Evaluation of Interim Remedial Measures at the Sherwin-Williams Facility
Emeryville, California

December 20, 1991
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Prepared for:

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December 20, 1991

Mr. Lester Feldman
San Francisco Bay Region
California Regional Water Quality Control Board
2101 Webster Street, Suite 500
Oakland, California 94612

Subject: Evaluation of Interim Remedial Measures
Sherwin-Williams Facility
1450 Sherwin Avenue
Emeryville, California

Dear Mr. Feldman,

Enclosed for your review are two copies of Levine-Fricke's report on the evaluation of interim remedial measures at the Sherwin-Williams Facility in Emeryville, California.

After you have reviewed the report, we would like to schedule a meeting between yourself, Sherwin-Williams and Levine-Fricke to discuss your questions and comments on the report. If possible, we anticipate scheduling a meeting sometime in January 1992. Mark Knox or Jim Levine will be in contact with you to arrange a mutually acceptable date and time.

In the meantime, if you have any questions, please call Mark Knox, Jim Levine or John DeReamer of Levine-Fricke.

Sincerely,

D B Gustafson

Dave Gustafson
Director of Engineering
Consumer Division

Nick L. Maoloni

Nick Maoloni
Director, Corporate
Environmental Services

Enclosure

cc: John Gerulis
Harry Simmons
Mary Lou Capichioni
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Jim Levine
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DISTRIBUTION LIST

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CERTIFICATION

All engineering information, conclusions, and recommendations have been prepared under the direct supervision of and have been reviewed by a Levine•Fricke Professional Engineer.

Mark D. Knox

Mark D. Knox
Corporate Chief Engineer
Professional Engineer (33194)

12/20/91
Date

EXECUTIVE SUMMARY

BACKGROUND

The Sherwin-Williams Company owns and operates a coatings manufacturing plant (known as the Oakland Plant) located at the corner of Horton Street and Sherwin Avenue (1450 Sherwin Avenue) in Emeryville, Alameda County, California ("the Site"; Figure 1). The plant has been in operation since the early 1900s, manufacturing various types of coating products and lead-arsenate pesticides (until the late 1940s). In 1987, Sherwin-Williams changed its manufacturing at the Site from oil-based products to water-based products. The change in manufacturing operations included the closure and dismantling of an oil tank storage facility and the closure and dismantling of a solvent tank storage facility.

Several phases of soil and ground-water investigation were subsequently conducted from 1988 to 1991 to assess the nature and extent of a range of volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and certain inorganic compounds (mostly arsenic and lead) detected at the Site as a result of the investigation of the closed tank storage facilities. Investigations of chemical compounds in soil were conducted in four areas of the Site: the former oil tank storage, the former solvent tank storage, a paved parking area that is near the former solvent tank storage, and an arsenic source area (Figure 2). Based on the results of these investigations, three general categories of chemicals were identified in A-zone ground water in the site vicinity that may require remediation: VOCs, SVOCs (including total petroleum hydrocarbons [TPH]), and arsenic. Analytical data indicate chemical compounds detected in A-zone ground water do not appear to have affected B-zone ground water at concentrations requiring remediation.

IDENTIFICATION OF INTERIM REMEDIAL MEASURES

In 1990, the Sherwin-Williams Company retained Levine•Fricke to develop interim remedial measures for the Site. This report presents an evaluation of potential technologies and engineering measures for interim remediation of soil and ground water affected by the release of chemical compounds at the Site. The evaluation was conducted in accordance with site investigation and treatability study work plans prepared by Levine•Fricke for Sherwin-Williams.

Objectives of the Interim Remedial Measures

The objectives for the interim remedial measures are to minimize or eliminate potential human exposure to affected soil and ground water, prevent or minimize off-site migration of the affected ground water, and control source areas to prevent or minimize further ground-water impacts on site.

Interim Remedial Goals

Proposed interim remedial goals were developed for the Site. The remedial goals for soil and ground water may vary, depending on whether active remediation is implemented (e.g., treatment of soils or ground water) or if containment of affected soils and ground water is implemented in combination with limited active remediation. More stringent cleanup standards would be necessary in the event containment is not implemented because the risk of human exposure is much greater. Alternatively, containment would reduce the extent of active remediation required, allowing soils containing higher concentrations of compounds to be left in place while minimizing or eliminating potential human exposure to them.

A no action alternative was evaluated for the Site; however, because this alternative would not address the goals and objectives for remediation, the no action option was not evaluated further as one of the interim remedial alternatives.

The following cleanup goals for soils were used to estimate the volume of soil requiring full source containment or remediation: 10 mg/kg for VOCs; 100 mg/kg for hydrocarbons; 50 mg/kg for arsenic; and 500 mg/kg for lead (Table 14).

A list of priority pollutants found in ground water, along with corresponding Federal or State standards for these compounds, is shown in Table 15. The ground water at the Site would be considered a beneficial use as a potential drinking water source because the total dissolved solids (TDS) levels are in the range of 460 mg/L to 870 mg/L, below the 3,000 mg/L State standard. Therefore, drinking water standards are conceptual remedial goals for ground water.

These conceptual goals provided a basis for estimating the volume of soil that may be remediated or contained as an interim remedial measure and for estimating the associated remedial costs. The actual long-term remedial goals for the Site may differ from these conceptual interim remedial measure goals.

The conceptual interim remedial goals for ground water presented are target concentrations identified primarily to define the extent of necessary ground-water remediation or containment.

Areas Requiring Remediation

Based on the interim remedial goals, volume estimates were made of the soils requiring remediation or containment. Approximately 2,200 cubic yards of soil require remediation or containment in the former oil tank storage area (Figure 10). Approximately 10,100 cubic yards were identified for remediation or containment in the former solvent tank storage area and paved parking area (Figures 11A and 11B). Finally, approximately 13,100 cubic yards of arsenic-affected soils require remediation or containment in the arsenic area (Figure 12).

Screening of Remedial Technologies

Based on previous investigation results, a number of remedial technologies were evaluated for soils, including:

- stabilization (arsenic- and organic-affected, saturated [i.e., below ground water] and unsaturated [i.e., above ground water] soils)
- containment (arsenic- and organic-affected, saturated and unsaturated soils)
- soil washing (unsaturated, arsenic- and organic-affected soils)
- excavation and disposal (unsaturated, arsenic- and organic-affected soils)
- thermal treatment (unsaturated, organic-affected soils)
- biotreatment (unsaturated, organic-affected soils).

Results of the screening indicated the following technologies should be used in developing remedial measures for soils at the Site:

Arsenic-affected unsaturated soils (above ground water):

- stabilization
- excavation and off-site disposal

- containment.

Organic-affected unsaturated soils (above ground water):

- biotreatment
- excavation, treatment and off-site disposal
- containment.

Saturated soils (below ground water)

- containment.

Similarly, numerous technologies were evaluated for ground water, including:

- dissolved air flotation (DAF) (floating hydrocarbons)
- biotreatment (floating hydrocarbons and dissolved organics)
- Klensorb absorption (floating hydrocarbons)
- ion exchange (arsenic)
- electrochemical co-precipitation (arsenic)
- evaporation (arsenic)
- ultraviolet oxidation (dissolved organics)
- carbon adsorption (dissolved organics)
- evaporation with vapor controls (dissolved organics).

Results of the screening indicated the following technologies should be used in developing remedial measures for ground water at the Site:

- biotreatment for VOCs and SVOCs
- electrochemical co-precipitation for arsenic.

Development of Interim Remedial Measures and Cost Estimates

Five alternatives were developed for remediation of soil and ground water at the Site. Development of the conceptual cost estimates was based on engineering judgment, data available from site investigations to date, conceptual soil cleanup levels, ground-water discharge standards, and the results of the treatability work conducted during this phase of work. All alternatives favor reuse of treated ground water over NPDES discharge options. The proposed interim remedial measures are listed below:

Alternative 1: Hydraulic Containment with Full Source (Soils) Excavation and Disposal

The conceptual site layout for Alternative 1 is presented in Figure 13 and the conceptual treatment schematic for ground water is shown in Figure 14. Figures 10, 11A, 11B, and 12 detail the area of soil that would be excavated and disposed off site.

Alternative 1 provides hydraulic control using ground-water extraction and treatment without engineered containment measures. As a result, source area soil remediation using excavation/disposal is assumed. This alternative (and Alternative 2) has the highest estimated extraction flow rates of all the alternatives and subsequently the highest annual O&M costs. The estimated capital and O&M costs for Alternative 1, are presented in Tables 16, 17, and 18. The estimated capital cost for Alternative 1 is $18.6 million. The estimated present worth for this alternative is $21.8 million.

Alternative 2: Hydraulic Containment with Full Source (Soils) Treatment

The conceptual site layout for Alternative 2 is presented in Figure 13 and the conceptual treatment schematic is shown in Figure 14. Figures 10, 11A, 11B, and 12 detail the area of soil that would be treated on site.

Alternative 2, as with Alternative 1, provides hydraulic control using ground-water extraction and treatment without engineered containment measures. Alternative 2 is similar to Alternative 1, with the exception that source area soil remediation by treatment is assumed instead of excavation and disposal. This alternative (and Alternative 1) has the highest estimated extraction flow rates of all the alternatives and subsequently the highest annual O&M costs.

The estimated capital and O&M costs for Alternative 2 are presented in Tables 16, 17, and 19. The estimated capital cost for Alternative 2 is $4.5 million. The estimated present worth for this alternative is $7.7 million.

Alternative 3: Engineered Containment with Limited Source (Soils) Treatment

Figure 15A presents the layout of the proposed engineered containment system under this alternative. Figures 11A and 12 detail the estimated areas required for soil remediation assuming limited source reduction. The conceptual ground-water treatment schematic shown in Figure 14 would apply to this alternative.

Alternative 3 is based on engineered containment (cap and slurry wall) with limited source treatment of soils. This alternative has the lowest extraction rate (identical to Alternatives 4 and 5) and subsequently the lowest annual O&M costs. The estimated capital and O&M costs for Alternative 3, engineered containment of the arsenic-, VOC-, and SVOC-affected area along with ground-water extraction and treatment, are presented in Tables 20, 21, and 22. The estimated capital cost for Alternative 3 is $4.5 million. The estimated present worth for this alternative is $6.1 million.

Alternative 4: Engineered Containment with "Hot Spot" Arsenic Source (Soil) Treatment

Figure 15A presents the layout of the proposed engineered containment system under this alternative. Figure 12 details the estimated areas required for soil remediation assuming "hot spot" arsenic source reduction. The conceptual treatment schematic shown in Figure 14 would apply to this alternative.

Alternative 4 is based on engineered containment with "hot spot" treatment of arsenic-affected soils. This alternative has the lowest extraction rate (identical to Alternatives 3 and 5) and subsequently the lowest annual O&M costs. The estimated capital and O&M costs for Alternative 4, engineered containment of the arsenic-, VOC-, and SVOC-affected area along with ground-water extraction and treatment, are presented in Tables 20, 21, and 23. The estimated capital cost for Alternative 3 is $3.6 million. The estimated present worth for this alternative is $5.2 million.

Alternative 5: Engineered Containment

Figure 15A presents the layout of the proposed engineered containment system under this alternative. The conceptual treatment schematic shown in Figure 14 would apply to this alternative.

Alternative 5 is based on engineered containment without treatment of soils. This alternative has the lowest extraction rate (identical to Alternatives 3 and 4) and subsequently the lowest annual O&M costs. The estimated capital and O&M costs for Alternative 5, engineered containment of the arsenic-, VOC-, and SVOC-affected area along with ground-water extraction and treatment, are presented in Tables 20 and 21. The estimated capital cost for Alternative 5 is $2.3 million. The estimated present worth for this alternative is an estimated $3.9 million.

RECOMMENDED INTERIM REMEDIAL MEASURE

Based on the stated remedial goals, cost effectiveness and other stated criteria, Alternative 5, Engineered Containment, is the recommended interim remedial measure. This alternative includes containment of the VOC-, SVOC-, and arsenic-affected soil and ground water.

Alternative 5 is recommended for the following reasons:

- saturated soils, which have probably sorbed substantial amounts of arsenic and organic compounds, would be contained and this source of degradation of site ground water, regardless of the ground-water extraction and treatment option selected, would be controlled

- containment of chemical affected areas would mitigate further off-site migration of ground water

- containment provides control of the affected areas without the need for soil treatment or disposal

- use restrictions (deed restrictions) could be imposed on the property in conjunction with containment to prevent potential future exposures as a result of site activities

- containment would reduce the amount of ground water requiring extraction and subsequent treatment, which meets both regulatory concerns regarding excessive pumping of ground water and reduces overall operational costs for implementation

- the alternative could be implemented relatively quickly in comparison to other alternatives, allowing for implementation of interim remedial measures sooner.

This alternative has the lowest estimated capital cost of $2.3 million and annual O&M costs of $125,000 per year with a 20-year present worth O&M value of $1.56 million. The total estimated present worth cost for this alternative is $3.9 million. Final evaluation of this alternative should be made during the design period to confirm and refine the cost estimates and feasibility for the recommended interim remedial measure.

SCHEDULE FOR IMPLEMENTATION

The estimated schedule for implementation of recommended Alternative 5 is presented in Figure 19. This schedule is highly dependent on the time required to receive approval from the regulatory agencies. We have assumed 4 months for regulatory approval for purposes of this evaluation. As a result, it is anticipated to take approximately 18 months (from time of submittal of the recommended remedial plan to the RWQCB) to complete implementation of the recommended remedial alternative.

December 20, 1991

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EVALUATION OF INTERIM REMEDIAL MEASURES AT THE SHERWIN-WILLIAMS FACILITY EMERYVILLE, CALIFORNIA

1.0 INTRODUCTION

This report presents an evaluation of potential technologies and engineering measures for the interim remediation of soil and ground water affected by the release of chemical compounds at the Sherwin-Williams Plant in Emeryville, California ("the Site"). It was prepared in accordance with site investigation and treatability study work plans prepared by Levine•Fricke for Sherwin-Williams.

The report includes a review of the nature and extent of chemical compounds found in soil and ground water (Sections 1.1 through 1.5); a screening of potential technologies and engineering measures for the interim remediation of affected soil and ground water (Sections 2.0, 3.0, and 4.0); and development of recommended measures for an interim remedial measure plan for the Site (Section 5.0).

The objectives for the interim remedial measures are to minimize or eliminate potential human exposure to affected soil and ground water, prevent or minimize off-site migration of the affected ground water, and control source areas to prevent or minimize further ground-water impacts on site. Based on a review of the nature and extent of affected media, a range of alternatives to achieve these objectives was evaluated. Each alternative was evaluated for effectiveness, implementability, and estimated cost. Other factors, such as potential risks associated with an alternative, also were considered. From this evaluation, a preferred alternative was identified and an interim remedial measure plan developed.

1.1 Site Background

The Sherwin-Williams Company owns and operates a coatings manufacturing plant (known as the Oakland Plant) located at the corner of Horton Street and Sherwin Avenue (1450 Sherwin Avenue) in Emeryville, Alameda County, California (Figure 1). The plant has been in operation since the early 1900s, manufacturing various types of coating products and lead-arsenate pesticides (until the late 1940s). In 1987, Sherwin-Williams changed its manufacturing at the Site from oil-based products to water-based products. The change in manufacturing operations included the closure and dismantling of an oil tank storage facility and the closure and dismantling of a solvent tank storage facility.

Several phases of soil and ground-water investigation were subsequently conducted from 1988 to 1991 to assess the nature and extent of a range of volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and certain inorganic compounds (mostly arsenic and lead), which have been detected at the Site as a result of the investigation of the closed tank storage facilities. A summary listing of the investigations conducted is presented in Table 1.

The first phase of investigation included the drilling of 15 soil borings and the installation and sampling of 7 shallow A-zone ground-water monitoring wells (LF-1 through LF-7) (Levine•Fricke 1989). The second phase of investigation included the drilling of 9 additional soil borings, and installation and sampling of 5 additional A-zone monitoring wells (LF-8 through LF-13) and three B-zone monitoring wells (LF-B1 through LF-B3) (Levine•Fricke 1990a). As a result of several additional phases of investigation, which included drilling through the concrete foundation of a dismantled building, a total of 86 soil borings, 16 A-zone monitoring wells, and 4 B-zone monitoring wells have been installed at or near the Site. The soil borings and monitoring wells have been located to provide information regarding the lateral and vertical extent of chemical compounds in soil and ground water and to provide information regarding hydrogeologic conditions at the Site.

The VOCs detected (using EPA Method 8240) in soil and/or ground water have included primarily acetone, benzene, ethylbenzene, toluene, xylene isomers, methyl ethyl ketone, 2-hexanone, and a range of tentatively identified straight chain (C-5 to C-13) hydrocarbon compounds. The SVOCs detected (using EPA Method 8270) in soil and/or ground water have included primarily naphthalene, 2-methyl naphthalene, 2-methyl phenol, 4-methyl phenol, 2,4-dimethyl phenol, phthalates, and a range of tentatively identified straight chain (C-7 to C-35) hydrocarbon compounds. The range of concentrations of detected organic compounds are presented in the following sections.

During the course of investigation of the closed tank storage facilities, two additional areas of affected soil were identified as a result of soil sampling conducted while drilling monitoring wells. An area affected by residual petroleum hydrocarbon compounds was identified in a paved parking area in the vicinity of monitoring wells LF-10 and LF-B3. This area is located near the downgradient boundary of the Site near the former solvent tank storage area (Figure 2). An additional area affected by arsenic and lead was identified under the remaining foundation of a dismantled building in the vicinity of monitoring well LF-1. This area is located near the upgradient boundary of the Site (Figure 2). The dismantled building reportedly had been used for the production of arsenic-based compounds in the early 1900s.

1.1.1 Ground-Water Monitoring Programs

During the 1990 through 1991 time period, a semiannual ground-water monitoring program was implemented and the results of monitoring have been reported to the Regional Water Quality Control Board (RWQCB) (Levine•Fricke 1990c, 1991a, and 1991b). The monitoring programs have provided information regarding the types and concentrations of chemical compounds detected in ground water in on-site and off-site areas. The analytical results of the monitoring programs are summarized in Tables 2 (VOCs), 3 (SVOCs), 4 (total petroleum hydrocarbons [TPH]), and 4 (inorganic compounds). The monitoring programs also have provided information regarding the direction of ground-water flow in the A and B zones. Ground-water flow direction in the A and B zones is generally toward the northwest, as illustrated in Figures 3A and 3B.

1.1.2 Site Geology and Hydrogeologic Characteristics

Information regarding the hydrogeologic characteristics of the lithologic units that underlie the Site has been obtained as a result of drilling and pump testing conducted during the first and second phases of investigation (Levine•Fricke 1989, and 1990a). The results of drilling indicate that shallow "A-zone" ground water is generally encountered at a depth of 6 to 12 feet below grade. The results of drilling of the on-site A-zone monitoring wells indicate A-zone ground water is generally present in relatively thin (2 to 5 feet thick) beds of sand and/or gravel interbedded with less permeable silty clayey sediments. The water-yielding units of the A zone are generally overlain by 5 to 6 feet of a confining to semiconfining layer of silty clay and gravelly silty clay sediments. The A zone is underlain by a silty clay interval approximately 10 to 18 feet thick. This clay-rich interval has a low permeability, and the unit acts as an aquitard to form a confining layer that separates the A zone from the B zone. The B zone consists of a thick interval of well-sorted, coarse-grained, sand and gravel units interbedded with some silty clay sediments. B-zone ground water is generally encountered at a depth of approximately 28 to 38 feet below grade.

1.2 Nature and Extent of Chemicals in Ground Water

There are three general categories of chemicals in A-zone ground water near the Site that may require remediation: VOCs, SVOCs (including TPH), and arsenic. Historical ground-water analytical data are summarized in Tables 2, 3, 4, and 5 for VOCs, SVOCs, TPH, and arsenic and other inorganic compounds, respectively. More detailed information regarding ground-water quality and existing site conditions is presented in previous Levine·Fricke reports (Levine·Fricke 1989, 1990a,d, and 1991a,b). Analytical data indicate chemical compounds detected in A-zone ground water do not appear to have affected B-zone ground water, with the exception of previous B-zone ground-water sampling data that had indicated very low arsenic concentrations (ranging from 0.002 mg/L to 0.008 mg/L). However, the most recent B-zone sampling data (June through August 1991) indicated nondetectable concentrations of arsenic in the B zone.

1.2.1 Volatile Organic Compounds

The highest concentrations of VOCs generally have been observed in ground-water samples collected from A-zone wells located in the former solvent tank storage area (wells LF-5 and LF-6) (Table 2). The primary VOCs detected in shallow ground water during the June through August 1991 round of ground-water monitoring (Levine·Fricke 1991b) included acetone (<0.010 mg/L to 9.900 mg/L), benzene (<0.005 mg/L to 0.061 mg/L), ethylbenzene (<0.005 mg/L to 7.5 mg/L), methyl ethyl ketone (<0.020 mg/L to 8.200 mg/L), xylenes (<0.005 mg/L to 44.0 mg/L), and toluene (<0.005 mg/L to more than 200 mg/L). The results from the June through August round of monitoring indicated concentrations ranged from very low to below detection limits for ground-water samples collected along the downgradient boundary of the Site (wells LF-8, LF-9, LF-10, and LF-11) to more than 200 mg/L for ground-water samples collected in the solvent tank storage area (LF-5) and more than 100 mg/L for ground-water samples collected from the former oils tank storage area (LF-3). A contour map of total quantified VOC concentrations in A-zone ground water is presented in Figure 4A.

It should be noted that the concentration of total VOCs in A-zone ground water in the former solvent tank storage area has decreased from a high of 920 mg/L (LF-5, June 1989) to an estimated 200 mg/L (or more) (LF-5, June 1991). The concentration of SVOCs also has decreased in the former solvent tank storage area (Tables 2 and 3). The decreased concentration of organic compounds in A-zone ground water in the former solvent tank storage area is a result of the excavation and removal of approximately 320 to 420 cubic yards of affected soil in August 1990. The excavated soil was disposed at a USPCI Class I landfill facility in Clyde, Utah.

Laboratory results for ground-water samples collected from the four monitoring wells installed in the B zone indicate B-zone ground-water quality is not affected with the same VOCs as have affected the A zone (Table 2). The June through August 1991 monitoring results (Levine•Fricke 1991b) indicate B-zone ground water contains concentrations of 1,2-dichloroethane (1,2-DCA) ranging from <0.005 mg/L to 0.180 mg/L. 1,2-DCA is a chlorinated VOC that has generally not been detected in A-zone ground-water samples collected at the Site. The presence of 1,2-DCA in B-zone ground water may originate from an upgradient, off-site source.

1.2.2 Semivolatile Organic Compounds

The highest concentrations of SVOCs generally have been observed in A-zone ground water in the former oil tank storage area (wells LF-2 and LF-3) (Table 3). During the June through August 1991 round of ground-water monitoring (Levine•Fricke 1991b), naphthalene and 2- and 4-methylphenol were detected near the former oil tank storage area (LF-3) at concentrations of 0.110 mg/L, 0.210 mg/L, and 0.630 mg/L, respectively. Monitoring well LF-2 was not sampled during the June through August 1991 round of sampling as a result of an organic compound found floating on top of the ground-water surface at the time of sampling. Floating compounds previously had not been observed in any monitoring wells at the Site. Other SVOCs that were detected at the Site in A-zone ground water included phenol (LF-3 at 0.039 mg/L) and 2,4-dimethylphenol (LF-3 at 0.050 mg/L). SVOCs were not detected in A-zone wells located downgradient from the Site (LF-14, LF-15, and LF-16). A contour map of total quantified SVOC concentrations for the June through August 1991 sampling round is presented as Figure 4B.

The June through August sampling results for B-zone ground water (Levine•Fricke 1991b) indicate the B zone does not contain measurable concentrations of quantifiable SVOCs, with the exception of ground-water samples collected from wells LF-B2 and LF-B4, which contained low concentrations of bis(2-ethylhexyl)phthalate (0.018 and 0.060 mg/L, respectively) (Table 3). Bis(2-ethylhexyl)phthalate is a common plastizing agent generally associated with the production of many plastic materials.

1.2.3 Total Petroleum Hydrocarbon (TPH) and Tentatively Identified Compounds

The first and second phases of ground-water investigation at the Site indicated a wide range of tentatively identified compounds (TICs) that were reported with semiquantified estimates of concentration (Levine•Fricke 1989 and 1990a). Many of these TICs were identified as volatile straight-chain hydrocarbon compounds in the C-5 to C-13, range using EPA Method 8240, and as semivolatile hydrocarbon compounds in the C-8 to C-35 range, using EPA Method 8270. These compounds are probably derived from the use of mineral spirits, paint naphtha, and other oils used in the commercial manufacture of oil-based coatings. Additional TICs that have been detected include alcohols, esters, ketones, and organic acids. TIC results have not been included in the summary figures of this report because of the lack of laboratory standards for the reported TICs and because the semiquantified estimates of TIC concentrations typically can vary by several orders of magnitude.

During the July 1990 sampling round (see Levine•Fricke 1990c), ground-water samples were analyzed using EPA Method 8015. These TPH results are summarized in Table 4. EPA Method 8015 was used to provide a quantified measure of the sum concentration of the straight-chain hydrocarbon compounds being detected and reported as TICs using EPA Methods 8240 and 8270. A contour map showing the results of the EPA Method 8015 analyses from the July 1990 sampling round is attached as Figure 4C. The results show that TPH compounds are concentrated in A-zone ground water in the vicinity of the dismantled tank storage areas. The TPH results for the solvent tank storage area included 1,500 mg/L for LF-6, 520 mg/L for LF-5, and 110 mg/L for LF-4. The TPH results for the former oil tank storage area included 630 mg/L for LF-2 and 440 mg/L for LF-3. No TPH compounds were detected, with a method detection limit of 1 mg/L, in downgradient monitoring wells LF-8, LF-9, LF-10, LF-11, LF-14, LF-15, and LF-16 (Figure 4C). TPH was detected at a concentration of 7.6 mg/L and 5.0 mg/L in upgradient monitoring wells LF-1 and LF-13, respectively. No TPH was detected for B-zone monitoring wells LF-B1 through LF-B4.

1.2.4 Arsenic

The highest concentrations of arsenic detected in A-zone ground water in the June through August 1991 sampling round (Levine•Fricke 1991b) was reported in wells LF-1 (58 mg/L) and LF-3 (60.4 mg/L). A grab sample of A-zone ground water collected from a treatability study soil boring (TS-2) reported an arsenic concentration of 320 mg/L (Figure 5). A-zone well LF-2 was not sampled in June 1991; previous sampling results in July 1990 reported a concentration of 110.0 mg/L arsenic. In the June through August 1991 sampling round, off-site, downgradient monitoring samples from wells LF-14, LF-15, and LF-16 reported arsenic in concentrations of 0.095, <0.010, and 0.010 mg/L, respectively. A contour map of A-zone ground-water arsenic concentrations reported for the June through August 1991 monitoring program (Levine•Fricke 1991b) is shown in Figure 5.

The June through August 1991 sampling results for B-zone monitoring wells LF-B1, LF-B2, LF-B3, and LF-B4 indicated nondetectable concentrations of arsenic in B-zone ground water at a method detection limit of <0.010 mg/L. B-zone ground water previously had indicated very low concentrations of arsenic, ranging from 0.002 mg/L to 0.008 mg/L (Table 5).

1.3 Nature and Extent of Chemicals in Soil

Investigations of chemical compounds in soil have been conducted in four areas of the Site. The four areas are the former oil tank storage area, the former solvent tank storage area, a paved parking area that is near the former solvent tank storage area, and an arsenic source area (Figure 2). The following sections provide a summary of the soil borings drilled in each of these areas and the results of laboratory analyses. Volume estimates of affected soils are presented in Section 1.5.

1.3.1 Former Oils Tank Storage Area

A total of 15 soil borings have been drilled in the former oil tank storage area. The results of soil sample analyses for this area are summarized in Tables 6 (VOCs), 7 (SVOCs), and 8 (inorganic elements). Soil boring locations are shown in Figure 6. Six soil borings had been drilled near the former oil tank storage area before initiation of the second phase of work. As part of subsequent work, an additional nine soil borings were drilled southeast of the former oil tank storage area to assess the extent of VOCs, SVOCs, and Texanol (an ester-alcohol-based semivolatile solvent). Approximately

2,500 gallons of Texanol reportedly was spilled in the area southeast of the former oil tank storage area on March 25, 1990. Five of these soil borings, drilled to a depth of 6 feet, were drilled in the area affected by the Texanol spill. The analytical results for the soil samples collected from the oil tank storage and Texanol spill area indicated the presence of some aromatic VOCs and some short-chain and longer-chain aliphatics in the range of volatile to semivolatile compounds. The results of the sampling were used to assess the lateral and vertical extent of affected soil that may require remediation in the unsaturated zone. SVOCs (and TPH) appear to be the primary compounds detected in soil samples from this area. The area potentially requiring remediation is discussed in Section 1.5.

1.3.2 Former Solvent Tank Storage Area

A total of 20 soil borings have been drilled in the general vicinity of the former solvent tank storage area. The analytical results for soil samples showed a range of different types of VOCs and some SVOCs. The results also showed concentrations of lead and zinc that were above background concentrations. The results of soil sample analyses for this area are summarized in Tables 9 (VOCs), 10 (SVOCs), and 11 (inorganic compounds). Boring locations are illustrated in Figure 7A. The results generally indicated concentrations of detected chemical compounds decreased with increasing distance from the former storage tank boundaries. The data from these soil borings were used to assess the extent of affected soil in the unsaturated zone that may require remediation.

Some interim remedial measures for soil were conducted in August 1990, which included excavating and disposing of lead-affected soil in a Class I landfill. These remedial measures were implemented on an expedited schedule to remove "hot spot" soils for off-site disposal to meet the August 8, 1991 schedule based on the Land Disposal Restrictions. Approximately 450 cubic yards of soil were removed and transported to USPCI's facility in Clyde, Utah. Abandonment of one A-zone well (LF-6), by sealing with cement was necessary because of soil excavation activities. In the process of implementing these interim soil disposal measures, Sherwin-Williams expended approximately $270,000 for engineering, hauling, disposal, and taxes. Figure 7B shows the area where soil was removed and the results of pre-excavation and post-excavation sampling for lead. The soils remaining that may require remediation are discussed in Section 1.5.

1.3.3 Paved Parking Lot Area

An investigation was conducted in the area within a paved parking area located along the western boundary of the Sherwin-Williams plant, just west of the former solvent tank storage area. This area was investigated because a brown, oily, tar-like compound (characterized by thin layer chromatography as a heavy petroleum-based compound) was encountered during drilling for installation of ground-water monitoring wells LF-10 and LF-B3. A total of 11 soil borings were drilled in the vicinity of these monitoring wells to investigate the extent of this petroleum-based substance (Figure 8). Soil borings were drilled to the depth of ground water (approximately 8 to 10 feet below grade) and soil samples were collected at approximately 2-foot intervals. The results of TPH sample analyses are summarized in Table 12.

1.3.4 Arsenic Source Area

A total of 39 soil borings for site characterization and three soil borings for treatability studies have been drilled in the arsenic source area. Results of soil samples from these borings were used to assess the lateral and vertical extent of arsenic-affected soils. The results of soil sample analyses for this area are summarized in Table 13 and Figure 10.

Samples from the soil borings were generally collected at 2-foot intervals to a depth of approximately 6 to 10 feet below grade. The samples were primarily analyzed for arsenic and lead compounds; analytical results indicated additional compounds were present, including barium, cadmium, copper, and zinc. The volume of arsenic-affected soil that may be targeted for interim remediation is presented in Section 1.5.

1.4 Objectives for Interim Remedial Measures

The objectives for the interim remedial measures are to minimize or eliminate potential human exposure to affected soil and ground water, prevent or minimize off-site migration of the affected ground water, and control source areas to prevent or minimize further ground-water impacts on site.

The remedial goals for soil and ground water may vary, depending on whether active remediation is implemented (e.g., treatment of soils or ground water) or if containment of affected soils and ground water is implemented. More stringent cleanup standards would be necessary in the event containment is not implemented because the risk of human exposure is much greater. Alternatively, containment would reduce the extent of active remediation required, allowing soils containing higher concentrations of compounds to be left in place while minimizing or eliminating potential human exposure to them.

A no action alternative was evaluated for the Site; however, because this alternative would not address the goals and objectives for remediation, the no action option was not evaluated further as one of the interim remedial alternatives.

The conceptual remedial goals for soils presented herein are target concentrations that were used to identify areas of soils requiring remediation or containment. These conceptual goals provided a basis for estimating the volume of soil that may be remediated or contained as an interim remedial measure and for estimating the associated remedial costs. The actual long-term remedial goals for the Site may differ from these conceptual interim remedial measure goals.

The conceptual interim remedial goals for ground water presented herein are target concentrations identified primarily to define the extent of necessary ground-water remediation or containment.

Soils and ground water containing concentrations of constituents above the conceptual remedial goals may be addressed using interim remedial measures. The affected soils and ground water targeted for remediation could be addressed by several options: containment, treatment, and/or removal for off-site disposal.

1.4.1 Containment Options for Soil and Ground Water

Containment measures could be used to address ground water and soil targeted for interim remediation; for example, affected soils could be capped in place to minimize potential impacts to ground water and to minimize potential human exposure to soils. Containment measures to address soils and ground water could be accomplished in combination with both active (i.e., extraction and treatment) and passive (i.e., slurry wall and capping) measures. An analysis of potential remedial options, including containment options, is presented in Section 3.0. The containment options include containment of soils with limited source treatment, containment of soils with "hot spot" arsenic source treatment, and containment of soils without any source treatment.

If containment options are selected as the remedial measures, soil and ground water with concentrations of chemicals in excess of conceptual remedial goals (described below for noncontainment options) might be left on site. The concentrations of chemicals allowed to remain in the contained soils may vary depending on regulatory requirements, Sherwin-Williams site needs, and cost effectiveness of the remedial option. As a result, various conceptual remedial goals using containment options are evaluated to assess the varying cost impacts. In any case, it is expected that use restrictions (i.e., deed restrictions) would be imposed on the property if containment of affected soils in place is chosen. Under these use restrictions, containment could be acceptable as long as the Site is used for industrial purposes. In the event that Site use requirements changed significantly, other remedial measures (treatment or removal) would be required before changes in site use could occur.

1.4.2 Noncontainment Options

The noncontainment options would include extraction and treatment of ground water. Because capping is not an element of these options, two alternatives for soils remediation would be included: (1) excavation and disposal of affected soils, and (2) treatment of affected soils that remain on site.

1.4.2.1 Conceptual Soil Remedial Goals. The chemical compounds found in soil at the Site and their proposed remedial goals are listed in Table 14. The discussion that follows provides the basis for the conceptual soil remedial goals for the noncontainment alternatives.

Arsenic and Lead. The remedial objective for arsenic- and lead-affected soils is to inhibit the leaching of these inorganic elements into ground water and to minimize the risks of potential exposure to impacted surface soils. The shallow depth of ground water, less than 10 feet, increases the potential risk of migration of these elements into ground water.

The conceptual remedial goals for the two inorganic elements differ because arsenic is more mobile than lead at the pH conditions of site soils, sediments, and ground water. The high concentrations of arsenic and nondetectable concentrations of lead in ground water at the Site support this supposition.

A soil remediation goal for arsenic at a Federal Superfund site (Selma Pressure-Treating, Selma, California) was recently established at 50 mg/kg. This concentration of arsenic is near the median value for naturally occurring arsenic concentrations for soils in the Western United States, which have been reported to range from less than 0.1 mg/kg to 97 mg/kg (Shacklette and Boerngen 1984). As a result, a conceptual remedial goal of 50 mg/kg for arsenic in soil would be expected to meet the overall remedial objectives for the noncontainment options.

A review of lead concentrations in on-site soils and ground water showed that lead was detected at concentrations above 500 mg/kg in soil in a few locations but was not detected in ground water. A larger number of case histories exists for lead remediation of soil than exists for arsenic. Where lead migration is not a problem and where potential human contact with soil can be minimized, common remedial goals for lead in soil have been set at 500 mg/kg and 1,000 mg/kg. Lead-affected soils likely have been present on site in excess of 50 years, and soils with lead concentrations at the Site greater than 500 mg/kg have not resulted in significant migration of lead to ground water (Table 5). Therefore, a soil remedial goal of 500 mg/kg for lead would minimize the potential for lead migration and reduce potential exposure to lead-affected soils.

Volatile Organic Chemicals. The predominant VOCs detected in soils at the Site are the monocyclic aromatics -- toluene, xylenes, and ethylbenzene. All of these compounds are relatively mobile, potentially moving from soil to ground water. However, none of these chemicals are listed carcinogens and each is subject to a significant degree of natural degradation. Toluene is relatively mobile and has the lowest drinking water standard concentration of the three aromatics; therefore, it was evaluated more closely for its potential impact to underlying ground water.

A simple transport analysis was conducted using EPA's Seasonal Soil Compartmental Model (SESOIL) (Bonazountas and Wagner 1984) to evaluate potential movement of toluene from the shallow silts and clays found at the Site. Toluene leachate concentrations over a 20-year period were modeled assuming 10 mg/kg toluene in soils in the source area and disregarding the effects of biodegradation. Allowing for mixing of the leachate in the approximately 3-meter thick A zone (Yeh 1981), modeling results showed a maximum ground-water concentration of 0.025 mg/L. The current EPA maximum contaminant level for toluene in drinking water is 1 mg/L; the drinking water standards for ethylbenzene and xylene isomers are more than five times greater than that for toluene. Therefore, a conceptual remedial goal of 10 mg/kg for each VOC in soil is anticipated to be reasonable and defensible.

Semivolatile Organic Chemicals. A review of SVOC data revealed a large number of detections of relatively long-chain aliphatic hydrocarbons, ranging from C_5 to C_{35}. Establishing a conceptual remedial goal for these compounds in soil is difficult because of the lack of similar remediation histories at other sites and the diversity of physico-chemical properties for this range of hydrocarbons. The materials could exhibit transport characteristics similar to mineral spirits, diesel fuel, or light oils given the range of the lengths of the carbon chains. In reviewing the State Water Resources Control Board Leaking Underground Fuel Tank (LUFT) Methodology for establishing soil cleanup levels, two possible conceptual goals of 100 mg/kg or 1,000 mg/kg of hydrocarbons in soils were presented on Table 2-1 of the Revised Luft Field Manual (April 1989). In lieu of extensive evaluation of the fate and transport of hydrocarbons at the Site, it is proposed that 100 mg/kg be used as the interim remedial goal for hydrocarbons in soil.

A review of priority pollutant SVOC data did not identify particularly high concentrations of these compounds. The highest concentrations noted were 10.2 mg/kg of bis-(2-ethyl hexyl)phthalate and 4.3 mg/kg of naphthalene. A transport analysis was conducted on naphthalene in shallow soils at this concentration. It was found that naphthalene does not migrate appreciably at these concentrations in the silty soil conditions present at the Site. The soils containing SVOCs are largely coincident with those containing long-chain aliphatic hydrocarbons or VOCs. Remediation of VOC- and hydrocarbon-affected soil (e.g., bioremediation) is expected to reduce concentrations of priority pollutant SVOCs. As a result, cleanup goals for specific SVOCs are not considered necessary for the Site because the SVOC concentrations in soil and ground water are relatively low and the remediation of VOCs likely would address SVOC remediation issues.

1.4.2.2 Conceptual Ground-Water Remedial Goals. Water quality at the Site is affected by arsenic, VOCs, and, to a much smaller degree, SVOCs. In most areas, organic and inorganic compounds are commingled. A list of priority pollutants found in ground water, along with corresponding Federal or State standards for these compounds is shown in Table 15. The ground water at the Site would be considered a beneficial use as a potential drinking water source because the total dissolved solids (TDS) levels are in the range of 460 mg/L to 870 mg/L, below the 3,000 mg/L State standard. Therefore, drinking water standards are conceptual remedial goals for ground water.

Restoration of on-site ground water to drinking water standards may be desirable, but it may not be technically feasible. Potential interim remedial measures focus on hydraulic capture of ground water containing constituents in excess of drinking water standards.

The remedial alternatives to achieve these potential remedial goals are screened in Section 2.2 and developed in Section 3.0.

1.4.3 Ground-Water Treatment Options

Extraction and treatment of targeted ground water are an element of all the remedial options. Treatment goals are dependent on the discharge option.

Three options for the discharge of treated ground water have been identified: treatment and reuse of the water on site; treatment and discharge to the sanitary sewer; and treatment and discharge to Temescal Creek under National Pollutant Discharge Elimination System (NPDES) permit. These options are discussed below.

Treatment and Reuse of the Water On Site. Extracted water could be treated and reused in an on-site industrial process. Based on preliminary discussions with Sherwin-Williams staff, it appears the major use of water on site is for domestic water use, formulation of paint products, and boiler feed-water. Sherwin-Williams likely could develop industrial process water needs on site, and therefore, treated ground water could be reused and discharged to the East Bay Municipal Utility District (EBMUD) in combination with the existing site wastewater discharges. In this case, the discharge limits would be subject to EBMUD's regulations for industrial wastewaters, which are covered by Ordinance Number 311. The discharge limit for arsenic (likely to be a key chemical with respect to discharge) under Ordinance 311 currently is 2.0 mg/L.

Treatment and Discharge to the Sanitary Sewer. Extracted ground water also could be treated and discharged directly to the sanitary sewer. EBMUD also would regulate this discharge by limiting the concentrations of BTEX and lead, as established in their Groundwater Discharge Guidelines (GDG).

These guidelines allow a maximum discharge of 25,000 gallons of ground water per day, and require initial daily monitoring until the reliability of the treatment unit has been established.

Treatment and Discharge Under NPDES Permit. Extracted ground water also could be treated and discharged to Temescal Creek under an NPDES permit. The Regional Water Quality Control Board (RWQCB) likely will require Sherwin-Williams to evaluate the feasibility and cost effectiveness of reuse and/or direct discharge after treatment to the sanitary sewer as a preferred option to NPDES discharge. If NPDES discharge is determined to be the preferred option, the treated discharge would be regulated by the RWQCB under established NPDES permit limitations and in accordance with the San Francisco Bay Basin Region 2 Water Quality Control Plan. The discharge standards for many of the organic compounds present at the Site would be determined by the RWQCB staff because standards do not exist for many of the specific compounds. For the predominant monocyclic aromatics (toluene, xylenes, and ethylbenzene), the individual compound NPDES discharge limits likely would be 0.005 mg/L. For the less toxic long-chain aliphatic hydrocarbons, the individual compound discharge limits likely would be 0.050 mg/L. In any case involving this method of discharge, limits for total organics likely would be 0.100 mg/L for all SVOCs and VOCs combined. In addition, the NPDES discharge limits would be 0.020 mg/L for arsenic and 0.0056 mg/L for lead. To the extent feasible, the previous two options (water reuse and/or sanitary sewer discharge) will be favored over NPDES discharge options.

1.5 Areas and Volumes of Affected Soil, Based on Remedial Measure Goals

The approximate areas and volumes of affected soil for the identified source areas (i.e., the former oil tank storage area, the former solvent tank storage area and back parking area combined, and the arsenic source area) have been outlined based upon the conceptual remedial goals discussed in the preceding sections and based on the remedial alternatives developed under Section 3.0. The engineered containment options discussed under Section 3.0 (Alternatives 3, 4, and 5) also include suboptions for varying degrees of soil treatment, which is also presented in that section of the report. The areas targeted for potential interim remedial measures are illustrated in Figures 10, 11A, 11B, and 12.

Former Oil Tank Storage Area. For the former oils storage tank area, the limits of affected soil are fairly well defined based upon a remedial goal of 100 mg/kg of hydrocarbon (SVOC and TPH) compounds in soil for noncontainment options. VOCs are found in the area within the area of hydrocarbon-affected soil such that remediating to the remedial goal of 10 mg/kg for VOCs should be coincident with remediation of SVOCs and TPH. The approximate area of hydrocarbon-affected soil is shown in Figure 10 with the results of EPA Method 8240 analysis and SVOCs results. Some uncertainty remains for the area northwest of the former storage tank area. This is an area where drilling is complicated by several layers of thick concrete. Identification of the limits of affected soil should be conducted during the design or implementation phase of soil remediation in this area. Soil near railroad tracks or buildings would be difficult to access. A discussion of access difficulties is included for the development of alternatives in Section 3.1. Using Figure 10 and the conceptual remedial goals of 100 mg/kg for SVOC/TPH compounds and 10 mg/kg for each VOC for noncontainment options, the approximate in-place volume of affected soil for the former oil tank storage and Texanol spill area would be approximately 2,200 cubic yards.

Former Solvent Tank storage Area and Paved Parking Area. For the former solvent tank area and paved parking areas combined, the limits of affected soil are well defined around the former storage tank area, but are less well defined in the paved parking area located farther west. The approximate areas of affected soil are shown in Figures 11A and 11B with VOC results using EPA Method 8240 and TPH using modified EPA Method 8015. The area shown on these figures includes the central area of the former solvent tank storage area where lead-affected soil previously had been excavated and disposed.

The area targeted for interim remedial measures has been assessed based on hydrocarbons (SVOC/TPH) concentrations in soil above the goal of 100 mg/kg and of VOCs concentrations in soil above the goal of 10 mg/kg for noncontainment options. Conceptually, soils under railroad tracks would be left in place. This is discussed further in Section 3.1.

The outlined oil-affected area within the paved parking area is approximated based upon existing soil-boring data. The approximate in-place volume of affected soil for the combined areas is approximately 10,100 cubic yards, based upon the conceptual remedial goals shown in Table 14 and the areas shown in Figures 11A and 11B.

Arsenic Area. For the arsenic-affected area, the limits of affected soil in on-site areas have been identified based on the results of over 40 soil borings. Figure 12 shows an approximate area known to be affected with concentrations of arsenic above 50 mg/kg, the remedial objective for arsenic for noncontainment options. The extent of lead-affected soil in this area appears to be limited to the area also affected with arsenic. To develop remedial plans and relative costs, volumes of affected soil have been estimated based on the analytical results illustrated in Figure 12. Based on these data and the conceptual remedial goal for arsenic, the volume of soil targeted for remediation has been estimated to be 13,100 cubic yards.

2.0 SCREENING OF TECHNOLOGIES

Previous site investigations indicate soil and ground water have been affected by organic and inorganic compounds. This section provides a screening of remediation technologies for soil and ground water (Sections 2.1 and 2.2, respectively). The technologies are screened based on demonstrated efficacy in pilot-scale or field applications, implementability and effectiveness, general cost effectiveness, and potential regulatory acceptance.

2.1 Technologies Considered for Soil

Site investigations have revealed that the unsaturated soils (i.e., soils above ground water) at the Site are affected by both organic compounds (primarily petroleum-based hydrocarbons) and inorganic chemicals (most notably arsenic). For the unsaturated soils, the physical isolation of organic-affected soils from arsenic-affected soils present at the Site allows the possibility that each area may be treated separately by a variety of treatment options. These options are presented in the following sections.

For the saturated shallow zone soils where the mix of organic chemicals and arsenic in the ground water will have partitioned to varying degrees onto soil surfaces, the separation of organic- and arsenic-affected soils is not possible.

The following interim soil remedial measures were screened:

- stabilization (arsenic- and organic-affected, saturated [i.e., below ground water] and unsaturated [i.e., above ground water] soils)
- containment (arsenic- and organic-affected, saturated and unsaturated soils)
- soil washing (unsaturated, arsenic- and organic-affected soils)
- excavation and disposal (unsaturated, arsenic- and organic-affected soils)
- thermal treatment (unsaturated, organic-affected soils)
- biotreatment (unsaturated, organic-affected soils).

2.1.1 Stabilization

Stabilization technologies bind inorganic and/or organic chemicals into immobile forms using a variety of cement-, silicate-, asphalt- or organic polymer-based substances. Some of these agents and their mixtures are proprietary compounds. Effectively stabilized soils may resist leaching for several reasons, including low permeability resulting from the formation of solid, cement-like monoliths, and/or the strong sorption or encapsulation of chemicals to, or within, the stabilized soil matrix. The second mechanism allows the stabilized soil to remain in a workable condition rather than to be transformed into a monolithic block.

Soil biotreatment is considered more cost effective for the treatment of organic-affected soils in comparison to stabilization. As a result, stabilization of organic-affected soils was not considered further.

Treatability studies were conducted to evaluate the potential for stabilizing the arsenic-affected soils. A total of eight formulations were tested in more than 20 different mixtures. Five of these formulations were proprietary compounds. Details of the treatability studies are presented in Appendix A. In summary, no formulation stabilized arsenic and lead in site soils to the regulatory leaching concentration (5 mg/kg for arsenic and lead) as produced by the California Waste Extraction Test (WET). However, based on the Federal Toxicity Characteristic Leaching Procedure (TCLP) and a water extraction test, one formulation from Chemfix Technologies, Inc. was able to lower extractable arsenic and lead concentrations to levels below 5 mg/kg.

Stabilization of soils can be performed in situ or ex-situ. However, these treatability studies were conducted in a manner consistent with ex-situ technologies. Although it is likely formulations found to be effective in the treatability studies should stabilize these soils using in situ mixing operations, uncertainties will persist until some level of pilot-scale testing is performed.

Application of stabilization technologies to the soils below ground water would be a far less effective remediation alternative because (1) in situ stabilization of arsenic- and organic-affected soils in saturated soils has not been proven successful and (2) excavation and treatment of the soils would produce dewatering problems requiring additional treatment and disposal.

As a results, stabilization of arsenic-affected, unsaturated soils is retained for further evaluation.

2.1.2 Containment

The containment option includes capping the affected areas, construction of new surface drainage structures, and installation of either a passive or active hydraulic barrier to control ground-water movement and/or reduce the amount of ground-water extraction required. Horizontal barriers (e.g., asphaltic, Portland cement concrete cap, or flexible membrane liner [FML]) would control direct infiltration, significantly reducing the potential for vertical migration of chemicals into the ground-water column, while providing a direct barrier to wind or water erosion, and human exposure.

An impermeable barrier placed around the perimeter of the arsenic- and organic-affected soils to depths below affected ground water should mitigate the movement of these chemicals off site. This impermeable barrier could be constructed with a variety of materials and mixtures, including bentonite, soil-bentonite, and bentonite-soil-cement.

Containment is considered a viable option for interim site remediation, and therefore, this technology is retained for further consideration.

2.1.3 Soil Washing

Soil washing is a process that employs an aqueous solution of extracting chemicals to remove a contaminant from the soil matrix. The washing fluid may be composed of organic solvents, surfactants, chelating agents, acids, or bases, depending on the chemicals of concern to be removed. Treatment technologies that are applicable to arsenic-affected soils would involve extraction with bases and/or chelating agents, while organic solvents and/or surfactants would be employed for organic-affected soils. The effectiveness of this technology for removing arsenic from soils is not well established for full-scale field applications. Furthermore, soil washing would produce substantial amounts of arsenic in the aqueous phase that would require treatment and disposal.

One chemical extraction process that has demonstrated potential in field applications for organic-affected soils is the BEST process, which uses a secondary or tertiary amine solvent to extract organics from soils. The solvent is recovered by a distillation process and, while some of the extracted organics are volatilized, the remaining organics would require further treatment and disposal.

Soil washing was not retained for the saturated soils because extracting arsenic and organics simultaneously has not been demonstrated to be effective, it is not cost effective, and excavation and treatment of soils using this technology would produce dewatering problems requiring additional treatment and disposal.

2.1.4 Excavation and Disposal at an Off-Site, Permitted Disposal Facility

The soil excavation and disposal option would consist of excavating chemical-affected soils from selected areas and disposing of them at an off-site disposal facility (TSDF). The removal of chemical-affected soils from the Site would eliminate or reduce the potential for those chemicals to move into ground water or into the atmosphere at the Site.

Soils from the oil tank storage area, the arsenic area, and the solvent tank storage area (Figures 10 through 12) were profiled for permitted disposal. Three disposal facilities (USPCI, U.S. Ecology, and Chemical Waste Management) were considered for disposal of the affected soils. Each facility was contacted to discuss their acceptance of the affected soils. The framework for regulating off-site disposal of these soils, along with the response from the disposal facilities, is presented below.

Arsenic Area Soils. According to Federal EPA regulations in Title 40 of the Code of Federal Regulations (CFR) 261.24, most of the arsenic-affected soil would be classified as Resource Conservation and Recovery Act (RCRA) D004 waste. These wastes were addressed in the Third Third of the Land Disposal Restriction (LDR) program. EPA has granted a national capacity variance (which expires May 1, 1992) for soil and debris contaminated with Third Third wastes for which the treatment standard was based on incineration, mercury retorting, vitrification, or wet-air oxidation. The treatment standard for D004 wastes was based on vitrification.

One sample location in the northeastern corner of the arsenic area contains high concentrations of lead and arsenic. Lead is a waste whose treatment standard under the LDR program is based on an available treatment technology, while arsenic is a waste whose treatment standard is based on a technology with insufficient national capacity. In the June 1990 Final Rule for the Third Third group of wastes in the LDR program, EPA noted that such "soil and debris would remain eligible for the national capacity variance."

For the arsenic area soils, profiling was pursued with U.S. Ecology and USPCI. Representatives of these two facilities indicated they would accept the soil containing both lead and arsenic without treatment, and they would accept the soil containing only arsenic. A written acceptance for this waste was received from U.S. Ecology in November 1990. USPCI has verbally reversed their earlier decision not to accept the portion of the soil containing both lead and arsenic without treatment.

The option of disposal at an off-site facility is viable (although cost prohibitive) for the soils from the arsenic area, including the soils from the area containing both lead and arsenic, assuming disposal is implemented before May 1992 when the variance for land disposal of these wastes expires. As a result, excavation and disposal of arsenic-affected soils was retained for further consideration.

Oils and Solvent Tank Storage Area Soils. For certain organic wastes addressed in the LDR program, the best demonstrated available technology (BDAT) chosen by the EPA is incineration. Because of a shortage of incinerators, the EPA granted a national capacity extension until June 8, 1991, for soil and debris contaminated with compounds addressed under the Third Third portion of the LDR program that have a BDAT of incineration. Because the national capacity extension has expired, it is no longer possible to excavate and dispose of the soils from the solvent and oil tank storage areas without treatment. Treatment could be achieved either on site or off site, depending on the remedial options chosen. As a result, excavation, treatment (on-site or off-site), and off-site disposal (although cost prohibitive) were retained for further consideration.

Saturated Soils. Soils in the saturated zone (below the ground-water table) have not been extensively analyzed, but it is likely they contain essentially the same constituents as the ground water with which they are in contact. Excavation of those soils would require dewatering, and subsequent treatment and disposal of the resulting water. Therefore, excavation and disposal of the saturated soils was screened out because of the significant logistical problems associated with dewatering, multiple treatment of the water, and disposal.

2.1.5 Thermal Treatment

Thermal treatment of soils involves heating the affected soils to a temperature range suitable to destroy and/or volatilize organic compounds in the soil. Arsenic is not removed from soils by this treatment process. Therefore, this technology is best suited for the organic-affected unsaturated soils. Several mobile systems for treating organic-affected soils with low temperatures (300° to 800°Fahrenheit) have been developed (including X*TRAX™ system, Weston Services, Recovery Specialists) that employ a rotary kiln dryer or heated-screw conveyor and an off-gas handling unit. Soils with high amounts of carbon (both natural and synthetic) and water can depress the effectiveness or increase the energy use and cost of this treatment technology. The uncertainty of this technology and the resultant treatment of the off gas makes this option relatively unreliable, and therefore, this option was not considered further.

2.1.6 Soil Biotreatment

Soils affected with hydrocarbons are known to be amenable, to varying degrees, to biotreatment. Therefore, site soils from the former oil tank storage and former solvent tank storage areas that are affected with hydrocarbons, and which contain less than 500 mg/kg lead and less than 50 mg/kg arsenic, were evaluated for their suitability for bioremediation.

The potential for biotreating hydrocarbon-affected soils in the former tank storage areas was investigated in the Levine•Fricke laboratory. Testing revealed that under appropriate soil conditions (e.g., moisture, oxygen, and nutrients) the soils in both tank storage areas can be treated to below the laboratory detection limit of 10 mg of total petroleum hydrocarbon (TPH) per kg of soil (refer to detailed laboratory report in Appendix B).

The time required to treat the soils in the laboratory to below 10 mg/kg TPH ranged from 3½ weeks to 5 weeks. The treatability study demonstrated that the indigenous populations of soil microorganisms were sufficient to produce successful treatment, thereby eliminating the necessity to amend the soils with inoculations of laboratory-grown microorganisms.

The biotreatment of soils in the field, because of the potential stresses of low temperatures and lack of laboratory-controlled conditions, may require longer treatment times than those observed in the laboratory. Likewise, the optimal additions of soil amendments and microorganisms in the field also may prove to deviate from the rates that were derived from the laboratory investigations.

Overall, soil biotreatment was considered a viable option for interim site remediation, and therefore, this technology was retained for further consideration.

2.1.7 Results of Screening - Soil

Based on the screening of the technologies described above, stabilization, biotreatment, excavation and disposal, and containment exhibited potential for treating at least some portion of the chemical-affected soils at the Site. Several other technologies, including thermal treatment, incineration, and soil washing, were screened out because of their lack of demonstrated effectiveness in reported field remediations and/or their excessive cost of implementation.

Saturated soils (i.e., soils below ground water) at the Site likely will contain a mixture of organic compounds and arsenic. Given the different physico-chemical properties and mobility characteristics of arsenic relative to organics, their combined presence in the soils poses a difficult problem for treatment. In addition, the presence of chemical-affected water in these soils would require dewatering and treatment for appropriate disposal. Consequently, several of the technology options that are appropriate for either organic or inorganic compounds under unsaturated conditions cannot be implemented for the saturated soils.

The soil regions and their respective applicable treatment technologies that will be evaluated further are as follows:

Arsenic-affected unsaturated soils (above ground water):

- stabilization
- excavation and off-site disposal
- containment.

Organic-affected unsaturated soils (above ground water):

- biotreatment
- excavation and treatment/disposal off site
- containment.

Saturated soils (below ground water)

- containment.

The implementability of these technologies at the Site in appropriate combinations of remedial alternatives will be discussed in Sections 3.0 and estimated costs will be presented in Section 4.0.

2.2 Technologies Considered for Ground Water

Site investigations revealed that the ground water at the Site has been affected by both organic compounds (primarily petroleum-based) and inorganic elements (most notably arsenic).

There are two major strategies available for containing affected ground water and inhibiting future degradation of actual and potential beneficial uses. One is to physically contain the affected ground water with a cut-off wall to stop lateral migration and a cap or solidification process to limit vertical migration. Physical containment also would require some limited ground-water extraction to prevent leakage of water from the containment barrier. Extracted water may require treatment before disposal, depending on the selected disposal option and volumes extracted. The other containment option for ground water is to install an extraction system to pump the affected ground water from the Site in a manner designed to prevent vertical and lateral migration. The extracted water would have to be treated before discharge, as discussed in Section 1.4.3. A remedial program to control the sources of affected ground water would be an element of this strategy. Treatment options for the source area soils were evaluated in Section 2.1.

The following sections focus on the ground-water extraction alternative and screen appropriate technologies for remediating the chemical-affected ground water. Containment options for the Site were discussed in Section 2.1.2.

2.2.1 Extraction of Ground Water

Active extraction has been considered for addressing ground-water remediation. The objective of ground-water extraction would be to hydraulically contain affected ground water, thereby eliminating migration to off-site areas or to deeper ground-water zones. In situ technologies for remediating ground water would be ineffective for the Site because

(1) in situ treatment technologies have not been demonstrated for the arsenic- and organic-affected saturated zone, and (2) in situ treatment would not achieve the hydraulic containment objectives stated above.

2.2.2 Treatment Technologies for Extracted Ground Water

The following ground-water treatment technologies were screened:

- dissolved air flotation (DAF) (floating hydrocarbons)
- biotreatment (floating hydrocarbons and dissolved organics)
- Klensorb absorption (floating hydrocarbons)
- ion exchange (arsenic)
- electrochemical co-precipitation (arsenic)
- evaporation (arsenic)
- ultraviolet oxidation (dissolved organics)
- carbon adsorption (dissolved organics)
- evaporation with vapor controls (dissolved organics).

2.2.2.1 Dissolved Air Flotation. Dissolved air flotation (DAF) is a process for removing insoluble hydrocarbons from water. This treatment technology forces air into the water under pressure before feeding the water into a nonpressurized (i.e., open) tank. Under a release of pressure, introduced air escapes as small bubbles that carry hydrophobic oils to the surface of the water where a skimmer accumulates the floating oil for removal. This treatment technology is not effective in removing dissolved organic compounds or arsenic, and therefore, was not considered further.

2.2.2.2 Biotreatment. Biotreatment technologies use microorganisms to degrade organic compounds in ground water. However, the presence of high concentrations of arsenic in site ground water presented a potential toxicity problem for biological remediation. Therefore, a preliminary study was conducted to evaluate whether microbial respiration would survive in the arsenic-affected ground water. The investigation revealed that microbial activity was not suppressed; however, only a study over a significant period of time would provide an adequate evaluation of biotreatment to effectively treat arsenic-affected ground water.

