the hypothesis that dissolved chromium in the ground water was present as organically complexed Cr(III) was verified at the Industri-Plex Site by analyzing the ground waters for Cr(VI) and organically complexed Cr(III) separately. Analysis of the dissolved organic material, however, demonstrated that the majority of the aqueous ligands were complex organic acids with more than five carbons, rather than acetate or other simple organic acids originally theorized. In addition, two important additions should be made to the paradigm: 1) the presence of ground-water zones with over 1 mg/L sulfide downgradient from the hide piles are keeping metals such as iron, zinc, and lead from migrating due to precipitation of sulfides (i.e., FeS, ZnS, and PbS); and 2) the ground-water redox conditions may be divided into three distinct zones—extremely reducing, reducing, and oxidizing—with arsenic most mobile in the extremely reducing zones due to methylation, less mobile in the reducing zone due to adsorption to minerals, and highly attenuated in the oxidizing zone due to adsorption to iron oxide precipitates.

Ground water downgradient from the East, West and East-Central Hide Piles is strongly reducing due to decomposition of remnant hide pile material. Consequently, ground waters interacting with these piles contain DO concentrations of less than 1 mg/L, aqueous sulfide above 1 mg/L (Figure 32), and DOC above 700 mg/L (Figure 37). In contrast, more oxidizing conditions exist across the remainder of the Site, with Eh potentials above zero (Figure 34) and dissolved oxygen above 1 mg/L. As ground water flows from reducing to oxidizing zones, geochemical reactions occur that limit the mobility of dissolved metals leached as precipitation infiltrates through impacted soils and hide material.

The presence of volatile, reduced sulfur compounds directly beneath the hide piles is indicative of anaerobic, reducing conditions. For example, in the East-Central Hide Pile, hydrogen sulfide (H₂S) and methylmercaptan (CH₃HS) gas were measured at up to 21,000

parts per million (ppm) and 500 ppm, respectively, with 250 ppm H₂S in the West Hide Pile and a sulfide odor recorded in the East Hide Pile (Roux Associates, Inc., 1984). The fact that the highest sulfide concentrations are found in the East-Central Hide Pile may be due to the water-table mound beneath the hide pile limiting oxygen transfer, as this hide pile has been interred the longest.

Breakdown of the hides has also resulted in the generation of organic acids. Ground water intersecting the East-Central Hide Pile has been affected by these conditions, resulting in the transport of reducing, high-DOC (i.e., > 100 mg/L) waters downgradient of the hide pile. The presence of dissolved organic acid anions may be important, because they form aqueous complexes with metal cations, thereby increasing metal solubility and mobility. In addition, DOC may act as a source of nutrients for facultative bacteria, which are capable of biochemically methylating inorganic arsenic compounds (Rai et al., 1984) and in aerobic environments, degrade benzene (Chiang et al., 1989).

Based on the chromium ground-water speciation data, the anoxic conditions also result in reduction of remnant Cr(VI) to Cr(III), which should co-precipitate with iron to form the sparingly soluble Cr_{0.25}Fe_{0.75}(OH)₃ or, in the absence of iron, amorphous Cr(OH)₃. Once reduced, Cr(III) is unlikely to re-oxidize to Cr(VI), even when oxygen is present, due to kinetic limitations (Bartlett and Kimble, 1976a and 1976b; Bartlett and James, 1979). Iron hydroxide also provides a source of surface sites for sorption of metal cations, following the selectivity sequence Cr(III) > Pb > Cu > Zn > Cd > Mg (Kinniburgh et al., 1976; Leckie et al., 1980).

However, despite theoretical solubility constraints, chromium is migrating in ground water (Figure 46). For example, based on the transport of chloride, a conservative tracer in ground water, there appears to be negligible attenuation of chromium between wells OW-16 and OW-12 as the Cl:Cr ratio remains constant (≈0.24) in both wells. The migration of chromium is thus postulated to be a result of aqueous organic complexation of Cr(III) by carboxylate anions, which is consistent with the geochemical paradigm. The general absence of base metals (e.g., lead) in ground water is attributed to sorption of these metals in the oxidized vadose zone or to precipitation by sulfide in reducing environments.

3.5 Tasks E-1, E-2 and E-3. Ecological Assessment

The purpose of the GSIP Phase 2 ecological assessment was to qualitatively and/or quantitatively appraise the actual or potential hazard that the Site might present to wildlife.

Task E-1. Sediment Bioassay

The purpose of the bioassay was to sample sediment from locations upstream and downstream of the Site, observe the response of laboratory reared macroinvertebrates to each individual sample under constant environmental conditions, and evaluate if an impact may exist. The results of this sediment bioassay show that the most severe affect was seen in SED-18, a background (upstream sample) in which 100 percent mortality was observed for both of the test organism populations. Also of interest were affects seen in the tests conducted on SED-19, another upstream sample. Test end points for this sediment were also relatively low for both *H. azteca* (62 percent survival; measurable decrease in reproduction) and *C. tentans* (77 percent survival). Of the samples collected in the HBHA (Wetland 5) and behind the Woburn Mall (Wetland 4B), only SED-21 showed a measurable effect (a significant decrease in reproduction of *H. azteca*). Because adverse effects were seen with samples taken from the upstream reference locations (SED-18 and SED-19), it is impossible to conclude if the response to samples SED-21 is a direct result of Site-related constituents.

Task E-2. Fish Sampling Survey

Fish were sampled in Phillips Pond and the HBHA for the purpose of comparing tissue concentrations of metals and SVOCs. An attempt was made to collect individuals from three trophic levels: forager, bottom feeder, and predator.

There appear to be no differences in fillet metal concentrations when comparing samples taken from the HBHA and PP. Positive detections for arsenic and lead were within "normal" ranges cited in the literature for muscle tissue. Mercury was detected twice in the HBHA and four times in PP. Metal concentrations in offal, with the exception of BF/005 in the HBHA and BF/001 in PP, were also within normal tissue concentration ranges (the excursions seen with the latter two samples may be a result of the presence of sediment in the gut, as gut contents were not irrigated prior to processing).

It appears that the concentration of arsenic in the tissue samples taken from the HBHA may be greater than PP. Arsenic in fish tissue, however: a) usually complexes as an organic species (e.g., arsenobetaine), which is known to be significantly less toxic than the inorganic form (ATSDR, 1987); b) is widely recognized that the metalloid does not biomagnify through the food chain. Arsenic, therefore, is not considered a threat to local wildlife.

The concentrations of chromium and lead generally appear to be comparable between the two ponds.

Task E-3. Assessment of Hazard to Semi-Aquatic Receptors

The purpose of this task was to evaluate the real or potential hazard that COC in surface water and sediment may pose to wetland dependant birds (e.g., ducks and geese). The assessment of hazards to semi-aquatic receptors adopted the mallard duck as the representative indicator species, and evaluates the potential impact of arsenic, chromium, and lead following the ingestion of Site-related sediments. Using exposure and toxicity information derived from the available literature, it appears that the Site related sediments pose no significant hazard to the mallard duck which is considered to be the most representative indicator species. The exposure scenario, the ingestion of sediment during feeding or to obtain grit, was highly conservative in that it assumed that:

1. the duck(s) reside at the Site for 3 months/year;
2. each duck consumes sediment at the highest rate observed in the wild; and
3. the availability of these metals in the gut is much higher than solubility limits observed in previous tests of soils taken from the Site.

Despite the conservatism built into the exposure scenario, hazard quotients never exceeded one. Additive affects, which would not be anticipated given the mechanism of toxicity for each COC were also less than one.

Respectfully Submitted,

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4.0 REFERENCES

- Allison, J.D., Brown, D.S., and Novo-Gradac, K.J., 1991. MINTEQA2/PRODEFA2, A Geochemical Assessment Model for Environmental Systems: Version 3 User's Manual. Environmental Research Laboratory, Office of Research and Development, USEPA Athens, GA. EPA/600/3-91/021.
- APHA, 1989. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Water Work Association, Water Pollution Control Federation, 17th edition. Franson, M.A. editor.
- APHA, 1980. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, American Water Work Association, Water Pollution Control Federation, 15th Edition, Greenberg, A.E, Connors, J.J., and Jenkins, D., editors (1980).
- ATSDR, 1987. Toxicological Profile for Arsenic. November, 1987. Agency for Toxic Substances and Disease Registry, US Public Health Service (in collaboration with USEPA).
- Bartlett, R.J., and James, B.R., 1979. Behavior of chromium in soils: III. oxidation. *J. Env. Qual.* 8, 31-35.
- Bartlett, R.J., and Kimble, J.M., 1976a. Behavior of chromium in soils: I. trivalent forms. *J. Env. Qual.* 5, 379-383.
- Bartlett, R.J., and Kimble, J.M., 1976b. Behavior of chromium in soils: II. hexavalent forms. *J. Env. Qual.* 5, 383-386.
- Bellrose, F.C., 1978. Ducks, Geese, and Swans of North America. Stackpole Books, Harrisburg, PA.
- Berner, R.A., Early Diagenesis. Princeton University Press. Princeton, New Jersey 243 pp.
- Beyer, N., 1992. Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service, Laurel, MD. Personal communication.
- Camardese, M.B., D.J. Hoffman, L.J. LeCaptain, and G.W. Pendleton, 1990. Effects of arsenate on growth and physiology of mallard ducklings. *Environ. Toxicol. Chem.*, 9:785-795.
- Carignan R., Rapin, F., and Tessier, A., 1985. Sediment porewater sampling for metal analysis: A comparison of techniques. *Geochim. Cosmochim. Acta.* 49, 2493-2497.
- Chiang, C.Y., Salainfro, J.P., Chai, E.Y., Colthart, J.D., and Klein, C.L., 1989. Aerobic biodegradation of benzene, toluene, and xylene in a sandy aquifer—data analysis and computer modeling. *Ground Water* 27, 823-834.
- Davis, A., Chappell, R., and Olsen, R., 1988. The use and abuse of Eh measurements: Are they meaningful in natural waters? Proceedings of the Ground Water Geochemistry Conference. Denver, Colorado. National Water Well Association, Dublin, Ohio.

- Davis, A.O., and Galloway, J.N., 1992. Distribution of lead between sediments and pore water in an acidified lake, Adirondacks State Park, New York, USA. *Appl. Geochem.* (in press).
- Davis, A., M.V. Ruby, P.D. Bergstrom, 1992. Bioavailability of arsenic and lead in soils from the Butte, Montana, mining district., *Environ. Sci. Technol.*, 26:461-468.
- Eisler, 1988a. Arsenic hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.12). 92 pp.
- Eisler, 1988b. Cadmium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.2). 46 pp.
- Eisler, 1988c. Chromium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.6). 60 pp.
- Eisler, 1988d. Lead hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.14). 134 pp.
- Eisler, 1988e. Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.10). 90 pp.
- Eisler, 1988f. Selenium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish Wildl. Serv. Biol. Rep. 85(1.5). 57 pp.
- Felmy, A. R., Girvin, D.C., and Jenne, E.A., 1984. MINTEQA2 - A Computer Program for Calculating Aqueous Geochemical Equilibria: Final Project Report, USEPA Contract 68-03-3089, USEPA, Washington, DC, 64 p.
- Finley, M.T., M.P. Dieter, and L.N. Locke, 1976. Sublethal effects of chronic lead ingestion in mallard ducks. *J. Toxicol. Environ. Health*, 1(6):929-937.
- Freeze, R.A., and Cherry, J.A., 1979. *Groundwater*. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 604 pp.
- Golder Associates, Inc., 1991. Aquifer Pumping Test, Industri-Plex Site, Woburn, Massachusetts. December 1991.
- Golder Associates, Inc., 1992. 100 Percent Design Report, Part I (submitted).
- Haramis, M., 1992. Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service, Laurel, MD. Personal communication.
- Haseltine, S.D., L. Sileo, D.J. Hoffman, and B.M. Mulhern, 1985. Effects of chromium on reproduction and growth of black ducks. Reported in Chromium hazards to fish, Wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildlife Service Biological Report 85(1.6), 1986.
- Heinz, G., 1992. Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service, Laurel, MD. Personal communication.

- Heusmann, H.W., 1991. The history and status of the mallard in the Atlantic flyway. *Wildl. Soc. Bull.*, 19:14-22.
- Heusmann, H.W., 1992. Massachusetts Division of Fisheries and Wildlife. Personal communication.
- Hoffman, D.J., 1992. Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service, Laurel, MD. Personal communication.
- Holm, T.R., Anderson, M.A., Iverson, D.G., and Stanforth, R.S., 1980. Heterogeneous interactions of arsenic in aquatic systems. In "Chemical Modeling in Aqueous Systems". E.A. Jenne editor. American Chemical Society, Washington, DC. pp 711-736.
- Horowitz, A.J., 1991. A Primer on Sediment-Trace Element Chemistry. Second Edition. Lewis Publishers, Chelsea, MI.
- ISRT, 1991. Letter to J. DeCola, USEPA I. October 28, 1991.
- James, B.R., and Bartlett, R.J., 1983b. Behavior of chromium in soils: VI. Interactions between oxidation-reduction and organic complexation. *J. Environ. Qual.* 12, 173-176.
- James, B.R., and Bartlett, R.J., 1983a. Behavior of chromium in soils: V. Fate of organically complexed Cr(III) added to soil. *J. Environ. Qual.* 12, 169-172.
- Karickhoff, S.W., 1984. Organic pollutant sorption in aquatic systems. *Journal of Hydraulic Engineering* 110, 707-735.
- Kinniburgh, D.G., Jackson, M.L., and Syers, J.K., 1976. Adsorption of alkaline earth, transition, and heavy metal cations by hydrous oxide gels of iron and aluminum. *Soil Sci. Soc. Am. J.* 40, 796-799.
- Leckie, J.O., Benjamin, M.M., Hayes, K., Kaufman, G., and Altmann, S., 1980. Adsorption/Coprecipitation of Trace Elements from Water With Iron Oxyhydroxide. Final Report CS-1513. Electric Power Research Institute. Palo Alto, CA.
- Martell, A.E., and Smith, R.M., 1982. Critical Stability Constants. Plenum Press, New York.
- Mertz, W., E.E. Roginski, and R.C. Reba, 1965. Biological activity and fate of trace quantities of intravenous chromium (III) in the rat., *Amer. J. Physiol.*, 209:489-494.
- ORNL, 1984. A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture, Baes, C.F., Sharp, R.D., Sjoreen, A.L., and Shor, R.W., Health and Safety Research Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Publication No. ORNL-5786.
- ORNL, 1986. User's Manual for Ecological Risk Assessment. Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, Tennessee. Publication No. 2679.
- Pierce, M.L., and Moore, C.B., 1980. Adsorption of arsenite on amorphous iron hydroxide from dilute aqueous solution. *Env. Sci. & Tech.* 14, 214-216.

- Pierce, M.L., and Moore, C.B., 1982. Adsorption of arsenite and arsenate on amorphous iron hydroxide. *Water Res.* 16, 1247-1253.
- Rai, D., Zachara, J.M., Schwab, A.P., Schmidt, R.L., Given, D.C., and Rogers, J.E., 1984. Chemical Attenuation Rates, Coefficients, and Constants in Leachate Migration (Final Report). Electric Power Research Institute. Palo Alto, CA. EA 3356. p 5, Appendix B, pp B1-B14.
- Robins, R.G., and Huang, J.C.Y., 1988. The adsorption of arsenate ion by ferric hydroxide. In Proceedings from the Arsenic Metallurgy Symposium, TMS/AIME Annual Meeting, January 25-29, Phoenix, AZ.
- Roux Associates, Inc., 1984. Woburn Environmental Studies, Phase II Report. Vols. 1 and 2. Roux Associate, Inc., Huntington, New York.
- Roux Associates, Inc., 1990. Pre-Design Investigation, Task S-1. Extent of Hazardous Substances in Soils Interim Final Report. Volumes 1 and 2. Roux Associates, Inc., Huntington, New York.
- Roux Associates, Inc., 1991a. Phase 1 Ground-Water/Surface-Water Investigation Plan, Vol. 1-5. Prepared by Roux Associates, Inc., Huntington, NY, Environmental Science and Engineering, Inc., Amherst, NH, and PTI Environmental Services, Boulder, CO.
- Roux Associates, Inc., 1991b. Work Plan for the Ground-Water/Surface-Water Investigation Plan, Phase 2 Remedial Investigation. Prepared by Roux Associates, Inc., Huntington, NY, Environmental Science and Engineering, Inc., Amherst, NH, and PTI Environmental Services, Boulder, CO.
- Roux Associates, Inc., 1991c. Letter to W. Smull, Industri-Plex Site Remedial Trust. August 14, 1991.
- Roux Associates, Inc., 1992. Letter to J. DeCola, USEPA-Region I. January 28, 1992.
- Stumm, W., and Morgan, J.J., 1970. *Aquatic Chemistry*. John Wiley & Sons, Inc., New York, New York. pp. 583.
- Sung, W., and Morgan, J.J., 1980. Kinetics and product of ferrous iron oxygenation in aqueous systems. *Environ. Sci. Technol.* 14, 561-568.
- Thurman, E.M., and Malcolm, R.L., 1981. Preparative isolation of aquatic humic substances. *Environ. Sci. Technol.* Vol 15; 463-466.
- USEPA, 1985. *Methods for Measuring the Acute Toxicity of Effluents to Freshwater and Marine Organisms*. Environmental Monitoring and Support Laboratory, Cincinnati, OH. U.S. Environmental Protection Agency, March, 1985. EPA/600/4-85-013.
- USEPA, 1988. *Region I Laboratory Data Validation Functional Guidelines for Evaluating Organic Analyses*. Prepared for the Hazardous Site Evaluation Division, U.S. Environmental Protection Agency by the USEPA Data Review Workgroup. November 1988.

- USEPA, 1989a. Ecological Assessment of Hazardous Waste Sites: A Field and Laboratory Reference. Corvallis Environmental Research Laboratory, Corvallis, OR. USEPA 600/3-89/013.
- USEPA, 1989b. Supplemental Risk Assessment Guidance for the Superfund Program, Part 1 and 2. Final Draft, U.S. USEPA Region I Risk Assessment Work Group. USEPA 901/5-89-001.
- USEPA, 1989c. Risk Assessment Guidance for Superfund. Volume II: Environmental Evaluation Manual (Interim Final). Office of Emergency and Remedial Response, Washington, D.C. USEPA/540/1-89/001
- USEPA, 1989d. Supplemental Risk Assessment Guidance for the Superfund Program, Part 1 and 2. Final Draft, U.S. USEPA Region I Risk Assessment Work Group. USEPA 901/5-89-001.
- USEPA, 1989e. Interim Final Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual. OSWER Directive 9285.7-01a.
- USEPA, 1989f. Region I Laboratory Data Validation Functional Guidelines for Evaluating Inorganic Analyses. Prepared for the Hazardous Site Evaluation Division, U.S. Environmental Protection Agency by the USEPA Data Review Workgroup. February 1989.
- USEPA, 1989g. Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual, Part A (Interim Final), Office of Emergency and Remedial Response, Washington, D.C. USEPA/540/1-89/001.
- USGS, 1989. Study and Interpretation of the Chemical Characteristics of Natural Water. United States Geological Survey, Water Supply Paper 2254, Third Edition. US Government Printing Office, Washington, D.C., 20402.
- Wetzel, R.G., 1975. Limnology. W.B. Saunders, Co., Philadelphia, Pennsylvania. pp. 743.

Table 1. Well Construction Data for the GSIP Phase 2 RI Observation Wells and Piezometers, Industri-Plex Site, Woburn, Massachusetts.

Well Number	Casing/Diameter Material	Elevation of Measuring Point (ft above mean sea level)	Stickup (ft above land surface)	Elevation of Bottom (ft relative to mean sea level)	Elevation of Screened Interval (ft relative to mean sea level)	Type of Formation
OW-37A	2" PVC	71.58	1.88	40.7	50.7 - 40.7	basal unconsolidated
OW-51B	6" steel	72.60	3.10	-15.7	32.5 - -15.7	bedrock
OW-52A	2" PVC	69.22	1.92	56.8	61.8 - 56.8	top unconsolidated
OW-52B	2" PVC	69.05	1.45	51.1	56.1 - 51.1	basal unconsolidated
OW-53B	6" steel	70.33	2.93	-11.5	35.9 - -11.5	bedrock
OW-54A	2" PVC	64.02	1.32	50.7	58.7 - 50.7	top unconsolidated
OW-54B	2" PVC	64.28	1.48	39.1	39.1 - 49.1	intermediate unconsolidated
OW-54C	2" PVC	64.33	1.63	17.7	22.7 - 17.7	basal unconsolidated
OW-55	6" steel	65.81	3.11	-7.3	4.7 - -7.4	bedrock
OW-56A	2" PVC	59.36	1.96	45.1	55.1 - 45.1	top unconsolidated
OW-56B	2" PVC	59.00	1.60	33.0	38.0 - 33.0	intermediate unconsolidated
OW-56C	2" PVC	59.33	1.93	27.3	32.3 - 27.3	basal unconsolidated
OW-57	6" steel	59.36	2.36	-5.8	5.0 - -5.8	bedrock
WP-1	2" steel	86.56	3.16	76.0	81.0 - 76.0	top unconsolidated
WP-2	2" steel	87.78	2.78	74.7	79.7 - 74.7	top unconsolidated
WP-3	2" steel	75.42	2.82	62.4	72.4 - 62.4	top unconsolidated
WP-4	2" steel	76.76	2.66	63.7	73.7 - 63.7	top unconsolidated
WP-5	2" steel	73.73	2.93	65.8	70.8 - 65.8	top unconsolidated

Table 2. Ground-Water Elevation Data Collected During the GSIP Phase 2 RI, Industri-Plex Site, Woburn, Massachusetts.

Well Number	January 13 & 14, 1992		February 18-21, 1992		March 19, 20 & 21, 1992		Elevation of Ground Water (ft above mean sea level)
	Elevation of Measuring Point (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	
OW-1*	80.32	7.66	72.66	7.70	72.62	7.66	72.66
OW-1A	79.72	6.53	73.19	7.73	71.99	6.55	73.17
OW-4*	71.54	5.74	65.80	5.88	65.66	5.96	65.58
OW-6	62.67	8.28	54.39	8.43	54.24	8.38	54.29
OW-7	57.88	6.58	51.30	6.63	51.25	6.68	51.20
OW-10	64.63	5.13	59.50	7.45	57.18	5.46	59.17
OW-11	71.22	4.31	66.91	4.37	66.85	4.40	66.82
OW-12	63.74	7.11	56.63	7.80	55.94	7.53	56.21
OW-13	64.99	4.30	60.69	4.57	60.42	4.34	60.65
OW-14	65.54	7.43	58.11		65.54	8.38	57.16
OW-15	64.60	4.18	60.42	4.19	60.41	4.20	60.40
OW-16	67.29	3.47	63.82	5.68	61.61	4.02	63.27
OW-17	57.86	5.93	51.93	6.69	51.17	6.06	51.80
OW-18	62.76	8.96	53.80	9.03	53.73	9.08	53.68
OW-18A	62.08	8.29	53.79	9.77	52.31	8.40	53.68
OW-19	55.97	4.19	51.78	4.09	51.88	4.29	51.68
OW-19A	55.87	4.13	51.74	3.99	51.88	4.17	51.70
OW-20	57.33	6.24	51.09	6.28	51.05	NM	--
OW-21	76.28	5.11	71.17	5.24	71.04	5.24	71.04
OW-22	81.76	8.73	73.03	9.18	72.58	8.93	72.83
OW-23	68.54	14.22	54.32	18.01	50.53	14.32	54.22
OW-24A	57.47	4.86	52.61	4.79	52.68	4.89	52.58
OW-24B	57.26	4.76	52.50	4.80	52.46	4.80	52.46
OW-25A	66.00	14.44	51.56	9.33	56.67	14.53	51.47
OW-25B	65.34		65.34		65.34	13.90	51.44
OW-26A	64.15	8.70	55.45	9.10	55.05	8.83	55.32
OW-26B	63.80	8.55	55.25	8.40	55.40	8.65	55.15
OW-27A	70.84	18.15	52.69	18.45	52.39	18.51	52.33
OW-27B	70.52	18.89	51.63	18.73	51.79	19.12	51.40
OW-28	77.20	10.62	66.58	dry	--	11.74	65.46
OW-29	61.17	5.44	55.73	5.72	55.45	NM	--
OW-30A	65.90	12.33	53.57	12.60	53.30	12.58	53.32
OW-30B	65.60	12.16	53.44	12.32	53.28	12.38	53.22
OW-31	74.16	4.17	69.99	4.13	70.03	4.08	70.08
OW-32	74.97	4.65	70.32	4.73	70.24	4.57	70.40
OW-33A	56.83	5.46	51.37	5.16	51.67	5.56	51.27
OW-33B	56.66	5.35	51.31	5.30	51.36	5.37	51.29
OW-36	74.86	5.06	69.80	5.17	69.69	4.87	69.99
OW-37	72.60	5.45	67.15	5.88	66.72	5.67	66.93
OW-37A	71.58	6.22	65.36	6.86	64.72	6.62	64.96

NOTES:

* Bedrock well.

** OW-51B and OW-53B wells abandoned on 2/20/92

NM Not measured

Table 2. Ground-Water Elevation Data Collected During the GSIP Phase 2 RI, Industri-Plex Site, Woburn, Massachusetts.

Well Number	January 13 & 14, 1992		February 18-21, 1992		March 19, 20 & 21, 1992		
	Elevation of Measuring Point (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)	Depth to Water from Measuring Point (ft below measuring point)	Elevation of Ground Water (ft above mean sea level)
OW-38	71.40	7.11	64.29	8.03	63.37	7.61	63.79
OW-39	74.14	6.00	68.14	9.79	64.35	6.41	67.73
OW-40	71.64	12.08	59.56	11.46	60.18	12.12	59.52
OW-41	66.95	6.78	60.17	7.15	59.80	6.79	60.16
OW-42	69.80	16.67	53.13	16.93	52.87	17.00	52.80
OW-43	76.17	7.48	68.69	7.69	68.48	7.56	68.61
OW-44	70.60	2.61	67.99	2.20	68.40	2.72	67.88
OW-45	70.84	4.65	66.19	4.99	65.85	4.90	65.94
OW-46	67.88	NM	--	NM	--	NM	--
OW-47	69.23	10.15	59.08	11.07	58.16	10.85	58.38
OW-48	64.72	7.98	56.74	8.36	56.36	8.16	56.56
OW-48A	64.39	7.61	56.78	7.99	56.40	7.80	56.59
OW-49	66.06	9.80	56.26	9.89	56.17	8.22	57.84
OW-49A	66.42	10.24	56.18	10.37	56.05	10.31	56.11
OW-50	68.38	13.06	55.32	13.22	55.16	13.22	55.16
OW-50A	68.00	12.63	55.37	12.84	55.16	12.86	55.14
OW-51B	72.60	78.91	-6.31	6.21	66.39	**	**
OW-52A	69.22	10.30	58.92	16.37	52.85	10.18	59.04
OW-52B	69.05	11.20	57.85	11.04	58.01	11.12	57.93
OW-53B	70.33	26.48	43.85	11.44	58.89	**	**
OW-54A	64.02	8.14	55.88	7.56	56.46	8.23	55.79
OW-54B	64.28	8.34	55.94	6.73	57.55	8.02	56.26
OW-54C	64.33	8.24	56.09	8.02	56.31	8.33	56.00
OW-55	65.81	10.08	55.73	10.22	55.59	9.99	55.82
OW-56A	59.36	7.46	51.90	7.48	51.88	7.53	51.83
OW-56B	59.00	7.09	51.91	7.02	51.98	7.12	51.88
OW-56C	59.33	7.45	51.88	7.38	51.95	7.44	51.89
OW-57	59.36	44.78	14.58	33.36	26.00	7.19	52.17
WP-1	86.56	9.63	76.93	dry	--	9.94	76.62
WP-2	87.78	dry	--	dry	--	dry	--
WP-3	75.42	5.31	70.11	5.30	70.12	5.22	70.20
WP-4	76.76	6.83	69.93	6.67	70.09	6.61	70.15
WP-5	73.73	3.77	69.96	3.64	70.09	3.57	70.16

NOTES:

- * Bedrock well.
- ** OW-51B and OW-53B wells abandoned on 2/20/92
- NM Not measured

Table 3. Organic Compounds Detected in Ground-Water Samples Collected on December 16, 1991 through December 19, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>OW-31</u>	<u>DATE:</u>	<u>12/18/91</u>
ANALYTE		CONCENTRATION	CRQL
Benzene		63000.0 ug/L	4000.0
Carbon disulfide		2.0 ug/L	10.0
Ethylbenzene		62.0 ug/L	10.0
4-Methyl-2-pentanone		4.0 ug/L	10.0
Toluene		84.0 ug/L	10.0
Xylenes, total		320.0 ug/L	10.0
<u>SAMPLE:</u>	<u>OW-52A</u>	<u>DATE:</u>	<u>12/17/91</u>
ANALYTE		CONCENTRATION	CRQL
Benzene		1.0 ug/L	10.0
<u>SAMPLE:</u>	<u>OW-52B</u>	<u>DATE:</u>	<u>12/17/91</u>
ANALYTE		CONCENTRATION	CRQL
Benzene		6.0 ug/L	10.0
Ethylbenzene		6.0 ug/L	10.0
Toluene		29.0 ug/L	10.0
Xylenes, total		66.0 ug/L	10.0
<u>SAMPLE:</u>	<u>OW-54A</u>	<u>DATE:</u>	<u>12/17/91</u>
ANALYTE		CONCENTRATION	CRQL
Benzene		1.0 ug/L	10.0
<u>SAMPLE:</u>	<u>OW-54B</u>	<u>DATE:</u>	<u>12/17/91</u>
ANALYTE		CONCENTRATION	CRQL
Benzene		620.0 ug/L	40.0
Xylenes, total		13.0 ug/L	40.0
<u>SAMPLE:</u>	<u>OW-54C</u>	<u>DATE:</u>	<u>12/17/91</u>
ANALYTE		CONCENTRATION	CRQL
Acetone		210.0 ug/L	10.0
Benzene		200.0 ug/L	40.0
Chloroform		4.0 ug/L	10.0
Ethylbenzene		4.0 ug/L	10.0
4-Methyl-2-pentanone		29.0 ug/L	10.0
Toluene		430.0 ug/L	40.0
1,1,2-Trichloroethane		1.0 ug/L	10.0
Xylenes, total		25.0 ug/L	10.0

NOTE: CRQL-Contract Required Quantitation Limit

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Table 3. Organic Compounds Detected in Ground-Water Samples Collected on December 16, 1991 through December 19, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>OW-55</u>	<u>DATE:</u>	<u>12/18/91</u>
ANALYTE		CONCENTRATION	CRQL
Acetone		1800.0 ug/L	200.0
Benzene		1800.0 ug/L	200.0
2-Butanone		110.0 ug/L	10.0
Ethylbenzene		8.0 ug/L	10.0
2-Hexanone		2.0 ug/L	10.0
4-Methyl-2-pentanone		83.0 ug/L	10.0
Toluene		2100.0 ug/L	200.0
Xylenes, total		49.0 ug/L	10.0

<u>SAMPLE:</u>	<u>OW-56A</u>	<u>DATE:</u>	<u>12/16/91</u>
ANALYTE		CONCENTRATION	CRQL
Benzene		360.0 ug/L	50.0
Carbon disulfide		10.0 ug/L	50.0

<u>SAMPLE:</u>	<u>OW-56B</u>	<u>DATE:</u>	<u>12/16/91</u>
ANALYTE		CONCENTRATION	CRQL
Benzene		3600.0 ug/L	250.0
Toluene		26.0 ug/L	250.0
Xylenes, total		100.0 ug/L	250.0

<u>SAMPLE:</u>	<u>OW-56C</u>	<u>DATE:</u>	<u>12/16/91</u>
ANALYTE		CONCENTRATION	CRQL
Benzene		12000.0 ug/L	800.0
Ethylbenzene		30.0 ug/L	200.0
Toluene		460.0 ug/L	200.0
Xylenes, total		290.0 ug/L	200.0

<u>SAMPLE:</u>	<u>WP-3</u>	<u>DATE:</u>	<u>12/19/91</u>
ANALYTE		CONCENTRATION	CRQL
Benzene		12000.0 ug/L	1000.0
Ethylbenzene		31.0 ug/L	10.0
Toluene		440.0 ug/L	1000.0
Xylenes, total		250.0 ug/L	1000.0

<u>SAMPLE:</u>	<u>WP-4</u>	<u>DATE:</u>	<u>12/19/91</u>
ANALYTE		CONCENTRATION	CRQL
4-Methyl-2-pentanone		3.0 ug/L	10.0
Toluene		41.0 ug/L	10.0
Xylenes, total		1.0 ug/L	10.0

NOTE: CRQL-Contract Required Quantitation Limit

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Table 3. Organic Compounds Detected in Ground-Water Samples Collected on December 16, 1991 through December 19, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	WP-5	<u>DATE:</u>	12/19/91	
ANALYTE		CONCENTRATION		CRQL
Benzene		2.0 ug/L		10.0

NOTE: CRQL-Contract Required Quantitation Limit

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Table 4. Inorganic Analytes Detected in Ground-Water Samples Collected on December 16, 1991 through December 19, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>OW-30A</u>	<u>DATE:</u>	<u>12/16/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Barium, dissolved		0.0870 mg/L	0.2000	0.0010
	Calcium, dissolved		60.8000 mg/L	5.0000	0.0080
	Cobalt, dissolved		0.0429 mg/L	0.0500	0.0040
	Iron, dissolved		3.9900 mg/L	0.1000	0.0080
	Magnesium, dissolved		4.8700 mg/L	5.0000	0.0340
	Manganese, dissolved		3.0800 mg/L	0.0150	0.0010
	Nickel, dissolved		0.0186 mg/L	0.0400	0.0100
	Potassium, dissolved		8.7900 mg/L	5.0000	0.6710
	Sodium, dissolved		31.7000 mg/L	5.0000	1.7370
	Zinc, dissolved		0.3350 mg/L	0.0200	0.0020
<u>SAMPLE:</u>	<u>OW-30B</u>	<u>DATE:</u>	<u>12/16/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Calcium, dissolved		55.1000 mg/L	5.0000	0.0080
	Magnesium, dissolved		9.2000 mg/L	5.0000	0.0340
	Potassium, dissolved		5.3700 mg/L	5.0000	0.6710
	Sodium, dissolved		38.0000 mg/L	5.0000	1.7370
<u>SAMPLE:</u>	<u>OW-31</u>	<u>DATE:</u>	<u>12/18/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Aluminum, dissolved		0.1520 mg/L	0.2000	0.0360
	Arsenic, dissolved		0.4840 mg/L	0.1000	0.0100
	Barium, dissolved		0.2300 mg/L	0.2000	0.0010
	Calcium, dissolved		365.0000 mg/L	5.0000	0.0080
	Iron, dissolved		0.2670 mg/L	0.1000	0.0080
	Magnesium, dissolved		169.0000 mg/L	5.0000	0.0340
	Manganese, dissolved		5.3000 mg/L	0.0150	0.0010
	Potassium, dissolved		40.2000 mg/L	5.0000	0.6710
	Sodium, dissolved		114.0000 mg/L	5.0000	1.7370
	Vanadium, dissolved		0.0293 mg/L	0.0500	0.0040
<u>SAMPLE:</u>	<u>OW-37</u>	<u>DATE:</u>	<u>12/18/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Arsenic, dissolved		0.1120 mg/L	0.0200	0.0020
	Barium, dissolved		0.0566 mg/L	0.2000	0.0010
	Calcium, dissolved		59.1000 mg/L	5.0000	0.0080
	Iron, dissolved		0.8300 mg/L	0.1000	0.0080
	Magnesium, dissolved		7.2600 mg/L	5.0000	0.0340
	Manganese, dissolved		0.5820 mg/L	0.0150	0.0010
	Potassium, dissolved		2.7600 mg/L	5.0000	0.6710
	Sodium, dissolved		21.0000 mg/L	5.0000	1.7370
	Zinc, dissolved		0.0141 mg/L	0.0200	0.0020

NOTE: CRDL-Contract Required Quantitation Limit
IDL -Instrument Detection Limit

Table 4. Inorganic Analytes Detected in Ground-Water Samples Collected on December 16, 1991 through December 19, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>OW-37A</u>	<u>DATE:</u>	12/18/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Arsenic, dissolved		2.0100 mg/L	0.5000	0.0500
	Barium, dissolved		0.0456 mg/L	0.2000	0.0010
	Calcium, dissolved		48.7000 mg/L	5.0000	0.0080
	Iron, dissolved		1.7700 mg/L	0.1000	0.0080
	Magnesium, dissolved		6.4500 mg/L	5.0000	0.0340
	Manganese, dissolved		0.3740 mg/L	0.0150	0.0010
	Potassium, dissolved		2.6200 mg/L	5.0000	0.6710
	Sodium, dissolved		28.9000 mg/L	5.0000	1.7370
	Zinc, dissolved		0.0328 mg/L	0.0200	0.0020
<u>SAMPLE:</u>	<u>OW-52A</u>	<u>DATE:</u>	12/17/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Arsenic, dissolved		0.4000 mg/L	0.0500	0.0050
	Barium, dissolved		0.0299 mg/L	0.2000	0.0010
	Calcium, dissolved		561.0000 mg/L	5.0000	0.0080
	Chromium, dissolved		0.0056 mg/L	0.0100	0.0040
	Iron, dissolved		14.0000 mg/L	0.1000	0.0080
	Magnesium, dissolved		7.3000 mg/L	5.0000	0.0340
	Manganese, dissolved		0.6070 mg/L	0.0150	0.0010
	Potassium, dissolved		12.3000 mg/L	5.0000	0.6710
	Sodium, dissolved		20.3000 mg/L	5.0000	1.7370
<u>SAMPLE:</u>	<u>OW-52B</u>	<u>DATE:</u>	12/17/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Aluminum, dissolved		0.0865 mg/L	0.2000	0.0360
	Arsenic, dissolved		0.3940 mg/L	0.1000	0.0100
	Barium, dissolved		0.0805 mg/L	0.2000	0.0010
	Calcium, dissolved		268.0000 mg/L	5.0000	0.0080
	Chromium, dissolved		0.0706 mg/L	0.0100	0.0040
	Iron, dissolved		0.1840 mg/L	0.1000	0.0080
	Magnesium, dissolved		19.9000 mg/L	5.0000	0.0340
	Manganese, dissolved		0.3130 mg/L	0.0150	0.0010
	Potassium, dissolved		18.1000 mg/L	5.0000	0.6710
	Sodium, dissolved		61.9000 mg/L	5.0000	1.7370
	Vanadium, dissolved		0.0062 mg/L	0.0500	0.0040
<u>SAMPLE:</u>	<u>OW-54A</u>	<u>DATE:</u>	12/17/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Barium, dissolved		0.0121 mg/L	0.2000	0.0010
	Calcium, dissolved		99.7000 mg/L	5.0000	0.0080
	Iron, dissolved		0.8390 mg/L	0.1000	0.0080
	Magnesium, dissolved		2.8200 mg/L	5.0000	0.0340
	Manganese, dissolved		0.3510 mg/L	0.0150	0.0010
	Nickel, dissolved		0.0115 mg/L	0.0400	0.0100
	Potassium, dissolved		4.1800 mg/L	5.0000	0.6710

NOTE: CRDL-Contract Required Quantitation Limit
IDL -Instrument Detection Limit

Table 4. Inorganic Analytes Detected in Ground-Water Samples Collected on December 16, 1991 through December 19, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>DATE:</u>	<u>ANALYTE</u>	<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
OW-54A	12/17/91	Sodium, dissolved	9.8700 mg/L	5.0000	1.7370
		Zinc, dissolved	0.0390 mg/L	0.0200	0.0020
<u>SAMPLE:</u>	<u>DATE:</u>	<u>ANALYTE</u>	<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
OW-54B	12/17/91	Arsenic, dissolved	0.0843 mg/L	0.0100	0.0010
		Barium, dissolved	0.0411 mg/L	0.2000	0.0010
		Calcium, dissolved	305.0000 mg/L	5.0000	0.0080
		Chromium, dissolved	0.0461 mg/L	0.0100	0.0040
		Iron, dissolved	0.1490 mg/L	0.1000	0.0080
		Magnesium, dissolved	88.2000 mg/L	5.0000	0.0340
		Manganese, dissolved	0.3730 mg/L	0.0150	0.0010
		Nickel, dissolved	0.0111 mg/L	0.0400	0.0100
		Potassium, dissolved	7.2800 mg/L	5.0000	0.6710
		Sodium, dissolved	108.0000 mg/L	5.0000	1.7370
		Vanadium, dissolved	0.0296 mg/L	0.0500	0.0040
		Zinc, dissolved	0.0143 mg/L	0.0200	0.0020
<u>SAMPLE:</u>	<u>DATE:</u>	<u>ANALYTE</u>	<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
OW-54C	12/17/91	Aluminum, dissolved	0.0411 mg/L	0.2000	0.0360
		Arsenic, dissolved	0.9490 mg/L	0.2000	0.0200
		Barium, dissolved	0.2320 mg/L	0.2000	0.0010
		Calcium, dissolved	23.0000 mg/L	5.0000	0.0080
		Chromium, dissolved	0.1450 mg/L	0.0100	0.0040
		Iron, dissolved	0.8490 mg/L	0.1000	0.0080
		Magnesium, dissolved	75.9000 mg/L	5.0000	0.0340
		Manganese, dissolved	0.0636 mg/L	0.0150	0.0010
		Nickel, dissolved	0.0375 mg/L	0.0400	0.0100
		Potassium, dissolved	34.5000 mg/L	5.0000	0.6710
		Sodium, dissolved	244.0000 mg/L	5.0000	1.7370
		Vanadium, dissolved	0.1810 mg/L	0.0500	0.0040
<u>SAMPLE:</u>	<u>DATE:</u>	<u>ANALYTE</u>	<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
OW-55	12/18/91	Antimony, dissolved	0.0293 mg/L	0.0600	0.0180
		Arsenic, dissolved	0.1930 mg/L	0.0500	0.0050
		Barium, dissolved	0.2010 mg/L	0.2000	0.0010
		Calcium, dissolved	98.7000 mg/L	5.0000	0.0080
		Chromium, dissolved	0.1220 mg/L	0.0100	0.0040
		Copper, dissolved	0.0524 mg/L	0.0250	0.0030
		Iron, dissolved	1.1600 mg/L	0.1000	0.0080
		Magnesium, dissolved	96.2000 mg/L	5.0000	0.0340
		Manganese, dissolved	0.3490 mg/L	0.0150	0.0010
		Nickel, dissolved	0.0604 mg/L	0.0400	0.0100

NOTE: CRDL-Contract Required Quantitation Limit
IDL -Instrument Detection Limit

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Table 4. Inorganic Analytes Detected in Ground-Water Samples Collected on December 16, 1991 through December 19, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>OW-55</u>	<u>DATE:</u>	12/18/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Potassium, dissolved		84.4000 mg/L	5.0000	0.6710
	Sodium, dissolved		570.0000 mg/L	5.0000	1.7370
	Vanadium, dissolved		0.0833 mg/L	0.0500	0.0040
	Zinc, dissolved		0.2590 mg/L	0.0200	0.0020
<u>SAMPLE:</u>	<u>OW-56A</u>	<u>DATE:</u>	12/16/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Arsenic, dissolved		0.5280 mg/L	0.0500	0.0050
	Barium, dissolved		0.0445 mg/L	0.2000	0.0010
	Calcium, dissolved		196.0000 mg/L	5.0000	0.0080
	Chromium, dissolved		0.0185 mg/L	0.0100	0.0040
	Iron, dissolved		0.1610 mg/L	0.1000	0.0080
	Magnesium, dissolved		29.7000 mg/L	5.0000	0.0340
	Manganese, dissolved		0.3620 mg/L	0.0150	0.0010
	Nickel, dissolved		0.0143 mg/L	0.0400	0.0100
	Potassium, dissolved		3.8000 mg/L	5.0000	0.6710
	Sodium, dissolved		41.3000 mg/L	5.0000	1.7370
	Vanadium, dissolved		0.0221 mg/L	0.0500	0.0040
<u>SAMPLE:</u>	<u>OW-56B</u>	<u>DATE:</u>	12/16/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Barium, dissolved		0.0852 mg/L	0.2000	0.0010
	Calcium, dissolved		105.0000 mg/L	5.0000	0.0080
	Chromium, dissolved		0.0539 mg/L	0.0100	0.0040
	Cobalt, dissolved		0.0194 mg/L	0.0500	0.0040
	Iron, dissolved		4.8700 mg/L	0.1000	0.0080
	Magnesium, dissolved		73.0000 mg/L	5.0000	0.0340
	Manganese, dissolved		2.5900 mg/L	0.0150	0.0010
	Nickel, dissolved		0.0180 mg/L	0.0400	0.0100
	Potassium, dissolved		39.6000 mg/L	5.0000	0.6710
	Selenium, dissolved		0.0037 mg/L	0.0050	0.0020
	Sodium, dissolved		1090.0000 mg/L	5.0000	1.7370
<u>SAMPLE:</u>	<u>OW-56C</u>	<u>DATE:</u>	12/16/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Aluminum, dissolved		0.0878 mg/L	0.4000	0.0720
	Barium, dissolved		0.0138 mg/L	0.4000	0.0020
	Cadmium, dissolved		0.0062 mg/L	0.0100	0.0060
	Calcium, dissolved		5030.0000 mg/L	10.0000	0.0160
	Chromium, dissolved		0.0408 mg/L	0.0200	0.0080
	Cobalt, dissolved		0.0266 mg/L	0.1000	0.0080
	Iron, dissolved		568.0000 mg/L	0.2000	0.0160
	Magnesium, dissolved		167.0000 mg/L	10.0000	0.0680
	Manganese, dissolved		15.4000 mg/L	0.0300	0.0020
	Potassium, dissolved		67.6000 mg/L	10.0000	1.3420

NOTE: CRDL-Contract Required Quantitation Limit
IDL -Instrument Detection Limit

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Table 4. Inorganic Analytes Detected in Ground-Water Samples Collected on December 16, 1991 through December 19, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>OW-56C</u>	<u>DATE:</u>	<u>12/16/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Selenium, dissolved		0.0042 mg/L	0.0050	0.0020
	Sodium, dissolved		2380.0000 mg/L	10.0000	3.4740
	Vanadium, dissolved		0.0298 mg/L	0.1000	0.0080
<u>SAMPLE:</u>	<u>WP-1</u>	<u>DATE:</u>	<u>12/19/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Calcium, dissolved		575.0000 mg/L	5.0000	0.0080
	Iron, dissolved		0.4360 mg/L	0.1000	0.0080
	Magnesium, dissolved		23.3000 mg/L	5.0000	0.0340
	Manganese, dissolved		0.6550 mg/L	0.0150	0.0010
	Nickel, dissolved		0.0195 mg/L	0.0400	0.0100
	Potassium, dissolved		17.6000 mg/L	5.0000	0.6710
	Selenium, dissolved		0.0075 mg/L	0.0050	0.0020
	Sodium, dissolved		16.0000 mg/L	5.0000	1.7370
	Zinc, dissolved		0.0228 mg/L	0.0200	0.0020
<u>SAMPLE:</u>	<u>WP-3</u>	<u>DATE:</u>	<u>12/19/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Arsenic, dissolved		0.0204 mg/L	0.0100	0.0010
	Calcium, dissolved		606.0000 mg/L	5.0000	0.0080
	Cobalt, dissolved		0.0775 mg/L	0.0500	0.0040
	Copper, dissolved		0.0767 mg/L	0.0250	0.0030
	Iron, dissolved		0.7200 mg/L	0.1000	0.0080
	Magnesium, dissolved		229.0000 mg/L	5.0000	0.0340
	Manganese, dissolved		0.4400 mg/L	0.0150	0.0010
	Nickel, dissolved		0.0163 mg/L	0.0400	0.0100
	Potassium, dissolved		15.8000 mg/L	5.0000	0.6710
	Sodium, dissolved		276.0000 mg/L	5.0000	1.7370
	Zinc, dissolved		0.1120 mg/L	0.0200	0.0020
<u>SAMPLE:</u>	<u>WP-4</u>	<u>DATE:</u>	<u>12/19/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Aluminum, dissolved		0.0527 mg/L	0.2000	0.0360
	Arsenic, dissolved		0.5450 mg/L	0.1000	0.0100
	Barium, dissolved		0.0704 mg/L	0.2000	0.0010
	Calcium, dissolved		256.0000 mg/L	5.0000	0.0080
	Chromium, dissolved		0.0616 mg/L	0.0100	0.0040
	Iron, dissolved		0.1270 mg/L	0.1000	0.0080
	Magnesium, dissolved		77.7000 mg/L	5.0000	0.0340
	Manganese, dissolved		3.2200 mg/L	0.0150	0.0010
	Nickel, dissolved		0.0218 mg/L	0.0400	0.0100
	Potassium, dissolved		18.3000 mg/L	5.0000	0.6710
	Sodium, dissolved		34.2000 mg/L	5.0000	1.7370
	Vanadium, dissolved		0.0051 mg/L	0.0500	0.0040
	Zinc, dissolved		0.0153 mg/L	0.0200	0.0020

NOTE: CRDL-Contract Required Quantitation Limit
IDL -Instrument Detection Limit

Table 4. Inorganic Analytes Detected in Ground-Water Samples Collected on December 16, 1991 through December 19, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	WP-5	<u>DATE:</u>	12/19/91		
ANALYTE		CONCENTRATION		CRDL	IDL
Aluminum, dissolved		0.0732 mg/L		0.2000	0.0360
Arsenic, dissolved		0.8690 mg/L		0.1000	0.0100
Barium, dissolved		0.0850 mg/L		0.2000	0.0010
Calcium, dissolved		328.0000 mg/L		5.0000	0.0080
Iron, dissolved		60.2000 mg/L		0.1000	0.0080
Magnesium, dissolved		77.2000 mg/L		5.0000	0.0340
Manganese, dissolved		4.5200 mg/L		0.0150	0.0010
Nickel, dissolved		0.0116 mg/L		0.0400	0.0100
Potassium, dissolved		19.3000 mg/L		5.0000	0.6710
Sodium, dissolved		110.0000 mg/L		5.0000	1.7370
Zinc, dissolved		0.0212 mg/L		0.0200	0.0020

NOTE: CRDL-Contract Required Quantitation Limit
IDL -Instrument Detection Limit

Table 5. Surface-Water Elevation Data Collected During the GSIP Phase 2 RI, Industri-Plex Site, Woburn, Massachusetts.