Therefore, a laboratory study using a pilot-scale bioreactor was conducted in the Levine•Fricke laboratory to evaluate the feasibility of this technology for treating the Site's arsenic-affected ground water (refer to detailed laboratory report in Appendix C). Testing revealed that under appropriate bioreactor conditions (e.g., oxygen content, pH, nutrients, and carbon source) VOCs and SVOCs in the ground water were degraded to below laboratory detection limits.

The potential for bioremediation to reduce arsenic concentrations in ground water also was evaluated in the laboratory study (see laboratory report in Appendix C). In the anaerobic cells of the bioreactor, the arsenic concentration in ground water was reduced by 30 to 50 percent. Arsenic may have been removed from solution as metallic arsenic, sulfitic arsenic, or as organic arsenic bound within the microbial biomass. The removal of arsenic in the aerobic cells was minimal (less than 10 percent) unless ferric chloride ($FeCl_3$) was added to catalyze the sorption of arsenic. Following the addition of $FeCl_3$, the concentration of arsenic in the effluent was decreased to about 2 mg/L, suggesting the possibility of further arsenic removal by lowering the pH with dilute hydrogen chloride (HCl) (arsenic sorption to Fe hydroxides is enhanced by acid pH). However, after about one week of low arsenic concentrations in the effluent, breakthrough of arsenic up to 30 mg/L was observed.

Consequently, further efforts to evaluate removal of arsenic from ground water were abandoned in favor of optimizing the bioreactor for VOC and SVOC degradation. The two anaerobic cells were therefore eliminated from the bioreactor configuration to create a smaller, and more easily operable, aerobic bioreactor. The two-stage aerobic bioreactor reduced VOC and SVOC concentrations in the ground water to nondetectable levels.

Biological treatment of ground-water samples from the Site demonstrated arsenic did not inhibit the biological activity, free-phase hydrocarbons were directly treatable, and dissolved organics also could be successfully treated. Biotreatment of site ground water to remove VOCs, SVOCs, and floating oils is technically feasible, and will be retained for further consideration.

2.2.2.3 Klensorb Absorption. Klensorb absorption removes oils from water by a process of absorption of oil into a solid-phase material. For the hydrophobic organic compounds comprising the floating hydrocarbons, this treatment technology would be an effective means of protecting subsequent treatment steps (i.e., arsenic removal) from oil-fouling. This process, however, is not effective for removing hydrophilic VOCs (e.g., acetone and MEK) present in site ground water. Klensorb has limited sorptive capacity for organic compounds, which would require disposal of the material as a waste. Because the biotreatment study demonstrated that floating hydrocarbons could be biotreated without prior removal of arsenic, Klensorb absorption was screened-out as unnecessary.

2.2.2.4 Ion Exchange. Ion exchange technology promotes the sorption of charged compounds by exchanging ions of like charge on a solid phase containing charged functional groups. This treatment process is highly effective for heavy metals, but removal of arsenic, which can exist in a variety of negatively charged forms in ground water, is not as well developed. Furthermore, the resultant arsenic residue from ion exchange is a voluminous, corrosive water solution that would require further treatment. Therefore, ion exchange was not considered further as a primary treatment option because of technical uncertainties and lack of cost effectiveness. Ion exchange could, however, serve as a polishing step if the preferred technology for arsenic removal could not achieve discharge limits.

2.2.2.5 Electrochemical Co-Precipitation. This treatment technology removes inorganic elements from water through adsorption and co-precipitation reactions. The electrochemical process considered for removing arsenic from ground water at the Site is a combination of arsenic oxidation and subsequent co-precipitation with ferric iron. Electrochemical co-precipitation uses a direct current across an iron-containing electrode to introduce ferric ions into the water phase. Ferric iron has a low solubility at near-neutral pH, and forms a fresh, active ferric hydroxide precipitate. Freshly precipitated ferric hydroxides are known to remove the oxyanions of arsenic by adsorption and co-precipitation processes. The most oxidized form of arsenic, arsenate, is known to respond to this treatment better than the arsenite ion. Therefore, hydrogen peroxide is commonly added to oxidize all of the arsenic to arsenate.

To evaluate the feasibility of this technology for the Site, samples of ground water composited from several monitoring wells were sent to two vendors for laboratory-scale testing. The vendor tests for the electrochemical process were conducted without removing organic compounds from the ground-water sample because, at the time, it was thought that arsenic would have to be removed before the biological treatment process for organic removal. (However, biotreatment evaluations demonstrated that arsenic did not inhibit biodegradation of VOCs and SVOCs [see Section 2.2.2.2].)

The first vendor, Andco Environmental Processes, Inc., demonstrated removal of arsenic to less than 1 mg/L by three methods: (1) a large excess of iron (300 mg/L); (2) a moderate dosage of iron (100 mg/L) with the addition of hydrogen peroxide (70 mg/L); and (3) a combination of 100 mg/L of iron, 40 mg/L of hydrogen peroxide, and 100 mg/L of calcium chloride. The third test was included because of the high concentration of organic compounds in the test sample. The second method has the economic advantage of generating the smallest amount of sludge of the three. In addition, Andco indicated they have achieved 0.004 mg/L effluent arsenic concentrations in similar arsenic-affected ground water. Andco's laboratory report is included in Appendix D. If this treatment technology is selected, additional design-level optimization testing may be required to demonstrate the reliability of meeting the discharge standard with this ground water.

It was not considered necessary to test dewatering of the sludge precipitate, but the amount of precipitate formed was estimated because of its impact on the cost of treatment. All arsenic removal processes will generate a residue containing arsenic, and a major portion of the annual costs for treatment will be for the final disposal of that residue. Costs for treatment are discussed in Section 4.2.

The second vendor to test ground water from the Site was the UNOCAL Chemicals Division of UNOCAL Corporation using its patented Unipure process. The Unipure system consists of a dual-pass treatment process. Using one pass through its system, Unipure achieved arsenic treatment to 3.8 mg/L. With dual passes, Unipure reported a reduction to 0.16 mg/L. Unipure's results of testing are included in Appendix B.

The test results reported by the vendors indicated these processes will remove arsenic to at least 0.2 mg/L. The electrochemical process is preferred over ion exchange because the arsenic residue from the former is a minimum volume filter cake of iron and arsenic while the arsenic residue from ion exchange is a higher volume, corrosive water solution, which requires further treatment. As a result, electrochemical treatment was retained for further consideration.

2.2.2.6 Evaporation. Evaporation technology can be used for the removal of a liquid from a solid. In this case, the method may be applied to the removal of extracted ground water from its dissolved inorganic constituents, particularly arsenic. Evaporation can be implemented using direct heat transfer equipment (e.g., vacuum dryers, furnaces, steam tube dryers, and rotary calciners). Evaporation is usually effective in applications where either the liquid is high in solids and/or there is a small amount of liquid to be removed.

Although evaporation is not typically applied to remediate ground water, this technology was identified for screening because of its possible application for very low-flow extraction alternatives.

While evaporation is usually not considered a treatment technology for dissolved VOCs, its operation should cause the volatilization of these chemicals. The release of VOCs may require treatment (e.g., thermal oxidizer). Because arsenic is relatively volatile for an inorganic, it is also possible the off-gas would contain some of that toxic metal. Thermal oxidation would not be effective in controlling arsenic emissions to the air.

Evaporation technology has not been evaluated further because of the uncertainties associated with treatment quality and control, and high energy costs.

2.2.2.7 Ultraviolet Oxidation. This treatment technology uses ultraviolet light (UV) with ozone and/or hydrogen peroxide to oxidize organic compounds. The technology is relatively new and produces variable results, depending on the types and concentrations of organic compounds present and the overall characteristic of the ground water. Samples of the ground water were strongly colored from particulates, VOCs, and longer chain hydrocarbons. Therefore, UV light transmission through site ground water would be inhibited. As a result, UV oxidation is not considered a potential treatment technology for the Site. Also, other technologies proposed herein (biotreatment) have been demonstrated effective for treatment and are considered to be more cost effective than UV oxidation.

2.2.2.8 Activated Carbon Adsorption. Activated carbon is a material commonly used to remove dissolved organics from water. Its effectiveness is based primarily on an extensive network of internal porosity, created during the activation process. Hydrophobic (low water solubility) organic compounds have a relatively strong tendency to adsorb onto the carbon surface provided by its porosity. There also have been reports in the literature (Chen and Gupta 1978) indicating some arsenic adsorption on activated carbon, but this process has not been well developed.

Activated carbon adsorption was screened out for removal of dissolved organics at the Site for two reasons. First, the floating hydrocarbons would have to be thoroughly removed ahead of an adsorption system to prevent carbon fouling. Because Klensorb absorption (the method of choice to protect carbon) has proven to be unnecessary for floating hydrocarbon removal before biotreatment, it would amount to adding a process step to include it for carbon protection. The second, more important, reason is that the hydrophilic organics (e.g., acetone and MEK) present in ground water are not effectively removed by this technology. Activated carbon adsorption could, however, serve as a polishing step if the preferred technology effectively removed the hydrophilic organics but not the hydrophobic ones.

2.2.3 Results of Screening - Ground Water

Based on the screening of the technologies described above, biotreatment coupled with electrochemical co-precipitation demonstrated effectiveness for treating ground water for organic compounds and arsenic, respectively. Several other technologies, including DAF, Klensorb absorption, ion exchange, and UV oxidation were screened out because they lacked demonstrated effectiveness in field remediations of ground water containing VOCs, SVOCs, and arsenic, or because they were shown to be unnecessary. Ion exchange and/or carbon adsorption, however, could be employed for polishing the effluent for discharge. Evaporation has been preliminarily screened out pending acquisition of more accurate extraction flow-rate data.

In summary, the applicable treatment technologies for ground water that will be evaluated further are as follows:

- biotreatment for VOCs and SVOCs
- electrochemical co-precipitation for arsenic.

The implementability of these technologies at the Site in appropriate combinations of remedial alternatives will be discussed in Sections 3.0 and estimated costs will be presented in Section 4.0.

3.0 DEVELOPMENT OF POTENTIAL INTERIM REMEDIAL MEASURES

In this section, individual technologies that were screened to be effective in Section 2 are developed for implementation at the Site and presented in the context of five alternatives:

1. Hydraulic containment with full source (soils) excavation and disposal.
2. Hydraulic containment with full source (soils) treatment.
3. Engineered containment of chemical-affected areas with limited source (soils) treatment.
4. Engineered containment of chemical-affected areas with "hot spot" arsenic source (soils) treatment.
5. Engineered containment of chemical-affected areas.

The development of these alternatives has been made based on screening of technologies, their ability to meet the interim remedial goals of minimizing or eliminating potential human exposure to affected soils and ground water, containing site ground water to reduce the potential for movement off site, preliminary cost effectiveness, and extracting ground water to mitigate further degradation of water-yielding soils and ground water.

A no action alternative was evaluated for the Site; however, because this alternative would not address the goals and objectives for remediation, the no action option was not evaluated further as one of the interim remedial alternatives.

These alternatives focus on two overall strategies: active ground-water extraction (hydraulic containment) and subsequent treatment of extracted ground water, and engineered containment with varying degrees of source treatment.

Alternatives 1 and 2 use the hydraulic containment strategy. Under these options, hydraulic containment would be obtained by extracting ground water through a series of on-site and off-site extraction wells. This extracted ground water would be treated for removal of VOCs, SVOCs, and arsenic before discharge or reuse. Because the hydraulic containment options do not include engineered containment (i.e., slurry wall and capping), full source excavation and disposal or full source treatment of soils would be required to minimize potential human exposure.

Alternatives 3 through 5 focus on a strategy of engineered containment with varying degrees of source treatment. These three alternatives would include a slurry wall and site capping with limited ground-water extraction. Varying degrees of source treatment have been evaluated under Alternatives 3 through 5 to evaluate their cost effectiveness.

The following text presents a more detailed description of each of these alternatives. Cost estimates for each of these developed alternatives is presented in Section 4.0.

3.1 Alternative 1: Hydraulic Containment with Full Source (Soils) Excavation and Disposal

Alternative 1 has been developed based on conventional ground-water extraction and treatment. Containment of affected ground water is sought through active extraction of the saturated A-zone aquifer. Based on modeling, the estimated flow of the ground-water extraction system would be as high as 10 gallons per minute (gpm). Extracted ground water would be treated for removal of VOCs, SVOCs, and arsenic. Ground water could be treated for discharge or reuse. The difficulty in achieving low arsenic concentrations in discharges, however, favors industrial reuse of the treated water over NPDES discharge. The conceptual site layout for Alternative 1 is presented in Figure 13 and the conceptual treatment schematic is shown in Figure 14.

The following provides a description of the remedial components involved with the implementation of Alternative 1.

3.1.1 Active Hydraulic Containment

A range of ground-water extraction alternatives was developed to examine the costs and benefits of attempting different degrees of interim remediation. Each of the alternatives is conceptually capable of restricting the off-site migration of affected ground water. The alternatives differ in the degree of source control and remediation provided, and in the degree of certainty in restricting further off-site migration. Each of these extraction alternatives would be combined with a treatment system to remove target chemicals before discharge or reuse of the water.

The different ground-water extraction alternatives were evaluated hydraulically using analytical solutions to the ground-water flow equation. Hydraulic parameters such as transmissivity, storage coefficient, and the hydraulic gradient were taken from Levine•Fricke's Phase II investigation report (Levine•Fricke 1990a).

Steady-state flow to a well was evaluated using the Theis equation. Transient long-term solutions were made using the THEIS computer code developed by S.S. Papadopulos & Associates (unpublished code written by Dr. Charles Andrews, 1984) for multiple wells in an aquifer. This computer model calculates solutions for the superposition of multiple production well solutions using the Theis equation. In evaluating these solutions, the total thickness of the aquifer must be considered explicitly because the analytical solutions will not indicate aquifer dewatering. For these hydraulic evaluations, the A-zone aquifer unit was taken to have an upper boundary of 5 feet above Mean Low Low Water (MLLW) and a lower boundary of -3 feet MLLW taken from cross sections for the Site.

This alternative captures ground water on site and off site that contains chemicals above respective drinking water standards. It would use seven extraction wells or three french drains and three extraction wells, depending on the design preferences for extraction at the Site. The layout of the three extraction wells and three french drains is shown in Figure 13 with the estimated capture area after sustained pumping. The conceptual layout would place additional extraction wells in the solvent and oil tank storage areas as source control measures and would place one additional well at the downgradient perimeter of the Site. Extraction rates for the total system are estimated to be approximately 10 gpm. This alternative appears to provide adequate capture of affected ground water.

3.1.2 Treatment of Ground Water

A treatment system would be required for treating affected ground water generated by the ground-water extraction system. The conceptual treatment schematic is shown in Figure 14. Biological treatment and electrochemical co-precipitation are the primary processes that would be used to treat the affected ground water. The following describes these treatment processes in more detail.

<u>**3.1.2.1 Biotreatment of VOCs and SVOCs.**</u> Screening evaluations in Section 2.0 and Appendix B revealed that biotreatment can effectively treat site ground water in the presence of arsenic. Consequently, the biotreatment process can be implemented in this remedial alternative before the

arsenic removal process (see next section). Based on modeling of the identified ground-water extraction system, the estimated flow would be approximately 10 gpm. As indicated by results of the pilot-scale laboratory study conducted in the Levine·Fricke laboratory, the optimum process design for removal of the VOCs and SVOCs appears to be a submerged, fixed-film, two-stage aerobic bioreactor. The full-scale biological treatment system also would include clarification for suspended solids removal, sludge thickening and handling equipment, and cartridge filters and carbon adsorption vessels for final polishing as required.

3.1.2.2 Electrochemical Treatment of Arsenic.

Electrochemical precipitation would be used to remove arsenic in extracted ground water. This process technology would be implemented after the biotreatment process to avoid potential organic fouling of the arsenic precipitation process. Discharge waters may be polished by ion exchange and/or activated carbon. The disposal of arsenic-affected sludge would require off-site disposal in accordance with regulatory guidelines. Estimates of sludge production have been made based on results of the treatability work (see Appendix D) and vendor estimates and are included in the cost estimates presented in Section 4.0. The high sludge production and operational difficulty in achieving low concentrations of arsenic, however, favors implementation of some industrial reuse of the treated water over NPDES discharge. Nevertheless, the electrochemical process was demonstrated to be effective in reducing effluent discharge to below sanitary sewer discharge limits.

3.1.3 Excavation and Disposal of Affected Soils

As discussed in Section 2.0, excavation and disposal of affected soils is a remedial alternative considered for soils in the unsaturated A zone. This action could be implemented on affected soils requiring remediation. Many of the soils would require Class I disposal and the arsenic-affected soils would require off-site treatment before disposal at a Class I facility after May 1992. Areas identified for full excavation and disposal are shown in Figures 10, 11A, 11B, and 12. Saturated A-zone soils have not been considered for removal, as measures to control their impact on site ground water are addressed through either the active or passive hydraulic containment.

Site preparation before excavation activities may require structural reinforcement of on-site and neighboring off-site buildings located adjacent to the affected areas. Structural reinforcing activities would lengthen the total excavation duration and add to remediation costs.

The excavation of the affected areas is limited to accessible areas within the Site. Areas beneath existing building footprints, and current daily operations pathways (such as railroad tracks located west of the shop and boiler house and railroad tracks running through the former solvent tank storage area) would have to be left unexcavated or require extensive measures so that operations were not affected.

Excavation of the affected soils could be performed using a conventional backhoe. The excavated, affected soils could be temporarily stockpiled on site or loaded directly onto trucks licensed for transporting hazardous wastes. The pad for temporarily stockpiling the affected soils would be lined with visquine or similar impermeable barrier. Stockpiled soils also would be covered with visquine. Whenever possible, the affected soils would be loaded directly onto trucks to minimize handling and temporary storage on site. The trucks would be lined with plastic liners, and tarpaulins would be used to cover the affected soils during transportation to the TSDF. The trucks would be brushed clean and weighed before leaving the Site.

Current site operations and excavation activities would be expected to affect each other. Although every effort would be made to minimize the interference between site operations and excavation activities, delays and temporary operational slow-downs would be inevitable because of safety concerns. The affected area at the former oil tank storage area may experience a certain amount of inconvenience because of the limited space and access between buildings on the west side of this area and the operational railroad track on the east side. It is not anticipated excavation activities at the former solvent tank storage area would be affected because this area currently is vacant land with open access and minimal ongoing site operations.

3.2 Alternative 2: Hydraulic Containment with Full Source (Soils) Treatment

Alternative 2 has been developed based on conventional ground-water extraction and treatment. Alternative 2 is identical to Alternative 1, with the exception that affected soils would be remediated through treatment on site instead of excavation, off-site treatment for organic-affected soils, and disposal. Containment of affected ground water would be sought through active extraction of the saturated A-zone aquifer. Based on modeling, the estimated flow of an extraction system would be as much as 10 gpm. Extracted ground water would be treated for removal of VOCs, SVOCs, and arsenic. Ground water could be treated for discharge or reuse. The difficulty in achieving low concentrations of arsenic in discharges, however, favors industrial reuse of the treated water over NPDES discharge. The conceptual site layout for Alternative 2 is presented in Figure 13 and the conceptual treatment schematic is shown in Figure 14.

The following provides a description of the remedial components involved with implementation of Alternative 2.

3.2.1 Active Hydraulic Containment

Hydraulic containment for this alternative is identical to that of Alternative 1, and would capture ground water on site and off site containing chemicals above respective drinking water standards. It would use seven extraction wells or three french drains and three extraction wells, depending on the design preferences for extraction at the Site. The layout of the three extraction wells and three french drains is shown in Figure 13 with the estimated capture area after sustained pumping. The conceptual layout would place additional extraction wells in the solvent and oil tank storage areas as source control measures and would place one additional well at the downgradient perimeter of the Site. Extraction rates for the total system are estimated to be approximately 10 gpm. This alternative appears to provide complete capture of affected ground water.

3.2.2 Treatment of Ground Water

A treatment system would be required for treating affected ground water generated by the ground-water extraction system. The treatment system would be identical to that proposed under Alternative 1, and the conceptual treatment schematic is shown in Figure 14. Biological treatment and electrochemical co-precipitation are the primary processes that would be used to treat the affected ground water. Section 3.1.2 describes the treatment processes selection and Section 2.2 describes the processes in greater detail.

3.2.3 Treatment of Affected Soils

As discussed above, the on-site remediation of affected soils may be a viable option for minimizing potential human exposure and for limiting migration of chemicals of concern to ground water. Selection of soil treatment may be independent of other control measures implemented. Soil treatment may be most beneficial when implementing options that do not include containment because noncontainment options do not include a site cap and would allow for continued infiltration and direct human exposure. Further evaluations of health effects or deed restrictions that may apply if soils are treated and left in place also may affect implementation of this alternative. Discussion of treatment for the organic- and arsenic-affected soils is presented below. Affected areas for treatment are identified in Figures 10, 11A, 11B, and 12.

3.2.3.1 Bio-Treatment of Organic-Affected Soils. As demonstrated during the screening treatability study, the organic-affected soils are amenable to bioremediation. The implementation of this alternative could enhance the control of off-site migration, particularly in cases where a site cap is not implemented or where regulatory requirements have established remediation goals for on-site soils. The site investigations have identified the source areas for the VOC- and SVOC-affected soils, respectively, and the assumed areas for treatment are depicted in Figures 10, 11A, and 11B. Quantities of affected soils have been estimated based on preliminary remediation goals, as presented in Section 1.4.2.

Biotreatment of the affected soils will require sufficient area to stage the excavation and to treat the soils. The limited area available may affect the time frame of this alternative. The excavation of affected soils may also disrupt the activities at the Site, both by limiting access to certain areas and by disrupting rail access to the Site. Other factors that have been taken into consideration in developing this option include implementation of a Health and Safety Plan. Because of the volatile nature of many of the organic compounds present, extensive efforts will be needed to control potential exposure to nearby residents and on-site personnel.

Successful treatment of organic-affected soils should reduce the potential for these soils to leach organic compounds to ground water, thereby restricting further degradation of water-yielding zones and the potential for human exposure.

3.2.3.2 Stabilization of Arsenic-Affected Soils. As demonstrated in the screening treatability studies, stabilization of arsenic-affected soils was achieved by a proprietary formulation from Chemfix Technologies, Inc. Stabilization of arsenic-affected soils would be implemented in situ, using a deep soil mixing technology available from several vendors. The in situ option would be implemented because of the difficulties anticipated in excavating adjacent to existing buildings and because of permitting/regulatory difficulties associated with excavating this arsenic-affected soil. Implementation of this option under this scenario may require relocation of existing utilities and railroad lines. The assumed areas for implementation of this alternative are presented in Figure 12.

3.3 Alternative 3: Engineered Containment of Chemical-Affected Areas with Limited Source (Soil) Treatment

This alternative would employ engineered containment to control migration of affected ground water and eliminate potential human exposure pathways. At the same time, this alternative would reduce the amount of ground water requiring extraction and treatment. Engineered containment would include installing a cap and slurry wall around the on-site areas of affected soil and ground water in conjunction with ground-water extraction and treatment within the containment zone to dewater the sediments and maintain an inward hydraulic gradient. Limited source remediation of arsenic-, lead-, VOC-, and SVOC-affected soils is included under this alternative. The conceptual soil remedial goals would be higher than those given in Section 1.4.2.1 because containment is part of this alternative. Under this alternative, it is assumed soils would be remediated (stabilization for inorganic elements and biotreatment for organic compounds) based on the following cleanup goals:

Chemical	Cleanup Goal	Basis
lead	1,000 mg/kg	TTLC*
arsenic	500 mg/kg	TTLC
VOCs	100 mg/kg	Conceptual
SVOCs	Contain in-place	Conceptual

*Total Threshold Limit Concentration

Figure 15A presents the layout of the proposed engineered containment system under this alternative. Figures 11A and 12 detail the estimated areas required for soil remediation assuming limited source reduction. This alternative includes capping the affected areas, construction of new surface drainage structures, and installation of a passive hydraulic barrier to control ground-water movement. The conceptual treatment schematic shown in Figure 14 would apply to this alternative.

The following provides a description of the remedial components involved with implementation of Alternative 3.

3.3.1 Containment

Containment includes construction of barriers to impede both vertical and horizontal infiltration or leakage. A detailed discussion of the implementation of these barriers follows.

3.3.1.1 Horizontal Barrier. Under this alternative, limited areas containing affected soils and ground water could be stabilized and sealed with a variety of capping materials, including asphalt, concrete, low permeability soils or clays, or flexible membrane liners. For this alternative, it is anticipated a multimedia cap would be designed using a combination of the above materials.

Drainage piping would be installed to channel precipitation and runoff from the Site. The cap would be installed over the areas of affected soil and ground water at the Site, as depicted in Figure 15A. The areas to be capped would be graded to allow proper drainage. Catch basins also would be installed to promote drainage and to reduce the potential for ponding in the vicinity of the affected areas. A sealant could be applied to the surface of the asphalt or concrete cap to further reduce infiltration.

In the affected areas where there is an existing concrete or asphalt cover (such as the former Oil Tank Storage area, located west and north of the boiler house and loading racks, respectively), an inspection should be performed to identify features that may affect the integrity of the cap, such as poor drainage zones, cracks, open joints, and damaged concrete or asphalt. These undesirable features would need to be repaired or replaced as necessary.

Horizontal barriers composed of asphalt or concrete pavement are subject to infiltration, which can allow collection of water within a horizontally contained zone. Because of the complexity and cost of treating the chemicals of concern in the ground water and the high operating costs of treatment, it is usually economical to make capital expenditures to reduce the operational costs associated with such infiltration. A multimedia cap capable of meeting these requirements for the

Site would probably consist of a low permeability flexible membrane liner (FML), covered with a layer of sand to protect its integrity. To provide a wearing surface for the cap, a low load-bearing wearing surface should be constructed, which could consist of a gravel subbase and an asphalt-cement paving section. Actual materials and design thickness for the cap will be determined in the design phase. To improve surface-water runoff, an asphaltic seal coat could be applied.

For evaluation purposes, assumptions of permeability have been made; it has been assumed approximately 99 percent of surface water would run off and 1 percent would infiltrate. Quantities of infiltrated water can be estimated based on local incident rainfall, surface area, and estimated permeabilities. The quantity of infiltrated water to be treated has been addressed as a potential cost and is included in the conceptual cost estimates presented in Section 4.0.

3.3.1.2 Vertical Barrier. Control of affected ground-water migration would be effected through the construction of an impermeable barrier and the extraction of ground water. A discussion of impermeable barriers follows, and ground-water extraction is discussed in Section 3.3.2.

Impermeable Barrier. An impermeable barrier may be implemented through construction of a slurry wall. A slurry wall is one of several types of subsurface cut-off walls that significantly reduce leaching of chemicals of concern by redirecting upgradient ground water away from an affected area, and/or by controlling horizontal leachate movement away from a site. A slurry wall is constructed by excavating a trench using a backhoe, and backfilling the trench with a soil bentonite slurry or bentonite-cement slurry. The slurry wall would be keyed into the low permeability Bay Mud materials, as shown in Figure 15B. The backfilled trench has a much lower coefficient of permeability than the surrounding soil and thus creates a barrier to ground-water flow. Because of the inherent flexibility of soil bentonite slurry walls and the ability to incorporate excavated soils into the slurry wall materials, thereby reducing disposal costs, this option is included in this alternative.

The slurry cut-off wall also would be integrated with the surface cover. The continuous bentonite slurry wall would be installed at the periphery of the affected areas to minimize lateral migration of the chemical compounds within the affected soils. The slurry wall would be keyed into the surface cap and the shallow zone low permeable clay soils at the top and bottom, respectively. The affected soils are thus isolated from ground-water movement using a combination of surface cover and cut-off wall.

Installation of a cut-off wall may require the structural support of building foundations along its alignment. The excavation of the slurry trench could cause foundation instabilities that would need to be addressed before this option can be implemented. Based on observations of the structures on the Site and neighboring properties, it is anticipated structural underpinning (probably consisting of slant piles and connecting beams) may be required. This safeguard, while costly, should allow for implementation of this option without disruption or damage to these structures.

The other physical features that could affect costs of this interim remedial measure are underground utilities and foundations. The occurrence of abandoned foundations may make excavation of the trench more difficult, or may require realignment of the cut-off wall. A review of existing structures and possibly a field exploration may be needed to evaluate the presence and condition of existing and abandoned foundations. Nevertheless, this option is implementable and technical construction issues would be addressed during the design phase.

3.3.2 Ground-Water Extraction and Treatment

3.3.2.1 Ground-Water Extraction. Ground-water extraction would be integrated with passive containment to provide full hydraulic containment of affected ground water. Ground water would be extracted from three shallow ground-water extraction wells within the containment area. An estimate of the total flow rate from these wells is less than 1 gpm. These wells would be designed to provide dewatering of the contained zone, both to provide a zone of lower hydraulic potential, and to effectively dewater this potential source area. Estimated flow rates have been developed based on soil permeabilities and anticipated ground-water production after dewatering the saturated A-zone soils.

3.3.2.2 Ground-Water Treatment. Treatment of extracted ground water under this alternative would follow the basic scheme identified in Section 2.0 and further developed under Alternative 1, as presented in Figure 14. The flow rates are anticipated to be significantly less (less than 1 gpm) than the 10 gpm flow rate discussed for Alternatives 1 and 2, with the majority of the extracted water containing arsenic, VOCs, and SVOCs. The treatment for the VOCs and SVOCs would use a submerged, fixed-film reactor for biological oxidation of these organic compounds. Discharge from the biotreatment system would still need treatment for reduction of the arsenic before discharge or reuse.

Electrochemical precipitation would be used for treatment of the arsenic in extracted ground water. At the low flow rates and the lower loading of arsenic, it is anticipated this equipment could be operated on a batch basis. The reduction in arsenic-affected ground-water flow rates reduces significantly the volume of sludge production and associated off-site disposal costs. The ground-water discharge may be polished using ion exchange and/or carbon adsorption technologies, depending on ultimate discharge or reuse applications.

3.3.3 Treatment of Affected Soils

As discussed above, the on-site remediation of affected soils may be a viable option for further reducing potential human exposure and for limiting migration of chemicals of concern to ground water. Application of soil treatment technologies may be independent of other control measures implemented. Health effects or deed restrictions that may apply if soils are left untreated also may affect implementation of this alternative. Discussion of treatment for the organic- and arsenic-affected soils are presented below.

Biotreatment of Organic-Affected Soils. Biotreatment of soils would be implemented similar to Alternative 2; however, only limited remediation of VOC-affected soils (conceptual cleanup goal of 100 mg/kg) in the solvent tank storage area is proposed under this alternative. SVOC-affected soils are proposed to be contained in place because capping also is included as part of this alternative. Affected areas for limited source biotreatment are shown in Figure 11A.

Biotreatment of affected soils would require sufficient area to stage the excavation and to treat the soils. The limited area available may affect the time frame of this alternative. Excavation of affected soils also may disrupt activities at the Site, both by limiting access to certain areas and by disrupting rail access to the Site. Other factors that have been taken into consideration in developing this option include implementation of a Health and Safety Plan. Because of the volatile nature of many of the organic compounds, efforts will need to be made to control potential exposure to nearby residents and on-site personnel.

Successful treatment of organic-affected soils should reduce the potential for these soils to leach organic compounds to ground water, thereby restricting further degradation of water-yielding zones and further reducing the potential for human exposure.

Stabilization of Arsenic-Affected Soils. Stabilization of arsenic-affected soils would be implemented similar to Alternative 2; however, only limited remediation of these soils (conceptual cleanup goal of 500 mg/kg) is proposed under this alternative because capping would be implemented as part of this alternative. Affected areas for limited source fixation of arsenic soils are shown in Figure 12.

As demonstrated in the screening treatability studies, stabilization of arsenic-affected soils was achieved by a proprietary formulation from Chemfix Technologies, Inc. Stabilization of arsenic-affected soils would be implemented in situ, using a deep soil mixing technology available from several vendors. The in situ option would be implemented because of the difficulties anticipated in excavating adjacent to existing buildings and because of permitting/regulatory difficulties associated with excavating this arsenic-affected soil. Implementation of this option under this scenario may require relocation of existing utilities and railroad lines. The assumed areas for implementation of this alternative are presented in Figure 12.

3.4 Alternative 4: Engineered Containment of Chemical-Affected Areas with "Hot-Spot" Arsenic Source Treatment

This alternative would employ engineered containment to control migration of affected ground water and eliminate potential human exposure pathways. At the same time, this alternative would reduce the amount of ground water requiring extraction and treatment. Engineered containment would include installing a cap and slurry wall around the on-site areas of affected soil and ground water in conjunction with ground-water extraction and treatment within the containment zone to dewater the sediments and maintain an inward hydraulic gradient. This alternative is similar to Alternative 3, with the exception that only remediation of "hot spot" arsenic-affected soils is proposed under this alternative because engineered containment (slurry wall and capping) would eliminate the potential exposure pathways for affected soils and ground water. The conceptual soil remedial goals would be above those given in Section 1.4.2.1 because containment is part of this alternative. The soil remedial goals assume only "hot spot" remediation of arsenic soils and containment of the remaining soils. Under this alternative, it is assumed arsenic-affected soils would be remediated (by solidification) based on the following cleanup goals:

Chemical	Cleanup Goal	Basis
lead	Contain in-place	Conceptual
arsenic	5,000 mg/kg	Ten Times the TTLC
VOCs	Contain in-place	Conceptual
SVOCs	Contain in-place	Conceptual

Figure 15A presents the layout of the proposed engineered containment system under this alternative. Figure 12 details the estimated areas required for soil remediation assuming "hot spot" arsenic source reduction. This alternative includes capping the affected areas, construction of new surface drainage structures, and installation of a passive hydraulic barrier to control ground-water movement. The conceptual treatment schematic shown in Figure 14 would apply to this alternative.

The following provides a description of the remedial components involved with the implementation of Alternative 4.

3.4.1 Containment

Containment includes construction of barriers to impede both vertical and horizontal infiltration or leakage. Identical to Alternative 3, a multimedia cap would be used as a horizontal barrier and a slurry wall would be used as a vertical barrier. A detailed discussion of the implementation of these barriers is presented in Sections 3.3.1.1 and 3.3.1.2.

3.4.2 Ground-Water Extraction and Treatment

3.4.2.1 Ground-Water Extraction. Ground-water extraction would be integrated with passive containment to provide full hydraulic containment of affected ground water. Identical to Alternative 3, ground water would be extracted from three shallow ground-water extraction wells within the containment area. An estimate of the total flow rate from these wells is less than 1 gpm. These wells would be designed to provide dewatering of the contained zone, both to provide a zone of lower hydraulic potential, and to effectively dewater this potential source area. Estimated flow rates have been developed based on soil permeabilities and anticipated ground-water production after dewatering the saturated A-zone soils.

<u>3.4.2.2 Ground-Water Treatment.</u> Treatment of extracted ground water under this alternative would be identical to Alternative 3 and as presented in Figure 14. The flow rates are anticipated to be significantly less (less than 1 gpm) than the 10 gpm discussed for Alternative 1 (Section 3.1.2), with the majority of the extracted water containing arsenic, VOCs, and SVOCs. The treatment technology would use a submerged, fixed-film bioreactor for biological oxidation of VOCs and SVOCs. Discharge from the biotreatment system would still need treatment for reducing arsenic concentrations, before discharge or reuse.

Electrochemical precipitation would be used for reducing arsenic concentrations in extracted ground water. At the low flow rates and the lower loading of arsenic, it is anticipated this equipment could be operated on a batch basis. The reduction in arsenic-affected ground-water flow rates significantly reduces the volume of sludge production and associated off-site disposal costs. The ground-water discharge may be polished using ion exchange and/or carbon adsorption, depending on ultimate discharge or reuse applications.

3.4.3 Treatment of Affected Soils

As discussed above, the on-site remediation of affected soils may be a viable option for further reducing potential human exposure and for limiting migration of chemicals of concern to ground water. Application of soil treatment technologies may be independent of other control measures implemented. Health effects or deed restrictions that may apply if soils are left untreated also may affect implementation of this alternative. Discussion of treatment for the organic- and arsenic-affected soils are presented below.

<u>Fixation of Arsenic-Affected Soils.</u> Fixation of arsenic-affected soils would be implemented similar to Alternative 2; however, only limited remediation of these soils (conceptual cleanup goal of 5,000 mg/kg) is proposed under this alternative because capping would be implemented as part of this alternative. Affected areas for "hot spot" arsenic source treatment are shown in Figure 12.

As demonstrated in the screening treatability studies, stabilization of arsenic-affected soils was achieved by a proprietary formulation from Chemfix Technologies, Inc.

Stabilization of arsenic-affected soils would be implemented in situ, using a deep soil mixing technology available from several vendors. The in situ option would be implemented because of the difficulties anticipated in excavating adjacent to existing buildings and because of permitting/regulatory difficulties associated with excavating this arsenic-affected soil. Implementation of this option under this scenario may require relocation of existing utilities and railroad lines. The assumed areas for implementation of this alternative are presented in Figure 12.

3.5 Alternative 5: Engineered Containment of Chemical-Affected Areas

This alternative would employ engineered containment to control migration of affected ground water and eliminate potential human exposure pathways. At the same time, this alternative would reduce the amount of ground water requiring extraction and treatment. Engineered containment would include installing a cap and slurry wall around the on-site areas of affected soil and ground water in conjunction with ground-water extraction and treatment within the containment zone to dewater the sediments and maintain an inward hydraulic gradient. This alternative is similar to Alternative 3, with the exception that no source remediation of soils is proposed under this alternative because engineered containment (slurry wall and capping) would eliminate the potential exposure pathways for affected soils and ground water.

Figure 15A presents the layout of the proposed engineered containment system under this alternative. The conceptual treatment schematic shown in Figure 14 would apply to this alternative.

The following provides a description of the remedial components involved with the implementation of Alternative 5.

3.5.1 Containment

Containment includes the construction of barriers to impede both vertical and horizontal infiltration or leakage. Identical to Alternative 3, a multimedia cap would be used as a horizontal barrier and a slurry wall would be used as a vertical barrier. A detailed discussion of the implementation of these barriers is presented in Sections 3.3.1.1 and 3.3.1.2.

3.5.2 Ground-Water Extraction and Treatment

3.5.2.1 Ground-Water Extraction. Ground-water extraction would be integrated with passive containment to provide full hydraulic containment of affected ground water. Identical to Alternative 3, ground water would be extracted from three shallow ground-water extraction wells within the containment area. An estimate of the total flow rate for these wells is less than 1 gpm. These wells would be designed to provide dewatering of the contained zone, both to provide a zone of lower hydraulic potential, and to effectively dewater this potential source area. Estimated flow rates have been developed based on soil permeabilities and estimated time to dewater the saturated A-zone soils.

3.5.2.2 Ground-Water Treatment. Treatment of extracted ground water under this alternative would be identical to Alternative 3 and as presented in Figure 14. The flow rates are anticipated to be significantly less (less than 1 gpm) than the 10 gpm rate discussed for Alternative 1 (Section 3.1.2), with the majority of the extracted water containing arsenic, VOCs, and SVOCs. The treatment technology would use a submerged, fixed-film bioreactor for biological oxidation of VOCs and SVOCs. Discharge from the biotreatment system would still need treatment for reducing the arsenic before discharge or reuse.

Electrochemical precipitation would be used for reducing arsenic concentrations in extracted ground water. At the low flow rates and the lower loading of arsenic, it is anticipated this equipment could be operated on a batch basis. The reduction in arsenic-affected ground-water flow rates reduces significantly the volume of sludge production and associated off-site disposal costs. The ground-water discharge may be polished using ion exchange and/or carbon adsorption, depending on ultimate discharge or reuse applications.

4.0 ANALYSIS OF COSTS FOR POTENTIAL INTERIM REMEDIAL MEASURES

4.1 Assumptions

Development of the proposed conceptual cost estimates have been prepared based on engineering judgement, data available from site investigations to date, conceptual soil cleanup levels, ground-water discharge standards, and the results of the treatability work conducted during this phase of work.

We have evaluated costs for alternative interim remedial alternatives as presented in Section 3.0. For the purposes of these cost estimates, the primary processes for treatment of ground water are anticipated to be biological oxidation for VOC- and SVOC-affected ground water, with a chemical precipitation step for removal of extracted arsenic-affected ground water. Costs for the various containment options (passive and active) have been prepared based on implementation of these ground-water treatment technologies. Final evaluation of applicability of these technologies would be made during the design period to confirm and more accurately estimate the costs and feasibility for the implemented interim remedial measures.

4.2 Capital Costs

The capital cost estimates developed for this evaluation include equipment and construction costs and engineering and permitting costs. The costs for further subsurface investigation (if required), regulatory interface, or permit fees have not been included in this evaluation because they are unknown at this time and relatively uncertain. A contingency factor, however, has been included in the cost estimates to cover some or all of these unknown costs.

The cost estimates have been developed from vendor and contractor quotes, treatability studies, a historical cost database, cost estimating manuals, and best engineering judgment. The reasons for the large range are based on (1) current site subsurface conditions, which cannot be fully characterized with respect to the extent and types of contamination and therefore cannot be expected to accurately reflect actual subsurface conditions, and (2) the complexity of regulatory issues and the possibility for significant change in regulatory requirements in the future, which would be expected to influence remedial efforts. Although some of these costs are not literally capital costs (i.e., construction management, engineering, and permitting), they have been included to clearly represent one-time initial costs versus longer term annual operations and maintenance (O&M) costs.

4.3 Operations and Maintenance

The O&M cost estimates developed for this evaluation include carbon, equipment, chemicals, laboratory, and power and waste disposal costs. The operations and maintenance cost estimates do not include necessary regulatory interface and permit fees. These estimates have been developed from vendor quotes, treatability studies, a historical cost database, cost estimating manuals, and best engineering judgement.

O&M costs can vary greatly depending on quality of the installation, inspection, specified equipment, preventive maintenance, and more important site-specific treatment efficiencies. Estimated O&M costs have been developed for each alternative. We have developed these cost projections based on preliminary estimated removal rates of chemicals from ground water and soil.

To provide an equitable way to evaluate alternatives with different capital and O&M costs, we have presented O&M costs on a present worth basis. The present worth has been calculated on a net interest rate (interest minus inflation) of 5 percent.

For purposes of cost comparison between the alternatives, duration of the site remedial measures has been assumed to be 20 years. The actual duration for the interim remedial measures is uncertain because of limitations of the site data and the technical and regulatory complexities which make prediction of cleanup time uncertain. To refine the cleanup time estimates for remedial alternatives, additional hydrogeologic modeling could be conducted as additional and/or supplemental data become available.

4.4 Alternatives Cost Analysis

Detailed costs for the five alternatives are presented in Tables 16 through 23. A comparative summary of all the costs are presented in Table 24. The following provides a brief description of the costs for each alternative.

4.4.1 Alternative 1: Hydraulic Containment with Full Source (Soils) Excavation and Disposal

The estimated capital and O&M costs for Alternative 1, are presented in Tables 16, 17, and 18. Alternative 1 provides hydraulic control using ground-water extraction and treatment without engineered containment measures. As a result, source area soil remediation using excavation/disposal is assumed. This alternative (and Alternative 2) has the highest estimated extraction flow rates of all the alternatives and subsequently the highest annual O&M costs of $256,000 per year. This alternative also has the highest overall capital cost of all the alternatives, with an estimated capital cost of $18.6 million. The estimated present worth for this alternative is $21.8 million.

4.4.2 Alternative 2: Hydraulic Containment with Full Source (Soils) Treatment

The estimated capital and O&M costs for Alternative 2 are presented in Tables 16, 17, and 19. Alternative 2, as with Alternative 1, provides hydraulic control using ground-water extraction and treatment without engineered containment measures. Alternative 2 is similar to Alternative 1, with the exception that source area soil remediation by treatment is assumed instead of excavation and disposal. This alternative (and Alternative 1) has the highest estimated extraction flow rates of all the alternatives and subsequently the highest annual O&M costs of $256,000 per year. The overall capital cost of this alternative is an estimated $4.5 million. The estimated present worth for this alternative is $7.7 million.

4.4.3 Alternative 3: Engineered Containment with Limited Source (Soils) Treatment

The estimated capital and O&M costs for Alternative 3, engineered containment of the arsenic-, VOC-, and SVOC-affected area along with ground-water extraction and treatment, are presented in Tables 20, 21, and 22. Alternative 3 is based on engineered containment with limited source treatment of soils. This alternative has the lowest extraction rate (identical to Alternatives 4 and 5) and subsequently the lowest annual O&M costs, estimated at $125,000 per year. The overall capital cost of this alternative is an estimated $4.5 million. The estimated present worth for this alternative is $6.1 million.

4.4.4 Alternative 4: Engineered Containment with "Hot Spot" Arsenic Source (Soils) Treatment

The estimated capital and O&M costs for Alternative 4, engineered containment of the arsenic-, VOC-, and SVOC-affected area along with ground-water extraction and treatment, are presented in Tables 20, 21, and 23. Alternative 4 is based on engineered containment with "hot spot" treatment of arsenic-affected soils. This alternative has the lowest extraction rate (identical to Alternatives 3 and 5) and subsequently the lowest annual O&M costs, estimated at $125,000 per year. The overall capital cost of this alternative is an estimated $3.6 million. The estimated present worth for this alternative is $5.2 million.

4.4.5 Alternative 5: Engineered Containment

The estimated capital and O&M costs for Alternative 5, engineered containment of the arsenic-, VOC-, and SVOC-affected area along with ground-water extraction and treatment, are presented in Tables 20 and 21. Alternative 5 is based on engineered containment without treatment of soils. This alternative has the lowest extraction rate (identical to Alternatives 3 and 4) and subsequently the lowest annual O&M costs, estimated at $125,000 per year. The overall capital cost of this alternative is an estimated $2.3 million. The estimated present worth for this alternative is an estimated $3.9 million.

5.0 RECOMMENDED INTERIM REMEDIAL MEASURE -- ALTERNATIVE 5, ENGINEERING CONTAINMENT

Selection of the recommended interim remedial measure has been based on estimated cost of implementation, applicability of the alternative, and perceived acceptance by regulators. The alternatives have been developed based on the concept that they are equal in their ability to meet the stated remedial goals for the project.

Alternative 5 would result in engineered containment of the soils known to be affected on site. This alternative would result in meeting the stated interim remedial goals for the site (i.e., to reduce the potential for exposure pathways from the affected soils and ground water, contain the affected ground water on site, and control source areas to minimize further ground-water impacts). Because affected materials on site would be contained through engineered remedial measures, it is anticipated the regulatory agencies may not require active remediation of soils on site.

Based on the stated remedial goals, cost effectiveness and other stated criteria, Alternative 5, Engineered Containment, is the recommended interim remedial measure. This alternative includes containment of the VOC-, SVOC-, and arsenic-affected soil and ground water.

Alternative 5 is recommended for the following reasons:

- saturated soils, which have probably sorbed substantial amounts of arsenic and organic compounds, would be contained and this source of degradation of site ground water, regardless of ground-water extraction and treatment option selected, would be controlled

- containment of chemical affected areas would mitigate further off-site migration of ground water

- containment provides control of the affected areas without the need for soil treatment or disposal

- use restrictions (deed restrictions) could be imposed on the property in conjunction with containment to prevent potential future exposures as a result of site activities

- containment would reduce the amount of ground water requiring extraction and subsequent treatment, which meets both regulatory concerns regarding excessive pumping of ground water and reduces overall operational costs for implementation

- this alternative could be implemented relatively quickly in comparison to other alternatives, allowing for implementation of interim remedial measures sooner.

This alternative has the lowest estimated capital cost of $2.3 million and annual O&M costs of $125,000 per year with a 20-year present worth O&M value of $1.56 million. The total estimated present worth cost for this alternative is $3.9 million. Final evaluation of this alternative should be made during the design period to confirm and refine the cost estimates and feasibility for the recommended interim remedial measure.

6.0 SCHEDULE FOR IMPLEMENTATION

The estimated schedule for implementation of recommended Alternative 5 is presented in Figure 19. This schedule is highly dependent on the time required to receive approval from the regulatory agencies. We have assumed 4 months for regulatory approval for purposes of this evaluation. As a result, it is anticipated to take approximately 18 months to completion of construction.

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TABLE 1

SUMMARY OF SITE SOIL AND GROUND-WATER INVESTIGATIONS

Date	Description
1987	Sherwin-Williams changed site manufacturing operations and dismantled two chemical tank storage facilities, including an oils tank storage area and a solvent tank storage area.
1988	Sherwin-Williams conducts a preliminary investigation to evaluate potential environmental impacts to soil in the former tank storage area. The investigation includes drilling three soil borings in the former oils tank storage area and three soil borings in the former solvent tank storage area. Eleven soil samples were submitted for analysis using EPA Methods 8240 and 8270 for organic compounds, and CAM Title 22 metals. Laboratory results indicated the need for further investigation to evaluate the extent of the affected areas.
1989	Levine•Fricke contracted to conduct a Phase I investigation of soil and ground-water quality in the former tank storage areas. Nine soil borings were drilled and seven shallow monitoring wells were installed in on-site areas. The results of the laboratory analyses of soil and ground-water samples indicated that both soil and ground water has been affected by a range of volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs), and some inorganic compounds, notably arsenic and lead. The results of the Phase I investigation were reported to the San Francisco Bay Regional Water Quality Control Board (RWQCB) and the Alameda County Health Department (Levine•Fricke July 17, 1989).
1989 - 1990	A Phase II investigation was conducted to gather further information on the lateral and vertical extent of detected chemical compounds in soil and ground water. This phase of investigation included installing nine additional monitoring wells and drilling 16 soil borings. Six of the wells were installed in the shallow A-zone and three were installed in the B-zone. The results of the investigation helped identify the direction of ground-water flow and the lateral and vertical extent of affected ground water in on-site areas. Further soil investigation was recommended for an identified arsenic source area and for the former oils tank storage area. The results of the Phase II investigation were reported to the RWQCB, the Alameda County Health Department, and the City of Emeryville (Levine•Fricke, April 4, 1990).
1990	A ground-water monitoring program was implemented to evaluate ground-water quality and ground-water flow directions in the A-zone and B-zone. Ground-water samples were analyzed for organic compounds (EPA Methods 8240 and 8270) and inorganic elements. Three additional A-zone monitoring wells were installed off site, downgradient from the Site. One additional B-zone well was installed upgradient from the Site. Results of the ground-water monitoring were reported to the RWQCB, the Alameda County Health Department, and the City of Emeryville (Levine•Fricke, November 29, 1990).
1990	An additional investigation of the chemical compounds present in soil was conducted in the former oils tank storage area, in the vicinity of a spill of Texanol, an ester-alcohol-based solvent. Soil samples from nine soil boring were analyzed for VOCs and SVOCs using EPA Methods 8240 and 8270. The results of these analyses are presented in this report.
1990 - 1991	An additional investigation of arsenic in soil was conducted by drilling 41 borings under the foundation of a dismantled building, which has been used for the production of arsenic-based compounds in the early 1900s. The purpose of this phase of investigation was to help identify the limits of the arsenic-affected soil. Results of that investigation are presented in this report.

Date	Description
1990 - 1991	An investigation was conducted to evaluate the extent of soil affected by a residual tar/diesel-like compound identified in a paved parking area, on the western boundary of the Site, in the vicinity of monitoring wells LF-10 and LF-B3. Eleven soil borings were drilled and soil samples were analyzed using EPA Method 8015. The results are presented in this report.
1990 - 1991	Additional ground-water monitoring programs were conducted and the results were reported to the RWQCB, the Alameda County Health Department, and the City of Emeryville (Levine•Fricke, April 22, 1991 and November 7, 1991).
1990 - 1991	Treatability and engineering studies were conducted to evaluate a range of interim remedial measures for affected soil and ground water at the Site. The results of this phase of work are presented in this report.

TABLE 2
HISTORICAL WATER-QUALITY DATA SUMMARY
VOLATILE ORGANIC COMPOUNDS, EPA METHOD 8240
(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. Number	Acetone	Benzene	Ethyl-Benzene	Methyl Ethyl Ketone	Total Xylenes	2-Hexanone	Toluene	1,1,1-TCA	1,2-DCA	PCE	TCE	Chlorobenzene	Total Quantified Conc.	Notes
LF-1	01-Jun-89	B&C	89060194	30.000	<0.200	0.900	20.000	3.600	15.000	6.000	<0.200	<0.200	<0.200	<0.200	<0.200	75.500	
LF-1	07-Dec-89	B&C	12-212-1	<0.010	<0.001	<0.001	<0.020	0.040	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.042	
LF-1	20-Jul-90	B&C	07-506-7	0.450	0.002	<0.001	0.200	0.160	<0.001	0.018	<0.001	<0.001	0.005	0.004	<0.001	0.840	#2
LF-1	21-Jun-91	ANA	9106274-08	<0.020	<0.005	0.019	<0.020	0.010	<0.010	<0.005	<0.005	<0.005	0.002	<0.005	<0.005	0.032	
LF-2	02-Jun-89	B&C	89060501	<0.050	0.015	0.015	<0.100	0.300	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.330	
LF-2	07-Dec-89	B&C	12-212-3	0.350	<0.020	<0.020	<0.400	0.840	<0.020	0.029	<0.020	<0.020	<0.020	<0.020	<0.020	1.219	
LF-2	20-Jul-90	B&C	07-506-5	<0.500	<0.050	0.066	8.800	0.910	12.000	0.051	<0.050	<0.050	<0.050	<0.050	0.050	21.827	
LF-3	02-Jun-89	B&C	89060502	<1.000	<0.100	2.500	<2.000	12.000	<0.100	17.000	<0.100	<0.100	<0.100	<0.100	<0.100	31.500	
LF-3	07-Dec-89	B&C	12-212-4	<5.000	<0.500	6.300	<10.000	32.000	<0.500	77.000	<0.500	<0.500	<0.500	<0.500	<0.500	115.300	
LF-3	20-Jul-90	B&C	07-506-6	10.000	0.110	5.000	7.700	22.000	1.900	52.000	<0.050	<0.050	<0.050	<0.050	<0.050	98.710	
LF-3	21-Jun-91	ANA	9106274-07	9.900	<1.000	7.500	8.200	44.000	<2.000	62.000	<1.000	<1.000	<1.000	<1.000	<1.000	139.800	
LF-4	02-Jun-89	B&C	89060503	1.300	<0.200	1.300	4.700	3.800	0.260	<0.200	<0.020	<0.020	<0.020	<0.020	<0.020	11.360	
Dup	02-Jun-89	B&C	89060504	1.300	<0.200	1.700	4.700	4.100	0.280	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	12.080	
LF-4	06-Dec-89	B&C	12-174-1	<0.020	<0.020	0.200	<0.040	0.650	<0.002	<0.004	<0.002	<0.002	<0.002	<0.002	<0.002	0.850	
DUP	06-Dec-89	B&C	12-174-6	<0.050	<0.005	0.250	<0.100	0.750	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	1.000	
LF-4	20-Jul-90	B&C	07-506-3	<1.000	<1.000	<0.100	<2.000	0.380	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	0.380	
LF-4	21-Jun-91	ANA	9106274-02	0.079	0.039	0.058	<0.040	0.350	<0.020	0.007	<0.010	<0.010	<0.010	<0.010	0.005	0.556	
DUP	21-Jun-91	ANA	9106274-03	<0.040	0.040	0.140	<0.040	0.380	<0.020	0.008	<0.010	<0.010	<0.010	<0.010	0.006	0.594	#4
LF-5	01-Jun-89	B&C	89060192	220.000	<2.000	2.000	390.000	8.000	<2.000	300.000	<1.000	<1.000	<1.000	<2.000	<1.000	920.000	
LF-5	06-Dec-89	B&C	12-174-4	51.000	<1.000	<1.000	320.000	<1.000	<1.000	310.000	<1.000	<1.000	<1.000	<1.000	<1.000	681.000	
LF-5	20-Jul-90	B&C	07-506-2	<10.000	<1.000	1.100	170.000	2.600	6.700	170.000	<1.000	<1.000	<1.000	<1.000	<1.000	350.400	
LF-5	21-Jun-91	ANA	9108069-05	<20.000	<5.000	<5.000	<20.000	5.400	<10.000	>200.00	<5.000	<5.000	<5.000	<5.000	<5.000	>200.000	
LF-6	01-Jun-89	B&C	89060193	280.000	<1.000	6.000	470.000	210.000	<1.000	22.000	<0.200	<0.200	<0.200	<1.000	<0.200	988.000	
LF-6	05-Dec-89	B&C	12-128-3	64.000	<1.000	5.000	320.000	17.000	<1.000	59.000	<1.000	<1.000	<1.000	<1.000	<1.000	465.000	
LF-6	20-Jul-90	B&C	07-506-4	200.000	<1.000	4.000	720.000	13.000	24.000	45.000	<1.000	<1.000	45.000	<1.000	<1.000	1051.000	

TABLE 2
HISTORICAL WATER-QUALITY DATA SUMMARY
VOLATILE ORGANIC COMPOUNDS, EPA METHOD 8240
(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. Number	Acetone	Benzene	Ethyl-Benzene	Methyl Ethyl Ketone	Total Xylenes	2-Hexa-none	Toluene	1,1,1-TCA	1,2-DCA	PCE	TCE	Chloro-benzene	Total Quantified Conc.	Notes
LF-7	01-Jun-89	B&C	89060191	<0.005	0.050	<0.005	<0.005	0.580	<0.005	0.270	<0.001	<0.001	<0.001	<0.005	<0.001	0.900	
LF-7	06-Dec-89	B&C	12-174-3	<0.010	0.031	0.052	<0.020	0.150	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	0.007	0.243	
LF-7	19-Jul-90	B&C	07-485-4	<0.010	<0.001	0.007	<0.020	0.044	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.052	
LF-7	20-Jun-91	ANA	9106251-06	<0.020	0.061	0.045	<0.020	0.120	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	0.007	0.233	
LF-8	05-Dec-89	B&C	12-128-4	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	
LF-8	19-Jul-90	B&C	07-485-5	<0.010	<0.001	0.007	<0.020	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.010	
LF-8	21-Dec-90	B&C	12-529-3	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-8	20-Jun-91	ANA	9106251-07	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	
LF-9	05-Dec-89	B&C	12-128-1	<0.010	<0.001	0.022	<0.020	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	0.005	0.030	
LF-9	19-Jul-90	B&C	07-485-6	<0.010	<0.001	0.011	<0.020	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.017	
LF-9	21-Dec-90	B&C	12-529-5	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-9	21-Jun-91	ANA	9106274-05	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	0.006	0.006	
LF-10	07-Dec-89	B&C	12-212-5	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-10	19-Jul-90	B&C	07-485-7	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
DUP	19-Jul-90	B&C	07-485-8	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-10	19-Dec-90	B&C	12-529-6	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
DUP	19-Dec-90	B&C	12-529-7	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-10	21-Jun-91	ANA	9106274-06	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	
LF-11	05-Dec-89	B&C	12-128-2	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	
DUP	05-Dec-89	B&C	12-128-5	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.023	<0.001	<0.001	<0.001	<0.001	<0.001	0.000	
LF-11	19-Jul-90	B&C	07-485-3	0.015	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.016	
LF-11	21-Dec-90	B&C	12-529-4	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-11	21-Jun-91	ANA	9106069-03	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	
DUP	21-Jun-91	ANA	9106251-04	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	

TABLE 2
HISTORICAL WATER-QUALITY DATA SUMMARY
VOLATILE ORGANIC COMPOUNDS, EPA METHOD 8240
(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. Number	Acetone	Benzene	Ethyl-Benzene	Methyl Ethyl Ketone	Total Xylenes	2-Hexa-none	Toluene	1,1,1-TCA	1,2-DCA	PCE	TCE	Chloro-benzene	Total Quantified Conc.	Notes
LF-12	06-Dec-89	B&C	12-174-2	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001	0.005	
LF-12	18-Jul-90	B&C	07-444-5	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.002	<0.001	0.003	
LF-12	19-Dec-90	B&C	12-474-5	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.003	<0.001	0.005	
LF-12	19-Jun-91	ANA	9106245-04	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	0.002	<0.005	0.002	
LF-13	06-Dec-89	B&C	12-174-7	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	0.002	0.029	<0.001	<0.001	<0.001	<0.001	0.031	
LF-13	18-Jul-90	B&C	07-444-4	<0.010	<0.001	<0.001	<0.020	0.001	<0.001	0.002	0.056	<0.001	0.001	<0.001	<0.001	0.060	
LF-13	19-Dec-90	B&C	12-474-4	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	0.042	0.002	0.002	<0.001	<0.001	0.046	#3
LF-13	19-Jun-91	ANA	9106245-03	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	0.032	<0.005	<0.005	<0.005	<0.005	0.032	
LF-14	04-Sep-90	B&C	07-444-4	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-14	21-Dec-90	B&C	12-505-7	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-14	20-Jun-91	ANA	9106251-08	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	
LF-15	04-Sep-90	B&C	07-444-5	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-15	21-Dec-90	B&C	12-505-6	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-15	20-Jun-91	ANA	9106251-09	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	
LF-16	04-Sep-90	B&C	07-444-6	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-16	20-Dec-90	B&C	12-505-5	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-16	20-Jun-91	ANA	9106251-10	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	
LF-B1	07-Dec-89	B&C	12-212-6	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	0.051	<0.001	<0.001	<0.001	0.051	
LF-B1	18-Jul-90	B&C	07-444-9	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.002	<0.001	0.170	0.001	<0.001	<0.001	0.171	
LF-B1	20-Dec-90	B&C	12-505-4	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	0.130	<0.001	<0.001	<0.001	0.130	
LF-B1	20-Jun-91	ANA	9106251-05	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	0.180	<0.005	<0.005	<0.005	0.180	
LF-B2	06-Dec-89	B&C	12-174-5	<0.010	<0.001	<0.001	<0.020	0.013	<0.001	<0.001	<0.001	0.007	<0.001	<0.001	<0.001	0.020	
LF-B2	18-Jul-90	B&C	07-444-6	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	0.002	<0.001	0.007	<0.001	<0.001	<0.001	0.009	
DUP	18-Jul-90	B&C	07-444-7	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	0.002	<0.001	0.007	<0.001	<0.001	<0.001	0.009	

TABLE 2
HISTORICAL WATER-QUALITY DATA SUMMARY
VOLATILE ORGANIC COMPOUNDS, EPA METHOD 8240
(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. Number	Acetone	Benzene	Ethyl-Benzene	Methyl Ethyl Ketone	Total Xylenes	2-Hexanone	Toluene	1,1,1-TCA	1,2-DCA	PCE	TCE	Chlorobenzene	Total Quantified Conc.	Notes
LF-B2	19-Dec-90	B&C	12-474-6	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	0.004	0.002	<0.001	<0.001	0.006	
LF-B2	20-Jun-91	ANA	9106251-04	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	0.006	<0.005	<0.005	<0.005	0.006	
LF-B3	07-Dec-89	B&C	12-212-8	<0.010	<0.001	<0.001	<0.020	<0.001	0.001	<0.001	<0.001	0.100	<0.001	<0.001	<0.001	0.101	#1
DUP	07-Dec-89	B&C	12-212-10	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	0.073	<0.001	<0.001	<0.001	0.073	
LF-B3	18-Jul-90	B&C	07-444-8	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	0.002	<0.001	0.086	<0.001	<0.001	<0.001	0.088	
LF-B3	20-Dec-90	B&C	12-505-3	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	0.084	<0.001	<0.001	<0.001	0.084	
LF-B3	19-Jun-91	ANA	9106245-05	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	0.110	<0.005	<0.005	<0.005	0.110	
LF-B4	18-Jul-90	B&C	07-444-3	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	0.002	<0.001	0.001	<0.001	<0.001	<0.001	0.003	
LF-B4	19-Dec-90	B&C	12-474-3	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	
LF-B4	19-Jun-91	ANA	9106245-01	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	
FIELD BLANKS & TRIP BLANKS																	
LF-1-FB	01-Jun-86	B&C	89060195	0.012	<0.001	<0.001	<0.020	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.016	
LF-1-FB	07-Dec-89	B&C	12-212-2	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-B1-FB	07-Dec-89	B&C	12-212-7	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-13-FB	06-Dec-89	B&C	12-174-12	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
Trip Blank	07-Dec-89	B&C	12-212-9	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-B4-TB	18-Jul-90	B&C	07-444-1	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-B4-BB	18-Jul-90	B&C	07-444-2	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-11-TB	19-Jul-90	B&C	07-485-1	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-11-BB	19-Jul-90	B&C	07-485-1	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-B4-BR	19-Dec-90	B&C	12-474-2	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-8-TB	21-Dec-90	B&C	12-529-1	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-8-BR	21-Dec-90	B&C	12-529-2	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	
LF-B3-BR	20-Dec-90	B&C	12-505-2	<0.010	<0.001	<0.001	<0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.020	

TABLE 2
HISTORICAL WATER-QUALITY DATA SUMMARY
VOLATILE ORGANIC COMPOUNDS, EPA METHOD 8240
(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. Number	Acetone	Benzene	Ethyl-Benzene	Methyl Ethyl Ketone	Total Xylenes	2-Hexanone	Toluene	1,1,1-TCA	1,2-DCA	PCE	TCE	Chloro-benzene	Total Quantified Conc.	Notes
LF-B3-BR	19-Jun-91	ANA	9106245-6	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	
LF-11-BR	20-Jun-91	ANA	9106251-2	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	
LF-4-TB	24-Jun-91	ANA	9106274-1	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	
Trip Blank	06-Aug-91	ANA	9108069-1	<0.020	<0.005	<0.005	<0.020	<0.005	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.020	

Explanation of Symbols and Abbreviations:

Signifies that there is a note of explanation for laboratory results.
B&C: BC Analytical (formerly Brown and Caldwell) Laboratory, Emeryville, California.
ANA: Anametrix Laboratory, San Jose, California

DUP = Duplicate Sample

1,1,1-TCA = 1,1,1-Trichloroethane
1,2-DCA = 1,2-Dichloroethane
PCE = Tetrachloroethene
TCE = Trichloroethene

NOTES:

#1 LF-B3 6/02/89 - Vinyl Acetate reported at 0.001 mg/L, Styrene reported at 0.001 mg/L, and Methyl Isobutyl Ketone reported at 0.001 mg/L.
#2 LF-1 7/20/90 - cis-Dichloroethene reported at 0.001 mg/L.
#3 LF-13 12/19/90 - 1,1-Dichloroethane reported at 0.002 mg/L.
#4 LF-4 DUP 06/21/91 - cis-1,2-Dichloroethene reported at 0.020 mg/L.

TABLE 3
HISTORICAL WATER-QUALITY DATA SUMMARY
SEMIVOLATILE ORGANIC COMPOUNDS, EPA METHOD 8270
(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. Number	Type of Analysis	2-Methyl-napthalene	Naphthalene	Phenol	2-Methylphenol	4-Methylphenol	2,4-Dimethylphenol	Bis(2-ethylhexyl)-phthalate	Total All Quantified Concentrations	Notes
LF-1	01-Jun-89	B&C	89060194	8270	<0.004	0.018	<0.020	0.011	<0.010	<0.005	<0.040	0.029	
LF-1	07-Dec-89	B&C	12-212-1	8270	<0.004	<0.004	<0.020	<0.010	<0.020	<0.010	*<0.170	<0.040	
LF-1	20-Jul-90	B&C	07-506-7	8270	<0.002	<0.002	0.011	<0.005	<0.010	<0.005	<0.020	0.011	
LF-1	21-Jun-91	ANA	9106274-08	8270	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	
LF-2	02-Jun-89	B&C	89060501	8270	<0.100	0.650	<0.500	<0.200	<0.500	<0.200	<1.000	0.650	
LF-2	07-Dec-89	B&C	12-212-3	8270	<0.020	0.320	<0.100	<0.050	<0.100	<0.050	<0.200	0.320	
LF-2	20-Jul-90	B&C	07-506-5	8270	<0.020	0.330	<0.100	<0.050	<0.100	<0.050	<0.200	0.330	
LF-3	02-Jun-89	B&C	89060502	8270	0.034	0.091	<0.100	0.020	<0.010	<0.005	<0.020	0.287	#1
LF-3	07-Dec-89	B&C	12-212-4	8270	<0.020	0.140	<0.100	0.070	0.450	<0.050	<0.200	0.660	
LF-3	20-Jul-90	B&C	07-506-6	8270	<0.020	0.160	<0.100	0.240	0.800	<0.050	<0.200	1.200	
LF-3	21-Jun-91	ANA	9106274-07	8270	<0.110	0.110	0.039	0.210	0.630	0.050	<0.110	1.039	
LF-4	02-Jun-89	B&C	89060503	8270	0.016	0.140	<0.010	<0.010	<0.010	<0.005	<0.200	0.156	
Duplicate	02-Jun-89	B&C	89060504	8270	0.009	0.095	<0.010	<0.010	<0.010	<0.005	<0.200	0.104	
LF-4	06-Dec-89	B&C	12-174-1	8270	<0.002	0.015	<0.010	<0.005	<0.010	<0.005	*<0.170	0.015	
Duplicate	06-Dec-89	B&C	12-174-6	8270	<0.002	0.007	<0.010	<0.005	<0.010	<0.005	*<0.170	0.007	
LF-4	20-Jul-90	B&C	07-506-3	8270	<0.002	0.010	0.015	<0.005	<0.010	<0.005	<0.020	0.025	
LF-4	21-Jun-91	ANA	9106274-02	8270	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	
DUP	21-Jun-91	ANA	9106274-03	8270	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	
LF-5	01-Jun-89	B&C	89060192	8270	<0.004	0.020	<0.020	0.220	0.600	<0.005	<0.040	0.840	
LF-5	06-Dec-89	B&C	12-174-4	8270	<0.002	0.025	0.056	0.280	0.790	0.039	*<0.170	1.190	
LF-5	20-Jul-90	B&C	07-506-2	8270	<0.020	<0.020	<0.100	0.280	0.850	<0.050	<0.200	1.350	#2
LF-5	06-Aug-91	ANA	9108069-05	8270	<0.050	<0.050	<0.050	0.180	0.250	<0.050	<0.050	0.467	
LF-6	05-Dec-89	B&C	12-128-5	8270	<0.040	0.060	0.380	0.160	1.000	<0.100	<0.400	1.600	
LF-6	20-Jul-90	B&C	07-506-2	8270	<0.020	<0.020	0.200	0.280	0.850	<0.050	<0.200	1.330	

TABLE 3
HISTORICAL WATER-QUALITY DATA SUMMARY
SEMIVOLATILE ORGANIC COMPOUNDS, EPA METHOD 8270
(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. Number	Type of Analysis	2-Methyl-naptha-lene	Naphtha-lene	Phenol	2-Methyl-phenol	4-Methyl-phenol	2,4-Di-methyl-phenol	Bis(2-ethyl-hexyl)-phthalate	Total All Quantified Concentrations	Notes
LF-7	01-Jun-89	B&C	89060191	8270	<0.004	0.008	<0.020	<0.010	<0.010	<0.005	<0.040	0.008	
LF-7	06-Dec-89	B&C	12-174-3	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	*<0.170	<0.040	
LF-7	08-Aug-90	B&C	08-171-3	8270	----	<0.002	<0.010	----	----	<0.005	<0.020	<0.020	
LF-7	06-Aug-91	ANA	9106251-06	8270	<0.013	0.005	<0.013	<0.013	<0.013	<0.013	<0.013	0.005	
LF-8	05-Dec-89	B&C	12-128-4	8270	<0.002	0.060	0.380	<0.005	<0.010	<0.005	*<0.170	0.440	
LF-8	08-Aug-90	B&C	08-171-4	8270	----	<0.002	<0.010	----	----	<0.005	<0.020	<0.020	
LF-8	21-Dec-90	B&C	12-529-3	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-8	20-Jun-91	ANA	9106251-07	8270	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013	
LF-9	05-Dec-89	B&C	12-128-1	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	*<0.170	<0.020	
LF-9	19-Jul-90	B&C	07-485-6	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.002	<0.020	
LF-9	21-Dec-90	B&C	12-529-5	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-9	21-Jun-91	ANA	9106274-05	8270	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.000	
LF-10	05-Dec-89	B&C	12-128-1	8270	<0.002	0.140	<0.010	<0.005	<0.010	<0.005	*<0.170	0.140	
LF-100	19-Jul-90	B&C	07-485-8	8270	<0.005	<0.002	<0.010	<0.005	<0.010	<0.005	<0.002	<0.010	
LF-10	21-Dec-90	B&C	12-529-6	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-100	21-Dec-90	B&C	12-529-7	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-10	21-Jun-91	ANA	9106274-06	8270	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	
LF-11	05-Dec-89	B&C	12-128-2	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	*<0.170	<0.010	
LF-11	08-Aug-90	B&C	08-171-5	8270	----	<0.002	<0.010	----	----	<0.005	<0.020	<0.010	
LF-11	21-Dec-90	B&C	12-529-4	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	0.034	0.034	
LF-11	21-Jun-91	ANA	9106251-03	8270	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	
DUP	20-Jun-91	ANA	9106251-04	8270	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	
LF-12	06-Dec-89	B&C	12-174-2	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	*<0.170	<0.020	
LF-12	18-Jul-90	B&C	07-444-5	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	0.028	0.028	
LF-12	19-Dec-90	B&C	12-474-5	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	

TABLE 3
HISTORICAL WATER-QUALITY DATA SUMMARY
SEMIVOLATILE ORGANIC COMPOUNDS, EPA METHOD 8270

(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. Number	Type of Analysis	2-Methyl-napthalene	Naphthalene	Phenol	2-Methyl-phenol	4-Methyl-phenol	2,4-Di-methyl-phenol	Bis(2-ethyl-hexyl)-phthalate	Total All Quantified Concentrations	Notes
LF-12	19-Jun-91	ANA	9106245-04	8270	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	
LF-13	06-Dec-89	B&C	12-174-7	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	*<0.170	<0.020	
LF-13	18-Jul-90	B&C	07-444-4	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.010	
LF-13	19-Dec-90	B&C	12-474-4	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-13	19-Jun-91	ANA	9106245-03	8270	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	
LF-14	04-Sep-90	B&C	09-014-1	8270	<0.005	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-14	20-Dec-90	B&C	12-505-7	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-14	20-Jun-91	ANA	9106251-08	8270	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	0.000	
LF-15	04-Sep-90	B&C	09-014-2	8270	<0.005	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-15	20-Dec-90	B&C	12-505-6	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-15	20-Jun-91	ANA	9106251-09	8270	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	
LF-16	04-Sep-90	B&C	09-014-3	8270	<0.005	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-16	20-Dec-90	B&C	12-505-5	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-16	20-Jun-91	ANA	9106251-10	8270	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	
LF-B1	07-Dec-89	B&C	12-212-6	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	*<0.170	<0.175	
LF-B1	18-Jul-90	B&C	07-444-9	8270	<0.005	<0.002	0.460	<0.005	<0.010	<0.005	0.140	0.600	
LF-B1	20-Dec-90	B&C	12-505-4	8270	<0.002	<0.002	0.041	<0.005	<0.010	<0.005	0.045	0.086	
LF-B1	20-Jun-91	ANA	9106251-05	8270	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	
LF-B2	06-Dec-89	B&C	12-174-5	8270	<0.002	<0.002	<0.010	<0.005	<0.010	0.029	*<0.170	0.029	
LF-B2	18-Jul-90	B&C	07-444-6	8270	<0.005	<0.002	0.140	<0.005	<0.010	<0.005	0.032	0.172	
LF-B2D	18-Jul-90	B&C	07-444-7	8270	<0.005	<0.002	0.088	<0.005	<0.010	<0.005	0.060	0.148	
LF-B2	20-Dec-90	B&C	12-474-6	8270	<0.005	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-B2	21-Jun-91	ANA	9106274-04	8270	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	0.018	0.018	

TABLE 3

HISTORICAL WATER-QUALITY DATA SUMMARY

SEMIVOLATILE ORGANIC COMPOUNDS, EPA METHOD 8270

(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. Number	Type of Analysis	2-Methyl-napthalene	Naphthalene	Phenol	2-Methyl-phenol	4-Methyl-phenol	2,4-Di-methyl-phenol	Bis(2-ethyl-hexyl)-phthalate	Total All Quantified Concentrations	Notes
LF-B3	07-Dec-89	B&C	12-212-10	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	*<0.170	<0.020	
LF-B3	18-Jul-90	B&C	07-444-6	8270	<0.005	<0.002	<0.010	<0.005	<0.010	<0.005	0.190	0.190	
LF-B3	20-Dec-90	B&C	12-505-3	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-B3	21-Jun-91	ANA	9106274-04	8270	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	
LF-B4	18-Jul-90	B&C	07-444-3	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	0.023	0.023	
LF-B4	19-Dec-90	B&C	12-474-3	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-B4	19-Jun-91	ANA	9106245-01	8270	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.064	0.064	
FIELD & TRIP BLANKS													
LF-1-FB	01-Jun-86	B&C	89060195	8270	<0.004	<0.004	<0.020	<0.010	<0.010	<0.005	<0.040	<0.020	
LF-1-FB	07-Dec-89	B&C	12-212-2	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-B1-FB	07-Dec-89	B&C	12-212-7	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
Trip Blank	07-Dec-89	B&C	12-212-9	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	0.035	0.035	
LF-B4-TB	18-Jul-90	B&C	07-444-1	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-B4-BB	18-Jul-90	B&C	07-444-1	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-7-BB	08-Aug-90	B&C	08-171-2	8270	----	<0.002	<0.010	<0.005	----	<0.005	<0.020	<0.020	
LF-B4-BR	19-Dec-90	B&C	12-474-2	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-B3-BR	20-Dec-90	B&C	12-505-2	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-8-TB	21-Dec-90	B&C	12-529-1	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-8-BR	21-Dec-90	B&C	12-529-2	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-B3-BR	19-Jun-91	ANA	9106245-6	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-11-BR	20-Jun-91	ANA	9106251-2	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	
LF-4-TB	21-Jun-91	ANA	9106274-1	8270	<0.002	<0.002	<0.010	<0.005	<0.010	<0.005	<0.020	<0.020	

NOTES TO TABLE 3:

Explanation of Symbols and Abbreviations:

* indicates value not accepted as valid based on positive results of 0.035 mg/L for trip blank sample. (dectection limit reported as 5 times 0.035 mg/L = 0.170 mg/L for indicated reporting period).

---- indicates results not reported by laboratory.

8270 = EPA Method 8270 for semivolatile organic compounds.

Analytical Laboratories:

B&C: BC Analytical (formerly Brown and Caldwell) Laboratory, Emeryville, California.
ANA: Anametrix Laboratory, San Jose, California

NOTES:

#1 LF-3 02/06/89 - Lab Data Reported the Following: Acenapthene at 0.016 mg/L; Anthracene at 0.005 mg/L; Benzo(a)anthracene at 0.005 mg/L; Chrysene at 0.005 mg/L; Dibenzofurena at 0.017 mg/L; Fluoranthene at 0.016 mg/L; Fluorene at 0.016 mg/L; Phenanthrene at 0.044 mg/L; Pyrene at 0.018 mg/L.

#2 LF-5 07/20/90 - Benzoic Acid reported at 0.220 mg/L.

TABLE 4
TOTAL PETROLEUM HYDROCARBONS, MODIFIED EPA METHOD 8015
(Results Reported in milligrams per liter (mg/L)

Well No.	Date	Lab	Lab I.D. No.	Total Petroleum Hydrocarbons
LF-1	20-Jul-90	B&C	07-506-7	7.6
LF-2	20-Jul-90	B&C	07-506-5	630.0
LF-3	20-Jul-90	B&C	07-506-6	440.0
LF-4	20-Jul-90	B&C	07-506-3	110.0
LF-5	20-Jul-90	B&C	07-506-2	520.0
LF-6	20-Jul-90	B&C	07-506-4	1500.0
LF-7	19-Jul-90	B&C	07-485-4	<1.0
LF-8	19-Jul-90	B&C	07-485-5	<1.0
LF-9	19-Jul-90	B&C	07-485-6	<1.0
LF-10	19-Jul-90	B&C	07-485-7	<1.0
Duplicate	19-Jul-90	B&C	07-485-8	<1.0
LF-11	19-Jul-90	B&C	07-485-3	<1.0
LF-12	18-Jul-90	B&C	07-444-5	<1.0
LF-13	18-Jul-90	B&C	07-444-4	<1.0
LF-14	04-Sep-90	B&C	07-444-4	<1.0
LF-15	04-Sep-90	B&C	07-444-5	<1.0
LF-16	04-Sep-90	B&C	07-444-6	<1.0
LF-B1	18-Jul-90	B&C	07-444-9	<1.0
LF-B2	18-Jul-90	B&C	07-444-6	<1.0
Duplicate	18-Jul-90	B&C	07-444-7	<1.0
LF-B3	18-Jul-90	B&C	07-444-8	<1.0
LF-B4	18-Jul-90	B&C	07-444-3	<1.0
FIELD BLANKS & TRIP BLANKS				
LF-B4-TB	18-Jul-90	B&C	07-444-1	<1.0
LF-B4-BB	18-Jul-90	B&C	07-444-2	<1.0
LF-11-TB	19-Jul-90	B&C	07-485-1	<1.0
LF-11-BB	19-Jul-90	B&C	07-485-1	<1.0

TABLE 5
HISTORICAL WATER-QUALITY DATA SUMMARY
INORGANIC ELEMENTS

(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. No.	Type of Analysis	Arsenic	Cadmium	Copper	Lead	Zinc	Barium	Nickel
LF-1	01-Jun-89	B&C	89060194	200/7000	200.000	<0.0400	<0.08	<0.300	0.590	NA	NA
LF-1	07-Dec-89	B&C	12-212-1	200/7000	190.000	<0.0400	<0.08	<0.300	0.020	NA	NA
LF-1	20-Jul-90	B&C	07-506-7	200/7000	120.000	<0.0500	<0.05	<0.200	0.260	0.060	NA
LF-1	20-Jun-91	ANA	9106274-08	200/7000	58.000	<0.005	<0.025	<0.004	0.236	NA	0.331
LF-2	02-Jun-89	B&C	89060501	200/7000	2.600	<0.0400	<0.08	<0.300	0.010	NA	NA
LF-2	07-Dec-89	B&C	12-212-3	200/7000	17.000	<0.0400	<0.08	<0.300	<0.010	NA	NA
LF-2	20-Jul-90	B&C	07-506-5	200/7000	110.000	<0.0500	<0.05	<0.200	<0.050	0.450	NA
LF-3	02-Jun-89	B&C	89060502	200/7000	27.000	<0.0400	<0.08	<0.300	<0.010	NA	NA
LF-3	07-Dec-89	B&C	12-212-2	200/7000	30.000	<0.0400	<0.08	<0.300	<0.010	NA	NA
LF-3	20-Jul-90	B&C	07-506-6	200/7000	21.000	<0.0500	<0.05	<0.200	<0.050	0.420	NA
LF-3	20-Jun-91	ANA	9106274-07	200/7000	60.400	<0.005	<0.025	<0.004	0.028	NA	<0.005
LF-4	02-Jun-89	B&C	89060503	200/7000	0.530	<0.0400	<0.08	<0.300	<0.010	NA	NA
Duplicate	02-Jun-89	B&C	89060504	200/7000	0.580	<0.0400	<0.08	<0.300	7.000	NA	NA
LF-4	06-Dec-89	B&C	12-174-1	200/7000	0.420	<0.0400	<0.08	<0.300	<0.010	NA	NA
Duplicate	06-Dec-89	B&C	12-174-6	200/7000	0.550	<0.0400	<0.08	<0.300	0.010	NA	NA
LF-4	20-Jul-90	B&C	07-506-3	200/7000	0.190	<0.0500	<0.05	<0.200	<0.050	0.160	NA
LF-4	20-Jun-91	ANA	9106274-02	200/7000	0.510	<0.005	<0.025	0.015	0.071	NA	<0.005
LF-4-DUP	20-Jun-91	ANA	9106274-03	200/7000	0.493	<0.005	<0.025	0.010	0.109	NA	<0.005
LF-5	01-Jun-89	B&C	89060192	200/7000	0.017	<0.0400	<0.08	<0.300	0.040	NA	NA
LF-5	06-Dec-89	B&C	12-174-2	200/7000	*<0.070	<0.0400	<0.08	<0.300	<0.010	NA	NA
LF-5	20-Jul-90	B&C	07-506-2	200/7000	0.020	<0.0500	<0.05	<0.200	0.050	0.170	NA
LF-5	20-Jun-91	ANA	9108069-05	200/7000	0.038	<0.005	<0.025	0.003	<0.020	NA	<0.005
LF-6	01-Jun-89	B&C	89060193	200/7000	13.000	0.0900	<0.08	<0.300	0.120	NA	NA
LF-6	05-Dec-89	B&C	12-128-3	200/7000	16.000	0.0600	<0.08	<0.300	<0.010	NA	NA
LF-6	20-Jul-90	B&C	07-506-4	200/7000	14.000	<0.0500	<0.05	<0.200	0.060	0.210	NA

TABLE 5
HISTORICAL WATER-QUALITY DATA SUMMARY
INORGANIC ELEMENTS
(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. No.	Type of Analysis	Arsenic	Cadmium	Copper	Lead	Zinc	Barium	Nickel
LF-7	01-Jun-89	B&C	89060191	200/7000	0.008	<0.0400	<0.08	<0.300	<0.010	NA	NA
LF-7	06-Dec-89	B&C	12-174-3	200/7000	*<0.070	<0.0400	<0.08	<0.300	0.020	NA	NA
LF-7	19-Jul-90	B&C	07-485-4	200/7000	<0.002	<0.0500	<0.05	<0.200	<0.050	0.060	NA
LF-7	20-Jun-91	ANA	9106251-06	200/7000	0.012	<0.005	<0.025	<0.004	<0.020	NA	<0.005
LF-8	05-Dec-89	B&C	12-128-4	200/7000	*<0.070	<0.0400	<0.08	<0.300	<0.010	NA	NA
LF-8	19-Jul-90	B&C	07-485-4	200/7000	<0.002	<0.0500	<0.05	<0.200	<0.050	0.120	NA
LF-8	21-Dec-90	B&C	12-529-3	200/7000	0.020	0.0015	0.09	<0.200	0.250	0.590	NA
LF-8	20-Jun-91	ANA	9106251-07	200/7000	0.021	<0.005	<0.025	<0.004	<0.020	NA	<0.005
LF-9	05-Dec-89	B&C	12-128-1	200/7000	0.067	<0.0400	<0.08	<0.300	0.020	NA	NA
LF-9	19-Jul-90	B&C	07-485-7	200/7000	0.008	<0.0500	<0.05	<0.200	<0.050	0.110	NA
LF-9	21-Dec-90	B&C	12-529-5	200/7000	0.120	0.0029	<0.05	<0.200	0.730	0.270	NA
LF-9	20-Jun-91	ANA	9106274-05	200/7000	0.075	<0.005	<0.025	0.012	0.100	NA	<0.005
LF-9	06-Aug-91	ANA	9108069-02	200/7000	0.131	NA	NA	NA	NA	NA	NA
LF-10	07-Dec-89	B&C	12-212-5	200/7000	0.650	<0.0400	<0.08	<0.300	<0.010	NA	NA
LF-10	19-Jul-90	B&C	07-485-7	200/7000	0.012	<0.0500	<0.05	<0.200	<0.050	0.110	NA
Duplicate	19-Jul-90	B&C	07-485-8	200/7000	0.008	<0.0500	<0.05	<0.300	0.070	0.140	NA
LF-10	21-Dec-90	B&C	12-529-6	200/7000	1.000	0.0009	<0.05	<0.200	<0.050	0.330	NA
Duplicate	21-Dec-90	B&C	12-529-7	200/7000	1.100	0.0007	<0.05	<0.300	0.070	0.350	NA
LF-10	20-Jun-91	ANA	9106274-06	200/7000	0.657	<0.005	<0.025	0.013	0.064	NA	0.006
LF-10	06-Aug-91	ANA	9108069-02	200/7000	1.090	NA	NA	NA	NA	NA	NA
LF-11	05-Dec-89	B&C	12-128-2	200/7000	*<0.070	<0.0400	<0.08	<0.300	0.020	NA	NA
LF-11	19-Jul-90	B&C	07-485-5	200/7000	0.007	<0.0500	<0.05	<0.200	<0.050	0.120	NA
LF-11	21-Dec-90	B&C	12-529-4	200/7000	0.011	0.0006	<0.05	<0.200	<0.050	0.180	NA
LF-11	20-Jun-91	ANA	9106251-06	200/7000	0.023	<0.005	<0.025	0.007	<0.020	NA	0.005
LF-11	20-Jun-91	ANA	9106251-07	200/7000	0.024	<0.005	<0.025	0.006	<0.020	NA	0.007
LF-11	06-Aug-91	ANA	9108069-04	200/7000	0.021	NA	NA	NA	NA	NA	NA

TABLE 5
HISTORICAL WATER-QUALITY DATA SUMMARY
INORGANIC ELEMENTS

(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. No.	Type of Analysis	Arsenic	Cadmium	Copper	Lead	Zinc	Barium	Nickel
LF-12	06-Dec-89	B&C	12-174-2	200/7000	*<0.070	<0.0400	<0.08	<0.300	0.020	NA	NA
LF-12	18-Jul-90	B&C	07-444-5	200/7000	0.004	<0.0500	<0.05	<0.300	<0.200	0.060	NA
LF-12	19-Jun-91	ANA	9106245-04	200/7000	<0.010	<0.005	<0.025	<0.004	<0.020	NA	0.014
LF-13	06-Dec-89	B&C	12-174-7	200/7000	*<0.070	<0.0400	<0.08	<0.300	0.020	NA	NA
LF-13	18-Jul-90	B&C	07-444-4	200/7000	<0.002	<0.0500	<0.05	<0.200	<0.050	<0.050	NA
LF-13	19-Dec-90	B&C	12-474-4	200/7000	<0.002	<0.0005	<0.05	<0.200	<0.050	0.100	NA
LF-13	19-Jun-91	ANA	9106245-03	200/7000	<0.010	<0.005	<0.025	<0.004	<0.020	NA	0.013
LF-14	04-Sep-90	B&C	09-014-1	200/7000	0.092	<0.0005	<0.005	0.007	<0.050	0.060	NA
LF-14	02-Oct-90	B&C	10-034-2	200/7000	0.077	NA	NA	NA	NA	NA	NA
LF-14	20-Dec-90	B&C	12-505-7	200/7000	0.150	0.0036	<0.050	<0.200	0.410	0.470	NA
LF-14	20-Jun-91	ANA	9106251-08	200/7000	0.095	<0.005	<0.025	<0.004	<0.020	NA	<0.005
LF-15	04-Sep-90	B&C	09-014-2	200/7000	0.002	<0.0005	<0.005	0.043	<0.050	0.060	NA
LF-15	20-Dec-90	B&C	12-505-6	200/7000	0.007	0.0007	<0.05	<0.200	0.100	0.230	NA
LF-15	20-Jun-91	ANA	9106251-09	200/7000	<0.010	<0.005	<0.025	<0.004	<0.020	NA	0.006
LF-16	04-Sep-90	B&C	09-014-3	200/7000	0.003	<0.0005	<0.005	<0.002	<0.050	0.060	NA
LF-16	20-Dec-90	B&C	12-505-5	200/7000	0.003	0.0007	<0.05	<0.200	0.070	0.170	NA
LF-16	20-Jun-91	ANA	9106251-10	200/7000	0.010	<0.005	<0.025	<0.004	<0.020	NA	0.018
LF-B1	07-Dec-89	B&C	12-212-6	200/7000	*<0.070	<0.0400	<0.08	<0.300	<0.010	NA	NA
LF-B1	18-Jul-90	B&C	7-444-6	200/7000	0.007	<0.0500	<0.05	<0.2	<0.050	0.08	NA
LF-B1	20-Dec-90	B&C	12-505-4	200/7000	0.005	0.0010	<0.05	<0.200	<0.050	0.100	NA
LF-B1	20-Jun-91	ANA	9106251-05	200/7000	<0.010	<0.005	<0.025	0.004	<0.020	NA	<0.005
LF-B2	06-Dec-89	B&C	12-174-5	200/7000	*<0.070	<0.0400	<0.08	<0.300	0.020	NA	NA
LF-B2	18-Jul-90	B&C	7-444-9	200/7000	0.005	<0.0500	<0.05	<0.200	<0.050	0.140	NA
Duplicate	18-Jul-90	B&C	7-444-	200/7000	0.004	<0.0500	<0.05	<0.200	<0.050	0.150	NA
LF-B2	19-Dec-90	B&C	12-474-6	200/7000	0.008	0.0026	<0.05	<0.200	0.170	0.320	NA

TABLE 5
HISTORICAL WATER-QUALITY DATA SUMMARY
INORGANIC ELEMENTS
(All concentrations expressed in milligrams per liter [mg/L])

Well Number	Date Sampled	Lab	Lab I.D. No.	Type of Analysis	Arsenic	Cadmium	Copper	Lead	Zinc	Barium	Nickel
LF-B3-BR	19-Jun-91	ANA	9106245-06	200/7000	<0.010	<0.005	<0.025	<0.004	<0.020	NA	<0.005
LF-B4-TB	19-Jun-91	ANA	9106245-02	200/7000	<0.010	<0.005	<0.025	<0.004	<0.020	NA	<0.005
LF-4-TB	20-Jun-91	ANA	9106274-01	200/7000	<0.010	<0.005	<0.025	<0.004	<0.020	NA	<0.005
LF-11-TB	20-Jun-91	ANA	9106251-01	200/7000	<0.010	<0.005	<0.025	<0.004	<0.020	NA	<0.005
LF-11-BR	20-Jun-91	ANA	9106251-02	200/7000	<0.010	<0.005	<0.025	<0.004	<0.020	NA	<0.005
Trip Blank	06-Aug-91	ANA	9108069-01	200/7000	<0.010	NA	NA	<0.003	<0.020	NA	NA

Notes:

* = Data not validated based on positive results of trip blank (0.014 mg/L) or bailer rinsate blank (0.013 mg/L) of submitted samples. Detection Limit for arsenic for December 1989 sampling period set at 0.070 or 5 times the reported value of 0.014 mg/L for trip blank sample.

NA = Not Analyzed

200/7000 = EPA Method 200/6000/7000 Series for selected metals.

On June 13, 1991, a grab A-zone ground-water samples was collected from soil boring TS-2 in the arsenic source area and analyzed by Anametrix for arsenic and lead. Analytical results indicated 320 mg/L arsenic and 0.17 mg/L lead.

Analytical Laboratories:

B&C: BC Analytical (formerly Brown and Caldwell) Laboratory, Emeryville, California.
ANA: Anametrix Laboratory, San Jose, California

TABLE 6

SUMMARY OF SOIL DATA FOR VOLATILE ORGANIC COMPOUNDS DETECTED IN THE FORMER OILS TANK STORAGE AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab	Lab I.D. No.	Type of Analysis	Ethyl-Benzene	Toluene	TCE	PCE	Total Xylenes	Other Quantified VOCs	Total Quantified Concentrations	TIC & SQ C5-C13 Hydrocarbons	TIC & SQ C7H14 Hydrocarbon*	Total TIC VOC TIC/SQ Concentrations	Notes
SW-1A	14-Jul-88	GTEL	27179A	8240	6.900	0.800	<0.005	<0.005	17.000	0.000	24.700	NR	NR	NR	
SW-1C	14-Jul-88	GTEL	27180A	8240	<0.005	<0.005	<0.005	<0.005	<0.005	0.000	0.000	NR	NR	NR	
SW-2B	14-Jul-88	GTEL	27181A	8240	32.000	13.000	<0.005	<0.005	450.000	0.000	495.000	NR	NR	NR	
SW-2D	14-Jul-88	GTEL	27182A	8240	0.450	<0.005	<0.005	<0.005	0.500	0.000	0.950	NR	NR	NR	
SW-3A	14-Jul-88	GTEL	27183A	8240	<0.005	<0.005	<0.005	<0.005	60.000	0.000	60.000	NR	NR	NR	
LF-2B	14-Jul-88	B & C	890564814	8240	1.900	<0.1	<0.1	<0.1	17.000	0.000	18.900	2,000.000	ND	2,000.000	
SB-22-1.5-2.0	26-Oct-89	B & C	10-739-14	8240	<2.0	<2.0	<2.0	<2.0	<2.0	0.000	0.000	7,000.000	ND	7,000.000	
SB-22-3.5-4.0	26-Oct-89	B & C	10-739-22	8240	<0.1	<0.1	<0.1	<0.1	<0.1	0.000	0.000	400.000	ND	400.000	
SB-23-1.5-2.0	26-Oct-89	B & C	10-739-15	8240	4.000	<2.0	<2.0	<2.0	72.000	0.000	76.000	10,000.000	ND	10,000.000	
SB-23-3.5-4.0	26-Oct-89	B & C	10-739-24	8240	<2.0	<2.0	<2.0	<2.0	<2.0	0.000	0.000	4,000.000	ND	4,000.000	
SB-24-0.5-1.0	26-Oct-89	B & C	10-739-16	8240	140.000	270.000	<2.0	<2.0	580.000	0.000	990.000	500.000	ND	500.000	
SB-41-2.0-2.5	28-Jun-90	B & C	06-665-17	8240	<0.2	<0.2	<0.2	<0.2	<0.2	0.000	0.000	200.000	ND	200.000	#4
SB-41-6.0-6.5	28-Jun-90	B & C	06-665-18	8240	<0.8	<0.8	<0.8	<0.8	<0.8	0.000	0.000	8,000.000	ND	8,000.000	#5
SB-41-8.0-8.5	28-Jun-90	B & C	06-665-19	8240	<2	<2	<2	<2	<2	0.000	0.000	3,000.000	ND	3,000.000	#6
SB-42-2.0-2.5	28-Jun-90	B & C	06-665-15	8240	0.300	<0.2	<0.2	<0.2	0.400	0.000	0.700	4,000.000	ND	4,000.000	#2
SB-42-6.0-6.5	28-Jun-90	B & C	06-665-16	8240	0.200	<0.2	<0.2	<0.2	<0.2	0.000	0.200	4,000.000	ND	4,000.000	#3
SB-43-2.0-2.5	28-Jun-90	B & C	06-665-14	8240	130.000	1.600	<0.2	<0.2	400.000	0.000	531.600	9,000.000	ND	9,000.000	#1
SB-45-2.0-2.5	28-Jun-90	B & C	06-665-20	8240	<2	<2	<2	<2	<2	0.000	0.000	6,000.000	ND	6,000.000	#7
SB-45-6.0-6.5	28-Jun-90	B & C	06-665-21	8240	6.000	<4	<4	<4	35.000	0.000	41.000	20,000.000	ND	20,000.000	#8
SB-45-8.0-8.5	28-Jun-90	B & C	06-665-22	8240	5.000	<4	<4	<4	4.000	0.000	9.000	9,000.000	ND	9,000.000	#9

EXPLANATION OF SYMBOLS AND ABBREVIATIONS:

TIC & SQ = Tentatively Identified Compoundand (TIC) with semiquantified estimates of compound concentrations.
8240 = EPA Method 8240 for volatile organic compounds.
NA = Not analyzed.
ND = Not detected.
NR = Not reported.
TCE = Trichloroethene
PCE = Tetrachloroethene
Analytical Laboratory: BC Analytical, Emeryville, California.

NOTES:

1 SB-43-2.0-2.5 - TIC C6-C13 Hydrocarbon at 9,000 mg/kg.
2 SB-42-2.0-2.5 - TIC C6-C13 Hydrocarbon at 4,000 mg/kg.
3 SB-42-6.0-6.5 - TIC C6-C13 Hydrocarbon at 4,000 mg/kg.
4 SB-41-2.0-2.5 - TIC C6-C13 Hydrocarbon at 200 mg/kg.
5 SB-41-6.0-6.5 - TIC C6-C13 Hydrocarbon at 8,000 mg/kg.
6 SB-41-8.0-8.5 - TIC C6-C13 Hydrocarbon at 3,000 mg/kg.
7 SB-45-2.0-2.5 - TIC C6-C13 Hydrocarbon at 6,000 mg/kg.
8 SB-45-6.0-6.5 - TIC C6-C13 Hydrocarbon at 20,000 mg/kg.
9 SB-45-8.0-8.5 - TIC C6-C13 Hydrocarbon at 9,000 mg/kg.

TABLE 7

SUMMARY OF SOIL DATA FOR SEMIVOLATILE ORGANIC COMPOUNDS DETECTED IN THE FORMER OILS TANK STORAGE AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab I.D. No.	Type of Analysis	Naphthalene	2-Methyl-phenol	4-Methyl-phenol	Total Phthalates	Other Detected VOC Compounds	Total Quantified Concentrations	Total TIC Semiquantified Concentrations	Note #
SW-1A	14-Jul-88	271798	8270	1.200	<0.3	<0.3	6.900	NR	8.100	NR	#1
SW-1C	14-Jul-88	27180B	8270	11.000	<0.3	<0.3	1.400	4.300	16.700	NR	#2
SW-2B	14-Jul-88	27181B	8270	4.900	<0.3	<0.3	0.700	1.800	7.400	NR	#3
SW-2D	14-Jul-88	27182B	8270	7.900	<0.3	<0.3	NR	3.100	11.000	NR	#4
SW-3A	14-Jul-88	27183B	8270	<0.3	<0.3	<0.3	1.000	NR	1.000	NR	#5
SB-22-3.5-4.0	26-Oct-89	10-739-22	8270	<0.1	<0.1	<0.1	NR	0.700	0.700	200.000	#6
SB-23-3.5-4.0	26-Oct-89	10-739-24	8270	<0.1	<0.1	<0.1	NR	6.800	6.800	2,000.000	#7
SB-41-2.0-2.5	28-Jun-90	06-665-17	8270	<0.07	<0.07	<0.07	NA	NR	0.000	100.0	#19
SB-41-6.0-6.5	28-Jun-90	06-665-18	8270	<0.07	<0.07	<0.07	NA	1.5	1.500	1,000.0	#20
SB-41-8.0-8.5	28-Jun-90	06-665-19	8270	0.2	<0.07	<0.07	NA	NR	0.200	6,000.0	#21
SB-42-2.0-2.5	28-Jun-90	06-665-15	8270	10.0	<0.03	<0.03	NA	1.4	11.400	1,000.0	#17
SB-42-6.0-6.5	28-Jun-90	06-665-16	8270	0.6	<0.03	<0.03	NA	2.3	2.900	4,000.0	#18
SB-43-2.0-2.5	28-Jun-90	06-665-14	8270	0.8	<0.03	<0.03	NA	NR	0.800	700.0	#16
SB-44-2.0-2.5	28-Jun-90	06-665-12	8270	1.1	<0.03	<0.03	NA	0.2	1.320	927.0	#14
SB-44-COMP	28-Jun-90	06-665-13	8270	<0.2	<0.2	<0.2	NA	NR	0.000	1,002.0	#15
SB-45-2.0-2.5	28-Jun-90	06-665-20	8270	6.6	<0.2	<0.2	NA	5.7	12.300	2,000.0	#22
SB-45-6.0-6.5	28-Jun-90	06-665-21	8270	3.2	<0.07	<0.07	NA	3.9	7.100	1,000.0	#23
SB-45-8.0-8.5	28-Jun-90	06-665-22	8270	0.2	<0.07	<0.07	NA	0.3	0.500	800.0	#24
SB-46-2.0-2.5	28-Jun-90	06-665-6	8270	<0.2	<0.2	<0.2	NA	NR	0.000	1,300.0	#8
SB-46-6.0-6.5	28-Jun-90	06-665-7	8270	5.5	<0.03	<0.03	NA	1.9	7.400	1,003.0	#9
SB-47-2.0-2.5	28-Jun-90	06-665-8	8270	4.1	<0.2	<0.2	NA	1.1	5.200	121.0	#10
SB-47-6.0-6.5	28-Jun-90	06-665-9	8270	0.1	<0.03	<0.03	NA	0.9	0.990	200.0	#11
SB-48-2.0-2.5	28-Jun-90	06-665-10	8270	0.1	<0.03	<0.03	NA	NR	0.060	0.6	#12
SB-48-6.0-6.5	28-Jun-90	06-665-11	8270	0.3	<0.03	<0.03	NA	NR	0.260	70.0	#13

EXPLANATION OF SYMBOLS AND ABBREVIATIONS:

TIC = Tentatively Identified Compound with semiquantified estimate of concentration.
8270 = EPA Method 8270 for semivolatile organic compounds.
NA = Not analyzed.
NR = Not reported.
Analytical Laboratory: BC Analytical, Emeryville, California.

NOTES TO TABLE 7:

# 1	SW-1A	Di-n-butylphthalate (0.7 mg/kg), and bis(2-Ethylhexyl)phthalate (6.2 mg/kg).
# 2	SW-1C	bis(2-Ethylhexyl)phthalate (1.4 mg/kg), and 2-Methylnaphthalene (4.3 mg/kg).
# 3	SW-2B	bis(2-Ethylhexyl)phthalate (0.7 mg/kg), and 2-Methylnaphthalene (1.8 mg/kg).
# 4	SW-2D	2-Methylnaphthalene (3.1 mg/kg).
# 5	SW-3A	bis(2-Ethylhexyl)phthalate (1 mg/kg).
# 6	SB-22-3.5-4.0	2-Methylnaphthalene detected at 0.7 mg/kg; TIC C8-C20 Hydrocarbon detected at 200 mg/kg.
# 7	SB-23-3.5-4.0	2-Methylnaphthalene detected at 6.6 mg/kg; Fluorene detected at 0.200 mg/kg; TIC C8-35 Hydrocarbon detected at 2,000 mg/kg.
# 8	SB-46-2.0-2.5	TIC C12H2403 at 1,000 mg/kg; C16H3004 at 100 mg/kg; C8H1802 at 200 mg/kg.
# 9	SB-46-6.0-6.5	2-Methylnapthalene detected at 1.7 mg/kg; TIC C12H2403 at 3 mg/kg; C8-C35 Hydrocarbon at 1,000 mg/kg, 4-Chloroaniline detected at 0.2 mg/kg.
#10	SB-47-2.0-2.5	2-Methylnapthalene detected at 1.1 mg/kg; TIC C16 Fatty Acid at 10 mg/kg; C18 Fatty Acid at 5 mg/kg; C20H30002(Acid) at 6 mg/kg
#11	SB-47-6.0-6.5	2-Methylnapthalene detected at 0.9 mg/kg. TIC C8-C35 Hydrocarbon Matrix at 200 mg/kg.
#12	SB-48-2.0-2.5	TIC Molecular Sulfur at 0.6 mg/kg.
#13	SB-48-6.0-6.5	TIC C8-C35 Hydrocarbon Matirix at 70 mg/kg.
#14	SB-44-2.0-2.5	2-Methylnapthalene detected at 0.22 mg/kg; TIC C14 Fatty Acid at 5 mg/kg; C16 Fatty Acid at 20 mg/kg; C18 Fatty Acid at 2 mg/kg; C8-C35 Hydrocarbon Matrix at 900 mg/kg.
#15	SB-44-COMP	TIC C16 Fatty Acid at 2 mg/kg; C8-C35 Hydrocarbon Matrix at 1,000 mg/kg.
#16	SB-43-2.0-2.5	TIC C8-C35 Hydrocarbon Matrix at 700 mg/kg.
#17	SB-42-2.0-2.5	TIC C8-C35 Hydrocarbon Matrix at 1,000 mg/kg
#18	SB-42-6.0-6.5	2-Methylnapthalene detected at 2.3 mg/kg; C8-C35 Hydrocarbon Matrix at 4,000 mg/kg.
#19	SB-41-2.0-2.5	TIC C8-C35 Hydrocarbon Matrix at 100 mg/kg.
#20	SB-41-6.0-6.5	2-Methylnapthalene detected at 1.5 mg/kg; TIC C8-C35 Hydrocarbon Matrix at 1,000 mg/kg.
#21	SB-41-8.0-8.5	TIC C8-C35 Hydrocarbon Matrix at 6,000 mg/kg.
#22	SB-45-2.0-2.5	2-Methylnapthalene detected at 5.7 mg/kg; TIC C8-C35 Hydrocarbon Matrix at 2,000 mg/kg.
#23	SB-45-6.0-6.5	2-Methylnapthalene detected at 3.7 mg/kg; Fluorene detected at 0.1 mg/kg; Phenathrene detected at 3.2 mg/kg; TIC C8-C35 Hydrocarbon Matrix at 1,000 mg/kg.
#24	SB-45-8.0-8.5	2-Methylnapthalene detected at 0.3 mg/kg; TIC C8-C35 Hydrocarbon Matrix at 800 mg/kg.

TABLE 8

HISTORICAL SOIL SAMPLING DATA SUMMARY
INORGANIC ELEMENTS DETECTED IN OILS TANK STORAGE AREA
[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab	Lab I.D. No.	Type of Analysis	Silver	Barium	Beryllium	Cadmium	Cobalt	Chromium	Copper	Nickel	Lead	Antimony	Vanadium	Zinc	Arsenic	Mercury	Selenium
Sherwin-Williams Soil Boring Samples of July 1988																			
SW-1A	14-Jul-89	GTEL	27179A	200/7000	<1.0	52	<0.5	0.7	72.0	49	43	26	240	<5.0	16	2	<15.0	1.00	<20
SW-1C	14-Jul-89	GTEL	27180C	200/7000	<1.0	17	<0.5	<0.5	6.7	26	22	26	8	<5.0	17	46	<15.0	0.02	<20
SW-2B	14-Jul-89	GTEL	27181C	200/7000	<1.0	32	<0.5	<0.5	4.9	25	24	23	102	<5.0	15	78	<15.0	0.03	<20
SW-2D	14-Jul-89	GTEL	27182C	200/7000	<1.0	34	<0.5	<0.5	6.5	24	20	25	10	<5.0	15	44	<15.0	0.01	<20
SW-3A	14-Jul-89	GTEL	27183C	200/7000	<1.0	46	<0.5	<0.5	8.1	27	27	28	21	<5.0	20	61	<15.0	0.03	<20

200/7000 = EPA Method 200/7000 for priority pollutant metals

TABLE 9

SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN SOIL OF THE FORMER SOLVENT TANK STORAGE AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab	Lab I.D. No.	Type of Analysis	Ethyl-Benzene	Toluene	TCE	PCE	Total Xylenes	Total Quantified Concentrations	TIC & SQ C5-C13 Hydrocarbons	TIC & SQ C7H14 Hydrocarbon*	Total TIC VOC TIC/SQ Concentrations
Levine*Fricke Soil Boring Samples of May 1989													
S9A	16-May-89	B & C	890552007	8240	730.000	2,400.000	<6	19.000	3,000.000	6,149.000	800.000	ND	800.000
S9B	16-May-89	B & C	890552013	8240	2.400	2.800	<0.1	<0.1	5.800	11.000	600.000	ND	600.000
S9C	17-May-89	B & C	890564805	8240	110.000	60.000	<2	<2	300.000	470.000	200.000	ND	200.000
SB-10C	17-May-89	B & C	890564801	8240	520.000	1,400.000	<2	<2	1,600.000	3,520.000	2,000.000	ND	2,000.000
S11A	16-May-89	B & C	890552009	8240	240.000	3,600.000	<6	<6	940.000	4,780.000	200.000	ND	200.000
S11B	16-May-89	B & C	890552012	8240	200.000	1,000.000	0.600	5.600	680.000	1,886.200	4,000.000	ND	4,000.000
S11C	16-May-89	B & C	890564813	8240	200.000	900.000	<6	<6	680.000	1,780.000	300.000	ND	300.000
SB-12C	17-May-89	B & C	890564806	8240	12.000	440.000	<2	<2	75.000	527.000	ND	20.000	20.000
SB-13A	17-May-89	B & C	890552005	8240	12.000	<6	<6	<6	150.000	162.000	3,000.000	ND	3,000.000
SB-13B	17-May-89	B & C	890552014	8240	50.000	3.000	<0.1	<0.1	450.000	503.000	4,000.000	ND	4,000.000
SB-13C	17-May-89	B & C	890564803	8240	42.000	35.000	<2	<2	280.000	357.000	300.000	ND	300.000
SB-14A	17-May-89	B & C	890552001	8240	0.100	<0.1	<0.1	<0.1	0.400	0.500	5.000	ND	5.000
SB-14B	17-May-89	B & C	890552002	8240	25.000	85.000	<0.1	0.400	170.000	280.400	3,000.000	ND	3,000.000
SB-14C	17-May-89	B & C	890564802	8240	0.400	<0.1	<0.1	<0.1	<0.1	0.400	200.000	ND	200.000

EXPLANATION OF SYMBOLS AND ABBREVIATIONS:

TIC & SQ = Tentatively Identified Compoundand (TIC) with Semiquantified Estimates of Compound Concentrations.
Note: TIC concentrations are only reported as estimates.
8240 = EPA Method 8240 for volatile organic compounds.
ND = Not Detected
TCE = Trichloroethene
PCE = Tetrachloroethene
B & C = BC Analytical (formerly Brown and Caldwell) Laboratory, Emeryville, California

TABLE 10

SUMMARY OF SEMIVOLATILE ORGANIC COMPOUNDS DETECTED IN SOIL OF THE FORMER SOLVENT TANK STORAGE AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab I.D. No.	Type of Analysis	Naphthalene	2-Methyl-phenol	4-Methyl-phenol	Total Phthalates	Other Detected VOC Compounds	Total Quantified Concentrations	Total TIC Semiquantified Concentrations	Note #
Levine*Fricke Soil Boring Samples of May 1989											
S9A	16-May-89	890552007	8270	<2	<2	<2	ND	ND	<2.000	600.000	#16
S9B	16-May-89	890552013	8270	0.500	<0.1	<0.1	ND	ND	0.500	800.000	#17
S11A	16-May-89	890552009	8270	<1	<1	<1	ND	8.000	8.000	1,000.000	#18
S11B	16-May-89	890552012	8270	0.500	<0.1	<0.1	ND	ND	0.500	80.000	#19
SB-13A	17-May-89	890552005	8270	2.300	<0.1	<0.1	ND	ND	2.300	2,030.000	#20
SB-13B	17-May-89	890552014	8270	1.100	<0.1	<0.1	ND	ND	1.100	1,000.000	#21
SB-14A	17-May-89	890552001	8270	<0.1	<0.1	<0.1	ND	ND	<0.100	22.000	#22
SB-14B	17-May-89	890552002	8270	0.300	<0.1	<0.1	ND	ND	0.300	900.000	#23

EXPLANATION OF SYMBOLS AND ABBREVIATIONS:

TIC = Tentatively Identified Compound with Semiquantified Estimate of Concentration.
8270 = EPA Method 8270 for semivolatile organic compounds
NA = Not Analyzed
Analytical Laboratory: BC Analytical (formerly Brown and Caldwell) Laboratories, Emeryville, California

NOTES:

#16	S9A	One TIC detected: C8-C15 Hydrocarbon matrix (600 mg/kg)
#17	S9B	One TIC detected: C8-C15 Hydrocarbon matrix (800 mg/kg)
#18	S11A	Isophorone (8 mg/kg), and one TIC detected: C8-C15 Hydrocarbon matrix (1,000 mg/kg).
#19	S11B	One TIC detected: C8-C15 Hydrocarbon matrix (80 mg/kg)
#20	SB-13A	Two TICs detected: C8-C15 Hydrocarbon matrix (2,000 mg/kg), and C20-30 Hydrocarbons (30 mg/kg).
#21	SB-13B	One TIC detected: C8-C15 Hydrocarbon matrix (1,000 mg/kg)
#22	SB-14A	Two TICs detected: C8-C15 Hydrocarbon matrix (20 mg/kg), and C20-25 Hydrocarbons (2 mg/kg).
#23	SB-14B	One TIC detected: C8-C15 Hydrocarbon matrix (900 mg/kg)

TABLE 11

SUMMARY OF INORGANIC ELEMENTS DETECTED IN SOIL OF THE FORMER SOLVENT TANK STORAGE AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab	Lab I.D. No.	Type of Analysis	Silver	Barium	Beryllium	Cadmium	Cobalt	Chromium	Copper	Nickel	Lead	Antimony	Vanadium	Zinc	Arsenic	Mercury	Selenium
Levine*Fricke Soil Boring Samples of May 1989																			
S9A	16-May-89	B&C	890552007	200/7000	0.6	530	<0.2	25.0	14.0	78	470	63	3,200	11.0	59	12,000	26.0	1.30	0.60
S9B	16-May-89	B&C	890552013	200/7000	<0.4	140	<0.2	5.3	13.0	55	17	52	<6	3.4	63	55	3.6	0.03	<0.2
S11A	16-May-89	B&C	890552009	200/7000	3.4	390	<0.2	9.9	13.0	93	170	49	480	19.0	55	760	22.0	0.60	8.80
S11B	16-May-89	B&C	890552012	200/7000	<0.4	99	<0.2	5.9	10.0	43	22	47	<6	<1.2	50	120	17.0	0.02	0.60
SB-13A	17-May-89	B&C	890552005	200/7000	<0.4	130	<0.2	4.4	9.1	39	20	45	56	<1.2	37	64	16.0	0.02	0.60
SB-13B	17-May-89	B&C	890552014	200/7000	<0.4	130	<0.2	4.4	10.0	43	18	39	<6	<1.2	47	63	6.0	0.06	0.60
SB-14A	17-May-89	B&C	890552001	200/7000	<0.4	250	<0.2	5.2	10.0	110	25	66	2,000	1.7	45	280	37.0	0.10	0.40
SB-14B	17-May-89	B&C	890552002	200/7000	<0.4	100	<0.2	4.5	9.6	48	13	47	<6	<1.2	54	47	19.0	<0.01	0.40

EXPLANATION OF SYMBOLS AND ABBREVIATIONS:

200/7000 = EPA Method 200/7000 for priority pollutant metals
NA = Not Analyzed

Analytical Laboratories:
B&C: BC Analytical (formerly Brown and Caldwell) Laboratory, Emeryville, California.