Staff Gauge Designation	Elevation of Measuring Point (ft above mean sea level)	January 13-14 , 1992			February 18-21, 1992		
		Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)	Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)
SW-1	72.44	0.67	2.63	69.81	0.84	2.46	69.98
SW-3	71.70	0.48	2.82	68.88	0.46	2.84	68.86
SW-7	71.73	0.78	2.52	69.21	0.72	2.58	69.15
SW-14	50.31	0.72	2.58	47.73	0.88	2.42	47.88
SW-56	--	--	--	--	--	--	--

Staff Gauge Designation	Elevation of Measuring Point (ft above mean sea level)	March 19-21, 1992		
		Depth of Surface Water (feet)	Depth to Water from Measuring Point* (ft below measuring point)	Elevation of Water Table (ft above mean sea level)
SW-1	72.44	0.91	2.39	70.05
SW-3	71.70	0.44	2.86	68.84
SW-7	71.73	0.72	2.58	69.15
SW-14	50.31	0.74	2.56	47.75
SW-56	54.47	0.45	2.85	51.62

NOTES:

- * Measuring Point at 3.30 ft mark on staff gauge.
- (1) Staff gauge located within Aberjona River adjacent to PZ-1 and PZ-2.

Table 6. Calculation of Vertical Gradients at Selected Observation Well Clusters During the GSIP Phase 2 RI, Industri-Plex Site, Woburn, Massachusetts.

Well Number	Elevation of Bottom of Screen (ft relative to mean sea level)	Elevation of Midpoint of Screen (ft relative to mean sea level)	Water-Level Elevation (ft relative to mean sea level)	January 13 & 14, 1992				February 18 & 19, 1992				
				dh (ft)	dl (ft)	Iv	Direction of Flow	Water-Level Elevation (ft relative to mean sea level)	dh (ft)	dl (ft)	Iv	Direction of Flow
OW-18	7.30	27.30	53.80					53.73				
OW-18A	46.11	51.11	53.79	-0.01	23.81	0.0004	upward	52.31	-1.42	23.81	0.0596	upward
OW-30A	45.18	50.25	53.57					53.30				
OW-30B	5.27	10.34	53.44	0.13	39.91	0.0033	downward	53.28	0.02	39.91	0.0005	downward
OW-54A	50.70	54.70	55.88					56.46				
OW-54C	17.70	20.20	56.09	-0.21	34.50	0.0061	upward	56.31	0.15	34.50	0.0043	downward
OW-54C	17.70	20.20	56.09					56.31				
OW-55	-7.40	-1.35	55.73	0.36	21.55	0.0167	downward	55.59	0.72	21.55	0.0334	downward
OW-56A	45.10	50.10	51.90					51.88				
OW-56C	27.30	29.80	51.88	0.02	20.30	0.0010	downward	51.95	-0.07	20.30	0.0034	upward
OW-56C	27.30	29.80	51.88					51.95				
OW-57	-5.80	-3.30	14.58	*	*	*	*	26.00	*	*	*	*

dh - Difference of water-level elevation

dl - Difference between midpoints of screen

Iv - Vertical hydraulic gradient

* - Gradient is not considered representative since water-level elevation in bedrock well OW-57 had not reached static level.

Table 6. Calculation of Vertical Gradients at Selected Observation Well Clusters During the GSIP Phase 2 RI, Industri-Plex Site, Woburn, Massachusetts.

Mar. 19-21, 1992							
Well Number	Elevation of Bottom of Screen (ft relative to mean sea level)	Elevation of Midpoint of Screen (ft relative to mean sea level)	Water-Level Elevation (ft relative to mean sea level)	dh (ft)	dl (ft)	Iv	Direction of Flow
OW-18	7.30	27.30	53.68				
OW-18A	46.11	51.11	53.68	0.00	23.81	0.0000	horizontal
OW-30A	45.18	50.25	53.32				
OW-30B	5.27	10.34	53.22	0.10	39.91	0.0025	downward
OW-54A	50.70	54.70	55.79				
OW-54C	17.70	20.20	56.00	-0.21	34.50	0.0061	upward
OW-54C	17.70	20.20	56.00				
OW-55	-7.40	-1.35	55.82	0.18	21.55	0.0084	downward
OW-56A	45.10	50.10	51.83				
OW-56C	27.30	29.80	51.89	-0.06	20.30	0.0030	upward
OW-56C	27.30	29.80	51.89				
OW-57	-5.80	-3.30	52.17	-0.28	33.10	0.0085	upward

dh - Difference of water-level elevation
dl - Difference between midpoints of screen
Iv - Vertical hydraulic gradient

Table 7. Organic Compounds Detected in Surface Water Samples Collected on October 2, 1991 and October 3, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	SW-18	<u>DATE:</u>	10/02/91
COMPOUND		CONCENTRATION	CRQL
1,2-Dichloroethene, total		11.0 ug/L	10.0
Ethylbenzene		1.0 ug/L	10.0
4-Methyl-2-pentanone		2.0 ug/L	10.0
Toluene		130.0 ug/L	10.0
Trichloroethene		11.0 ug/L	10.0
Xylenes, total		7.0 ug/L	10.0
2-Methylphenol		6.0 ug/L	10.0

<u>SAMPLE:</u>	SW-19	<u>DATE:</u>	10/02/91
COMPOUND		CONCENTRATION	CRQL
Trichloroethene		2.0 ug/L	10.0

<u>SAMPLE:</u>	SW-21	<u>DATE:</u>	10/03/91
COMPOUND		CONCENTRATION	CRQL
1,1-Dichloroethane		2.0 ug/L	10.0
1,2-Dichloroethene, total		3.0 ug/L	10.0
Trichloroethene		3.0 ug/L	10.0

<u>SAMPLE:</u>	SW-22	<u>DATE:</u>	10/03/91
COMPOUND		CONCENTRATION	CRQL
1,2-Dichloroethene, total		1.0 ug/L	10.0
Trichloroethene		2.0 ug/L	10.0

<u>SAMPLE:</u>	SW-23	<u>DATE:</u>	10/03/91
COMPOUND		CONCENTRATION	CRQL
Trichloroethene		1.0 ug/L	10.0

NOTE: CRQL-Contract Required Quantitation Limit

Table 8. Inorganic Analytes Detected in Surface-Water Samples Collected on October 2, 1991 and October 3, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	SW-18	<u>DATE:</u>	10/02/91		
	ANALYTE		CONCENTRATION	CRDL	IDL
	Aluminum, dissolved	0.1360	mg/L	0.2000	0.0430
	Barium, dissolved	0.0268	mg/L	0.2000	0.0010
	Calcium, dissolved	30.7000	mg/L	5.0000	0.0410
	Chromium, dissolved	0.0156	mg/L	0.0100	0.0080
	Cobalt, dissolved	0.0074	mg/L	0.0500	0.0050
	Copper, dissolved	0.0067	mg/L	0.0250	0.0040
	Iron, dissolved	0.3610	mg/L	0.1000	0.0100
	Magnesium, dissolved	5.5700	mg/L	5.0000	0.0730
	Manganese, dissolved	0.7530	mg/L	0.0150	0.0020
	Nickel, dissolved	0.1080	mg/L	0.0400	0.0130
	Potassium, dissolved	4.9400	mg/L	5.0000	1.0090
	Sodium, dissolved	107.0000	mg/L	5.0000	0.0530
	Zinc, dissolved	0.0238	mg/L	0.0200	0.0030
	Aluminum, total	1.6400	mg/L	0.2000	0.0430
	Arsenic, total	0.0036	mg/L	0.0100	0.0010
	Barium, total	0.0257	mg/L	0.2000	0.0010
	Calcium, total	28.9000	mg/L	5.0000	0.0410
	Chromium, total	0.1950	mg/L	0.0100	0.0080
	Cobalt, total	0.0095	mg/L	0.0500	0.0050
	Iron, total	1.7600	mg/L	0.1000	0.0100
	Magnesium, total	5.1300	mg/L	5.0000	0.0730
	Manganese, total	0.7770	mg/L	0.0150	0.0020
	Potassium, total	4.9600	mg/L	5.0000	1.0090
	Sodium, total	94.2000	mg/L	5.0000	0.0530
	Vanadium, total	0.0060	mg/L	0.0500	0.0060
	Zinc, total	0.0282	mg/L	0.0200	0.0030

<u>SAMPLE:</u>	SW-19	<u>DATE:</u>	10/02/91		
	ANALYTE		CONCENTRATION	CRDL	IDL
	Barium, dissolved	0.0258	mg/L	0.2000	0.0010
	Calcium, dissolved	22.0000	mg/L	5.0000	0.0410
	Copper, dissolved	0.0084	mg/L	0.0250	0.0040
	Iron, dissolved	0.4210	mg/L	0.1000	0.0100
	Lead, dissolved	0.0019	mg/L	0.0030	0.0010
	Magnesium, dissolved	3.8700	mg/L	5.0000	0.0730
	Manganese, dissolved	0.0406	mg/L	0.0150	0.0020
	Potassium, dissolved	3.9300	mg/L	5.0000	1.0090
	Sodium, dissolved	36.3000	mg/L	5.0000	0.0530
	Zinc, dissolved	0.0173	mg/L	0.0200	0.0030
	Aluminum, total	0.0755	mg/L	0.2000	0.0430
	Barium, total	0.0278	mg/L	0.2000	0.0010
	Calcium, total	20.4000	mg/L	5.0000	0.0410
	Chromium, total	0.0109	mg/L	0.0100	0.0080
	Copper, total	0.0324	mg/L	0.0250	0.0040
	Iron, total	0.6070	mg/L	0.1000	0.0100
	Magnesium, total	3.5500	mg/L	5.0000	0.0730
	Manganese, total	0.0485	mg/L	0.0150	0.0020
	Nickel, total	0.0135	mg/L	0.0400	0.0130
	Potassium, total	4.4200	mg/L	5.0000	1.0090
	Sodium, total	28.5000	mg/L	5.0000	0.0530
	Zinc, total	0.0287	mg/L	0.0200	0.0030

NOTE: CRDL-Contract Required Detection Limit
IDL -Instrument Detection Limit

Table 8. Inorganic Analytes Detected in Surface-Water Samples Collected on October 2, 1991 and October 3, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	SW-21	<u>DATE:</u>	10/03/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Arsenic, dissolved		0.0075 mg/L	0.0100	0.0010
	Barium, dissolved		0.0316 mg/L	0.2000	0.0010
	Calcium, dissolved		32.3000 mg/L	5.0000	0.0410
	Copper, dissolved		0.0090 mg/L	0.0250	0.0040
	Iron, dissolved		0.6890 mg/L	0.1000	0.0100
	Magnesium, dissolved		5.5600 mg/L	5.0000	0.0730
	Manganese, dissolved		0.3800 mg/L	0.0150	0.0020
	Potassium, dissolved		6.0300 mg/L	5.0000	1.0090
	Sodium, dissolved		46.8000 mg/L	5.0000	0.0530
	Zinc, dissolved		0.0890 mg/L	0.0200	0.0030
	Aluminum, total		0.1230 mg/L	0.2000	0.0430
	Arsenic, total		0.0146 mg/L	0.0100	0.0010
	Barium, total		0.0318 mg/L	0.2000	0.0010
	Calcium, total		30.3000 mg/L	5.0000	0.0410
	Chromium, total		0.0146 mg/L	0.0100	0.0080
	Iron, total		1.7000 mg/L	0.1000	0.0100
	Magnesium, total		5.1600 mg/L	5.0000	0.0730
	Manganese, total		0.3800 mg/L	0.0150	0.0020
	Potassium, total		4.8400 mg/L	5.0000	1.0090
	Sodium, total		40.2000 mg/L	5.0000	0.0530
	Zinc, total		0.2060 mg/L	0.0200	0.0030

<u>SAMPLE:</u>	SW-22	<u>DATE:</u>	10/03/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Arsenic, dissolved		0.0065 mg/L	0.0100	0.0010
	Barium, dissolved		0.0311 mg/L	0.2000	0.0010
	Calcium, dissolved		31.3000 mg/L	5.0000	0.0410
	Copper, dissolved		0.0068 mg/L	0.0250	0.0040
	Iron, dissolved		0.8980 mg/L	0.1000	0.0100
	Lead, dissolved		0.0011 mg/L	0.0030	0.0010
	Magnesium, dissolved		5.3300 mg/L	5.0000	0.0730
	Manganese, dissolved		0.4600 mg/L	0.0150	0.0020
	Potassium, dissolved		4.9600 mg/L	5.0000	1.0090
	Sodium, dissolved		40.7000 mg/L	5.0000	0.0530
	Zinc, dissolved		0.1060 mg/L	0.0200	0.0030
	Aluminum, total		0.0927 mg/L	0.2000	0.0430
	Arsenic, total		0.0131 mg/L	0.0100	0.0010
	Barium, total		0.0318 mg/L	0.2000	0.0010
	Calcium, total		31.7000 mg/L	5.0000	0.0410
	Chromium, total		0.0123 mg/L	0.0100	0.0080
	Iron, total		2.5300 mg/L	0.1000	0.0100
	Magnesium, total		5.2700 mg/L	5.0000	0.0730
	Manganese, total		0.4970 mg/L	0.0150	0.0020
	Potassium, total		5.2600 mg/L	5.0000	1.0090
	Sodium, total		40.7000 mg/L	5.0000	0.0530
	Zinc, total		0.2060 mg/L	0.0200	0.0030

<u>SAMPLE:</u>	SW-23	<u>DATE:</u>	10/03/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Arsenic, dissolved		0.0090 mg/L	0.0100	0.0010

NOTE: CRDL-Contract Required Detection Limit
IDL -Instrument Detection Limit

Table 8. Inorganic Analytes Detected in Surface-Water Samples Collected on October 2, 1991 and October 3, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>SW-23</u>	<u>DATE:</u>	<u>10/03/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Barium, dissolved	0.0322	mg/L	0.2000	0.0010
	Calcium, dissolved	33.1000	mg/L	5.0000	0.0410
	Iron, dissolved	0.7490	mg/L	0.1000	0.0100
	Lead, dissolved	0.0012	mg/L	0.0030	0.0010
	Magnesium, dissolved	5.6400	mg/L	5.0000	0.0730
	Manganese, dissolved	0.5030	mg/L	0.0150	0.0020
	Potassium, dissolved	5.6100	mg/L	5.0000	1.0090
	Sodium, dissolved	42.9000	mg/L	5.0000	0.0530
	Zinc, dissolved	0.1210	mg/L	0.0200	0.0030
	Aluminum, total	0.1030	mg/L	0.2000	0.0430
	Antimony, total	0.0306	mg/L	0.0600	0.0240
	Arsenic, total	0.0145	mg/L	0.0100	0.0010
	Barium, total	0.0316	mg/L	0.2000	0.0010
	Calcium, total	31.8000	mg/L	5.0000	0.0410
	Chromium, total	0.0109	mg/L	0.0100	0.0080
	Iron, total	2.3100	mg/L	0.1000	0.0100
	Magnesium, total	5.3000	mg/L	5.0000	0.0730
	Manganese, total	0.4890	mg/L	0.0150	0.0020
	Potassium, total	5.2600	mg/L	5.0000	1.0090
	Sodium, total	40.8000	mg/L	5.0000	0.0530
	Zinc, total	0.1930	mg/L	0.0200	0.0030
<u>SAMPLE:</u>	<u>SW-24</u>	<u>DATE:</u>	<u>10/02/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Aluminum, dissolved	0.0742	mg/L	0.2000	0.0430
	Arsenic, dissolved	0.0105	mg/L	0.0100	0.0010
	Barium, dissolved	0.0243	mg/L	0.2000	0.0010
	Calcium, dissolved	30.3000	mg/L	5.0000	0.0410
	Copper, dissolved	0.0057	mg/L	0.0250	0.0040
	Iron, dissolved	0.7210	mg/L	0.1000	0.0100
	Lead, dissolved	0.0022	mg/L	0.0030	0.0010
	Magnesium, dissolved	5.6700	mg/L	5.0000	0.0730
	Manganese, dissolved	0.1610	mg/L	0.0150	0.0020
	Nickel, dissolved	0.1260	mg/L	0.0400	0.0130
	Potassium, dissolved	3.3800	mg/L	5.0000	1.0090
	Sodium, dissolved	31.7000	mg/L	5.0000	0.0530
	Zinc, dissolved	0.0238	mg/L	0.0200	0.0030
	Aluminum, total	0.0852	mg/L	0.2000	0.0430
	Arsenic, total	0.0126	mg/L	0.0100	0.0010
	Barium, total	0.0248	mg/L	0.2000	0.0010
	Calcium, total	28.4000	mg/L	5.0000	0.0410
	Chromium, total	0.0085	mg/L	0.0100	0.0080
	Iron, total	1.0900	mg/L	0.1000	0.0100
	Magnesium, total	5.1800	mg/L	5.0000	0.0730
	Manganese, total	0.1700	mg/L	0.0150	0.0020
	Potassium, total	3.1300	mg/L	5.0000	1.0090
	Sodium, total	23.6000	mg/L	5.0000	0.0530
	Zinc, total	0.0469	mg/L	0.0200	0.0030

NOTE: CRDL-Contract Required Detection Limit
IDL -Instrument Detection Limit

Table 9. Organic Compounds Detected in Stream-Sediment Samples Collected on October 2, 1991 and October 3, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>SED-18</u>	<u>DATE:</u>	<u>10/02/91</u>
COMPOUND		CONCENTRATION	CRQL
Acctone		880.0 ug/kg	140.0
2-Butanone		140.0 ug/kg	140.0
Bis (2-Ethylhexyl) phtalate		2200000.0 ug/kg	450000.0

<u>SAMPLE:</u>	<u>SED-19</u>	<u>DATE:</u>	<u>10/02/91</u>
COMPOUND		CONCENTRATION	CRQL
Acetone		110.0 ug/kg	16.0
2-Butanone		31.0 ug/kg	16.0
Toluene		9.0 ug/kg	16.0
Anthracene		65.0 ug/kg	520.0
Benzo (a) anthracene		170.0 ug/kg	520.0
Benzo (a) pyrene		190.0 ug/kg	520.0
Benzo (b) fluoranthene		310.0 ug/kg	520.0
Benzo (g,h,i) perylene		97.0 ug/kg	520.0
Benzo (k) fluoranthene		110.0 ug/kg	520.0
Chrysene		200.0 ug/kg	520.0
Fluoranthene		440.0 ug/kg	520.0
Indeno (1,2,3-cd) pyrene		130.0 ug/kg	520.0
4-Methylphenol		220.0 ug/kg	520.0
Phenanthrene		250.0 ug/kg	520.0
Pyrene		310.0 ug/kg	520.0

<u>SAMPLE:</u>	<u>SED-21</u>	<u>DATE:</u>	<u>10/03/91</u>
COMPOUND		CONCENTRATION	CRQL
Acetone		640.0 ug/kg	83.0
2-Butanone		170.0 ug/kg	83.0
Chlorobenzene		13.0 ug/kg	83.0
1,2-Dichloroethene, total		12.0 ug/kg	83.0
Benzo (a) anthracene		690.0 ug/kg	2700.0
Benzo (a) pyrene		1100.0 ug/kg	2700.0
Benzo (b) fluoranthene		2000.0 ug/kg	2700.0
Benzo (g,h,i) perylene		720.0 ug/kg	2700.0
Benzo (k) fluoranthene		580.0 ug/kg	2700.0
Bis (2-Ethylhexyl) phtalate		16000.0 ug/kg	2700.0
Chrysene		1100.0 ug/kg	2700.0
Fluoranthene		2200.0 ug/kg	2700.0
Indeno (1,2,3-cd) pyrene		600.0 ug/kg	2700.0
Phenanthrene		620.0 ug/kg	2700.0
Pyrene		1600.0 ug/kg	2700.0

<u>SAMPLE:</u>	<u>SED-22</u>	<u>DATE:</u>	<u>10/03/91</u>
COMPOUND		CONCENTRATION	CRQL
Acetone		1900.0 ug/kg	120.0
2-Butanone		550.0 ug/kg	120.0
Ethylbenzene		15.0 ug/kg	120.0
Vinyl chloride		52.0 ug/kg	120.0
Benzo (a) anthracene		1900.0 ug/kg	4100.0
Benzo (a) pyrene		3100.0 ug/kg	4100.0
Benzo (b) fluoranthene		5300.0 ug/kg	4100.0
Benzo (g,h,i) perylene		1700.0 ug/kg	4100.0
Benzo (k) fluoranthene		1200.0 ug/kg	4100.0

NOTE: CRQL-Contract Required Quantitation Limit

ROUX ASSOCIATES INC

Table 9. Organic Compounds Detected in Stream-Sediment Samples Collected on October 2, 1991 and October 3, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>SED-22</u>	<u>DATE:</u>	<u>10/03/91</u>
COMPOUND		CONCENTRATION	CRQL
Bis (2-Ethylhexyl) phthalate		10000.0 ug/kg	4100.0
Chrysene		2600.0 ug/kg	4100.0
Dibenzo (a,h) anthracene		460.0 ug/kg	4100.0
Fluoranthene		5100.0 ug/kg	4100.0
Indeno (1,2,3-cd) pyrene		1500.0 ug/kg	4100.0
Phenanthrene		1500.0 ug/kg	4100.0
Pyrene		4100.0 ug/kg	4100.0
<u>SAMPLE:</u>	<u>SED-23</u>	<u>DATE:</u>	<u>10/03/91</u>
COMPOUND		CONCENTRATION	CRQL
Acetone		2200.0 ug/kg	190.0
2-Butanone		410.0 ug/kg	48.0
1,2-Dichloroethene, total		10.0 ug/kg	48.0
Anthracene		240.0 ug/kg	1600.0
Benzo (a) anthracene		780.0 ug/kg	1600.0
Benzo (a) pyrene		1200.0 ug/kg	1600.0
Benzo (b) fluoranthene		2000.0 ug/kg	1600.0
Benzo (g,h,i) perylene		560.0 ug/kg	1600.0
Benzo (k) fluoranthene		720.0 ug/kg	1600.0
Bis (2-Ethylhexyl) phthalate		2800.0 ug/kg	1600.0
Chrysene		1200.0 ug/kg	1600.0
Dibenzo (a,h) anthracene		170.0 ug/kg	1600.0
Fluoranthene		2700.0 ug/kg	1600.0
Indeno (1,2,3-cd) pyrene		530.0 ug/kg	1600.0
N-Nitrosodiphenylamine		680.0 ug/kg	1600.0
Phenanthrene		890.0 ug/kg	1600.0
Pyrene		2100.0 ug/kg	1600.0
<u>SAMPLE:</u>	<u>SED-24</u>	<u>DATE:</u>	<u>10/02/91</u>
COMPOUND		CONCENTRATION	CRQL
Acetone		460.0 ug/kg	47.0
2-Butanone		120.0 ug/kg	23.0
Anthracene		1200.0 ug/kg	7700.0
Benzo (a) anthracene		5800.0 ug/kg	7700.0
Benzo (a) pyrene		8700.0 ug/kg	7700.0
Benzo (b) fluoranthene		15000.0 ug/kg	7700.0
Benzo (g,h,i) perylene		5700.0 ug/kg	7700.0
Benzo (k) fluoranthene		4900.0 ug/kg	7700.0
Bis (2-Ethylhexyl) phthalate		4400.0 ug/kg	7700.0
Carbazole		1500.0 ug/kg	7700.0
Chrysene		8900.0 ug/kg	7700.0
Dibenzo (a,h) anthracene		2100.0 ug/kg	7700.0
Fluoranthene		19000.0 ug/kg	19000.0
Indeno (1,2,3-cd) pyrene		6100.0 ug/kg	7700.0
Phenanthrene		8000.0 ug/kg	7700.0
Pyrene		13000.0 ug/kg	7700.0

NOTE: CRQL-Contract Required Quantitation Limit

ROUX ASSOCIATES INC

Table 10. Inorganic Analytes Detected in Stream-Sediment Samples Collected on October 2, 1991 and October 3, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>SED-18</u>	<u>DATE:</u>	10/02/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Aluminum, total	16600.00	mg/kg	108.00	23.20
	Arsenic, total	80.00	mg/kg	5.40	2.70
	Barium, total	38.40	mg/kg	108.00	0.54
	Beryllium, total	2.30	mg/kg	2.70	0.54
	Cadmium, total	1.60	mg/kg	2.70	1.60
	Calcium, total	3000.00	mg/kg	2703.00	22.20
	Chromium, total	1530.00	mg/kg	5.40	4.30
	Cobalt, total	13.40	mg/kg	27.00	2.70
	Copper, total	34.80	mg/kg	13.50	2.20
	Iron, total	33900.00	mg/kg	54.10	5.40
	Lead, total	46.50	mg/kg	1.60	5.40
	Magnesium, total	1100.00	mg/kg	2703.00	39.50
	Manganese, total	216.00	mg/kg	8.10	1.10
	Nickel, total	21.70	mg/kg	21.60	7.00
	Vanadium, total	27.40	mg/kg	27.00	3.20
	Zinc, total	175.00	mg/kg	10.80	1.60
<u>SAMPLE:</u>	<u>SED-19</u>	<u>DATE:</u>	10/02/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Aluminum, total	2880.00	mg/kg	63.40	13.60
	Arsenic, total	4.10	mg/kg	3.20	0.32
	Barium, total	13.40	mg/kg	63.40	0.32
	Calcium, total	889.00	mg/kg	1585.00	13.00
	Chromium, total	24.90	mg/kg	3.20	2.50
	Cobalt, total	2.40	mg/kg	15.80	1.60
	Copper, total	13.00	mg/kg	7.90	1.30
	Iron, total	4710.00	mg/kg	31.70	3.20
	Lead, total	25.30	mg/kg	1.00	3.20
	Magnesium, total	959.00	mg/kg	1585.00	23.10
	Manganese, total	108.00	mg/kg	4.80	0.63
	Nickel, total	6.80	mg/kg	12.70	4.10
	Potassium, total	580.00	mg/kg	1585.00	320.00
	Vanadium, total	7.60	mg/kg	15.80	1.90
<u>SAMPLE:</u>	<u>SED-21</u>	<u>DATE:</u>	10/03/91		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Aluminum, total	8840.00	mg/kg	331.00	71.10
	Arsenic, total	607.00	mg/kg	16.50	8.30
	Barium, total	63.30	mg/kg	331.00	1.70
	Cadmium, total	26.80	mg/kg	8.30	5.00
	Calcium, total	6350.00	mg/kg	8264.00	67.80
	Chromium, total	441.00	mg/kg	16.50	13.20
	Cobalt, total	52.10	mg/kg	82.60	8.30
	Copper, total	650.00	mg/kg	41.30	6.60
	Iron, total	97500.00	mg/kg	165.30	16.50
	Lead, total	294.00	mg/kg	5.00	16.50
	Magnesium, total	1490.00	mg/kg	8264.00	121.00
	Manganese, total	1820.00	mg/kg	24.80	3.30
	Mercury, total	0.91	mg/kg	0.83	0.83
	Nickel, total	42.60	mg/kg	66.10	21.50

NOTE: CRDL-Contract Required Detection Limit
IDL -Instrument Detection Limit

Table 10. Inorganic Analytes Detected in Stream-Sediment Samples Collected on October 2, 1991 and October 3, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	<u>SED-21</u>	<u>DATE:</u>	<u>10/03/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Selenium, total		3.60 mg/kg	8.30	3.30
	Vanadium, total		36.00 mg/kg	82.60	9.90
	Zinc, total		5730.00 mg/kg	33.10	5.00
<u>SAMPLE:</u>	<u>SED-22</u>	<u>DATE:</u>	<u>10/03/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Aluminum, total		19900.00 mg/kg	494.00	106.20
	Arsenic, total		1380.00 mg/kg	24.70	12.30
	Barium, total		282.00 mg/kg	494.00	2.50
	Beryllium, total		2.90 mg/kg	12.30	2.47
	Cadmium, total		77.40 mg/kg	12.30	7.40
	Calcium, total		16700.00 mg/kg	12346.00	101.20
	Chromium, total		1040.00 mg/kg	24.70	19.80
	Cobalt, total		121.00 mg/kg	123.00	12.30
	Copper, total		1100.00 mg/kg	61.70	9.90
	Iron, total		376000.00 mg/kg	247.00	24.70
	Lead, total		452.00 mg/kg	7.40	24.70
	Magnesium, total		2900.00 mg/kg	12346.00	180.00
	Manganese, total		7220.00 mg/kg	37.00	4.90
	Mercury, total		2.40 mg/kg	1.20	1.20
	Nickel, total		88.10 mg/kg	98.80	32.10
	Selenium, total		7.20 mg/kg	12.30	4.90
	Vanadium, total		96.90 mg/kg	123.00	14.80
	Zinc, total		17900.00 mg/kg	49.40	7.40
<u>SAMPLE:</u>	<u>SED-23</u>	<u>DATE:</u>	<u>10/03/91</u>		
	<u>ANALYTE</u>		<u>CONCENTRATION</u>	<u>CRDL</u>	<u>IDL</u>
	Aluminum, total		24500.00 mg/kg	191.00	41.10
	Arsenic, total		791.00 mg/kg	9.60	19.10
	Barium, total		91.60 mg/kg	191.00	1.00
	Beryllium, total		1.60 mg/kg	4.80	0.96
	Cadmium, total		32.50 mg/kg	4.80	2.90
	Calcium, total		5660.00 mg/kg	4785.00	39.20
	Chromium, total		2180.00 mg/kg	9.60	7.70
	Cobalt, total		39.00 mg/kg	47.80	4.80
	Copper, total		2450.00 mg/kg	23.90	3.80
	Iron, total		69400.00 mg/kg	95.70	9.60
	Lead, total		348.00 mg/kg	2.90	9.60
	Magnesium, total		1270.00 mg/kg	4785.00	69.90
	Manganese, total		854.00 mg/kg	14.40	1.90
	Mercury, total		5.70 mg/kg	0.48	0.48
	Nickel, total		34.20 mg/kg	38.30	12.40
	Potassium, total		978.00 mg/kg	4785.00	966.00
	Selenium, total		8.10 mg/kg	4.80	1.90
	Vanadium, total		48.60 mg/kg	47.80	5.70
	Zinc, total		5630.00 mg/kg	19.10	2.90

NOTE: CRDL-Contract Required Detection Limit
IDL -Instrument Detection Limit

Table 10. Inorganic Analytes Detected in Stream-Sediment Samples Collected on October 2, 1991 and October 3, 1991 at the Industri-Plex Site, Woburn, Massachusetts.

<u>SAMPLE:</u>	SED-24	<u>DATE:</u>	10/02/91		
ANALYTE		CONCENTRATION		CRDL	IDL
Aluminum, total	8000.00	mg/kg		93.20	20.00
Arsenic, total	91.50	mg/kg		4.70	2.30
Barium, total	41.90	mg/kg		93.20	0.47
Beryllium, total	0.63	mg/kg		2.30	0.47
Cadmium, total	4.20	mg/kg		2.30	1.40
Calcium, total	3080.00	mg/kg		2331.00	19.10
Chromium, total	116.00	mg/kg		4.70	3.70
Cobalt, total	8.30	mg/kg		23.30	2.30
Copper, total	112.00	mg/kg		11.70	1.90
Iron, total	17600.00	mg/kg		46.60	4.70
Lead, total	108.00	mg/kg		1.40	4.70
Magnesium, total	2400.00	mg/kg		2331.00	34.00
Manganese, total	229.00	mg/kg		7.00	0.93
Mercury, total	2.40	mg/kg		0.23	0.23
Nickel, total	16.30	mg/kg		18.60	6.10
Potassium, total	1090.00	mg/kg		2331.00	470.00
Selenium, total	1.00	mg/kg		2.30	0.93
Vanadium, total	32.20	mg/kg		23.30	2.80
Zinc, total	387.00	mg/kg		9.30	1.40

NOTE: CRDL-Contract Required Detection Limit
IDL -Instrument Detection Limit

Table 11. Surface-Water Flow Measurements Collected During the GSIP Phase 2 RI, Industri-Plex Site, Woburn, Massachusetts.

October 4, 1991						
Sampling Station	Width (feet)	Number of Intervals	Width of Interval (feet)	Depth (feet)	Flow Rate (feet/sec)	Discharge (cubic feet/second)
SW-14	13.5	10	1.35			
			1.35	0.54	0.85	0.62
			2.70	0.73	1.38	1.36
			4.05	0.73	1.42	1.40
			5.40	0.74	1.36	1.36
			6.75	0.73	0.97	0.96
			8.10	0.74	0.22	0.22
			9.45	0.44	0.17	0.10
			10.80	0.75	0.09	0.09
			12.15	--		0.00
			13.50	--		0.00
Total:						6.11
SW-5	5.1	--	3.10	1	0.365	1.13
				Total: 1.13		
SW-12	9.5	5	1.90			
			1.90	0.58	0.01	0.01
			3.80	0.96	0.28	0.51
			5.70	1.17	0.42	0.93
			7.60	0.95	0.26	0.47
			9.50	0.84	0.01	0.02
Total:						1.94
SW-10	6.6	6	1.1			
			0.55	0.30	0.91	0.30
			1.65	0.86	0.53	0.50
			2.75	0.53	0.77	0.45
			3.85	0.82	0.73	0.66
			4.95	0.74	0.72	0.59
			6.05	0.50	0.52	0.29
Total:						2.79

Table 11. Surface-Water Flow Measurements Collected During the GSIP Phase 2 RI, Industri-Plex Site, Woburn, Massachusetts.

October 4, 1991						
Sampling Station	Width (feet)	Number of Intervals	Width of Interval (feet)	Depth (feet)	Flow Rate (feet/sec)	Discharge (cubic feet/second)
SW-17	4	4	1.00			
			0.50	ND	ND	ND
			1.50	ND	ND	ND
			2.50	ND	ND	ND
			3.50	ND	ND	ND
					Total:	0.00
					Timed Bucket:	0.43
SW-13	12	10	1.20			
			1.20	0.96	0.23	0.26
			2.40	1.30	0.30	0.47
			3.60	1.15	0.27	0.37
			4.80	1.27	0.22	0.34
			6.00	1.24	0.31	0.46
			7.20	1.16	0.32	0.45
			8.40	1.00	0.32	0.38
			9.60	0.91	0.27	0.29
			10.80	0.77	0.26	0.24
			12.00	0.70	0.01	0.01
					Percent Ground Water:	15.08

TABLE 12. SUMMARY OF ANALYSIS BY AREA

Sample Area	23 TAL Metals	As, Cr, Pb	BTEX	Anions	TOC
SC-1 (South Area)	2	3	4	0	4
SC-2 (Central Area)	3	2	5	0	3
SC-3 (North Area)	2	3	5	0	4

**TABLE 13. DESCRIPTION OF HALL'S BROOK HOLDING AREA
SEDIMENT CHARACTERISTICS**

SAMPLE IDENTIFICATION	SEDIMENT DEPTH (cm)	PERCENT WATER	SAMPLE DESCRIPTION
<u>South Area</u>			
SC-1-01	-2	89%	Black gelatinous suspension, distinct petroleum odor
SC-1-02	-6	89%	Black gelatinous suspension
SC-1-03	-10	89%	Black gelatinous suspension
SC-1-05	-17	84%	Black gelatinous suspension
SC-1-06	-20	88%	Black gelatinous suspension
SC-1-07	-24	84%	Black gelatinous suspension
SC-1-10	-36	40%	Tan sand
SC-1-12	-43	23%	Tan sand
SC-1-14	-54	21%	Tan sand
<u>Central Area</u>			
SC-2-01	-4	90%	Black gelatinous suspension
SC-2-03	-18	87%	Black gelatinous suspension
SC-2-05	-32	82%	Black gelatinous suspension
SC-2-06B	-39	86%	Black gelatinous suspension
SC-2-07	-39	77%	Black gelatinous suspension
SC-2-08	-49	66%	Black gelatinous suspension
SC-2-09B	-59	27%	Clay material
SC-2-11	-73	19%	Tan sand
SC-2-13B	-87	20%	Tan sand

TABLE 13. (Continued)

SAMPLE IDENTIFICATION	SEDIMENT DEPTH (cm)	PERCENT WATER	SAMPLE DESCRIPTION
<u>North Area</u>			
SC-3-01	-3	91%	Black gelatinous suspension, hydrocarbon odor
SC-3-02	-7	88%	Black gelatinous suspension, hydrocarbon odor
SC-3-03	-14	87%	Black gelatinous suspension, hydrocarbon odor
SC-3-04	-20	87%	Black gelatinous suspension, hydrocarbon odor
SC-3-05	-26	84%	Black gelatinous suspension, hydrocarbon odor
SC-3-06	-32	64%	Black gelatinous suspension, hydrocarbon odor
SC-3-08	-42	25%	Mixture of tan and black clay in distinct swirls
SC-3-09	-48	26%	Tan sand
SC-3-10	-54	20%	Tan sand

**TABLE 14. PARTICLE SIZE CLASSIFICATION OF SELECTED
HALL'S BROOK HOLDING AREA SEDIMENTS**

SAMPLE IDENTIFICATION	PERCENT OF SOLIDS				WATER
	V. COARSE SAND >0.81 mm	COARSE TO V. FINE SAND 0.081mm-0.038mm	COARSE SILT 0.061mm-0.038mm	SILT & CLAY	
SC-1-8 (South Area)	24%	7%	27%	43%	87%
SC-1-11 (South Area)	0%	82%	14%	4%	22%

TABLE 15. SEEPAGE METER DISCHARGE RATES

SEEPAGE METER ID	CALCULATED AREA (M ²)	SEEPAGE METER DISCHARGE (l/M ² /day)	TOTAL DISCHARGE (l/day)
SM-1 (South Area)	7381	2.24	16546
SM-3 (North Area)	8399	0.21	1793
SM-4 (Seepage Area 4)	2138	0.98	2085

**TABLE 16. TOTAL ORGANIC CARBON IN
HALL'S BROOK HOLDING AREA SEDIMENT**

Sample ID #	Depth (cm)	% Total Organic Carbon
<u>South Area</u>		
SC-1-1	2	2.20
SC-1-4	13	10.19
SC-1-5	17	2.88
SC-1-12	44	0.02
<u>Central Area</u>		
SC-2-2	10	13.09
SC-2-6	39	8.69
SC-2-8	53	2.88
<u>North Area</u>		
SC-3-1	3	13.42
SC-3-3	14	1.98
SC-3-5	26	1.98
SC-3-7	39	3.12

TABLE 17. DISSOLVED ORGANIC CARBON IN HALL'S BROOK HOLDING AREA PORE WATERS

SAMPLE LOCATION	DEPTH (cm)	DISSOLVED ORGANIC CARBON (mg/l)	FRACTIONATION OF DISSOLVED ORGANIC CARBON IN PORE WATERS					
			HYDROPHOBIC BASE	HYDROPHOBIC ACID	HYDROPHOBIC NEUTRAL	HYDROPHILIC BASE	HYDROPHILIC ACID	HYDROPHILIC NEUTRAL
South	-6	27.0	0%	31%	12%	4%	50%	2%
South	-33	8.0	3%	25%	44%	13%	13%	3%
Central	-9	6.8	3%	12%	35%	6%	35%	9%
Central	-57	19.6	0%	3%	14%	2%	28%	53%
North	-3	247.5	1%	12%	11%	6%	66%	5%
North	-51	146.0	1%	7%	10%	8%	59%	14%

**TABLE 18. ARSENIC SPECIATION IN
HALL'S BROOK HOLDING AREA AQUEOUS SAMPLES**

SAMPLE AREA	DEPTH (cm)	As (tot) μg/l	MMA μg/l	DMA μg/l	As(III) μg/l	As(V) μg/l
SOUTH (Pore Water)	-22	1600	<1.9	<1.8	1200	330
CENTRAL (Pore Water)	-50	3	<2	<2	NA	NA
CENTRAL (Pore Water)	-38	27	<2	<2	NA	NA
NORTH (Pore Water)	-48	410	<2	<2	NA	NA
NORTH (Pore Water)	-34	20	<1.9	<1.8	10	10
NORTH (Pore Water)	6	1700	<1.9	<1.8	1100	610
SEEPAGE METER SOUTH (SM-1)	0	1400	<1.9	<1.8	110	1200
SEEPAGE METER NORTH (SM-3)*	NA	NA	NA	NA	NA	NA
SEEPAGE METER 4	0	3	<2	<2	NA	NA

* Sample not analyzed due to insufficient sample volume.