TABLE 12

SUMMARY OF PETROLEUM HYDROCARBON CONCENTRATIONS DETECTED IN SOILS IN THE PARKING LOT AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

SAMPLE ID	DATE SAMPLED	LAB	LOG NO.	TYPE OF ANALYSIS	TOTAL FUEL HYDROCARBONS*
PA1 3.0-3.5	02-Jul-90	BCA	07-023-1	8015	4,100 oil
PA1 8.0-8.5	02-Jul-90	BCA	07-023-2	8015	<10
PA1 6.0-6.5	02-Jul-90	BCA	07-023-3	8015	<10
PA2 3.0-3.5	02-Jul-90	BCA	07-023-4	8015	<10
PA2 8.0-8.5	02-Jul-90	BCA	07-023-5	8015	<10
PA3 5.0-5.5	02-Jul-90	BCA	07-023-6	8015	460 diesel
PA3-11	02-Jul-90	BCA	07-023-7	8015	<10
PA9105B-8	21-Jan-91	BCA	01-441-1	8015	950 m. spirits
PA9104-3	21-Jan-91	BCA	01-441-2	8015	1,400 mixed
PA9104-8	21-Jan-91	BCA	01-441-3	8015	50 m. spirits
PA9103-3	21-Jan-91	BCA	01-441-4	8015	410 m. spirits
PA9103-6.5	21-Jan-91	BCA	01-441-5	8015	<10
PA9101-3	21-Jan-91	BCA	01-441-6	8015	1,200 mixed
PA9101-6	21-Jan-91	BCA	01-441-7	8015	<10
PA9106-3	21-Jan-91	BCA	01-441-8	8015	750 mixed
PA9106-5.5	21-Jan-91	BCA	01-441-9	8015	430 mixed
PA9105B-3	21-Jab-91	BCA	01-441-10	8015	NA/VISIBLE
PA9102B-3	21-Jan-91	BCA	01-441-11	8015	NA/VISIBLE
PA9102B-8	21-Jan-91	BCA	01-441-12	8015	NA/VISIBLE

* = Fuel Characterization - Oil, Diesel, Mineral Spirits, or Mixed
BCA = BC Analytical (formerly Brown and Caldwell) Analytical Laboratory
NA/VISIBLE = Sample not analyzed; visible field evidence of TPH

TABLE 13

SUMMARY OF INORGANIC ELEMENTS IN SOIL
DETECTED IN THE ARSENIC SOURCE AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab	Lab I.D. No.	Type of Analysis	Lead	Arsenic	Other Elements
Soil Data From Drilling In November 1989							
LF-B1-2.5-3.0	08-Nov-89	B&C	11-244-1	200/7000	50	480	Cr/38; Cu/54; Zn/77
LF-B1-4.5-5.0	08-Nov-89	B&C	11-244-2	200/7000	<6	6	Cr/42; Cu/85; Zn/110
LF-B1-6.0-6.5	08-Nov-89	B&C	11-244-3	200/7000	<6	6	Cr/48; Cu/34; Zn/98
Soil Data From Drilling In April and June 1990							
SB-27-2	18-Apr-90	B&C	04-522-37	200/7000	2,600	2,200	Ba/85; Cd/4; Cu/19; Zn/84
SB-27(4.0-4.5)	28-Jun-90	B&C	06-665-4	200/7000	1,200	500	Cd/9; Cu/63; Zn/940
SB-27(5.0-5.5)	28-Jun-90	B&C	06-665-5	200/7000	3,000	800	Cd/10; Cu/78; Zn/940
SB-28-2	18-Apr-90	B&C	04-522-1	200/7000	19	5	Ba/170; Cd/6; Cu/23; Zn/82
SB-28-4	18-Apr-90	B&C	04-522-2	200/7000	<6	5	Ba/130; Cd/7; Cu/19; Zn/55
SB-29-2	18-Apr-90	B&C	04-522-4	200/7000	110	8	Ba/170; Cd/10; Cu/31; Zn/13
SB-29-4	18-Apr-90	B&C	04-522-5	200/7000	<6	4	Ba/110; Cd/6; Cu/15; Zn/50
SB-30-2	18-Apr-90	B&C	04-522-7	200/7000	<6	4	Ba/200; Cd/11; Cu/33; Zn/66
SB-30-4	18-Apr-90	B&C	04-522-8	200/7000	48	6	Ba/150; Cd/7; Cu/25; Zn/72
SB-31-2	18-Apr-90	B&C	04-522-10	200/7000	120	10	Ba/120; Cd/9; Cu/45; Zn/180
SB-31-4	18-Apr-90	B&C	04-522-11	200/7000	24	4	Ba/130; Cd/6; Cu/17; Zn/56
SB-32-2	18-Apr-90	B&C	04-522-13	200/7000	68	18	Ba/91; Cd/7; Cu/19; Zn/100
SB-32-4	18-Apr-90	B&C	04-522-14	200/7000	<6	5	Ba/180; Cd/6; Cu/20; Zn/64
SB-33-2	18-Apr-90	B&C	04-522-16	200/7000	<6	4	Ba/150; Cd/6; Cu/17; Zn/66
SB-33-4	18-Apr-90	B&C	04-522-17	200/7000	<6	4	Ba/120; Cd/7; Cu/18; Zn/59
SB-34-2	18-Apr-90	B&C	04-522-19	200/7000	27	10	Ba/160; Cd/7; Cu/20; Zn/67
SB-34-4	18-Apr-90	B&C	04-522-20	200/7000	<6	5	Ba/120; Cd/7; Cu/18; Zn/60
SB-35-2	18-Apr-90	B&C	04-522-22	200/7000	2,600	2,200	Ba/180; Cd/7; Cu/160; Zn/11
SB-35-4	18-Apr-90	B&C	04-522-23	200/7000	410	52,000	Ba/140; Cd/8; Cu/350; Zn/35
SB-35-6	18-Apr-90	B&C	05-516-1	200/7000	26	51,000	Ba/130; Cd/6; Cu/110; Zn/23
SB-36-2	18-Apr-90	B&C	04-522-25	200/7000	260	710	Ba/180; Cd/7; Cu/210; Zn/11
SB-36-4	18-Apr-90	B&C	04-522-26	200/7000	<6	6	Ba/160; Cd/7; Cu/17; Zn/56
SB-37(5.5-6.0)	28-Jun-90	B&C	06-665-1	200/7000	6	7,300	Cd/5; Cu/19; Zn/44
SB-37(8.0-8.5)	28-Jun-90	B&C	06-665-2	200/7000	5	10,000	Cd/5; Cu/24; Zn/44
SB-37(10.0-10.5)	28-Jun-90	B&C	06-665-3	200/7000	8	19,000	Cd/7; Cu/64; Zn/340

TABLE 13

SUMMARY OF INORGANIC ELEMENTS IN SOIL
DETECTED IN THE ARSENIC SOURCE AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab	Lab I.D. No.	Type of Analysis	Lead	Arsenic	Other Elements
SB-38-2	18-Apr-90	B&C	05-516-2	200/7000	4,100	12,000	Ba/590; Cd/10; Cu/130; Zn/1
SB-38-4	18-Apr-90	B&C	05-516-3	200/7000	500	28,000	Ba/200; Cd/8; Cu/350; Zn/17
SB-38-6	18-Apr-90	B&C	05-516-4	200/7000	64	11,000	Ba/110; Cd/6; Cu/32; Zn/73
SB-39-2	18-Apr-90	B&C	04-522-31	200/7000	<6	4,200	Ba/170; Cd/7; Cu/18; Zn/57
SB-39-4	18-Apr-90	B&C	04-522-32	200/7000	<6	1,400	Ba/99; Cd/6; Cu/16; Zn/50
SB-39-6	18-Apr-90	B&C	05-516-5	200/7000	<6	910	Ba/100; Cd/5; Cu/11; Zn/37
SB-40-2	18-Apr-90	B&C	04-522-34	200/7000	14	96	Ba/150; Cd/5; Cu/21; Zn/66
SB-40-4	18-Apr-90	B&C	04-522-35	200/7000	24	150	Ba/110; Cd/5; Cu/14; Zn/71
SB-40-6	18-Apr-90	B&C	05-516-6	200/7000	<6	33	Ba/150; Cd/6; Cu/19; Zn/77
Soil Data From Drilling In January 1991							
AA9101-2	18-Jan-91	B&C	01-395-5	200/7000	25	45	
AA9101-4	18-Jan-91	B&C	01-395-6	200/7000	15	14	
AA9101-6	18-Jan-91	B&C	01-395-18	200/7000	NA	NA	
AA9101-8	18-Jan-91	B&C	01-395-19	200/7000	8	8	
AA9101-10	18-Jan-91	B&C	01-395-20	200/7000	NA	NA	
AA9102-2	17-Jan-91	B&C	01-376-3	200/7000	1,600	1,300	
AA9103-2	17-Jan-91	B&C	01-376-4	200/7000	1,400	1,800	
AA9103-4	17-Jan-91	B&C	01-376-5	200/7000	270	60	
AA9103-6	17-Jan-91	B&C	02-434-2	200/7000	7	8	
AA9103-8	17-Jan-91	B&C	01-376-12	200/7000	NA	NA	
AA9103-10	17-Jan-91	B&C	04-269-2	200/7000	5	760	
AA9104-2	18-Jan-91	B&C	01-395-3	200/7000	330	4,400	
AA9104-4	18-Jan-91	B&C	01-395-4	200/7000	52	220	
AA9104-6	18-Jan-91	B&C	02-434-14	200/7000	10	11	
AA9104-8	18-Jan-91	B&C	01-395-16	200/7000	NA	NA	
AA9104-10	18-Jan-91	B&C	04-269-10	200/7000	83	2,000	
AA9105-2	18-Jan-91	B&C	01-395-1	200/7000	4,900	8,700	
AA9105-4	18-Jan-91	B&C	01-395-2	200/7000	11	4,100	
AA9105-6	18-Jan-91	B&C	02-434-13	200/7000	7	990	
AA9105-8	18-Jan-91	B&C	01-395-14	200/7000	NA	NA	
AA9105-10	18-Jan-91	B&C	04-269-9	200/7000	180	3,900	
AA9106-2	18-Jan-91	B&C	01-377-1	200/7000	120	2,700	
AA9106-4	18-Jan-91	B&C	01-377-2	200/7000	11	990	

TABLE 13

SUMMARY OF INORGANIC ELEMENTS IN SOIL
DETECTED IN THE ARSENIC SOURCE AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab	Lab I.D. No.	Type of Analysis	Lead	Arsenic	Other Elements
AA9106-6	18-Jan-91	B&C	02-434-6	200/7000	72	1,500	
AA9106-8	18-Jan-91	B&C	04-269-5	200/7000	11	28,000	
AA9107-2	17-Jan-91	B&C	01-376-1	200/7000	1,700	11,000	
AA9107-4	17-Jan-91	B&C	01-376-2	200/7000	190	1,800	
AA9107-6	17-Jan-91	B&C	02-434-1	200/7000	74	1,700	
AA9107-8	17-Jan-91	B&C	01-376-8	200/7000	NA	NA	
AA9107-10	17-Jan-91	B&C	04-269-1	200/7000	33	1,900	
AA9108-2	17-Jan-91	B&C	01-376-6	200/7000	52	58	
AA9108-4	17-Jan-91	B&C	01-376-7	200/7000	230	110	
AA9108-6	17-Jan-91	B&C	02-434-3	200/7000	9	3,300	
AA9108-8	17-Jan-91	B&C	01-376-14	200/7000	NA	NA	
AA9108-10	17-Jan-91	B&C	04-269-4	200/7000	13	32,000	
AA9109-2	18-Jan-91	B&C	01-395-6	200/7000	49,000	110,000	
AA9109-4	18-Jan-91	B&C	01-395-6	200/7000	19	2,200	
AA9109-6	18-Jan-91	B&C	01-395-9	200/7000	NA	NA	
AA9109-8	18-Jan-91	B&C	01-395-10	200/7000	NA	NA	
AA9109-10	18-Jan-91	B&C	04-269-8	200/7000	9	4,500	
AA9110-2	17-Jan-91	B&C	02-434-7	200/7000	20,000	4,200	
AA9110-4	17-Jan-91	B&C	02-434-8	200/7000	340	580	
AA9110-6	17-Jan-91	B&C	01-377-12	200/7000	NA	NA	
AA9110-8	17-Jan-91	B&C	01-377-13	200/7000	NA	NA	
AA9110-10	17-Jan-91	B&C	04-269-10	200/7000	9	4,000	
AA9111-2	17-Jan-91	B&C	02-434-4	200/7000	530	4,000	
AA9111-4	17-Jan-91	B&C	02-434-5	200/7000	480	1,700	
AA9111-6	17-Jan-91	B&C	01-377-5	200/7000	NA	NA	
AA9111-8	17-Jan-91	B&C	01-377-6	200/7000	NA	NA	
AA9111-10	17-Jan-91	B&C	04-269-5	200/7000	9	930	
AA9112-2	17-Jan-91	B&C	02-434-9	200/7000	48	96	
AA9112-4	17-Jan-91	B&C	02-434-10	200/7000	7	5	
AA9112-6	17-Jan-91	B&C	01-378-3	200/7000	NA	NA	
AA9112-8	17-Jan-91	B&C	01-378-4	200/7000	NA	NA	
AA9112-10	17-Jan-91	B&C	04-269-7	200/7000	5	850	
Soil Data From Drilling In June 1991							
AA9113-2	13-Jun-91	ANA	9106188-1	200/7000	7	210	
AA9113-4	13-Jun-91	ANA	9106188-2	200/7000	9	129	

TABLE 13

SUMMARY OF INORGANIC ELEMENTS IN SOIL
DETECTED IN THE ARSENIC SOURCE AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab	Lab I.D. No.	Type of Analysis	Lead	Arsenic	Other Elements
AA9114-2	13-Jun-91	ANA	9106189-14	200/7000	12	318	
AA9114-4	13-Jun-91	ANA	9106189-15	200/7000	6	180	
AA9114-6	13-Jun-91	ANA	9106189-16	200/7000	60	672	
AA9115-2	13-Jun-91	ANA	9106189-11	200/7000	116	692	
AA9115-4	13-Jun-91	ANA	9106189-12	200/7000	4	198	
AA9115-6	13-Jun-91	ANA	9106189-13	200/7000	17	535	
AA9116-2	13-Jun-91	ANA	9106189-01	200/7000	121	555	
AA9116-4	13-Jun-91	ANA	9106189-02	200/7000	16	374	
AA9116-6	13-Jun-91	ANA	9106189-03	200/7000	13	400	
AA9117-2	12-Jun-91	ANA	9106187-15	200/7000	7	69	
AA9117-4	12-Jun-91	ANA	9106187-16	200/7000	16	91	
AA9118-2	12-Jun-91	ANA	9106187-01	200/7000	44	28	
AA9118-4	12-Jun-91	ANA	9106187-02	200/7000	6	5	
AA9118-6	12-Jun-91	ANA	9106187-03	200/7000	8	4	
AA9118-8	12-Jun-91	ANA	9106187-04	200/7000	8	48	
AA9119-2	12-Jun-91	ANA	9106187-05	200/7000	930	46	
AA9119-4	12-Jun-91	ANA	9106187-06	200/7000	8	5	
AA9119-6	12-Jun-91	ANA	9106187-07	200/7000	5	4	
AA9120-2	13-Jun-91	ANA	9106188-3	200/7000	12	115	
AA9120-4	13-Jun-91	ANA	9106188-4	200/7000	142	329	
AA9120-6	13-Jun-91	ANA	9106188-5	200/7000	11	147	
AA9121-2	13-Jun-91	ANA	9106189-07	200/7000	31	13	
AA9121-4	13-Jun-91	ANA	9106189-08	200/7000	9	39	
AA9121-6	13-Jun-91	ANA	9106189-09	200/7000	77	302	
AA9121-8	13-Jun-91	ANA	9106189-10	200/7000	6	1,260	
AA9122-2	13-Jun-91	ANA	9106189-04	200/7000	32	293	
AA9122-4	13-Jun-91	ANA	9106189-05	200/7000	18	461	
AA9122-6	13-Jun-91	ANA	9106189-06	200/7000	8	208	
AA9123-2	12-Jun-91	ANA	9106187-10	200/7000	6	8	
AA9123-4	12-Jun-91	ANA	9106187-11	200/7000	6	4	
AA9123-6	12-Jun-91	ANA	9106187-12	200/7000	6	12	
AA9123-8	12-Jun-91	ANA	9106187-13	200/7000	4	2,810	

TABLE 13

SUMMARY OF INORGANIC ELEMENTS IN SOIL
DETECTED IN THE ARSENIC SOURCE AREA

[All concentrations expressed in milligrams per kilogram (mg/kg)]

Sample ID	Date	Lab	Lab I.D. No.	Type of Analysis	Lead	Arsenic	Other Elements
AA9124-2	12-Jun-91	ANA	9106187-08	200/7000	6	11	
AA9124-4	12-Jun-91	ANA	9106187-09	200/7000	6	6	
AA9124-6	12-Jun-91	ANA	9106187-10	200/7000	7	11	
AA91TS1-1-3	13-Jun-91	ANA	9106186-1	200/7000	15,400	23,800	
AA91TS1-8-10	13-Jun-91	ANA	9106186-1	200/7000	242	1,260	
AA91TS2-10-12	13-Jun-91	ANA	9106186-1	200/7000	50	10,500	
AA91TS2-12-14	13-Jun-91	ANA	9106186-1	200/7000	9	1,830	
AA91TS3-2-5	13-Jun-91	ANA	9106186-1	200/7000	10,000	34,000	

200/7000 = EPA Method 200/7000 for inorganic compounds.
NA = Not Analyzed

Analytical Laboratories: B&C = BC Analytical (formerly Brown and Caldwell), Emeryville, California.
ANA = Anametrix Laboratory of San Jose, California

Ba = Barium; Cd = Cadmium; Cu = Copper; Zn = Zinc

TABLE 14

PROPOSED SOIL REMEDIAL GOALS

Chemical	Maximum Concentration Detected in Soil (mg/kg)	Federal/State Ground-Water Goal (mg/L)(1)	Proposed Soil Remedial Goal (mg/kg)
Ethylbenzene	1,500	0.680	10
Toluene	14,000	0.100(2)	10
Xylene Isomers	9,900	1.750	10
Naphthalene	4.3	---	---
PCB(3)	0.36	$9x10^{-8}$(4)	---
Bis(2-ethylhexyl) phthalate	10.2	15.000(4)	---
Isophorone(3)	8	5.200(4)	---
2-Methyl phenol(3)	2	---	---
4-Methyl phenol(3)	2	---	---
Pyrene(3)	1.2	$2.8x10^{-6}$(4)	---
Fluoranthrene(3)	1.4	0.042(4)	---
Phenanthrene(3)	2.4	$2.8x10^{-6}$(4)	---
Hydrocarbons	20,000(5)	---	100
Arsenic	52,000	0.050	50
Lead	2,300	0.050	500

mg/kg = milligrams per kilogram
--- = No applicable standard was found

---

(1) Based on EPA and/or State Maximum Contaminant Levels (MCLS), unless otherwise noted.

(2) California State Recommended Drinking Water Action Level.

(3) Chemicals detected at one location only.

(4) National Ambient Water Quality Criteria (NAWQC), based on health effects.

(5) Semiquantified concentration.

TABLE 15

PROPOSED GROUND-WATER REMEDIAL GOALS

Chemical Compound	Maximum Concentration Detected (mg/L)	Proposed Remedial Goal[1] (mg/L)
Benzene	0.110	0.001
Ethylbenzene	6.300	0.680
Toluene	310	0.100[2]
Xylenes	210	1.750
Methyl ethyl ketone	720	0.170[3]
2-Hexanone	24	---
Acetone	280	---
Naphthalene	0.650	---
Phenol	0.380	0.005[4]
2-Methyl phenol	0.280	---
4-Methyl phenol	1.000	---
Bis(2-ethylhexyl) phthalate	0.028	0.005
Arsenic	200	0.050
Lead	0.200	0.050

mg/L = milligrams per liter.
--- = No applicable standard was found.

---

[1] Based on Federal or State Maximum Contaminant Levels (MCLs), unless otherwise noted.

[2] California State Recommended Drinking Water Action Level.

[3] Based on EPA Suggested No Adverse Response Levels (SNARLs).

[4] Based on Department of Health Services Taste and Odor Threshold.

TABLE 16

ALTERNATIVES 1 AND 2: HYDRAULIC CONTAINMENT
ESTIMATED CAPITAL COSTS

DESCRIPTION	QUANTITY/UNIT	UNIT COST (1)	TOTAL COST (1)	REFERENCE
1. EXTRACTION SYSTEM				
a. Installation of extraction wells	3 EA	$10,000	$30,000	Cost Files
b. Piping, valves, and flow meters	1 LS	15,000	15,000	Cost Files
c. Well pump and wellhead	6 EA	4,000	24,000	Cost Files
d. Trenching and backfill	800 LF	50	40,000	Cost Files
e. Dewatering trenches, piping, and well points	360 LF	100	36,000	Cost Files
f. Electrical	1 EA	10,000	10,000	Cost Files
g. Engineering, permitting and construction management (35% of items a. through f.)	35 %		54,250	
h. Contingency (20% of items a. through g.)	20 %		41,850	
Subtotal 1:			$251,100	
2. GROUND-WATER TREATMENT SYSTEM EQUIPMENT				
a. Bioreactors and clarifier	1 EA	$65,000	$65,000	Vendor Quote
b. Electrochemical precipitator	1 EA	150,000	150,000	Vendor Quote
c. Carbon vessels with carbon charge liquid-phase vessels for polish	2 EA	9,000	18,000	Vendor Quote
d. Equalization tank	1 EA	5,000	5,000	Cost Files
e. Pumps, piping, filters, valves, and skid	1 EA	12,000	12,000	Cost Files
f. Electrical, instrumentation, and control panel	1 LS	17,000	17,000	Cost Files
g. Well controls	1 LS	10,000	10,000	Cost Files
h. Fencing	1 LS	6,000	6,000	Cost Files
i. Concrete pad and miscellaneous	1 LS	15,000	15,000	Cost Files
j. Engineering, permitting, and construction management (35% of items a. through i.)	35 %		104,300	
k. Contingency (20% of items a. through j.)	20 %		80,500	
Subtotal 2:			$482,800	
ESTIMATED TOTAL CAPITAL COSTS			$733,900	

NOTES:

1. All costs are in 1991 dollars.
2. Costs do not include further subsurface investigations (if needed), regulatory interface, or permit fees.

TABLE 17

ALTERNATIVES 1 AND 2: HYDRAULIC CONTAINMENT
ESTIMATED OPERATIONS AND MAINTENANCE COSTS

DESCRIPTION	QUANTITY	UNIT	UNIT COST (1	TOTAL COST (1)	REFERENCE
1. ANNUAL OPERATIONS AND MAINTENANCE					
a. Carbon transportation/regeneration	2500	LB	$2.50	$6,250	Cost Files
b. Power (extraction wells and process pumps)	50000	KWH	0.10	5,000	PG&E
c. Power (bioreactors)	75000	KWH	0.10	7,500	PG&E
d. Disposal of arsenic sludge	170	BBL	250	42,500	Vendor Quote
e. Manpower for operations/maintenance/ treatment system sampling	600	MHR	60	36,000	Cost Files
f. Chemicals - (Bio) nutrients, pH, carbon	1	EA	5,500	5,500	Cost Files
g. Chemicals and power - electrochemical (H202 & Fe)	1	LS	30,000	30,000	Vendor Quote
h. Laboratory - treatment system and wells	1	LS	35,000	35,000	Cost Files
i. Manpower for water-level measurements and and sampling wells	200	MHR	70	14,000	Cost Files
j. Data evaluation and reporting	4	EA	5,000	20,000	Cost Files
k. Sampling equipment	1	LS	4,000	4,000	Cost Files
l. Spare parts/repairs (1% of total capital costs)	1	%		7,200	Cost Files
m. Contingency (20% of items a. through l.)	20	%		42,590	Cost Files
Subtotal Annual O&M Costs :				$255,540	
2. ESTIMATED 20-YEAR PRESENT WORTH (20 YEARS @ 5%)				$3,185,000	(2)

NOTES:
1) All costs are in 1991 dollars.
2) The present values have been calculated on a net interest rate (interest rate minus inflation) of 5 percent. Present worth evaluations based on a 20-year operating period.
3) Total O&M costs for this alternative reflect costs to operate and maintain a remedial system and to conduct quarterly ground-water monitoring. Regulatory interface and permit fees are not included in the estimated costs.

TABLE 18

ALTERNATIVE 1: FULL SOURCE EXCAVATION AND DISPOSAL
ESTIMATED CAPITAL COSTS

DESCRIPTION	QUANTITY/UNIT	UNIT COST (1)	TOTAL COST (1)	REFERENCE
1. OIL TANK STORAGE AREA SOILS				
a. Excavation	2,200 CY	$25	$55,000	Vendor Quote
b. Hauling	2,200 CY	130	286,000	Vendor Quote
c. Off-site treatment and disposal fees	2,200 CY	280	616,000	Vendor Quote
d. Taxes	2,200 CY	120	264,000	Vendor Quote
e. Generator fee	1 LS	48,000	48,000	Cost Files
e. Remove and replace railroad spur	150 LF	90	13,500	Cost Files
f. Replacement fill	2,200 CY	5	11,000	Cost Files
g. Resurfacing	2,800 SY	22	61,600	Cost Files
i. Analytical sampling	1 LS	5,000	5,000	Cost Files
j. Engineering, permitting and construction management (10% of items a. through i.)	10 %		118,400	Cost Files
h. Contingency (20% of items a. through j.)	20 %		250,500	Cost Files
Subtotal 1:			$1,729,000	
2. SOLVENT TANK STORAGE AREA AND PARKING AREA SOILS				
a. Excavation	10,100 CY	$25	$252,500	Vendor Quote
b. Hauling	10,100 CY	130	1,313,000	Vendor Quote
c. Off-site treatment and disposal fees	10,100 CY	280	2,828,000	Vendor Quote
d. Taxes	10,100 CY	120	1,212,000	Vendor Quote
e. Generator fee	1 LS	48,000	48,000	Cost Files
f. Remove and Replace Railroad Spur	600 LF	90	54,000	Cost Files
g. Replacement fill	10,100 CY	5	50,500	Cost Files
h. Resurfacing	4,300 SY	22	94,600	Cost Files
i. Analytical sampling	1 LS	5,000	5,000	Cost Files
j. Engineering, permitting and construction management (10% of items a. through i.)	10 %		505,000	Cost Files
h. Contingency (20% of items a. through j.)	20 %		1,110,900	Cost Files
Subtotal 2:			$7,473,500	

TABLE 18

ALTERNATIVE 1: FULL SOURCE EXCAVATION AND DISPOSAL
ESTIMATED CAPITAL COSTS

DESCRIPTION	QUANTITY/UNIT	UNIT COST (1)	TOTAL COST (1)	REFERENCE
3. ARSENIC-AFFECTED SOILS				
a. Excavation	13,100 CY	$25	$327,500	Vendor Quote
b. Hauling	13,100 CY	130	1,703,000	Vendor Quote
c. Disposal fees	13,100 CY	200	2,620,000	Vendor Quote
d. Taxes	13,100 CY	120	1,572,000	Vendor Quote
e. Generator fee	1 LS	48,000	48,000	Cost Files
f. Remove and replace railroad spur	200 LF	90	18,000	Cost Files
g. Structural foundation reinforcement	500 LF	225	112,500	Vendor Quote
h. Replacement fill	13,100 CY	5	65,500	Cost Files
i. Resurfacing	4,300 SY	22	94,600	Cost Files
j. Analytical sampling	1 LS	5,000	5,000	Cost Files
k. Engineering, permitting, etc.	10 %		656,600	Cost Files
j. Contingency (20% of items a. through j.)	20 %		1,444,500	Cost Files
Subtotal 3:			$8,667,200	
ESTIMATED CAPITAL COSTS FOR EXCAVATION AND DISPOSAL			$17,869,700	

NOTE: All costs are in 1991 dollars.

TABLE 19

ALTERNATIVE 2: FULL SOURCE TREATMENT
ESTIMATED CAPITAL COSTS

DESCRIPTION	QUANTITY/UNIT	UNIT COST (1)	TOTAL COST (1)	REFERENCE
1. OIL TANK STORAGE AREA				
a. Excavation	2,200 CY	$10	$22,000	Cost Files
b. Bio-treatment of soils	2,200 CY	55	121,000	Cost Files
c. Backfill treated soils	2,200 CY	10	22,000	Cost Files
d. Analytical sampling	20 EA	150	3,000	Cost Files
e. Remove and replace railroad spur	150 LF	90	13,500	Cost Files
f. Resurfacing	2,800 SY	22	61,600	Cost Files
f. Structural foundation reinforcement	220 LF	220	48,400	Contractor Quote
g. Engineering, permitting, and construction management (20% of items a. through g.)	20 %		58,300	Cost Files
h. Contingency (20% of items a. through h.)	20 %		70,000	Cost Files
Subtotal 1:			$419,800	
2. SOLVENT TANK STORAGE AREA AND PARKING AREA				
a. Excavation	10,100 CY	$10	$101,000	Cost Files
b. Bio-treatment of soils	10,100 CY	55	555,500	Cost Files
c. Backfill treated soils	10,100 CY	10	101,000	Cost Files
d. Analytical sampling	20 EA	150	3,000	Cost Files
e. Remove and replace railroad spur	600 LF	90	54,000	Cost Files
f. Resurfacing	4,300 SY	22	94,600	Cost Files
g. Engineering, permitting, and construction management (20% of items a. through f.)	20 %		181,800	Cost Files
h. Contingency (20% of items a. through g.)	20 %		218,200	Cost Files
Subtotal 2:			$1,309,100	
3. ARSENIC AFFECTED SOILS				
a. Fixation/solidification	13,100 CY	$91	$1,192,100	Contractor Quote
b. Analytical Sampling	50 EA	120	6,000	Cost Files
c. Remove and replace railroad spur	200 LF	90	18,000	Cost Files
d. Resurfacing	4,300 SY	22	94,600	Cost Files
e. Structural foundation reinforcement	500 LF	225	112,500	Contractor Quote
f. Engineering, permitting, and construction management (20% of items a. through e.)	20 %		284,600	Cost Files
g. Contingency (20% of items a. through f.)	20 %		341,600	Cost Files
			$2,049,400	
ESTIMATED TOTAL CAPITAL COSTS FOR FULL SOURCE REDUCTION			$3,778,300	

NOTE: All costs are in 1991 dollars.

TABLE 20

ALTERNATIVES 3, 4, AND 5: ENGINEERED CONTAINMENT
ESTIMATED CAPITAL COSTS

DESCRIPTION	QUANTITY/UNIT	UNIT COST (1)	TOTAL COST (1)	REFERENCE
1. GROUND-WATER EXTRACTION SYSTEM				
a. Installation of extraction wells	3 EA	$10,000	$30,000	Cost Files
b. Piping, valves and flow meters	1 LS	5,000	5,000	Cost Files
c. Well pump and wellhead	3 EA	4,000	12,000	Cost Files
d. Trenching and backfill	500 LF	50	25,000	Cost Files
e. Electrical	1 EA	5,000	5,000	Cost Files
f. Engineering, permitting, and construction management (35% of items a. through e.)	35 %		27,000	Cost Files
g. Contingency (20% of items a. through f.)	20 %		20,800	Cost Files
Subtotal 1:			$124,800	
2. GROUND-WATER TREATMENT SYSTEM EQUIPMENT				
a. Bioreactors and clarifier	1 EA	$40,000	$40,000	Vendor Quote
b. Electrochemical precipitator	1 EA	100,000	100,000	Vendor Quote
c. Carbon vessels with carbon charge liquid-phase vessel for polish	2 EA	3,000	6,000	Vendor Quote
d. Equalization tank	1 EA	5,000	5,000	Cost Files
e. Pumps, piping, filters, valves, and skid	1 EA	10,000	10,000	Cost Files
f. Electrical, instrumentation and control panel	1 LS	12,000	12,000	Cost Files
g. Well controls	1 LS	7,000	7,000	Cost Files
h. Fencing	1 LS	6,000	6,000	Cost Files
i. Concrete pad and miscellaneous	1 LS	12,000	12,000	Cost Files
j. Engineering, permitting, and construction management (35% of items a. through i.)	35 %		69,300	Cost Files
k. Contingency (20% of items a. through j.)	20 %		53,500	Cost Files
Subtotal 2:			$320,800	

TABLE 20

ALTERNATIVES 3, 4, AND 5: ENGINEERED CONTAINMENT
ESTIMATED CAPITAL COSTS

DESCRIPTION	QUANTITY/UNIT	UNIT COST (1)	TOTAL COST (1)	REFERENCE
3. SOIL REMEDIAL SYSTEM CONTAINMENT OF AS-, VOC-, AND SVOC-AFFECTED SOILS				
a. Structural reinforcement of building	820 LF	$215	$176,300	Vendor Quote
b. Installation of slurry cut-off wall	50,000 SF	6	300,000	Vendor Quote
c. Soil disposal	400 CY	400	160,000	Vendor Quote
d. Flexible membrane liner	17,000 SY	6	102,000	Cost Files
e. Capping	17,000 SY	15	255,000	Cost Files
f. Installation of surface drainage	1 LS	50,000	50,000	Cost Files
g. Replace fencing	300 LF	15	4,500	Cost Files
h. Remove and replace existing utilities	1 LS	35,000	35,000	Cost Files
i. Excavate foundations	1 LS	25,000	25,000	Cost Files
j. Remove and replace existing railroad spurs	7 EA	3,000	21,000	Cost Files
k. Analytical sampling	1 LS	15,000	15,000	Cost Files
l. Engineering, permitting, and construction management (35% of items a. through k.)	35 %		400,300	Cost Files
m. Contingency (20% of items a. through l.)	20 %		308,800	Cost Files
Subtotal 3:			$1,852,900	
ESTIMATED TOTAL CAPITAL COSTS			$2,298,500	

NOTES:

1. All costs are in 1991 dollars.
2. Costs do not include further subsurface investigations (if needed), regulatory interface, or permit fees.

TABLE 21

ALTERNATIVES 3, 4, AND 5: ENGINEERED CONTAINMENT
ESTIMATED OPERATIONS AND MATINENANCE COSTS

	QUANTITY	UNIT	UNIT COST (1)	TOTAL COST (1)	REFERENCE
1. ANNUAL OPERATIONS AND MAINTENANCE					
a. Carbon transportation/regeneration	500	LB	$2.50	$1,250	Cost Files
b. Power (extraction wells and process pumps)	30,000	KWH	0.10	3,000	PG&E
c. Power (bioreactors)	40,000	KWH	0.10	4,000	PG&E.
d. Disposal of arsenic sludge	20	BBL	250	5,000	Vendor Quote
e. Manpower for operations/maintenance	500	MHR	60	30,000	Cost Files
f. Chemicals - (bio) nutrients, pH, carbon	1	EA	3,500	3,500	Cost Files
g. Chemicals and power - electrochemical (H202 & Fe)	1	LS	3,500	3,500	Vendor Quote
h. Laboratory - treatment system and wells	1	LS	15,000	15,000	Cost Files
i. Manpower for water-level measurement and sampling wells	150	MHR	70	10,500	Cost Files
j. Data evaluation and reporting	4	EA	5,000	20,000	Cost Files
k. Sampling equipment	1	LS	4,000	4,000	Cost Files
l. Spare parts/repairs (1% of extraction and treatment system)	1	%		4,500	Cost Files
m. Contingency (20% of items a. through i.)	20	%		20,900	Cost Files
Subtotal Annual O&M Costs :				$125,150	
2. ESTIMATED 20-YEAR PRESENT WORTH (20 YEARS @ 5%)				$1,560,000	(2)
3. ESTIMATED CAPITAL COSTS, ENGINEERED CONTAINMENT				$2,298,500	
4. ESTIMATED TOTAL PRESENT WORTH, ENGINEERED CONTAINMENT				$3,858,500	

NOTES

1. All costs in 1991 dollars.
2. The present values have been calculated on a net interest rate (interest rate minus inflation) of 5 percent. Present worth evaluations based on 20-year operating period.
3. Total O&M costs for this alternative reflect costs to operate and maintain a remedial system and to conduct quarterly ground-water monitoring. Regulatory interface and permit fees are not included in the estimated costs.

TABLE 22

ALTERNATIVE 3: LIMITED SOURCE REDUCTION
ESTIMATED CAPITAL COSTS

DESCRIPTION	QUANTITY/UNIT	UNIT COST (1)	TOTAL COST (1)	REFERENCE
1. SOLVENT TANK STORAGE AREA				
a. Excavation	3,300 CY	10	33,000	Cost Files
b. Bio-treatment of soils	3,300 CY	75	247,500	Cost Files
c. Backfill treated soils	3,300 CY	10	33,000	Cost Files
d. Analytical sampling	15 EA	150	2,250	Cost Files
e. Resurfacing	1,000 SY	22	22,000	Cost Files
f. Engineering, permitting and construction management (20% of items a. through e.)	20 %		67,600	Cost Files
g. Contingency (20% of items a. through f.)	20 %		81,100	Cost Files
			------------	
Subtotal 2:			$486,450	
2. ARSENIC-AFFECTED SOILS				
a. Fixation/solidification	10,000 CY	103	1,030,000	Contractor Quote
b. Analytical sampling	40 EA	120	4,800	Cost Files
c. Remove and replace railroad spur	140 LF	90	12,600	Cost Files
d. Resurfacing	928 SY	22	20,400	Cost Files
e. Structural foundation reinforcement	450 LF	225	101,250	Contractor Quote
f. Engineering, permitting and construction management (20% of items a. through e.)	20 %		233,800	Cost Files
g. Contingency (20% of items a. through f.)	20 %		280,600	Cost Files
			------------	
			$1,683,500	
ESTIMATED TOTAL CAPITAL COSTS FOR LIMITED SOURCE REDUCTION			$2,170,000	
			============	

NOTES:

1) All costs are in 1991 dollars.

2) Excavation quantities based on cleanup standard of 100 mg/kg for VOC- and SVOC-affected soils and 1,000 mg/kg for arsenic-affected soils.

TABLE 23

ALTERNATIVE 4: HOT SPOT ARSENIC SOILS SOURCE REDUCTION
ESTIMATED CAPITAL COSTS

DESCRIPTION	QUANTITY/UNIT	UNIT COST (1)	TOTAL COST (1)	REFERENCE
1. ARSENIC-AFFECTED SOILS				
a. Fixation/solidification	6,600 CY	117	772,200	Contractor Quote
b. Analytical sampling	40 EA	120	4,800	Cost Files
c. Remove and replace railroad spur	140 LF	90	12,600	Cost Files
d. Structural foundation reinforcement	450 LF	225	101,250	Contractor Quote
e. Engineering, permitting, and construction management (20% of items a. through d.)	20 %		178,200	Cost Files
f. Contingency (20% of items a. through e.)	20 %		213,800	Cost Files
ESTIMATED TOTAL CAPITAL COSTS FOR HOT SPOT AS SOURCE REDUCTION			$1,282,900	

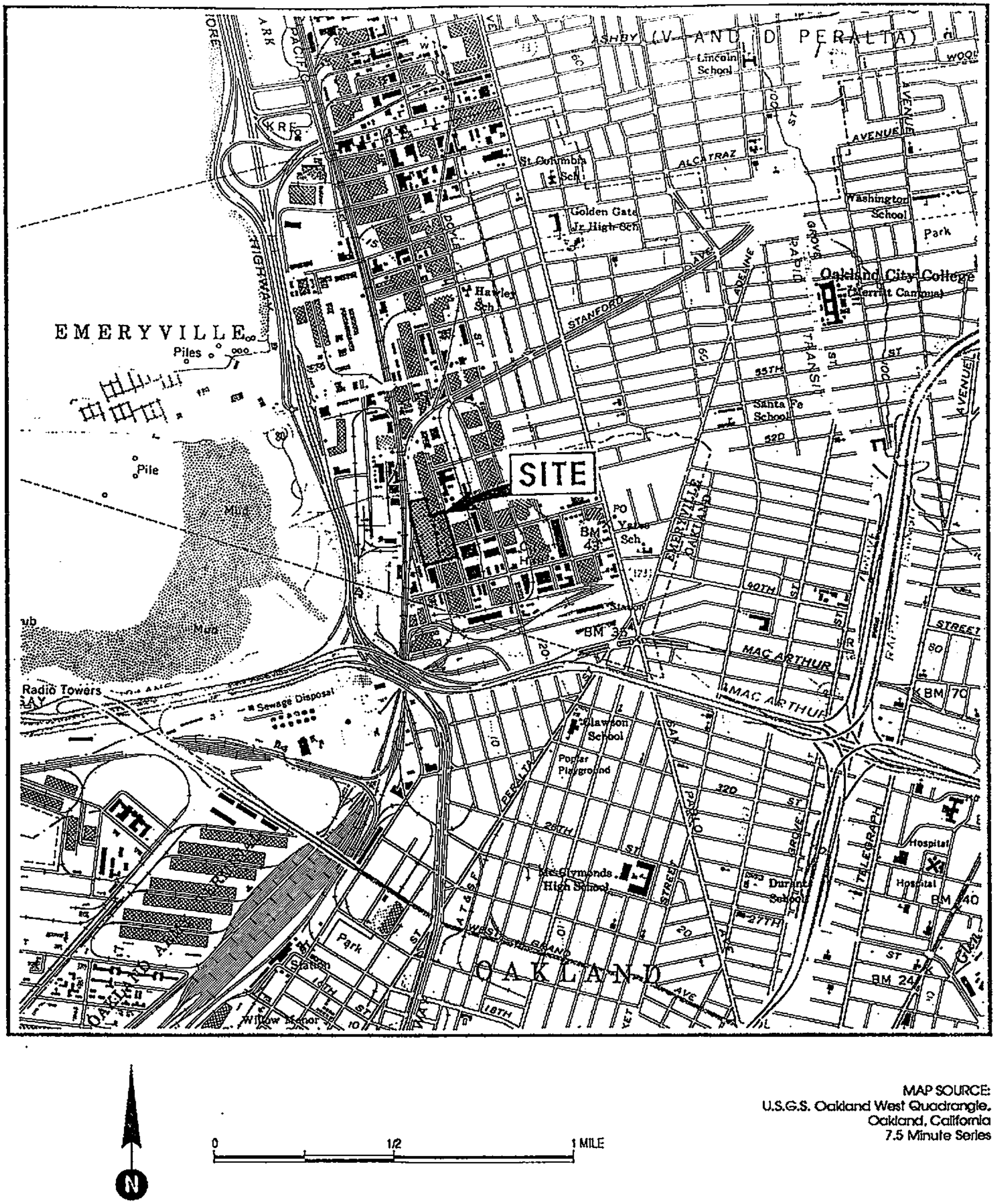
NOTES:

1) All costs are in 1991 dollars.
2) Excavation quantities based on cleanup standard of 100 mg/kg for VOC- and SVOC-affected soils and 1,000 mg/kg for arsenic-affected soils.

TABLE 24

SUMMARY OF COSTS FOR INTERIM REMEDIAL ALTERNATIVES

Alternative	Capital Costs		Operating Costs		Total Present Worth
	Containment	Source Remediation	Annual	20-Year Present Worth	
1. Hydraulic Containment with Full Source Excavation and Disposal	$0.7 million	$17.9 million	$ 256,000	$3.2 million	$21.8 million
2. Hydraulic Containment with Full Source Treatment	$0.7 million	$3.8 million	$ 256,000	$3.2 million	$7.7 million
3. Engineered Containment with Limited Source Treatment	$2.3 million	$2.2 million	$ 125,000	$1.6 million	$6.1 million
4. Engineered Containment with "Hot Spot" Arsenic Source Treatment	$2.3 million	$1.3 million	$ 125,000	$1.6 million	$5.2 million
5. Engineered Containment	$2.3 million	0	$ 125,000	$1.6 million	$3.9 million



MAP SOURCE:
U.S.G.S. Oakland West Quadrangle,
Oakland, California
7.5 Minute Series

Figure 1 : SITE LOCATION MAP

Project No. 1563

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JDR11JUL89em

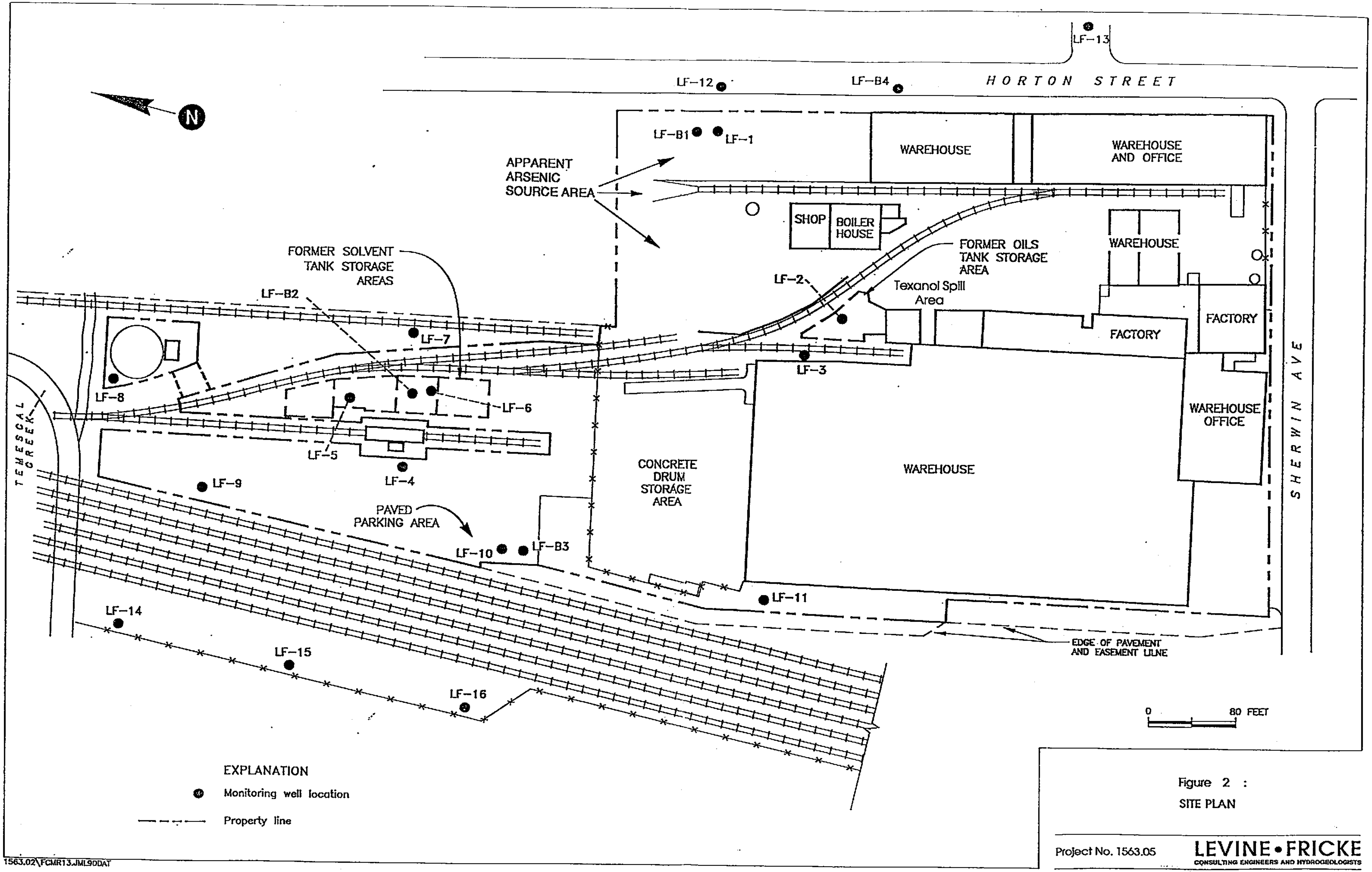

Figure 2 :

SITE PLAN

Project No. 1563.05

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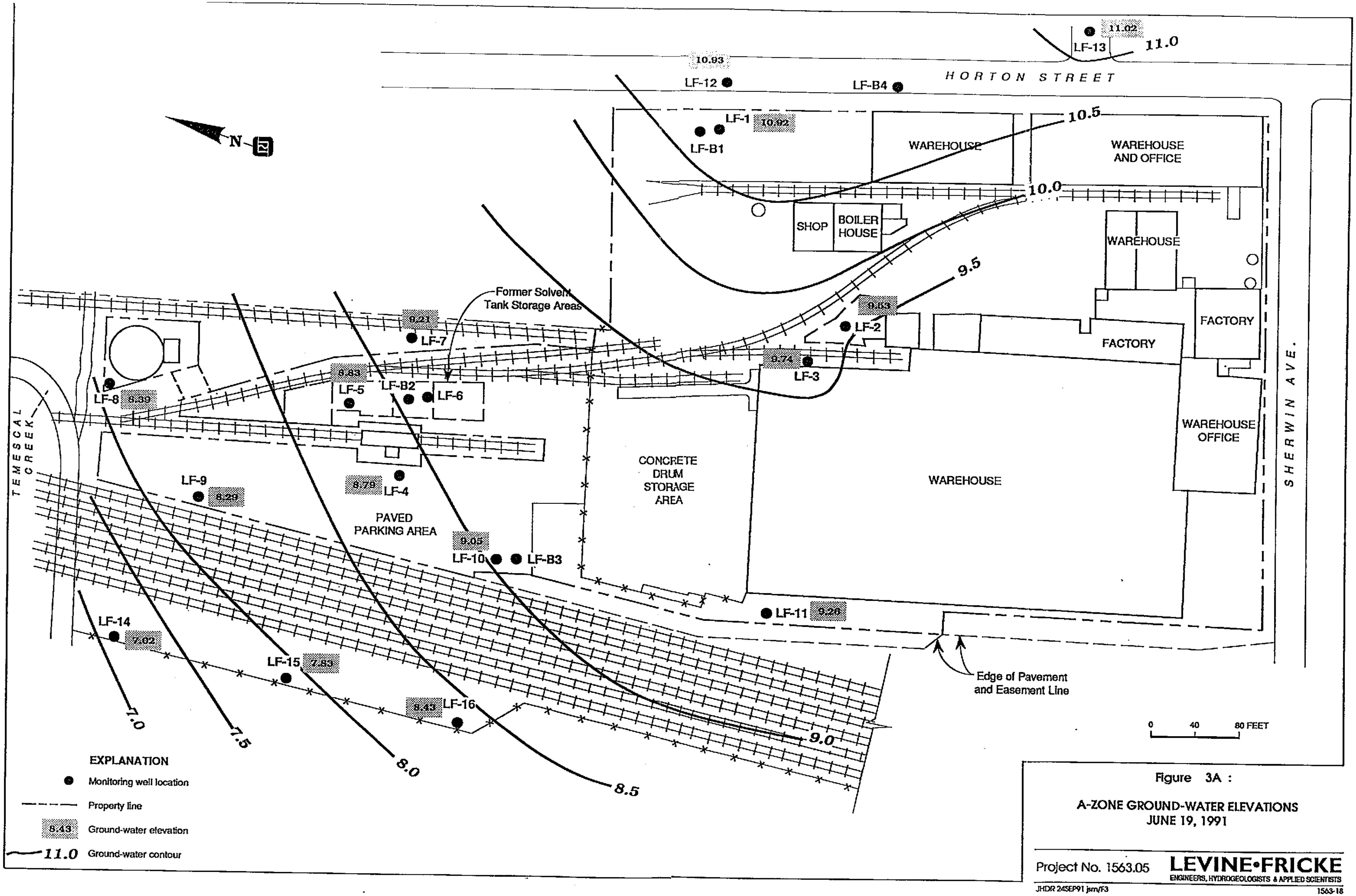

Figure 3A :

A-ZONE GROUND-WATER ELEVATIONS
JUNE 19, 1991

Project No. 1563.05

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ENGINEERS, HYDROGEOLOGISTS & APPLIED SCIENTISTS

JHDR 24SEP91 jsm/F3

1563-18

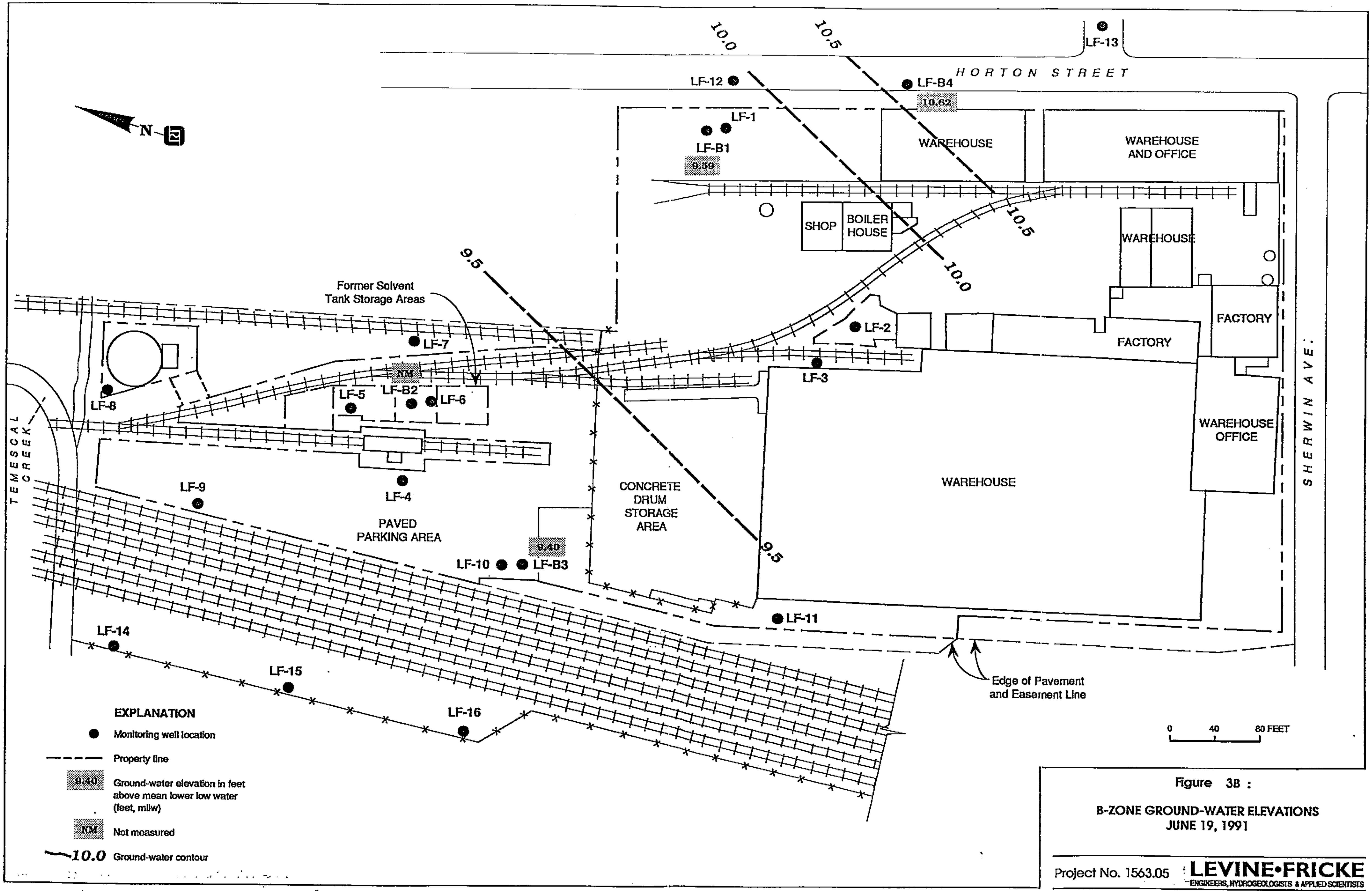


Figure 3B :

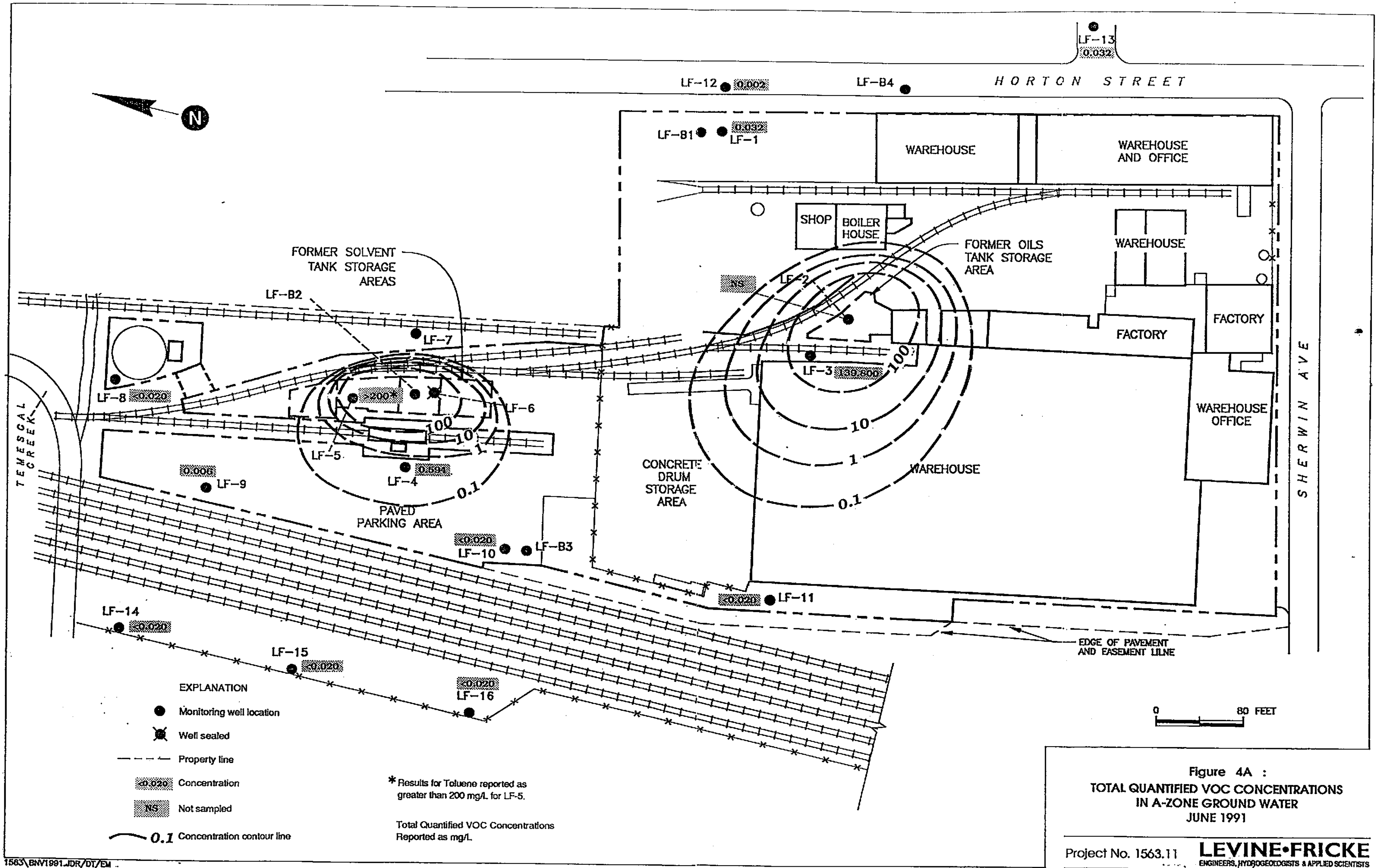
B-ZONE GROUND-WATER ELEVATIONS
JUNE 19, 1991

Project No. 1563.05

LEVINE•FRICKE
ENGINEERS, HYDROGEOLOGISTS & APPLIED SCIENTISTS

JHDR 24SEP91 jsm/F4

1563-40



* Results for Toluene reported as greater than 200 mg/L for LF-5.

Total Quantified VOC Concentrations Reported as mg/L

Figure 4A :
TOTAL QUANTIFIED VOC CONCENTRATIONS
IN A-ZONE GROUND WATER
JUNE 1991

Project No. 1563.11

LEVINE•FRICKE
ENGINEERS, HYDROGEOLOGISTS & APPLIED SCIENTISTS

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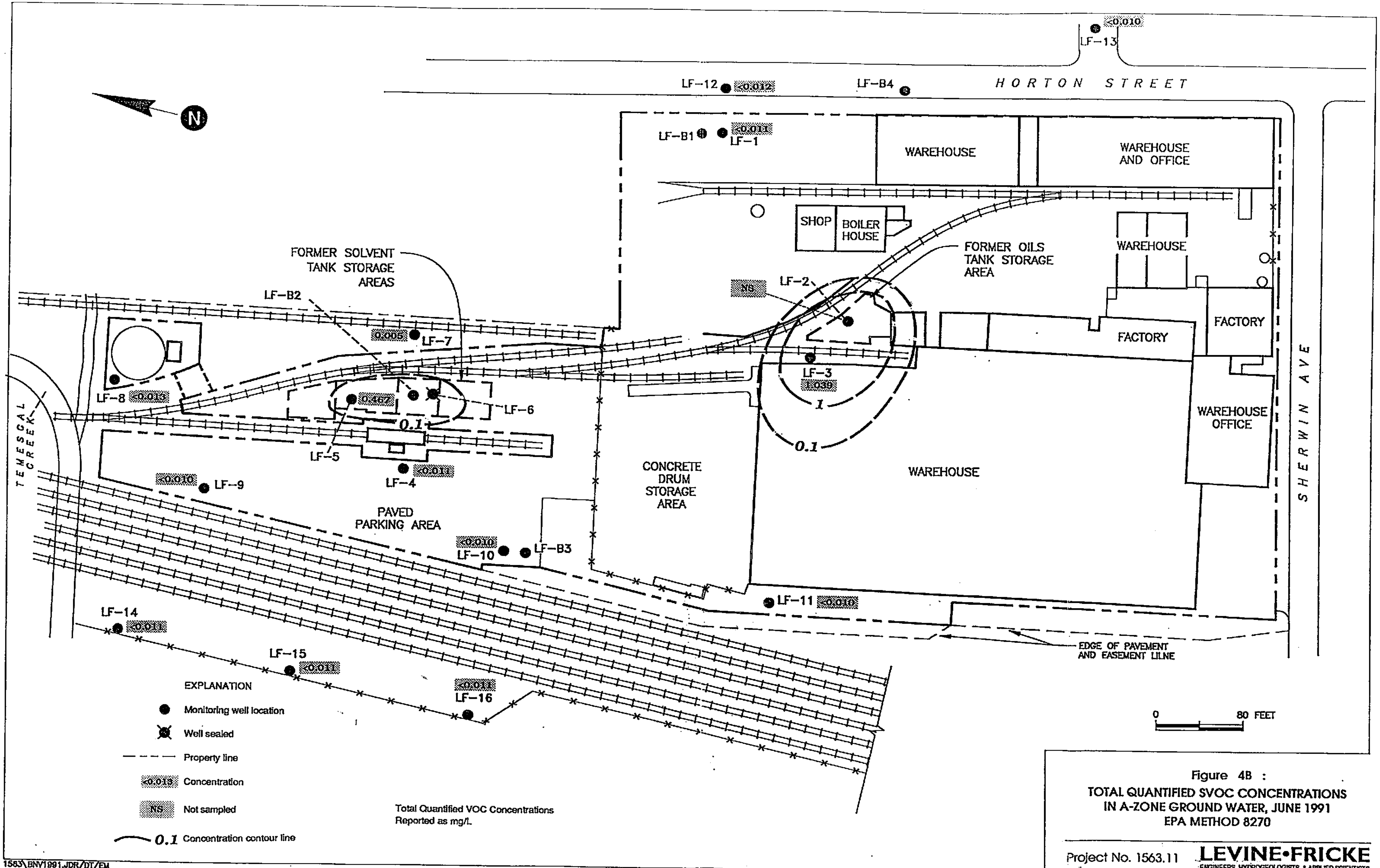
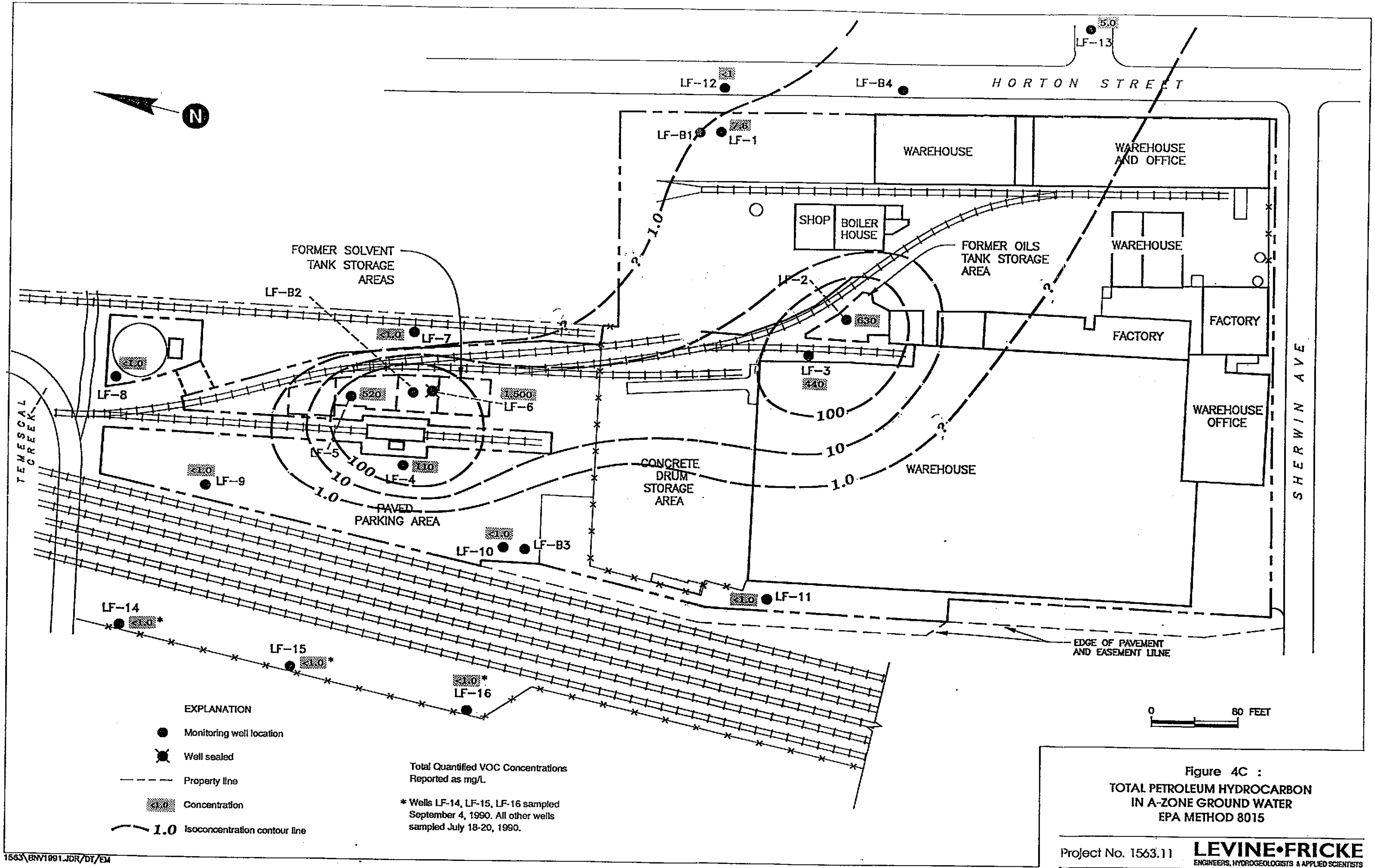


Figure 4B :
TOTAL QUANTIFIED SVOC CONCENTRATIONS
IN A-ZONE GROUND WATER, JUNE 1991
EPA METHOD 8270

Project No. 1563.11

LEVINE•FRICKE
ENGINEERS, HYDROGEOLOGISTS & APPLIED SCIENTISTS

JDR19NOV91em



Total Quantified VOC Concentrations Reported as mg/L

* Wells LF-14, LF-15, LF-16 sampled September 4, 1990. All other wells sampled July 18-20, 1990.