**TABLE 19. CHROMIUM SPECIATION IN
HALL'S BROOK HOLDING AREA PORE WATER AQUEOUS SAMPLES**

SAMPLE AREA	DEPTH (cm)	TOTAL Cr μg/l	Cr(VI) μg/l	ORGANIC Cr (III) μg/l
SOUTH	29	<13.0	-	-
SOUTH	15	64.7	-	-
SOUTH	13	-	<10	-
SOUTH	-1	42.5	-	-
SOUTH	-11	30.8	-	-
SOUTH	-14	-	-	26.6
SOUTH	-17	-	<10	-
SOUTH	-23	20.0	-	-
SOUTH	-34	-	-	7.2
SOUTH	-41	11.6	-	-
CENTRAL	11	<3.0	-	-
CENTRAL	0	143.0	-	-
CENTRAL	-9	-	<10	-
CENTRAL	-12	-	-	96.6
CENTRAL	-15	94.4	-	-
CENTRAL	-17	33.4	-	-
CENTRAL	-31	61.9	-	-
CENTRAL	-38	-	-	17.5
CENTRAL	-64	-	<10	-
CENTRAL	-55	13.8	-	-
CENTRAL	-71	13.5	-	-
NORTH	9	56.2	-	-
NORTH	-5	31.4	-	-
NORTH	-9	-	<10	-
NORTH	-10	202.0	-	-
NORTH	-12	-	-	19.4
NORTH	-15	21.4	-	-

TABLE 19. (Continued)

SAMPLE AREA	DEPTH (cm)	TOTAL Cr μg/l	Cr(VI) μg/l	ORGANIC Cr(III) μg/l
NORTH	-31	13.4	-	-
NORTH	-38	-	-	10.9
NORTH	-41	-	<10	-
NORTH	-45	11.8	-	-
NORTH	-57	7.1	-	-
NORTH	-73	8.1	-	-

TABLE 20. BENZENE CONCENTRATION IN SEEPAGE METER SAMPLES

SAMPLE LOCATION	BENZENE (mg/l)
SEEPAGE METER 1 (South Area)	0.15
SEEPAGE METER 3 (North Area)	0.12
SEEPAGE METER 4	0.0012

TABLE 21. PERCENT OF TOTAL METALS EVOLVED WITH ACID VOLATILE SULFIDES

	As	Cr	Pb
SC-1-9 (South Area)	3.1%	30.2%	25%
SC-2-4 (Central Area)	7.7%	48.4%	57%
SC-3-4 (North Area)	1.1%	18.2%	34%

**TABLE 22. ACID VOLATILE SULFIDE AND ASSOCIATED METALS
FROM HALL'S BROOK HOLDING AREA**

SAMPLE	AVS	AS	CR	PB	Fe	% Fe Sulfidized
	$\mu\text{mole per g}$					
SC-1-9 (South Area)	425	0.632	4.951	1.222	3375	12.6%
SC-2-4 (Central Area)	438	1.239	7.34	2.266	2464	17.8%
SC-3-4 (North Area)	617	0.277	6.055	1.077	2250	27.4%

**TABLE 23. SATURATION INDICES OF MINERALS FROM
MINTEQA2 RUNS OF HBHA PORE WATERS**

	EQ-1A Ooze (South Area)	EQ-2A Ooze (Central Area)	EQ-2A Sand (Central Area)
(FeOOH)	0.893	0.477	0.183
(CaCO ₃)	0.001	-0.223	-1.035
Al(OH) ₃	0.877	1.557	0.795
FeS	-33.83	2.11	1.936
FeS ₂	-50.39	18.95	21.98
ZnS	-31.92	1.056	-0.122
PbS		5.167	4.03
FeCr ₂ O ₄	11.06	13.57	8.94
Cr(OH) ₃ (aq)	0.885	1.851	0.198
Cr _{0.25} Fe _{0.75} (OH) ₃	-0.688	-0.969	-3.501
Charge balance error (speciated)	6.0%	2.4%	0.9%

Table 24. Summary Table of Physical Soil Parameters

Sample	Grain Size Analysis				TOC ¹ (%)	CEC ² (meq/100g)
	<0.81 mm V.Coarse Sand (%)	0.81 - 0.061 mm Coarse to V. Fine Sand (%)	0.061 - 0.038 mm Coarse Silt (%)	<0.038 mm Silt + Clay (%)		
OW-12	2	78	2	2	0.12	5.59
MW-53b	26	38	5	14	6.71	2.00

¹ Total organic carbon

² Cation exchange capacity
meq = milliequivalents

TABLE 25. SATURATION INDICES

SATURATION INDICES				
Formula	OW-1A	OW-11	OW-12	OW-15
FeOOH	0.569	2.974	-3.538	-0.051
CaCO ₃	-1.517	-1.031	1.395	-3.03
CaMg(CO ₃) ₂	-3.469	-2.65	2.789	-6.556
Al(OH) ₃	2.633	1.952	0.531	
FeS		-63.81	1.264	-71.27
FeS ₂		-101.59	17.76	-112.04
ZnS		-59.52		
PbS		-57.5		
CaSO ₄		-1.271	-1.260	-2.553
As ₂ S ₃		-195.51	-47.09	-212.3
FeCr ₂ O ₄	3.24		10.99	
Cr(OH) ₃ (Amorphous)	-0.064		1.958	
Cr(OH) ₃	-2.783		-0.698	

TABLE 25. (Continued)

SATURATION INDICES				
Formula	OW-16	OW-17B	OW-19A	OW-31
FeOOH	3.668	0.278	0.472	1.577
CaCO ₃	0.411	0.616	-2.573	0.431
CaMg(CO ₃) ₂	2.036	0.79	-5.665	0.682
Al(OH) ₃	0.428	1.149	0.81	1.088
FeS	1.102	1.832	-66.76	0.195
FeS ₂	29.78	21.83	-104.76	32.3
ZnS		-0.278	-61.7	-3.28
PbS	4.113			2.9
CaSO ₄		0.250	-1.940	-0.269
As ₂ S ₃		9.913	-199.74	0.037
FeCr ₂ O ₄	11.64	16.54		6.27
Cr(OH) ₃ (Amorphous)	1.972	3.971		0.72
Cr(OH) ₃	-0.711	1.302		-1.972

TABLE 25. (Continued)

SATURATION INDICES				
Formula	OW-32	OW-33A	OW-36	OW-38
FeOOH	3.523	-0.249	2.27	1.809
CaCO ₃	0.359		0.72	-1.937
CaMg(CO ₃) ₂	0.078		0.887	-4.227
Al(OH) ₃	0.504	0.798	1.142	0.559
FeS	1.154	-76.97	-97.5	-61.02
FeS ₂	30.475	-121.13	-159.53	-96.24
ZnS	-1.976	-72.1	-89.86	-56.69
PbS				
CaSO ₄	-1.062		-5.043	-1.614
As ₂ S ₃	13.04	-227.29	-302.86	-184.82
FeCr ₂ O ₄	8.373	0.891	6.274	6.649
Cr(OH) ₃ (Amorphous)	0.515	-1.213	1.113	-0.271
Cr(OH) ₃	-2.191	-3.902	-1.605	-2.877

TABLE 25. (Continued)

SATURATION INDICES				
Formula	OW-41	OW-43	OW-47	OW-48A
FeOOH	-7.119	3.395	4.1	5.735
CaCO ₃	0.812	-0.623	-0.128	-0.643
CaMg(CO ₃) ₂	1.071	-2.198	-1.467	-1.974
Al(OH) ₃	0.755	0.989	0.791	1.854
FeS	-0.331	-70.59	-75.39	-98.32
FeS ₂	15.55	-112.7	-121.7	-161.44
ZnS		-68.66	-71.89	-90.3
PbS		-63.74	-67.67	-88.35
CaSO ₄	-0.732	-0.131	0.200	-0.359
As ₂ S ₃	21.79	-214.02	-234.27	-313.43
FeCr ₂ O ₄	7.589	6.754		
Cr(OH) ₃ (Amorphous)	1.568	-0.169		
Cr(OH) ₃	-1.03	-2.903		

Table 26

Survival, Growth, and Reproduction of *Hyallolella azteca*
(21-Day Test Sediments)

Industri-Plex Site Remedial Trust
Woburn, MA

Sediment	Replicate	N(1)	Survival (percent)	Number of Offspring	Mean Length of Surviving Adults
Control	A	30	83	35	-
	B	30	80	32	-
	Mean		82	33.5	5.641
1 (SED-18)	A	30	0	-	-
	B	30	0	-	-
	Mean		0*	-	-
2 (SED-19)	A	30	63	21	-
	B	30	60	22	-
	Mean		62	21.5*	5.069
3 (SED-21)	A	30	70	14	-
	B	30	53	16	-
	Mean		62	15*	5.126
4 (SED-22)	A	30	90	42	-
	B	30	87	46	-
	Mean		88	44	5.137
5 (SED-23)	A	30	77	26	-
	B	30	70	25	-
	Mean		73	25.5	5.559
6 (SED-24)	A	30	73	25	-
	B	30	87	37	-
	Mean		80	31	5.151

(1) Number of 2-3 mm organisms placed in test chamber. Number with asterisk indicate statistically different from the control sediment ($P < 0.05$).

Source: ESE, 1992.

Table 27

Survival and Growth (Length and Weight) of Chironomus tentans
(14-Day Test Sediments)

Industri-Plex Site Remedial Trust
Woburn, MA

Sediment	Replicate	N(1)	Survival (Percent)	Avg. Weight of Surviving Larvae	Avg. Length of Surviving Larvae
Control	A	30	80	-	-
	B	30	90	-	-
	Mean		85	0.037	19.37
1 (SED-18)	A	30	0	-	-
	B	30	0	-	-
	Mean		0*	-	-
2 (SED-19)	A	30	63	-	-
	B	30	90	-	-
	Mean		77	0.033	18.26
3 (SED-21)	A	30	93	-	-
	B	30	87	-	-
	Mean		90	0.035	19.88
4 (SED-22)	A	30	83	-	-
	B	30	97	-	-
	Mean		90	0.039	20.78
5 (SED-23)	A	30	83	-	-
	B	30	77	-	-
	Mean		80	0.035	18.63
6 (SED-24)	A	30	93	-	-
	B	30	77	-	-
	Mean		85	0.032*	18.44

(1) Number of 2nd instar larvae placed in chamber. Number with asterisk indicates statistically different from the control sediment (P<0.05).

Source: ESE, 1992.

Table 28

Water Quality Parameters
in *H. azteca* Test Chambers
(21-Day Test Sediments)

Industri-Plex Site Remedial Trust
Woburn, MA

Sediment		Temp. (C)	pH	D.O. (ppm)	Cond. (uhms/cm)
Control	Min.	20.2	7.8	8.2	611
	Max.	21.0	8.1	9.3	659
	Mean	20.6	7.9	8.8	630
1 (SED-18)	Min.	20.2	7.2	7.0	513
	Max.	21.0	7.9	8.9	581
	Mean	20.6	7.6	8.3	549
2 (SED-19)	Min.	20.2	7.0	7.2	488
	Max.	21.0	7.8	8.8	584
	Mean	20.6	7.6	8.1	532
3 (SED-21)	Min.	20.2	6.8	7.3	577
	Max.	21.0	7.6	8.7	673
	Mean	20.6	7.4	8.2	624
4 (SED-22)	Min.	20.2	6.9	4.5*	536
	Max.	21.0	7.8	8.7	604
	Mean	20.6	7.5	7.1	569
5 (SED-23)	Min.	20.2	6.8	3.6*	472
	Max.	21.0	7.6	8.8	601
	Mean	20.6	7.4	8.0	513
6 (SED-24)	Min.	20.2	6.5	7.5	408
	Max.	21.0	7.6	8.5	642
	Mean	20.6	7.4	8.2	492

* Dissolved oxygen reading prior to aeration.

Source: ESE, 1992.

Table 29

Water Quality Parameters
in *C. tentans* Test Chambers
(14-Day Test Sediments)

Industri-Plex Site Remedial Trust
Woburn, MA

Sediment		Temp. (C)	pH	D.O. (ppm)	Cond. (uhms/cm)
Control	Min.	20.2	7.7	7.0	628
	Max.	21.0	8.1	8.6	670
	Mean	20.6	7.9	8.0	652
1 (SED-18)	Min.	20.2	7.2	6.7	564
	Max.	21.0	7.8	8.5	582
	Mean	20.6	7.6	7.6	573
2 (SED-19)	Min.	20.2	7.0	2.5*	527
	Max.	21.0	7.8	8.8	587
	Mean	20.6	7.5	6.1	555
3 (SED-21)	Min.	20.2	6.8	2.5*	631
	Max.	21.0	7.8	8.6	669
	Mean	20.6	7.5	6.7	627
4 (SED-22)	Min.	20.2	6.9	2.2*	534
	Max.	21.0	7.8	8.5	660
	Mean	20.6	7.4	6.6	606
5 (SED-23)	Min.	20.2	6.8	5.3*	439
	Max.	21.0	7.6	8.6	599
	Mean	20.6	7.3	7.8	513
6 (SED-24)	Min.	20.2	6.5	7.4	418
	Max.	21.0	7.5	8.6	643
	Mean	20.6	7.3	8.1	516

* Dissolved oxygen reading prior to aeration.

Source: ESE, 1992.

TABLE 30

PHYSICAL AND CHEMICAL PARAMETERS OF FISH SAMPLED
FROM PHILLIP'S POND AND THE HALL'S BROOK HOLDING AREA

Ground-Water/Surface-Water Investigation Plan
Industri-Plex Site Remedial Trust
Woburn, MA

FIELD IDENTIFICATION	LABORATORY I.D. (Offal)	LABORATORY I.D. (Fillet)	COLLECTION DATE	SPECIES	LENGTH ² (cm)	WEIGHT ² (grams)	% LIPID (OFFAL)	% LIPID (FILLET)	
HB/BF/001	IP-O*8	IP-F*5	10/22/91	Brown Bullhead	25.4	136.4	7.0	6.4	
HB/BF/002	IP-O*13	IP-F*9	10/23/91	White Sucker	25	97.8	1.8	1.2	
HB/BF/003	IP-O*19	IP-F*15	11/01/91	White Sucker	22.7	60.6	5.2	4.9	
HB/BF/004	IP-O*20	IP-F*16	11/01/91	White Sucker	24.8	110.8	2.8	2.7	
HB/BF/005	IP-O*21	IP-F*17	11/01/91	White Sucker	23.2	72.4	10.0	2.8	
HB/ P/001	IP-O*22	IP-F*18	11/01/91	Golden Shiner	24	54.7	14.0	4.3	
HB/ P/002	IP-O*23	IP-F*19	11/01/91	Golden Shiner	16.5	37.6	8.7	2.8	
HB/ P/003	IP-O*24	IP-F*20	11/01/91	Golden Shiner	13	17.5	3.2	9.8	
PP/BF/001	IP-O*3	IP-F*1	10/18/91	White Sucker	26	148.8	5.2	2.9	
PP/BF/002	IP-O*4	IP-F*2	10/18/91	White Sucker	25.5	121.9	3.3	2.2	
PP/BF/003	IP-O*5	IP-F*3	10/18/91	White Sucker	24.5	97.0	8.6	3.7	
PP/BF/004	IP-O*14	IP-F*10	10/23/91	White Sucker	24.8	100.7	28.0	1.5	
PP/BF/005	IP-O*15	IP-F*11	10/23/91	White Sucker	22.9	66.3	3.6	1.3	
PP/BF/006	IP-O*16	IP-F*12	10/23/91	White Sucker	23.2	101.6	5.5	2.0	
PP/ P/001	NA	IP-F*4	10/18/91	Golden Shiner	0	24.1	--	2.3	
PP/ P/002	IP-O*10	IP-F*6	10/22/91	Golden Shiner	22.1	62.3	6.6	3.6	
PP/ P/003	IP-O*11	IP-F*7	10/22/91	Golden Shiner	16.5	33.6	10.0	2.1	
PP/ P/004	IP-O*12	IP-F*8	10/22/91	Golden Shiner	19.8	51.9	7.6	5.1	
PP/ P/005	IP-O*17	IP-F*13	10/23/91	Golden Shiner	24.2	72.0	9.7	2.4	
PP/ P/006	IP-O*18	IP-F*14	10/23/91	Golden Shiner	18.4	51.5	15.0	3.5	
PP/ F/001	IP-O*1	NA	10/17/91	Pumpkinseed	2.5-6.0	5.3	3.9	NA	
PP/ F/002	IP-O*2	NA	10/18/91	Pumpkinseed	2.5-6.0	3.0	21.0	NA	
PP/ F/003	IP-O*6	NA	10/21/91	Pumpkinseed	2.5-6.0	8.8	6.0	NA	
PP/ F/004	IP-O*7	NA	10/21/91	Pumpkinseed	2.5-6.0	6.0	22.0	NA	
PP/ F/005	IP-O*9	NA	10/23/91	Pumpkinseed	2.5-6.0	5.4	5.0	NA	
1					MEAN =	21.1	64.5	8.9	3.4

HB = Hall's Brook Holding Area; PP = Phillip's Pond;
BF = Bottom Feeder; P = Predator/Forager; NA = not applicable

2

Sample PP/ P/001 only had fillet sent for analysis.
PP/F/001 through PP/F/005 were pooled for analysis.

TABLE 31

**METAL CONCENTRATION IN FISH TISSUE (FILLET)
SAMPLED FROM HALL'S BROOK HOLDING AREA
AND PHILLIP'S POND**

Industri-Plex Site Remedial Trust
Woburn, MA

1 SAMPLE	2 ANALYTE CONCENTRATION IN FILLET		
Hall's Brook Holding Area	As (ppm)	Cr (ppm)	Pb (ppm)
BF/001	1.19	< 0.14	< 0.62
BF/002	< 0.96	< 0.14	< 0.63
BF/003	< 0.98	< 0.15	< 0.64
BF/004	< 0.98	< 0.15	< 0.64
BF/005	< 0.96	< 0.14	< 0.63
P/001	< 0.99	< 0.15	< 0.64
P/002	< 0.98	< 0.15	< 0.64
P/003	< 1.00	< 0.15	0.73
Phillip's Pond			
BF/001	< 0.93	< 0.14	< 0.60
BF/002	< 0.94	< 0.14	< 0.61
BF/003	1.18	< 0.15	< 0.64
BF/004	< 0.98	< 0.15	< 0.64
BF/005	< 0.93	< 0.14	< 0.61
BF/006	< 0.94	< 0.14	< 0.61
P/001	< 0.93	< 0.14	< 0.60
P/002	< 0.97	< 0.15	< 0.63
P/003	< 0.92	< 0.14	< 0.60
P/004	< 0.94	< 0.14	< 0.61
P/005	< 0.92	< 0.14	< 0.60
P/006	< 0.94	< 0.14	< 0.61

1

Fish were filleted in the field, frozen, and sent to ESE St. Louis Analytical Laboratory. Analysis was performed using EPA 600/8-80-038 and 600/4-79-0200 Methodology. BF = bottom feeder; P = predator/forager.

2

Mercury, with an average detection limit of 0.081 ppm, was detected twice in the HBHA (BF/001, 0.189 ppm; BF/002, 0.137 ppm) and four times in Phillip's Pond (BF/003, 0.122 ppm; BF/006, 0.309 ppm; P/001, 0.092 ppm; P/002, 0.117 ppm). A complete summary of the analytical results is presented in Appendix D3.

TABLE 32

**METAL CONCENTRATION IN FISH TISSUE (OFFAL)
SAMPLED FROM HALL'S BROOK HOLDING AREA
AND PHILLIP'S POND**

Industri-Plex Site Remedial Trust
Woburn, MA

1 SAMPLE	2 ANALYTE CONCENTRATION IN OFFAL		
Hall's Brook Holding Area	As (ppm)	Cr (ppm)	Pb (ppm)
BF/001	1.480	< 0.150	< 0.640
BF/002	1.300	< 0.140	< 0.600
BF/003	< 0.920	< 0.140	0.710
BF/004	< 0.980	< 0.150	0.950
BF/005	3.800	2.850	3.860
P/001	< 0.930	< 0.140	< 0.600
P/002	< 0.980	< 0.150	< 0.640
P/003	1.590	< 0.150	< 0.640
Phillip's Pond			
BF/001	< 0.950	8.870	4.760
BF/002	< 0.970	< 0.150	1.290
BF/003	< 0.940	0.160	1.450
BF/004	< 0.910	< 0.140	0.870
BF/005	0.940	< 0.140	1.740
BF/006	< 0.960	< 0.140	< 0.630
P/002	< 0.920	< 0.140	< 0.600
P/003	0.960	< 0.140	1.560
P/004	< 0.880	< 0.130	0.750
P/005	< 0.900	< 0.140	1.440
P/006	< 0.930	< 0.140	0.730
F/001	1.150	< 0.150	< 0.650
F/002	< 0.970	< 0.150	< 0.630
F/003	1.110	< 0.140	0.670
F/004	1.040	< 0.130	0.580
F/005	< 0.950	< 0.140	< 0.620

1

Offal was separated from fillet in the field, frozen, and sent to ESE St. Louis Analytical Laboratory. Analysis was performed using EPA 600 /8-80-038 and 600/4-79-0200 Methodology. BF = bottom feeder; P = predator/forager; F = forager.

2

Cadmium, with an average detection limit of 0.094 ppm, was only detected twice: BF/005 (HBHA, 0.11 ppm) and BF/001 (Phillip's Pond, 0.190 ppm). Mercury, with an average detection limit of 0.081 ppm, was only detected once: P/002 (Phillip's Pond, 0.107 ppm).

Complete analytical results are presented in Appendix D3.

TABLE 33

TOTAL AND DISSOLVED METALS IN SURFACE WATER
OF SHALLOW (LENTIC) WETLANDSINDUSTRI-PLEX SITE REMEDIAL TRUST
Woburn, MA

1 ANALYTE	2 DETECTION LIMIT		3 FREQUENCY OF DETECTION	RANGE ug/L		LOCATION OF MAXIMUM VALUE	4 ARITHMETIC MEAN
	CRDL	IDL		MIN	MAX		
METALS, TOTAL							
Arsenic	10	2	9 / 11	ND	14.6	SW-21	7.2
Chromium	10	6	8 / 11	ND	195	SW-18	23.7
Lead	4	2	6 / 11	ND	4.9	SW-13	2.4
Aluminum	200	29	7 / 11	ND	1640	SW-18	209.6
Antimony	60	22	1 / 11	ND	30.6	SW-23	12.6
Barium	200	1	11 / 11	18.5	32.1	SW-09	27.5
Calcium	5000	28	11 / 11	15100	31800	SW-23	27390.9
Cobalt	50	4	2 / 11	ND	9.5	SW-18	3.0
Copper	25	4	5 / 11	ND	21.8	SW-19	6.1
Iron	100	7	11 / 11	608	2530	SW-22	1649.2
Magnesium	5000	48	11 / 11	2940	5300	SW-23	4647.3
Manganese	15	2	11 / 11	48.6	777	SW-18	363.0
Potassium	5000	719	11 / 11	2320	5260	SW-22	4125.5
Sodium	5000	36	11 / 11	10100	94200	SW-18	38136.4
Zinc	20	5	11 / 11	16.85	276	SW-09	117.8
METALS, DISSOLVED							
Arsenic	10	2	7 / 11	ND	10.5	SW-24	5.0
Chromium	10	6	1 / 11	ND	15.6	SW-18	3.9
Lead	4	2	4 / 11	ND	2.2	SW-24	1.1
Aluminum	200	29	6 / 11	ND	136	SW-18	47.4
Barium	200	1	11 / 11	14.6	85.7	SW-09	37.8
Calcium	5000	28	11 / 11	16550	33700	SW-09	28640.9
Cobalt	50	4	1 / 11	ND	7.4	SW-18	2.5
Copper	25	4	7 / 11	ND	9.25	SW-19	4.8
Iron	100	7	11 / 11	339	1050	SW-09	668.3
Magnesium	5000	48	11 / 11	3170	5670	SW-24	4945.5
Manganese	15	2	11 / 11	42.9	753	SW-18	350.3
Nickel	40	19	2 / 11	ND	126	SW-24	28.8
Potassium	5000	719	11 / 11	1990	6030	SW-21	4423.6
Silver	10	3	1 / 11	ND	2.2	SW-13	1.6
Sodium	5000	36	11 / 11	10600	107000	SW-18	42713.6
Zinc	20	5	10 / 11	ND	276	SW-09	80.7

1 All values are ppb. Duplicate samples were averaged together. Values cited are only for open-water wetlands (lentic), which and include samples taken from stations SW-1, -8, -9, -11, -13, -18, -19, -21, -22, -23, and -24.

2 CRDL = Contract Required; IDL = Instrument. These detection limits represent the average detection limit for all samples.

3 Total and dissolved forms of beryllium, cadmium, mercury, selenium, thallium, vanadium, and tin were not detected above the instrument detection limit in any of the above surface water samples taken during Phase I or II. Antimony was not detected in the dissolved suite, while silver and nickel were not detected in the total suite.

4 The sample mean is the arithmetic mean, using one-half of the instrument detection limit for trace and/or non-detected values. Note that, because non-detects are considered one-half of the detection limit when calculating means, some metals may have means that are lower than the minimum value for that dataset.

TABLE 34

TOTAL METALS IN SEDIMENT
OF SHALLOW WETLANDS (LENTIC)

INDUSTRI-PLEX SITE REMEDIAL TRUST
Woburn, MA

ANALYTE	AVERAGE DETECTION LIMIT		FREQUENCY OF DETECTION	RANGE		LOCATION OF MAXIMUM VALUE	ARITHMETIC MEAN
	CRDL	IDL		MIN	MAX		
Arsenic	10	6	33 / 34	1.6	9830	ERR	459.7
Chromium	10	8	34 / 34	5.9	2180	ERR	231.4
Lead	3	9	31 / 34	3.6	1210	ERR	138.5
Aluminum	191	41	13 / 13	3020	24500	ERR	3457.2
Antimony	57	24	6 / 13	ND	41.5	ERR	2.1
Barium	191	1	13 / 13	4	282	ERR	25.1
Beryllium	5	1	8 / 13	ND	3.7	ERR	0.3
Cadmium	5	3	9 / 13	ND	77.4	ERR	6.6
Calcium	4773	39	13 / 13	595	16700	ERR	1802.1
Cobalt	48	5	13 / 13	1.3	121	ERR	8.9
Copper	24	4	13 / 13	0.59	2450	ERR	177.0
Iron	95	10	13 / 13	1900	376000	ERR	23641.7
Magnesium	4773	70	13 / 13	286	4880	ERR	692.7
Manganese	14	2	13 / 13	22.4	7220	ERR	361.9
Mercury	0.5	0.5	9 / 13	ND	5.7	ERR	0.5
Nickel	38	12	10 / 13	ND	88.1	ERR	8.8
Potassium	4773	963	11 / 13	ND	2040	ERR	267.5
Selenium	5	2	9 / 13	ND	10.9	ERR	1.3
Silver	10	6	5 / 13	ND	15.3	ERR	0.7
Sodium	4773	68	8 / 13	ND	12700	ERR	458.6
Thallium	10	2	5 / 13	ND	6.3	ERR	0.4
Vanadium	48	6	13 / 13	3.6	96.9	ERR	11.6
Zinc	19	9	13 / 13	8.3	17900	ERR	1286.9

1

All values are ppm. Duplicate samples were averaged together. Values cited are only for open-water wetlands (lentic), which and include samples taken from stations SW-1, -8, -9, -11, -13, -18, -19, -21, -22, -23, -24, CORE, SW1/001, SW1/030, SW1/032 - SW1/037, SW1/039 - SW1/050, SW1/055 - SW1/057, and SW1/059.

2

CRDL = Contract Required; IDL = instrument. These detection limits represent the average detection limit for all samples.

3

The sample mean is the arithmetic mean, using one-half of the instrument detection limit for trace and/or non-detected values. Note that, because non-detects are considered one-half of the detection limit when calculating means, some metals may have means that are lower than the minimum value for that dataset.

**TABLE 35
TOXICITY ASSESSMENT FOR MALLARD DUCK**

Industri-Plex Site Remedial Trust
Woburn, MA

ANALYTE	ROUTE OF EXPOSURE	ENVIRONMENTAL MEDIUM	AVAILABILITY FACTOR (AF) ¹	FRACTION INGESTED (FI)	EXPOSURE FREQUENCY (EF, days)	EXPOSURE DURATION (ED, years)	REFERENCE DOSE (mg/kg-day) ²
Arsenic	Ingestion	Sediment	11.0	0.5	90	3	1.27
Chromium	Ingestion	Sediment	3.0	0.5	90	3	6.36
Lead	Ingestion	Sediment	5.6	0.5	90	3	3.18

1) Availability factors were based on data from available literature for arsenic, lead (Davis, et al., 1992), and chromium (Mertz et al., 1965).

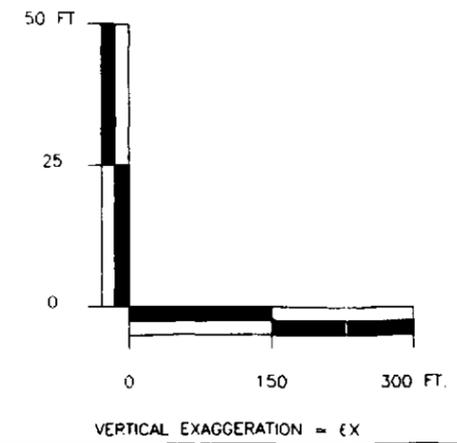
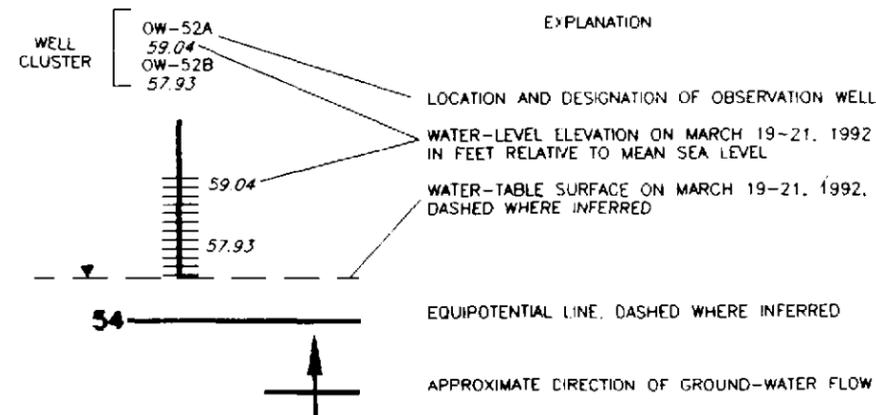
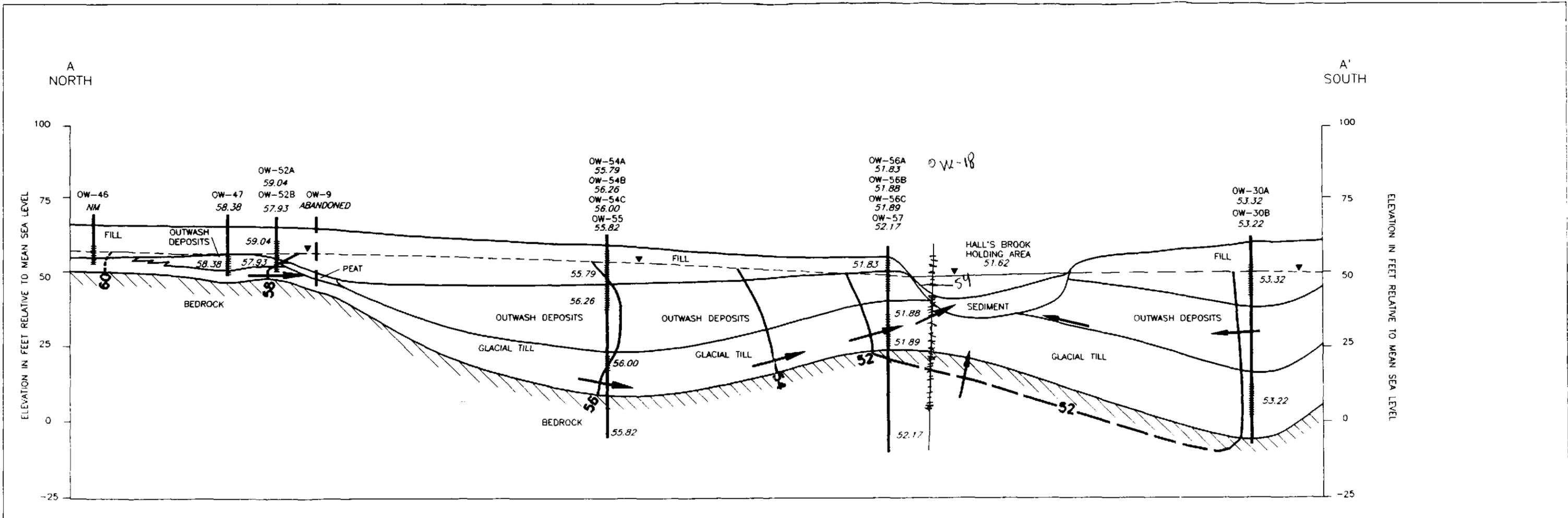
2) Reference doses were calculated from available literature on the effects of arsenic (Camardese, et al, 1990), chromium (Haseltine, et al., 1985), and lead (Finley, et al., 1976).

TABLE 36
RISK CHARACTERIZATION

Industri-Plex Site Remedial Trust
Woburn, MA

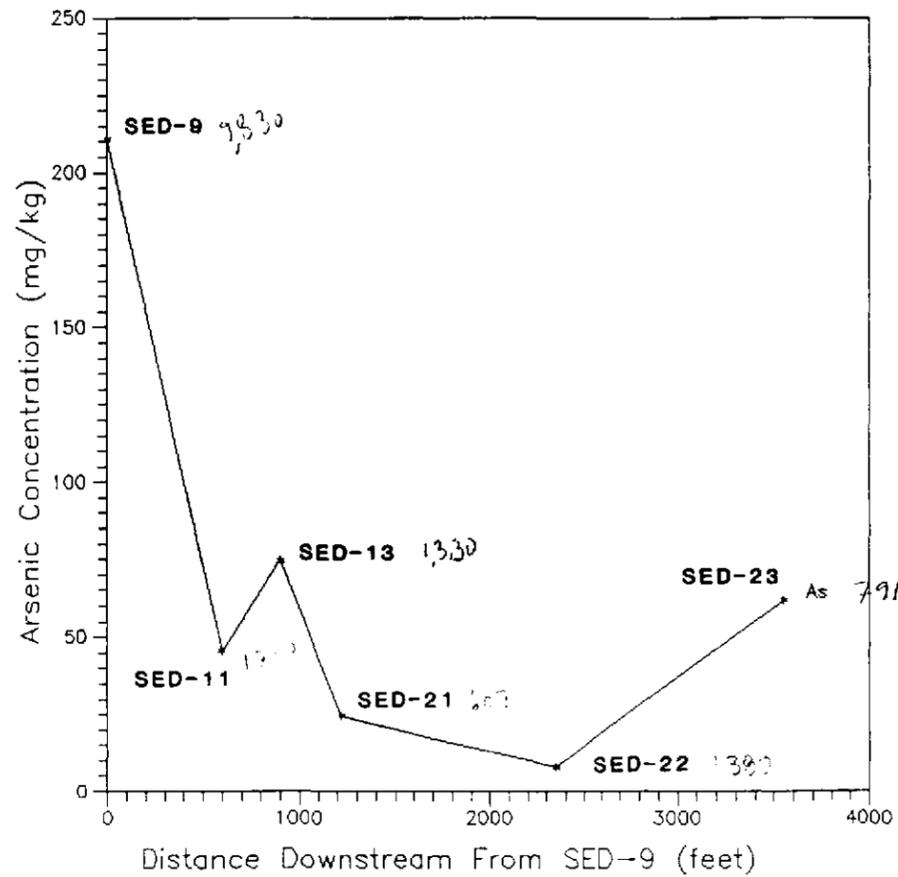
ANALYTE ¹	CHRONIC DAILY INTAKE (mean)	HAZARD QUOTIENT (mean)	CHRONIC DAILY INTAKE (max)	HAZARD QUOTIENT (max)
Arsenic	5.92E-02	4.66E-02	1.27E+00	9.96E-01
Chromium	8.11E-03	1.28E-03	7.65E-02	1.20E-02
Lead	9.76E-03	3.07E-03	8.50E-02	2.67E-02
HAZARD INDEX		5.10E-02		1.04E+00

1) Hazard quotient was calculated by dividing the chronic daily intake by the reference dose (Table 37).

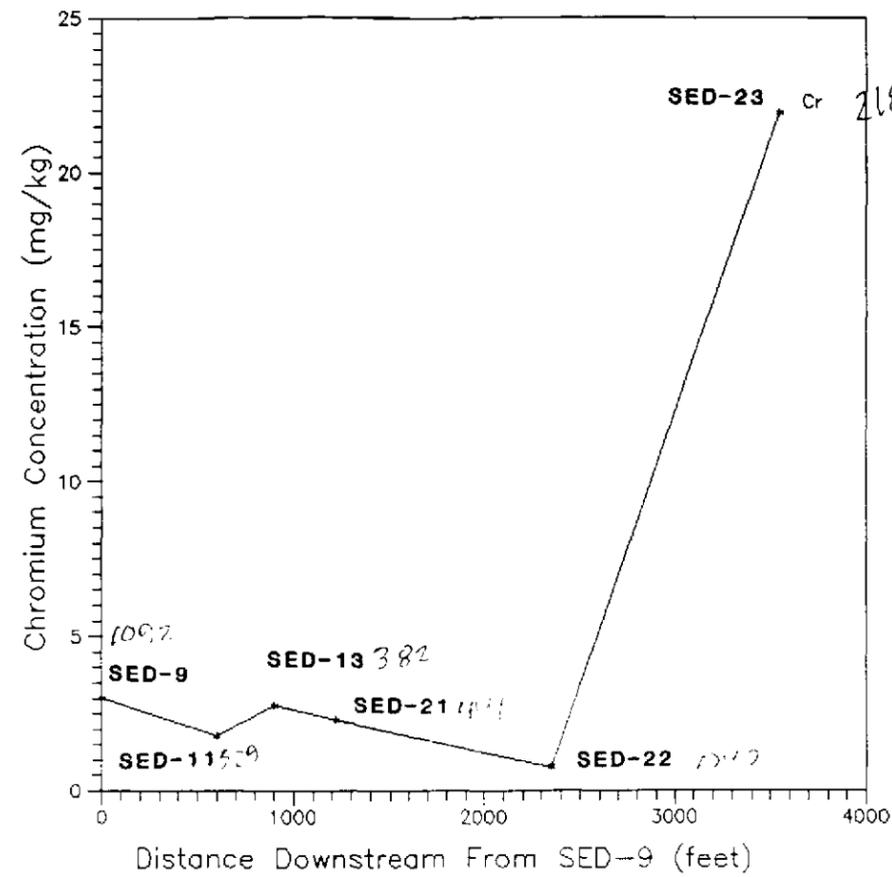


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HYDROGEOLOGIC CROSS SECTION A - A' MARCH 19-21, 1992			
Prepared For: INDUSTRI-PLEX REMEDIAL TRUST SITE			
ROUX ROUX ASSOCIATES INC Environmental Consulting & Management	Compiled by: J.Y.	Date: 4/92	Figure 2
	Prepared by: C.L.	Scale: SHOWN	
	Project Mgr.: D.S.	Revision: 0	
	File No.: MO624015		

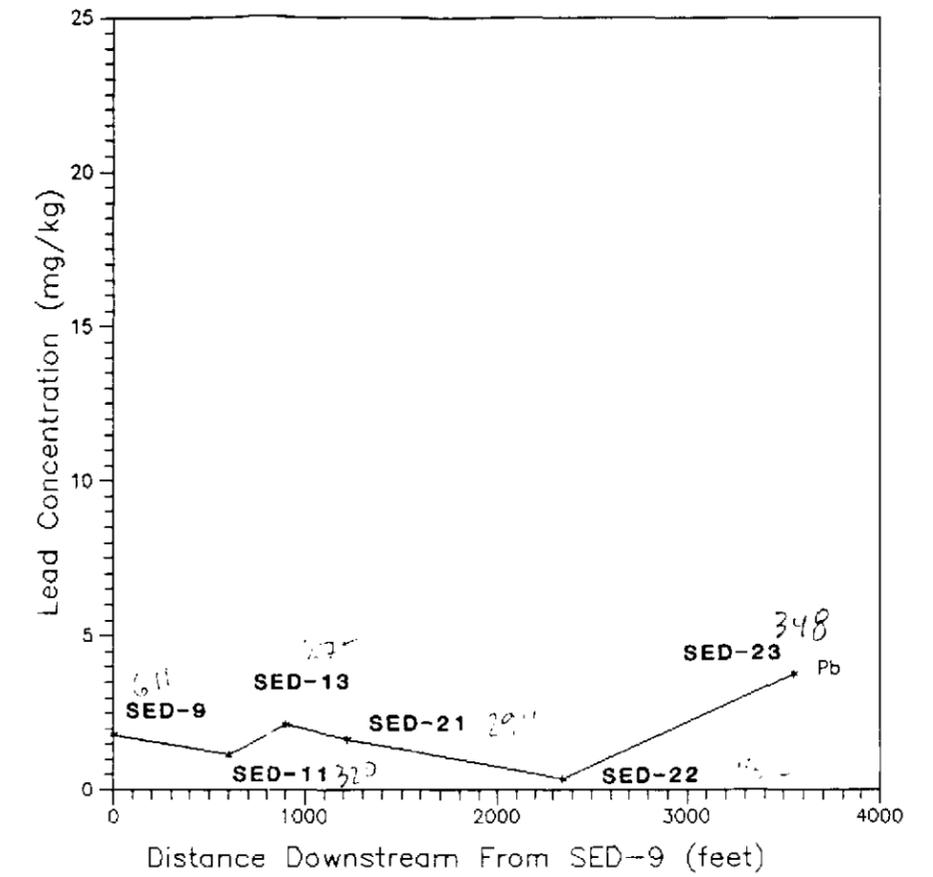
Arsenic in Sediment



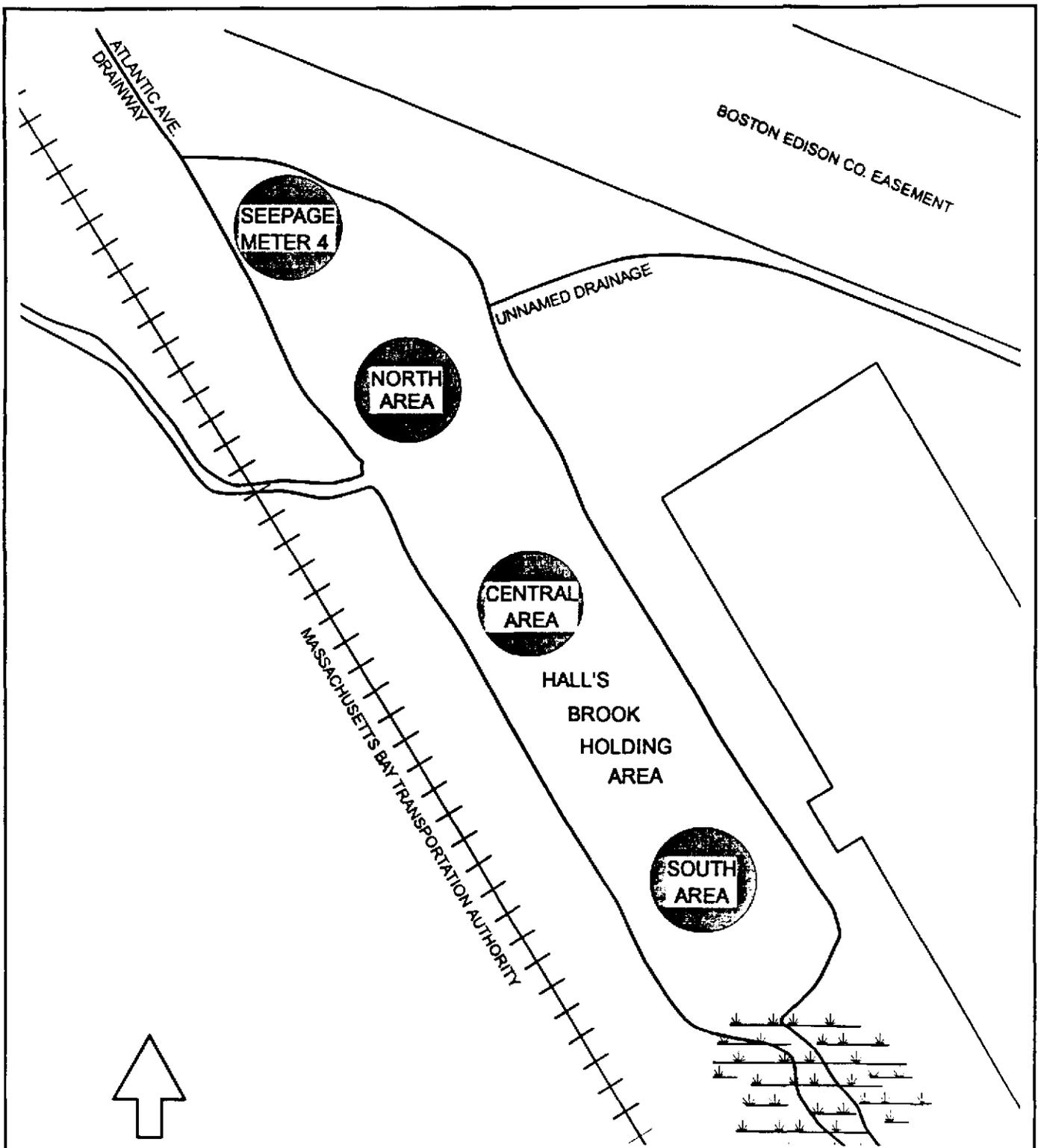
Chromium in Sediment



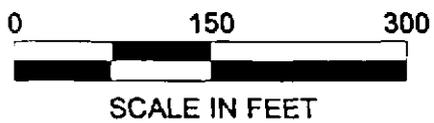
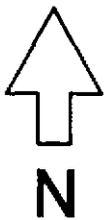
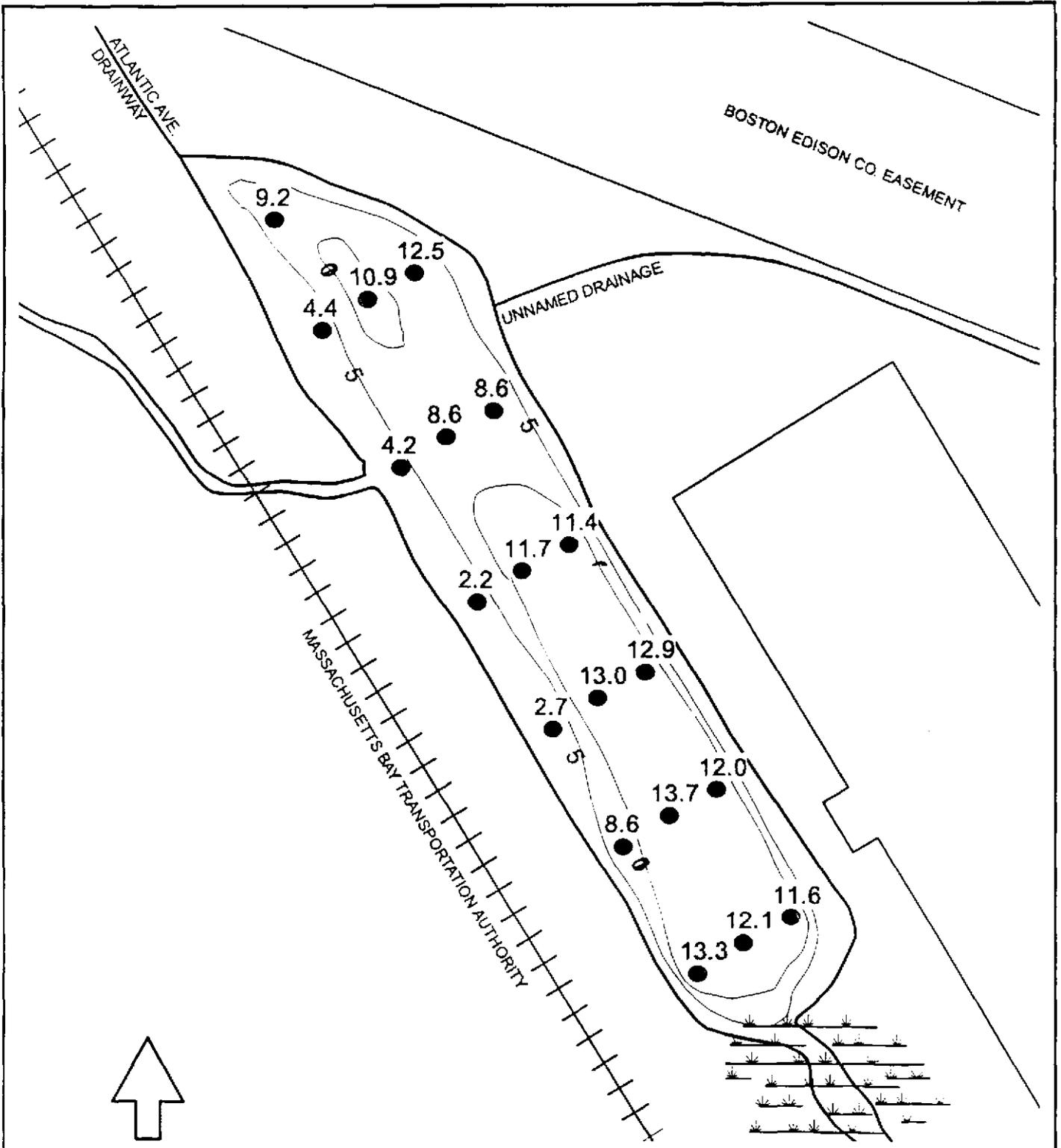
Lead in Sediment



Title:			
NORMALIZED METAL CONCENTRATIONS IN SEDIMENT			
Prepared for:			
INDUSTRI-PLEX SITE REMEDIAL TRUST			
ROUX ROUX ASSOCIATES INC Environmental Consulting & Management	Completed by: J. Y.	Date: 5/92	Figure 3
	Prepared by: C. R.	Scale: SHOWN	
	Project Mgr: D. S.	Revision: 0	
	File No: 06624Y		



TITLE: PORE WATER, SEDIMENT CORE, AND SEEPAGE METER SAMPLING LOCATIONS OCTOBER/NOVEMBER 1991	
HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE 4
PTI Environmental Services	



TITLE:

WATER DEPTH IN FEET

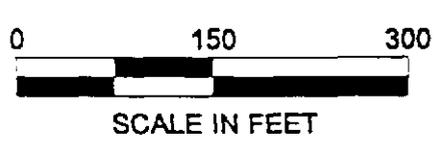
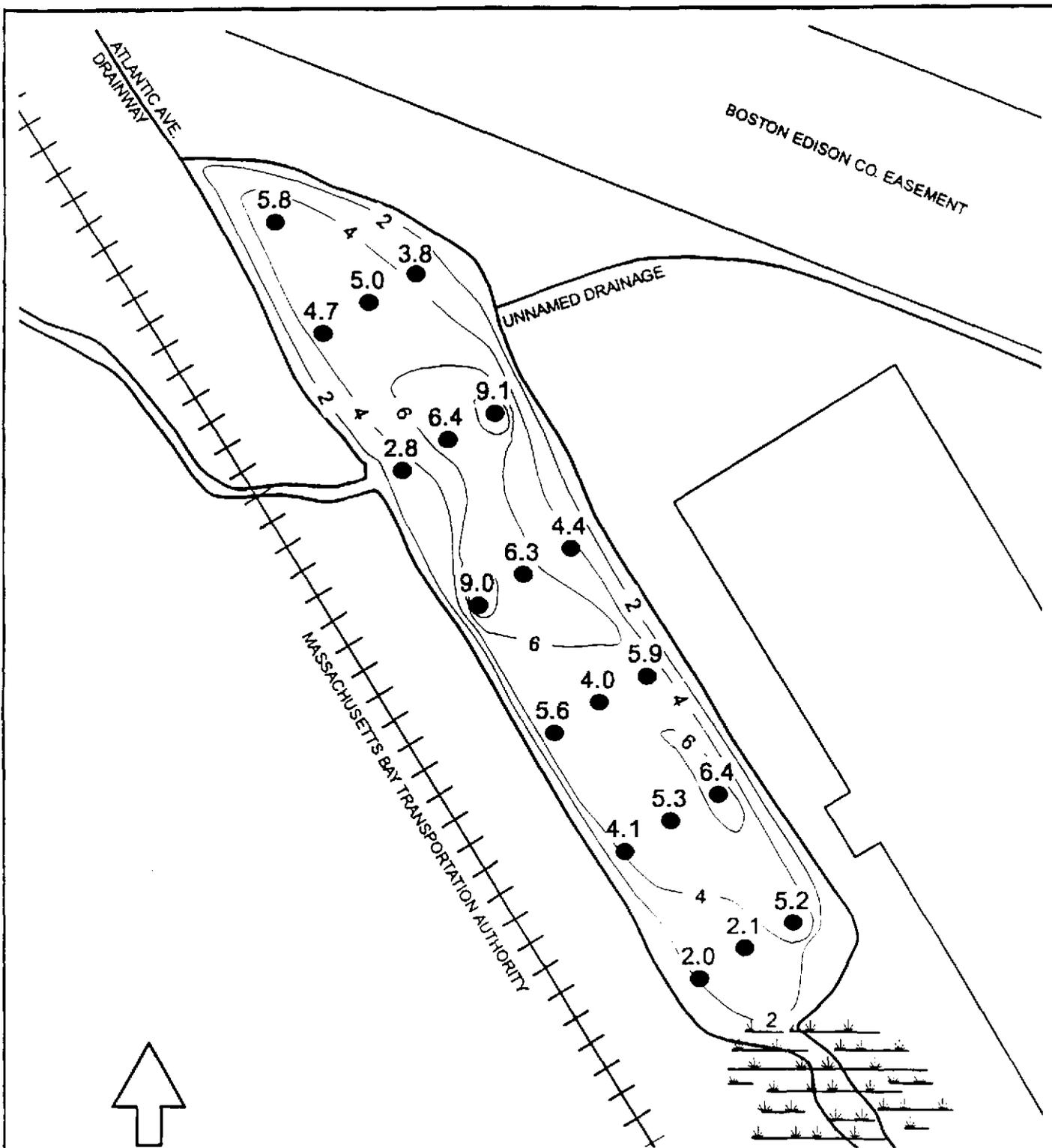
OCTOBER/NOVEMBER 1991

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

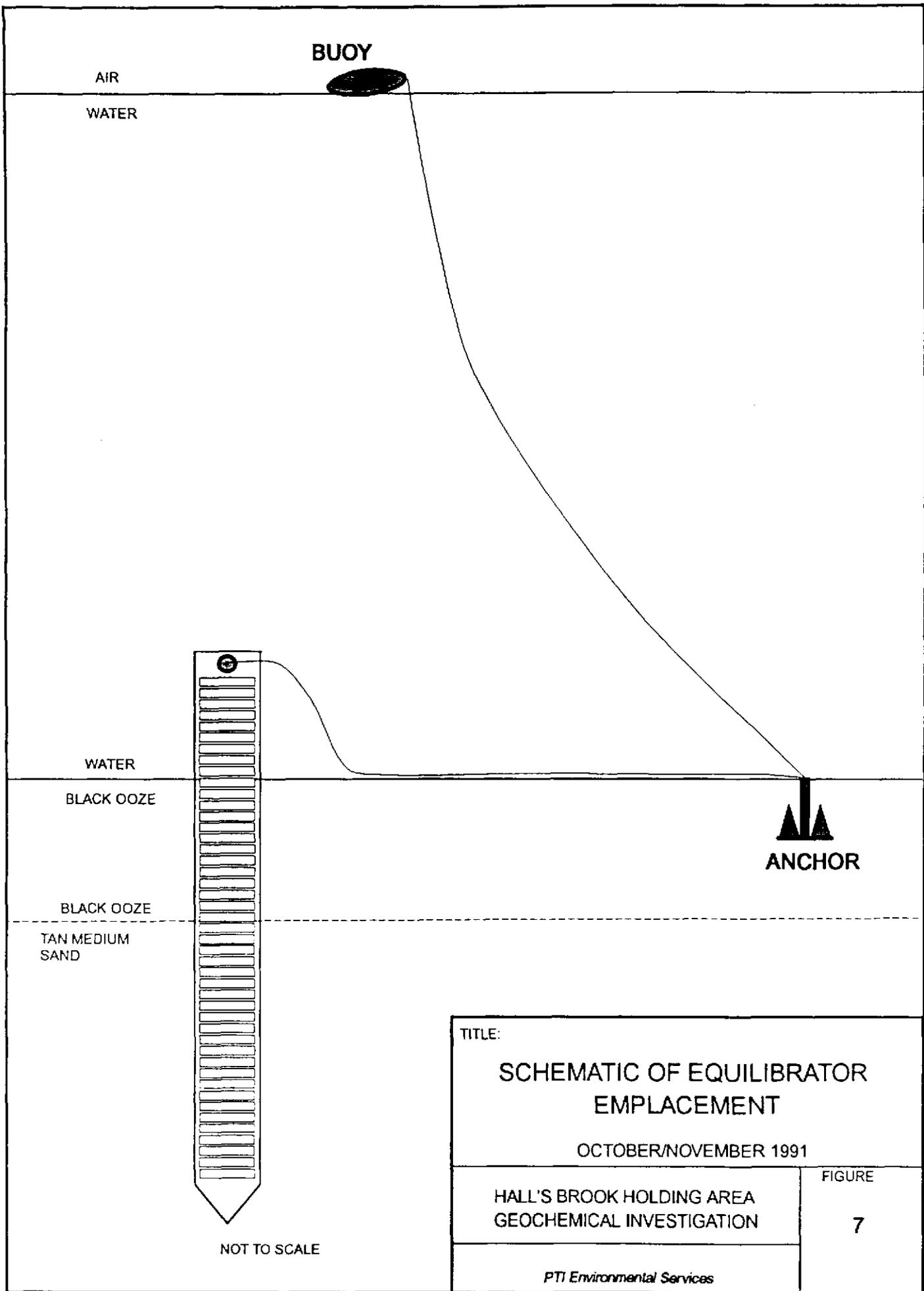
FIGURE

5

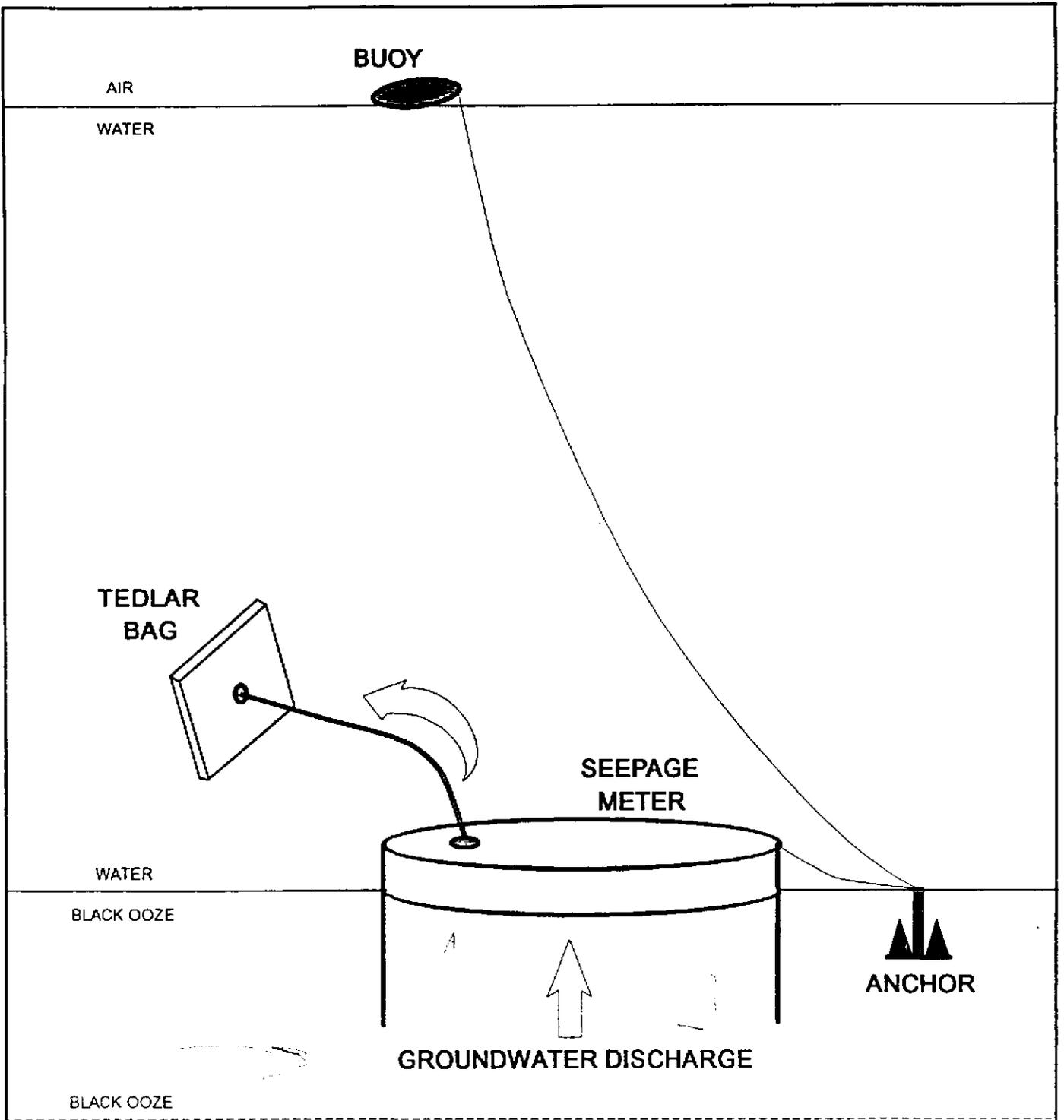
PTI Environmental Services



TITLE: COMBINED LINER/SEDIMENT THICKNESS IN FEET OCTOBER/NOVEMBER 1991	
HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE 6
PTI Environmental Services	



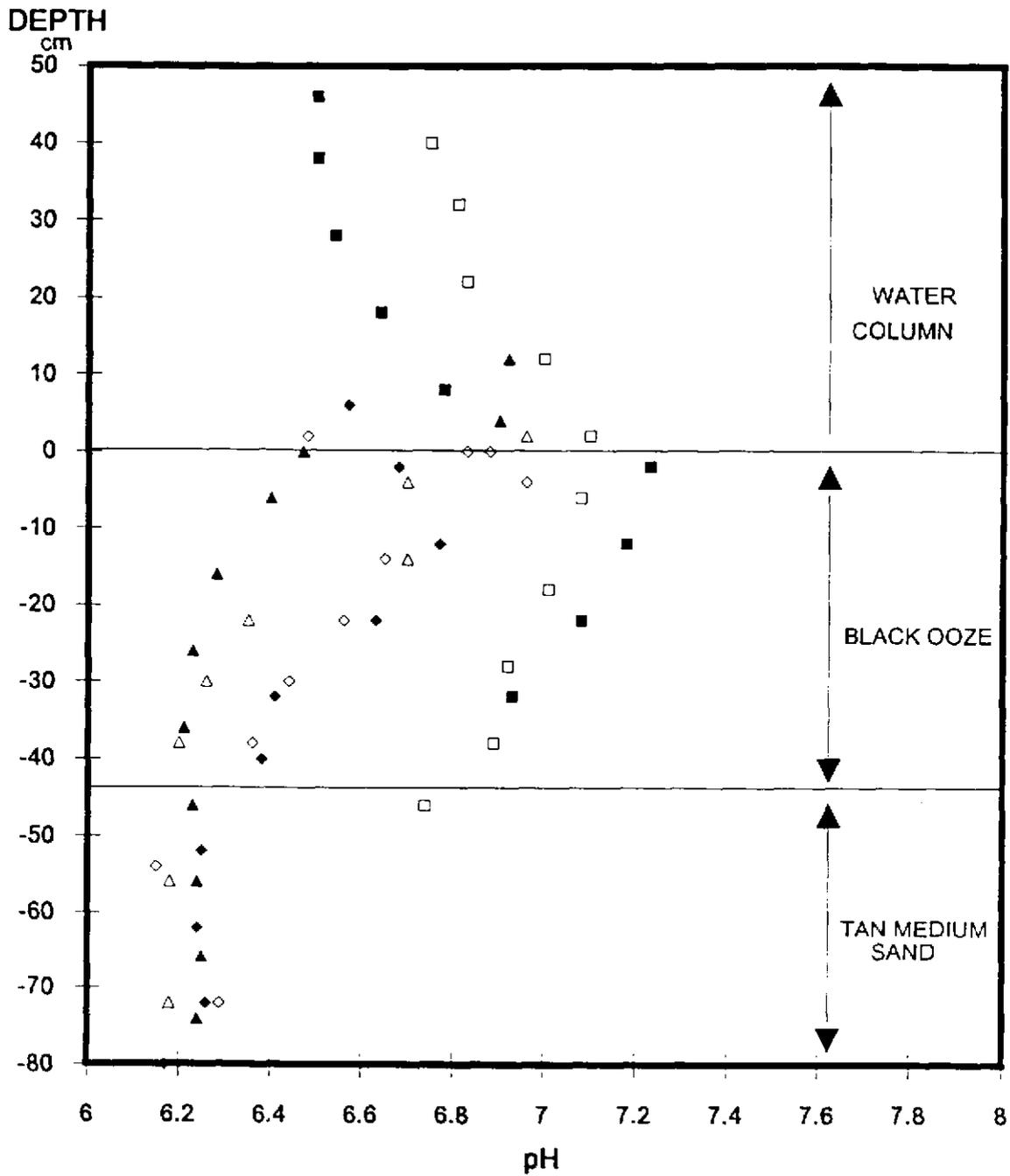
TITLE: SCHEMATIC OF EQUILIBRATOR EMPLACEMENT OCTOBER/NOVEMBER 1991	
HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE 7
<i>PTI Environmental Services</i>	



TAN MEDIUM SAND

TITLE: SCHEMATIC OF SEEPAGE METER EMPLACEMENT	
HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE 8
PTI Environmental Services	

NOT TO SCALE



- SOUTH-A
- SOUTH-B
- ◇ CENTRAL-A
- ◆ CENTRAL-B
- △ NORTH-A
- ▲ NORTH-B

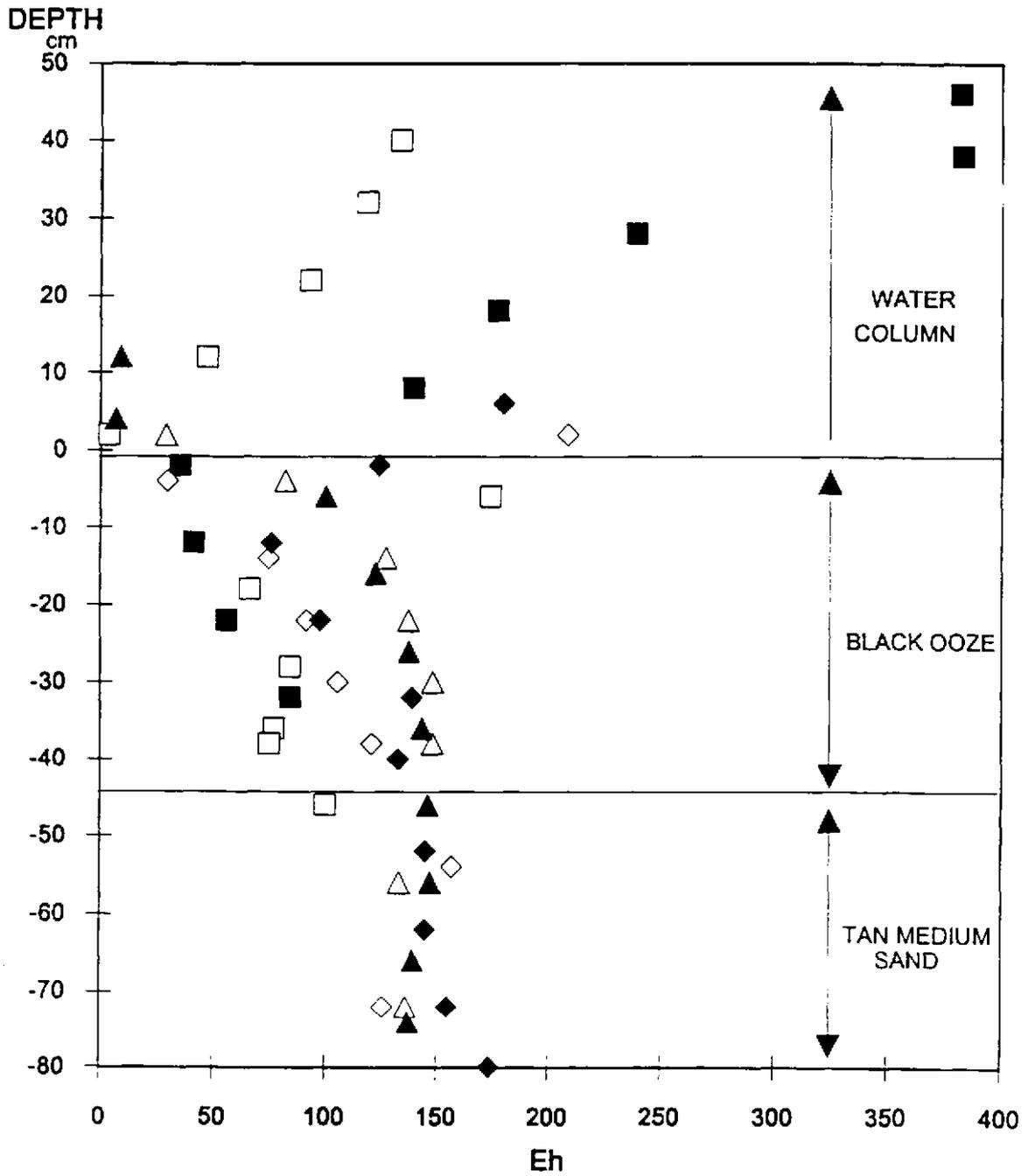
TITLE:

PORE WATER pH MEASUREMENTS
NOVEMBER 1991

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

FIGURE

9



- SOUTH-A
- SOUTH-B
- ◇ CENTRAL-A
- ◆ CENTRAL-B
- △ NORTH-A
- ▲ NORTH-B

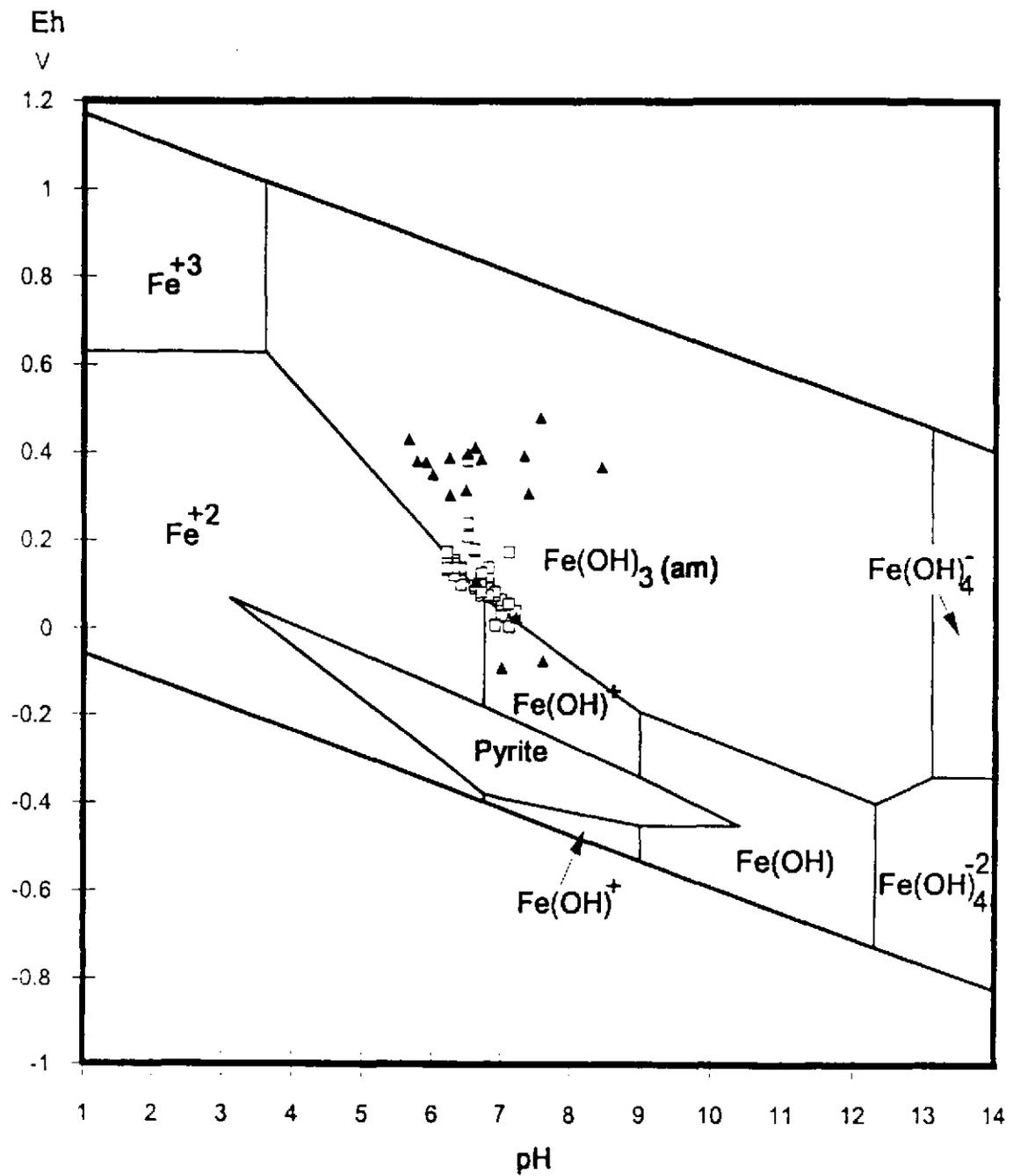
TITLE:

PORE WATER Eh MEASUREMENTS
NOVEMBER 1991

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

FIGURE

10



▲ ONSITE GROUNDWATER
 □ HBHA PORE WATERS

TITLE:

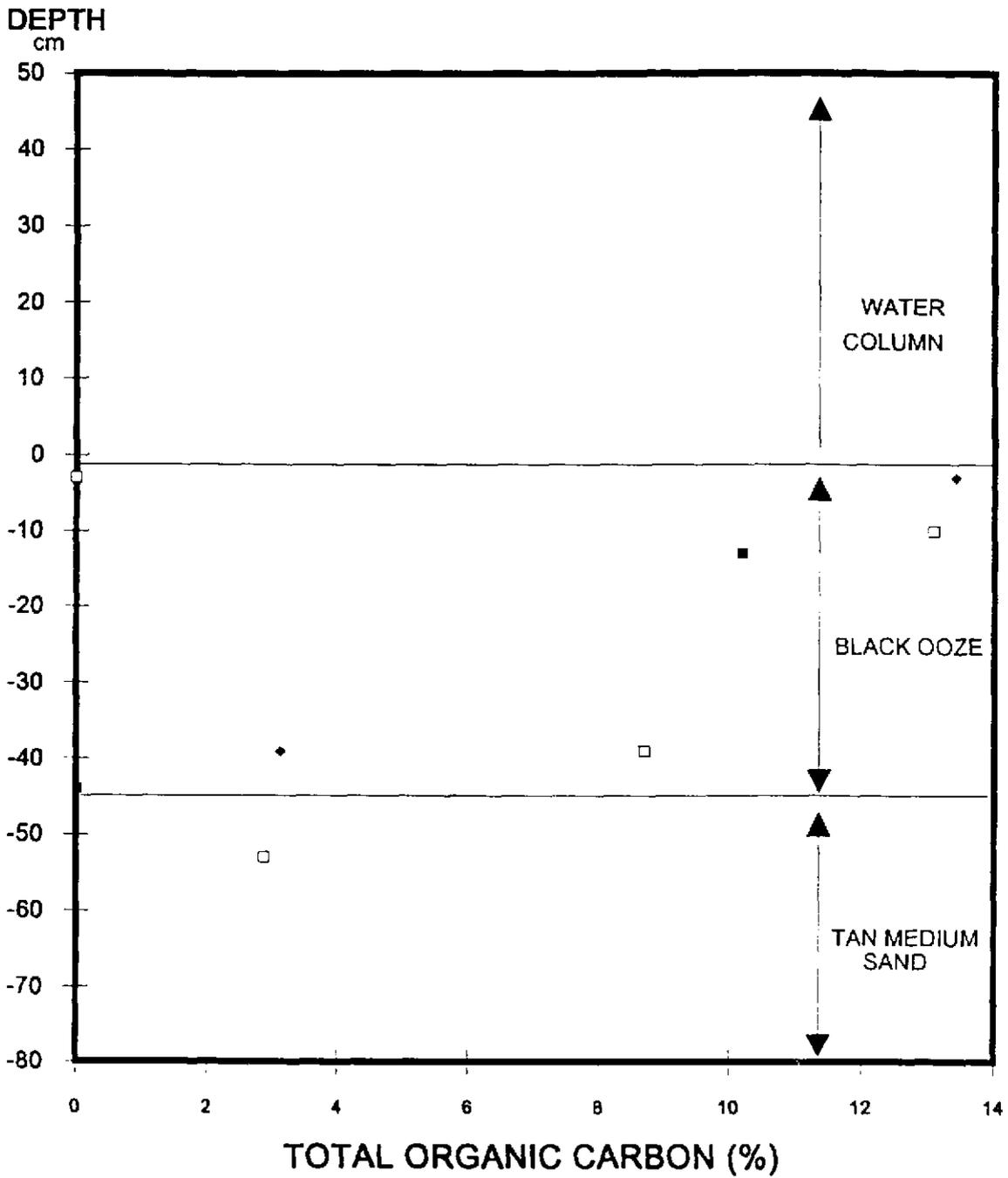
Eh-pH DIAGRAM SHOWING
 PREDOMINANT FE SPECIES

HALL'S BROOK HOLDING AREA
 GEOCHEMICAL INVESTIGATION

FIGURE

11

PTI Environmental Services



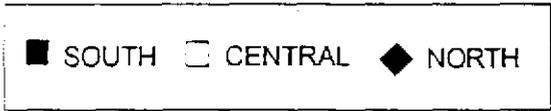
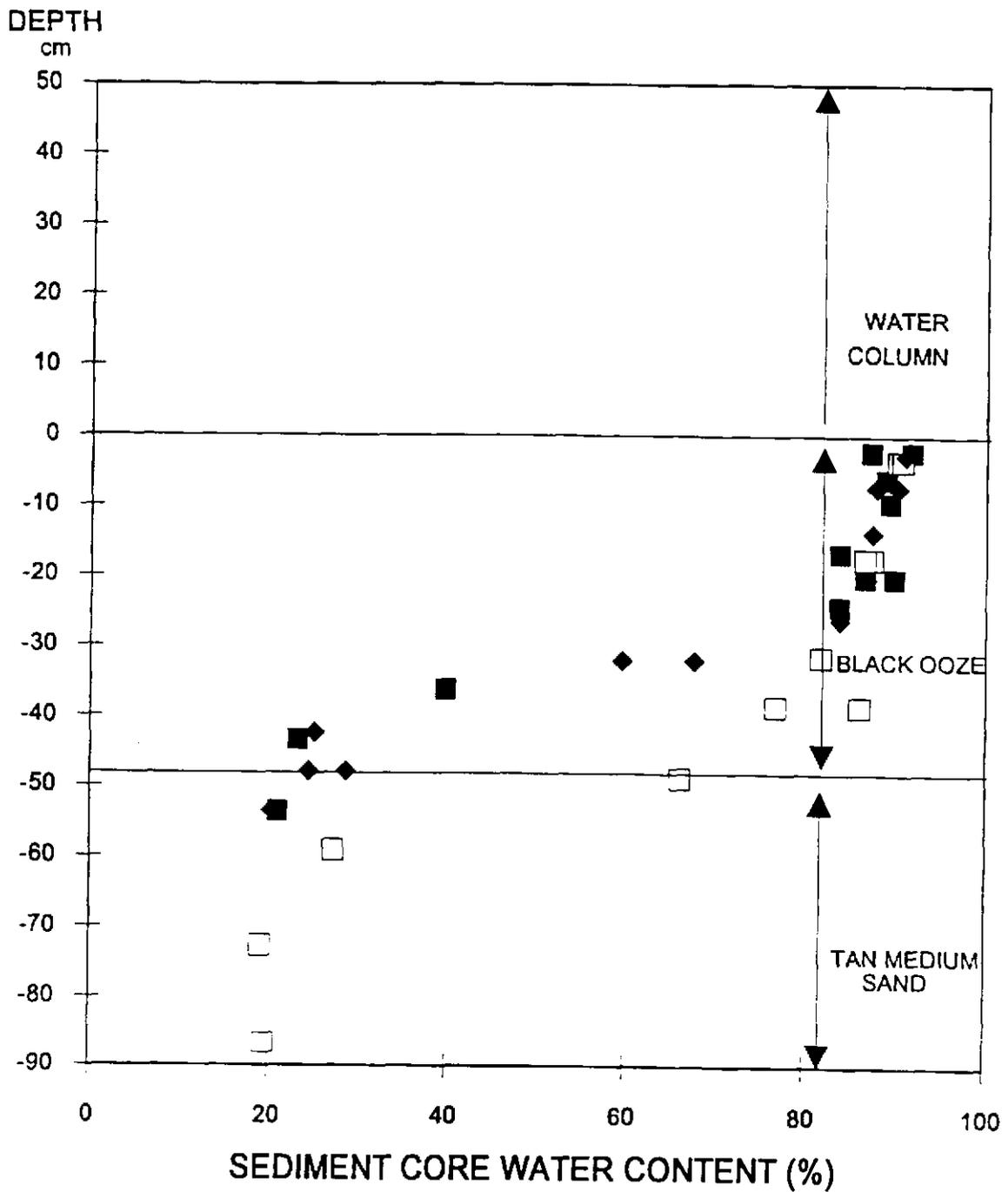
■ SOUTH □ CENTRAL ◆ NORTH

TITLE:
TOTAL ORGANIC CARBON IN BULK SEDIMENTS (%)

HALL'S BROOK HOLDING AREA
 GEOCHEMICAL INVESTIGATION

PTI Environmental Services

FIGURE
12



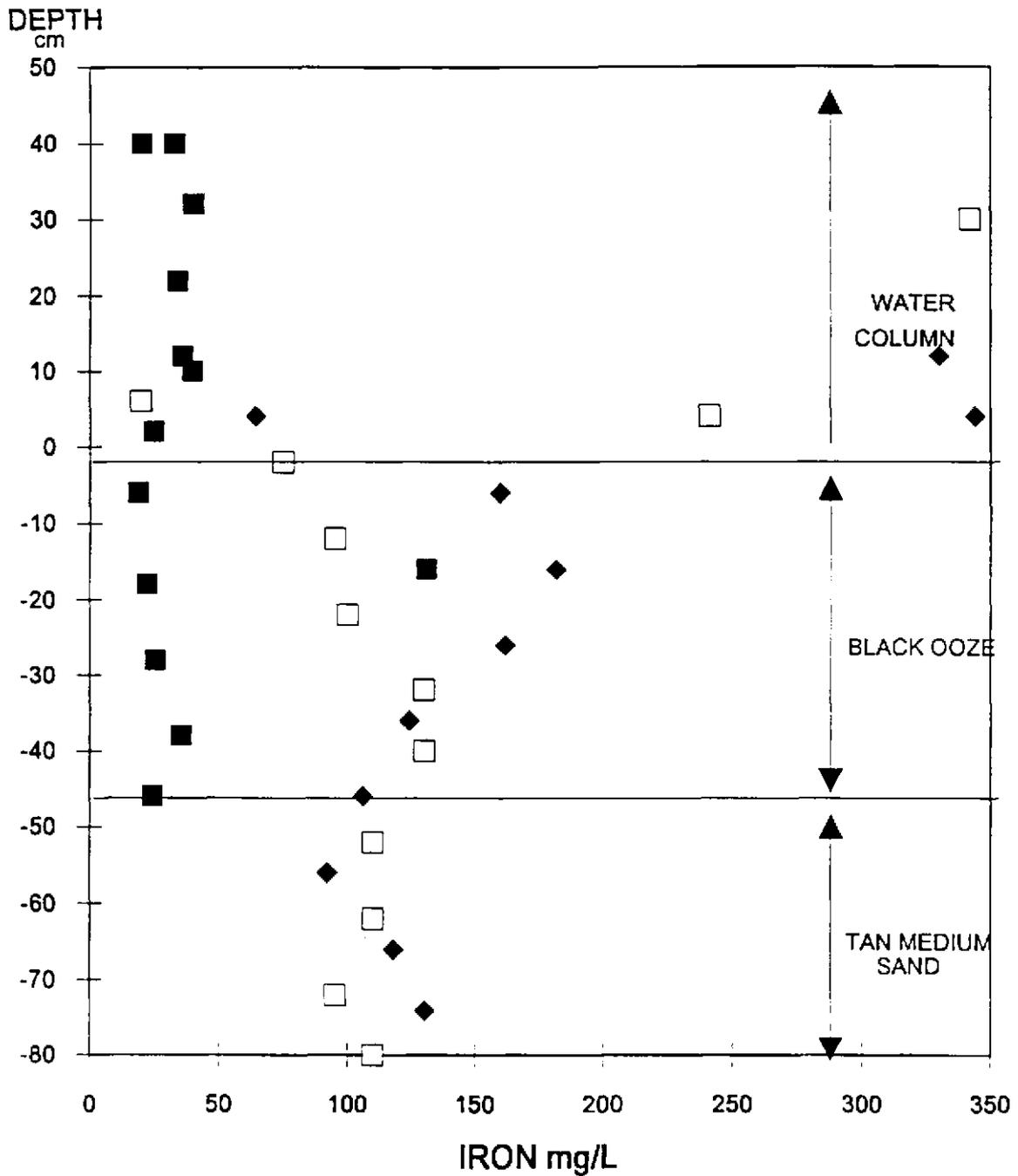
TITLE:

**BULK SEDIMENT
WATER CONTENT (%)**

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

FIGURE

13

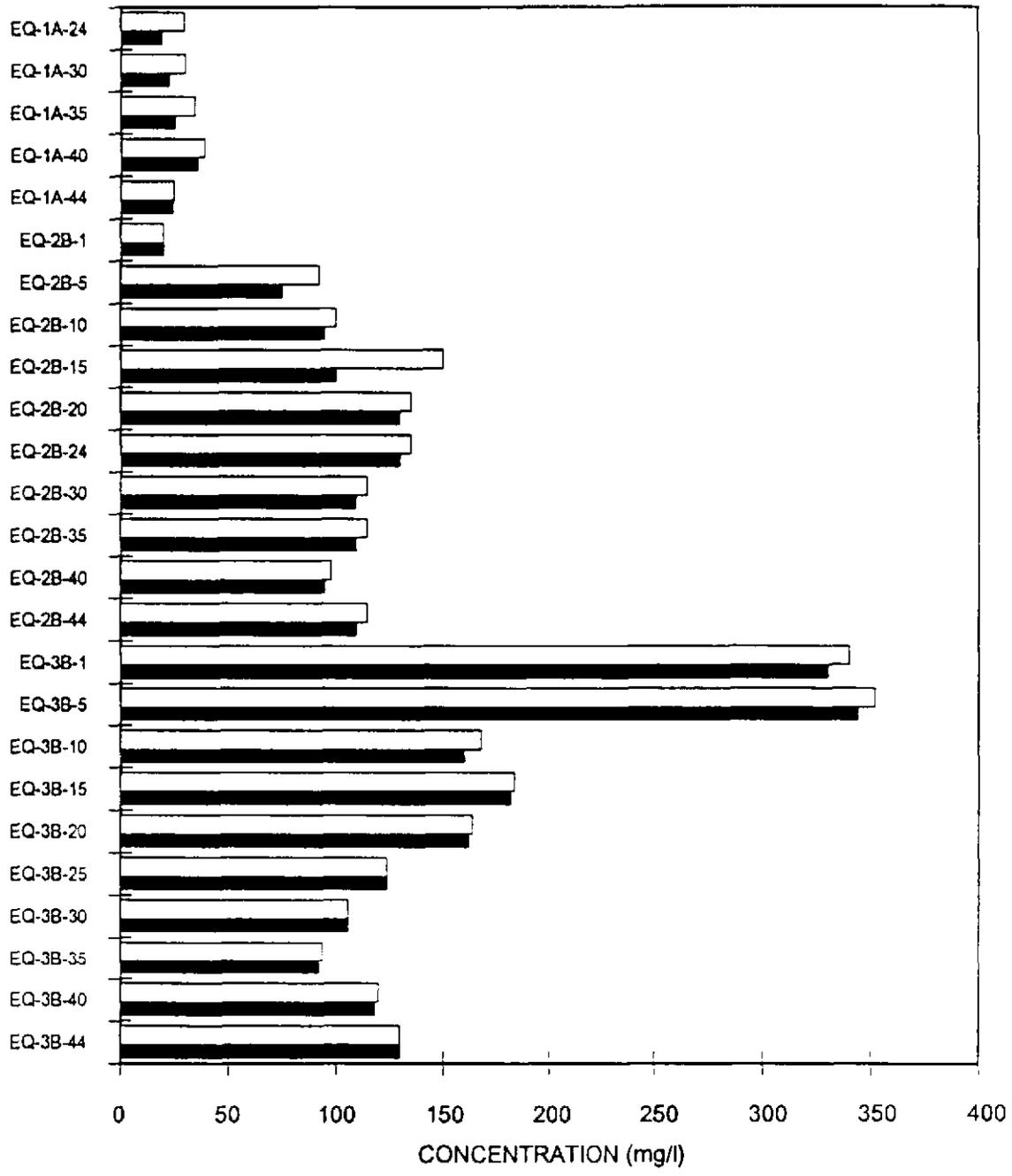


SOUTH
 CENTRAL
 NORTH

TITLE: IRON IN PORE WATER (mg/L)	
HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE 14
<i>PTI Environmental Services</i>	

10%

■ FERROUS IRON □ TOTAL IRON

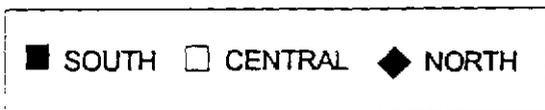
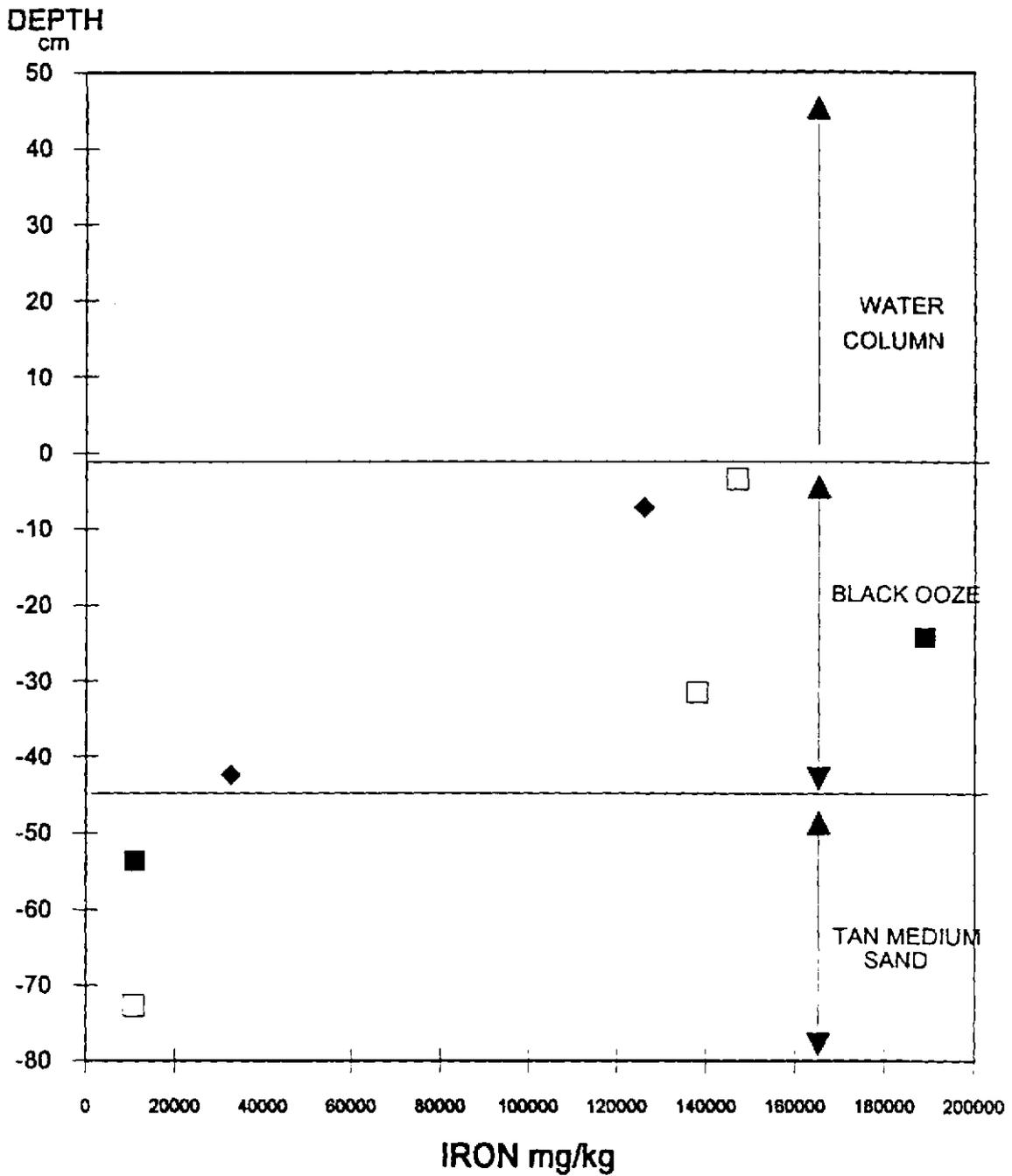


TITLE:
COMPARISON OF FERROUS AND TOTAL IRON IN PORE WATERS

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

FIGURE
15

PTI Environmental Services



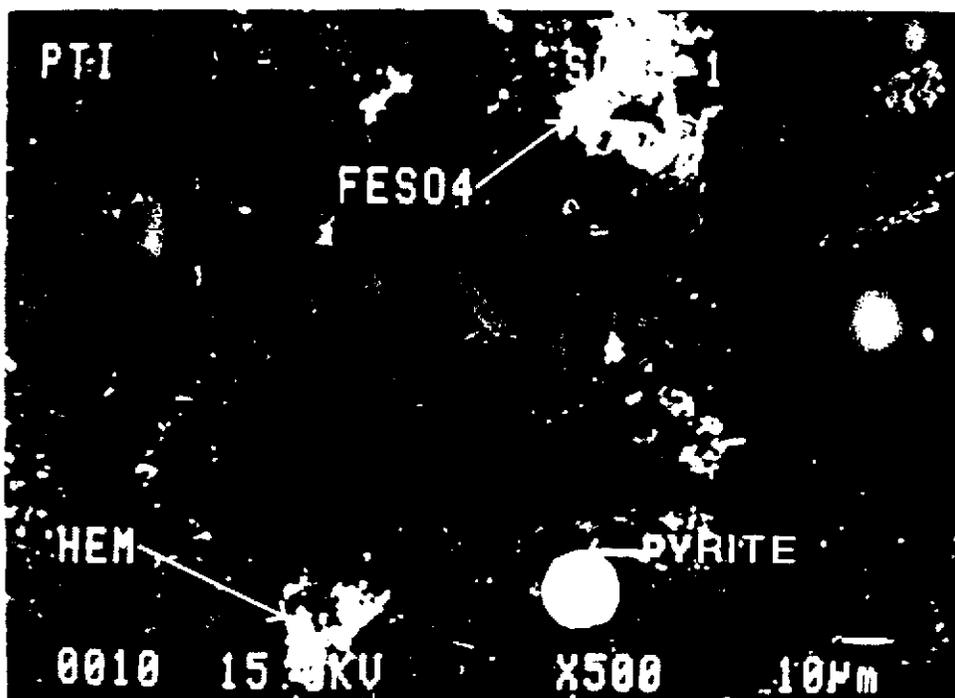
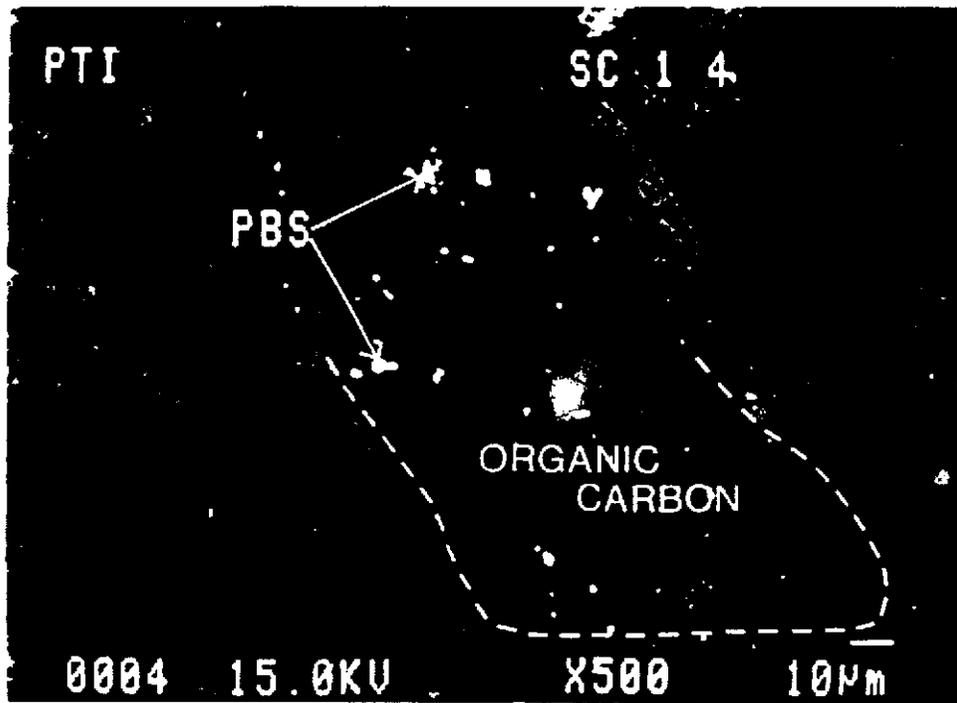
TITLE:

**IRON IN BULK
SEDIMENTS (mg/kg)**

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

FIGURE

16



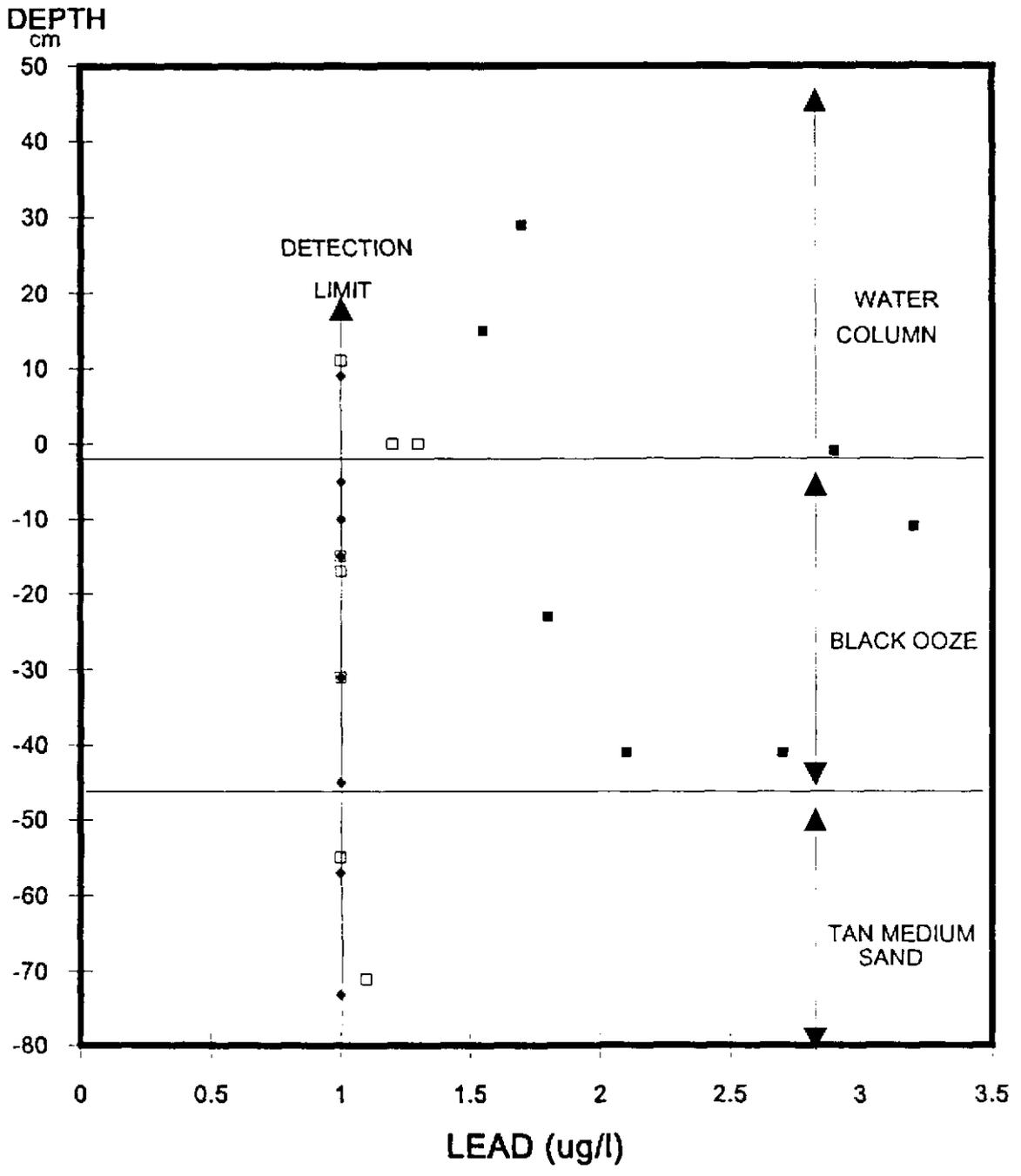
TITLE:

SCANNING ELECTRON
 MICROGRAPH OF BLACK OOZE SAMPLES
 COLLECTED FROM SOUTH AREA (SC-1)
 AND NORTH AREA (SC-2)

HALL'S BROOK HOLDING AREA
 GEOCHEMICAL INVESTIGATION

FIGURE

17

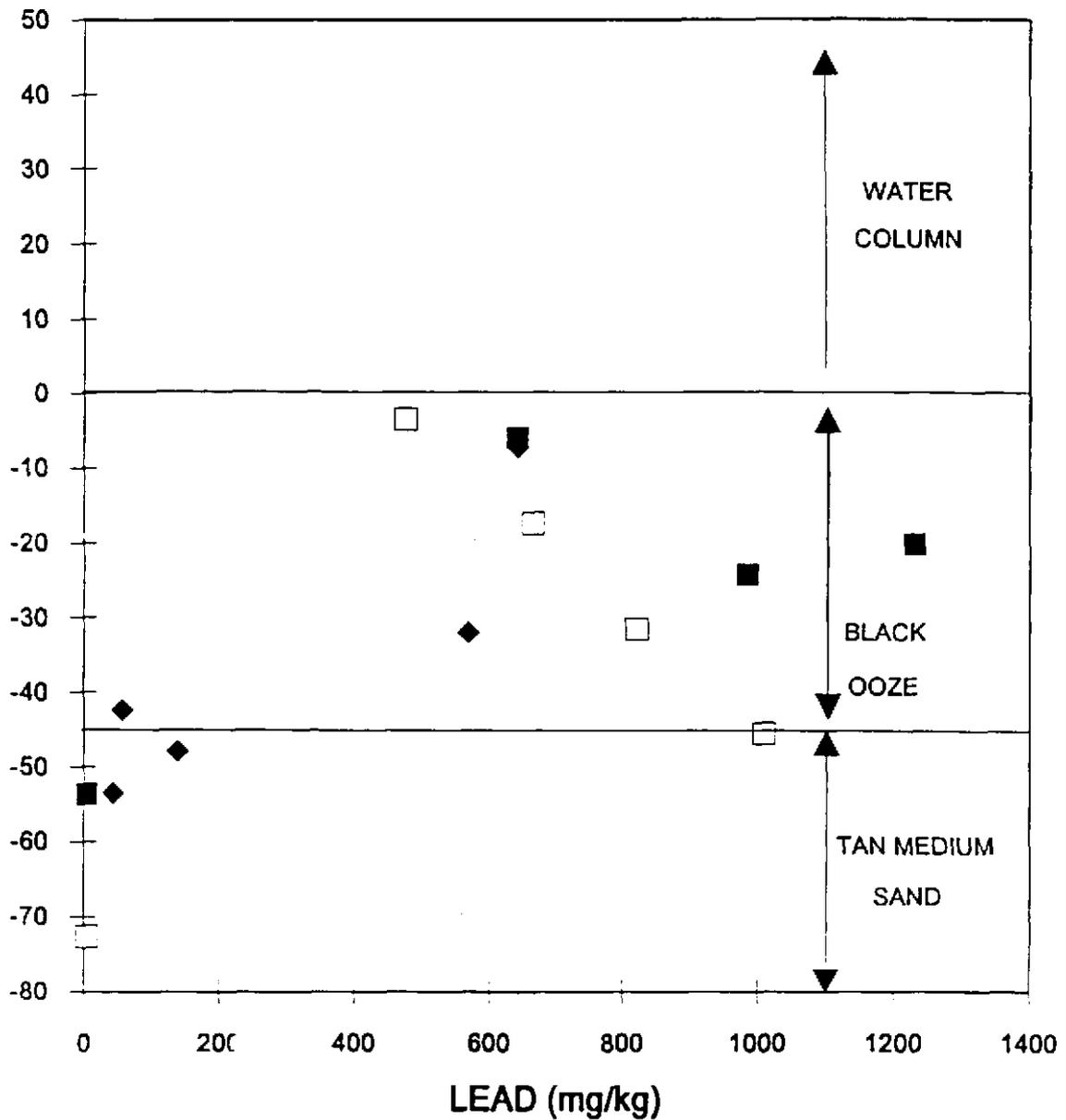


SOUTH
 CENTRAL
 NORTH

TITLE: LEAD IN PORE WATERS ($\mu\text{g/L}$)	
HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE 18
<i>PTI Environmental Services</i>	

DEPTH

cm



■ SOUTH □ CENTRAL ◆ NORTH

TITLE:

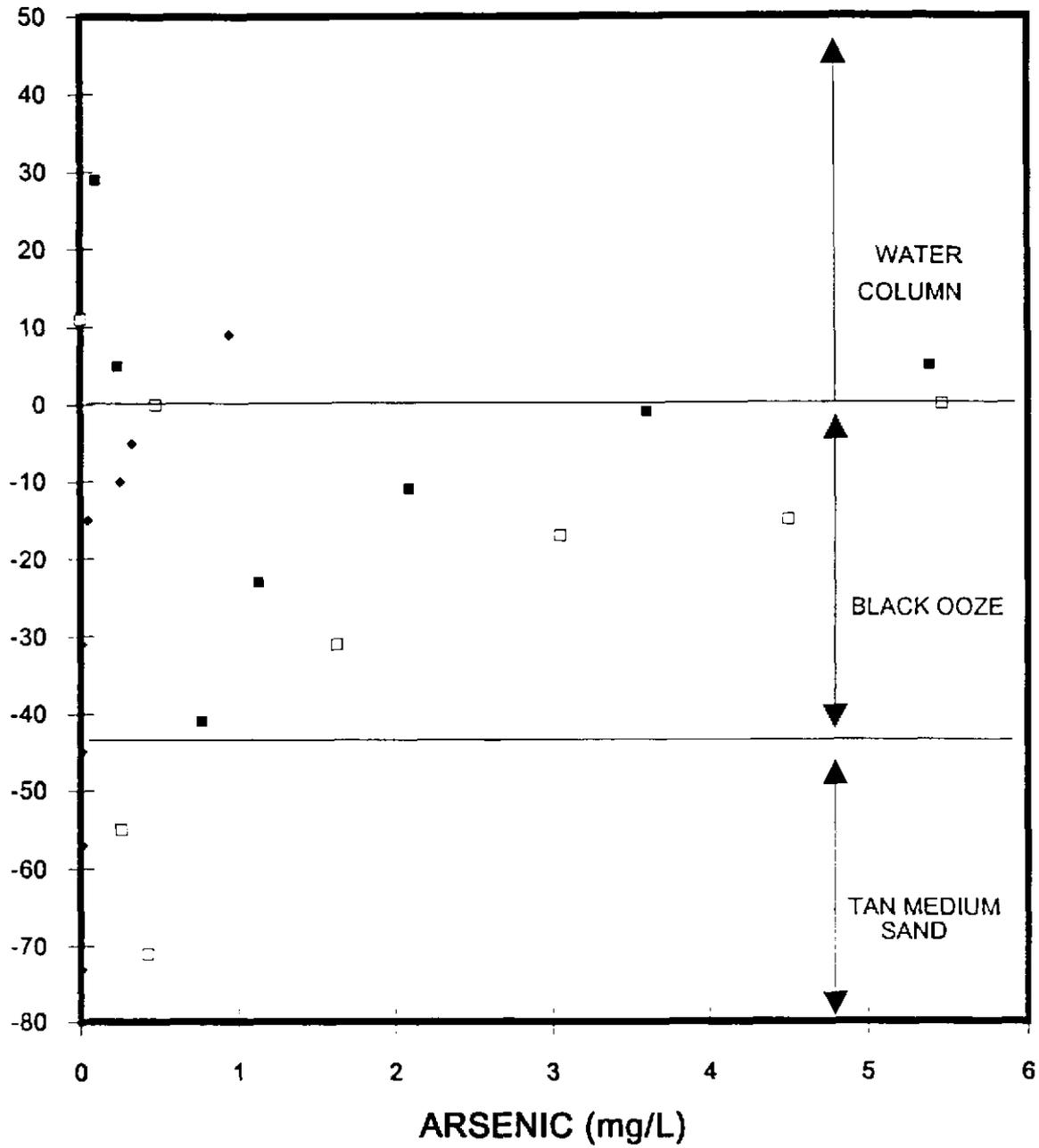
LEAD IN BULK
SEDIMENTS (mg/kg)

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

FIGURE

19

DEPTH
cm



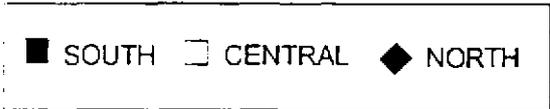
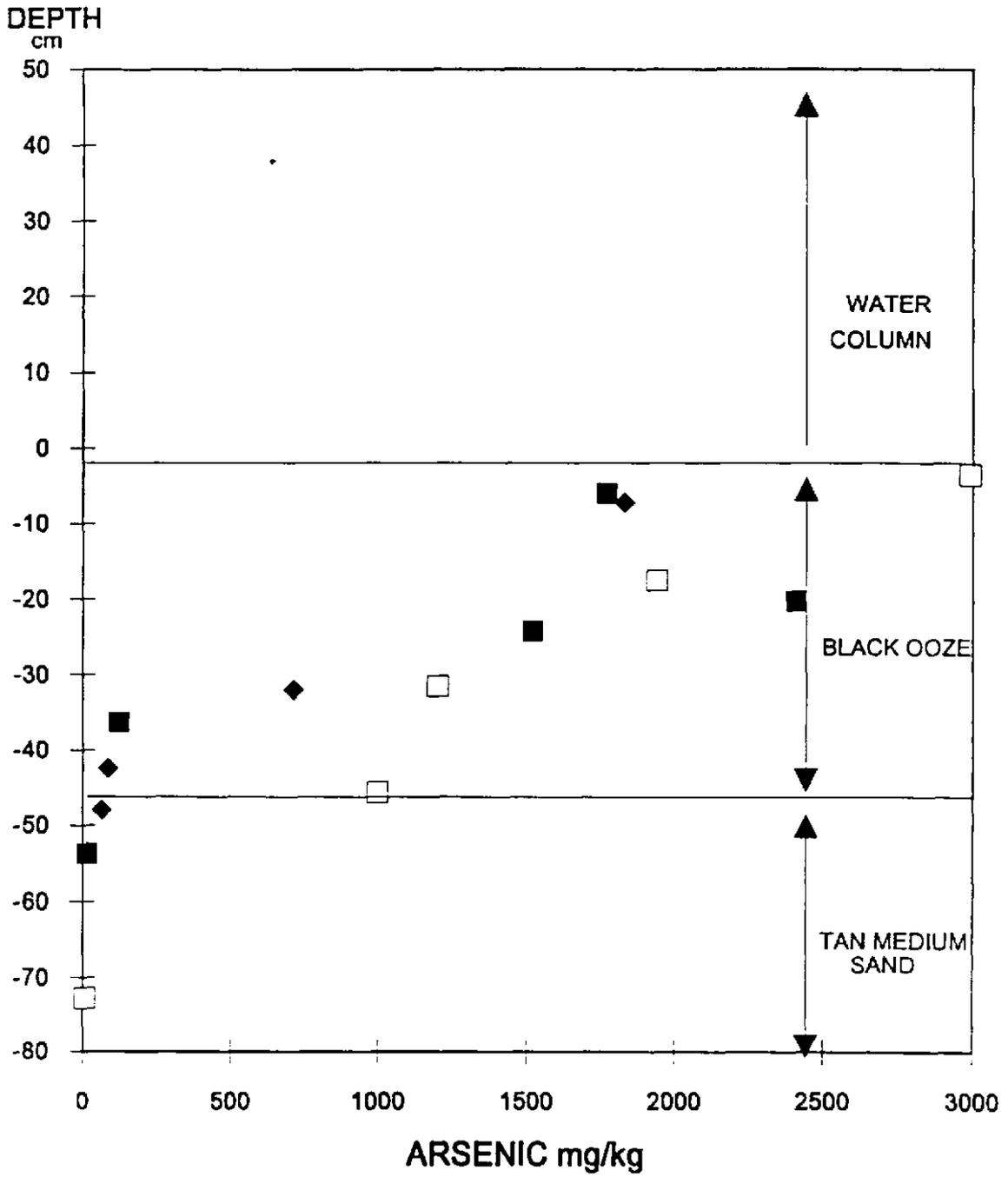
■ SOUTH □ CENTRAL ◆ NORTH

TITLE:
ARSENIC IN PORE WATERS (mg/L)

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

PTI Environmental Services

FIGURE
20



TITLE:

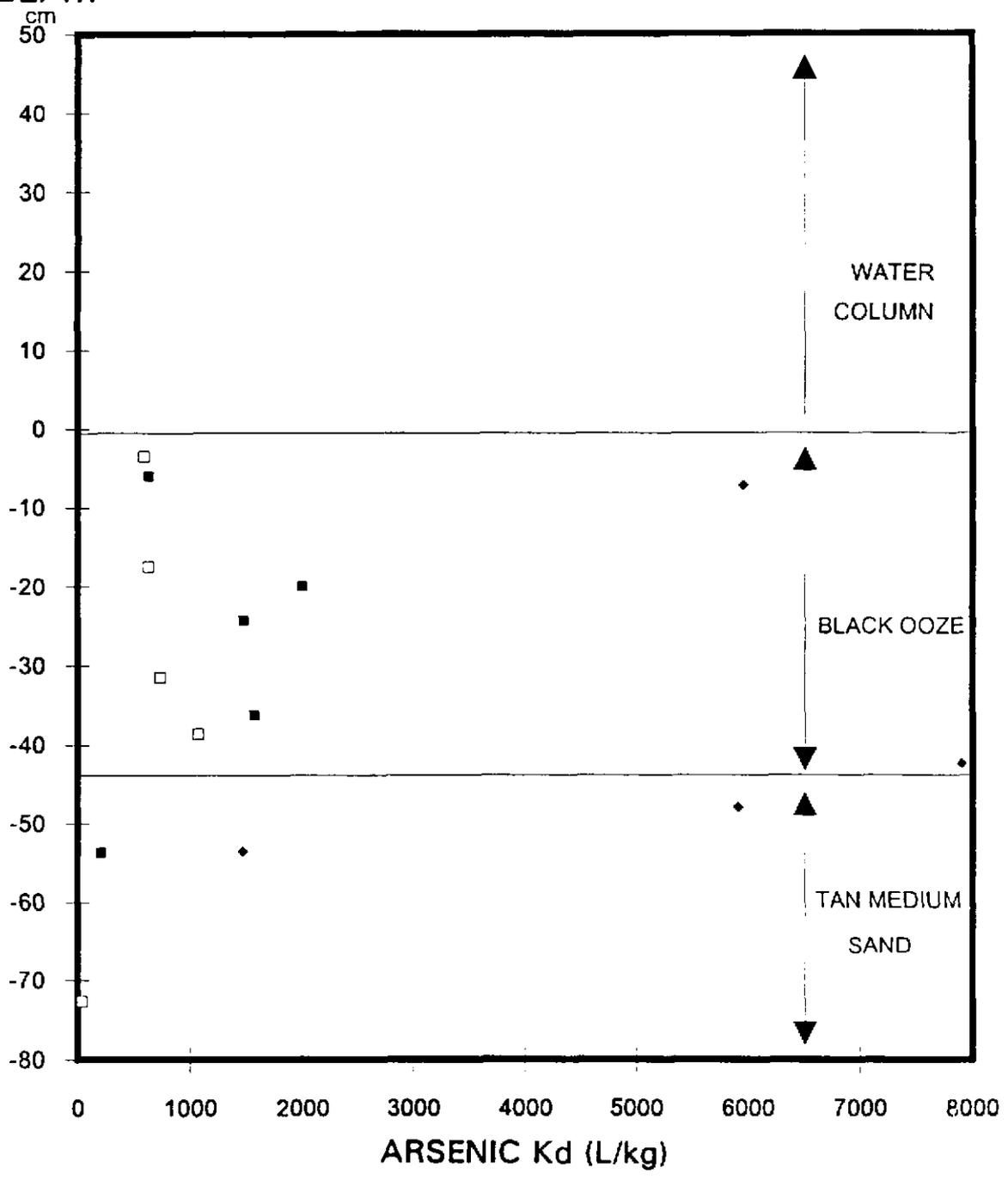
ARSENIC IN BULK
SEDIMENTS (mg/kg)

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

FIGURE

21

DEPTH



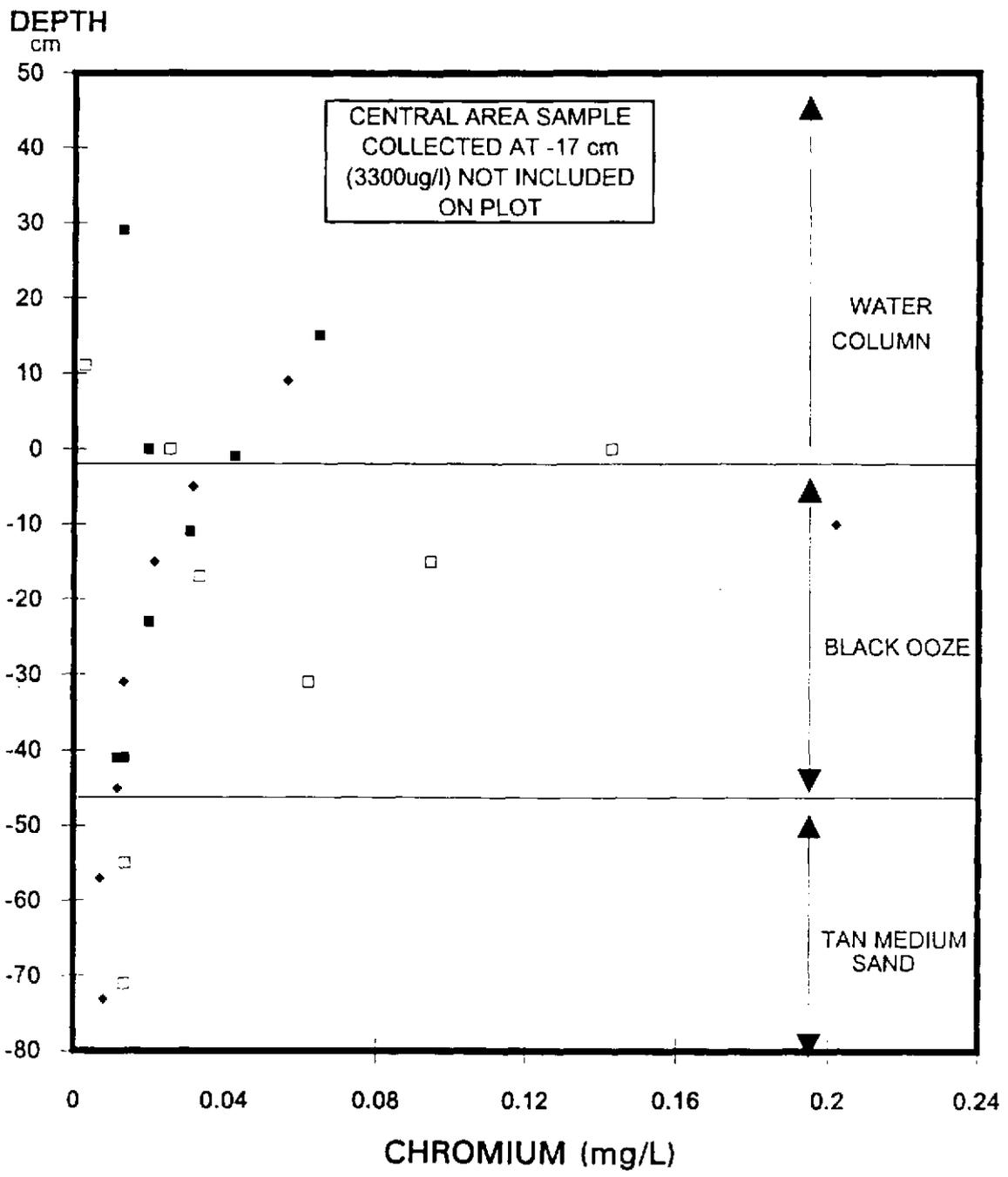
■ SOUTH □ CENTRAL ◆ NORTH

TITLE:
ARSENIC DISTRIBUTION COEFFICIENTS (L/kg)

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

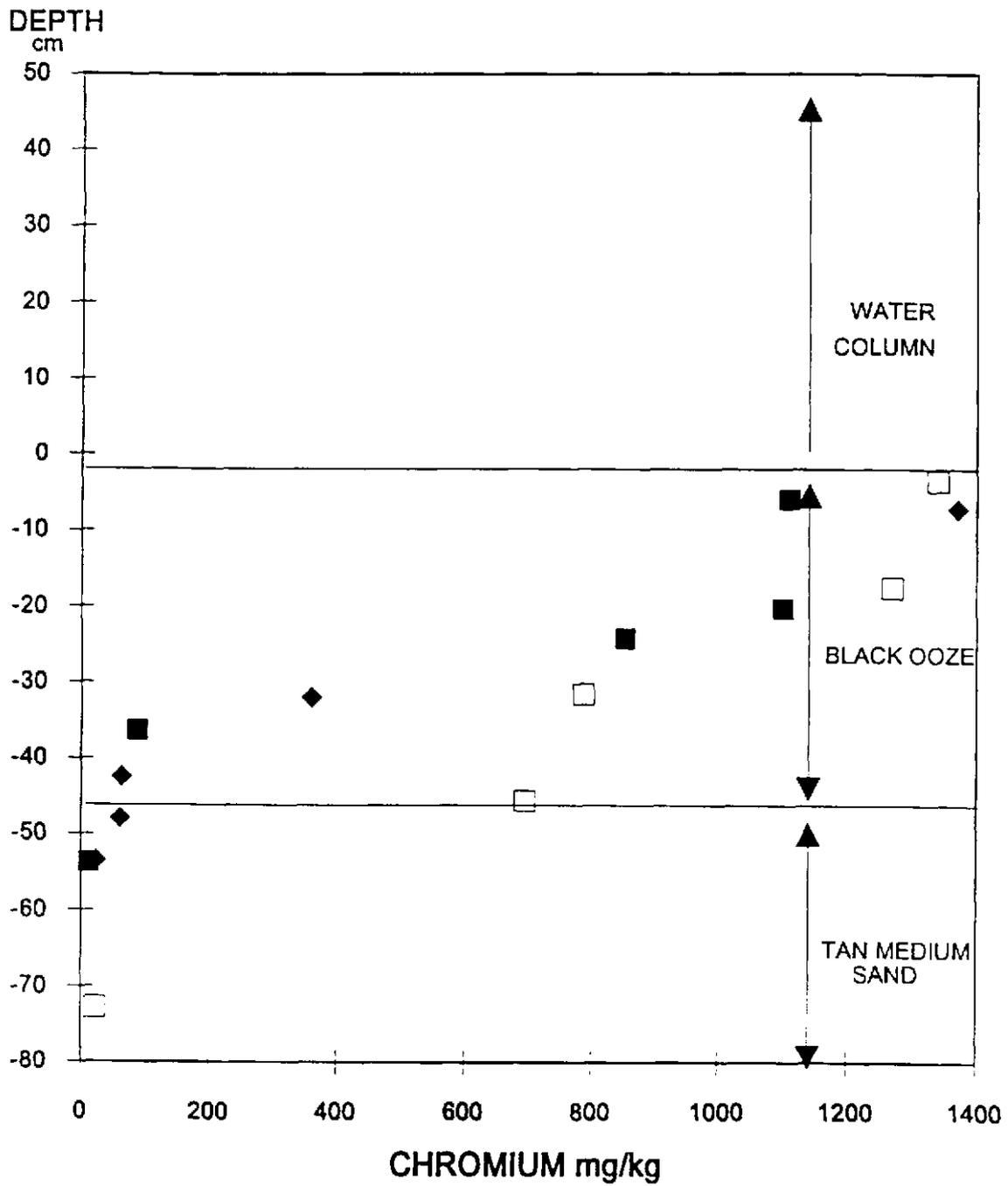
PTI Environmental Services

FIGURE
22



■ SOUTH □ CENTRAL ◆ NORTH

TITLE:	
TOTAL CHROMIUM IN PORE WATERS (mg/L)	
HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE
	23
<i>PTI Environmental Services</i>	



SOUTH
 CENTRAL
 NORTH

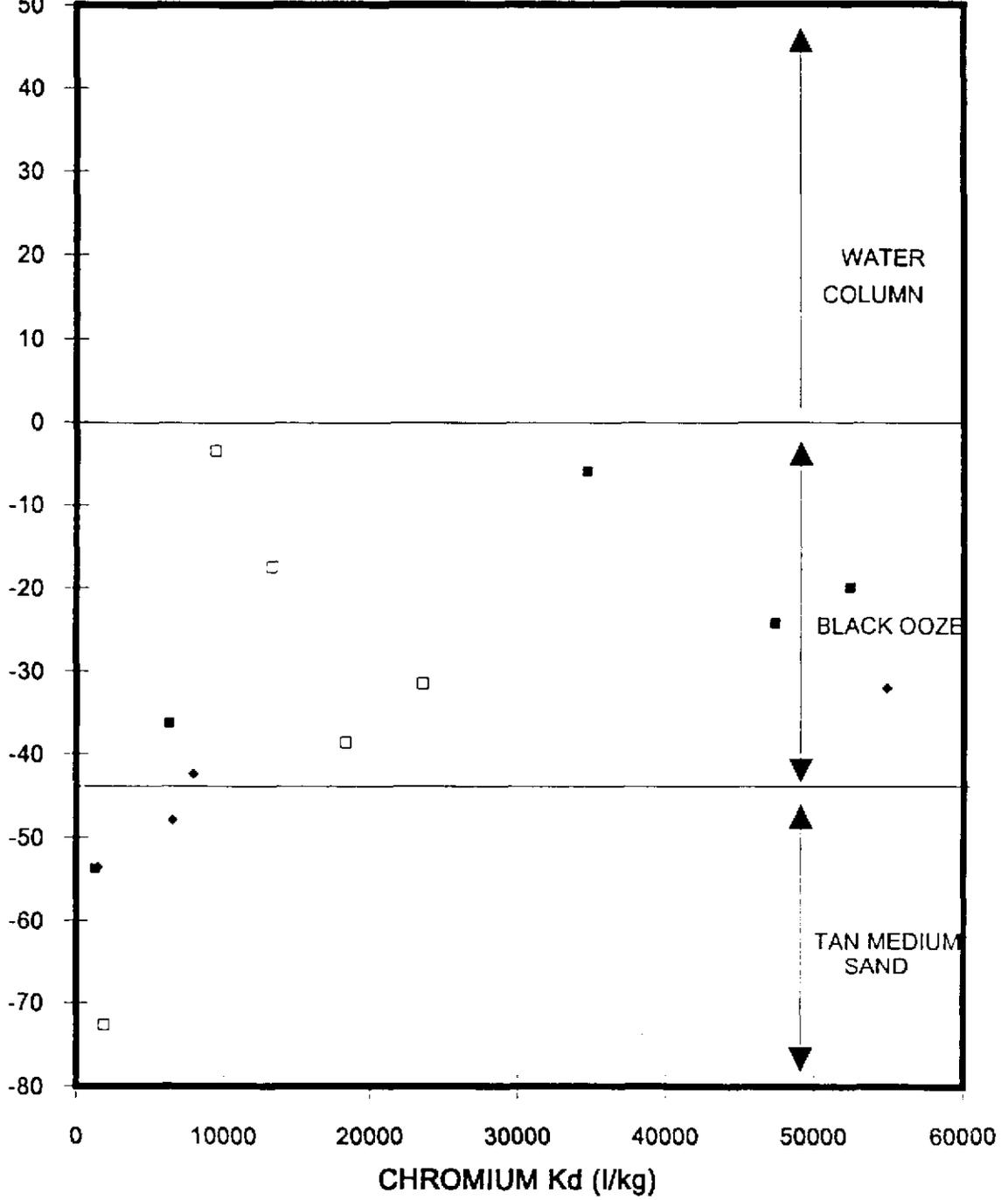
TITLE:

TOTAL CHROMIUM IN BULK SEDIMENTS (mg/kg)

HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE
<i>PTI Environmental Services</i>	24

DEPTH

cm



■ SOUTH □ CENTRAL ◆ NORTH

TITLE:

TOTAL CHROMIUM
DISTRIBUTION
COEFFICIENTS (l/kg)

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

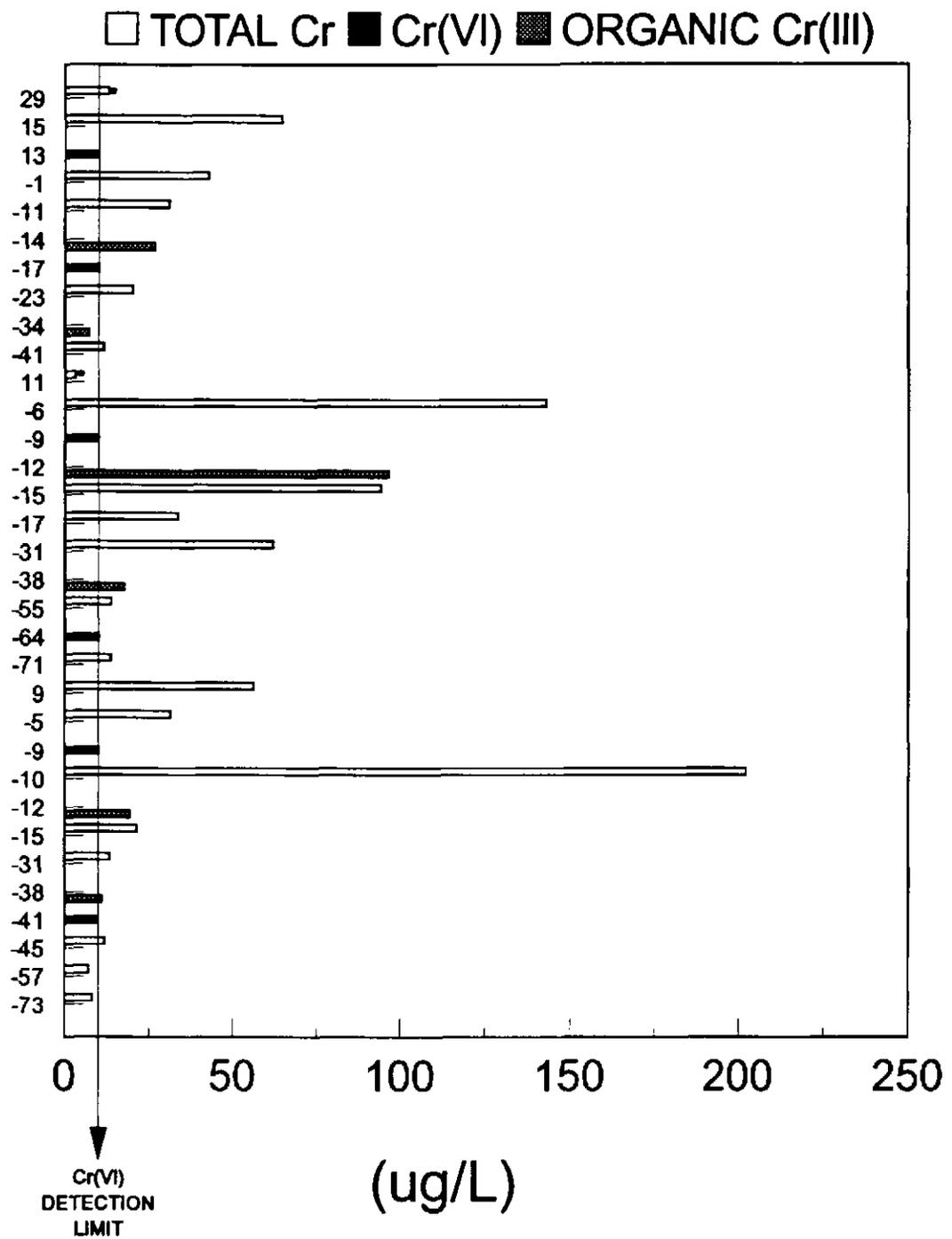
FIGURE

25

PTI Environmental Services

DEPTH IN SEDIMENTS (cm)

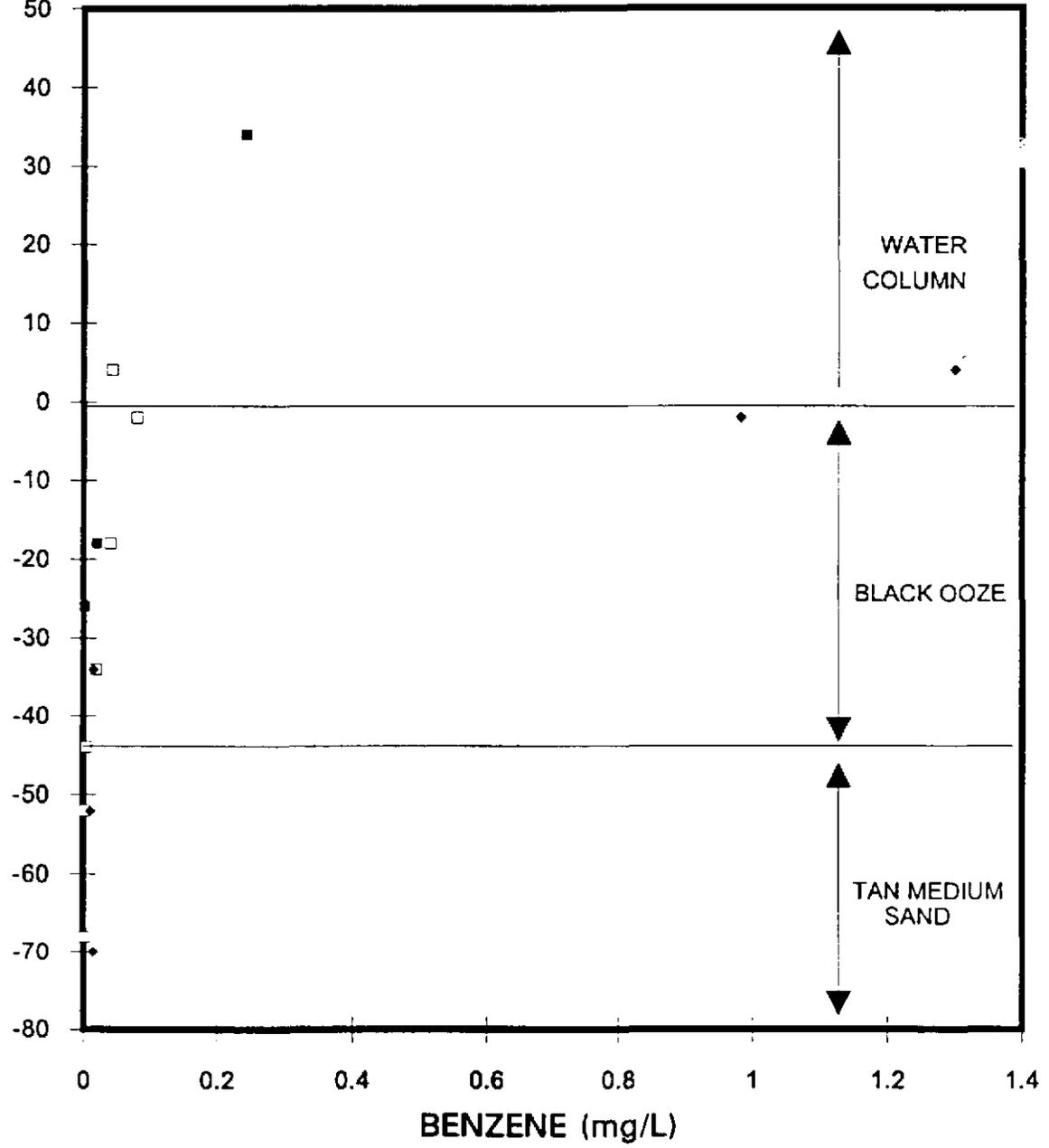
NORTH AREA CENTRAL AREA SOUTH AREA



* DETECTION LIMIT VALUE

TITLE: DISTRIBUTION OF CHROMIUM SPECIES IN HBHA WATERS	
HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE 26
PTI Environmental Services	

DEPTH
cm



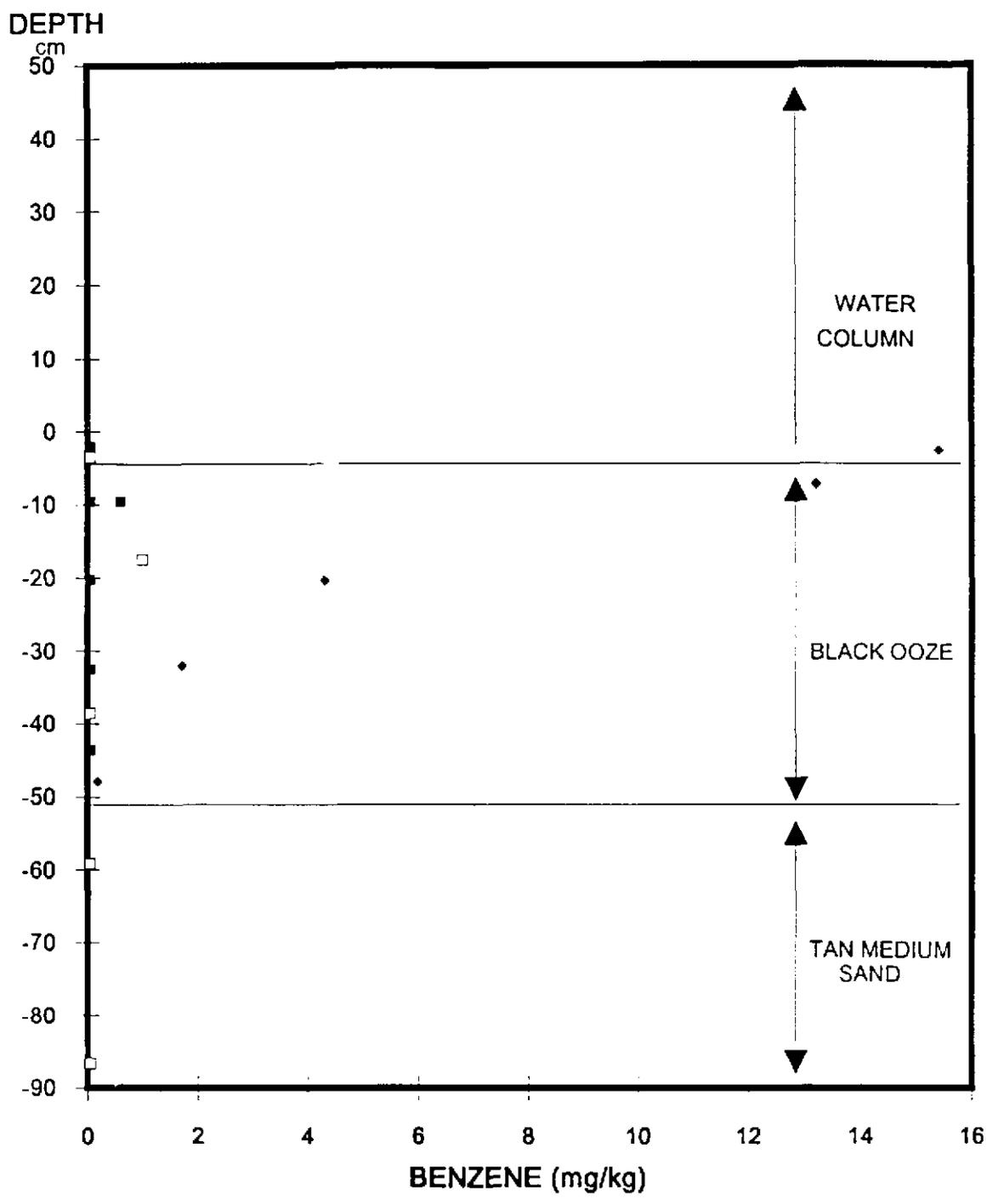
■ SOUTH □ CENTRAL ◆ NORTH

TITLE:
BENZENE IN PORE WATERS (mg/L)

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

PTI Environmental Services

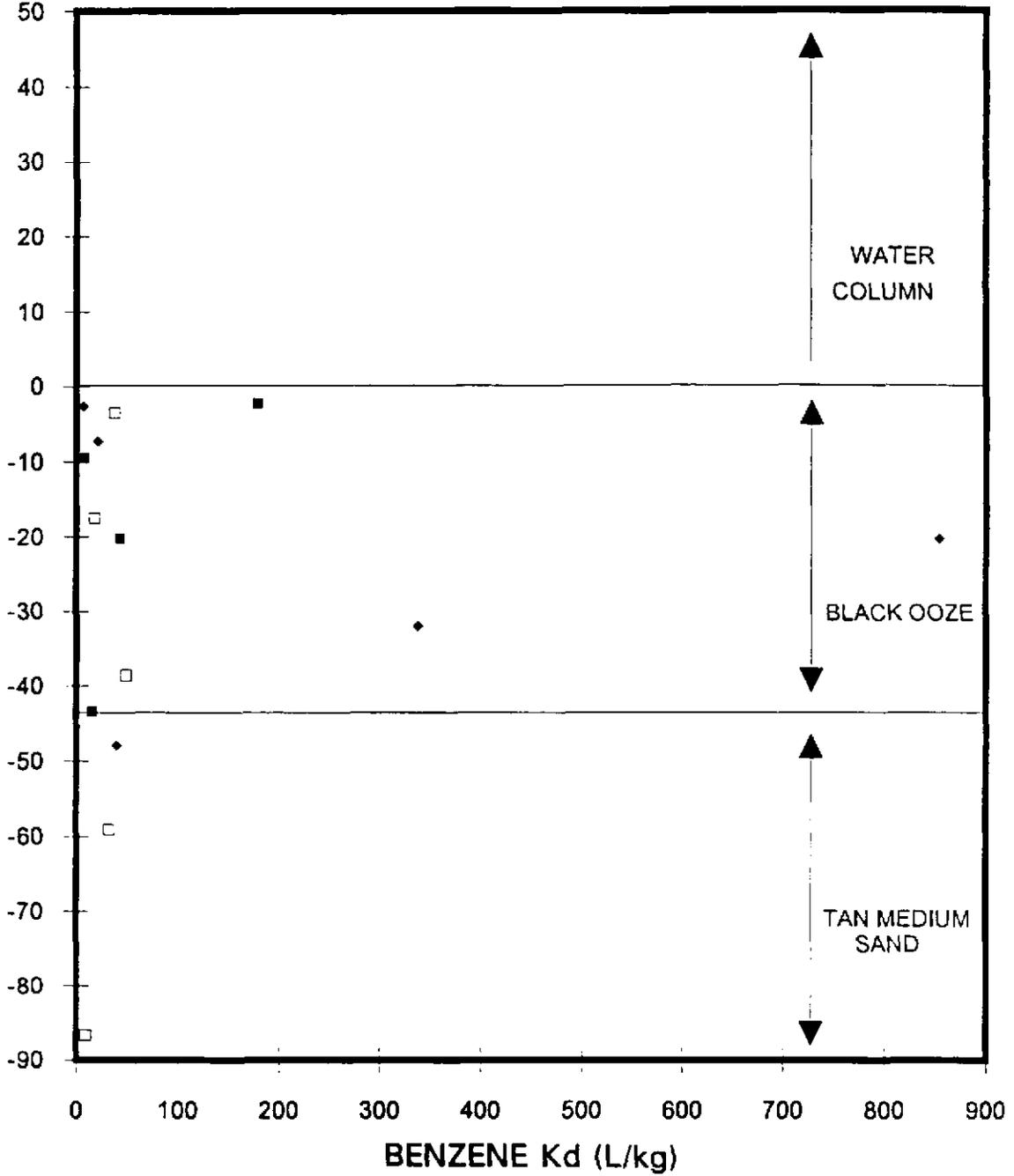
FIGURE
27



SOUTH
 CENTRAL
 NORTH

TITLE: BENZENE IN BULK SEDIMENTS (mg/kg)	
HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE 28
<i>PTI Environmental Services</i>	

DEPTH
cm



■ SOUTH □ CENTRAL ◆ NORTH

TITLE:

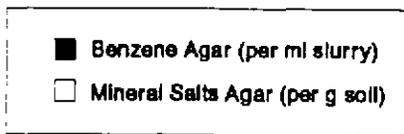
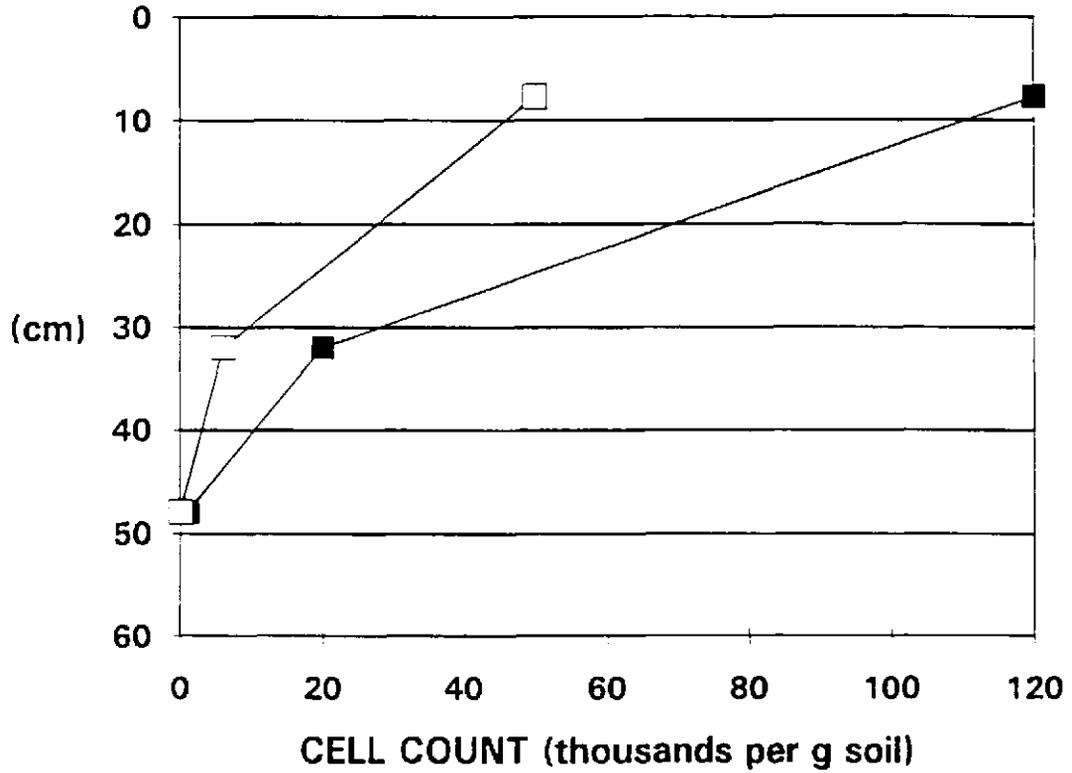
**BENZENE DISTRIBUTION
COEFFICIENTS (L/kg)**

HALL'S BROOK HOLDING AREA
GEOCHEMICAL INVESTIGATION

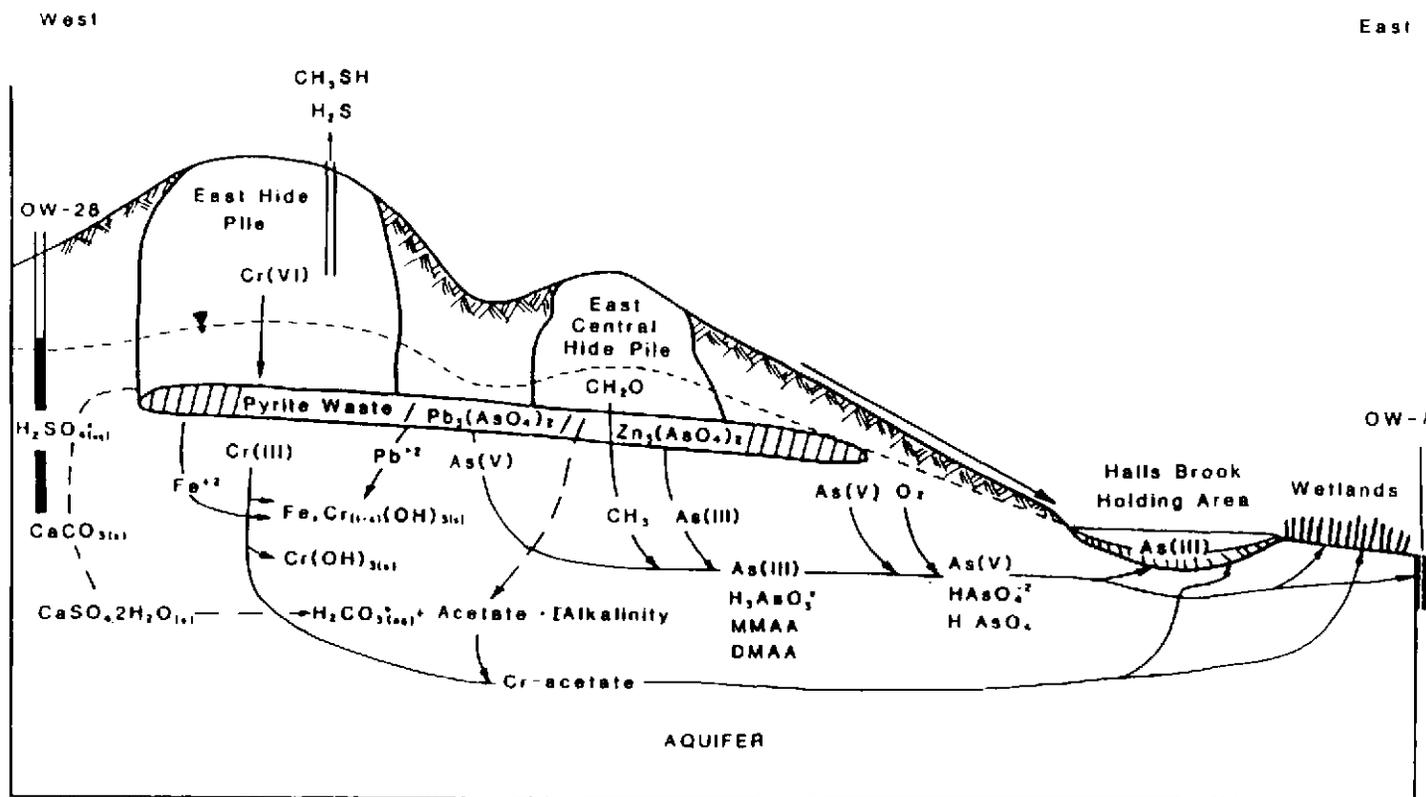
FIGURE

29

SEDIMENT DEPTH

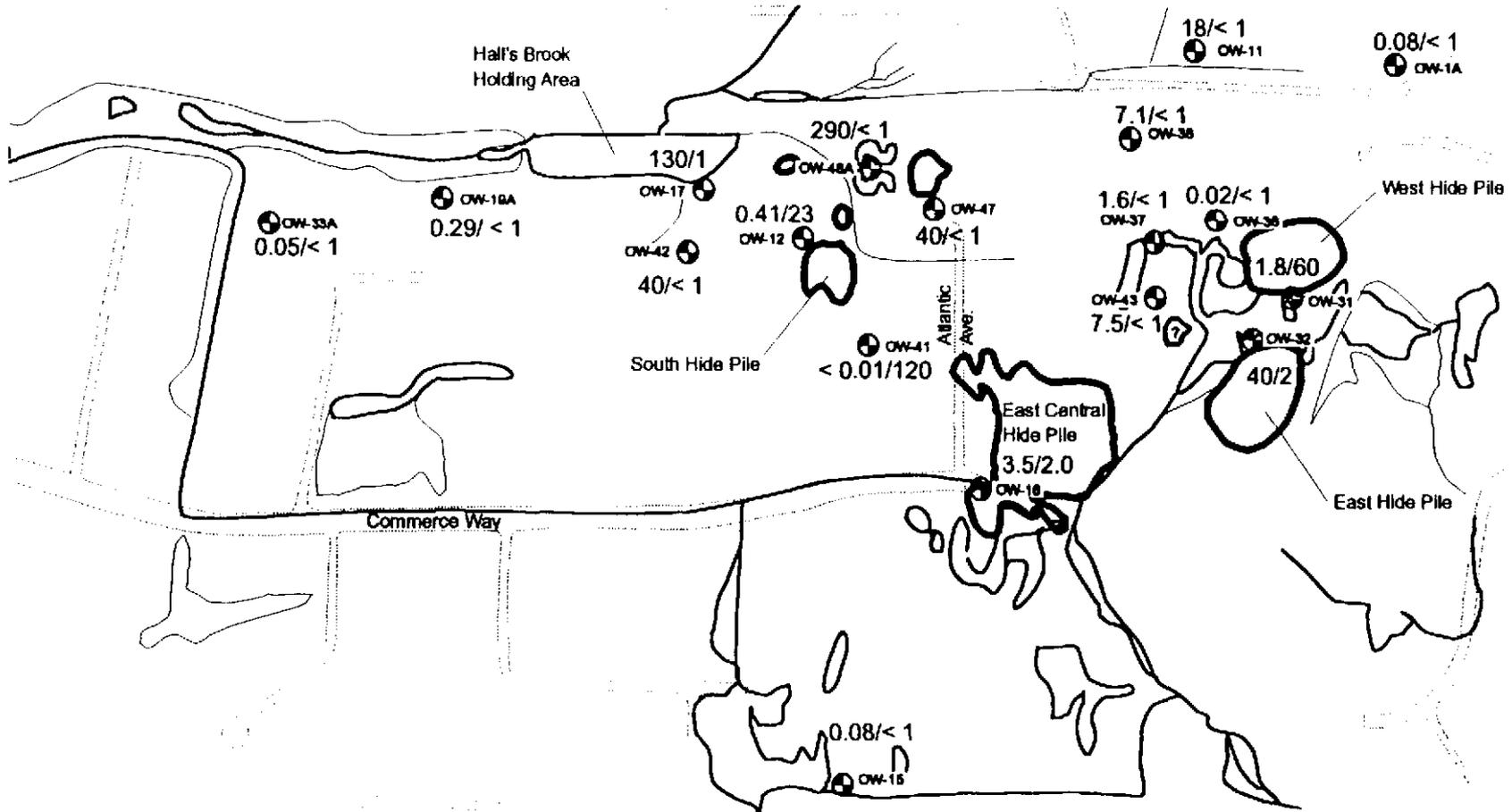


TITLE: BACTERIAL COUNT IN HBHA CORE 3	
HALL'S BROOK HOLDING AREA GEOCHEMICAL INVESTIGATION	FIGURE 30
<i>PTI Environmental Services</i>	



CROSS SECTION

TITLE:	
PHASE I GSIP RI INDUSTRI-PLEX SITE GEOCHEMICAL PARADIGM	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 31
<i>PTI Environmental Services</i>	



TITLE:
Fe(II) AND SULFIDE (mg/L)

METALS MOBILITY
 GEOCHEMICAL INVESTIGATION

FIGURE
 32

PTI Environmental Services

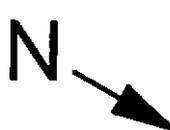
LEGEND

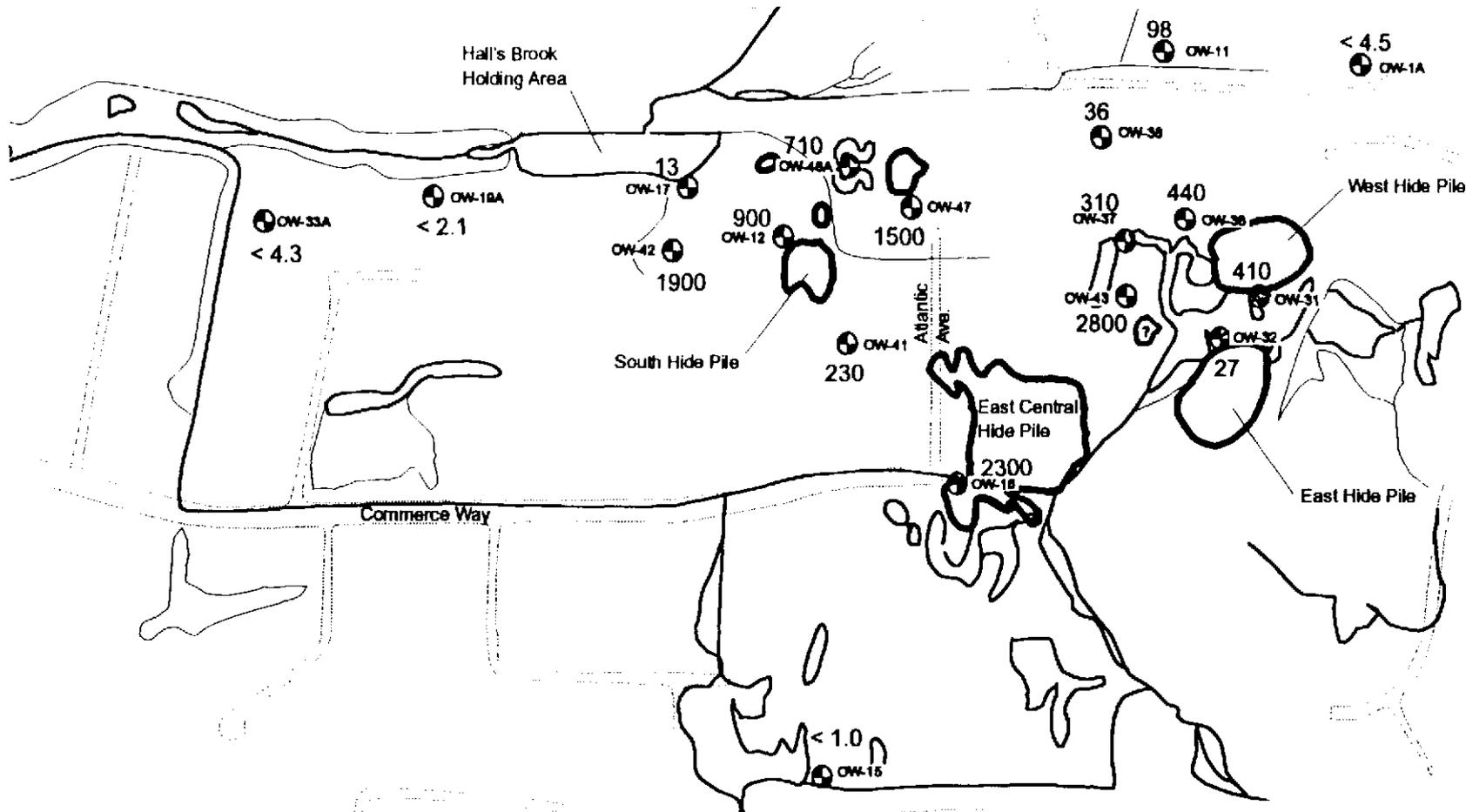
130/1 Fe(II) (mg/L)/Sulfide (mg/L)
 (Values rounded to significant figures)

OW-12 GROUND WATER SAMPLING WELL LOCATION AND DESIGNATION

Scale in Feet: 0, 800, 1600

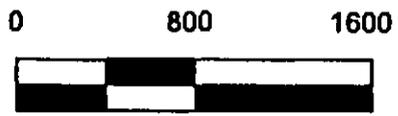
Samples collected 11/91





LEGEND

- 13 Arsenic ($\mu\text{g/L}$)
(Values rounded to significant figures)
- OW-12 GROUND WATER SAMPLING WELL LOCATION AND DESIGNATION

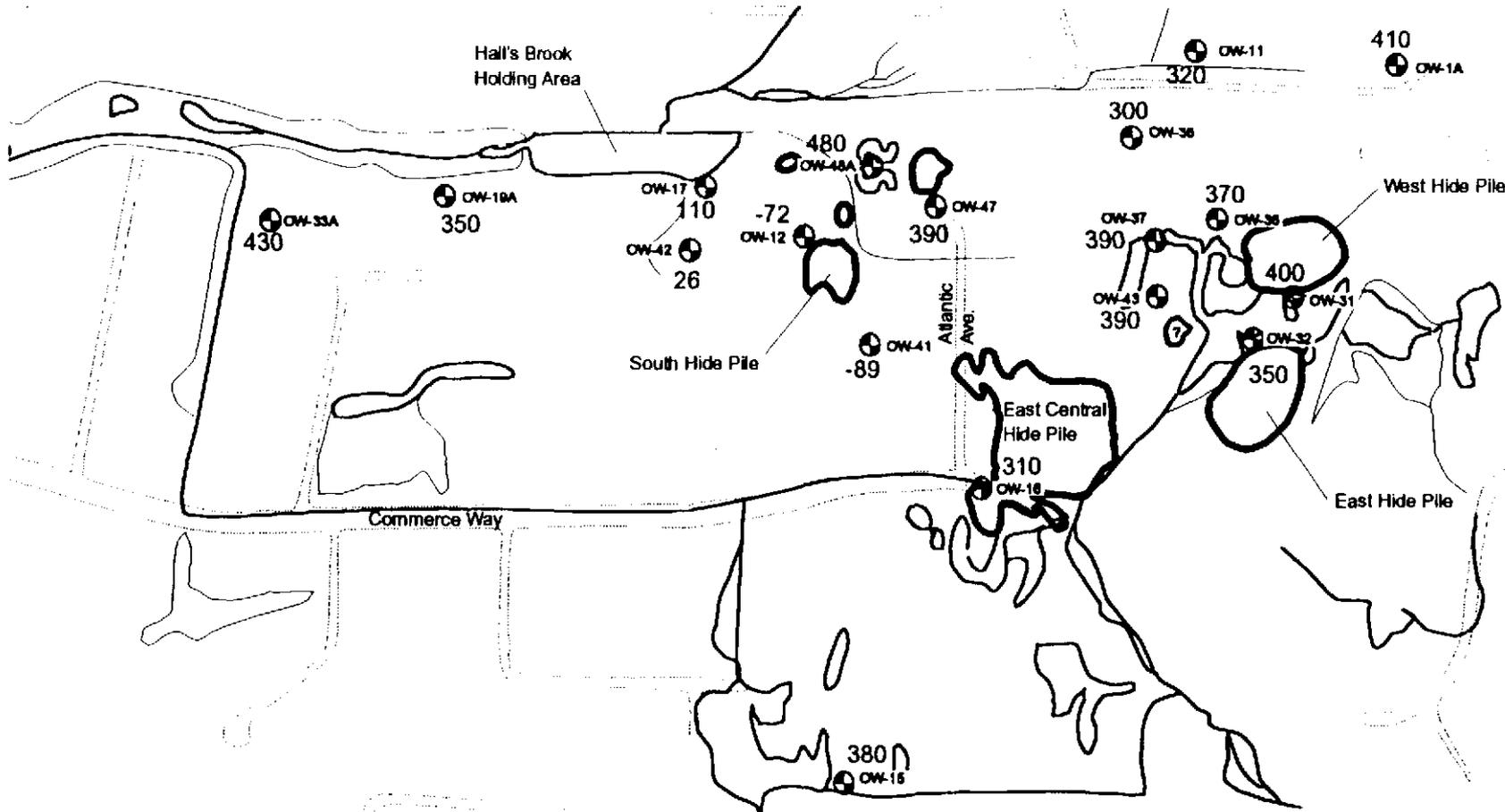


SCALE IN FEET



Samples collected 11/91

TITLE:	
Total Arsenic ($\mu\text{g/L}$)	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE
	33
PTI Environmental Services	



LEGEND

430 Measured Platinum Eh (mV)
(Values rounded to significant figures)

0 800 1600



SCALE IN FEET



OW-12  GROUND WATER SAMPLING WELL LOCATION AND DESIGNATION

Samples collected 11/91

TITLE:

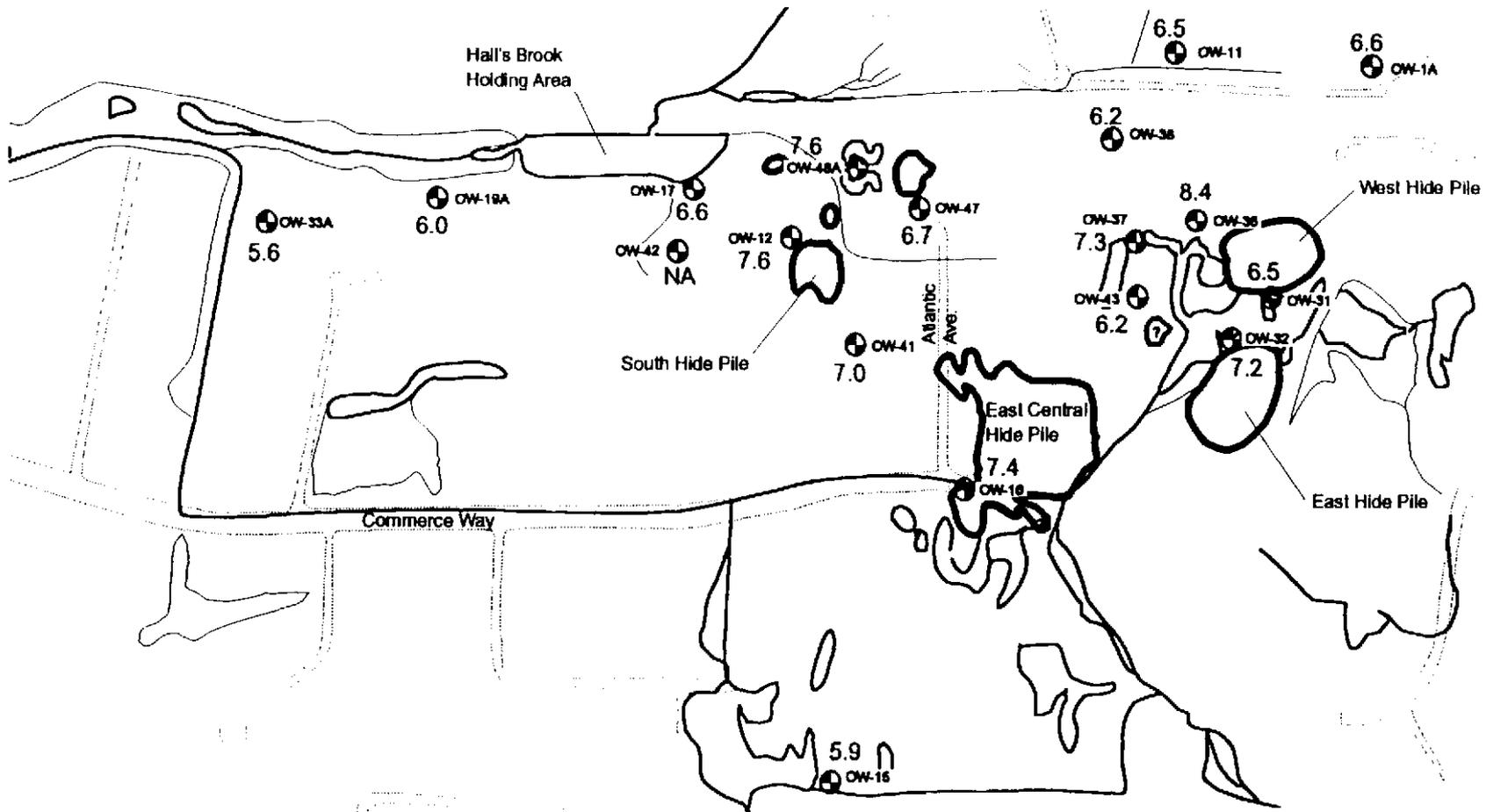
Measured Platinum Eh

METALS MOBILITY
GEOCHEMICAL INVESTIGATION

FIGURE

34

PTI Environmental Services

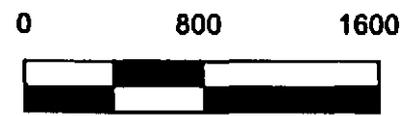


TITLE:	
Field Measured pH	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 35
PTI Environmental Services	

LEGEND

5.6 Field Measured pH (S. U.)
(Values rounded to significant figures)

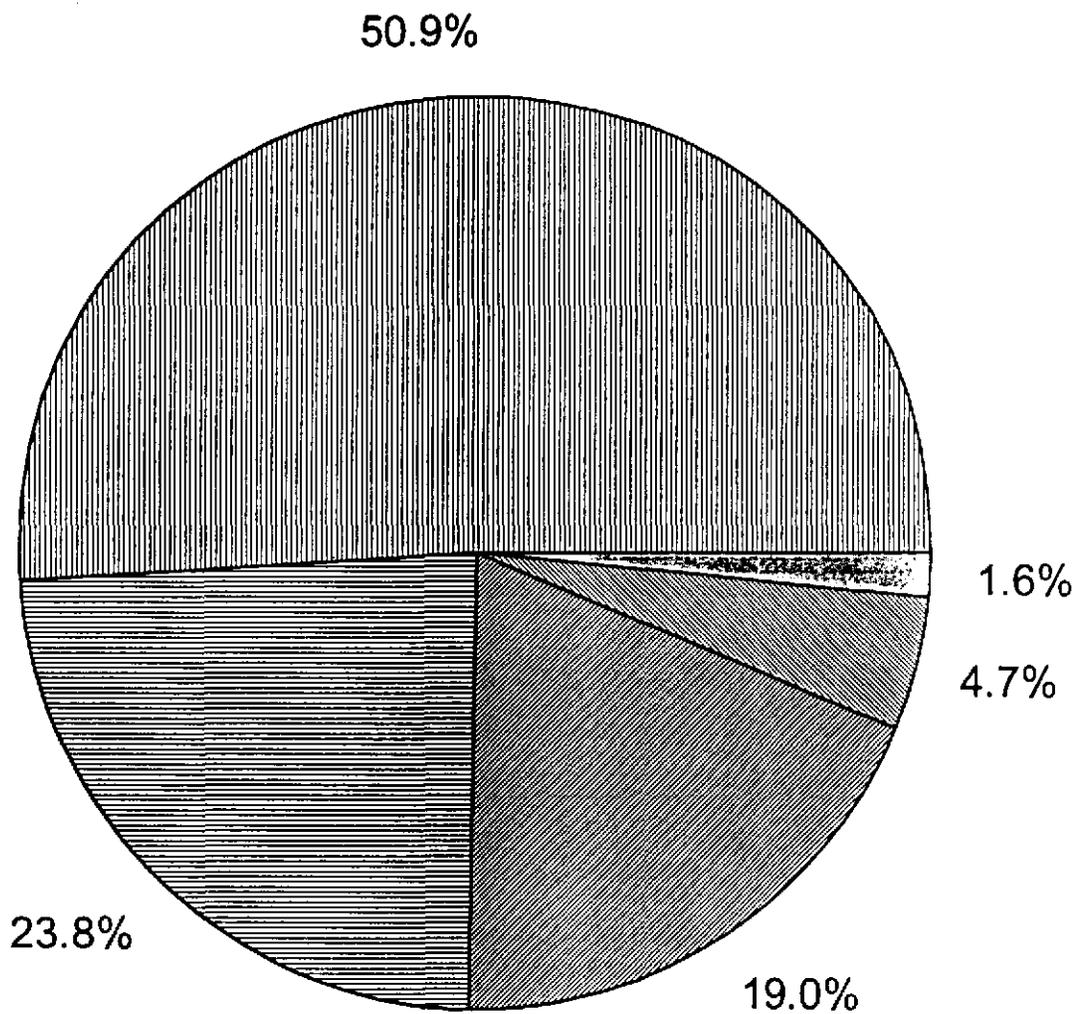
OW-12 GROUND WATER SAMPLING WELL LOCATION AND DESIGNATION



SCALE IN FEET

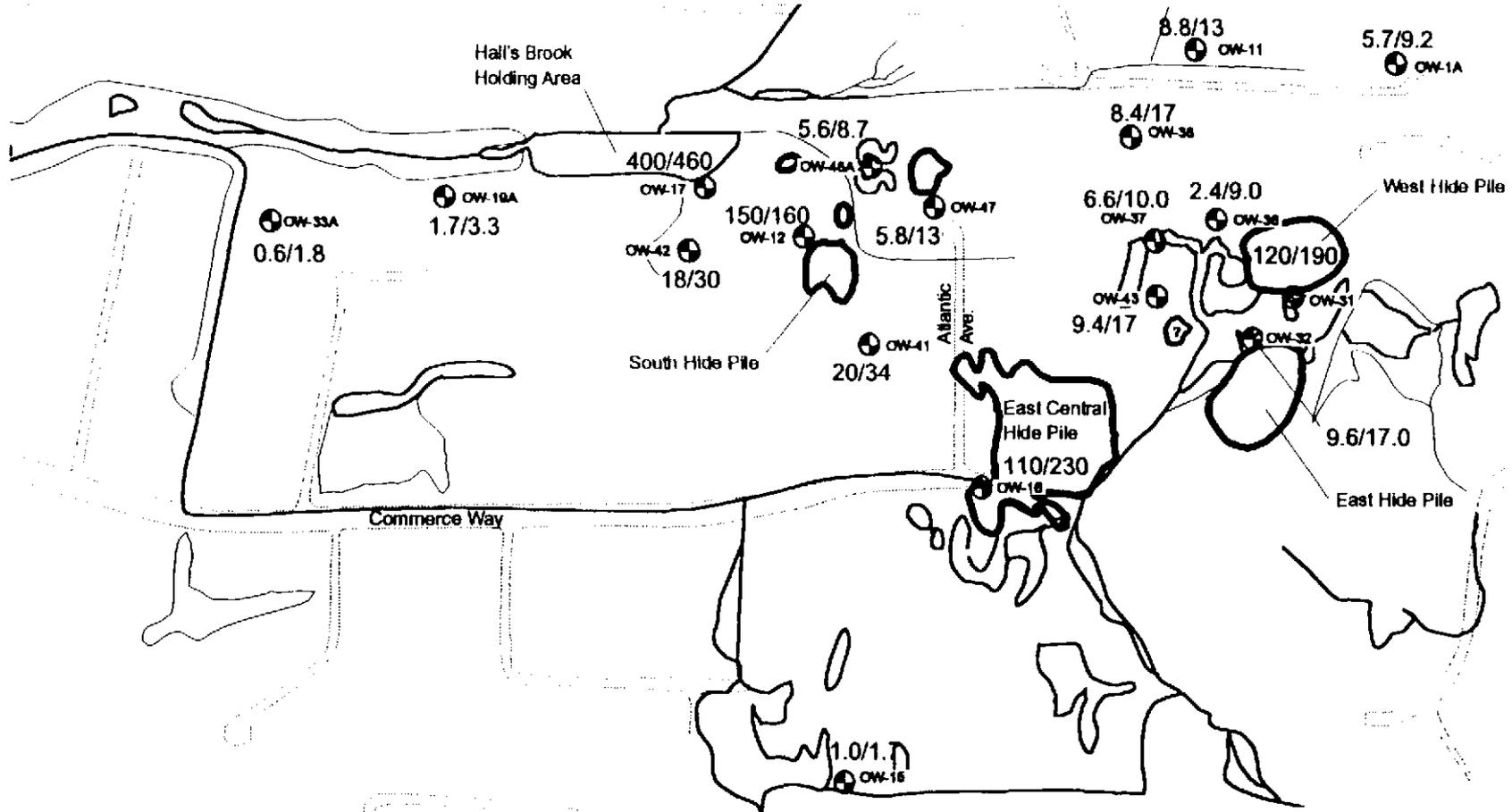


Samples collected 11/91



Hydrophilic Acid
 Hydrophobic Acid
 Hydrophilic Base
 Hydrophilic Neutral
 Hydrophobic Base

TITLE: AVERAGE DISTRIBUTION OF DISSOLVED ORGANIC CARBON	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 36
<i>PTI Environmental Services</i>	

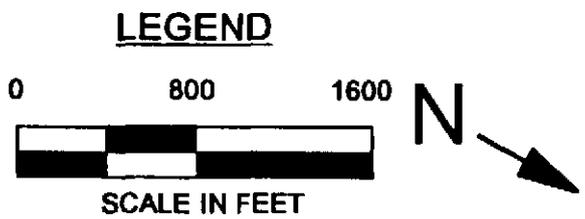


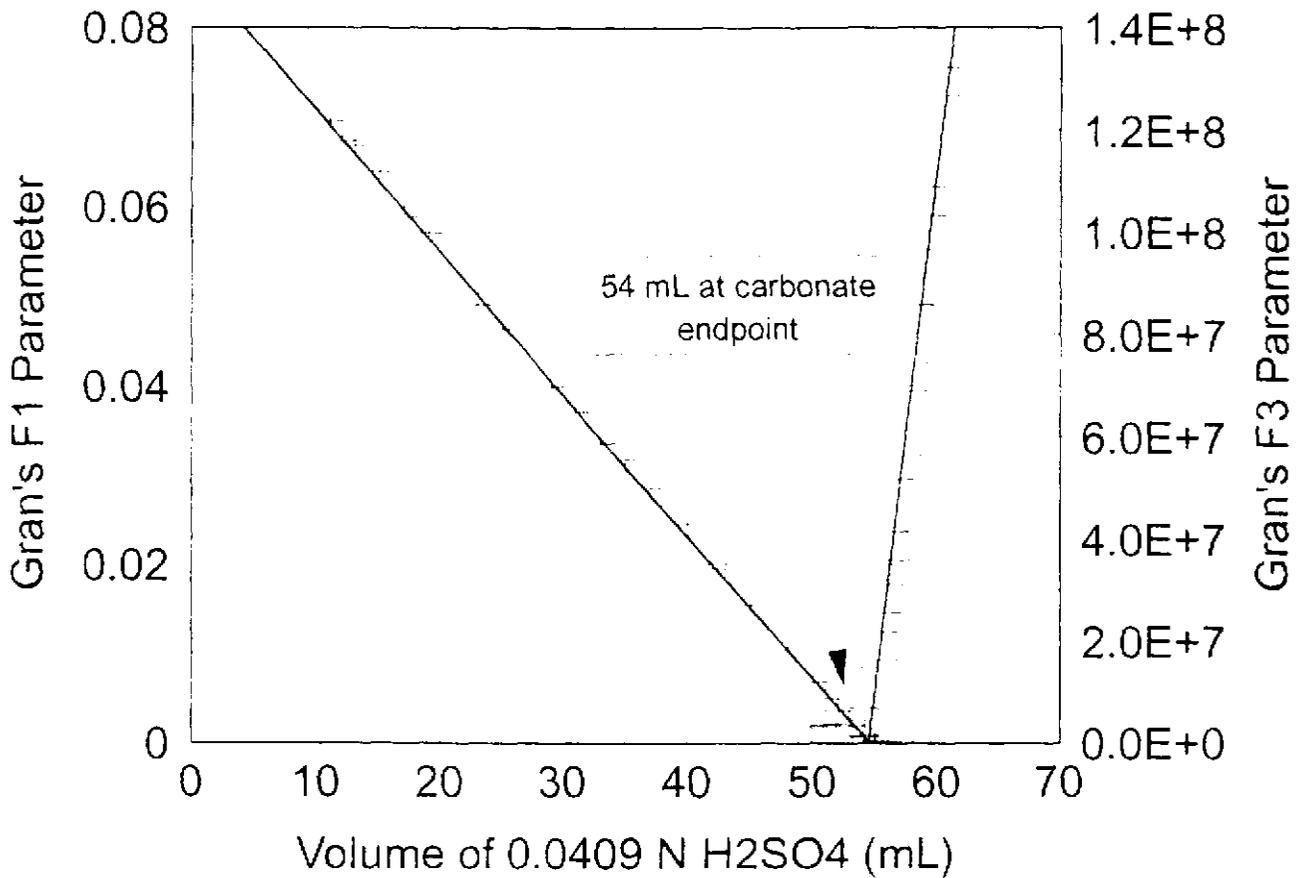
TITLE: Total Hydrophilic Acids/Total Dissolved Organic Carbon (mg/L)	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 37
PTI Environmental Services	

0.6/1.8 Total Hydrophilic Acids(mg/L)/Total Dissolved Organic Carbon(mg/L) (Values rounded to significant figures)

OW-12 GROUND WATER SAMPLING WELL LOCATION AND DESIGNATION

Samples collected 11/91





F1 Parameter F3 Parameter

TITLE

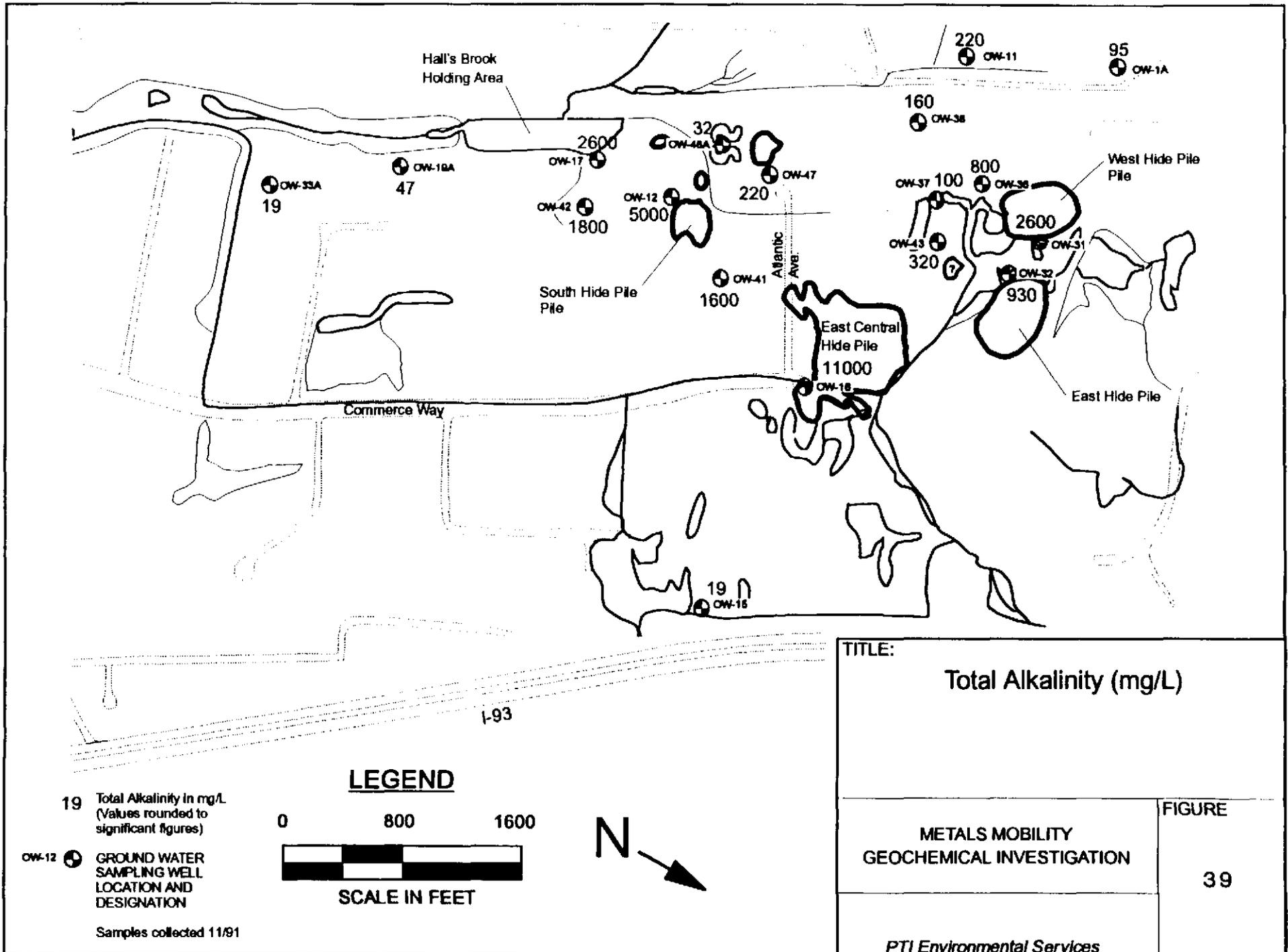
GRANS PLOT OF OW-16
 WATER TITRATION
 (F2 parameter, $Y_0 = \text{CO}_3^{2-}$ Equivalence)

METALS MOBILITY
 GEOCHEMICAL INVESTIGATION

FIGURE

38

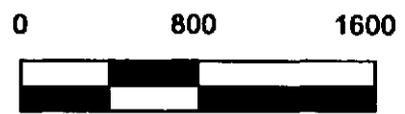
PTI Environmental Services



TITLE:	
Total Alkalinity (mg/L)	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE
	39
PTI Environmental Services	

19 Total Alkalinity in mg/L
(Values rounded to significant figures)

LEGEND

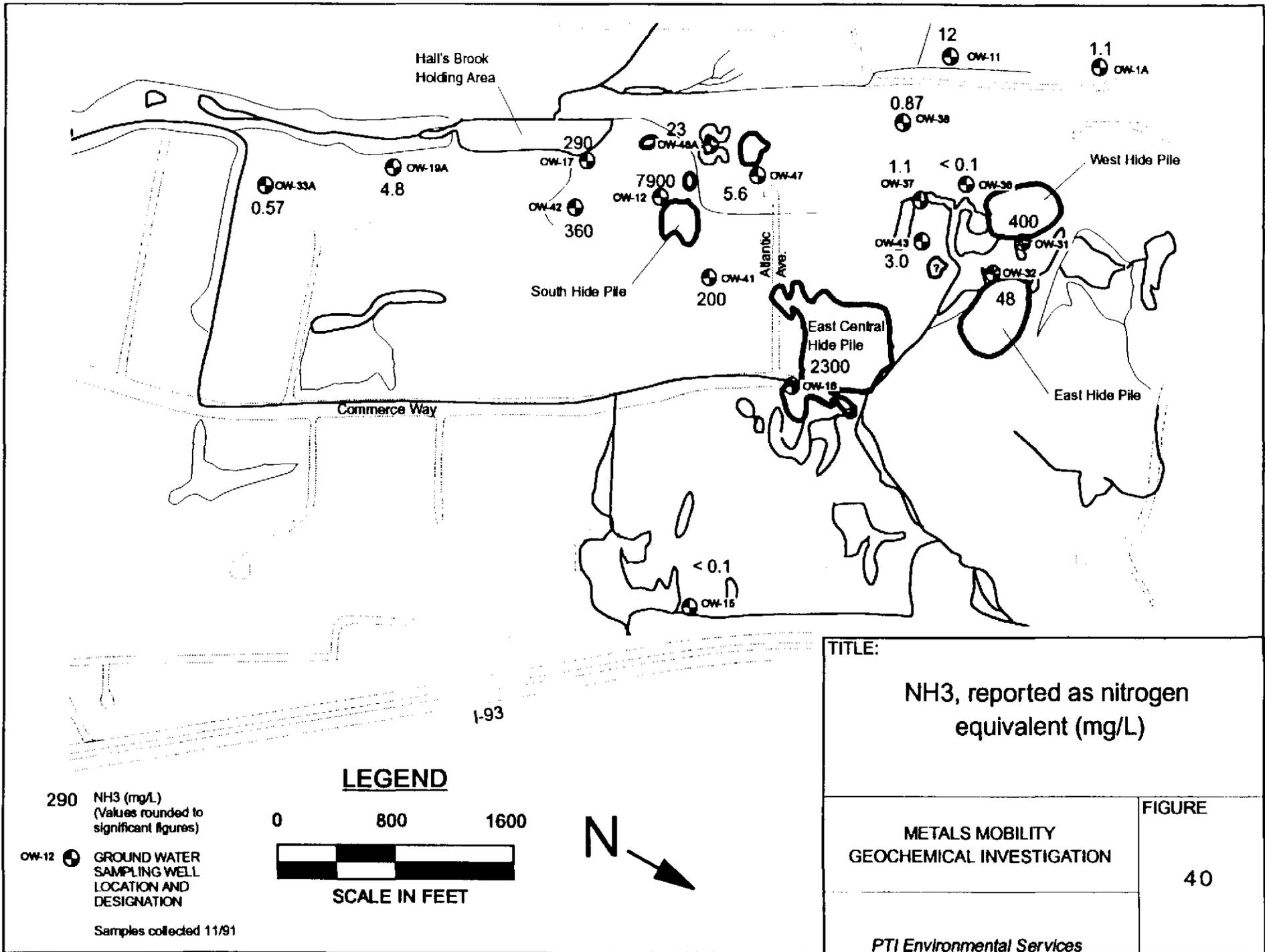


SCALE IN FEET



OW-12 GROUND WATER SAMPLING WELL LOCATION AND DESIGNATION

Samples collected 11/91



TITLE: NH3, reported as nitrogen equivalent (mg/L)	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 40
PTI Environmental Services	