Figure 4C :
TOTAL PETROLEUM HYDROCARBON
IN A-ZONE GROUND WATER
EPA METHOD 8015

Project No. 1563.11

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ENGINEERS, HYDROGEOLOGISTS & APPLIED SCIENTISTS

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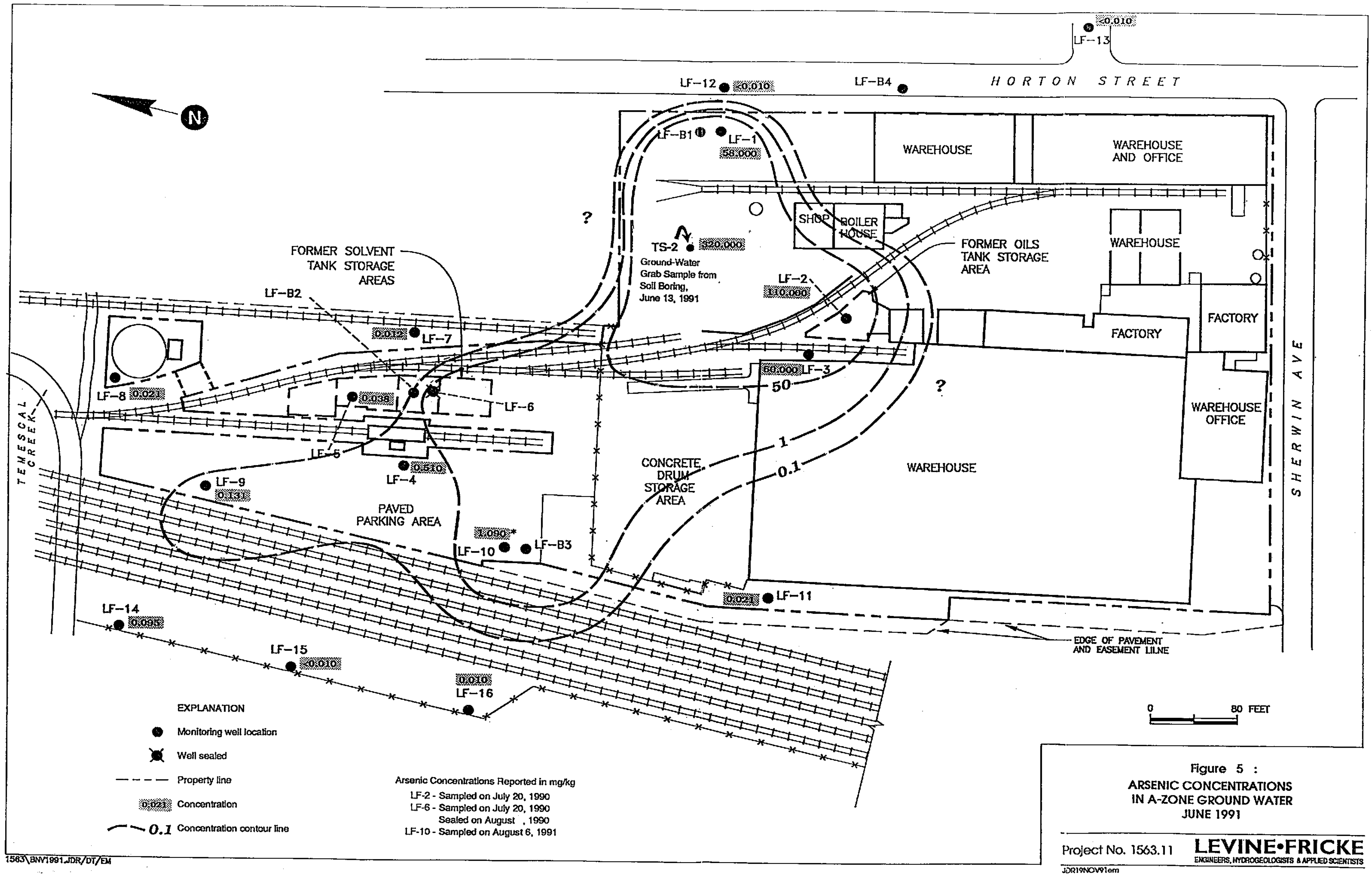

Arsenic Concentrations Reported in mg/kg
LF-2 - Sampled on July 20, 1990
LF-6 - Sampled on July 20, 1990
Sealed on August , 1990
LF-10 - Sampled on August 6, 1991

Figure 5 :
ARSENIC CONCENTRATIONS
IN A-ZONE GROUND WATER
JUNE 1991

Project No. 1563.11

LEVINE•FRICKE
ENGINEERS, HYDROGEOLOGISTS & APPLIED SCIENTISTS

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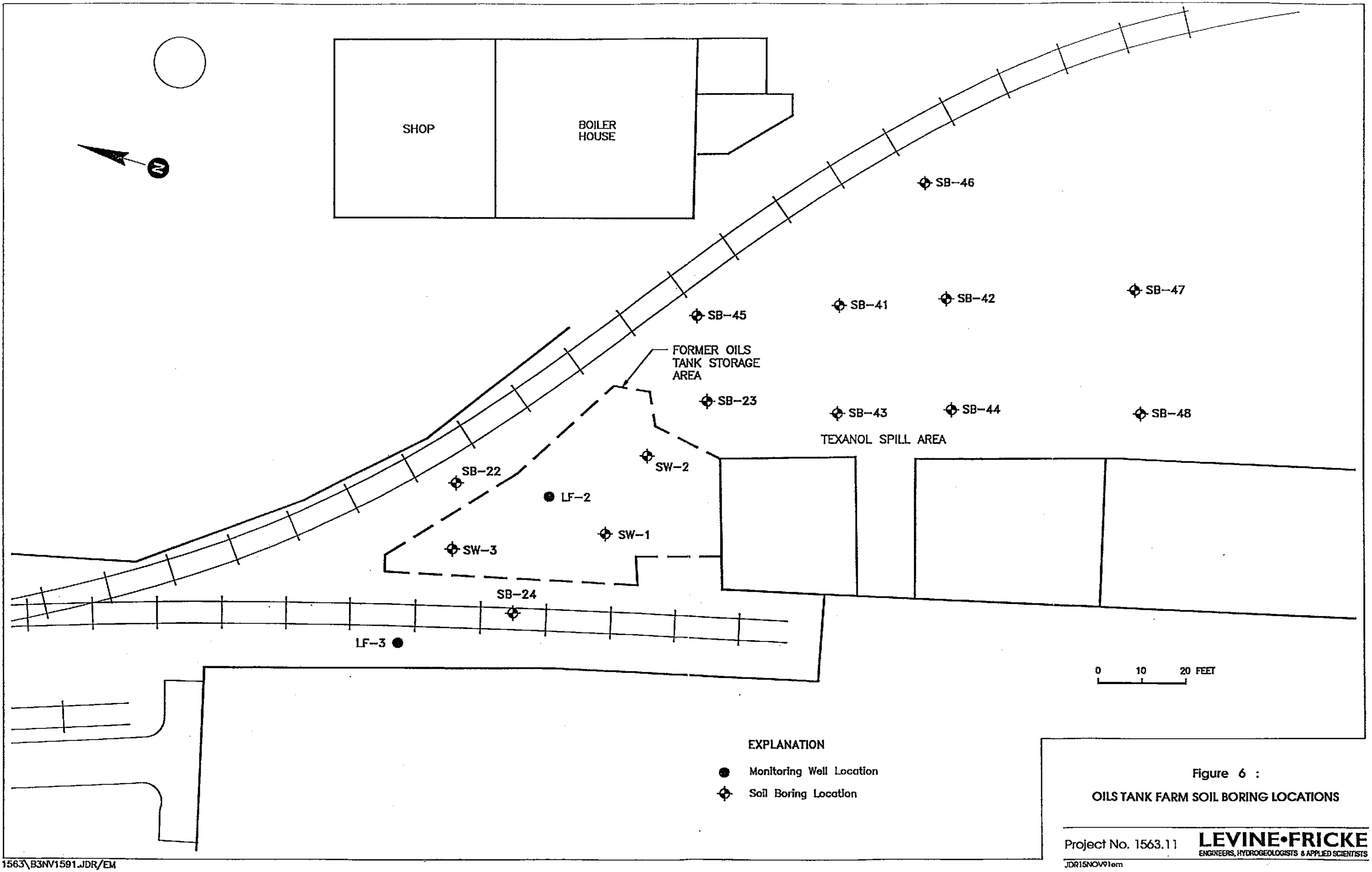

Figure 6 :

OILS TANK FARM SOIL BORING LOCATIONS

Project No. 1563.11

LEVINE•FRICKE

ENGINEERS, HYDROGEOLOGISTS & APPLIED SCIENTISTS

JDR15NOV91em

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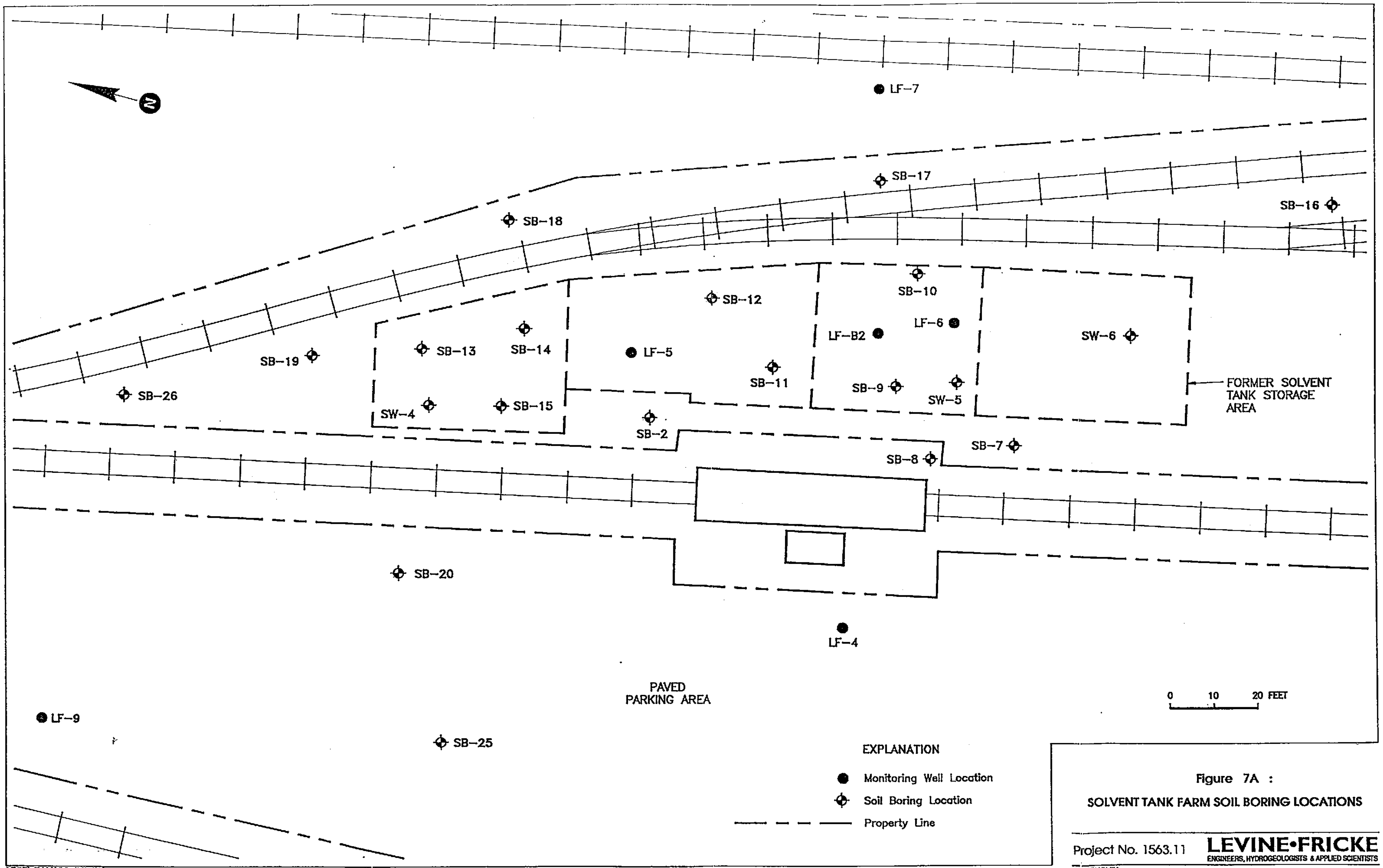

Figure 7A :

SOLVENT TANK FARM SOIL BORING LOCATIONS

Project No. 1563.11

LEVINE•FRICKE
ENGINEERS, HYDROGEOLOGISTS & APPLIED SCIENTISTS

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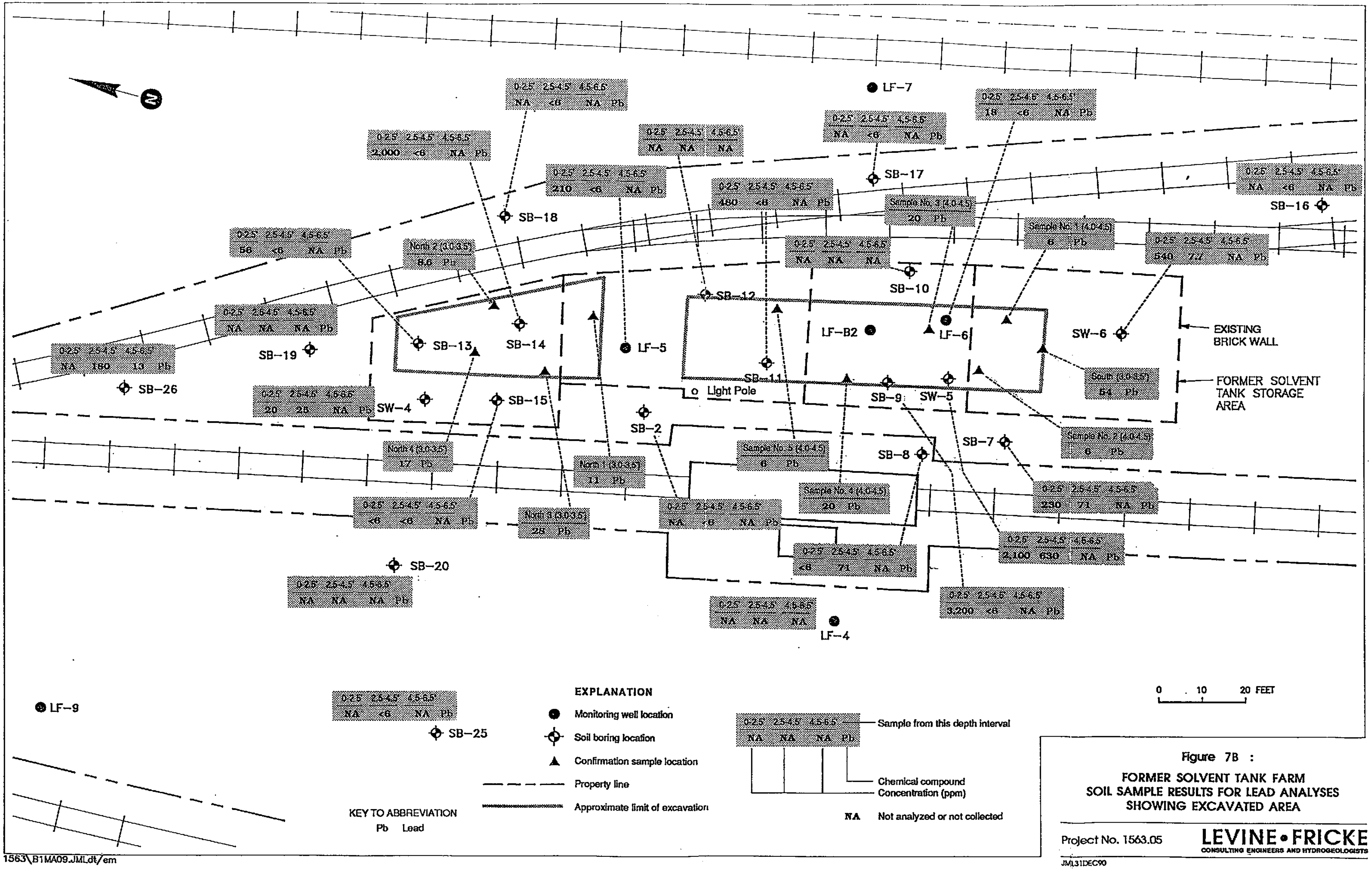

Figure 7B :

FORMER SOLVENT TANK FARM SOIL SAMPLE RESULTS FOR LEAD ANALYSES SHOWING EXCAVATED AREA

Project No. 1563.05

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CONSULTING ENGINEERS AND HYDROGEOLOGISTS

JML31DEC90

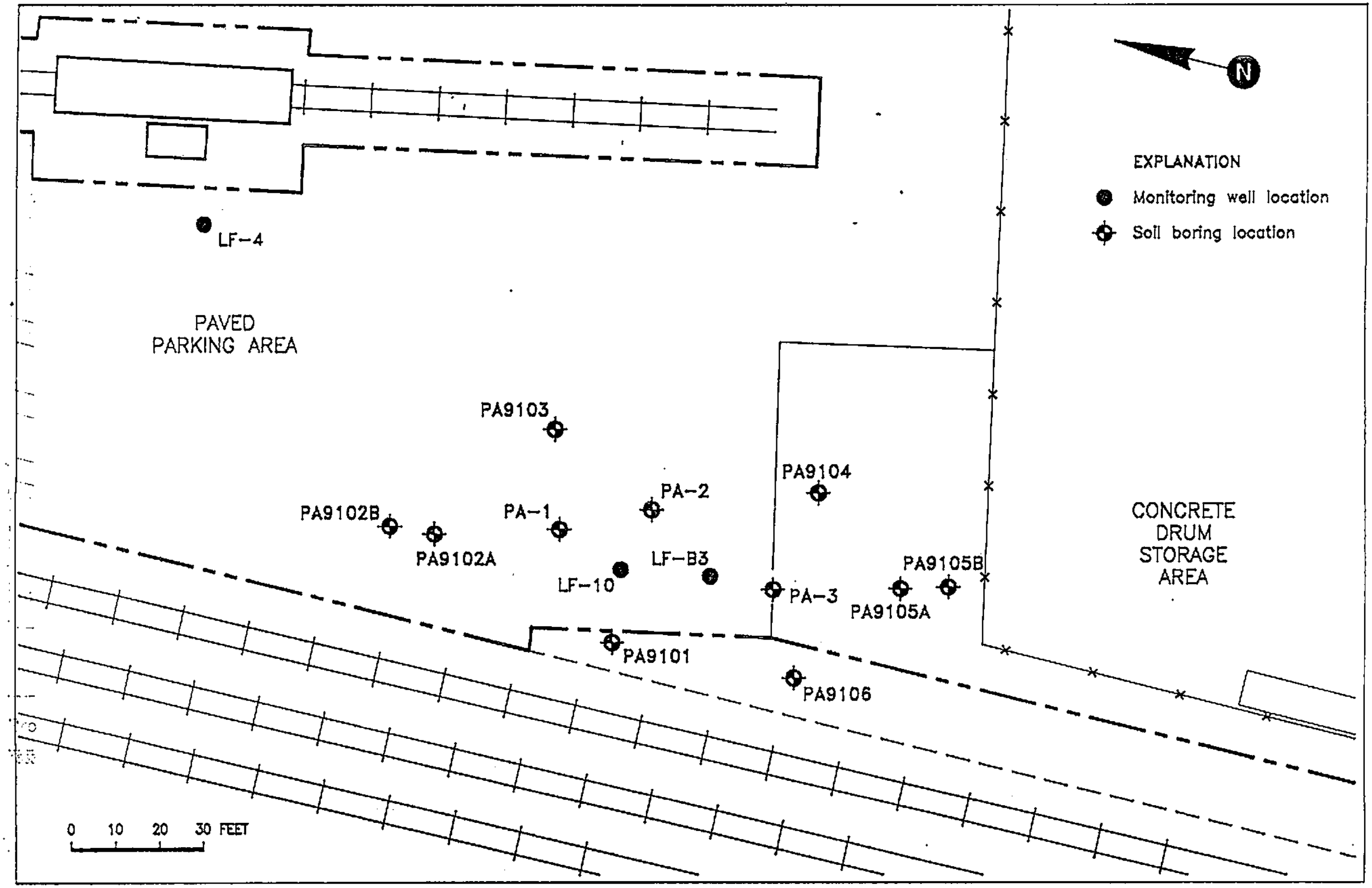

Figure 8 : PARKING AREA SOIL BORING LOCATIONS

Project No. 1563

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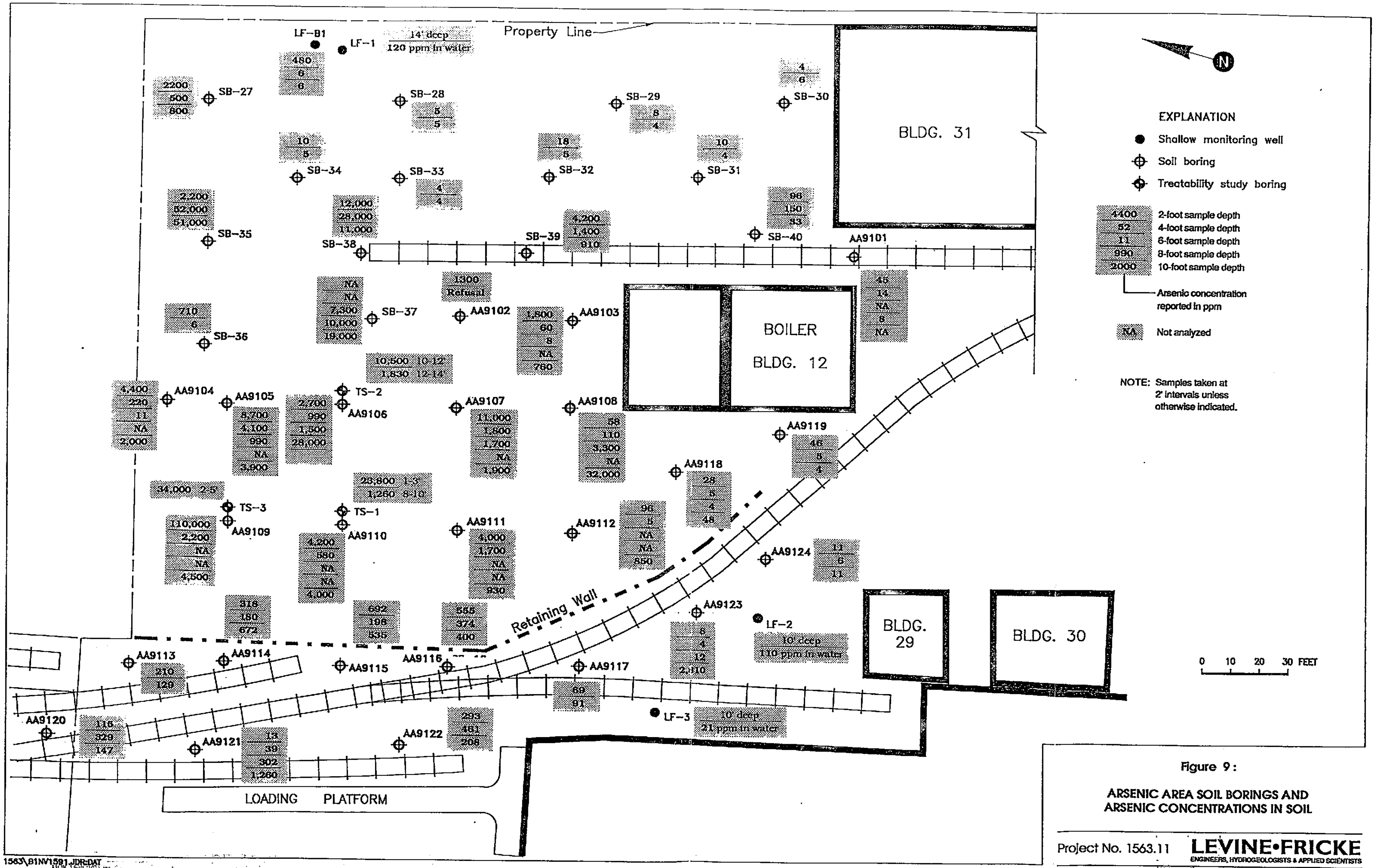

Figure 9:

ARSENIC AREA SOIL BORINGS AND ARSENIC CONCENTRATIONS IN SOIL

Project No. 1563.11

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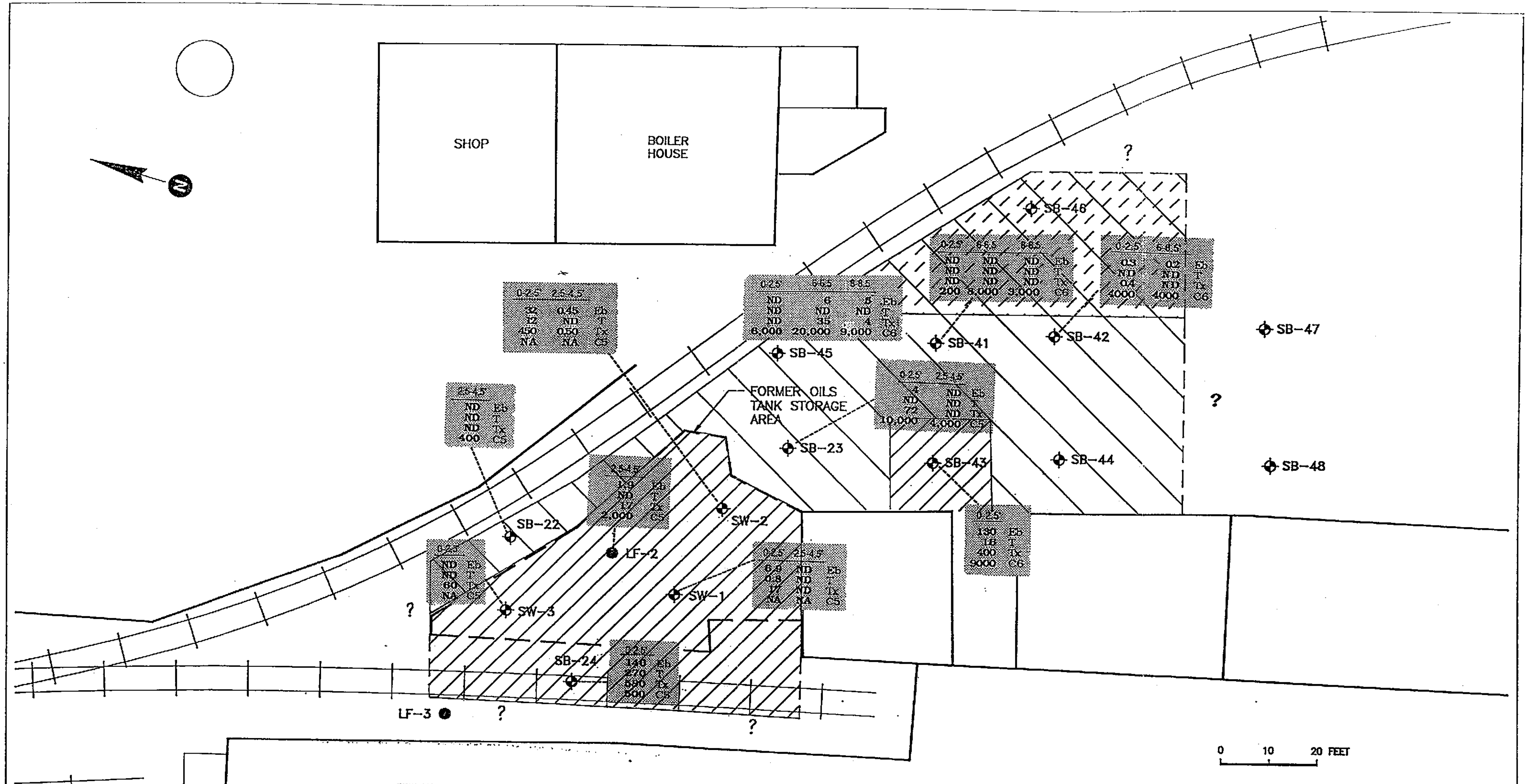

EXPLANATION

● Monitoring well location

⊕ Soil boring location

0-2.5'	2.5-4.5'	4.5-6.5'		— Depth intervals
4	<2	NA	Eb	— Compound

Soil sample results (ppm)

ND Not detected

NA Sample not analyzed and/or not collected

KEY TO ABBREVIATIONS

Eb	Ethylbenzene
T	Toluene
Tx	Total Xylenes
C5	Tentatively Identified Compound as C5 Hydrocarbon
C6	Tentatively Identified Compound as C6-C13 Hydrocarbon

▧ Oil affected soil above 100 ppm

▨ Xylene and oil affected soil above 100 ppm

▨ Oil affected soil below 5ft.

Figure 10 :

ASSUMED AREAS FOR FULL REMEDIATION OF OIL AND SOLVENT AFFECTED SOIL NEAR THE FORMER OIL TANK FARM

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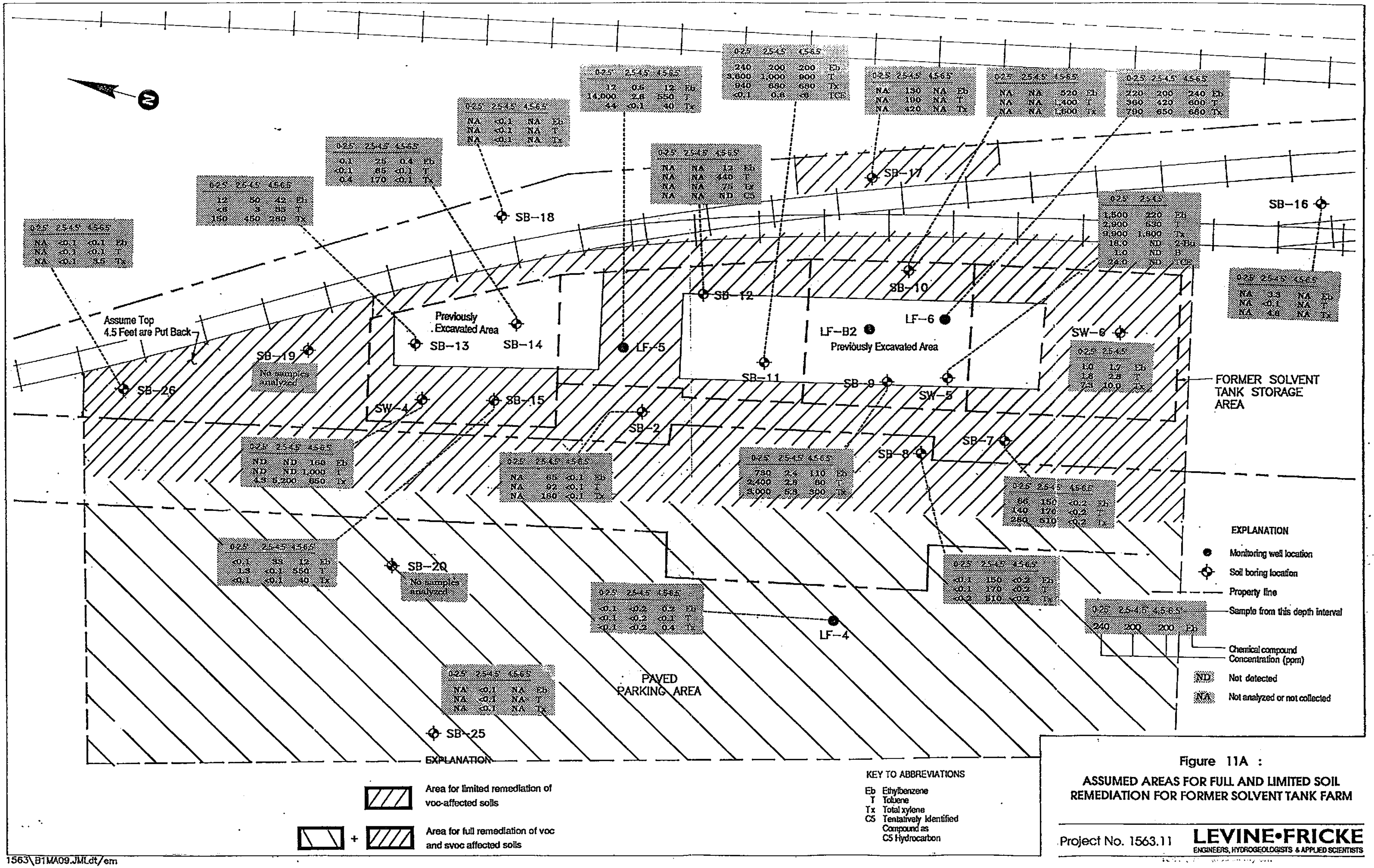

Figure 11A :

ASSUMED AREAS FOR FULL AND LIMITED SOIL REMEDIATION FOR FORMER SOLVENT TANK FARM

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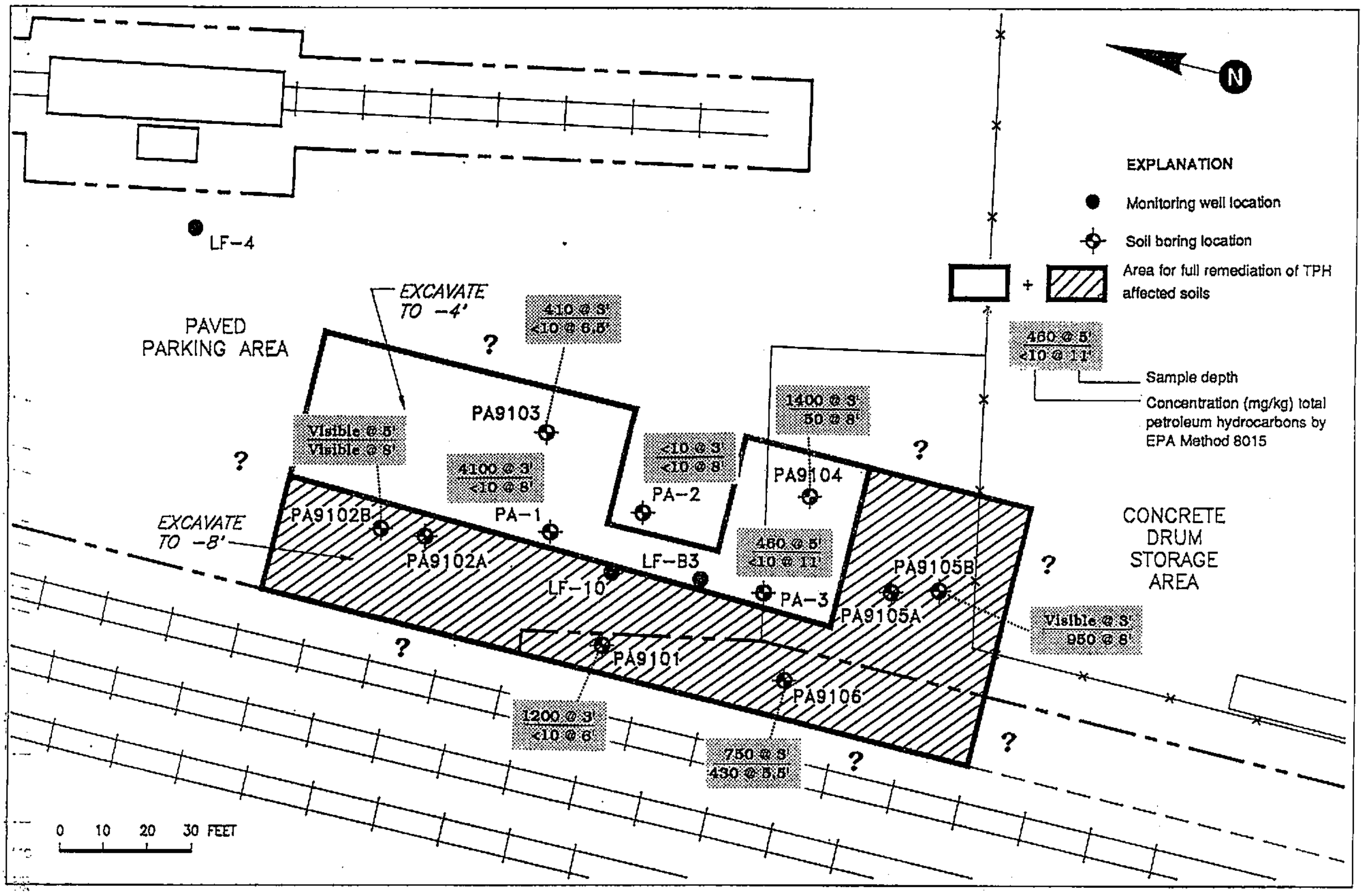

Figure 11B: ASSUMED AREAS FOR FULL SOIL REMEDIATION IN PARKING AREA

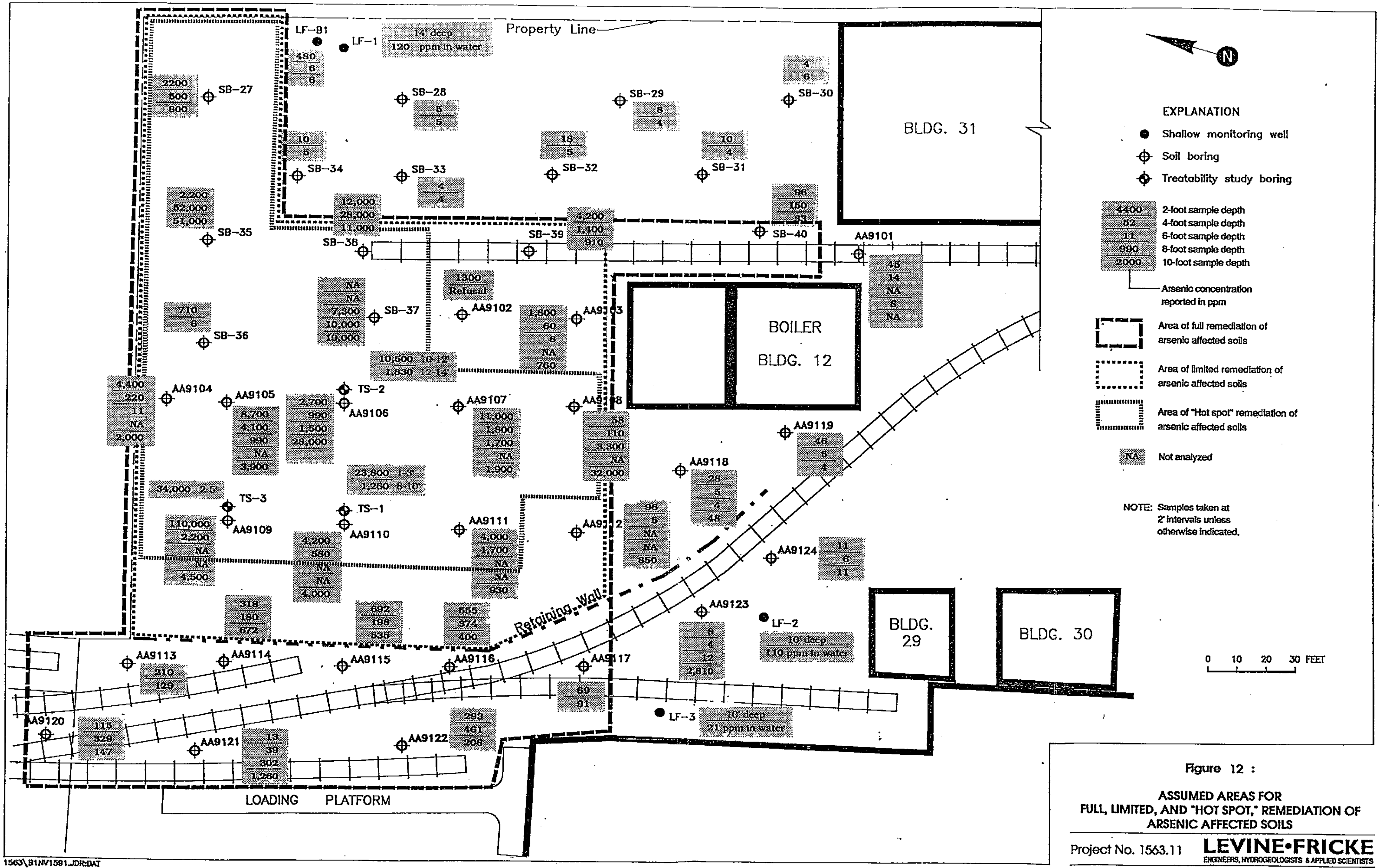

Figure 12 :

ASSUMED AREAS FOR FULL, LIMITED, AND "HOT SPOT," REMEDIATION OF ARSENIC AFFECTED SOILS

Project No. 1563.11

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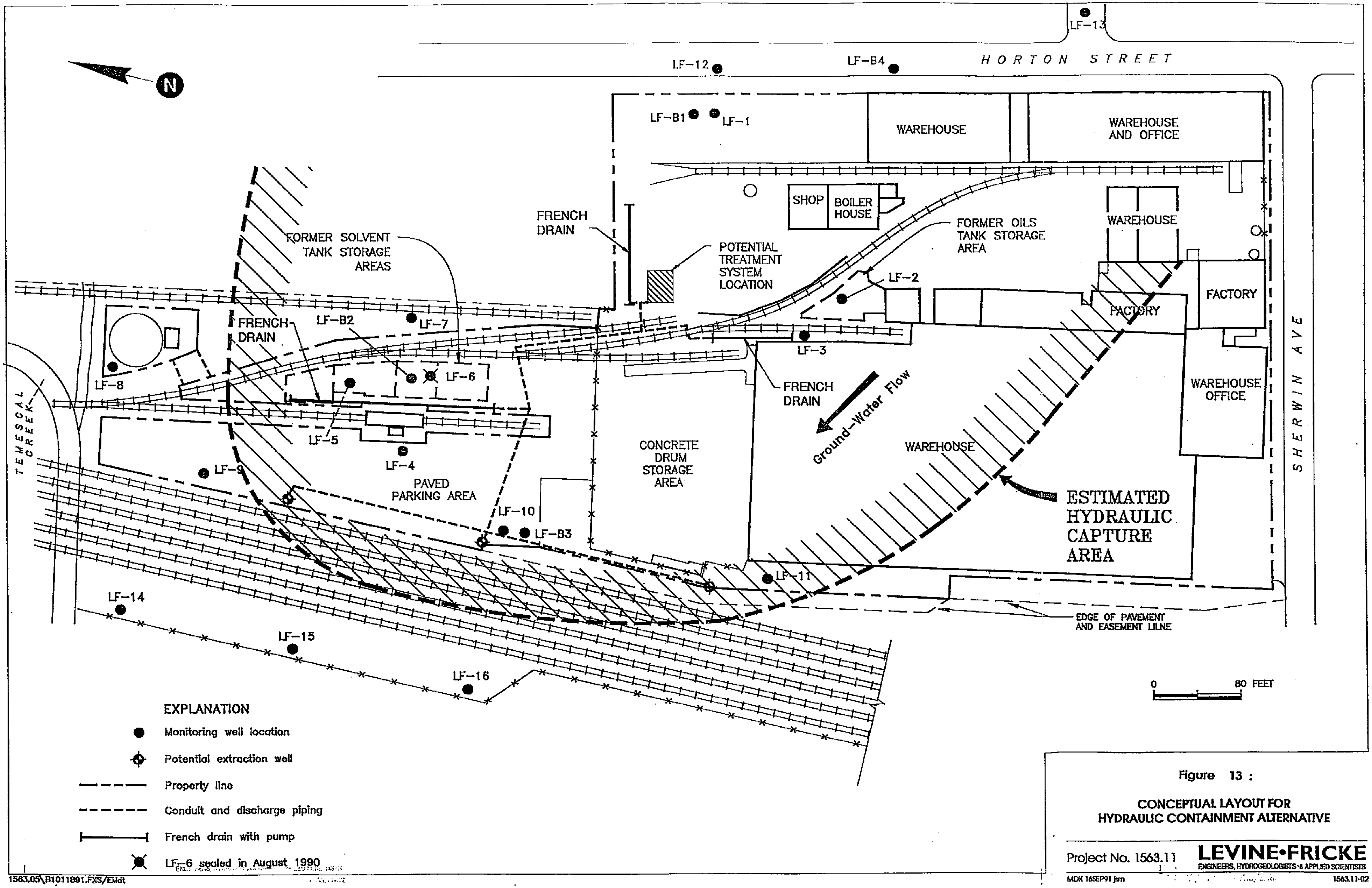

Figure 13 :

CONCEPTUAL LAYOUT FOR HYDRAULIC CONTAINMENT ALTERNATIVE

Project No. 1563.11 **LEVINE•FRICKE**
ENGINEERS, HYDROGEOLOGISTS & APPLIED SCIENTISTS

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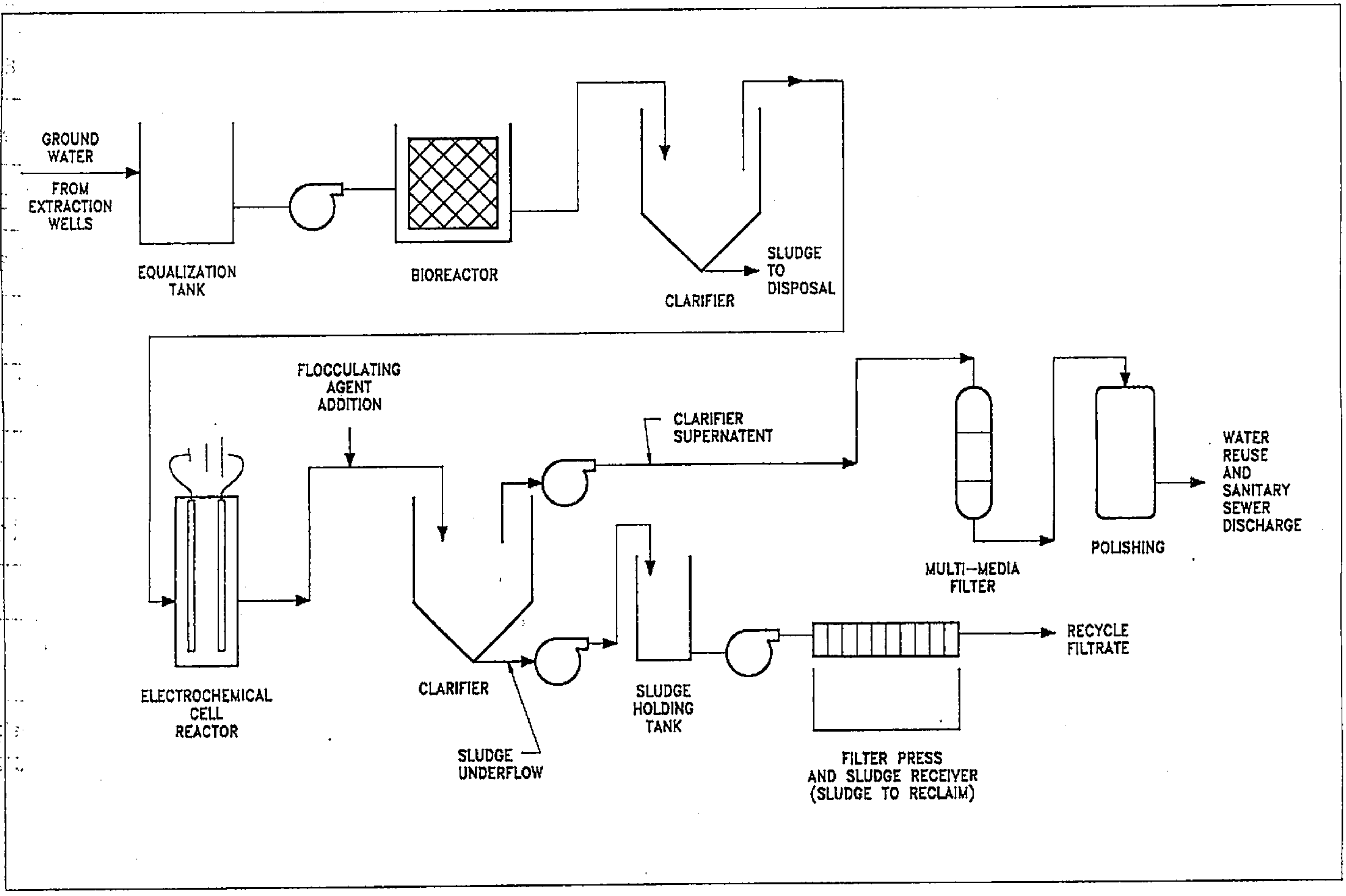

Figure 14 : CONCEPTUAL GROUND-WATER TREATMENT PROCESS SCHEMATIC

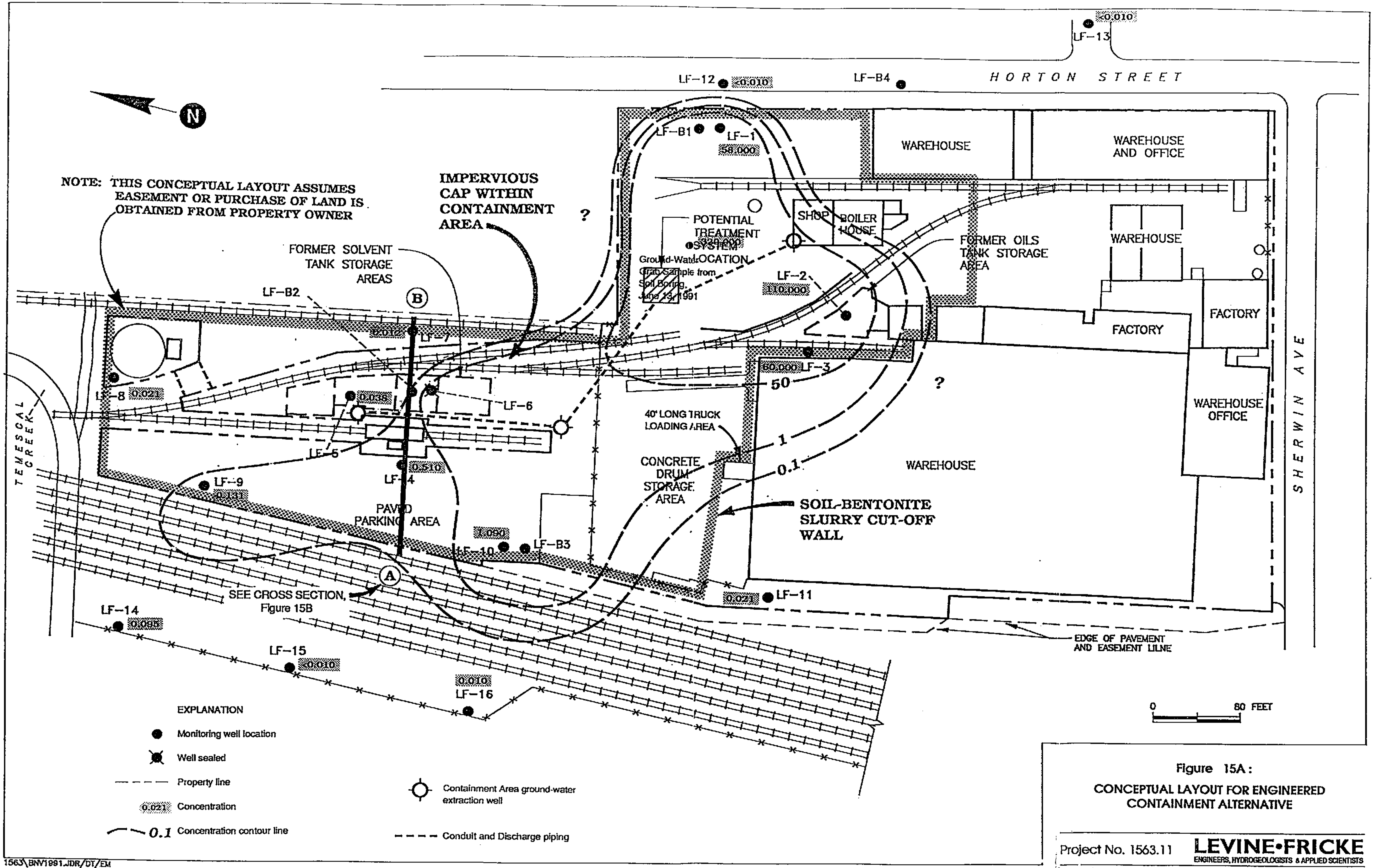

Figure 15A:

CONCEPTUAL LAYOUT FOR ENGINEERED CONTAINMENT ALTERNATIVE

Project No. 1563.11

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ENGINEERS, HYDROGEOLOGISTS & APPLIED SCIENTISTS

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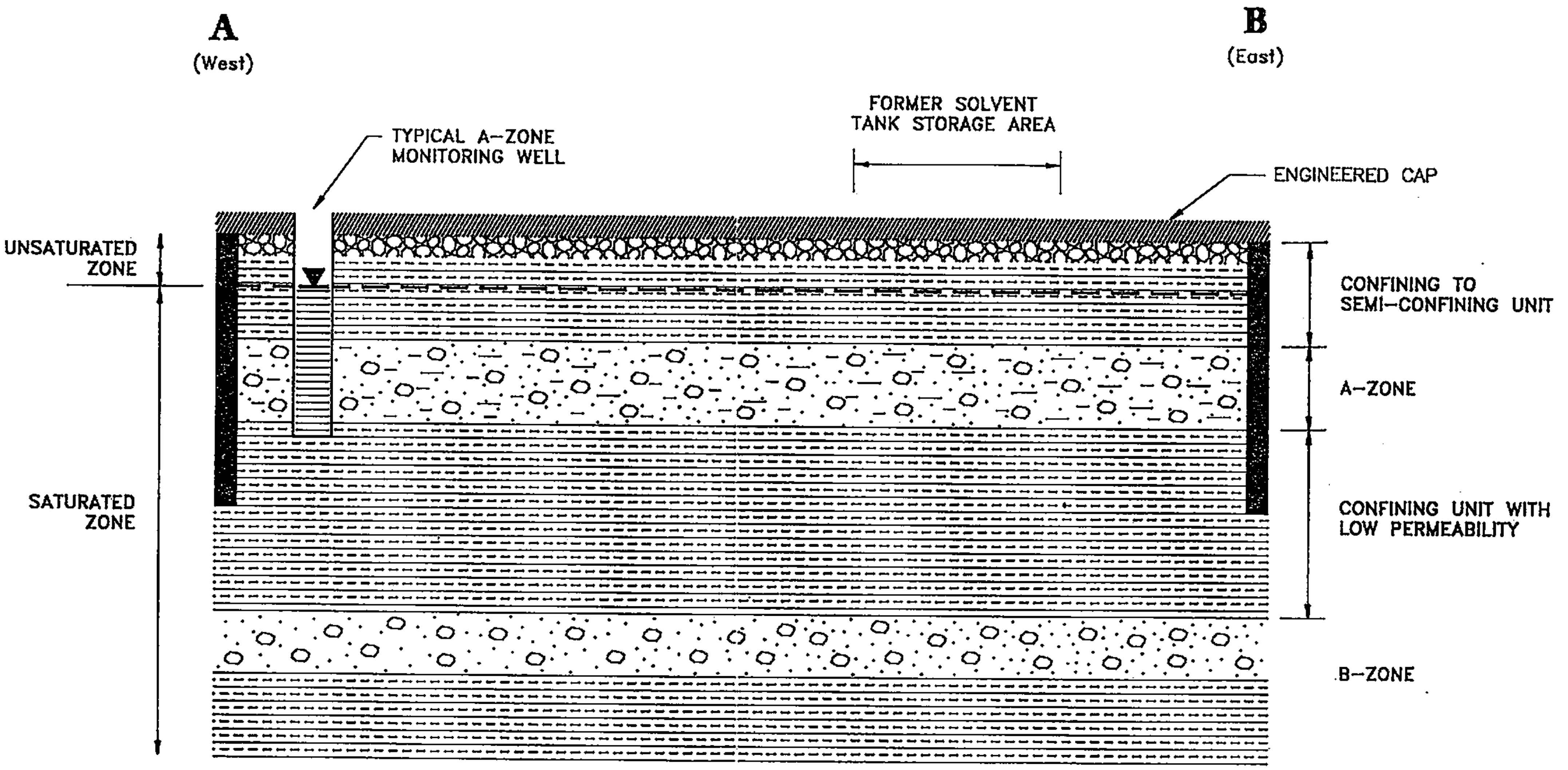

NOT DRAWN TO SCALE

EXPLANATION

▨ ENGINEERED CAP

▩ GRAVELLY UNIT

☰ SILTY CLAY

⁘ INTERBEDDED SAND, SILT AND GRAVEL

⁖ SANDY GRAVEL TO GRAVELLY SAND

— ▼ — STATIC LEVEL OF A–ZONE GROUND–WATER

▮ SLURRY WALL

Figure 15B:

GENERALIZED CROSS SECTION FOR ENGINEERED CONTAINMENT

Project No. 1563

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ENGINEERS, HYDROGEOLOGISTS, & APPLIED SCIENTISTS

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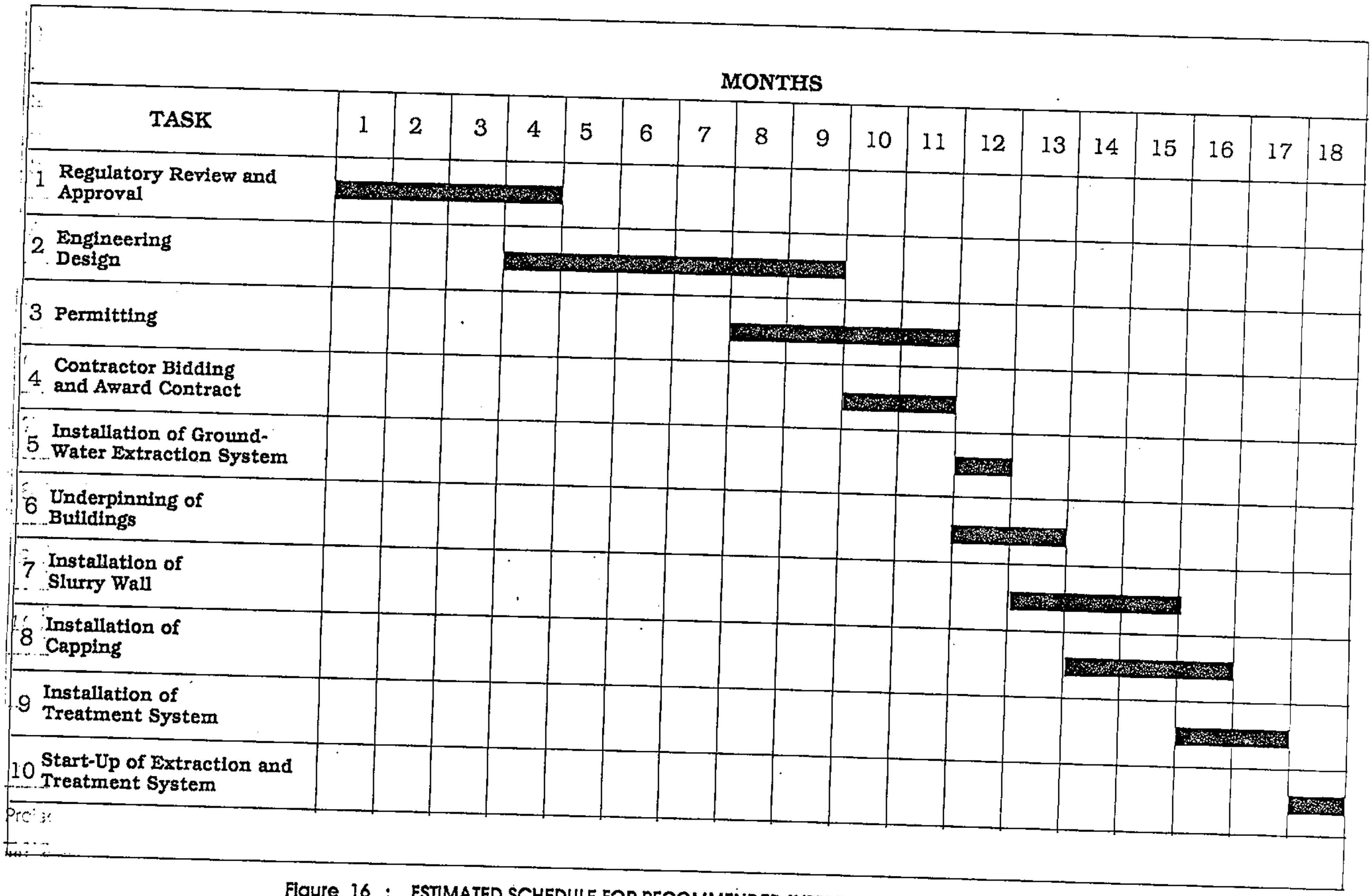

Figure 16 : ESTIMATED SCHEDULE FOR RECOMMENDED INTERIM REMEDIAL ALTERNATIVE
SHERWIN-WILLIAMS EMERYVILLE, CA

Project 1563.09

1563.09 RX/SD 11/13/91

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APPENDIX A

STABILIZATION STUDIES ON ARSENIC-AFFECTED SOILS

CENTER

TABLES

ATTACHEMENT

LIST OF TABLES

December 20, 1991

LF 1563.11

STABILIZATION STUDIES ON ARSENIC-AFFECTED SOILS

A1.0 INTRODUCTION

Site soils affected primarily with elevated concentrations of arsenic were collected from three areas of the Site to evaluate their potential to be stabilized using chemical fixation technologies. In addition, the soils are affected to varying degrees with lead and petroleum hydrocarbons (TPH). Descriptions of the important physico-chemical properties of these soils as well as their boring locations and depths of sampling are presented in Table A1. For stabilization treatability testing, subsamples of each of the three well-mixed samples were sent to two laboratories identified in the Work Plan (Levine·Fricke 1990): Kiber Associates, Inc. (Kiber), Atlanta, Georgia, and Chemfix Technologies, Inc. (Chemfix), Metarie, Louisiana. The most pertinent results of these treatability studies are summarized and discussed briefly below. The full reports from Kiber and Chemfix are presented in the Attachment to this appendix.