290 NH3 (mg/L)
(Values rounded to significant figures)

OW-12  GROUND WATER SAMPLING WELL LOCATION AND DESIGNATION

Samples collected 11/91

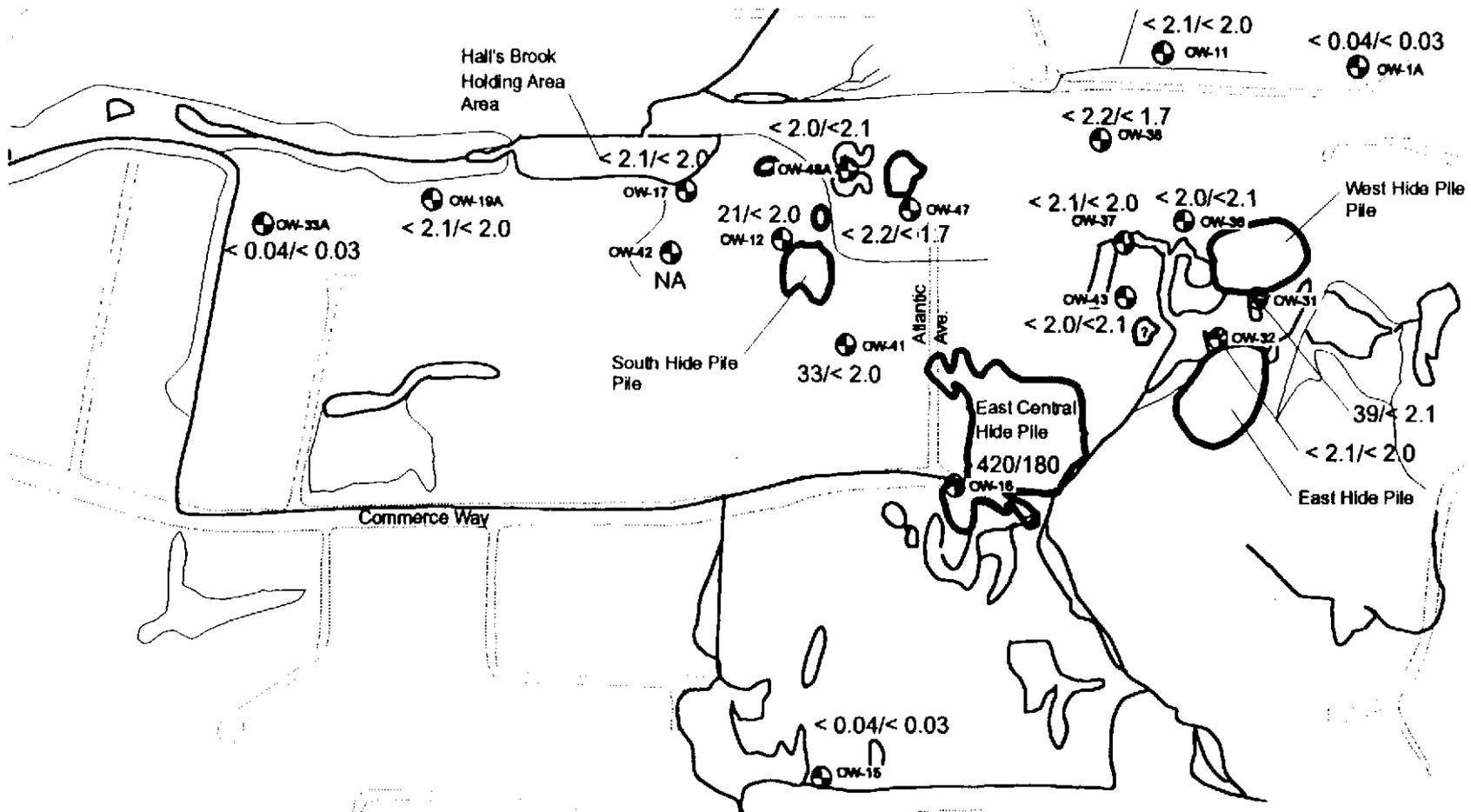
LEGEND

0 800 1600



SCALE IN FEET

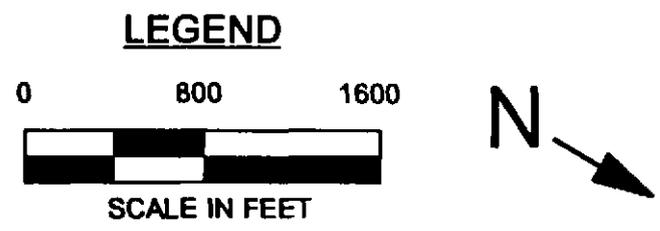




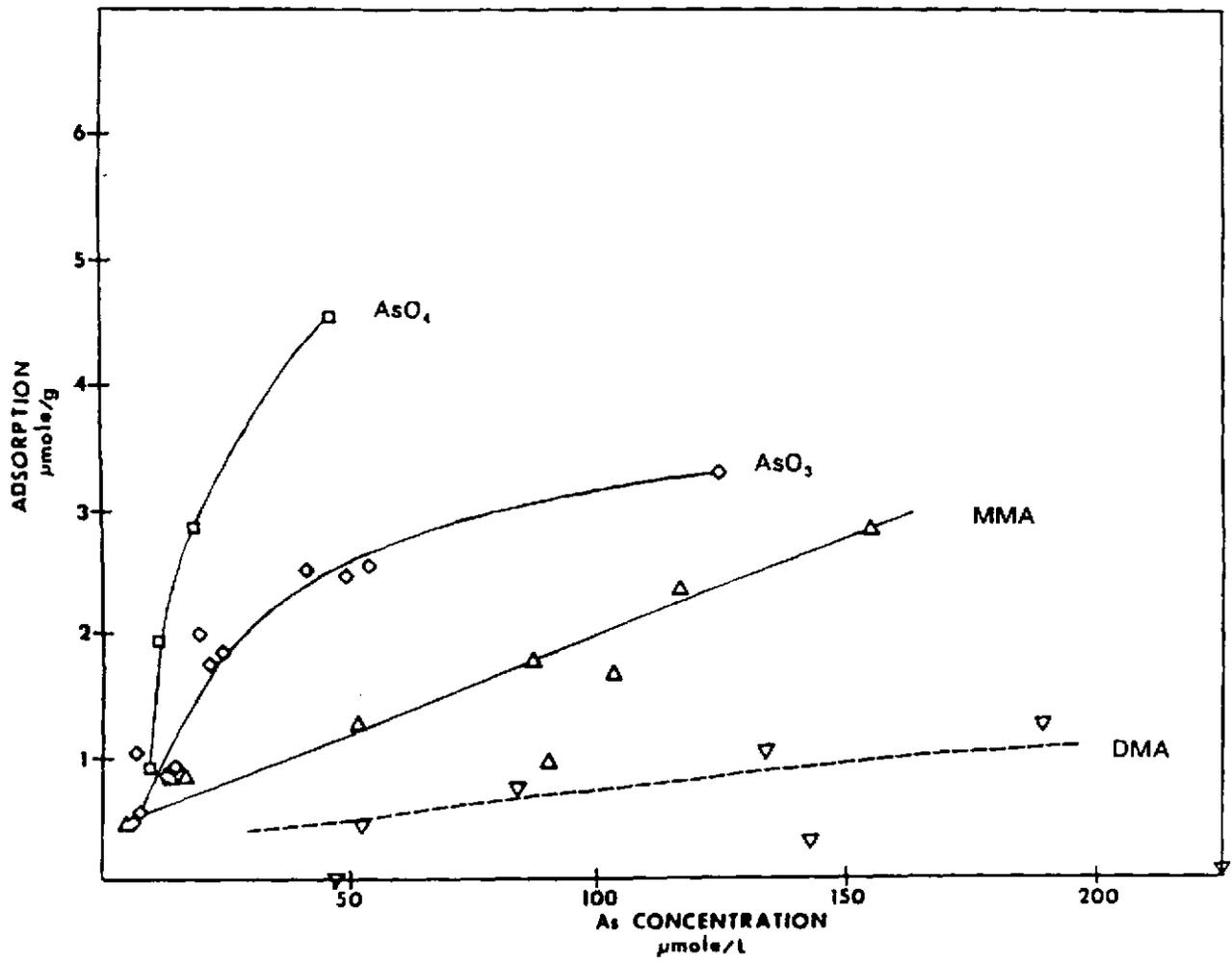
<math>< 2.1 / < 2.0</math> MMA($\mu\text{g/L}$)/DMA($\mu\text{g/L}$)
 (Values rounded to significant figures)

OW-12 GROUND WATER SAMPLING WELL LOCATION AND DESIGNATION

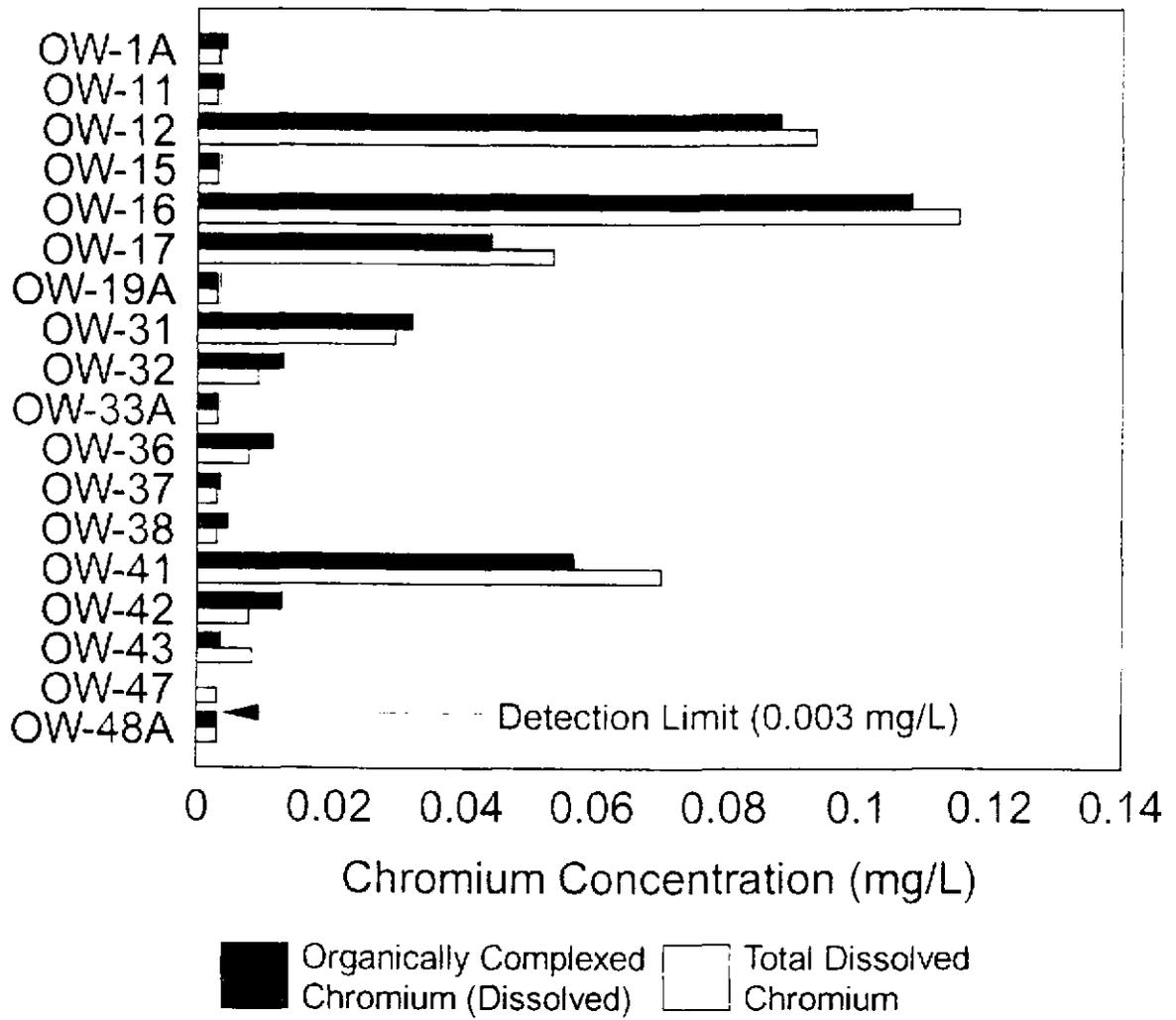
Samples collected 11/91



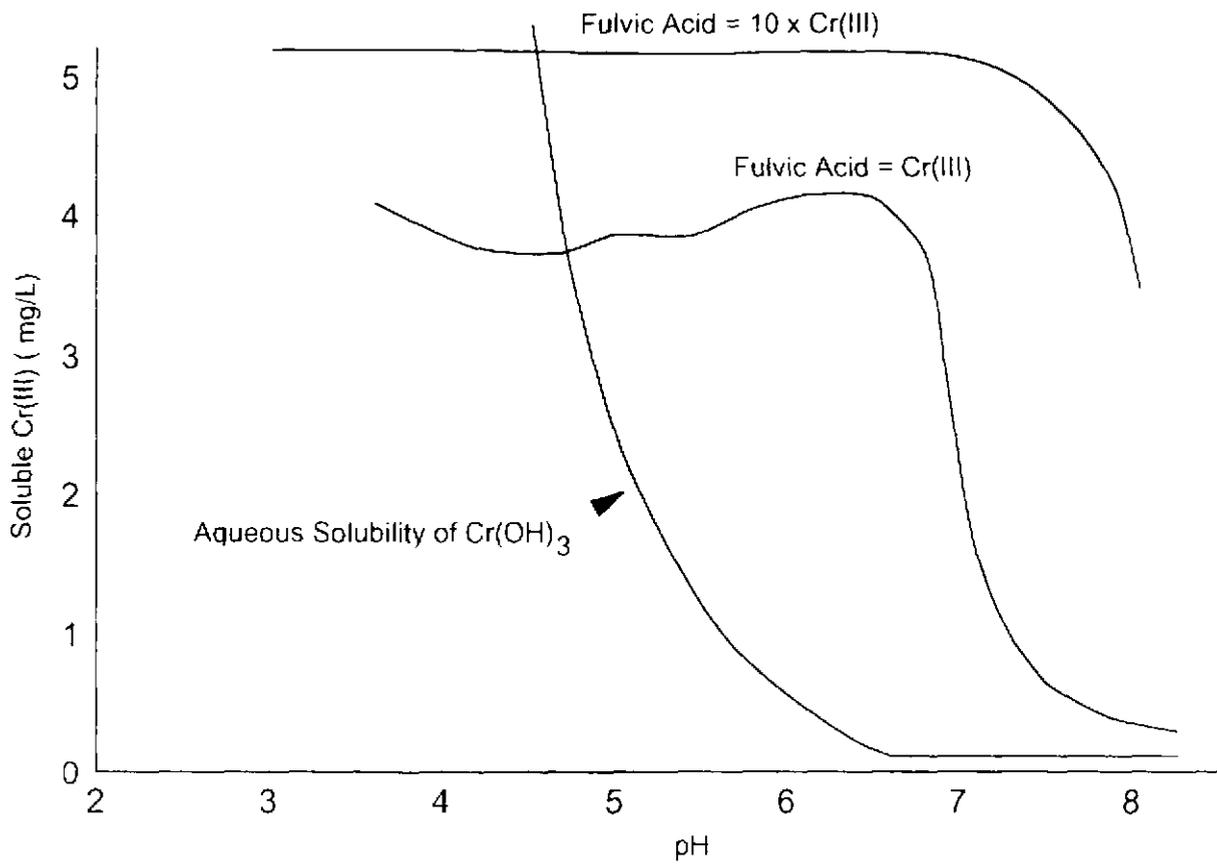
TITLE: Methylated Arsenic ($\mu\text{g/L}$). Values reported as MMA/DMA.	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 41
PTI Environmental Services	



TITLE: RELATIVE MOBILITY OF ARSENIC SPECIES (after Holm et al., 1980)	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 42
PTI Environmental Services	



TITLE: RELATIVE CONCENTRATIONS OF LABILE AND ORGANICALLY COMPLEXED Cr(III)	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 43
PTI Environmental Services	



TITLE

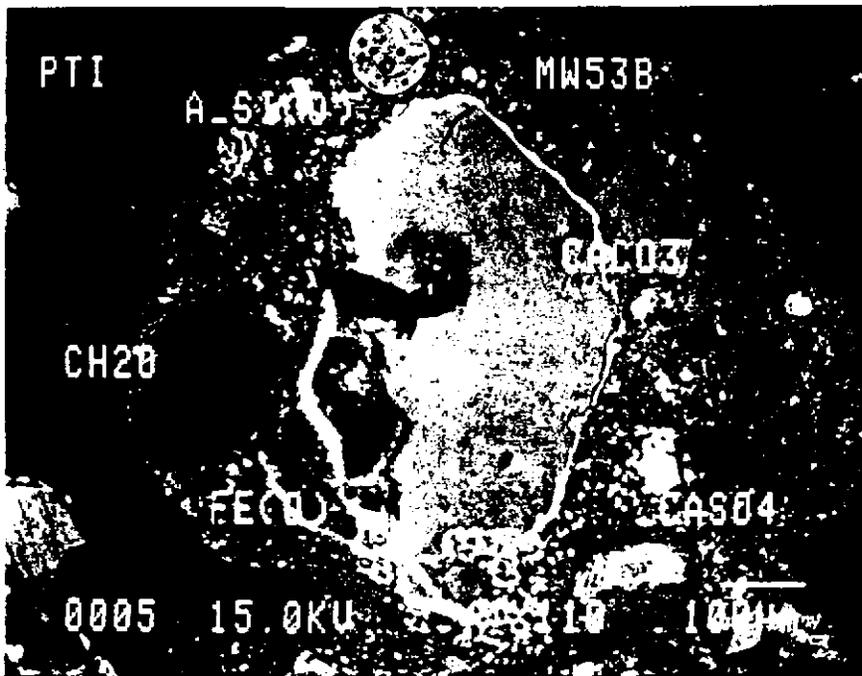
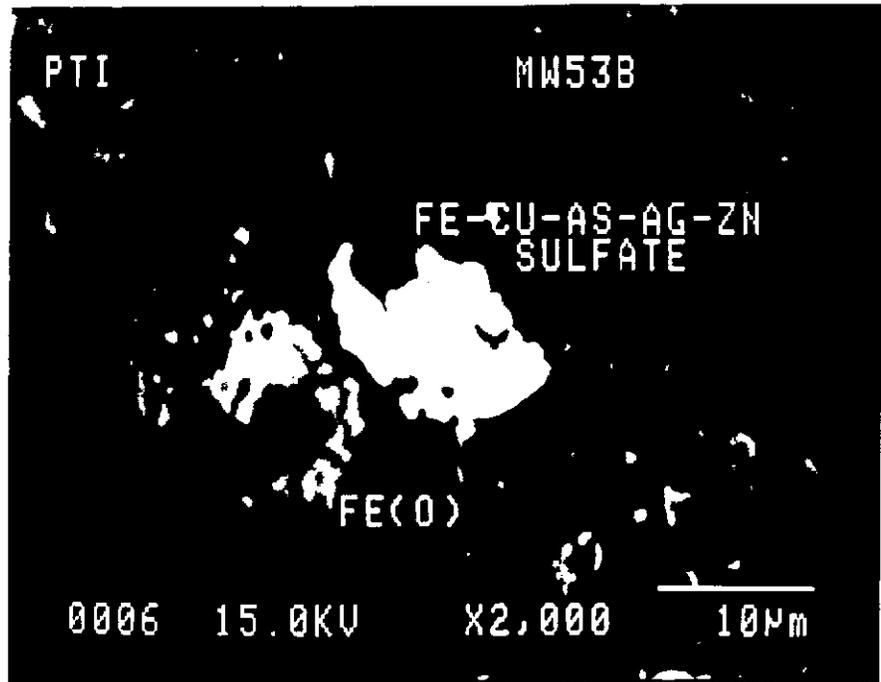
Soluble Cr(III) vs. pH in fulvic acid.
 Total Cr(III) added = 5.2 mg/L.
 After James and Bartlett, 1983.

METALS MOBILITY
 GEOCHEMICAL INVESTIGATION

FIGURE

44

PTI Environmental Services



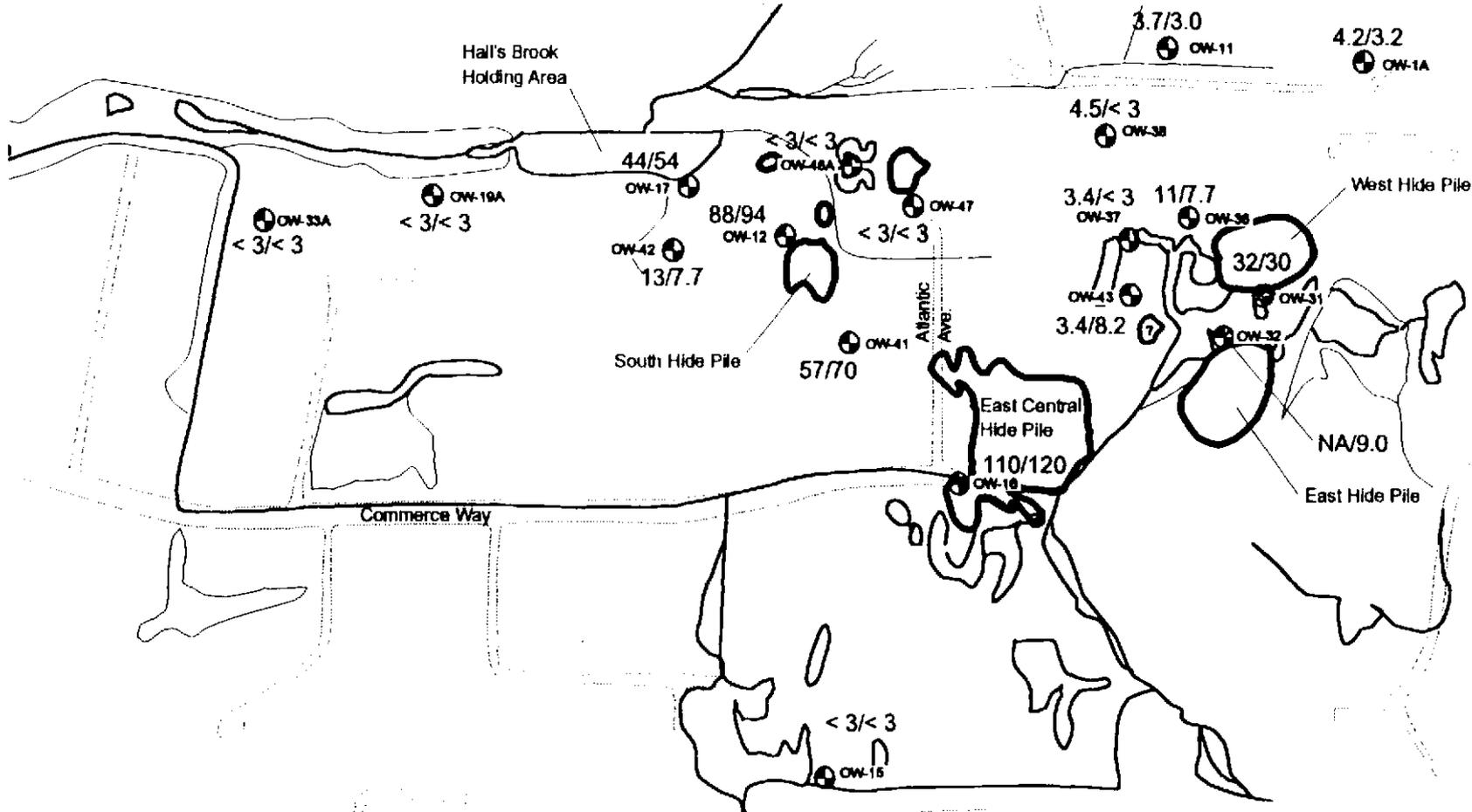
TITLE:

PHOTOMICROGRAPHS FROM
MICROPROBE SCANS OF OW-53B
AQUIFER MATERIAL

METALS MOBILITY
GEOCHEMICAL INVESTIGATION

FIGURE

45



TITLE: Organic Cr/Total Cr (µg/L)	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 46
PTI Environmental Services	

LEGEND

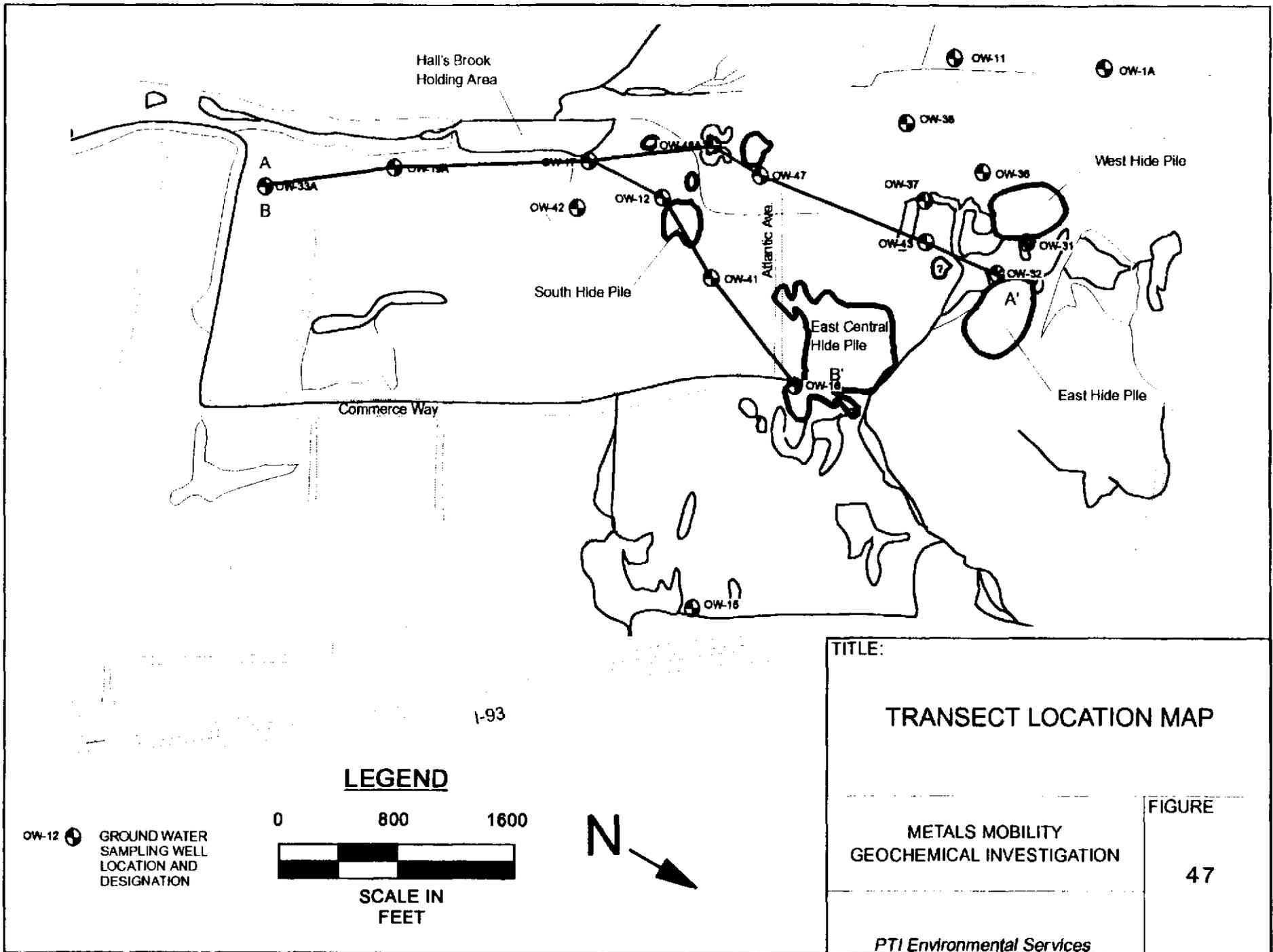
44/54 Organic Cr (µg/L)/Total Cr (µg/L)
(Values rounded to significant figures)

OW-12 GROUND WATER SAMPLING WELL LOCATION AND DESIGNATION

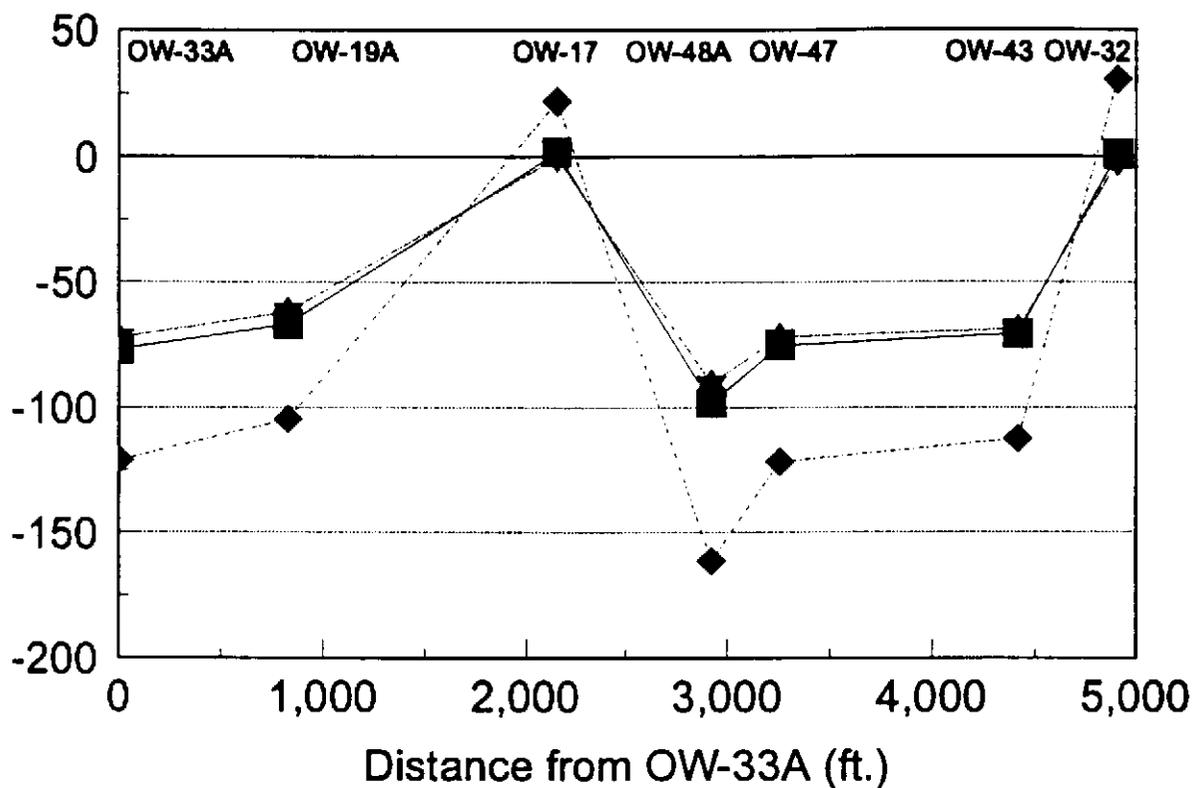
Samples collected 11/91

0 800 1600

SCALE IN FEET



Solubility Index



FeS Pyrite ZnS

—■— —◆— —★—

TITLE:

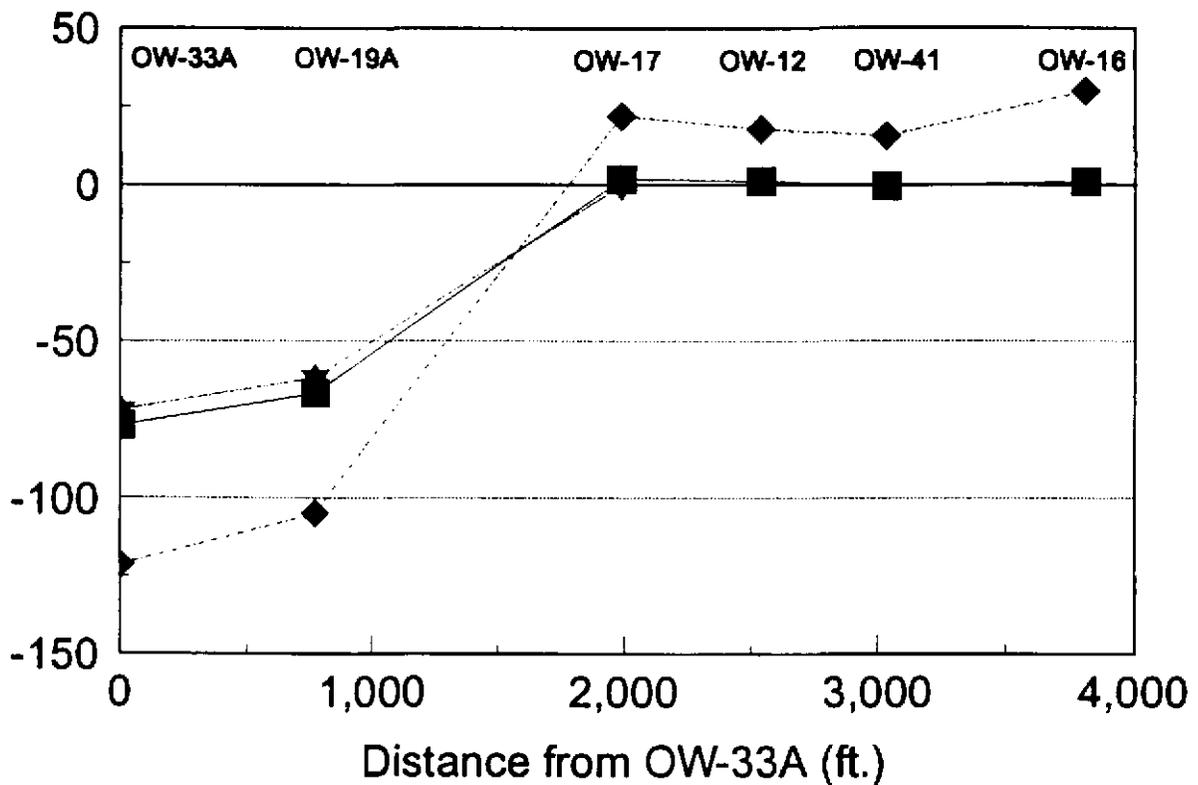
TRANSECT A
FeS, Pyrite, ZnS

METALS MOBILITY
GEOCHEMICAL INVESTIGATION

FIGURE

48

Solubility Index



FeS Pyrite ZnS

■ ◆ ★

TITLE:

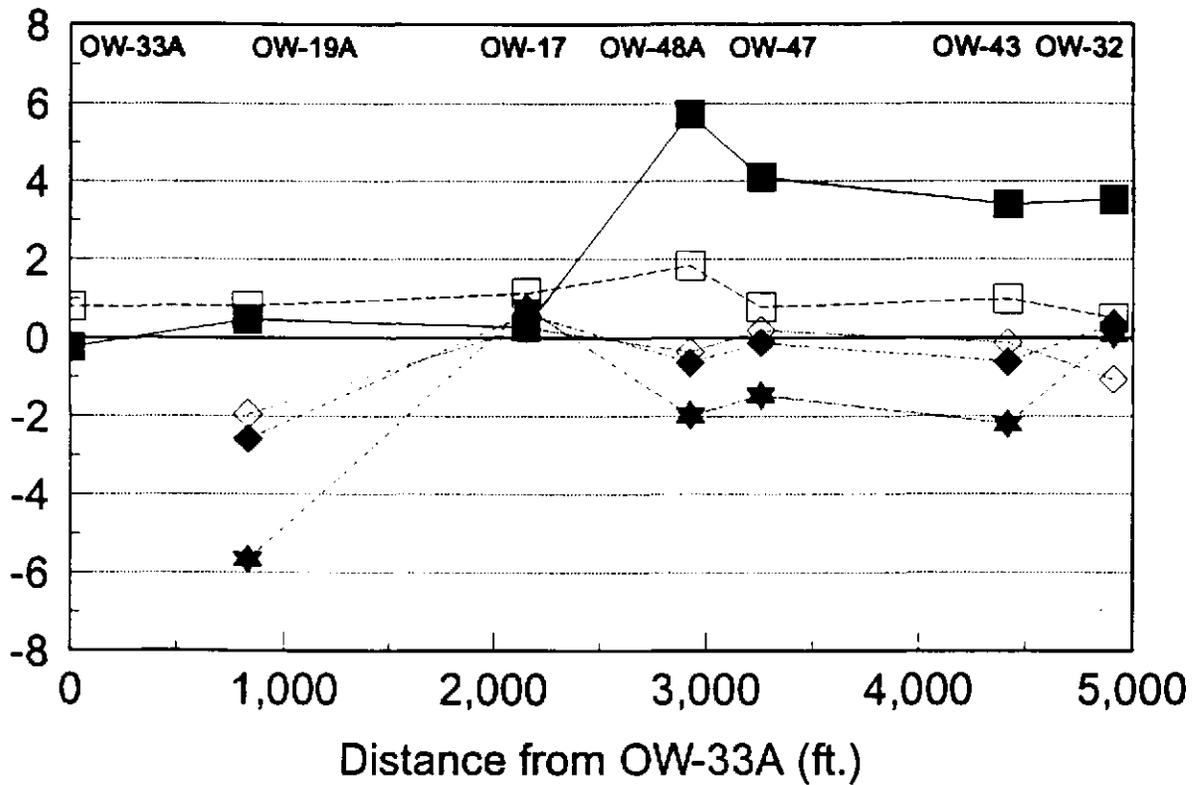
TRANSECT B
FeS, Pyrite, ZnS

METALS MOBILITY
GEOCHEMICAL INVESTIGATION

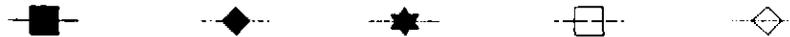
FIGURE

49

Solubility Index



Ferrihydrite Calcite Dolomite Gibbsite Gypsum



TITLE:

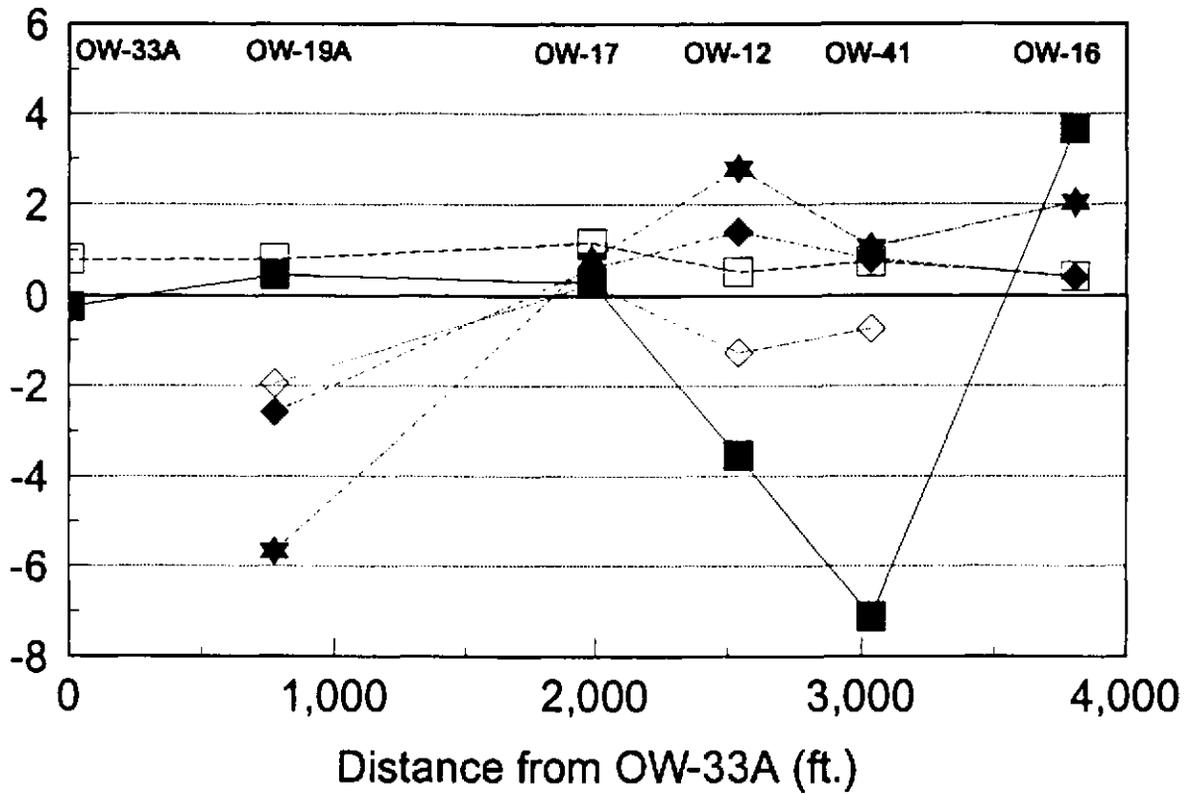
TRANSECT A
 Ferrihydrite, Calcite, Dolomite,
 Gibbsite, and Gypsum

METALS MOBILITY
 GEOCHEMICAL INVESTIGATION

FIGURE

50

Solubility Index

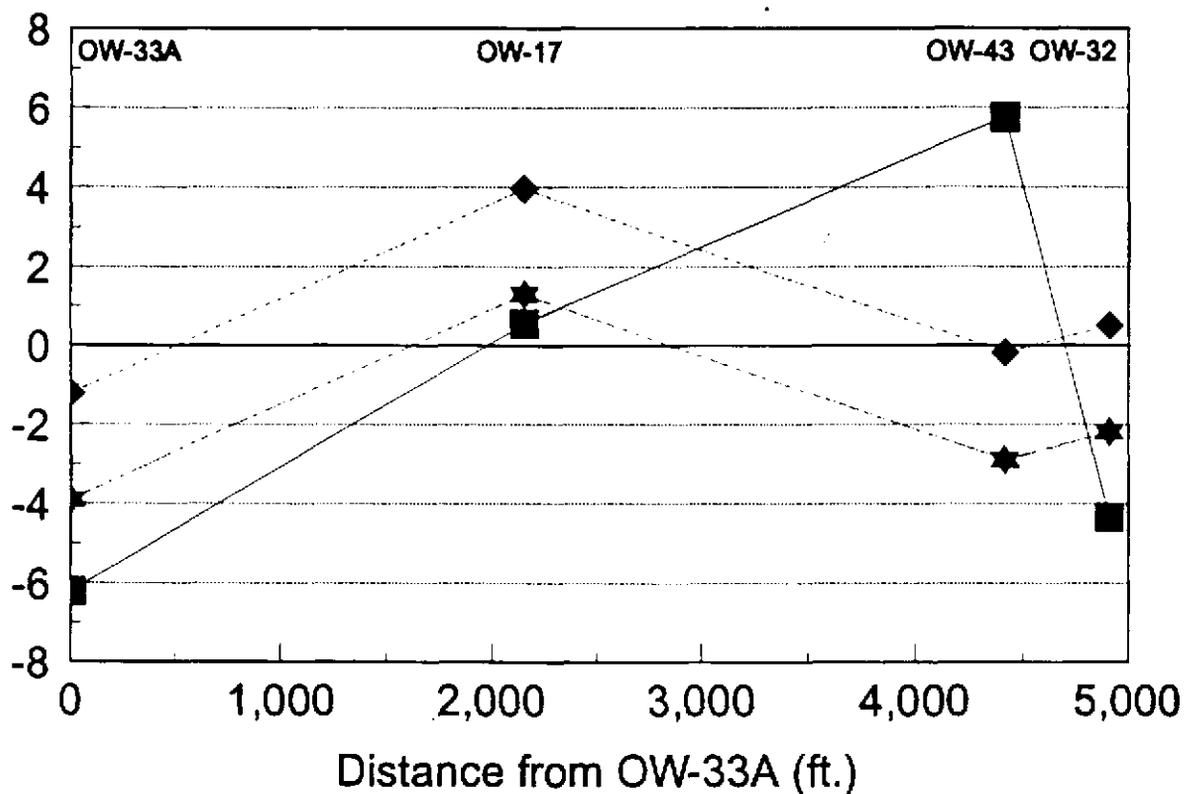


Ferrihydrite Calcite Dolomite Gibbsite Gypsum

■ ◆ ★ □ ◇

TITLE:	
TRANSECT B Ferrihydrite, Calcite, Dolomite, Gibbsite, and Gypsum	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 51
<i>PTI Environmental Services</i>	

Solubility Index



Fe(.75)Cr(.25)(OH)₃ Cr(OH)₃ (am) Cr(OH)₃



TITLE:

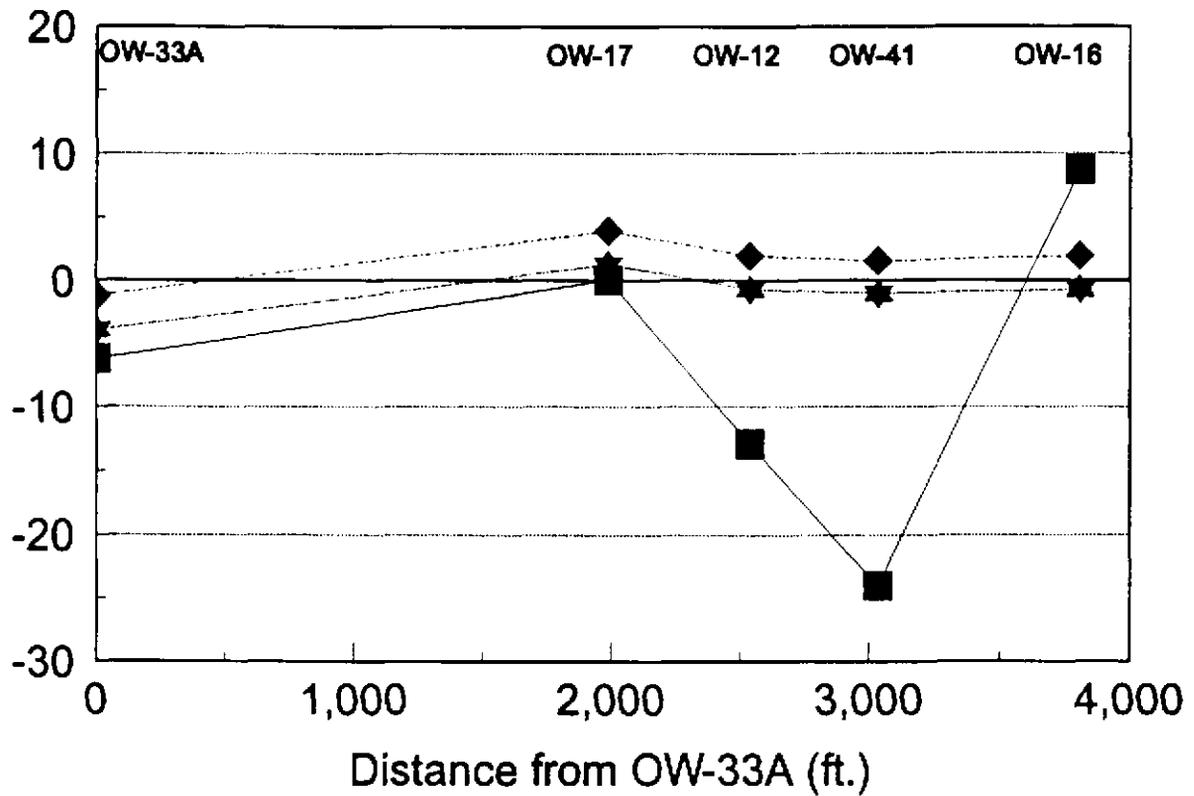
TRANSECT A
 Fe(.75)Cr(.25)(OH)₃, Cr(OH)₃ (am),
 Cr(OH)₃

METALS MOBILITY
 GEOCHEMICAL INVESTIGATION

FIGURE

52

Solubility Index



Fe(.75)Cr(.25)(OH)3 Cr(OH)3 (am) Cr(OH)3



TITLE:

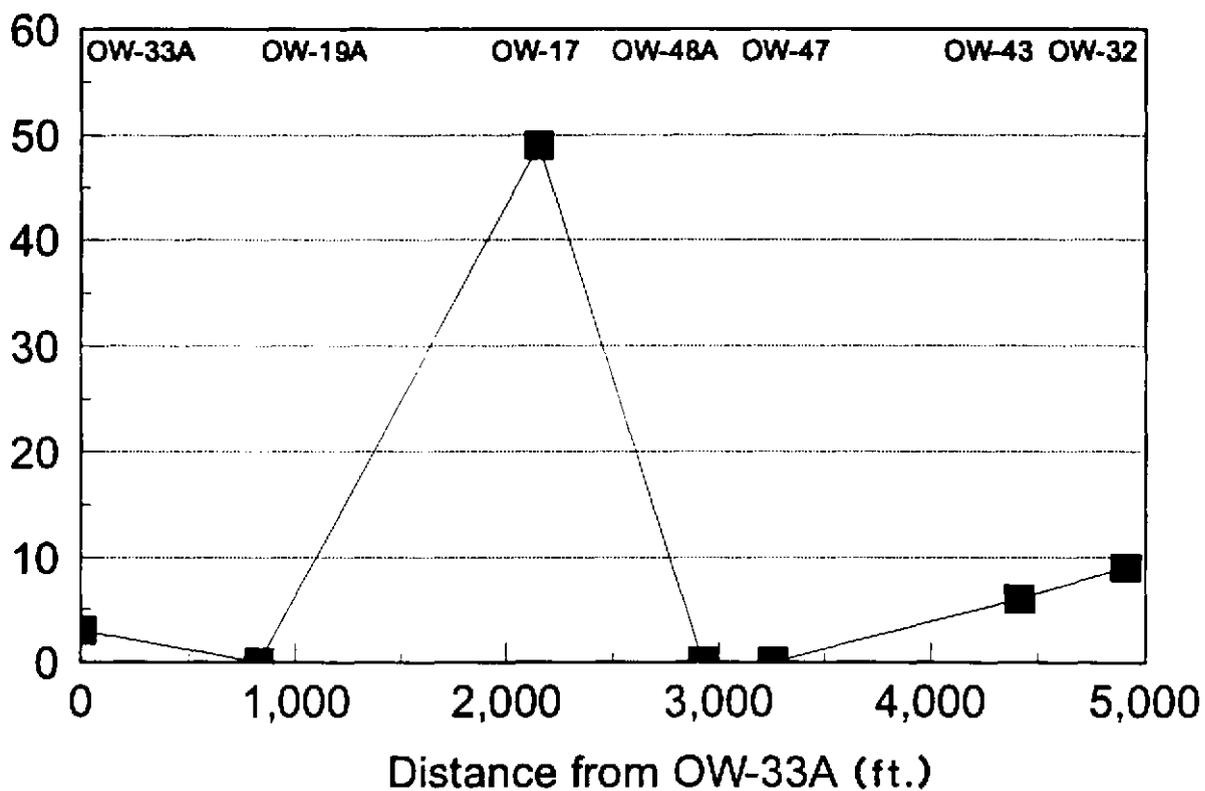
TRANSECT B
 Fe(.75)Cr(.25)(OH)3, Cr(OH)3 (am),
 Cr(OH)3

METALS MOBILITY
 GEOCHEMICAL INVESTIGATION

FIGURE

53

Metal Concentration ($\mu\text{g/L}$)



Chromium



TITLE:

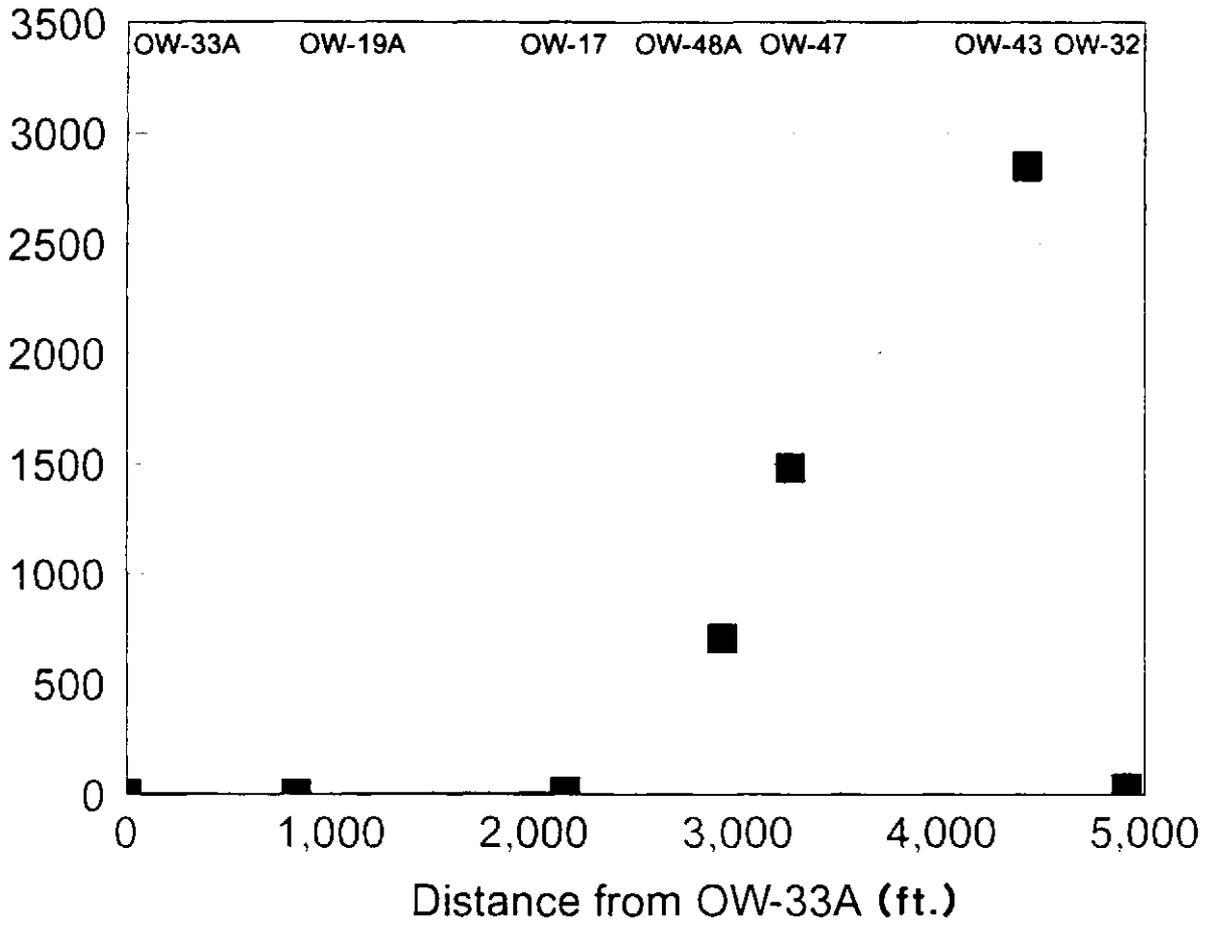
TRANSECT A
Chromium

METALS MOBILITY
GEOCHEMICAL INVESTIGATION

FIGURE

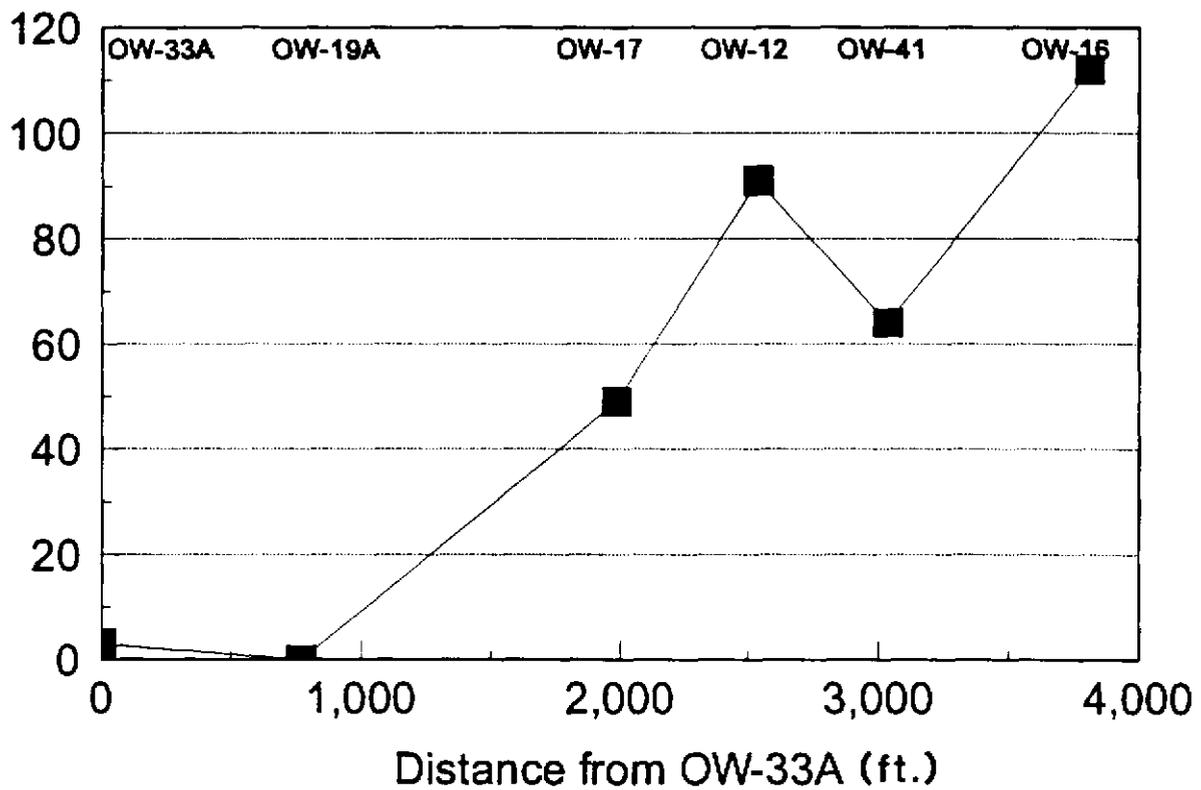
54

Arsenic Concentration ($\mu\text{g/L}$)



TITLE: TRANSECT A Arsenic	
METALS MOBILITY GEOCHEMICAL INVESTIGATION	FIGURE 55
<i>PTI Environmental Services</i>	

Metal Concentration ($\mu\text{g/L}$)



Chromium



TITLE:

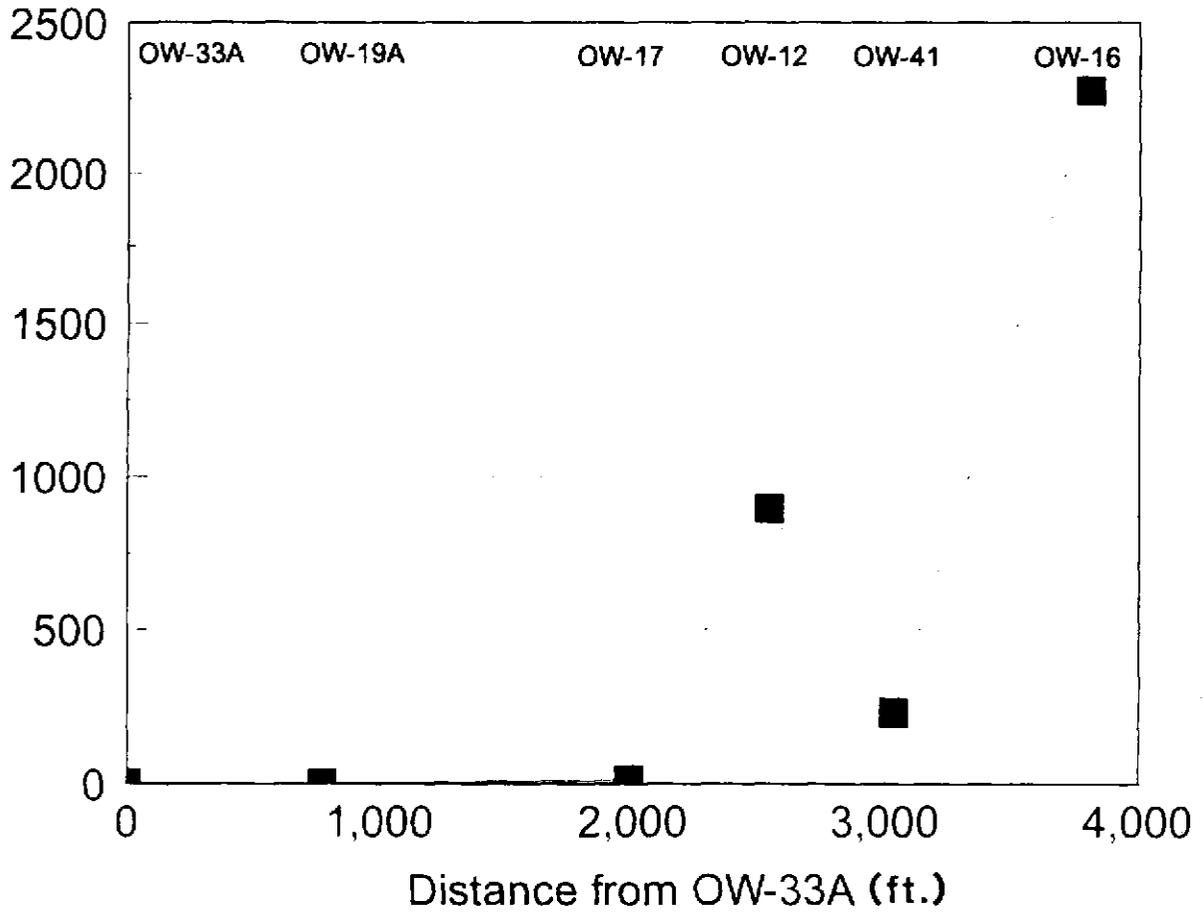
TRANSECT B
Chromium

METALS MOBILITY
GEOCHEMICAL INVESTIGATION

FIGURE

56

Arsenic Concentration ($\mu\text{g/L}$)



TITLE:

TRANSECT B
Arsenic

METALS MOBILITY
GEOCHEMICAL INVESTIGATION

FIGURE

57

CHARACTERISTICS	SYSTEM Eh (mV)	INDICATOR COUPLE	QUALITATIVE FACIES DESCRIPTION	EXAMPLE WELLS
0.1 < Fe(II) < 1 mg/L D. O. < 1 mg/L S ²⁻ Absent	+770 > Eh > +370	Fe(II)/Fe(III)	SLIGHTLY REDUCING	OW-1A, OW-15, OW-19A, OW-33
Fe(II) > 1 mg/L NH ₃ > 5 mg/L S ²⁻ Absent	+370 > Eh > -190	NO ₃ ⁻ /NH ₄ ⁺	MODERATELY REDUCING	OW-47, OW-48A, OW-11, OW-38, OW-43, OW-37
S ²⁻ > 1 mg/L NH ₃ > 5 mg/L	Eh < -190	SO ₄ ²⁻ /S ²⁻	VERY REDUCING	OW-41, OW-31, OW-12, OW-16, OW-32, OW-17

TITLE:

**GROUND WATER REDOX FACIES
AT THE INDUSTRI-PLEX SITE**

METALS MOBILITY
GEOCHEMICAL INVESTIGATION

FIGURE

58



EXPLANATION

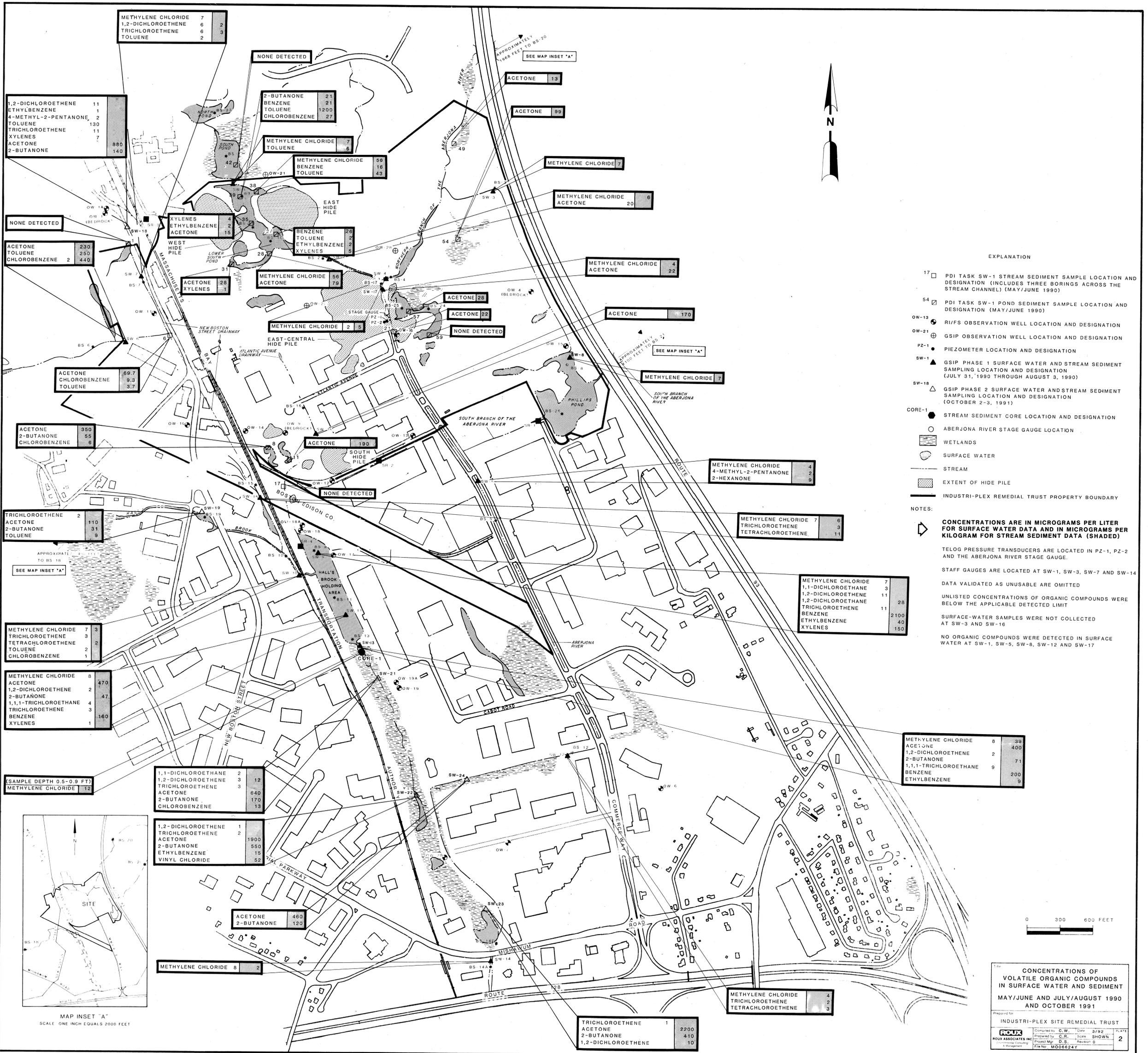
- OW-6 ● RI/FS OBSERVATION WELL LOCATION AND DESIGNATION
- OW-21 ⊕ GSP OBSERVATION WELL LOCATION AND DESIGNATION
- OW-29 ● POI OBSERVATION WELL LOCATION AND DESIGNATION
- SW-1 ▲ SURFACE WATER SAMPLING LOCATION AND DESIGNATION
- BS-1 * BIOLOGICAL SAMPLING LOCATION AND DESIGNATION
- SITE BOUNDARY
- ▨ AREA WHERE TOP OF GLACIAL TILL OR BEDROCK ELEVATION IS HIGHER THAN GROUND WATER ELEVATION LIMITS OF THE AQUIFER ACQUIRED FROM FIGURE 5 OF LUDLUM ASSOCIATES, INC. DECEMBER 1997 REPORT TITLED "AQUIFER PUMPING TEST, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS"
- ▨ POTENTIAL SOURCE AREA
- A — A' LINE OF HYDROGEOLOGIC CROSS SECTION



Title: OBSERVATION WELL LOCATIONS AND LINE OF HYDROGEOLOGIC CROSS SECTION

Prepared For: INDUSTRI-PLEX SITE REMEDIAL TRUST

ROUX ROUX ASSOCIATES, INC. Environmental Consulting & Management	Compl. by: J.E.	Date: 5/92	PLATE 1
	Prepared by: J.L.	Scale: SHOWN	
	Project Mgr: D.S.	Revision: 0	
	File No.: M1624A17		



- EXPLANATION**
- 17 □ PDI TASK SW-1 STREAM SEDIMENT SAMPLE LOCATION AND DESIGNATION (INCLUDES THREE BORINGS ACROSS THE STREAM CHANNEL) (MAY/JUNE 1990)
 - 54 □ PDI TASK SW-1 POND SEDIMENT SAMPLE LOCATION AND DESIGNATION (MAY/JUNE 1990)
 - OW-13 ○ RIFS OBSERVATION WELL LOCATION AND DESIGNATION
 - OW-21 ○ GISP OBSERVATION WELL LOCATION AND DESIGNATION
 - PZ-1 ● PIEZOMETER LOCATION AND DESIGNATION
 - SW-1 ▲ GISP PHASE 1 SURFACE WATER AND STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION (JULY 31, 1990 THROUGH AUGUST 3, 1990)
 - SW-18 △ GISP PHASE 2 SURFACE WATER AND STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION (OCTOBER 2-3, 1991)
 - CORE-1 ● STREAM SEDIMENT CORE LOCATION AND DESIGNATION
 - ABERJONA RIVER STAGE GAUGE LOCATION
 - ▨ WETLANDS
 - SURFACE WATER
 - STREAM
 - ▨ EXTENT OF HIDE PILE
 - ▬ INDUSTRI-PLEX REMEDIAL TRUST PROPERTY BOUNDARY

NOTES:

CONCENTRATIONS ARE IN MICROGRAMS PER LITER FOR SURFACE WATER DATA AND IN MICROGRAMS PER KILOGRAM FOR STREAM SEDIMENT DATA (SHADED)

TELOG PRESSURE TRANSDUCERS ARE LOCATED IN PZ-1, PZ-2 AND THE ABERJONA RIVER STAGE GAUGE.

STAFF GAUGES ARE LOCATED AT SW-1, SW-3, SW-7 AND SW-14

DATA VALIDATED AS UNUSABLE ARE OMITTED

UNLISTED CONCENTRATIONS OF ORGANIC COMPOUNDS WERE BELOW THE APPLICABLE DETECTED LIMIT

SURFACE-WATER SAMPLES WERE NOT COLLECTED AT SW-3 AND SW-16

NO ORGANIC COMPOUNDS WERE DETECTED IN SURFACE WATER AT SW-1, SW-5, SW-8, SW-12 AND SW-17



CONCENTRATIONS OF VOLATILE ORGANIC COMPOUNDS IN SURFACE WATER AND SEDIMENT MAY/JUNE AND JULY/AUGUST 1990 AND OCTOBER 1991

Prepared for:
INDUSTRI-PLEX SITE REMEDIAL TRUST

ROUX ASSOCIATES INC.
 Completed by: G.W. Date: 3/92 P. 4 of 4
 Prepared by: G.F. Scale: SHOWN
 Project Mgr: D.S. Revision: 0
 File No.: MO06624Y

1,2-DICHLOROETHENE	11
ETHYLBENZENE	1
4-METHYL-2-PENTANONE	2
TOLUENE	130
TRICHLOROETHENE	11
XYLENES	7
ACETONE	880
2-BUTANONE	140

METHYLENE CHLORIDE	7
1,2-DICHLOROETHENE	6
TRICHLOROETHENE	6
TOLUENE	2

NONE DETECTED

2-BUTANONE	21
BENZENE	21
TOLUENE	1200
CHLOROETHENE	27

ACETONE	13
---------	----

ACETONE	99
---------	----

METHYLENE CHLORIDE	7
TOLUENE	6

METHYLENE CHLORIDE	56
BENZENE	18
TOLUENE	43

METHYLENE CHLORIDE	7
METHYLENE CHLORIDE	20
ACETONE	6

ACETONE	230
TOLUENE	250
CHLOROETHENE	2
CHLOROETHENE	440

NONE DETECTED

XYLENES	4
ETHYLBENZENE	2
ACETONE	15

BENZENE	26
TOLUENE	2
ETHYLBENZENE	2
XYLENES	5

METHYLENE CHLORIDE	4
ACETONE	22

METHYLENE CHLORIDE	56
ACETONE	79

ACETONE	28
---------	----

ACETONE	22
---------	----

ACETONE	170
---------	-----

METHYLENE CHLORIDE	2
ACETONE	5

NONE DETECTED

METHYLENE CHLORIDE	7
--------------------	---

ACETONE	69.7
CHLOROETHENE	9.3
TOLUENE	3.7

ACETONE	350
2-BUTANONE	55
CHLOROETHENE	6

ACETONE	190
---------	-----

METHYLENE CHLORIDE	4
4-METHYL-2-PENTANONE	2
2-HEXANONE	9

NONE DETECTED

METHYLENE CHLORIDE	7
TRICHLOROETHENE	3
TETRACHLOROETHENE	11

TRICHLOROETHENE	2
ACETONE	110
2-BUTANONE	31
TOLUENE	9

METHYLENE CHLORIDE	7
1,1-DICHLOROETHANE	3
1,2-DICHLOROETHANE	11
1,2-DICHLOROETHANE	28
TRICHLOROETHANE	11
BENZENE	2100
ETHYLBENZENE	40
XYLENES	150

METHYLENE CHLORIDE	7
TRICHLOROETHENE	3
TETRACHLOROETHENE	2
TOLUENE	2
CHLOROETHENE	1

METHYLENE CHLORIDE	8
ACETONE	470
1,2-DICHLOROETHANE	2
2-BUTANONE	47
1,1,1-TRICHLOROETHANE	4
TRICHLOROETHENE	3
BENZENE	160
XYLENES	1

(SAMPLE DEPTH 0.5-0.9 FT)	
METHYLENE CHLORIDE	12

1,1-DICHLOROETHANE	2
1,2-DICHLOROETHANE	3
TRICHLOROETHENE	12
ACETONE	640
2-BUTANONE	170
CHLOROETHENE	13

1,2-DICHLOROETHENE	1
TRICHLOROETHENE	2
ACETONE	1900
2-BUTANONE	550
ETHYLBENZENE	15
VINYL CHLORIDE	52

ACETONE	460
2-BUTANONE	120

METHYLENE CHLORIDE	8
ACETONE	2

METHYLENE CHLORIDE	8
ACETONE	39
1,2-DICHLOROETHENE	2
2-BUTANONE	400
1,1,1-TRICHLOROETHANE	9
BENZENE	71
ETHYLBENZENE	200
XYLENES	9

TRICHLOROETHENE	1
ACETONE	2200
2-BUTANONE	410
1,2-DICHLOROETHENE	10

METHYLENE CHLORIDE	4
TRICHLOROETHENE	2
TETRACHLOROETHENE	3

MAP INSET "A"
SCALE ONE INCH EQUALS 2000 FEET



EXPLANATION

- OW-6 ● RI/FS OBSERVATION WELL LOCATION AND DESIGNATION
- OW-21 ⊕ GSP OBSERVATION WELL LOCATION AND DESIGNATION
- OW-29 ● PDI OBSERVATION WELL LOCATION AND DESIGNATION
- SW-1 ▲ SURFACE-WATER SAMPLING LOCATION AND DESIGNATION
- BS-1 * BIOLOGICAL SAMPLING LOCATION AND DESIGNATION
- SITE BOUNDARY
- ▨ AREA WHERE TOP OF GLACIAL TILL OR BEDROCK ELEVATION IS HIGHER THAN GROUND-WATER ELEVATION (LIMITS OF THE AQUIFER) ADAPTED FROM FIGURE 5 OF GOLDER ASSOCIATES, INC. DECEMBER 1991 REPORT TITLED "AQUIFER PUMPING TEST, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS"
- ▨ POTENTIAL SOURCE AREA OF ARSENIC
- 100— LINE OF EQUAL DISSOLVED ARSENIC CONCENTRATION, ug/L
- ND NOT DETECTED
- 20— LINE OF EQUAL ELEVATION OF BOTTOM OF AQUIFER ADAPTED FROM FIGURE 5 OF GOLDER ASSOCIATES, INC. DECEMBER 1991 REPORT TITLED "AQUIFER PUMPING TEST, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS"
- APPROXIMATE EXTENT OF ARSENIC PLUME

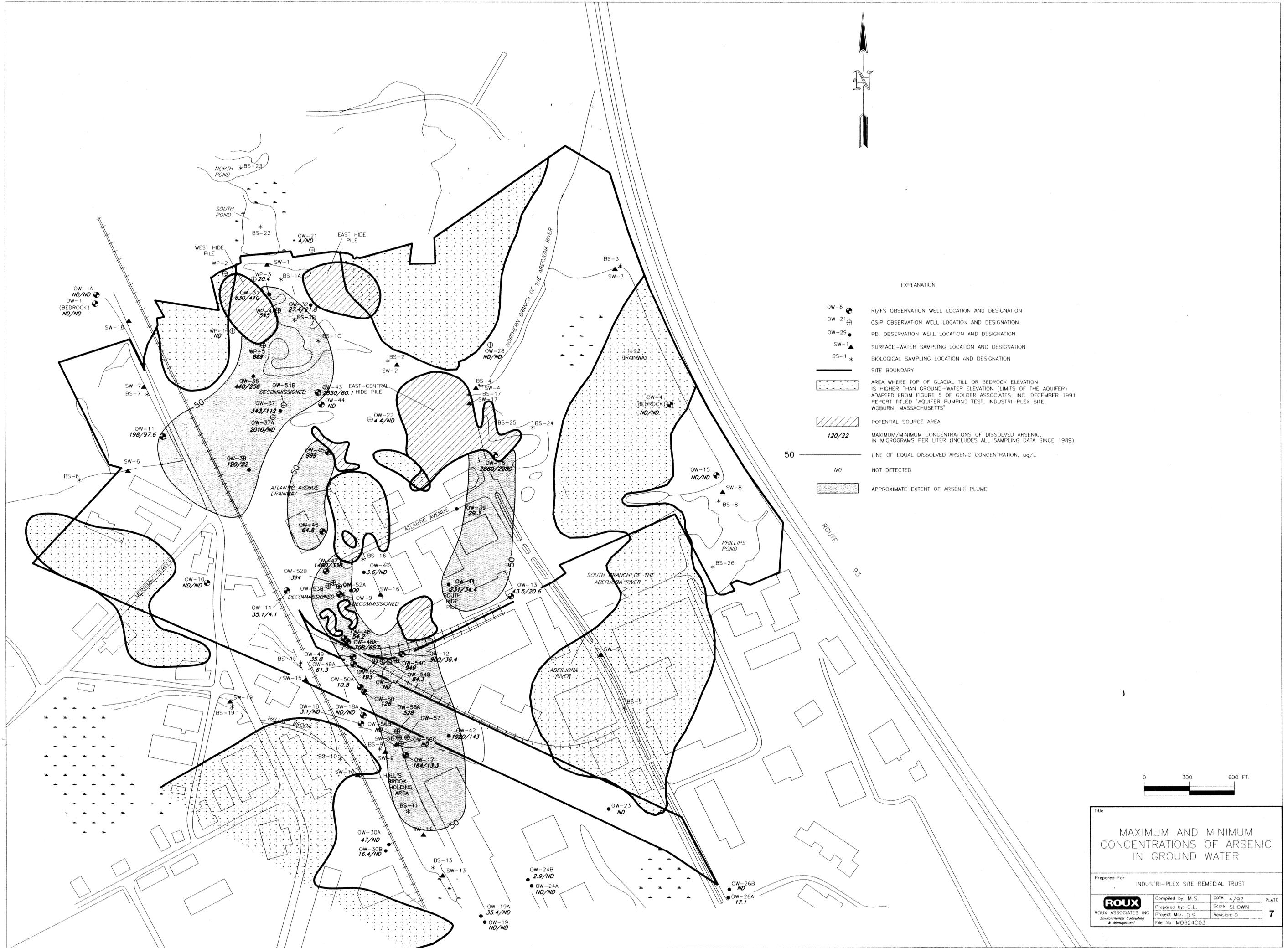


Title: ELEVATION OF BOTTOM OF UNCONSOLIDATED AQUIFER			
Prepared For: INDUSTRI-PLEX SITE REMEDIAL TRUST			
ROUX ROUX ASSOCIATES, INC. Environmental Consulting & Management	Compiled by: M.S.	Date: 4/92	PLATE
	Prepared by: C.L.	Scale: SHOWN	4
	Project Mgr: D.S.	Revision: 0	
	File No: M0624C09		



EXPLANATION

- OW-6 ● RI/FS OBSERVATION WELL LOCATION AND DESIGNATION
- OW-21 ⊕ GSIP OBSERVATION WELL LOCATION AND DESIGNATION
- OW-29 ⊕ PDI OBSERVATION WELL LOCATION AND DESIGNATION
- SW-1 ▲ SURFACE-WATER SAMPLING LOCATION AND DESIGNATION
- BS-1 * BIOLOGICAL SAMPLING LOCATION AND DESIGNATION
- SITE BOUNDARY
- ▨ AREA WHERE TOP OF GLACIAL TILL OR BEDROCK ELEVATION IS HIGHER THAN GROUND-WATER ELEVATION (LIMITS OF THE AQUIFER) ADAPTED FROM FIGURE 5 OF GOLDER ASSOCIATES, INC. DECEMBER 1991 REPORT TITLED "AQUIFER PUMPING TEST, INDUSTRI-PLEX SITE, WOBURN, MASSACHUSETTS"
- ▨ POTENTIAL SOURCE AREA
- 120/22 MAXIMUM/MINIMUM CONCENTRATIONS OF DISSOLVED ARSENIC, IN MICROGRAMS PER LITER (INCLUDES ALL SAMPLING DATA SINCE 1989)
- 50 LINE OF EQUAL DISSOLVED ARSENIC CONCENTRATION, ug/L
- ND NOT DETECTED
- ▨ APPROXIMATE EXTENT OF ARSENIC PLUME



Title			
MAXIMUM AND MINIMUM CONCENTRATIONS OF ARSENIC IN GROUND WATER			
Prepared For			
INDUSTRI-PLEX SITE REMEDIAL TRUST			
ROUX	Compiled by: M.S.	Date: 4/92	PLATE
ROUX ASSOCIATES, INC. Environmental Consulting & Management	Prepared by: C.L.	Scale: SHOWN	7
	Project Mgr: D.S.	Revision: 0	
	File No: MO624C03		

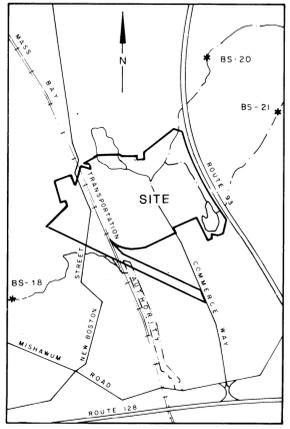
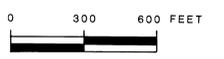


EXPLANATION

- OW-13 ● RI/FS OBSERVATION WELL LOCATION AND DESIGNATION
- OW-21 ⊕ GSP OBSERVATION WELL LOCATION AND DESIGNATION
- PZ-1 ● PIEZOMETER LOCATION AND DESIGNATION
- SW-1 ▲ GSP PHASE 1 SURFACE WATER AND STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION (JULY 31, 1990 THROUGH AUGUST 3, 1990)
- SW-18 △ GSP PHASE 2 SURFACE WATER AND STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION (OCTOBER 2-3, 1991)
- BS-8 ● BIOLOGICAL SAMPLING LOCATION AND DESIGNATION
- ABERJONA RIVER STAGE GAUGE LOCATION
- ▨ WETLANDS
- SURFACE WATER
- STREAM
- ▨ EXTENT OF HIDE PILE
- ▬ INDUSTRI-PLEX REMEDIAL TRUST PROPERTY BOUNDARY

NOTES

- ◁ CONCENTRATIONS ARE IN MICROGRAMS PER LITER FOR SURFACE WATER DATA
- ◁ CONCENTRATIONS OF DISSOLVED METALS IN SURFACE WATER ARE BRACKETED
- TELOG PRESSURE TRANSDUCERS ARE LOCATED IN PZ-1, PZ-2 AND THE ABERJONA RIVER STAGE GAUGE.
- STAFF GAUGES ARE LOCATED AT SW-1, SW-3, SW-7 AND SW-14
- DATA VALIDATED AS UNUSABLE ARE OMITTED
- UNLISTED CONCENTRATIONS OF ARSENIC, CHROMIUM AND LEAD WERE BELOW THE APPLICABLE DETECTION LIMIT
- NO SURFACE WATER DATA COLLECTED AT SW-3 AND SW-16 DUE TO DRY CONDITIONS



ARSENIC 13.1 [6.5]
 CHROMIUM 12.3 [1.1]
 LEAD

ARSENIC 13.9 [7.2]
 CHROMIUM 6.3
 LEAD 5.9

ARSENIC 14.5 [9.0]
 CHROMIUM 10.9 [1.2]
 LEAD

ARSENIC 12.6 [10.5]
 CHROMIUM 8.5 [2.2]
 LEAD

ARSENIC 8.9 [5.4]
 LEAD 3.2

ARSENIC [1.1]
 LEAD 3.6

ARSENIC 8.1 [7.7]
 CHROMIUM 4.9
 LEAD 4.3

ARSENIC 15.1 [13.9]
 LEAD 2.9

ARSENIC 2.0
 LEAD 3.7

ARSENIC 29.6 [17.5]
 LEAD 6.3

LEAD 4.2

ARSENIC 40.6 [24.5]
 CHROMIUM 3.9
 LEAD 3.0

ARSENIC 3.6
 CHROMIUM 195.0 [15.8]
 LEAD

ARSENIC 62.6 [2.7]
 CHROMIUM
 LEAD

ARSENIC 17.9 [1.4]
 CHROMIUM 11.6
 LEAD 2.2

File: CONCENTRATIONS OF ARSENIC, CHROMIUM AND LEAD DETECTED IN SURFACE WATER JULY/AUGUST 1990 AND OCTOBER 1991

Prepared for: INDUSTRI-PLEX SITE REMEDIAL TRUST

Compiled by: G.W.	Date: 3/92	Plate:
Prepared by: G.R.	Scale: SHOWN	
Project Mgr: D.S.	Revision: 0	
File No: M06624Y		8

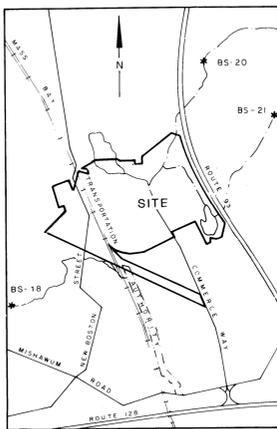


EXPLANATION

- CORE-1 ● STREAM SEDIMENT CORE LOCATION AND DESIGNATION
- 9.9 — CONCENTRATION OF ARSENIC IN MILLIGRAMS PER KILOGRAM
- OW-13 ○ RI/FS OBSERVATION WELL LOCATION AND DESIGNATION
- OW-21 ⊕ GISIP OBSERVATION WELL LOCATION AND DESIGNATION
- PZ-1 ● PIEZOMETER LOCATION AND DESIGNATION
- SW-1 ▲ GISIP PHASE 1 SURFACE WATER AND STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION (JULY 31, 1990 THROUGH AUGUST 3, 1990)
- 4.8 — CONCENTRATION OF ARSENIC IN MILLIGRAMS PER KILOGRAM
- SW-18 △ GISIP PHASE 2 SURFACE WATER AND STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION (OCTOBER 2-3, 1991)
- 19 — PDI TASK SW-1 STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION
- 172 — CONCENTRATION OF ARSENIC IN MILLIGRAMS PER KILOGRAM
- BS-8 * BIOLOGICAL SAMPLING LOCATION AND DESIGNATION
- ABERJONA STAGE GAUGE LOCATION
- ▨ WETLANDS
- ▭ SURFACE WATER
- STREAM
- ▨ EXTENT OF HIDE PILES
- INDUSTRI-PLEX REMEDIAL SITE TRUST PROPERTY BOUNDARY

NOTES:

- TELOG PRESSURE TRANSDUCERS ARE LOCATED IN PZ-1, PZ-2 AND THE ABERJONA RIVER STAGE GAUGE
- STAFF GAUGES ARE LOCATED AT SW-1, SW-3, SW-7 AND SW-14
- DATA VALIDATED AS UNUSABLE ARE OMITTED
- UNLISTED CONCENTRATIONS OF ARSENIC WERE BELOW THE APPLICABLE DETECTION LIMIT
- PDI TASK SW-1 STREAM SEDIMENT SAMPLE DATA FROM SHALLOWEST SAMPLE COLLECTED; MULTIPLE SAMPLES ARE AVERAGED



MAP INSET "A"
SCALE: ONE INCH EQUALS 2000 FEET

Title: CONCENTRATIONS OF ARSENIC DETECTED IN STREAM SEDIMENT

Prepared for: INDUSTRI-PLEX SITE REMEDIAL TRUST

ROUX ASSOCIATES INC.	Prepared by: C.W.	Date: 3/92	Plate: 9
	Project Mgr: D.S.	Scale: SHOWN	
	Revision: 0	File No: M06624	

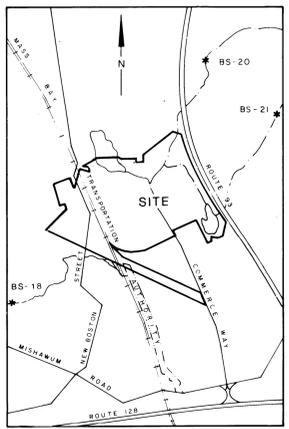


EXPLANATION

- CORE-1 ● STREAM SEDIMENT CORE LOCATION AND DESIGNATION
- 13.9 — CONCENTRATION OF CHROMIUM IN MILLIGRAMS PER KILOGRAM
- OW-13 ○ RI/FS OBSERVATION WELL LOCATION AND DESIGNATION
- OW-21 ⊕ GSIP OBSERVATION WELL LOCATION AND DESIGNATION
- PZ-1 ● PIEZOMETER LOCATION AND DESIGNATION
- * BIOLOGICAL SAMPLING LOCATION AND DESIGNATION
- SW-1 ▲ GSIP PHASE 1 SURFACE WATER AND STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION (JULY 31, 1990 THROUGH AUGUST 3, 1990)
- 28.6 — CONCENTRATION OF CHROMIUM IN MILLIGRAMS PER KILOGRAM
- SW-18 △ GSIP PHASE 2 SURFACE WATER AND STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION (OCTOBER 2-3, 1991)
- 57 □ PDI TASK SW-1 STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION
- 8.6 — CONCENTRATION OF CHROMIUM IN MILLIGRAMS PER KILOGRAM
- ABERJONA RIVER STAGE GAUGE LOCATION
- ▨ WETLANDS
- SURFACE WATER
- STREAM
- ▨ EXTENT OF HIDE PILES
- INDUSTRI-PLEX SITE REMEDIAL TRUST PROPERTY BOUNDARY

NOTES:

- TELOG PRESSURE TRANSDUCERS ARE LOCATED IN PZ-1, PZ-2 AND THE ABERJONA RIVER STAGE GAUGE
- STAFF GAUGES ARE LOCATED AT SW-1, SW-3, SW-7 AND SW-14
- DATA VALIDATED AS UNUSABLE ARE OMITTED
- UNLISTED CONCENTRATIONS OF CHROMIUM WERE BELOW THE APPLICABLE DETECTION LIMIT
- PDI TASK SW-1 STREAM SEDIMENT SAMPLE DATA FROM SHALLOWEST SAMPLE COLLECTED; MULTIPLE SAMPLES ARE AVERAGED



Title: CONCENTRATIONS OF CHROMIUM DETECTED IN STREAM SEDIMENT

Prepared for: INDUSTRI-PLEX SITE REMEDIAL TRUST

ROUX ASSOCIATES INC. Environmental Consulting & Management	Compiled by: C.W. Prepared by: C.R. Project Mgr.: D.S. File No.: M068247	Date: 3/92 Scale: SHOWN Revision: 0	Plot# 10
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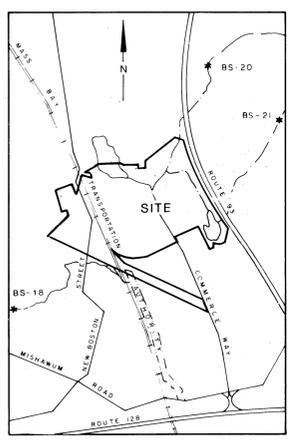


EXPLANATION

- CORE-1 ● STREAM SEDIMENT CORE LOCATION AND DESIGNATION
- 5.7 — CONCENTRATION OF LEAD IN MILLIGRAMS PER KILOGRAM
- OW-13 ● RI/FS OBSERVATION WELL LOCATION AND DESIGNATION
- OW-21 ⊕ GSP OBSERVATION WELL LOCATION AND DESIGNATION
- PZ-1 ● PIEZOMETER LOCATION AND DESIGNATION
- * ● BIOLOGICAL SAMPLING LOCATION AND DESIGNATION
- SW-1 ▲ GSP PHASE 1 SURFACE WATER AND STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION (JULY 31, 1990 THROUGH AUGUST 3, 1990)
- 11.6 — CONCENTRATION OF LEAD IN MILLIGRAMS PER KILOGRAM
- SW-18 △ GSP PHASE 2 SURFACE WATER AND STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION (OCTOBER 2-3, 1991)
- 19 □ PDI TASK SW-1 STREAM SEDIMENT SAMPLING LOCATION AND DESIGNATION
- 139 — CONCENTRATION OF LEAD IN MILLIGRAMS PER KILOGRAM
- ABERJONA RIVER STAGE GAUGE LOCATION
- ▨ WETLANDS
- SURFACE WATER
- STREAM
- ▨ EXTENT OF HIDE PILES
- INDUSTRI-PLEX SITE REMEDIAL TRUST PROPERTY BOUNDARY

NOTES:

- TELOG PRESSURE TRANSDUCERS ARE LOCATED IN PZ-1, PZ-2 AND THE ABERJONA RIVER STAGE GAUGE
- STAFF GAUGES ARE LOCATED AT SW-1, SW-3, SW-7 AND SW-14
- DATA VALIDATED AS UNUSABLE ARE OMITTED
- UNLISTED CONCENTRATIONS OF LEAD WERE BELOW THE APPLICABLE DETECTION LIMIT
- PDI TASK SW-1 STREAM SEDIMENT SAMPLE DATA FROM SHALLOWEST SAMPLE COLLECTED; MULTIPLE SAMPLES ARE AVERAGED



Title:
CONCENTRATIONS OF LEAD DETECTED IN STREAM SEDIMENT

Prepared for:
INDUSTRI-PLEX SITE REMEDIAL TRUST

ROUX ROUX ASSOCIATES INC Environmental Consulting & Management	Prepared by: C.W. Project Mgr: D.S.	Date: 3/92 Scale: SHOWN Revision: 0	Plot# 11
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File No: MQ06824Y