A2.0 METHODS

Six stabilization formulations were selected for testing by Kiber based on its previous experience with stabilization technologies and its conversations with Levine·Fricke personnel regarding the high arsenic concentrations contained in site soils. These formulations included three proprietary compounds (HWT-7 and HWT-25 from International Waste Technologies [IWT] and Chembond II from Fluid Tech, Inc.) and three nonproprietary compounds (Portland Cement, Class C Fly Ash, and a Cement-Ferric Chloride combination). Four mixtures of each formulation were tested, thereby producing a total of 24 test mixtures per soil sample. The most effective mixture of each formulation (according to physical examination by cone penetrometer) was evaluated by the California Title 22 Waste Extraction Test (WET). The best three formulations for each soil sample (according to the lowest WET arsenic concentrations) were then evaluated by the Federal Toxicity Characteristic Leaching Procedure (TCLP) and a water solubility procedure (Water) that mimics the WET protocol, except that it does not contain citric acid buffered at pH 5.

Chemfix tested two formulations ("F04" and "F05") for their ability to stabilize the soil samples. The WET, TCLP, and Water leaching tests were all used to evaluate the effectiveness of their treatments.

All soil samples at both laboratories were mixed with each respective formulation in a manner comparable to ex-situ stabilization treatment processes. Only larger-scale (and, thus much more expensive) treatment tests could mimic in situ treatment applications. Because a formulation to effectively treat the arsenic-affected soils must be developed first, smaller laboratory-scale trials were determined to be the best first phase approach.

The Water test was included as a measure of a formulation's success because site soils will not experience organic acid production similar to that of a landfill, for which the WET and TCLP tests were developed.

A3.0 RESULTS

The results of the WET, TCLP, and Water leaching tests on the treated soil samples are presented in Table A2. The regulatory levels for arsenic and lead in the extracts of the WET and TCLP tests are both 5 mg/L. The results show that all of the treated soils produced arsenic WET concentrations well above the regulatory level. Treated samples #1 and #2 also had WET lead concentration well above 5 mg/L. Sample #3, which had an untreated WET lead concentration of only 5.1 mg/L, produced WET lead results below 5 mg/L for all treatments. The Chemfix formulations (particularly "F05") decreased WET concentrations of arsenic by up to 10 times more than the formulations tested by Kiber. WET concentrations of lead also were lower in soils that were treated with the Chemfix formulations.

For TCLP arsenic concentrations, only Chemfix "F05" produced arsenic leaching concentrations below the regulatory limit for all three soil samples. None of the Kiber formulations tested produced arsenic TCLP extract concentrations below the TCLP regulatory limit. Of the Kiber formulations, Class C Fly Ash provided the best stabilization of arsenic using the TCLP test (8.4 mg/L). TCLP lead concentrations for the untreated soil samples were all below the regulatory level. Consequently, all treated soil samples also generated TCLP lead concentrations equal to or below the regulatory limit.

Similar to the results based on TCLP analysis, only Chemfix "F05" produced Water arsenic concentrations below 5 mg/L for all three soil samples. Of the three Kiber formulations analyzed by the Water extract, Portland cement succeeded in producing a Water arsenic concentration below 5 mg/L for samples #2 and #3 and cement plus Ferric chloride succeeded for sample #3. Water lead concentrations for the untreated soil samples were all below 5 mg/L. Consequently, all treated soil samples also generated Water lead concentrations below 5 mg/L, except for sample #1 treated by Chemfix "F05" (13.1 mg/L). This last result is suspect because of the low Water leachability of lead from the untreated sample (< 0.5 mg/L).

A4.0 CONCLUSIONS

Although none of the stabilization technologies were effective in treating soils to achieve the WET regulatory levels for arsenic and lead, Chemfix "F05" was able to lower TCLP concentrations of arsenic and lead to below the regulatory limit of 5 mg/L. Chemfix formulation "F05" also was successful in lowering Water leachable arsenic and lead to below 5 mg/L. Therefore, it appears Chemfix "F05" could be used to stabilize the arsenic- and lead-affected soils at the Site.

REFERENCES

Levine•Fricke, Inc. 1990. Proposed work plan, site investigation/treatability study, Sherwin-Williams Project in Emeryville, California. June 8.

TABLE A1

Sample Locations and Some Physico-Chemical Characteristics of the Soils Tested

Sample	Location	Depth	% Moisture*	pH*	Arsenic*	Lead*	TPH**
		--feet--			--mg/kg--		
#1	near SB-10	1 to 3	16	6.7 to 6.9	15,000 to 22,500	14,600 to 30,200	2,741
#2	near SB-9	2 to 5	17 to 18	6.5	12,588 to 23,600	5,500 to 6,900	1,413
#3	near SB-6	10 to 12	20 to 25	5.8	6,600 to 10,400	75 to 100	<40

* Data are the range of results reported by Kiber and Chemfex.

** Results reported by Chemfix only.

TABLE A2

Summary of Stabilization Tests on Arsenic- and Lead-Affected Soils

				Sample #1						Sample #2						Sample #3					
				WET		TCLP		Water		WET		TCLP		Water		WET		TCLP		Water	
Lab	Formulation *	Company	Volume Expansion #	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb	As	Pb
			---%---	mg/L																	
Kiber:	UNTREATED			2,237	310	422	<0.5	1,588	<0.5	2,361	251	391	<0.5	2,175	<0.5	2299	5.1	250	<0.5	348	<0.5
	HWT-7 **	IWT	11.7	6,409	171	NA	NA	NA	NA	3,590	27	NA	NA	NA	NA	4,329	1.4	NA	NA	NA	NA
	HWT-25 **	IWT	9.3	6,750	180	NA	NA	NA	NA	4,699	47	NA	NA	NA	NA	4,422	1.9	NA	NA	NA	NA
	Chembond II **	Fluid tech	16.3	4,880	176	NA	NA	NA	NA	4,699	101	NA	NA	NA	NA	4,574	2.0	NA	NA	NA	NA
	Portland Cement	none	15.7	4,880	210	154	<0.5	10.4	0.5	2,759	26	107	<0.5	3.7	<0.5	3,221	1.0	121	<0.5	1.6	<0.5
	Class C Fly Ash	none	23.0	1,991	141	121	<0.5	111	<0.5	5,715	241	91	<0.5	89	<0.5	4,699	4.4	8.4	<0.5	24	<0.5
	Cement/Ferric Chloride	none	12.7	1,781	391	181	0.5	115	<0.5	1,650	24	128	0.5	28.3	<0.5	1,977	1.1	67	0.5	1.3	<0.5
Chemfix:	UNTREATED			1,117	256	250	0.61	NA	NA	1,395	198	263	0.45	NA	NA	411	0.16	22	<0.02	NA	NA
	"F04"	Chemfix	29.3	340	82	4.1	<0.02	8.9	<0.02	404	40.8	82	<0.02	1.6	0.77	182	<0.02	0.36	<0.02	0.75	0.48
	"F05"	"	30.3	536	139	2.3	3.00	3.4	13.1	230	24	1.9	0.17	2.3	0.17	213	<0.02	<0.01	<0.02	0.52	0.08

Notes:

- * only those mixtures that produced the best results for each formulation are presented.
- ** indicate proprietary formulations
- \# percentages are average increases for all three samples

NA = not analyzed.
AS = Arsenic
Pb = Lead
WET = Waste Extraction Test
TCLP = Toxicity Characteristic Leaching Procedure

1563/FIX-TAB2.wq1

ATTACHMENT TO APPENDIX A

TREATABILITY STUDY REPORT
STABILIZATION \ FIXATION
OF ARSENIC & LEAD CONTAMINATED SOILS

PRESENTED TO:

LEVINE-FRICKE, INC.
1900 POWELL ST.
EMERYVILLE, CA 94608

PRESENTED BY:

KIBER ASSOCIATES, INC.
4000 DEKALB TECHNOLOGY PARKWAY, N.E.
SUITE 200
ATLANTA, GEORGIA 30340
(404) 455-3944

AUGUST 28, 1991

TABLE OF CONTENTS
TREATABILITY STUDY REPORT ON LEAD AND ARSENIC STABILIZATION

List of Tables

List of Appendices

TREATABILITY STUDY REPORT FOR LEVINE/FRICKE, INC.

1.0 INTRODUCTION

In June of 1991, Kiber Associates, Inc. (KIBER), was retained by Levine/Fricke, Inc. of Emeryville, California to perform a bench scale immobilization treatability study on soils contaminated primarily with lead and arsenic.

The purpose of the bench scale immobilization testing process is to identify a method or methods which will reduce the mobility of lead and arsenic. "Immobilization refers to treatment processes that are designed to accomplish one or more of the following: 1) improve handling and physical characteristics of the waste; 2) decrease the surface area of the waste mass across which transfer or loss of contaminants can occur; and 3) limit the solubility of any hazardous constituents of the waste." (Stabilization/Solidification of CERCLA and RCRA Wastes EPA/625/6-89/022).

The primary objectives of the study were as follows:

- Determine the feasibility of the treatment process for stabilization of lead and arsenic in the waste material provided;
- Determine the analytical characteristics of the treated material through the TCLP, WET and water solubility tests;
- Determine the engineering/geotechnical properties of the solidified materials.

Through the treatability testing, KIBER was tasked with evaluating immobilization technologies to determine which method and which particular agent would be suitable and effective for treatment of the material.

The ensuing discussions will detail the procedures employed to evaluate the immobilization agents and will provide all analytical data which was derived from the study.

2.0 TREATMENT METHODOLOGY AND ANALYTICAL RESULTS

2.1 TESTING TECHNIQUES USED FOR THE STUDY

The testing procedures used to evaluate the efficiency of the treatment technology include a variety of leachate generating tests. These tests were used in the study to characterize the untreated waste and to produce comparable results in the treated solidified materials developed later in the study. Each can be described as follows:

- The **Toxicity Characteristic Leaching Procedure** (TCLP) is a nationally recognized test which recently replaced the EP Toxicity procedure as a criterion for determining if a waste is considered hazardous. In this procedure, the solidified sample is crushed so that it will pass through a 9.5 mm screen. One of two buffered acidic leaching solutions is introduced to the waste depending of the alkalinity and buffering capacity of the waste. The solution is added to a container at a liquid to solid ratio of 20:1 and the sample is agitated at 30 rpm for 18 hours. The leaching solution is then filtered and analyzed for the subject constituents.

- The **California Waste Extraction Test** (WET) differs from TCLP in the following parameters:
    - The leaching solution used is sodium citrate at a pH of 5.
    - Smaller liquid to solid ratio (10:1)
    - Smaller particle size (less than 2.0mm)
    - Longer extraction period (48 hours)

  The State of California uses WET to classify hazardous waste. Because of the different metal chelating ability of sodium citrate solution, WET is a more stringent leach test than TCLP for some metals.

- The third leachate test employed for this study involved the evaluation of the solubility of the target compounds in water, which will hereafter be referred to as the **Water Solubility Test**. This extraction method was performed identically to the WET test except that the addition of acid was eliminated. This test was performed at the request of the client to evaluate the solubility of lead and arsenic.

2.2 UNTREATED SAMPLE ANALYSIS

Three 5 gallon samples were shipped to KIBER's Atlanta facility on June 20, 1991 via Federal Express. Upon receipt, each sample was mixed thoroughly to homogenize the material and subsamples were portioned from each for analysis prior to treatment.

The parameters evaluated prior to treatment included the following:

- Total Petroleum Hydrocarbons (TPH)
- Total Lead
- Total Arsenic
- TCLP Lead
- TCLP Arsenic
- WET Lead
- WET Arsenic
- Water Solubility for Lead
- Water Solubility for Arsenic
- Percent Moisture
- pH

The analytical results of the untreated sample analysis are given in Table 1.

2.3 MIXTURE PREPARATION

Six different types of immobilization agents were tested in this study. These were selected by Kiber and by the client to represent those materials which are inexpensive and readily available to the site, as well as other more specialized proprietary agents designed specifically to target inorganic compounds. The agents used are as follows:

- Type 1 Portland Cement (cement)
- HWT-7 *
- HWT-25 *
- Chembond II *
- Cement/Ferric Chloride
- Class C Fly Ash

* These materials are proprietary mixtures developed by International Waste Technologies (IWT, HWT-7 and HWT-25) and Fluid Systems (HAZCO Chemical Bond II).

> **International Waste Technologies** (IWT), based in Wichita, Kansas, has developed a series of agents many of which have been designed specifically to target high levels of inorganic contaminants while maintaining favorable physical properties. These compounds have been labeled "Poly-functional Reactive Silicates". IWT materials have been tested successfully through the EPA SITE program and are currently being used for the full scale remediation of the General Electric Site in Hialeah, Florida. KIBER has worked on a number of projects with IWT and is familiar with their blending methods and techniques for application.
>
> **Fluid Tech, Inc.**, also known as **HAZCO**, of Las Vegas, Nevada, is the developer of a series of stabilization agents now widely used in the long-term management of nuclear wastes, where the requirements for performance, leach-resistance and economy of volume expansion are stringent. Recent work shows that they are also effective in treating organics and metals, while controlling increases in volume. They have been demonstrated to be less exothermic than common stabilizers such as cement/pozzalan technologies. A recent California site test illustrated that, in a conventional approach, the temperature rose 26°C, while Fluid Tech rose only 3°C. This low heat release is a significant advantage in soils containing high levels of VOCs.

KIBER developed a total of 24 mixtures for each sample, using the above agents or the combinations thereof. The types of agents and concentrations used are presented in Tables 2 through 4. In order to facilitate the mixing process and to activate the binding mechanism of the agent, it was necessary to add water to the agent to form a slurry prior to blending. Tables 2 through 4 also list the quantities of water used in each mixture. The agent/water slurry was added to the contaminated soil on a by weight basis. As an example, in a mixture using 20% cement and 20% water, 40 grams of agent and 40 grams of water were mixed together and then added to 200 grams of contaminated soil.

The mixes were developed by measuring a portion of the sample using a triple beam balance. The agent is similarly weighed to equal the specified percentage to be used in the mixture. The blending was performed by placing the sample/waste/water slurry in a stainless steel bowl and mixing using a paddle-type mixer. The sample/agent/water mixture was blended at a rate of 25-30 rpm for 2-3 minutes, until visually homogenous. The blended sample is then compacted in a container measuring approximately 2 x 4 inches in size where it is allowed to cure at room temperature and at 90%-95% humidity.

2.4 AGENT/MIXTURE EVALUATION

The first series of tests performed by Kiber involved the testing of each sample/agent mixture for increases in volume and for physical integrity using the pocket penetrometer. Penetrometer readings and volume increase data are given in Tables 2 through 4.

Each mixture was tested after cure times of 1, 3, 7, 14, and 21 days using the pocket penetrometer. Although the penetrometer provides only general values as to the physical strength of a mixture, it is very useful in providing results which often later correlate with more expensive physical strength tests. With the exception of Class C Fly Ash, the mixes demonstrated favorable physical properties (>4.5 tons/sq.ft. = >62.5 psi) after one to three days of curing.

Based on the penetrometer readings, on volume increase data and on visual evaluation of the mixtures, Kiber selected one mixture from each agent type for leachate analysis. These mixtures were subjected to the Cal WET after a curing period of 21 days. The resulting leachate from this test was analyzed for the presence of lead and arsenic. The analytical results are presented in Tables 2 through 4. These results indicate that high concentrations of both lead and arsenic will continue to leach from all of the mixtures tested (including proprietary compounds). In fact, arsenic concentrations commonly increased from the untreated sample data while lead showed a slight decrease. Some improvement in arsenic and lead concentrations through the WET test were noted with the use of the cement and ferric chloride combination. This combination demonstrated the only decrease in arsenic levels; however, the results remained high. Slight decreases in lead concentrations were also observed in the cement and ferric chloride combination.

In the next series of tests, selected mixtures were subjected to the TCLP and Water Solubility tests and the leachate was analyzed for lead and arsenic. The results of this testing are presented in Table 6. These results indicate that leachate concentrations of lead and arsenic will be reduced when applying either of these two tests.

3.0 SUMMARY

As is illustrated in Table 1, there is considerable differences in the data generated from the untreated material when comparing the WET, TCLP, and water solubility leach tests for arsenic and lead.

The results of the treatability testing demonstrate that the immobilization technology will reduce levels of arsenic and lead only to the extent that less stringent leachate tests are employed as the evaluation criterion.

When applying the Cal WET, arsenic and lead leaches in concentrations that sometimes exceed the untreated analysis, indicating that significant variations in pH resulting from the addition of agents is having an adverse effect on the binding mechanism. The presence of sodium citrate in the WET procedure additionally dissolves soil surfaces (e.g. iron hydroxide) that retain arsenic.

DISCLAIMER

When performing treatability studies, Kiber Associates is typically provided with samples from a given site. These samples usually have been collected by site personnel and are intended to be representative of the site materials. The accuracy of the treatability study, however, is only as accurate as the accuracy of the sample taken in the field. Since KIBER has no control over the sample collection, the results of the study are assumed to be only estimations of the anticipated results.

Kiber Associates has applied our best technical and scientific knowledge to the performance of the work under the economic parameters of this study. The information contained in this report in no way guarantees the same results in full scale adaption, and is only meant to be used as a guideline for operational procedures.

Furthermore, the study period defined by the client limits the evaluation of technologies to a specified time frame. KIBER can evaluate the technologies based on this time frame, however, we cannot comment on the long term effects.

TABLES 1 THROUGH 5

KIBER ASSOCIATES, INC.
TREATABILITY STUDY FOR LEVINE-FRICKE
UNTREATED SAMPLE RESULTS
TABLE 1

Bucket 1

ANALYTICAL PARAMETER	RESULTS
pH	6.88
Percent Moisture	16.1%
Total Lead	30,200 mg/kg
Total Arsenic	14,961 mg/kg
Total Petroleum Hydrocarbons (TPH) Method 418	11,054 mg/kg
TPH Method 8015 (modified)	Appendix A
TCLP Lead	<0.5 mg/l
TCLP Arsenic	422 mg/l
WET Lead	310 mg/l
WET Arsenic	2,237 mg/l
Water Solubility for Lead	<0.5 mg/l
Water Solubility for Arsenic	1,588 mg/l

Bucket 2

ANALYTICAL PARAMETER	
pH	6.53
Percent Moisture	17.1%
Total Lead	6,900 mg/kg
Total Arsenic	12,490 mg/kg
Total Petroleum Hydrocarbons (TPH) Method 418	7,218 mg/kg
TPH Method 8015 (modified)	Appendix A
TCLP Lead	<0.5 mg/l
TCLP Arsenic	391 mg/l
WET Lead	251 mg/l
WET Arsenic	2,361 mg/l
Water Solubility for Lead	<0.5 mg/l
Water Solubility for Arsenic	2,175 mg/l

Bucket 3

ANALYTICAL PARAMETER	RESULTS
pH	5.8
Percent Moisture	19.7%
Total Lead	100 mg/kg
Total Arsenic	6,621 mg/kg
Total Petroleum Hydrocarbons (TPH) Method 418	1,008 mg/kg
TPH Method 8015 (modified)	Appendix A
TCLP Lead	<0.5 mg/l
TCLP Arsenic	250 mg/l
WET Lead	5.1 mg/l
WET Arsenic	2,299 mg/l
Water Solubility for Lead	<0.5 mg/l
Water Solubility for Arsenic	348 mg/l

KIBER ASSOCIATES, INC.
TREATABILITY STUDY FOR LEVINE/FRICKE
SERIES I TESTING
TABLE 2
BUCKET #1

SAMPLE ID#	AGENT TYPE	PERCENT AGENT	PERCENT WATER	POCKET PENETROMETER READINGS (tons/square foot)					VOLUME INCREASE	TEMP INCREASE °C
				DAY 1	DAY 3	DAY 7	DAY 14	DAY 21		
1-1	HWT-7	15%	12%	>4.5	>4.5	>4.5	>4.5	>4.5	0%	8.4
2-1	HWT-7	20%	14%	>4.5	>4.5	>4.5	>4.5	>4.5	4%	9.9
3-1	HWT-7	25%	18%	>4.5	>4.5	>4.5	>4.5	>4.5	11%	10.8
4-1	HWT-7	30%	22%	>4.5	>4.5	>4.5	>4.5	>4.5	18%	11.6
5-1	HWT-25	15%	13%	4.5	4.5	>4.5	>4.5	>4.5	1%	6.7
6-1	HWT-25	20%	15%	4.5	>4.5	>4.5	>4.5	>4.5	2%	8.6
7-1	HWT-25	25%	18%	4.5	>4.5	>4.5	>4.5	>4.5	11%	9.2
8-1	HWT-25	30%	22%	4.5	>4.5	>4.5	>4.5	>4.5	18%	10.4
9-1	CHEM BOND II	15%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	7%	2.5
10-1	CHEM BOND II	20%	20%	>4.5	>4.5	>4.5	>4.5	>4.5	18%	2.7
11-1	CHEM BOND II	25%	25%	>4.5	>4.5	>4.5	>4.5	>4.5	25%	3.2
12-1	CHEM BOND II	30%	30%	>4.5	>4.5	>4.5	>4.5	>4.5	39%	2.4
13-1	TYPE I PORTLAND CEMENT	15%	13%	4.5	>4.5	>4.5	>4.5	>4.5	1%	3.5
14-1	TYPE I PORTLAND CEMENT	20%	15%	4.5	>4.5	>4.5	>4.5	>4.5	2%	3.6
15-1	TYPE I PORTLAND CEMENT	25%	18%	4.5	>4.5	>4.5	>4.5	>4.5	11%	3.0
16-1	TYPE I PORTLAND CEMENT	30%	22%	3.0	>4.5	>4.5	>4.5	>4.5	17%	3.4
17-1	CLASS C F/A	15%	13%	0	0	0.25	3.5	>4.5	2%	0.3
18-1	CLASS C F/A	20%	15%	0	0	0	2.5	>4.5	4%	0.3
19-1	CLASS C F/A	25%	16%	0	0	0	2.5	4.5	21%	0.7
20-1	CLASS C F/A	30%	17%	0	0	0.50	3.0	4.5	25%	0.9
21-1	CEMENT/FERRIC CHLORIDE	20%,1%	15%	4.5	>4.5	>4.5	>4.5	>4.5	7%	6.1
22-1	CEMENT/FERRIC CHLORIDE	20%,1.5%	16%	4.5	>4.5	>4.5	>4.5	>4.5	7%	8
23-1	CEMENT/FERRIC CHLORIDE	20%,2%	16%	4.5	>4.5	>4.5	>4.5	>4.5	8%	8.3
24-1	CEMENT/FERRIC CHLORIDE	20%,1.4961%	16%	4.5	>4.5	>4.5	>4.5	>4.5	7%	7.4

*WET = Wet Extraction Test Performed After 21 Day Cure Time
na = Not Analyzed

SAMPLE ID#	AGENT TYPE	PERCENT AGENT	PERCENT WATER	pH OF TREATED SAMPLE	WET* ARSENIC (mg/l)	WET* LEAD (mg/l)
2-1	HWT-7	20%	14%	11.906	6,409	171
6-1	HWT-25	20%	15%	11.251	6,750	180
10-1	CHEM BOND II	20%	20%	11.358	4,880	176
15-1	TYPE I PORTLAND CEMENT	25%	18%	12.380	4,880	210
20-1	CLASS C F/A	30%	17%	9.160	1,991	141
22-1	CEMENT/FERRIC CHLORIDE	20%,1.5%	16%		1,977	250
23-1	CEMENT/FERRIC CHLORIDE	20%,2%	16%	11.870	1,781	391
UNTREATED SAMPLE RESULTS					2,237	310

KIBER ASSOCIATES, INC.
TREATABILITY STUDY FOR LEVINE/FRICKE
SERIES I TESTING
TABLE 3
BUCKET #2

SAMPLE ID#	AGENT TYPE	PERCENT AGENT	PERCENT WATER	POCKET PENETROMETER READINGS (tons/square foot)					VOLUME INCREASE	TEMP INCREASE °C
				DAY 1	DAY 3	DAY 7	DAY 14	DAY 21		
1-2	HWT-7	15%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	7%	8.7
2-2	HWT-7	20%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	11%	10.1
3-2	HWT-7	25%	18%	>4.5	>4.5	>4.5	>4.5	>4.5	14%	11.3
4-2	HWT-7	30%	22%	>4.5	>4.5	>4.5	>4.5	>4.5	25%	11.6
5-2	HWT-25	·15%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	1%	8.7
6-2	HWT-25	20%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	3%	9.3
7-2	HWT-25	25%	18%	>4.5	>4.5	>4.5	>4.5	>4.5	12%	11.0
8-2	HWT-25	30%	22%	>4.5	>4.5	>4.5	>4.5	>4.5	21%	12.5
9-2	CHEM BOND II	15%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	7%	5.9
10-2	CHEM BOND II	20%	20%	>4.5	>4.5	>4.5	>4.5	>4.5	11%	3.6
11-2	CHEM BOND II	25%	25%	>4.5	>4.5	>4.5	>4.5	>4.5	30%	4.0
12-2	CHEM BOND II	30%	30%	>4.5	>4.5	>4.5	>4.5	>4.5	40%	4.0
13-2	TYPE I PORTLAND CEMENT	15%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	1%	5.2
14-2	TYPE I PORTLAND CEMENT	20%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	7%	5.4
15-2	TYPE I PORTLAND CEMENT	25%	18%	>4.5	>4.5	>4.5	>4.5	>4.5	18%	5.4
16-2	TYPE I PORTLAND CEMENT	30%	22%	>4.5	>4.5	>4.5	>4.5	>4.5	22%	5.6
17-2	CLASS C F/A	15%	12%	0.25	0.50	0.50	3.0	>4.5	7%	1.1
18-2	CLASS C F/A	20%	13%	0.25	0.50	1.0	2.5	4.0	10%	0.8
19-2	CLASS C F/A	25%	14%	0.25	0.50	1.0	>4.5	>4.5	14%	1.6
20-2	CLASS C F/A	30%	15%	0.25	0.50	2.0	>4.5	>4.5	18%	1.8
21-2	CEMENT/FERRIC CHLORIDE	20%,1%	16%	>4.5	>4.5	>4.5	>4.5	>4.5	8%	7.1
22-2	CEMENT/FERRIC CHLORIDE	20%,1.5%	17%	>4.5	>4.5	>4.5	>4.5	>4.5	10%	8.9
23-2	CEMENT/FERRIC CHLORIDE	20%,2%	18%	>4.5	>4.5	>4.5	>4.5	>4.5	12%	9.2
24-2	CEMENT/FERRIC CHLORIDE	20%,1.249%	19%	>4.5	>4.5	>4.5	>4.5	>4.5	9%	8.0

*WET = Wet Extraction Test Performed After 21 Day Cure Time
na = Not Analyzed

SAMPLE ID#	AGENT TYPE	PERCENT AGENT	PERCENT WATER	pH OF TREATED SAMPLE	WET* ARSENIC (mg/l)	WET* LEAD (mg/l)
2-2	HWT-7	20%	15%	11.304	3,590	27.1
6-2	HWT-25	20%	15%	10.844	4,699	47.1
10-2	CHEM BOND II	20%	20%	10.929	4,699	101
15-2	TYPE I PORTLAND CEMENT	25%	18%	12.386	2,759	26.1
20-2	CLASS C F/A	30%	15%	8.923	5,715	241
22-2	CEMENT/FERRIC CHLORIDE	20%,1.5%	17%	11.875	2,435	22.1
23-2	CEMENT/FERRIC CHLORIDE	20%,2%	18%	11.812	1,650	23.9
UNTREATED SAMPLE ANALYSIS					2,361	251

320.600\table3

KIBER ASSOCIATES, INC.
TREATABILITY STUDY FOR LEVINE/FRICKE
SERIES I TESTING
TABLE 4
BUCKET #3

SAMPLE ID#	AGENT TYPE	PERCENT AGENT	PERCENT WATER	POCKET PENETROMETER READINGS (tons/square foot)					VOLUME INCREASE	TEMP INCREASE °C
				DAY 1	DAY 3	DAY 7	DAY 14	DAY 21		
1-3	HWT-7	15%	12%	>4.5	>4.5	>4.5	>4.5	>4.5	20%	8.9
2-3	HWT-7	20%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	26%	10.5
3-3	HWT-7	25%	18%	>4.5	>4.5	>4.5	>4.5	>4.5	28%	11.2
4-3	HWT-7	30%	22%	>4.5	>4.5	>4.5	>4.5	>4.5	44%	12.1
5-3	HWT-25	15%	13%	3.5	4.5	>4.5	>4.5	>4.5	23%	8.6
6-3	HWT-25	20%	15%	4.0	>4.5	>4.5	>4.5	>4.5	28%	11.5
7-3	HWT-25	25%	18%	4.5	>4.5	>4.5	>4.5	>4.5	32%	8.5
8-3	HWT-25	30%	22%	4.0	>4.5	>4.5	>4.5	>4.5	34%	11.3
9-3	CHEM BOND II	15%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	20%	3.5
10-3	CHEM BOND II	20%	20%	4.5	>4.5	>4.5	>4.5	>4.5	32%	4.1
11-3	CHEM BOND II	25%	25%	4.0	>4.5	>4.5	>4.5	>4.5	35%	3.7
12-3	CHEM BOND II	30%	30%	4.5	>4.5	>4.5	>4.5	>4.5	49%	4.3
13-3	TYPE I PORTLAND CEMENT	15%	13%	>4.5	>4.5	>4.5	>4.5	>4.5	8%	5.9
14-3	TYPE I PORTLAND CEMENT	20%	15%	>4.5	>4.5	>4.5	>4.5	>4.5	18%	6.9
15-3	TYPE I PORTLAND CEMENT	25%	18%	>4.5	>4.5	>4.5	>4.5	>4.5	34%	5.9
16-3	TYPE I PORTLAND CEMENT	30%	22%	>4.5	>4.5	>4.5	>4.5	>4.5	46%	6.2
17-3	CLASS C F/A	15%	12%	0	0.25	0.50	2.0	>4.5	9%	1.6
18-3	CLASS C F/A	20%	13%	0	0.25	0.50	2.5	4.0	12%	1.5
19-3	CLASS C F/A	25%	14%	0	0.25	1.0	>4.5	>4.5	20%	1.3
20-3	CLASS C F/A	30%	15%	0	0.25	1.0	2.5	>4.5	26%	1.6
21-3	CEMENT/FERRIC CHLORIDE	20%,0.3%	19%	>4.5	>4.5	>4.5	>4.5	>4.5	12%	6.1
22-3	CEMENT/FERRIC CHLORIDE	20%,0.6%	19%	>4.5	>4.5	>4.5	>4.5	>4.5	15%	7.0
23-3	CEMENT/FERRIC CHLORIDE	20%,0.9%	19%	>4.5	>4.5	>4.5	>4.5	>4.5	18%	7.4
24-3	CEMENT/FERRIC CHLORIDE	20%,0.6621	19%	>4.5	>4.5	>4.5	>4.5	>4.5	17%	7.3

*WET = Wet Extraction Test Peformed After 21 Day Cure Time
na = Not Analyzed

SAMPLE ID#	AGENT TYPE	PERCENT AGENT	PERCENT WATER	pH OF TREATED SAMPLE	WET* ARSENIC (mg/l)	WET* LEAD (mg/l)
1-3	HWT-7	15%	12%	11.439	4,329	1.41
5-3	HWT-25	15%	13%	10.912	4,422	1.92
9-3	CHEM BOND II	15%	15%	10.940	4,574	1.98
14-3	TYPE I PORTLAND CEMENT	20%	15%	12.148	3,221	1.02
20-3	CLASS C F/A	30%	15%	8.480	4,699	4.41
22-3	CEMENT/FERRIC CHLORIDE	20%,0.6%	19%	12.157	2,174	1.23
23-3	CEMENT/FERRIC CHLORIDE	20%,0.9%	19%	12.042	1,977	1.10
UNTREATED SAMPLE ANALYSIS					2,299	5.1

KIBER ASSOCIATES, INC.
TREATABILITY STUDY FOR LEVINE/FRICKE
TCLP AND WATER SOLUBILITY TEST RESULTS
TABLE 5

SAMPLE ID#	AGENT TYPE	PERCENT AGENT	PERCENT WATER	TCLP ARSENIC (mg/l)	WATER SOLUBILITY ARSENIC (mg/l)	TCLP LEAD (mg/l)	WATER SOLUBILITY LEAD (mg/l)
BUCKET # 1							
15-1	TYPE I PORTLAND CEMENT	25%	18%	154	10.40	<0.5	0.50
20-1	CLASS C FLY ASH	30%	17%	121	111	<0.5	<0.5
23-1	CEMENT/FERRIC CHLORIDE	20%,2.0%	16%	181	111/118*	0.51	<0.5
BUCKET # 2							
15-2	TYPE I PORTLAND CEMENT	25%	18%	107	3.7	<0.5	<0.5
20-2	CLASS C FLY ASH	30%	15%	91	91/86*	<0.5	<0.5
23-2	CEMENT/FERRIC CHLORIDE	20%,2.0%	18%	128	28.3	0.50	<0.5
BUCKET # 3							
14-3	TYPE I PORTLAND CEMENT	20%	15%	121	1.58	<0.50	<0.5
20-3	CLASS C FLY ASH	30%	15%	8.42	23.6	<0.50	<0.5
23-3	CEMENT/FERRIC CHLORIDE	20%,0.9%	19%	67	1.28	0.50	<0.5

* Duplicate analysis performed

APPENDIX A

KIBER ANALYTICAL SERVICES SAMPLE # : 17001-1

TOTAL PETROLEUM HYDROCARBONS by GC

KAI/LEVINE-FRICKE
Bucket # 1

SAMPLED (Date/Time/Init): 7/8/91, 10:00, BDJ
ANALYSIS (Date/Time/Init): 8/5/91, 23:48, DLC

MATRIX : SOLID
METHOD : CAL-DHS Volatiles (8015M)

COMPONENT	MDL	mg/Kg Concentration	mg/Kg Blank Conc.
Gasoline	0.5	ND	ND
Naphtha	0.5	ND	ND
Spirits	0.5	ND	ND
Other Volatile HC (as gasoline)	0.5	14	ND

ND: Not Detected
MDL: Method Detection Limit

HYDROCARBON PATTERN DESCRIPTION: Does not match volatile hydrocarbon product patterns. Volatile HC's chiefly composed of C7 and C8 naphthenic hydrocarbons (cyclic aliphatics). Some xylenes and paraffins are present.

Dale Chappelow

KIBER ANALYTICAL SERVICES SAMPLE # : 17001-2

TOTAL PETROLEUM HYDROCARBONS by GC

KAI/LEVINE-FRICKE
Bucket # 2

SAMPLED (Date/Time/Init): 7/8/91, 10:00, BDJ
ANALYSIS (Date/Time/Init): 8/6/91, 00:22, DLC

MATRIX : SOLID
METHOD : CAL-DHS Volatiles (8015M)

COMPONENT	MDL	mg/Kg Concentration	mg/Kg Blank Conc.
Gasoline	0.5	ND	ND
Naphtha	0.5	ND	ND
Spirits	0.5	ND	ND
Other Volatile HC (as gasoline)	0.5	100	ND

ND: Not Detected
MDL: Method Detection Limit

HYDROCARBON PATTERN DESCRIPTION: Does not match volatile hydrocarbon product patterns. Volatile HC's chiefly composed of C7 and C8 aromatic and naphthenic hydrocarbons. Some paraffins are present.

Dale Chappelow

KIBER ANALYTICAL SERVICES SAMPLE # : 17001-3

TOTAL PETROLEUM HYDROCARBONS by GC

KAI/LEVINE-FRICKE
Bucket # 3

SAMPLED (Date/Time/Init): 7/8/91, 10:00, BDJ
ANALYSIS (Date/Time/Init): 8/6/91, 00:51, DLC

MATRIX : SOLID
METHOD : CAL-DHS Volatiles (8015M)

COMPONENT	MDL	mg/Kg Concentration	mg/Kg Blank Conc.
Gasoline	0.5	ND	ND
Naphtha	0.5	ND	ND
Spirits	0.5	ND	ND
Other Volatile HC (as gasoline)	0.5	<MDL	ND

ND: Not Detected
MDL: Method Detection Limit

HYDROCARBON PATTERN DESCRIPTION: Pattern indicates the presence of a semivolatile hydrocarbon.

Dale Chappelow

CHEMFIX
TECHNOLOGIES, INC.

LABORATORY REPORT

Prepared for: Levine Fricke

Laboratory Number: 001-008-

Date Received: 7/91

Date of Report: 8/28/91

Sample Identification/Description: [001-008]

Three, medium percents solids soil wastes (numbered "*1","*2", and "3") were submitted for this analysis. They were assumed to be contaminated with leachable arsenic, lead, and purgeable hydrocarbons.

Treatment Study Goals:

The goal of the study was to formulate an arsenic, lead, and purgeable hydrocarbon (TPH) treatment system which would reduce their respective leachabilities to levels below regulatory standards. The untreated wastes were analyzed for their total concentrations of arsenic, lead, and TPH. Next, each waste was analyzed for its respective leachable arsenic and lead level by the Toxicity Characteristic Leaching Procedure (TCLP), and the California Waste Extraction Test (Cal WET). Also each untreated sample was analyzed for pH, bulk density, and percent solids.

Two waste treatment formulae were applied to each waste with the six resulting treatment samples being tested. The samples were then tested for their leachable concentrations of arsenic and lead via TCLP, Cal WET, and the non-acid Cal WET or "water soluble" metals analysis. They were also tested for Unconfined Compressive Strength (UCS), bulk density, and volume expansion ratio.

None of the treatments produced successful Cal WET leachable data, in spite of posting some successes for the TCLP and the water soluble metals test.

RESULTS

001-008-ROA
Untreated Waste
#1
TCLP Data

Test	Concentration	Units	PQL
Arsenic	250.00	mg/l	0.010
Lead	0.61	mg/l	0.015

001-008-ROA
Untreated Waste
#1
Cal WET Data

Test	Concentration	Units	PQL
Arsenic	1117.00	mg/l	0.010
Lead	256.00	mg/l	0.015

001-008-ROA
Untreated Waste
#1
Totals Data

Test	Concentration	Units	PQL
Arsenic	22,475.00	mg/kg	0.010
Lead	14,645.00	mg/kg	0.015
TPH	2740..50	mg/kg	39.30

001-008-ROB
Untreated Waste
*2
TCLP Data

Test	Concentration	Units	PQL
Arsenic	263.00	mg/l	0.010
Lead	0.45	mg/l	0.015

001-008-ROB
Untreated Waste
*2
Cal WET Data

Test	Concentration	Units	PQL
Arsenic	1395.00	mg/l	0.010
Lead	198.00	mg/l	0.015

001-008-ROB
Untreated Waste
*2
Totals Data

Test	Concentration	Units	PQL
Arsenic	23,635.00	mg/kg	0.010
Lead	5524.50	mg/kg	0.015
TPH	1413.00	mg/kg	39.30

001-008-ROC
Untreated Waste
#3
TCLP Data

Test	Concentration	Units	PQL
Arsenic	21.6	mg/l	0.010
Lead	BQL	mg/l	0.015

001-008-ROC
Untreated Waste
#3
Cal WET Data

Test	Concentration	Units	PQL
Arsenic	411.00	mg/l	0.010
Lead	0.16	mg/l	0.015

001-008-ROC
Untreated Waste
#3
Totals Data

Test	Concentration	Units	PQL
Arsenic	10,420.00	mg/kg	0.010
Lead	75.1.50	mg/kg	0.015
TPH	BQL	mg/kg	40.00

001-008-F05A
Cal WET Data

Test	Concentration	Units	PQL
Arsenic	536.00	mg/l	0.010
Lead	139.00	mg/l	0.015

001-008-F05A
Water Soluble Metals Data

Test	Concentration	Units	PQL
Arsenic	3.40	mg/l	0.010
Lead	13.10	mg/l	0.015

Treated Waste Data
(Cont.)

(Waste Sample *2)

001-008-F04B
TCLP Data

Test	Concentration	Units	PQL
Arsenic	82.00	mg/l	0.010
Lead	BQL	mg/l	0.015

001-008-F04B
Cal WET Data

Test	Concentration	Units	PQL
Arsenic	404.00	mg/l	0.010
Lead	40.80	mg/l	0.015

Lab Number: 001-008-
Page Number: 8

001-008-F04B
Water Soluble Metals Data

Test	Concentration	Units	PQL
Arsenic	1.60	mg/l	0.010
Lead	0.77	mg/l	0.015

001-008-F05B
TCLP Data

Test	Concentration	Units	PQL
Arsenic	1.90	mg/l	0.010
Lead	0.17	mg/l	0.015

001-008-F05B
Cal WET Data

Test	Concentration	Units	PQL
Arsenic	230.00	mg/l	0.010
Lead	24.00	mg/l	0.015

001-008-F05B
Water Soluble Metals Data

Test	Concentration	Units	PQL
Arsenic	2.30	mg/l	0.010
Lead	0.17	mg/l	0.015

(Waste Sample #3)

001-008-F04C
TCLP Data

Test	Concentration	Units	PQL
Arsenic	0.36	mg/l	0.010
Lead	BQL	mg/l	0.015

001-008-F04C
Cal WET Data

Test	Concentration	Units	PQL
Arsenic	182.00	mg/l	0.010
Lead	BQL	mg/l	0.015

001-008-F04C
Water Soluble Metals Data

Test	Concentration	Units	PQL
Arsenic	0.75	mg/l	0.010
Lead	0.48	mg/l	0.015

001-008-F05C
TCLP Data

Test	Concentration	Units	PQL
Arsenic	BQL	mg/l	0.010
Lead	BQL	mg/l	0.015

Lab Number: 001-008-
Page Number: 10

001-008-F05C
Cal WET Data

Test	Concentration	Units	PQL
Arsenic	213.00	mg/l	0.010
Lead	BQL	mg/l	0.015

001-008-F05C
Water Soluble Metals Data

Test	Concentration	Units	PQL
Arsenic	0.52	mg/l	0.010
Lead	0.078	mg/l	0.015

Untreated Waste
Physical Data
(Waste #1)

Unconfined Compressive Strength (U.C.S.)

U.C.S.-----> 0.00 tons/ft.2

Test	Concentration	Units	PQL
pH	6.70	S.U.	----
Bulk Density	1.70	g/ml	----
Percent Solids	84	%	---

Untreated Waste
Physical Data
(Waste #2)

Unconfined Compressive Strength (U.C.S.)

U.C.S.-----> 0.00 tons/ft.2

Test	Concentration	Units	PQL
pH	6.50	S.U.	----
Bulk Density	1.70	g/ml	----
Percent Solids	82	%	----

Untreated Waste
Physical Data
(Waste #3)

Unconfined Compressive Strength (U.C.S.)

U.C.S.-----> 0.00 tons/ft.2

Test	Concentration	Units	PQL
pH	5.80	S.U.	----
Bulk Density	1.50	g/ml	----
Percent Solids	75	%	----

Lab Number: 001-008-
Page Number: 12

Treated Waste
Physical Data

001-008-F04A

Unconfined Compressive Strength (U.C.S.)

U.C.S. ----> greater than 4.5 tons/ft.2

Test	Concentration	Units	PQL
Bulk Density	1.21	g/ml	----
Volume Expansion	29	%	----

001-008-F05A

Unconfined Compressive Strength (U.C.S.)

U.C.S. ----> greater than 4.5 tons/ft.2

Test	Concentration	Units	PQL
Bulk Density	1.2	g/ml	----
Volume Expansion	29	%	----

001-008-F04B

Unconfined Compressive Strength (U.C.S.)

U.C.S. ----> greater than 4.5 tons/ft.2

Test	Concentration	Units	PQL
Bulk Density	1.22	g/ml	----
Volume Expansion	28	%	----

Lab Number: 001-008-
Page Number: 14

QUALITY CONTROL LAB BLANK

Test	Concentration	Units	PQL
Arsenic	BQL	mg/l	0.050
Lead	BQL	mg/l	0.130

BQL: BELOW QUANTITATION LIMIT
PQL: PRACTICAL QUANTITATION LIMIT

Lab Number: 001-008-
Page Number: 15

METHODS

Test Methods for Evaluating Solid Waste
Physical/Chemical Methods, SW-846, USEPA 3rd Edition, Revised, November, 1986

Arsenic	Method 6010
Lead	Method 6010
TPH (LUFT)	Method 8015
pH	Method 9040

$$\text{VER} = \frac{\text{INITIAL DENSITY - FINAL DENSITY}}{\text{INITAL DENSITY}} \times 100$$

** VER DATA HAS BEEN CORRECTED BY FACTOR OF TWO FROM LAST PRELIMINARY REPORT

Technical Review/Clerical Accuracy/Report Completeness Certified By:

Wilbert [illegible]
Technical Services Coordinator

8/28/91
Date

Wayne A. Bro[illegible]
Supervisor, Development Laboratory

8/28/91
Date

Phil N. Baldwin
V. P. Technology Development & Management

8/29/91
Date

APPENDIX B

SOIL BIOTREATMENT STUDIES

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LEVINE·FRICKE

December 20, 1991

LF 1563.11

LABORATORY TREATABILITY STUDY: BIOTREATMENT OF HYDROCARBON-AFFECTED SOILS

B1.0 INTRODUCTION

A laboratory study was undertaken to evaluate the effectiveness of bioremediation for treating hydrocarbon-affected soils from the Sherwin-Williams Facility at Emeryville, California (herein referred to as "the Site").

B2.0 METHODS AND MATERIALS

Soils

Composite soil samples were collected from three different areas of the Site that were known to be contain petroleum hydrocarbons: (1) the Oils Tank Farm (OTF), (2) the Solvent Tank Farm - Area A (STF-A), and (3) the Solvent Tank Farm - Area B (STF-B) (Figure 2). The quantity and type of total petroleum hydrocarbons (TPH) in the affected soils were evaluated using a modified EPA Method 8015 analysis in the Levine•Fricke laboratory. A 20 μg soil subsample was extracted with 10 milliliters (mL) of pentane and 10 mL of deionized water in a TFE-lined, capped vial. The vials were shaken for five minutes and placed into an ultrasonic bath for five minutes, followed by centrifugation to separate the pentane from the water. The pentane was removed from the extraction vial and placed into 2-mL auto sampler vials for sample introduction into a gas chromatograph. A Hewlett-Packard (HP) 5890A gas chromatograph, equipped with an HP 7673A Autosampler, a 30 m x 0.25 mm inside-diameter SPB-5 capillary column, and a flame ionization detector, was used to characterize and quantify the TPH. The OTF, STF-A, and STF-B soils were determined to contain TPH (quantified as Mineral Spirits-66) at concentrations of 178±61 mg/kg, 178±56 mg/kg, and 212±42 mg/kg, respectively (see Section 1.3 of the main text for a more detailed description of these soils).

It should be noted that the hydrocarbon concentrations in site soils have been quantified using several approaches. Field investigations originally characterized the subject soils as containing toluene, xylenes, and other TPH in the range of 1 mg/kg to 10,000 mg/kg, using EPA Methods 8240 and 8270. The composite samples, which were collected for the laboratory treatability studies, were analyzed using modified EPA Method 8015 to more accurately quantify TPH.

Phase I: Soil Amendments

The pH, soluble ammonia-nitrogen (N), and soluble ortho-phosphorus (P) of the hydrocarbon-affected soils were determined to evaluate requirements for appropriate soils amendments (e.g., nutrients, neutralizing agents, chelating agents, etc.). Subsamples of 25 g from the OTF, STF-A, and STF-B soils were placed in 100-mL glass beakers. A range of specially designed Levine•Fricke nutrient solutions (SS) were added to the trials. A chelating agent (C) also was added to selected trials to increase the availability of phosphorus. After allowing the amendments to react with the soil for at least 48 hours, the soils were shaken with 0.1 M KCl for 1 hour to extract the soluble N and P. The samples were centrifuged and the supernatant solutions were analyzed for N and P. Measurements of pH were also conducted in order to monitor acid or alkaline reactions induced by the soil amendments.

Phase II: Surfactants

A variety of nonionic surfactants, Adsee 799, Triton-X-100, and Hyonic-NP-90, were evaluated for their ability to solubilize petroleum hydrocarbons from the affected soils. Subsamples of 25 g from the OTF, STF-A, and STF-B soils were placed in 100-mL glass beakers. Surfactants (SF) were mixed with water so that a final surfactant concentration of 10 mg/kg was added to the soil after soil watering. After allowing the surfactant to react with the soils for at least 48 hours, the soils were shaken with 25 mL of water to extract solubilized hydrocarbons. The samples were centrifuged (after adding 0.25 mL concentrated KCl to promote clay flocculation) and the supernatant solutions were collected for TPH analysis.

Phase III: Microcosm Bioremediation

Based on the information produced by Phases I and II, the most promising soil amendment combinations were tested in a "microcosm" study for their ability to enhance the biodegradation of TPH in site soils. A summary of all of the treatments and trials is presented in Table B1 through B3. Subsamples of 600 g from the OTF, STF-A, and STF-B soils were placed in 1-L glass canning jars. A large volume of headspace (approximately 30 percent by volume) was left in the jars so that adequate amounts of oxygen remained after sealing the jars with screw-top lids. The selected soil amendment combinations were added to the jars with 15 mL of water. All of the trials received a 2-mL inoculation of microorganisms (B) except for trials #13, 14, and the control trials #15, 16, and 20, which received 2 mL of tap water. Control trials that received no amendments (#5, 12, 16, and 20) were treated with the same volume of water and the same frequency of mixing as all other trials.

The trials were sampled (10 g) twice per week for pH, N, and P analyses. Thorough mixing was performed before a sample was collected. Similarly, a 20 g subsample was collected 1 to 2 times per week for TPH analysis using modified EPA Method 8015, described above. According to decreases in soluble N and P, and the soil moisture content, the appropriate amendments (including water) were added to the suitable trials. To assure that each trial maintained a similar soil moisture content, trials that did not receive a particular soil amendment received the same volume of water.

B3.0 RESULTS AND DISCUSSION

Phase I: Soil Amendments

Preliminary screening of the samples for pH showed that some of the STF soils were acidic (pH = 5.4 to 6.1). The pH of the OTF soils was near neutral (pH = 6.8 to 7.4). Considering the potential problems of acidity on P availability and on microbial growth, the total neutralizable acidity (TNA) of the STF soils was measured so that the required amount of neutralizing agent could be determined. According to the SMP buffer method (McLean 1982), the TNA of the STF-A and STF-B soils was determined to be 3.6 meq/100 g and 2.9 meq/100 g, respectively. Consequently, 0.2% (w/w) of $CaCO_3$ (1 meq/50 mg) was determined to be the appropriate amount of neutralizing agent to add to the STF soils.

The N and P analyses of the OTF, STF-A, and STF-B soils were used to estimate the appropriate amounts of nutrients required to bring the soluble N and soluble P concentrations to proper concentrations for active microbial growth. The Phase I study revealed that less than 2.5 mg/L of soluble P was present in the STF soils, indicating the strong tendency for these soils to adsorb P. The adsorption of P in the OTF soils was not as great as in the STF soils, as approximately 10 to 20 mg/L of soluble P was observed in the former soil.

To increase soluble P concentrations in these soils, three concentrations (0.01 mol L^{-1}, 0.02 mol L^{-1}, and 0.1 mol L^{-1}) of a natural chelating agent were tested for their ability to enhance soluble P concentrations. The specific chelating agent and the applied concentrations were determined from previous studies conducted in the Levine•Fricke laboratory. The chelating agent was observed to successfully increase the soluble P concentrations up to 7.5 mg/L in the STF soils and up to 30 mg/L in the OTF soils. No significant differences in soluble P concentrations were observed between the three levels of chelating agent that were tested. Consequently, the lowest chelating agent concentration was selected for use in the bioremediation trials of Phase III.

Phase II: Surfactants

Results of the surfactant tests revealed that no detectable amounts of TPH (<10 mg/kg) were solubilized by any of the surfactants studied. Because of the limitation of evaluating the effectiveness of the surfactants by simply measuring extractable TPH, the surfactants were still tested in Phase III for their ability to enhance biodegradation rates.

Phase III: Microcosm Bioremediation

The results of the microcosm bioremediation studies for the OTF, STF-A, and STF-B soils are reported in Tables B1 through B9. The degradation of soil TPH is given in Tables B1 through B3 and selected trials are illustrated in Figures B1, B2, and B3. The changes in soil pH are presented in Tables B4 through B6, and the levels of soluble P and N are provided in Tables B7 through B9.

The results clearly show the soil TPH declined to below 10 mg/kg in all of the soils studied. For one STF-A trial that received an inoculation of microorganisms and no soil amendments, the final analysis revealed a presence of 12 mg/kg TPH. It must be noted that gaseous emissions of petroleum hydrocarbons from the soils were not monitored in this study. Therefore, it is possible losses of petroleum hydrocarbons by volatilization (i.e., the transfer of a chemical from the solid or aqueous phase into the gas phase) may have contributed to some of the perceived biodegradation.

The time required for nondetectable levels of TPH to be achieved varied slightly between soils and treatments, but was generally established between 3½ to 5 weeks after the biotreatment was initiated. Although Figures B1, B2, and B3 show there were some small variations between the rates of TPH degradation between different treatments, it is difficult to discern any significant differences. The apparent rapid rates of TPH biodegradation in the control trials for OTF and STF-A soils were probably because of the almost 4-week "pre-degradation" that these trials experienced while sitting in sealed sample buckets in the Levine•Fricke laboratory before the beginning of the microcosm biotreatment. Similar rapid rates of TPH degradation were observed for the STF-B soils, (which also experienced a one month "pre-degradation" before biotreatment), as nondetectable levels of TPH were attained within 2½ weeks for soils that were treated with amendments. The control trial for STF-B took almost twice as long to achieve nondetectable levels of TPH, suggesting that the addition of soil amendments positively influenced the rate of TPH removal from this soil.

The evidence for microbial activity in the biotreatment microcosms was exemplified by decreases in soil pH during the course of the study for the OTF, STF-A, and STF-B soils (Tables B4, B5, and B6, respectively). Decreases in soil pH suggest active microbial processes, which are known to produce acidity (e.g., organic carbon degradation to organic acids and CO_2 and the nitrification of ammonia to nitrate [Alexander 1977]). The addition of $CaCO_3$ to the more acidic STF soils proved to buffer changes in pH more effectively than untreated soils. For example, STF-A soils that received no $CaCO_3$ displayed a final soil pH below pH 5, whereas $CaCO_3$-treated soils resulted in a pH above 5.5. Although the lower pHs appeared to have no effect on TPH degradation in the laboratory, for field biotreatment that may take longer than three to five weeks to complete, high levels of acidity could cause micronutrient deficiencies that depresses microbial activity.

Microbial activity in the biotreatment microcosms also was manifested in the consumption of nutrients, which is shown in Tables B7, B8, and B9, for the OTF, STF-A, and STF-B soils, respectively. Decreases in soluble N to 50 mg/L were used as a basis to determine whether nutrients should be added to the biotreatment microcosms. During the eight-week biotreatment study, nutrients and the appropriate soil amendments were added three times for the OTF and STF-A soils, while only one nutrient addition was made to the STF-B soils during their shorter five-week biotreatment. Soluble P in all soils throughout the duration of the study proved to be very low, usually below 2.5 mg/L. Although Phase I experiments showed that additions of a chelating agent could increase soluble P by at least two times, this effect was not apparent in the microcosm trials. This may be the result of several possibilities: (1) microbial activity was higher in the microcosm studies conducted about two weeks after the Phase I tests, and (2) unlike Phase I, Phase III nutrient analyses were not usually conducted within 24 hours of the nutrient additions, thereby allowing more time for the adsorption of P by soils and/or the consumption of P by microorganisms. Soils receiving no soil amendments or inoculations of microorganisms were able to achieve nondetectable TPH levels within a period of time comparable to that of amended soils. This observation suggests that, with adequate soil mixing and watering, the native microorganisms and natural fertility of the soils can promote substantial biodegradation of the petroleum hydrocarbons.

B4.0 CONCLUSIONS AND RECOMMENDATIONS

This study showed that bioremediation of site soils is an effective technology for lowering soil petroleum hydrocarbons to below TPH detection limits (<10 mg/kg). With adequate moisture and mixing, the indigenous soil microorganisms were observed to catalyze the degradation of TPH to nondetectable levels within 3½ to 5 weeks. The addition of the appropriate nutrients and soil amendments (neutralizing agents and chelating agents) appeared to increase the remedial effectiveness in some cases, but generally did not significantly enhance the rates of TPH biodegradation or the final measured TPH levels. The testing in Phase I, however, revealed that selected additions of nutrients, chelating agents, and neutralizing agents had a marked effect on raising the fertility level of site soils to conditions that will more likely stimulate microbial activity in the field.

Considering that field conditions at the Site during the winter months will not be as ideal as the laboratory controlled conditions of this study, particularly temperature, we recommend that the aforementioned soil amendments be added to site soils to mitigate potential stresses and limitations that can inhibit microbial activity in the field. Additionally, when field-treating large volumes of hydrocarbon-affected soils, the application of nutrients, chelating agents, and pH controls will allow higher rates of degradation, which will shorten the treatment period.

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McLean, E.O. 1982. Soil pH and lime requirement. In: methods of soil analysis, part 2; chemical and microbiological properties. A.L. Page, R.H. Miller, and D.R. Keeney, eds. ASA, Madison, WI. pp.199-224.

TABLE B1

Total Petroleum Hydrocarbons (as MS-66 Solvent) Present in Field-Moist OTF Soils During Five Weeks of Biotreatment
Biotreatment started July 25, 1990

OTF			Days									
Trial	Treatment	5	8	13	15	19	23	26	29	36	44	51
			mg/kg									
# 1	SS, C, B		151	54	<10	59	67	93	81	12	<10	<10
# 2	SS, C, SF, B		105	64	<10	51	55	132	95	<10	<10	<10
# 3	SS, SF, B		196	26	<10	37	102	119	NA	19	<10	<10
# 4	SS, B		268	24	<10	82	97	124	73	22	<10	<10
# 5	B		119	30	<10	116	25	75	33	<10	<10	<10
#13	SS, C, SF		245	58	<10	18	53	135	54	56	<10	<10
#15	Control **	157	163	34	78	NA	14	NA	11	<10	<10	<10
** Started 8/21; actual days are:				12					30		41	43

Notes:

* Recent additions of amendments.
MS-66 = mineral spirits 66 solvent supplied by Sherwin-Williams.
SS = 6 percent special nutrient solution of N, P, and micronutrients.
C = 0.005 percent chelating agent.
SF = 0.001 percent non-ionic sufactant.
B = Levine-Fricke laboratory-reared microorganisms.
NA = Not analyzed.
OTF = Oil Tank Farm

TABLE B2

Total PTotal Petroleum Hydrocarbons (as MS-66 Solvent) Present in Field-Moist STF-A Soils During five Weeks of Biotreatment
Biotreatment started July 25, 1990

STF-A		Days											
Trial	Treatment	5	8	13	15	19	23	26	29	33	36	44	51
		mg/kg											
# 6	SS,C,B		285	45	11	59	29	79	34	<10	<10	<10	<10
# 7	SS,C,SF,B		176	198	16	168	114	176	75	18	<10	<10	<10
# 8	SS,SF,B		241	85	<10	179	83	118	78	38	27	<10	<10
# 9	SS,B		107	25	<10	65	<10	55	11	<10	<10	<10	<10
#10	SS,C,Ca,B		163	60	<10	61	15	103	29	<10	<10	<10	<10
#11	SS,Ca,B		176	23	<10	55	<10	88	30	18	<10	<10	<10
#12	B		177	15	<10	88	43	189	62	78	62	<10	12
#14	SS,C,Ca,SF		159	55	<10	41	<10	69	21	12	<10	<10	<10
#16	Control **	158	115	91	106	11	12	<10	25	<10	<10	<10	<10
**	Started 8/21; actual days are:			12					30		36	41	43

Notes:

* Recent additions of amendments.
MS-66 = mineral spirits 66 solvent supplied by Sherwin-Williams.
SS = 6 percent special nutrient solution of N, P, and micronutrients.
C = 0.005 percent chelating agent.
SF = 0.001 percent non-ionic sufactant.
B = Levine-Fricke laboratory-reared microorganisms.
NA = Not analyzed.
STF = Solvent Tank Farm

TABLE B3

Total Petroleum Hydrocarbons (as MS-66 Solvent) Present in Field-Moist STF-B Soils During Five Weeks of Biotreatment
Biotreatment started July 25, 1990

STF-B Trial	Treatment	Days										
		1	5	7	14	18	20	25	27	32	34	39
		mg/kg										
#17	SS,C,Ca,SF,B	270	132	25	32	20	<10	<10	<10	<10	<10	<10
#18	SS,C,Ca,B	182	87	25	17	<10	<10	<10	10	<10	<10	<10
#19	SS,Ca,B	180	61	24	24	<10	21	<10	<10	<10	<10	<10
#20	Control	215	119	26	15	14	12	14	27	<10	<10	<10

Notes:

* Recent additions of amendments.
MS-66 = mineral spirits 66 solvent supplied by Sherwin-Williams.
SS = 6 percent special nutrient solution of N, P, and micronutrients.
C = 0.005 percent chelating agent.
SF = 0.001 percent non-ionic sufactant.
B = Levine-Fricke laboratory-reared microorganisms.
NA = Not analyzed.
STF = Solvent Tank Farm

TABLE B4

The pH of OTF Soils During Five Weeks of Biotreatment

OTF Trial	Treatment	Days 8*	14	21*	28	35*	42	50*
		pH						
# 1	SS,C,B	7.6	NA	7.1	7.1	6.9	6.6	6.4
# 2	SS,C,SF,B	7.6	7.1	7.3	7.2	6.8	6.7	6.7
# 3	SS,SF,B	7.5	NA	7.3	7.2	7.1	7.0	6.7
# 4	SS,B	7.5	NA	7.3	7.2	7.0	7.0	6.8
# 5	B	7.3	6.8	7.2	7.4	7.1	7.3	7.1
#13	SS,C,SF	7.6	7.2	7.0	6.6	6.9	6.7	6.5
#15	Control **	6.9	6.9	7.1	6.9	7.1	7.4	7.4
** Started 8/21; actual days are:			15	23	29	36	43	

Notes:

* Recent additions of amendments.
MS-66 = mineral spirits 66 solvent supplied by Sherwin-Williams.
SS = 6 percent special nutrient solution of N, P, and micronutrients.
C = 0.005 percent chelating agent.
SF = 0.001 percent non-ionic surfactant.
B = Levine-Fricke laboratory-reared microorganisms.
NA = not analyzed.

TABLE B5

The pH of STF-A Soils During Five Weeks of Biotreatment

STF-A Trial	Treatment	Days						
		8*	14	21*	28	35*	42	50*
		pH						
# 6	SS,C,B	6.5	NA	6.4	5.7	5.9	5.1	4.9
# 7	SS,C,SF,B	6.4	6.2	6.3	5.7	5.8	4.8	4.9
# 8	SS,SF,B	6.6	NA	6.3	5.9	6.3	5.3	5.2
# 9	SS,B	6.2	NA	6.0	5.4	5.4	4.6	4.5
#10	SS,C,Ca,B	7.3	7.1	6.9	6.3	6.0	5.1	5.5
#11	SS,Ca,B	7.2	NA	6.9	6.6	6.6	5.6	5.5
#12	B	6.2	NA	5.9	5.5	5.7	5.4	5.4
#14	SS,C,SF,Ca	7.2	7.3	6.9	6.5	6.4	6.0	5.8
#16	Control **	4.8	4.7	4.7	4.7	4.8	4.9	4.8
**	Started 8/21; actual days are:		15	23	29	36	43	

Notes:

* Recent additions of amendments.

MS-66 = mineral spirits 66 solvent supplied by Sherwin-Williams.

SS = 6 percent special nutrient solution of N, P, and micronutrients.

C = 0.005 percent chelating agent.

SF = 0.001 percent non-ionic surfactant.

B = Levine-Fricke laboratory-reared microorganisms.

NA = not analyzed.

TABLE B6

The pH of STF-B Soils During Five Weeks of Biotreatment

STF-B Trial	Treatment	Days							
		7*	15*	21	28	35	42	49	56
		pH							
#17	SS,C,Ca,SF,B	7.0	7.3	7.4	6.9	6.8	6.9	6.7	6.5
#18	SS,C,Ca,B	7.0	7.4	7.6	7.3	6.9	6.7	6.5	6.4
#19	SS,Ca,B	6.9	7.3	7.3	6.9	6.9	6.8	6.9	6.6
#20	Control	5.9	6.3	6.4	6.3	6.2	6.3	6.4	6.3

Notes:

* Recent additions of amendments.
MS-66 = mineral spirits 66 solvent supplied by Sherwin-Williams.
SS = 6 percent special nutrient solution of N, P, and micronutrients.
C = 0.005 percent chelating agent.
SF = 0.001 percent non-ionic surfactant.
B = Levine-Fricke laboratory-reared microorganisms.
NA = not analyzed.

TABLE B7

Soluble Phosphate (P) and Ammonia (N) in OTF Soils During Five Weeks of BioTreatment

OTF Trial	Sample	Days															
		8*		14		21*		28		33		35*		42		50*	
		P	N	P	N	P	N	P	N	P	N	P	N	P	N	P	N
		mg/L															
# 1	SS,C,B	25	50-75	NA	NA	2.5	75	<2.5	15	<2.5	5	<2.5	15	<2.5	5	<2.5	<2.5
# 2	SS,C,SF,B	25	50-75	2.5	2.5	2.5	75-10	<2.5	25	NA	NA	<2.5	15	<2.5	10	<2.5	5-7.5
# 3	SS,SF,B	10	50-75	NA	NA	<2.5	100	<2.5	25	NA	NA	<2.5	15	<2.5	10-15	<2.5	2.5
# 4	SS,B	5	50-75	NA	NA	<2.5	75	<2.5	25-50	<2.5	10-15	<2.5	25	<2.5	15	<2.5	15
# 5	B	5	<2.5	<2.5	2.5	<2.5	<2.5	<2.5	2.5	NA	NA	<2.5	<2.5	<2.5	5	<2.5	<2.5
#13	SS,C,SF	2.5-5.0	100-125	1	125	<2.5	50	<2.5	15	NA	NA	<2.5	25	<2.5	20	<2.5	2.5
#15	Control	<2.5	2.5-5.0	NA	NA	<2.5	<2.5	<2.5	5	<2.5	2.5	<2.5	<2.5	NA	NA	NA	NA
** Started 8/21; actual days are:				15		23		29				36					

Notes:

* Recent additions of amendments.
MS-66 = mineral spirits 66 solvent supplied by Sherwin-Williams.
SS = 6 percent special nutrient solution of N, P, and micronutrients.
C = 0.005 percent chelating agent.
SF = 0.001 percent non-ionic surfactant.
B = Levine-Fricke laboratory-reared microorganisms.
NA = not analyzed.

TABLE B9

Soluble Phosphate (P) and Ammonia (N) in STF-B Soils During Five Weeks of Biotreatment

STF-B Trial	Treatment	7* P	7* N	15* P	15* N	21 P	21 N	28 P	28 N	35 P	35 N
		mg/L									
#17	SS,C,Ca,SF,B	<2.5	50-75	<2.5	125-150	<2.5	75	<2.5	75-100	2.5-5	75-100
#18	SS,C,Ca,B	<2.5	150	<2.5	200-250	<2.5	200	<2.5	50-75	2.5-5	75-100
#19	SS,Ca,B	<2.5	175	<2.5	125	<2.5	200-250	<2.5	50-75	2.5-5	75-100
#20	Control	<2.5	7.5	<2.5	5-7.5	<2.5	5	<2.5	2.5-5	2.5-5	15-20

Notes:

* Recent additions of amendments.
MS-66 = mineral spirits 66 solvent supplied by Sherwin-Williams.
SS = 6 percent special nutrient solution of N, P, and micronutrients.
C = 0.005 percent chelating agent.
SF = 0.001 percent non-ionic surfactant.
B = Levine-Fricke laboratory-reared microorganisms.
NA = not analyzed.

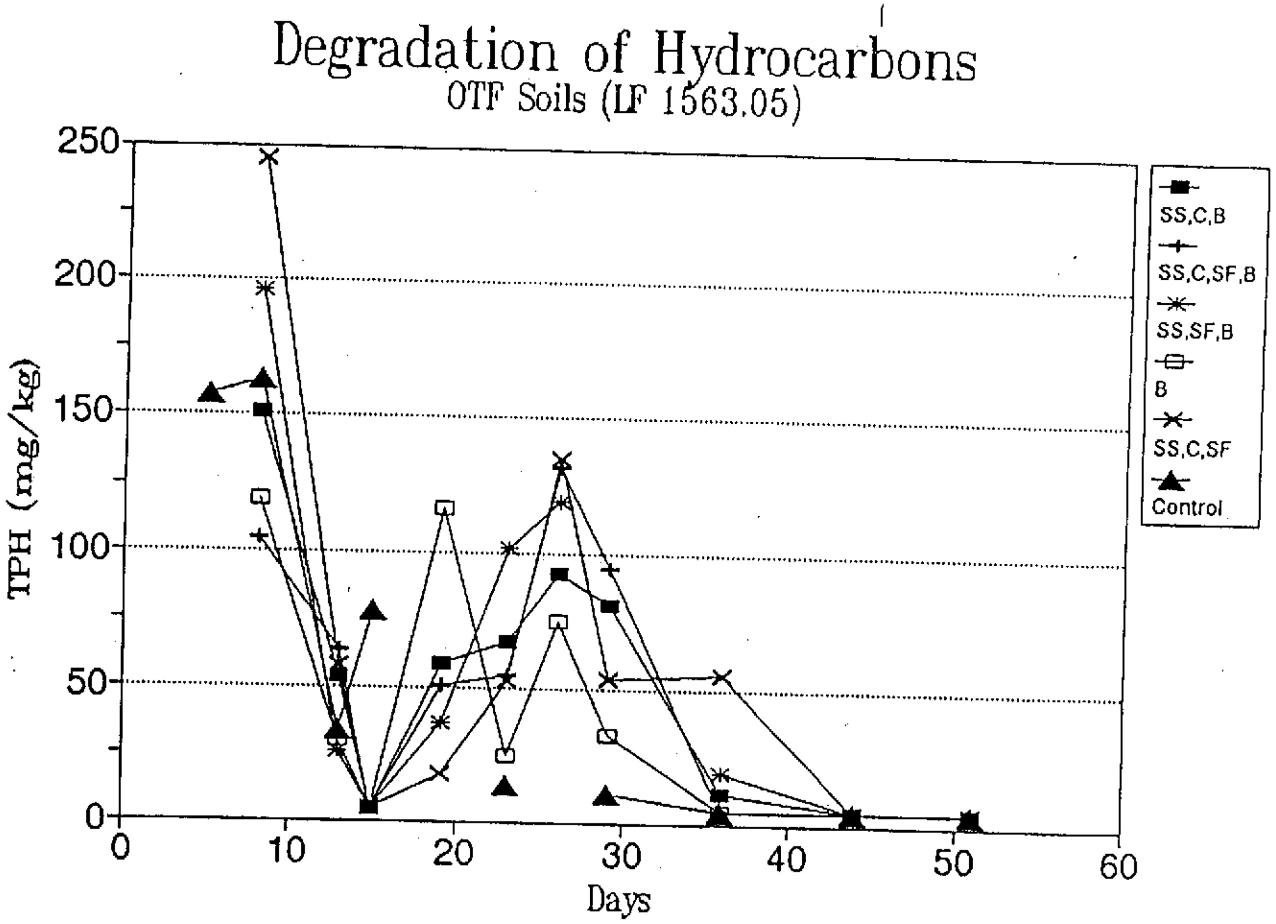

FIGURE B1: CONCENTRATIONS OF TOTAL PETROLEUM HYDROCARBONS (TPH) IN THE OILS TANK FARM (OTF) SOILS DURING BIOTREATMENT. (TPH WAS QUANTIFIED AGAINST A MINERAL SPIRITS-LABORATORY STANDARD.)

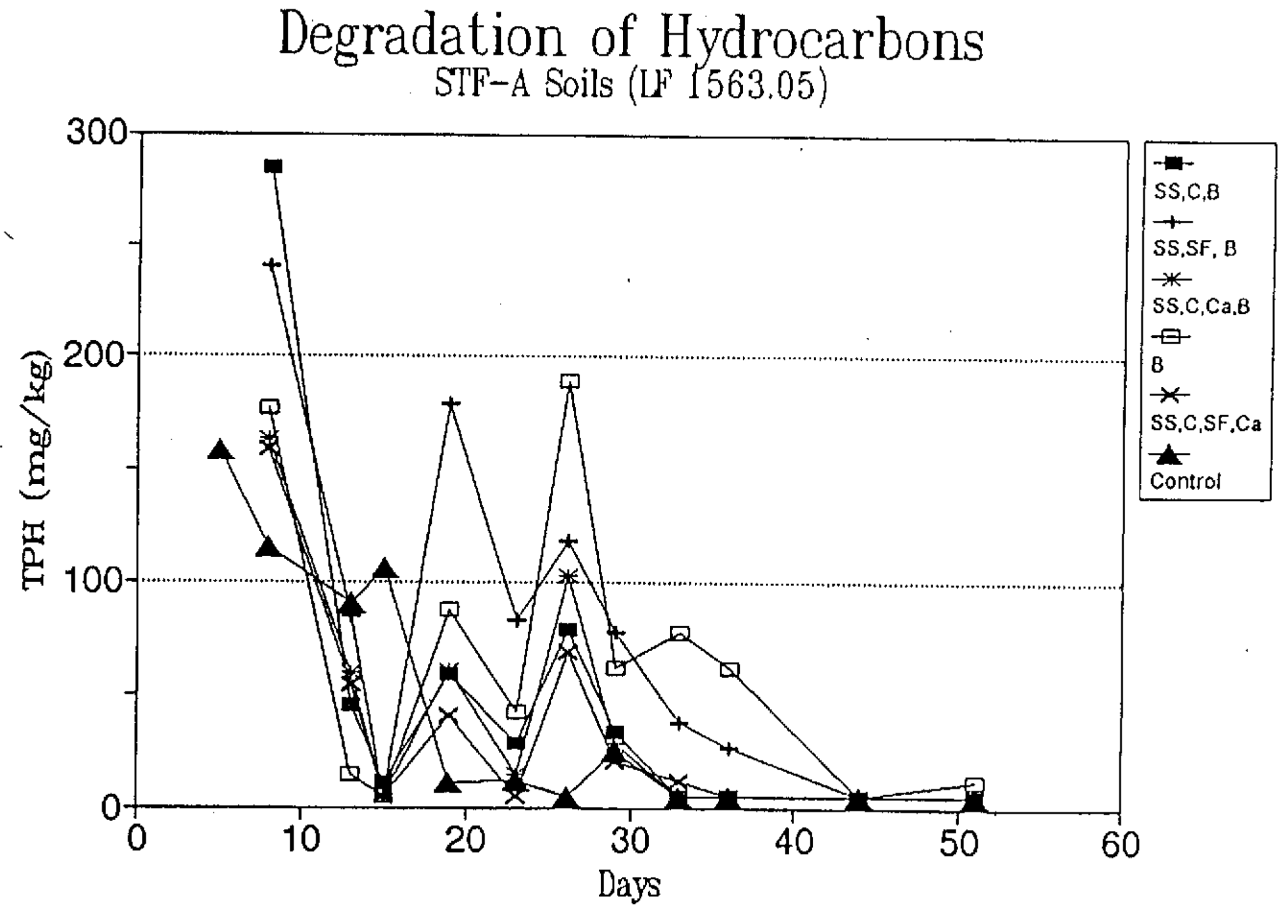

FIGURE B2: CONCENTRATIONS OF TOTAL PETROLEUM HYDROCARBONS (TPH) IN THE SOLVENT TANK FARM AREA A (STF-A) SOILS DURING BIOTREATMENT. (TPH WAS QUANTIFIED AGAINST A MINERAL SPIRITS-LABORATORY STANDARD.)

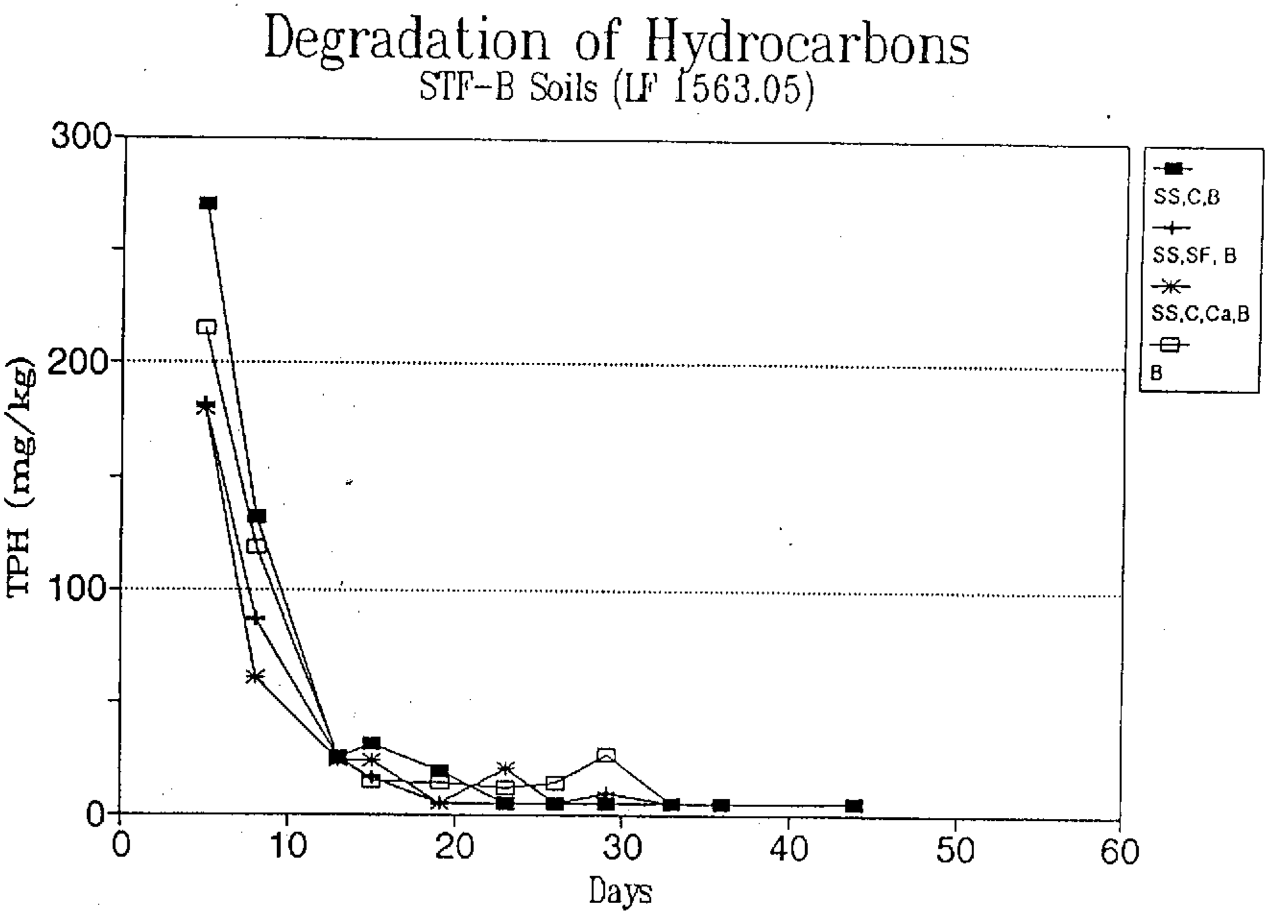

FIGURE B3: CONCENTRATIONS OF TOTAL PETROLEUM HYDROCARBONS (TPH) IN THE SOLVENT TANK FARM AREA B (STF-B) SOILS DURING BIOTREATMENT. (TPH WAS QUANTIFIED AGAINST A MINERAL SPIRITS-LABORATORY STANDARD.)

APPENDIX C
WATER BIOTREATMENT STUDIES

CONTENTS

LIST OF TABLES

LIST OF FIGURES

December 20, 1991

LF 1563.11

LABORATORY TREATABILITY STUDY BIOLOGICAL TREATMENT OF VOC- AND SVOC-AFFECTED GROUND WATER

C1.0 INTRODUCTION

A laboratory study was undertaken to evaluate the effectiveness of biological treatment on ground water from the Sherwin-Williams Site in Emeryville, California (herein referred to as the Site), which contains nonchlorinated volatile and semivolatile organic compounds (VOCs and SVOCs, respectively). The literature is replete with examples from both the laboratory and the field demonstrating the ability of biological treatment systems to degrade nonchlorinated VOCs and SVOCs to concentrations below the detection limits of accepted EPA analyses.

In addition to the organic compounds present, the ground water from the Site also contained high concentrations of arsenic (up to 200 mg/L), which also may required treatment and removal. The initial treatment concept for arsenic reduction included the use of an electrochemical process to remove arsenic before the biotreatment step. This arrangement of process technologies was conceived because of the potential toxicity of arsenic on the microorganisms in the Bioreactor. Alternatively, it appeared that removal of arsenic from the aqueous phase via biological reduction under anaerobic conditions was a possibility. The reduced forms of arsenic would then be retained in the Bioreactor biomass or sludge. Further removal of arsenic from the ground water in the Bioreactor also would be enhanced by the addition of iron salts into the aerobic portion of the Bioreactor. Therefore, the biotreatment study was designed to evaluate the biodegradation of VOCs and SVOCs before arsenic removal.

C2.0 OBJECTIVES

The overall objective of this study was to evaluate the effectiveness of a biological treatment process for degrading VOCs and SVOCs in ground water. Specific objectives were as follows:

1. determine the potential toxicity or inhibition of arsenic on microbial growth in the Bioreactor

2. evaluate the potential for the Bioreactor to remove arsenic from ground water
3. determine the optimal operating conditions for effective degradation of VOCs and SVOCs
4. develop process and design parameters for full-scale bioreactor and ancillary equipment.

C3.0 METHODS AND MATERIALS

C3.1 Biological Toxicity Screening Study

Before initiating the biological treatment study, a toxicity screening study was performed to determine the effect of the arsenic present in ground water on microbial activity. The evaluation was performed by Tri-Bio of Allentown, Pennsylvania, using ground-water samples collected from the Site. The testing procedures and detailed results of the study are included in the attachment to this appendix.

In summary, the results of the toxicity screening indicated the presence of arsenic in the ground water did not exhibit inhibitory effects on microbial populations capable of biodegrading the organic compounds of concern. Based on these results, it was determined to proceed with the laboratory biological treatability study without pretreatment for arsenic removal.

C3.2 Ground-Water Sampling and Quality

Ground water from the Site was collected from various monitoring wells and placed into two, polyethylene 55-gallon drums for transportation to the Levine·Fricke Laboratory in Emeryville, California. The ground-water sampling was designed to represent a mixture of ground water that a full-scale Bioreactor would receive under field conditions. Another ground-water sample was collected from wells LF-2 and LF-3 to approximate the VOC, SVOC, and arsenic concentrations of the earlier sampling while minimizing the cost of sampling. A final ground-water sample was collected from the storage tank on the Site and mixed with arsenic-affected ground water from well LF-1 and spiked with a variety of VOCs.

The ground-water samples collected from the Site and treated in the Levine·Fricke laboratory may differ somewhat in quality from that which the field-scale Bioreactor would experience for two reasons: (1) VOC, SVOC, and chemical oxygen demand concentrations may be reduced by biodegradation and volatilization; and (2) adsorption of arsenic to the storage vessel walls may affect arsenic concentrations. The most notable difference was a reduction in COD concentration, as initial COD analyses showed an average COD concentration of 910 mg/L, while influent concentrations to the pilot-scale Bioreactor were measured in the range of 400 to 500 mg/L. The pH of the received water was measured at 8.3 pH units.

C3.3 Biological Reactor Pilot Plant (Bioreactor)

The study was conducted using a flow-through, submerged fixed-film Bioreactor, consisting of four reactor cells that can be operated under either anaerobic or aerobic conditions. The total reactor volume was 20.4 L, with each of the four cells having a capacity of 5.1 L. All of the reactor cells contained rigid polyvinyl chloride (PVC) media with a high surface-area-to-volume ratio. The influent ground water, plus nutrients and supplemental carbon sources, was pumped constantly into Cell 1 and then flowed sequentially through Cells 2, 3, and 4. Each cell was equipped with a top-mounted, downdraft turbine type mixer that provided thorough mixing within the cell, as well as the transfer of gases in the cell headspace back into solution. In the anaerobic cells of the Bioreactor (Cells 1 and 2), the cells were sealed off from the atmosphere to prevent the introduction of oxygen or the release of headspace gases. The Bioreactor is shown in Figure C1.

The treated liquid effluent and the suspended biomass, which was sloughed from the PVC media, flowed into a clarifier where the solids settled to the bottom. The clarified effluent was then discharged over a clarifier weir while the settled solids (biological sludge) were collected at the bottom of the clarifier.

The hydraulic flows of all liquids (i.e., ground water, nutrients, and spike) to the Bioreactor were regulated through timer-controlled peristaltic pumps. Timer settings that controlled pump operations were optimized to promote the most continuous flows into the Bioreactor. The hydraulic residence time (HRT) of the ground water in the Bioreactor was adjusted at various times during the study from 8 to 46 hours.

The pH and the oxidation reduction potential (ORP) were continuously monitored by a Cole-Parmer (Model Number 5656-00) pH/ORP set-point controller, which was connected to a combination pH/temperature compensating probe and an ORP probe. The output signal from the pH unit controlled peristaltic pumps that added 0.2 mol/L HCl or 0.2 mol/L NaOH, as required for the maintenance of selected pH ranges. Unlike the pH, the ORP in the cells was not controlled automatically.

C3.4 Biological Treatment Process Design

For this investigation, the Bioreactor was configured to operate in both the anaerobic and aerobic modes. The treatment process was designed to have the first two cells (Cells 1 and 2) function under anaerobic conditions and the last two cells (Cells 3 and 4) operate under aerobic conditions. The Bioreactor is designed to operate at ambient temperatures.

Anaerobic Cells

To promote a reducing environment in Cells 1 and 2, a readily degradable source of carbon (high-fructose corn syrup) was added to Cell 1 using the timer-controlled peristaltic pump described above. The intense biological activity resulting from the readily degradable carbon source, coupled with the lack of introduced oxygen in Cells 1 and 2, was anticipated to produce a highly reducing environment. The anaerobic condition was evaluated by measuring the ORP in Cell 1, and by qualitatively assessing the presence of the products of anaerobic microbial activity: methane and hydrogen sulfide gas. Cell 2 received the effluent from Cell 1 and also was expected to maintain an anaerobic condition through the exclusion of oxygen.

The anaerobic conditions in Cells 1 and 2 were established to create a highly reducing environment, which should promote the removal of some forms of arsenic present in the ground water as metallic arsenic and arsenic sulfides. Some arsenic also may be removed from ground water in the anaerobic cells through its sorption by microbial biomass. The anaerobic cells in the Bioreactor also will promote the degradation of chlorinated organic chemicals (Levine•Fricke 1990). Although the ground water at the Site was not observed to contain chlorinated organic chemicals to any significant degree, limited pockets of chlorinated VOCs and SVOCs were found (1,2-DCE in two B-zone wells and traces of chlorobenzene and chloroethane in one A-zone well; see Section 1.2 of the main text). Additionally, the biodegradation of some nonchlorinated compounds in the ground water, such as methyl ethyl ketone (MEK) and acetone, also would be anticipated to occur under the anaerobic conditions of Cells 1 and 2.

Aerobic Cells

The last two cells of the Bioreactor, Cells 3 and 4, were maintained in an aerobic condition (dissolved oxygen > 2 mg/L) to catalyze the biodegradation of hydrocarbons flowing from the anaerobic cells. A previous treatment study, using the same Levine•Fricke Bioreactor configuration as described above, demonstrated the complete removal (i.e., below laboratory detection limits) of hydrocarbons from ground water (Levine•Fricke 1990).

Cells 3 and 4 were sustained in an aerobic condition through the introduction of air into each cell using an air pump. As described previously, the mixer mounted on top of each cell provided thorough mixing and transfer of oxygen into the liquid contents of Cells 3 and 4. The aerobic conditions of Cells 3 and 4 were monitored daily by measuring the dissolved oxygen with a YSI dissolved oxygen meter.

Additional removal of arsenic from the ground water was not anticipated in the aerobic cells at the standard operating conditions of the Bioreactor. Therefore, ferric chloride was added to Cell 3 to provide ferric hydroxide surfaces for arsenic adsorption/precipitation reactions to occur. The pH in Cell 4 was adjusted from pH 8 to 6.5 to promote the adsorption of the most oxidized form of arsenic, arsenate, to hydroxide and sludge surfaces present in the cell.

Nutrients and Supplemental Carbon Sources

Nutrients and supplemental carbon sources (specialty solution) were pumped as liquids into Cell 1 through Tygon tubing connected to timer-controlled peristaltic pumps. The nutrient solution was prepared by dissolving concentrated phosphoric acid and ammonium hydroxide into tap water at concentrations previously determined in the Levine•Fricke laboratory to be optimum levels for microbial growth in the Bioreactor. Nutrients were added in amounts so that ammonia-nitrogen (N) and ortho-phosphate (P) concentrations were maintained between 2 to 10 mg/L in the bioreactor effluent.

Spike Solution

During certain periods of the treatability study, the influent ground water was spiked with a variety of VOCs to compensate for the loss of VOCs during collection, shipment, and storage of the ground water. The loss of VOCs from ground water were anticipated and were caused by a variety of processes, including volatilization into the headspace of the drums, naturally occurring microbial degradation in the collected samples, and sorption to the interior surfaces of the sample storage drum.

The spike solution was created by dissolving selected VOCs into an acetone/demineralized water solution, which was added directly to the ground-water storage drum. The VOCs in the spike solution were acetone, methyl ethyl ketone (MEK), toluene, xylenes, and 2-hexanone. In addition, naphthalene was added to the spike solution.

The spike solution was formulated and added to the ground water to represent the relative amounts and concentrations of known organic compounds in the ground water, based on ground-water monitoring data.

pH Control

Control of the Bioreactor pH was especially critical during the operation of the anaerobic Cells where the production of organic acids must be buffered to near neutral conditions for optimum methanogenesis. The pH was controlled to between 6.8 and 7.4 in Cell 1 using a pH controller connected to a pH/automatic temperature compensating combination probe that controlled the pumping of 0.2 mol L^{-1} HCl or NaOH through Tygon tubing, as required. There was no pH control in Cells 2 and 3. The pH in Cell 4 was lowered to pH 6.5 (in a manner similar to Cell 1) during the arsenic removal study in which Cells 1 and 2, functioning as anaerobic cells, were included in the Bioreactor configuration. During the strictly aerobic process (i.e., when Cells 1 an 2 were removed from the Bioreactor configuration), the pH of Cell 4 was not controlled.

Hydraulic Retention Time

The hydraulic retention time (HRT) in the Bioreactor ranged from 24 to 46 hours in the combined anaerobic/aerobic configuration. After removing the anaerobic cells from the Bioreactor configuration, the HRT was controlled to range from 8 to 36 hours.

Bioreactor Monitoring

Samples from the Bioreactor were collected from Cells 1, 2, 3, and 4 by opening a sample tap located at the bottom of each cell. The influent ground water was sampled before the addition of nutrients, feed, and spike solutions. The effluent was collected from the liquid that discharged from Cell 4, before entering the clarifier. The pH of each cell was measured immediately following sample collection. For nutrient and chemical oxygen demand (COD) analyses, the solutions were filtered through Whatman #2 general purpose filter paper. The filtrate was then analyzed for COD using a Hach COD kit. A subsample was analyzed for N using a Chemetrics colorimetric assay kit (Model Number K-1510) and for P with a Chemetrics colorimetric assay kit (Model Number K-8510D).

Other parameters that were monitored in specific cells included ORP in Cell 1, dissolved oxygen (DO) in Cells 3 and 4, and total hydraulic flow from the Cell 4 effluent point (pre-clarifier). The ORP was measured in Cell 1 using a probe that was inserted through the top of Cell 1 via a rubber stopper and that was connected to a panel-mounted ORP monitor. Dissolved oxygen was measured in the Cell 3 and Cell 4 liquid using a YSI Dissolved Oxygen Meter and Probe. The hydraulic flow was determined by diverting the effluent flow from the clarifier and measuring the volume collected during a measured period of time.

The concentration of organic compounds in the Bioreactor system was evaluated by a State-certified laboratory that used EPA Method 8240 and EPA Method 8270 procedures for determining VOCs and SVOCs, respectively.

It should be noted that influent samples were diluted by about 30 percent with nutrient, feed, and spike solutions before entering the Bioreactor. Because the reactor cells in the bioreactor were mixed rapidly, the samples that were collected from each Cell sample tap represented the contents of the entire reactor cell.

C4.0 RESULTS AND DISCUSSION

C4.1 Anaerobic/Aerobic Configuration

Bioreactor Monitoring

The ORP, pH, COD, P, N, and DO measured in the Bioreactor cells during the course of the study are presented in Table C1. The results can be summarized as follows:

ORP: The ORP of Cell 1 was observed to be in the range of -0.20 V to -0.47 V, with an average of -0.42 V. This redox condition is highly reducing and is in the redox stability range where arsenic can be transformed to its elemental form and precipitated as sulfides of arsenic.

pH: The pH of the Bioreactor cells ranged from 6.8 to 8.2. The pH of Cell 1 was controlled to a pH between 6.8 to 7.4 to optimize the activity of anaerobic bacteria. The pH of anaerobic Cells 1 and 2 averaged 7.0 and 7.1, respectively, which was significantly lower than the pH of aerobic Cells 3 and 4, which had an average pH of 7.9. For a period of about three weeks, the pH in Cell 4 was lowered from 7.9 to 6.4 to promote the adsorption of arsenic or oxyanions (e.g., arsenate) by iron hydroxides.

COD: The COD of the Bioreactor cells decreased significantly as the ground water passed from Cell 1 to Cell 4, indicating the removal of organic compounds. The COD in Cell 1 ranged from 190 to 500 mg/L (mean = 289 mg/L), while the COD in the effluent ranged from 30 to 460 (mean = 78 mg/L). The largest decreases in COD occurred in the aerobic cells where average COD levels declined by approximately 50 percent in each cell.

P&N: The concentrations of P in the Bioreactor were generally not observed to decrease significantly from Cell 1 to Cell 4, while N concentrations decreased from approximately 10 mg/L in Cell 1 to less than 2.5 mg/L in Cell 4. The decline in N concentrations are the consequence of microbial activity and growth in the Bioreactor. The apparent stable concentration of P throughout the Bioreactor suggests that a steady state was established, whereby excess P was not a limiting factor.

DO: The DO concentrations in Cells 3 and 4 averaged 4.2 and 3.4 mg/L, respectively, indicating adequate concentrations of dissolved oxygen for aerobic microbial activity.

Arsenic Removal

The concentrations of arsenic in the bioreactor are presented in Table C3 and illustrated in Figure C2. The influent concentrations of arsenic, after adjusting for dilution from the added feed solutions, ranged from 18 to 42 mg/L, while the effluent levels of arsenic ranged from 2 to 25 mg/L. Most of the arsenic removal, except during the time subsequent to $FeCl_3$ addition to Cell 3, was observed to occur in Cell 1. Arsenic removal in the anaerobic cells most likely was due to a variety of factors, including precipitation with sulfides, sorption by microbial biomass, and reduction to elemental arsenic. The average decrease in arsenic, before the addition of $FeCl_3$ on October 24, was 43 percent. Within the week after the addition of $FeCl_3$, the arsenic removal was observed to increased to almost 90 percent as the effluent arsenic concentrations declined to about 2 mg/L. The pH of Cell 4 was subsequently reduced to 6.4 to stimulate increased arsenic adsorption by iron hydroxides, which were forming in Cell 4. However, breakthrough of about 20 mg/L of arsenic was observed in the effluent shortly thereafter. Consequently, the arsenic study was terminated and the Bioreactor was converted to a strictly aerobic configuration to down-size the reactor volume and to focus on organics removal only.

VOC and SVOC Removal

The concentrations of target VOCs and SVOCs in the Bioreactor are presented in Tables C4 and C5, respectively. The total concentrations of all EPA Method 8240 and Method 8270 organic compounds in the influent and effluent are displayed in Figure C3, while total priority pollutant organics in the effluent are shown in Figure C4 on an expanded scale. Organic compounds in the ground water that were not identifiable by accepted EPA procedures are quantified by commercial laboratories as "semiquantified" results, which are often called TICs (tentatively identified compounds). Because of the lack of laboratory standards for TICs, their quantitation can be wrong by several orders of magnitude. Consequently, TICs are not regulated by the agencies and thus have not been included in the total organic concentrations illustrated in Figures C2 and C3.

The results show the Bioreactor in the anaerobic/aerobic configuration has the capability of removing VOCs and SVOCs to below detectable levels for all EPA Method 8040 and Method 8270 compounds. After an initial "start-up" and acclimation time of about three weeks, the Bioreactor produced the most consistently nondetectable concentrations of organics in the effluent when the HRT was around 30 hours. When the Bioreactor HRT was decreased to 24 hours, detectable concentrations of 2-hexanone, acetone, and MEK appeared in the effluent. However, this breakthrough of organics may have been a result of the concomitant manipulations of Cell 4 pH (lowered to affect arsenic adsorption), which began about one week before the detection of organics in the effluent. With additional time for acclimatization to the new pH in Cell 4, the Bioreactor would be expected to produce lower effluent concentrations of these compounds. However, this portion of the study was halted to evaluate the treatment of ground water by only the aerobic portion of the Bioreactor (Cells 3 and 4).

C4.2 Aerobic Configuration

Bioreactor Monitoring

The pH, COD, P, N, and DO measured in the aerobic Bioreactor cells (Cells 3 and 4) during the course of the study are presented in Table 2. The results can be summarized as follows:

pH: The pH of the Bioreactor Cells ranged from 6.4 to 8.3. After acidification of Cell 4 was terminated (December 10, 1990), the pH of Cell 4 averaged 8.0, which was significantly higher than the pH of Cell 3 (mean pH = 7.3).

COD: The COD in the Bioreactor Cells decreased significantly as the ground water passed from Cell 3 to Cell 4. Early in the transition from the anaerobic/aerobic mode to the strictly aerobic configuration, high concentrations of COD were observed in the effluent (over 400 mg/L). Once the HRTs were increased, the system stabilized and produced CODs in the range of 50 to 200 mg/L (mean = 121 mg/L).

P&N: The concentrations of P and N in the Bioreactor generally were not observed to decrease significantly from Cell 3 to Cell 4, suggesting a substantial amount of nutrient recycling within the microbial biomass.

DO: The DO concentrations in Cells 3 and 4 averaged 5.5 and 6.1 mg/l, respectively, indicating adequate concentrations of dissolved oxygen for aerobic microbial activity. Additional air was pumped into Cell 4 to assure maximum oxidation conditions during this stage of the study.

Arsenic Removal

The concentrations of arsenic in the effluent, as displayed in Table C3 and Figure C2, approached 40 mg/L. These results confirmed our suspicion that arsenic removal in the strictly aerobic configuration would be minimal. Addition of $FeCl_3$ to the Bioreactor cells may increase arsenic removal, but this was not evaluated.

VOC and SVOC Removal

The concentrations of target VOCs and SVOCs in the aerobically configured Bioreactor are presented in Tables C4 and C5, respectively. The anaerobic cells (Cell 1 and 2) were removed from the Bioreactor configuration on November 16. The total concentrations of priority pollutant organics in the influent and effluent are displayed in Figure C3, while total priority pollutant organics in the effluent are shown in Figure C4 on an expanded scale.

The results show that the Bioreactor in the strictly aerobic configuration was able to remove VOCs and SVOCs to below detectable levels for all priority pollutants. No acclimation time for this phase of the study was anticipated because the same aerobic cells (Cell 3 and 4) were used. Initially, however, there was some breakthrough of organic compounds, such as 2-hexanone, acetone, MEK, and xylenes. In addition to the possible upset of the system by the removal of the anaerobic cells from the Bioreactor, the reduction of the HRT to 8 hours may have provoked the organic breakthrough. Therefore, the HRT was increased to 36 hours to ensure more complete oxidation of organic compounds. This alternative produced effluent with nondetectable concentrations of VOCs and SVOCs, and also decreased the COD from about 400 mg/L to less than 100 mg/L. The HRT was decreased during the next three weeks to 16 hours. During this time, no detectable concentrations of EPA Method 8240 or 8270 compounds were observed in the effluent.

C5.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the preliminary toxicity study revealed that arsenic in the ground water did not inhibit biological activity. This indicated biological treatment of the ground water would be possible without pretreatment to remove arsenic.

The pilot-scale biotreatability study showed that VOCs and SVOCs in site ground water were effectively degraded to below laboratory detection limits. The biotreatment process demonstrated effectiveness in both a combined anaerobic/aerobic configuration and in a strictly aerobic configuration. Therefore, biotreatment demonstrated efficacy for removing VOCs and SVOc from ground water without pretreatment for arsenic.

Arsenic concentrations were reduced during treatment of the ground water in the Bioreactor. Arsenic removal efficiencies, however, were much greater in the anaerobic/aerobic operating mode than in the aerobic mode alone. With additional testing, the treatment process could possibly be further optimized to provide additional arsenic removal. (Recent advances in the Levine•Fricke laboratory have produced biotreatment effluent concentrations of arsenic below 0.2 mg/L.) The amount of arsenic reduction achieved during this laboratory study is not presently adequate to meet anticipated effluent discharge requirements.

The Bioreactor system demonstrated good stability in terms of withstanding changes in COD and arsenic concentrations of the influent. The biotreatment process also produced very low amounts of sludge during the treatment study.

The optimum process configuration for a biological submerged, fixed-film reactor to remove organic compounds only (no arsenic removal) would be an aerobic, two-stage reactor design. The first stage would reduce the primary COD loading from the staring concentrations of 600 to 800 mg/L COD to 200 to 300 mg/L, while the second stage should provide additional treatment to 50 to 100 mg/L COD. The hydraulic residence time of an aerobic reactor for this ground water is estimated to be 12 to 16 hours. Additional operating conditions for optimum biological activity include dissolved oxygen > 2.0 mg/L, N and P = 2 to 5 mg/L, and pH = 6.8 to 8.3.

The full-scale biological treatment system also should be designed to incorporate clarification for suspended solids removal, sludge thickening and handling equipment, and cartridge filters and carbon adsorption vessels for final polishing as necessary.

REFERENCES

Levine•Fricke, Inc. 1991. Application for filing a report of waste discharge, Katzenbach and Warren, c/o Wickes Companies Inc., Albert Van Luit Site, Los Angeles, California. File Number 88-16. February 25.

TABLE C1

Bioreactor Conditions When the System Was Configured in the Anaerobic (Cells 1 and 2)/Aerobic (Cells 3 and 4) Mode

Date	CELL 1					CELL 2				CELL 3					CELL 4				
	pH	ORP	COD	P	N	pH	COD	P	N	pH	DO	COD	P	N	pH	DO	COD	P	N
		--V--	mg/L				mg/L				mg/L					mg/L			
04-Sep	7.4	-.33	160	15-20	25	6.9	80	15-20	25	7.6	1.5	0	15-20	25	6.8	2.4	0	25	20
05-Sep	7.0	-.49	410	25-50	25	6.9	290	20-25	25	7.8	1.0	40	20-25	25	7.1	2.8	10	20	25
06-Sep	7.3	-.50	230	25	50	7.1	270	25	75-100	8.0	5.1	80	25	25	7.5	1.9	50	25	15-20
07-Sep	7.4	-.34	190	25	25	7.2	190	25	50-75	8.0	4.5	60	25	50	7.4	1.2	40	25-25	7.5
10-Sep *	7.1	-.35	199	7.5	10	7.1	170	6	10	7.6	5.9	10	7.5-10	10	8.1	4.6	40	10	10
11-Sep *	7.4	-.45	200	10-15	25	7.1	199	15	25	8.0	5.5	60	15-20	15-20	7.8	3.9	40	10	2.5-5
12-Sep	7.0	-.45	220	5-7.5	2.5-5	6.8	210	15	5-7.5	7.8	5.3	80	7.5-10	<2.5	8.1	5.7	40	5-7.5	<2.5
13-Sep	7.2	-.45	320	10	2.5	6.8	350	7.5	2.5	7.7	6.5	150	5	2.5	8.1	4.8	40	5-7.5	2.5
14-Sep	7.4	-.45	300	2.5	5	7.1	299	7.5	5	7.9	3.9	130	5	2.5	8.2	5.0	70	15	<2.5
17-Sep	7.4	-.37	310	25	2.5	7.1	290	7.5	2.5	8.1	5.4	170	5	2.5	8.1	3.0	90	5	2.5
18-Sep	7.0	-.17	305	15	2.5	7.0	300	10	2.5	8.0	3.9	200	5	2.5	7.9	7.0	205	10-15	2.5
19-Sep	7.0	-.44	340	5-7.5	2.5	7.2	330	5-7.5	5-7.5	8.2	7.0	210	<2.5	2.5-5	8.1	2.5	105	20-25	<2.5
20-Sep	7.0	-.44	305	5	2.5	7.1	300	5	5	8.0	5.1	110	2.5-5	2.5	8.1	2.1	100	10	<2.5
21-Sep	7.0	-.44	340	10-12.5	2.5-5	7.1	320	2.5	2.5	8.1	6.0	200	7.5-10	2.5	8.1	1.5	105	5	<2.5
24-Sep *	7.0	-.29	305	7.5	2.5	7.0	305	7.5	2.5	8.1	6.5	190	5	2.5	8.0	0.7	105	10-15	<2.5
26-Sep	7.0	-.45	300	15	2.5-5	7.1	299	15-20	2.5-5	7.5	2.5	150	5	2.5-5	8.2	6.0	105	15	2.5-5
27-Sep	7.0	-.43	240	10-15	2.5	7.2	220	15-20	<2.5	7.4	0.2	199	7.5-10	<2.5	7.6	1.2	270	7.5	2.5
28-Sep	7.1	-.45	299	10-15	25	7.2	299	15	25	7.8	NA	160	7.5-10	25	7.8	0.1	80	25	2.5-5
01-Oct	7.0	-.44	410	10	7.5	7.1	280	10-15	5	8.1	5.7	110	10	<2.5	7.8	1.5	80	25	2.5-5
02-Oct *	7.0	-.45	320	15-20	10	7.2	320	20	7.5-10	8.0	5.5	120	20	2.5-5	8.2	2.1	60	20	<2.5
03-Oct	7.0	-.45	320	10-15	15-20	7.2	320	15-20	15-20	7.9	4.5	120	15-20	10-15	8.1	4.0	80	20	7.5
04-Oct	7.0	-.44	299	15-20	15	7.2	310	10-15	10-15	8.0	1.8	150	10-15	10	8.1	4.0	100	25	2.5
05-Oct	7.0	-.45	300	20	25	7.3	290	20	20	8.1	4.5	110	15-20	7.5-10	8.2	2.5	50	15	5
08-Oct	7.1	NA	340	20	25	7.1	310	20	20	7.6	6.3	120	10	15	7.7	4.3	50	10	10
09-Oct	7.0	-.43	220	20	25	7.0	190	20	20	7.6	4.3	80	10-15	10-15	7.6	5.8	30	10	10
10-Oct	7.0	-.42	500	25	15	7.3	430	20-25	15	7.9	7.5	260	10-15	7.5	7.9	2.5	50	25	2.5
11-Oct	7.0	-.45	290	20-25	25	7.5	220	15-20	25	7.9	2.5	170	10	25	7.9	2.5	60	20-25	10-15
12-Oct	7.0	-.46	290	20	5	7.4	250	15-20	5	7.8	1.8	110	20	2.5-5	7.9	4.0	80	25	2.5
15-Oct	7.0	-.46	290	10	5	7.2	280	15	5	8.0	3.7	140	20	2.5-5	8.2	3.7	70	20-25	2.5
16-Oct	7.0	-.46	300	20-25	2.5-5	7.4	270	15	5	8.1	6.2	50	15	2.5	7.9	4.1	60	25	2.5
17-Oct	6.9	-.45	290	20	2.5-5	6.9	280	20	2.5-5	8.0	6.3	120	25	2.5	8.1	3.6	80	25	<2.5
18-Oct	6.8	-.28	190	20	<2.5	7.1	190	20	<2.5	7.8	4.1	130	25	<2.5	7.9	4.2	70	20	<2.5
19-Oct	6.8	-.39	200	7.5	<2.5	7.3	199	7.5	<2.5	7.9	4.3	120	20	<2.5	7.9	2.2	100	20-25	<2.5
22-Oct	6.8	-.43	399	10-15	2.5-5	6.9	270	7.5-10	5	7.8	1.9	130	10	5	7.9	2.1	120	25	2.5-5
23-Oct	6.8	-.43	280	15-20	2.5-5	7.1	220	10-15	2.5-5	7.8	1.9	120	25	2.5	7.9	2.4	120	25	2.5
24-Oct %	6.8	-.44	280	2.5-5	2.5-5	7.1	240	5	2.5-5	7.9	4.0	120	7.5-10	<2.5	7.9	6.4	90	7.5-10	<2.5
25-Oct *%	6.8	-.42	299	10	2.5-5	7.1	250	5-10	2.5-5	7.6	4.3	110	<2.5	1-2	7.8	5.2	80	10-15	<2.5
26-Oct %	6.8	-.45	299	10	2.5-5	7.1	250	5	2.5-5	7.4	5.0	130	2.5	1-2	7.6	4.7	80	5	<2.5
29-Oct %	6.9	-.33	290	15	2.5-5	6.9	250	10	2.5-5	7.2	5.8	130	2.5-5	<2.5	7.0	6.1	110	2.5	<2.5
30-Oct %	6.8	-.45	300	10	2.5-5	6.9	280	10	2.5-5	7.4	4.7	130	2.5	<2.5	7.8	5.7	130	2.5	<2.5
31-Oct	6.8	-.45	305	7.5-10	7.5-10	7.1	290	10-15	5-7.5	7.8	4.2	170	2.5-5	2.5-5	7.8	4.1	80	2.5-5	<2.5

**** Continued on following page ****

TABLE C1

Bioreactor Conditions When the System Was Configured in the Anaerobic (Cells 1 and 2)/Aerobic (Cells 3 and 4) Mode

Date	CELL 1					CELL 2				CELL 3					CELL 4				
	pH	ORP	COD	P	N	pH	COD	P	N	pH		COD	P	N	pH	DO	COD	P	N
		--V--	--------mg/L		---------		--------mg/L		---------		------------mg/L			------------		------------mg/L			------------
01-Nov	6.8	-.45	240	10-15	2.5	7.0	220	7.5	2.5	7.8	0.2	130	2.5	2.5	7.8	5.0	30	5	<2.5
02-Nov	6.8	-.45	300	10-15	5	7.1	290	10-15	5	7.9	4.5	110	7.5-10	2.5-5	7.8	6.1	80	7.5-10	<2.5
05-Nov	6.8	-.45	300	7.5-10	5	6.9	270	10-15	7.5	7.8	4.5	200	5-7.5	7.5-10	7.8	6.4	60	7.5-10	<2.5
06-Nov	6.8	-.20	200	7.5	7.5	6.8	200	7.5	7.5	7.2	5.6	170	5	2.5	7.4	6.7	40	2.5	<2.5
07-Nov	6.8	-.45	250	7.5	7.5	6.9	225	7.5	5	7.6	5.9	100	5	2.5	7.4	6.7	50	2.5	<2.5
08-Nov %	6.8	-.45	200	10	7.5	6.9	200	7.5	5	7.1	5.0	75	5	2.5	7.2	5.5	50	5	<2.5
09-Nov %	6.8	-.44	250	10	10	6.9	250	5	10	7.1	5.8	60	5	5	7.0	6.2	70	2.5-5	2-5
12-Nov *%	7.1	.-47	340	5	10	7.5	310	2.5	20	8.1	4.0	210	5	10-15	7.3	5.3	80	15	2.5-5
13-Nov %	7.1	-.45	305	5	10	7.2	305	5	15	7.6	5.6	200	5	10	6.7	6.0	100	2.5	2.5
14-Nov %	7.0	.-47	305	10-15	2.5-5	7.2	300	7.5-10	2.5	7.7	5.5	220	5	5	7.0	5.6	90	10-15	2.5-5
15-Nov %	7.0	.-47	330	20	15	7.4	310	15	10	8.1	4.1	250	5	5-7.5	7.1	5.4	105	15	2.5
16-Nov *	7.2	.-47	305	7.5	2.5-5	7.3	310	5	15	7.7	6.5	300	2.5-5	7.5	6.5	6.4	90	2.5	5

* HRT Changed
# Spike added
% Ferric chloride added

TABLE C2

Bioreactor Conditions When the System Was Configured in Only the Aerobic Mode (Cells 3 and 4)

	CELL 1					CELL 2				CELL 3					CELL 4				
Date	pH	ORP	COD	P	N	pH	COD	P	N	pH	DO	COD	P	N	pH	DO	COD	P	N
											mg/L					mg/L			
19-Nov *										7.7	1.0	140	15	15	6.4	4.1	30	15-20	7.5
21-Nov										7.4	2.4	105	25-50	25	6.4	2.4	105	25	20
26-Nov	Cells #1 and #2 Removed from Bioreactor System									7.3	2.3	110	25-50	15-20	6.9	2.9	105	25	20
28-Nov										7.5	6.3	110	20	15-20	6.9	6.1	110	20	15
03-Dec										6.7	6.1	60	10-15	2.5-5	6.5	4.1	450	15	2.5-5
04-Dec *										7.1	4.9	580	25	2.5-5	6.5	0.2	460	25	2.5-5
05-Dec										7.1	5.1	510	10-15	2.5-5	6.4	1.3	410	25-50	2.5
06-Dec										7.3	7.1	300	25-50	7.5	6.4	7.1	350	15-20	<2.5
07-Dec										7.1	6.1	140	25-50	15	6.4	7.1	70	10-15	2.5
10-Dec *										7.5	7.1	140	25	15-20	6.7	7.5	80	15-20	2.5-5
11-Dec										7.7	7.2	90	25-50	7.5-10	7.5	5.0	60	15	<2.5
12-Dec										7.2	6.5	100	20	2.5	7.6	7.5	60	15-20	<2.5
13-Dec										7.2	6.5	NA	15-20	2.5	8.1	7.8	NA	15	2.5
14-Dec *										7.2	6.5	300	20	2.5-5	8.2	7.9	150	20-25	2.5-5
17-Dec										7.3	6.5	380	20	2.5-5	8.1	7.8	180	15-20	2.5-5
18-Dec										7.4	6.4	530	15-20	5	8.2	7.9	140	20	2.5-5
19-Dec										7.1	6.6	370	10-15	2.5-5	8.1	8.0	200	7.5-10	2.5-5
20-Dec										7.4	7.0	305	25	2.5	8.3	8.3	180	25	<2.5
21-Dec #										7.3	7.1	350	20	2.5-5	8.1	8.2	140	25	<2.5
24-Dec *										7.2	7.2	300	15-20	2.5-5	8.0	8.1	140	20	2.5
27-Dec *										7.1	2.3	299	20	5	8.0	8.2	130	20	5
28-Dec										7.2	2.0	299	15	5	8.0	7.2	120	20	5
02-Jan #										7.3	6.7	80	15-20	2.5	7.9	5.6	50	25	2.5-5

* HRT Changed
# Spike added
NA = not analyzed

TABLE C3

Concentrations of Total Arsenic in the Bioreactor Aqueous Phase During Laboratory Biotreatment of Ground Water

DATE		HRT	Influent	Adjusted* Influent	Cell 1	Cell 2	Cell 3	Effluent
		--h--	mg/L					
18-Sep		29	47	33	19	17	26	25
24-Sep		24	42	29	24	23	25	23
03-Oct		46	44	31	12	12	14	10
11-Oct		"	60	42	NA	NA	NA	15
19-Oct		46	41	29	NA	NA	NA	21
26-Oct	#	38	31	22	21	18	2	4
29-Oct		"	25	18	NA	NA	NA	2
07-Nov		"	NA	NA	NA	NA	NA	18
09-Nov		"	61	43	32	34	26	21
12-Nov		24	58	41	28	22	22	20
13-Nov		"	39	27	15	24	51	19
16-Nov		"	60	42	27	22	18	14
24-Dec	**	"	62	43	--	--	NA	30
27-Dec		16	57	40	--	--	NA	38

* Adjusted influent concentration based on dilution by added solutions.
Influent adjustment = 0.7.

** Aerobic configuration only.

After FeCl3 added on October 24, 1990.

TABLE C4

Concentrations of VOCs in the Influent Ground Water and in the Effluent from the Bioreactor

Sample	Date	HRT	2-Hexanone	Acetone	Ethyl Benzene	MEK	Toluene	Total Xylenes	Total* VOCs	Total* VOCs	Adjusted VOCs **
		--h--	ug/L							mg/L	
Influent:											
918I	13-Sep	27	3,200	7,200	<100	1,300	4,000	370	16,070	16.07	11.25
924I	24-Sep	24	3,600	5,700	75	8,700	4,200	420	22,695	22.70	15.89
103I	03-Oct	46	1,500	14,000	<50	35,000	2,500	290	53,290	53.29	37.30
1011I	11-Oct	"	4,000	3,700	70	6,800	4,000	410	18,980	18.98	13.29
1019I	19-Oct	"	1,700	<500	<50	2,800	880	61	5,441	5.44	3.81
1026I	26-Oct	38	2,200	2,500	<20	2,800	1,400	<20	8,900	8.90	6.23
119I	09-Nov	"	2,300	2,500	21	3,300	1,900	160	10,181	10.18	7.13
1112I	12-Nov	24	2,500	3,500	60	3,700	3,700	380	13,840	13.84	9.69
1116I	16-Nov	"	2,700	4,100	60	4,300	4,100	400	15,660	15.66	10.96
123I	03-Dec	8	250	1,300	<50	1,100	1,400	500	4,550	4.55	3.19
NA	07-Dec	12	NA	NA	NA	NA	NA	NA	NA	NA	NA
1217I	17-Dec	24	<1	<10	<1	<20	60	64	124	0.12	0.09
1227I	27-Dec	16	<1	8,000	<1	14,000	1,900	500	24,400	24.40	17.08
Effluent:											
918FE	13-Sep	27	1,200	13	1	3,300	38	9	4,561	4.56	
924FE	24-Sep	24	100	98	<1	30	3	1	232	0.23	
103FE	03-Oct	46	NA	NA	NA	NA	NA	NA	NA	NA	
1011FE	11-Oct	"	<1	<10	<1	<20	<1	<1	0	0.00	
1019FE	19-Oct	"	<1	<10	<1	<20	<1	<1	0	0.00	
1026FE	26-Oct	38	<1	<10	<1	<20	<1	<1	0	0.00	
119FE	09-Nov	"	160	210	<1	61	<1	<1	431	0.43	
1112FE	12-Nov	24	170	93	<1	<20	<1	<1	263	0.26	
1116FE	16-Nov	"	120	41	<1	<20	<1	<1	161	0.16	
123FE	03-Dec	8	64	280	<1	58	<1	51	453	0.45	
127FE	07-Dec	12	<1	<10	<1	<20	<1	<1	0	0.00	
1217FE	17-Dec	24	<1	<10	<1	<20	<1	<1	0	0.00	
1227FE	27-Dec	16	<1	<10	<1	<20	<1	<1	0	0.00	

* Includes all detected VOCs except TICs.

** Adjusted influent concentration based on dilution by added solutions. Influent adjustment = 0.7.

NA = not analyzed

TABLE C5

Concentrations of SVOCs in the Influent Ground Water and in the Effluent from the Bioreactor

Sample	Date	HRT	O-Cresol	Benzoate	Naphth.	Phenol	Total SVOCs *	Total SVOCs *	Adjusted SVOCs **
		--h--	ug/L					mg/L	
Influent:									
1112I	12-Nov	24	55	550	86	120	756	0.76	0.53
123I	03-Dec	8	NA	NA	NA	NA	NA	NA	NA
1224I	24-Dec	24	<5	<50	8	<10	8	0.01	0.01
1227I	27-Dec	16	<50	<500	22	<100	22	0.02	0.02
Effluent:									
1112FE	12-Nov	24	<5	<50	<2	<10	0	0.00	0.00
123FE	03-Dec	8	<5	<50	<2	<10	0	0.00	0.00
1217FE	17-Dec	24	<5	<50	<2	<10	0	0.00	0.00
1224FE	24-Dec	24	<5	<50	<2	<10	0	0.00	0.00
1227FE	27-Dec	16	<50	<500	<20	<100	0	0.00	0.00

TICs are tentatively identified compounds which are reported as "semi-quantified" results by certified. laboratories.

* Includes all detected SVOCs except TICs.

** Adjusted influent concentration based on dilution by added solutions.
Influent adjustment = 0.7.

ATTACHMENT TO APPENDIX C

TRI-BIO, INC.

BIOLOGICAL PROCESS DESIGN

BIOTOX TEST

for a

GROUNDWATER CONTAINING ARSENIC

A LABORATORY REPORT

to

LEVINE•FRICKE CONSULTING ENGINEERS
AND HYDROGEOLOGISTS

by

TRI-BIO, INC., ALLENTOWN, PA

TEST COMPLETED	AUGUST 12, 1990
REPORTED RESULTS	AUGUST 17, 1990
THIS REPORT	AUGUST 18, 1990

INTRODUCTION

Biological treatment of organic chemical laden waters is recognized by the majority of engineers as the most cost effective method for decontamination of industrial wastewaters prior to discharge to sewers, or to receiving streams under the NPDES program.

TRI-BIO, Inc. has developed test procedures which enable the engineer to determine the amenability of wastewaters to biological treatment. The procedures permit the engineer to establish the toxicity of the wastewater relative to other wastewaters and/or pure chemicals. These results permit the engineer to avoid application of expensive long term pilot tests under adversely toxic/inhibitory conditions and thus to minimize the costs for such tests. When toxic/inhibitory wastewaters are encountered, the engineer can use the results of these tests to develop biological treatment schemes and operating procedures which can reliably deal with these wastewater streams.

TRI-BIO test procedures are divided into two parts, both of which use the oxygen respiration processes (oxygen uptake) of bacteria.

Part I of the test procedure, the BIOTOX TEST, is used to track the short term "TOXICITY" response of large food-rich (preferred simple food stuffs) populations of bacteria when exposed to specific chemicals or wastewater samples. If the contaminants of the wastewater sample interfere with the normal oxygen respiration processes of bacteria in the process of consuming their preferred substrates, then the sample tested is deemed toxic or inhibitory.

Part II. the BIODEGRADATION TEST, when completed, determines the rate and extent to which bacteria populations will utilize the wastewater contaminants as a carbon (nutrient) source for growth and energy, thus removing the contaminants from the water. This longer term test is conducted in respirometers or continuous flow pilot plant biological reactors under carefully controlled conditions. Growth and substrate utilization are confirmed by monitoring oxygen uptake and completing tests for specific wastewater components.

The subject of this report, is a Part I, BIOTOXICTY test for the toxic/inhibitory properties of a groundwater sample known to contain a mixture of components which may be toxic/inhibitory to biological systems, including a substantial arsenic concentration (undefined chemical form and valence state).

The subject Arsenic contaminated groundwater (Arsenic GW), was supplied to TRI-BIO, Inc., from a project site by Levine•Fricke Consulting Engineers and Hydrogeologists of Emeryville, California.

THE BIOTOX METHOD

The BIOTOX test method [1] employs commercially available, dry-biological cultures which have been developed for use in domestic and industrial biological wastewater treatment systems. The dry cultures are used because they have reasonable consistency of oxygen respiration performance, they contain bacteria suitable for biological wastewater treatment and they have typical shelf-lives of greater than 12 months. The latter makes testing with dry cultures convenient and reasonably reproducible.

The BIOTOX test procedure involves exposure of a measured quantity of the dry cultures [2] directly to the contaminated water or a solution of the chemical(s) being tested, i.e., the "test sample". Exposure to the bacteria is made under controlled conditions of pH ($NaHCO_3$ is used as a buffer), temperature and concentration, in a standard BOD_5 test bottle. The rate at which the exposed bacteria culture respires (consumes dissolved oxygen) in the BOD bottle with the test sample is monitored after about 20-30 minutes of exposure using a dissolved oxygen probe.[3]

The rate of respiration of the bacteria when exposed to the test sample is compared with the rate of respiration of the same quantity of culture and buffer when they are rehydrated in clean chlorine free water. The clean water test is completed to provide the "baseline" respiration rate.

A lower rate of respiration of the rehydrating dry culture which is exposed to the test sample, as opposed to distilled or tap water, indicates the inhibitory or toxic/inhibitory nature of the test sample. By comparing the baseline rate with

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[1] The detailed BIOTOX TOXICITY TEST procedure is provided in Appendix A to this report.

[2] These cultures typically contain 2-5 billion active bacteria per dry weight gram when rehydrated with distilled or deionized water.

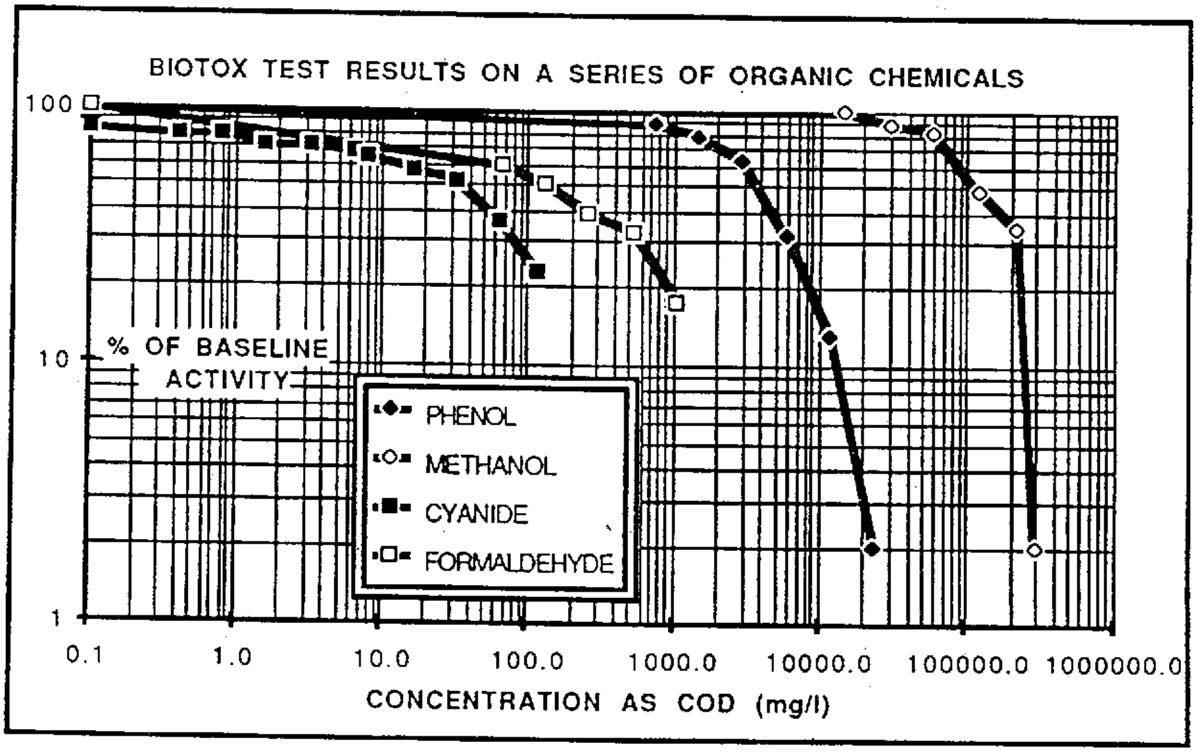
[3] The dissolved oxygen probe is preferably of the self stirring BOD type, as for example probes manufactured by Yellow Springs Instruments, Yellow Springs, Ohio.

the test sample rate, a percent recovery of respiration can be calculated and reported.

If the full strength test sample water is significantly toxic/inhibitory, a series of test sample runs at various dilutions of the wastewater or chemical solution concentration makes it possible to develop a curve of percent recovery of activity versus concentration as COD (mg/l), i.e., the test sample "activity/concentration (COD) profile".

Data of the type shown in figure 1 below has been developed for four different common chemicals so that the engineer can compare the activity/concentration (COD) profile of the test sample with common chemical activity/concentration (COD) profiles. The latter thus relates the toxicity of the test sample to the toxicity of chemicals commonly treated in biological wastewater treatment plants.

FIGURE 1 - THE ACTIVITY / CONCENTRATION (COD) PROFILES OF FOUR COMMON CHEMICALS AS DETERMINED USING BIOTOX



If each of the the BIOTOX tests, i.e., the baselines and different concentrations, is carried out at different temperatures the observed results of the baseline and test samples must be corrected for temperature before comparison. The rates are typically corrected to a temperature of 20°C using the appropriate equation given in Appendix A.

INTERPRETATION / BIODEGRADATION

If the percent recovery of respirometric activity in a test sample drops below 80-75% of the baseline respiration activity, the toxicity of the test sample is considered significant. Biological growth and degradation in batch testing is greatly retarded or stopped in tests wherein starting concentrations demonstrate lower than 80-75% recovery of respirometric activity in the BIOTOX test. The latter guideline was established by a series of batch biodegradation tests carried out on phenol solutions of increasing concentrations in electrolytic respirometers (batch tests).

Development of appropriate treatment strategies for wastewaters, leachates or contaminated groundwaters exhibiting BIOTOX test activity recoveries of less than 80% is important if biological processes are to be successful for more toxic/inhibitory wastewaters. However it is becoming quite routine to biologically treat these more toxic/inhibitory wastewaters. For example, even though cyanide is apparently toxic at concentrations of 1 to 4 mg/l according to figure 1, it is possible to biologically degrade a solution of 40 mg/l of cyanide if proper design and control of the biological treatment system are exercised.

TESTING OF ARSENIC CONTAMINATED GROUNDWATER

A representative sample of a highly contaminated ground water was received from Levine•Fricke, at TRI-BIO's laboratory in Allentown, PA., on August 10, 1990. The sample (stored in the refrigerator after receipt), was contained in four air-tight quart polyethylene bottles with a small amount of air space in the neck of the bottle. The sample was cool upon receipt; it was slightly cloudy, had a very slight yellow green color and each bottle contained a small quantity of flocculated sediment. The samples had a sour disagreeable odor and a pH of approximately 6.5. As the samples were warmed to room temperature, bubbles of gas were formed on the walls of the sample bottles.

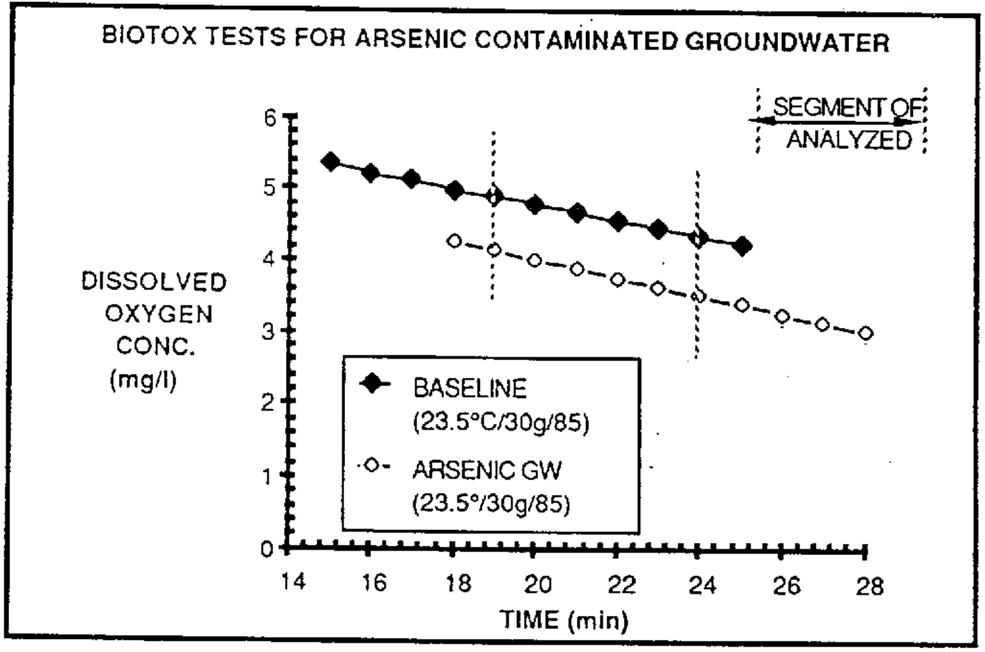
The groundwater sample was subjected to the BIOTOX toxicity test procedure described in APPENDIX A. with the following results:

STEP 1 - A baseline respiration curve was developed for BIOLYTE CX-85 dry culture for wastewater treatment, using tap water from the laboratory sink which was allowed to stand for 16 hours before use. The oxygen depletion curve is shown in figure 2 below.

STEP 2 - One of the samples of groundwater was shaken and a portion discarded so that the remainder of the sample could be aerated by shaking with air inside the bottle. This very turbid, tan/brown slurry was used for development of the second respiration curve shown in figure 2.

The temperatures recorded during the respective respiration curves are recorded in figure 2. The baseline curve and the test sample curves shown in figure 2 have very similar slopes. The initial conclusion must follow that the wastewater sample is not toxic.

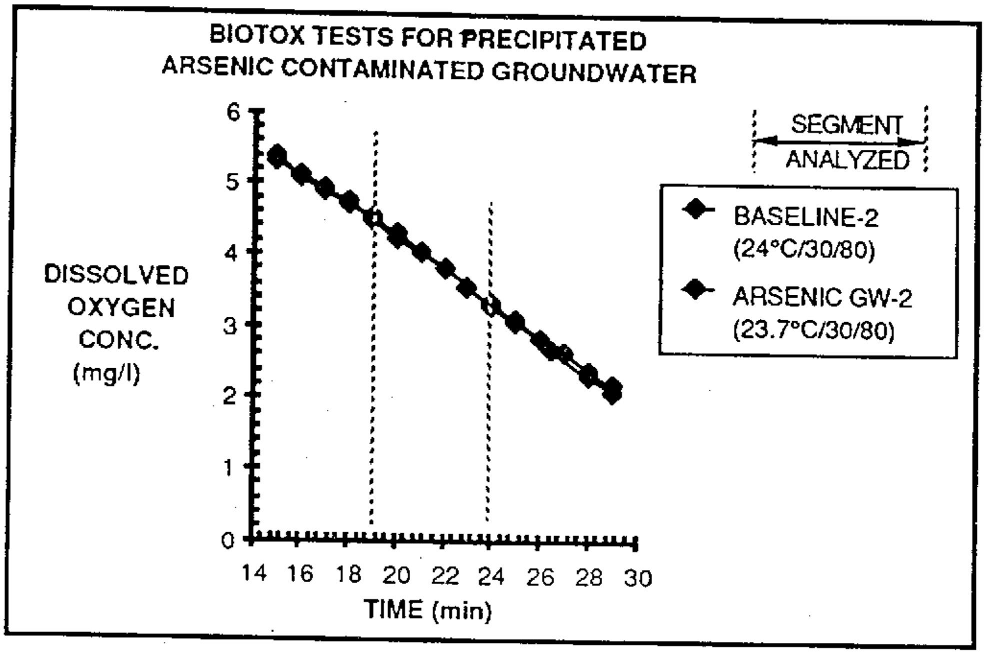
FIGURE 2 - GRAPHIC PRESENTATION OF RESULTS



Because the Arsenic contaminated groundwater sample contained significant quantity of iron (200+ mg/l) and because ferrous iron oxidation catalyzed by bacteria can give false oxygen uptake data (i.e. the water could be toxic but the oxidation of ferrous ions to ferric ions could appear to be biological oxygen uptake) the entire BIOTOX procedure was repeated on a neutralized sample of the Arsenic GW which was first precipitated at a pH of 10.3 with KOH pellets.

The iron flock was settled and removed, the sample neutralized and the following BIOTOX data obtained (see Figure 3).

FIGURE 3. - BIOTOX TEST FOR IRON PRECIPITATED ARSENIC GW



The data from figures 2 and 3 is formally interpreted in Table 1 below. The observed oxygen uptake rate for the baseline and test sample was calculated from computer fitted trend lines for the 19-24 minute test interval of the baseline and test curves, shown in figures 2 and 3. The calculated rates were then corrected for the effects of temperature and weight of dry culture used. The respiration rates of the baseline and test samples were then compared and final results reported as percent recovery of respiration activity (last column on right of TABLE#1).

CONCLUSIONS FROM BIOTOX TEST RESULTS

These results indicate that the wastewater contaminated with arsenic and other chemicals is not directly toxic/inhibitory to bacteria which are capable of industrial wastewater treatment. The full baseline respiration activity was recovered and exceeded. The 109% and 103% activity recoveries, for the untreated and pretreated groundwater may reflect ferrous ion oxidation and/or metal catalytic acceleration of biological respiratory processes.

TABLE 1 - BIOTOX TESTING DATA, INTERPRETATION

ARSENIC CONTAMINATED GROUNDWATER BIOTOX TEST DATA ANALYSIS

TEST SUBJECT	CX-85 USED (g)	START DO (mg/l)	FINAL DO (mg/l)	START TIME (min)	FINISH TIME (min)	TOTAL LAPSED TIME (min)	RATE (mg/ l-min)	TEMP (°C)	(mg/l-min) CORECTD RATE (mg/ l-min @ 20°C)	RECOVERY OF AVG RATE (%)
BASELINE-1	30.010	4.88	4.32	19	24	5	0.113	23.5	0.096	-
GROUNDWATER-1	30.005	4.12	3.50	19	24	5	0.124	23.5	0.105	109.84%
BASELINE-2	30.019	4.48	3.32	19	24	5	0.233	23.5	0.198	-
GROUNDWATER-2	30.008	4.51	3.31	19	24	5	0.242	23.5	0.206	103.93%

CONCLUSION: NO APPARENT TOXICITY, BUT RATES ARE SLIGHTLY HIGHER THAN BASELINE RATES POSSIBLY DUE TO FEROUS ION OXIDATION IN IRON RICH GW AND/OR ACCELERATED BIOLOGICAL ACTIVITY WITH THE MINERAL CONSTITUENTS OF THE WASTEWATER.

APPENDIX A

TEST PROCEDURES USED FOR BIOTOX TOXICITY TESTING

ITEMS OF EQUIPMENT REQUIRED

1. A Stopwatch (0 to 30 minute elapsed time)
2. STANDARD, 300 ml BOD_5 Bottles
3. A dissolved oxygen meter with self-stirring dissolved oxygen probe. Must be YSI model 5720A with a self-stirring BOD probe, or, a magnetic stirrer will be required to suspend BIOTOX bacteria. Temperature readout required as well.
4. A 1.5 liter jug (aeration jug) with a water tight screw top.

BIOTOX PREPARATORY PROCEDURES

Step

1. Calibrate the dissolved oxygen probe and meter.
2. Aerate 500 ml of deionized or distilled water in the aeration jug by shaking the jug vigorously for 2 minutes. Allow the jug to stand for 2-3 min to allow the air bubbles to escape.
3. Place 20.00 grams of BIOLYTE CX-80 culture[4] in a dry BOD bottle and add 0.8 grams of sodium bicarbonate to the bottle as well. It will be efficient to make up a series of "prepared BOD bottles" with these contents all at one time, but new distilled water baselines should be run each day if the prepared BOD bottles are held for use from day to day.

TEST PROCEDURE

To complete a "BASELINE" test, proceed as follows:

A. With stopwatch in hand, pour 50 ml of the aerated distilled or deionized water into the test BOD bottle prepared as above and immediately start the stop watch to follow elapsed time.

B. Pick up the BOD bottle and swirl it gently for 25 to 30 seconds to be sure the culture is thoroughly wetted

C. Hold the bottle at an angle of 45°, and flow additional aerated water down the side of the bottle in a manner to avoid entrainment of bubbles. Fill the bottle to a level halfway up the ground glass joint.

D. Place the self-stirring probe in the BOD bottle and stir the slurry until the end of the 5th minute of elapsed time

F. Stop the stirrer and remove the probe. Allow the BOD bottle to stand undisturbed for 5 minutes while air bubbles come to the surface.Refill the bottle to the top of the ground glass joint and

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[4] BIOLYTE CX-85 or CX-80 cultures are available from TRI-BIO, Inc., Allentown Pa. (215) 395-8309.

carefully insert the self-stirring dissolved oxygen probe into the joint excluding all bubbles. Tilt the bottle if necessary. Start the stirrer and allow the dissolved oxygen probe to come to equilibrium until the 15th minute of elapsed time.

G. Measure and record the temperature of the sample with the probe thermocouple.

H. Record the dissolved oxygen concentration as a function of time every minute for the next 10 minutes through the 26th minute or more of elapsed time and then terminate the test.Calculate the BASELINE respiration rate (DOUR) using the calculations below. Be sure to correct for temperature as this can be a significant factor in the rate of respiration.

PROCEDURE FOR TOXICITY TESTING

FIRST CROSS CHECK FOR IMMEDIATE CHEMICAL BASED OXYGEN DEMAND AS FOLLOWS

A. Adjust the pH of the raw sample or pretreated sample to pH 7.

B. Place 800 mls of the sample in the aeration jug and aerate by shaking for 2 minutes.

C. Check the dissolved oxygen (DO) concentration of the sample in the aeration jug. If the DO concentration is less than 6 mg/l, repeat the aeration process.

D. Pour 300 ml of the aerated/pH adjusted test sample into a BOD bottle and insert the dissolved oxygen probe carefully to avoid bubbles below the probe membrane.

E. Measure and record dissolved oxygen concentrations in the bottle over a five- to ten-minute period. Calculate the oxygen consumption rate (Immediate Oxygen Demand, IOD) using the equations below. The rate should be less than .02 mg/l•min without the BIOTOX bacteria present[5].

THEN COMPLETE BIOTOX PROCEDURE

To complete a BIOTOX test, proceed as follows:

A. With stopwatch in hand, pour 50 ml of the pH adjusted, aerated test sample water into a "prepared" BOD bottle and immediately start the stop watch to follow elapsed time.

B. Pick up the BOD bottle and swirl it gently for 25 to 30 seconds to be sure the culture is thoroughly wetted.

C. Hold the bottle at an angle of 45°, and flow additional pH adjusted aerated sample water, down the side of the bottle in a manner to avoid entrainment of bubbles. Fill the bottle to a level halfway up the ground glass joint.

D. Place the bottle on the magnetic stirrer and gently stir the slurry until the end of the 5th minute of elapsed time.

E. Stop and remove the self-stirring probe and allow to stand undisturbed for 5 minutes while all bubbles come to the surface.

F. Refill the bottle to the top of the ground glass joint and carefully insert the self-stirring dissolved oxygen probe into the joint excluding all bubbles. Tilt the bottle if necessary. Start the stirrer and allow the dissolved oxygen probe to come to equilibrium until the 15th minute of elapsed time.

G. Measure and record the temperature of the sample with the BOD probe thermocouple

H. Record the dissolved oxygen concentration as a function of time every minute for the next 10 minutes through the 26st minute or more of elapsed time and then terminate the test sample test.

I. Calculate the BASELINE respiration rate using the calculations below. Be sure and correct for temperature as this can be a significant factor in the rate of respiration

COMMENTS

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[5] If the rates are higher than 0.02 mg/l•min the BIOTOX test procedure will be erroneous. The immediate oxygen demand may be due the presence of biological populations, ferrous ion oxidation, sulfite oxidation, sulfide oxidation or some other chemical oxygen demand. Chemical pretreatment (acidify sample to 2 pH and stir for 1/2 hr then add caustic to a pH of 10 stir gently and then allow to settle for 30 minutes, decant clear supernate for testing and adjust pH to 7 with sulfuric acid) of the sample should be carried out to eliminate IOD.

Initial and final DO Concentrations - During the BIOTOX tests the dissolved oxygen should not fall below 2 mg/l at any time. The starting dissolved oxygen concentration should be at least 6 mg/l.
Excessive Respiration Rates - On occasion the immediate oxygen demand of a test sample will be higher than the rate of the "BASELINE" test. Methods of satisfying the sulfite immediate chemical oxygen demand must be devised if a successful BIOTOX test is to be conducted.

CALCULATIONS

OXYGEN DEMAND RATE CALCULATIONS

To determine the Dissolved Oxygen Uptake Rate **(DOUR)** for the "BASELINE", the BIOTOX test and/or the IMMEDIATE OXYGEN DEMAND at AMBIENT temperature, use the following equation:

$$\mathrm{DOUR}_{\text{Ambient temp.}} = \frac{\mathrm{DO}_{@\ t,\ \text{initial}}\ (\text{min}(\text{mg/l}) - \mathrm{DO}_{@\ t,\ \text{final}}\ (\text{min})(\text{mg/l})}{t_1 - t_2\ (\text{min})} = \text{mg/l}\cdot\text{min}$$

CORRECTION OF $\mathrm{DOUR}_{\text{obs}}$ TO 20°C PER TEMPERATURE EFFECTS

To convert the $\mathrm{DOUR}_{\text{Ambient temp.}}$ to DOUR at 20°C use the following equation:

$$\mathrm{DOUR}\ @20^\circ = \frac{\mathrm{DOUR}_{\text{Ambient temp.}}}{\text{Å}^X} = \text{mg/l}\cdot\text{min}$$

Where: X = Ambient temperature(°C) - 20°C
Å = 1.047

PERCENT INHIBITION OF "TEST SAMPLE" VERSUS "BASELINE"

To determine the percent inhibition of the test sample to the bacteria versus the BASELINE distilled water test use the following equation:

$$\%\ \text{Inhibition} = \left[\, 1 - \left\{ \frac{\mathrm{DOUR}_{20^\circ\text{ C, obs BIOTOX test}}}{\mathrm{DOUR}_{20^\circ\text{C, BASELINE test}}} \right\} \right] \text{X } 100$$

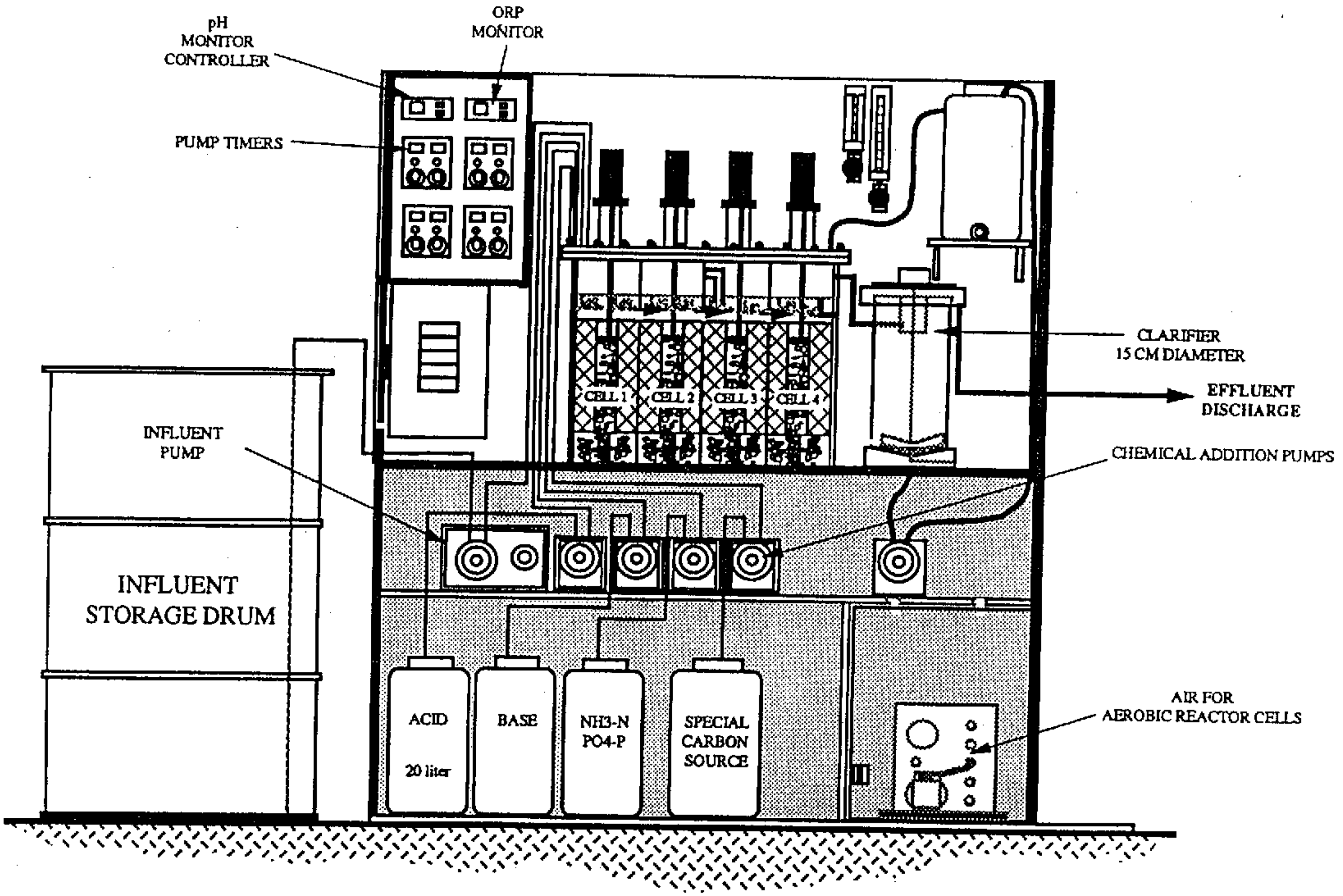

Figure C1 : ANAEROBIC/AEROBIC SUBMERGED FIXED-FILM BIOREACTOR PILOT PLANT

91N134SERIES 5"-4 SKID/29APR91MPO

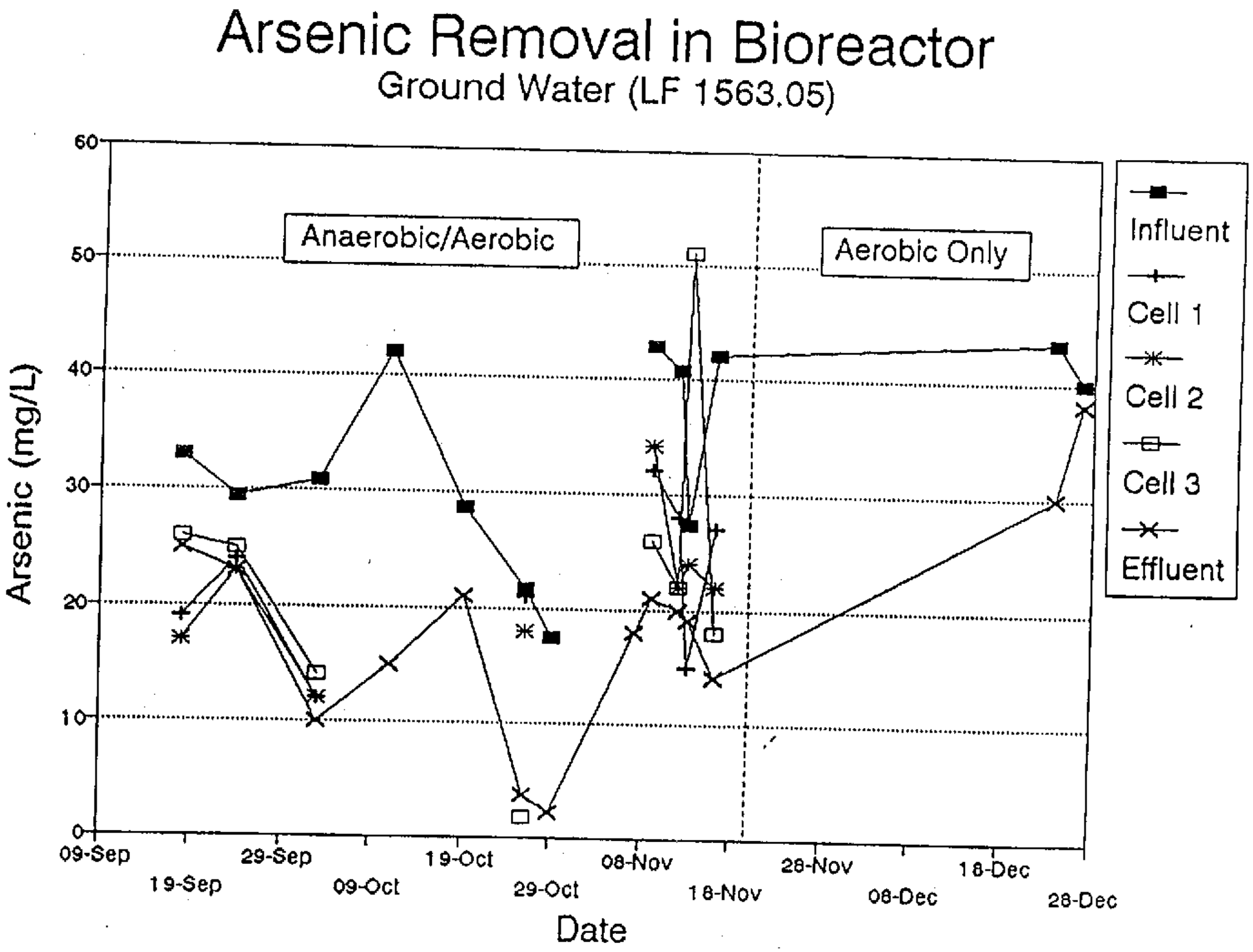

FIGURE C2: PROFILE OF ARSENIC CONCENTRATIONS THROUGH THE BIOREACTOR, CONFIGURED IN THE ANAEROBIC/AEROBIC AND AEROBIC ONLY MODES

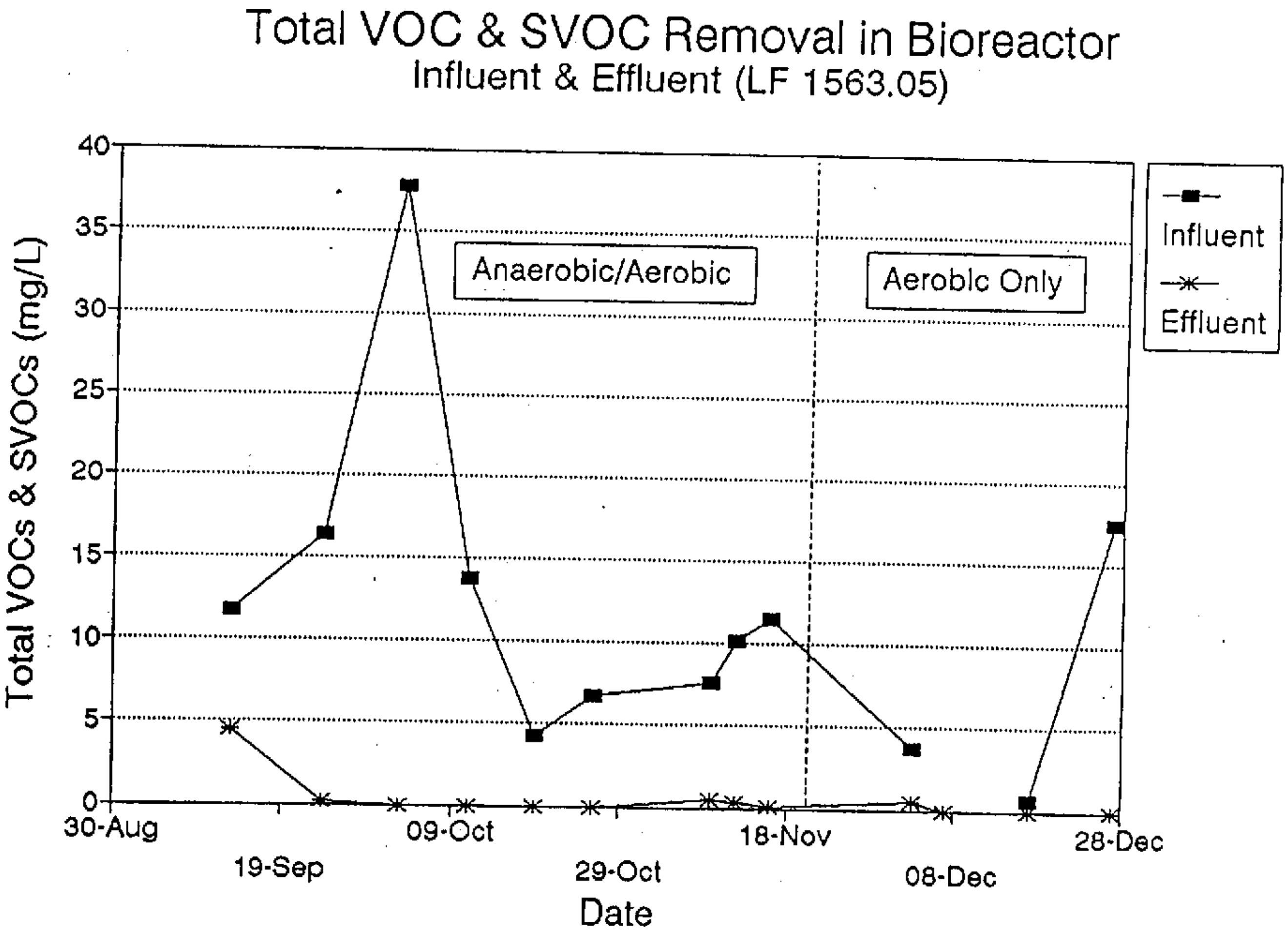

FIGURE C3: CONCENTRATIONS OF TOTAL VOCs AND SVOCs IN THE INFLUENT AND EFFLUENT OF THE BIOREACTOR, CONFIGURED IN THE ANAEROBIC/AEROBIC AND AEROBIC ONLY MODES

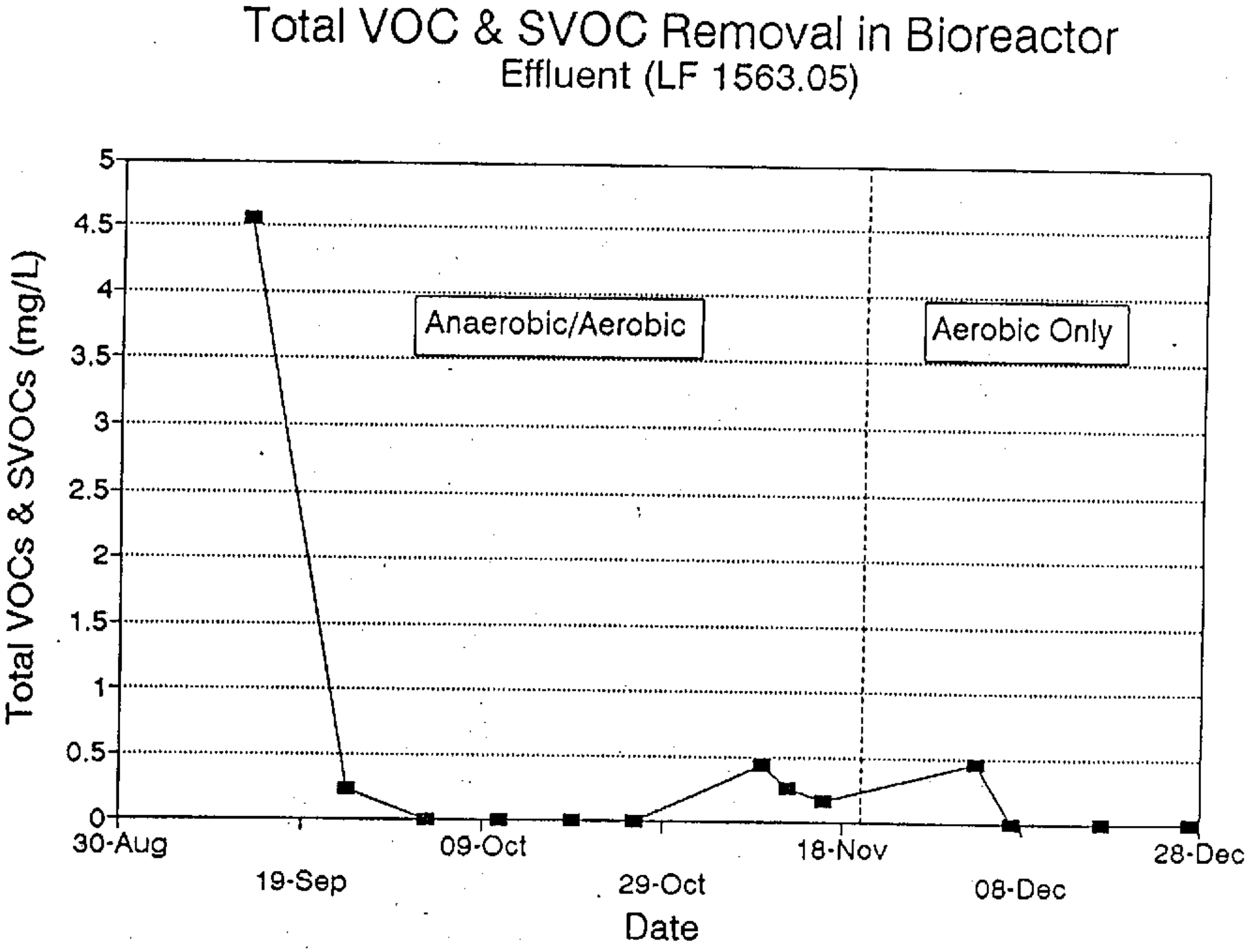

FIGURE C4: CONCENTRATIONS OF TOTAL VOCs AND SVOCs IN THE EFFLUENT OF THE BIOREACTOR, CONFIGURED IN THE ANAEROBIC/AEROBIC AND AEROBIC ONLY MODES (NOTE THE EXPANDED SCALE OF THE Y-AXIS RELATIVE TO FIGURE C2.)

APPENDIX D

ELECTROCHEMICAL TREATMENT VENDOR RESULTS

Andco Environmental Processes, Inc.
595 Commerce Drive, Amherst, NY 14150 (716) 691-2100/Telex 91-547

August 13, 1990

LEVINE FRICKE
1900 Powell Street, 12th Floor
Emeryville, CA 94608

Attention: Mr. Bruce Page

Subject: **Lab Report on Arsenic Removal**

Dear Mr. Page:

One five-gallon sample was received on July 26, 1990. The dark green/brown sample was highly turbid, contained a substantial amount of settleable particulate matter and had a strong organic-like odor. Conductivity and pH were measured and determined to be 1,550 μmho and 6.69, respectively. The results of the electrochemical (EC) treatability study, with and without the addition of hydrogen peroxide, are contained in this report.

Electrochemical Treatment Procedure:

The water sample was subjected to standard Andco electrochemical treatment tests. Usually, pH adjustment is utilized to bring the pH to around 7.5 prior to iron generation. From past arsenic work, good removal occurs from pH 6.5 - 7.5. Since your water sample was in that range, no initial pH adjustment was necessary. After placing a known amount of wastewater in a 600 ml beaker, steel electrodes were added and a specific amount of ferrous ion (Fe^{+2}) was generated in this mini-cell. Faraday's Law is used to determine the generation time for a specific sample size at a controlled amperage.

To allow hydrogen formed during EC treatment to dissipate, a ten-minute degassing period is allowed. At this point, hydrogen peroxide may be added. The low hydrogen peroxide treatment level was determined by adding 10 ppm increments until excess peroxide was present (EM Quant Peroxide Test) and the sample color went from green to rust (Fe^{+2} to Fe^{+3}). For two tests, calcium chloride was added. Calcium chloride and sodium hydroxide pH adjustment were used in place of calcium hydroxide (lime) to accurately control pH, but also simulate the effect that lime treatment would have. Calcium chloride has been proven to work well when the wastewater contains oil and grease. For this sample, it was anticipated that in the presence of all of the miscellaneous organics, calcium chloride may improve clarification.

After all chemical additions were done, pH adjustment was performed to maintain a solids separation pH between 6.6 and 7.3. $Fe(OH)_2$ and $Fe(OH)_3$ precipitate from solution and are capable of removing arsenic by adsorption/co-precipitation processes. Andco 3640, an anionic polyelectrolyte, was added to assist floc formation and clarification for samples LF-4-95-1 to LF-4-95-11. After thirty minutes of settling, the samples were filtered through Whatman #40 filter paper. For tests LF-4-95-1, LF-4-95-2, LF-4-95-6, and LF-4-95-7, decanted samples were collected and analyzed to determine how much arsenic remained in solution in combination with the suspended solids.

Located in Table 1 are the pH's before any treatment, following degassing and chemical addition, and also following pH adjustment immediately before performing the polymer assisted solids separation.

Iron, hydrogen peroxide, and calcium chloride addition levels and the resulting arsenic concentrations are listed in Table 2.

Polymer Testing:

To a 1000 ml sample, 100 ppm iron was added electrochemically. After degassing, the pH was adjusted to 6.84 (from 7.29) by adding six drops of 10% H_2SO_4. Four 200 ml samples were taken and the remaining 200 ml was saved for proper disposal. For this comparison, 5 ppm (by weight) of four different polymers was added and visual observations were used to rank their performance.

See Table 3 for the observations and ranking.

Analyses:

Following preservation with nitric acid (5 ml conc. HNO_3 per liter) the samples were sent to Ecology and Environment, Inc., (Lancaster, New York) for arsenic analysis. It was performed according to procedures set forth in "Methods for the Chemical Analysis of Water and Wastes", EPA -600/4-79-020, March, 1983.

Conclusions:

The data in Table 2 indicates that arsenic in the paint manufacturer's groundwater can be removed by iron generation, polymer assisted clarification, and filtration. In order to keep sludge volumes to a minimum, slight additions of hydrogen peroxide and calcium chloride were utilized at the lowest iron concentration to see if successful treatment could be achieved.

For all tests (except LF-4-95-3) where no oxidation was performed, arsenic concentrations still remained high. Removal efficiencies (see Table 4) ranged from 52.4% (LF-4-95-1A) to 83.8% (LF-4-95-2B). LF-4-95-3 was a successful test in that it reduced the arsenic concentration to less than 1 ppm (95.6% removed) but at the expense of generating a substantial amount of iron hydroxide sludge.

There are two reasons why hydrogen peroxide is added. First, it is important to oxidize all of the arsenic to arsenate. Many previous studies have shown that arsenate is much more easily removed by adsorption/coprecipitation processes than arsenite. Secondly, ferric (Fe^{+3}) iron is usually better at removing arsenic than ferrous (Fe^{+2}) iron. The chemical nature of the ferric hydroxide solid and the resulting floc formation account for the improved metals removal. The main advantage of adding iron electrochemically and following that with the addition of hydrogen peroxide, versus ferric chloride chemical precipitation systems, is that there will be no contribution to total suspended or total dissolved solids after the floc has been formed and removed. Any chloride, introduced during $FeCl_3$ treatment, will also remain after filtration. All tests involving peroxide and filtration yielded arsenic concentrations the organisms can probably handle.

Previously, you expressed concern about the presence of oil and grease. For my tests, they were not a problem. After each beaker test, I looked for a layer or sign of oil and grease. It was either removed by the floc or remained adequately mixed. If it is a problem in the full-scale system, calcium chloride could be used to minimize it. Polymer assisted floc formation was excellent for the tests involving calcium chloride. The expense of another addition portion of a system may make it undesirable since iron generation and peroxide oxidation also yielded good floc conditions.

For most tests, unfiltered (decanted) samples yielded poor results. It appears that a substantial amount of arsenic remains suspended with the small, unsettleable particulates. Multi-media filtration should be performed before subjecting the water to biological treatment.

If you have any questions or comments, please feel free to contact me at (716) 691-2100.
Sincerely yours,

ANDCO ENVIRONMENTAL PROCESSES, INC.

Michael D. Brewster

Michael D. Brewster
Research Chemist

MDB/cmh

TABLE 1

Sample	pH initial	pH[1] out	pH[2] final
LF-0	6.69	---	---
LF-4-95-1A	7.01	7.16	6.76
LF-4-95-1B	7.01	7.16	6.76
LF-4-95-2A	7.02	7.63	7.18[3]
LF-4-95-2B	7.02	7.63	7.18[3]
LF-4-95-3	7.01	7.54	7.17[3]
LF-4-95-4	7.01	7.17	6.72
LF-4-95-5	7.01	6.95	6.79
LF-4-95-6A	6.96	7.64	6.70
LF-4-95-6B	6.96	7.64	6.70
LF-4-95-7A	6.96	7.29	6.69
LF-4-95-7B	6.96	7.29	6.69
LF-4-95-8	6.97	6.84	7.14[3]
LF-4-95-9	6.97	6.84	7.12[3]
LF-4-95-10[4]	6.97	7.23	6.74
LF-4-95-11[4]	7.02	7.79	7.18[3]
LF-4-95-12	7.01	7.29	6.84
LF-4-95-13	7.01	7.29	6.84
LF-4-95-14	7.01	7.29	6.84
LF-4-95-15	7.01	7.29	6.84

1 - pH (out) was measured following iron generation and all chemical additions except final pH adjustment.

2 - pH (final) was taken following adjustment and is the pH at which polymer assisted solids separation was performed.

3 - Adjustment to pH's above 7 was done because it appeared that iron (Fe^{+2}) remained in solution when no peroxide addition was used.

4 - LF-4-95-10 and LF-4-95-11 tests were performed by adding iron electrochemically from hot rolled steel electrodes instead of Andco's normal electrodes.

TABLE 2

Sample	Fe mg/l	H_2O_2 mg/l	$CaCl_2 \cdot 2H_2 0$ mg/l	Filter[1]	As mg/l
LF-0	17	—	—	No	21
LF-4-95-1A	100	—	---	No	10.0
1B	100	---	---	Yes	6.1
2A	200	---	---	No	6.1
2B	200	---	---	Yes	3.4
3	300	—	—	Yes	0.93
4	100	40	---	Yes	1.2
5	100	100	---	Yes	0.36
6A	200	100	---	No	0.86
6B	200	100	---	Yes	0.12
7A	200	200	—	No	6.1
7B	200	200	---	Yes	0.14
8	100	40	100	Yes	0.42
9	100	40	300	Yes	0.66
10[2]	100	---	---	Yes	9.3
11[2]	200	—	---	Yes	6.3

1 - Unfiltered samples were decanted following a thirty-minute settling period. For all others, filtration was done using Whatman #40 (8um) filter paper.

2 - LF-4-95-10 and LF-4-95-11 tests were performed by adding iron electrochemically from hot rolled steel electrodes instead of Andco's normal ones.

TABLE 3

Sample	Polymer 5 ppm (by wt.)	Observations	Rank
LF-4-95-12	3640[1]	Excellent floc, coarse, low suspended solids	1
LF-4-95-13	A73[2]	Good floc, fine, high suspended solids	3
LF-4-95-14	530[3]	Excellent floc, coarse higher suspended solids than LF-4-95-12	2
LF-4-95-15	215[4]	Good floc, fine, highest suspended solids	4

1 - Andco 3640 anionic polymer

2 - Hexafloc A73 anionic emulsion polymer

3 - Hexafloc 215 cationic emulsion polymer

4 - Hexafloc 530 cationic polymer

TABLE 4

Sample	Arsenic mg\l	Removal %
LF-4-95-1A	10	52.4
1B	6.1	70.9
2A	6.1	70.9
2B	3.4	83.8
3	0.93	95.6
4	1.2	94.3
5	0.36	98.3
6A	0.86	95.9
6B	0.12	99.4
7A	6.1	70.9
7B	0.14	99.3
8	0.42	98.0
9	0.66	96.9
10	9.3	55.7
11	6.3	70.0

Unocal Chemicals Division
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UNOCAL 76

Unipure

September 6, 1990

Mr. Bruce W. Page
Levine·Fricke
1900 Powell Street
Emeryville, California 94608

RE: Sherwin-Williams Facility

Dear Mr. Page:

Here are the results of the Unipure Screens that were run on the ground water sample that you supplied. As I told you, we were able to get good results with a single screen and excellent results using a double screen, which approximates a standard Unipure Process installation followed by a Unipure Polish application.

The raw sample was acidified and analyzed. It contained 38 ppm of arsenic and 97 ppm of iron. After the initial Unipure Screen, a flocced, decanted and acidified sample contained 5.1 ppm of arsenic and 3.1 ppm iron. The same sample after filtration, had an arsenic level of 3.8 ppm while the iron level was less than .25 ppm.

The initial decanted sample was split into 2 smaller samples and another standard Unipure Screen was run on one of them. The decanted and acidified liquid had an arsenic level of .30 ppm with little iron remaining. A filtered sample had .16 ppm arsenic with little iron.

The other decanted sample was given a pH adjustment and treatment prior to running the Unipure Screen. The decanted and acidified sample had .05 ppm arsenic and 2.3 ppm iron. When filtered the level of arsenic was less than .01 ppm and the iron was .25 ppm.

Thus a single pass through the Unipure Process showed a removal rate of 90%. A second treatment with the Unipure Process reduced the first pass levels by 96+% and the over all level by over 99%. A second pass through a Unipure treatment with some pretreatment that simulated sludge recycle, showed stage removal rates of 99.8 % and an overall rate in excess of 99.9 %.

These are laboratory results, and though indicative of what can be achieved, they should not be taken as absolute values that would be obtained in actual operation.

The enclosed Process Flow Diagrams are for a standard, 25 gpm, skid mounted system that could be used for a single pass Unipure Process application and a modified skid system. The modified unit would still handle a 25 gpm flow but could be used for the dual pass, pretreated approach.

Ball park equipment prices for the 2 approaches are:

1. 25 gpm, single pass, standard skid mounted, system

A. Equipmnet	........$	140,000
B. Operations Costs	........$	250
C. Sample Removal Rate		90 %

2. 25 gpm, dual pass, modified skid system with pretreatment capabilities

A. Equipmnet	........$	230,000
B. Operations Costs	........$	600
C. Sample Removal Rate		99.9%

Neither system's equipment cost includes transportation or installation. Operating costs, are exclusive of labor and solids handling charges, are based on a 24 hour day.

I hope this information meets your present requirements. I will be up to see you one day this coming week to review the results and answer any questions you may have.

Sincerely yours,

John A. Schroth

John A. Schroth
Technical Sales Representative

Enclosures:
cc:Mr. Al Peters, ABP Engineering
1329S1JS

UNIPURE SCREEN REPORT
SCREEN No. 1189

Client Name: LEVINE-FRICKE
Project No.: 1329
Report Date: 08/16/90
Operator : LJS

Requested by: JAS
Request Date: 07/26/90
Distribution: JAS,PLD

1. SAMPLE DATA

Sample Description: Waste Water
Unipure ID No. : 1329-1189
Sample Source : N/A

Conductivity: 1500 mohms
pH: 6.9

2. PRETREATMENT

None

3. TREATMENT

Iron Dose: 200 ppm Base/Acid: NaOH/HCl

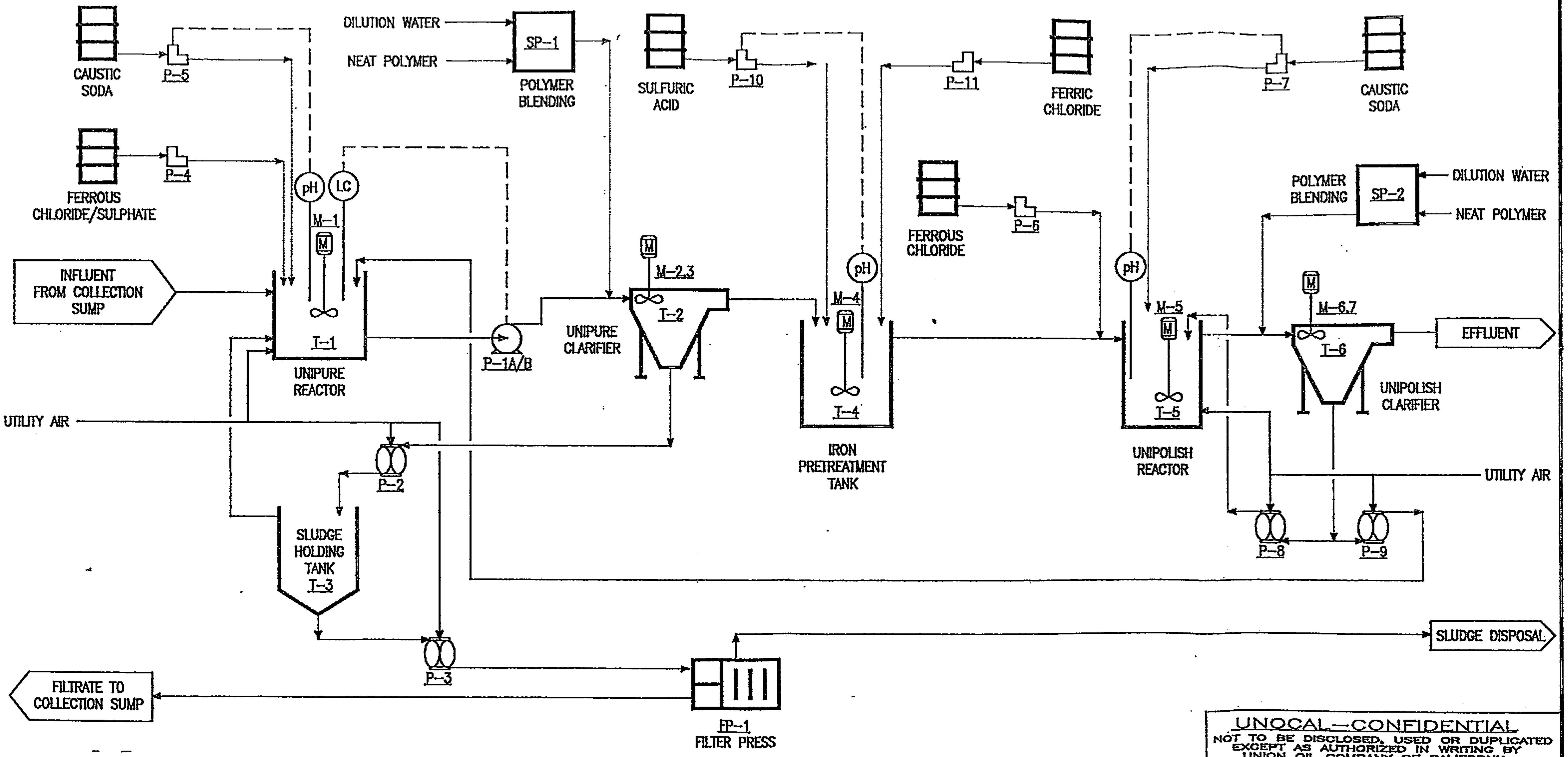
4. RESULTS

ample				Analyses (mg/L)				
Time	Prep	Iron	1	2	3	4	5	6
(MIN.)		Fe	As					
AW	A	97	38					
0	Po20DA	3.1	5.1					
60	PoFA	<.25	3.8					
60*	Po20DA	2.1	0.30					
0*	PoFA	<.25	0.16					
**	FA	<.25	0.02					
60**	Po20DA	2.3	0.05					
0**	PoFA	<.25	<.01					

|X| Analyzed by Unipure

Abbrevations

<	Less than the value indicated
<<	None detected
Po	Flocced
F	Filtered
D	Settled and decanted
A	Acidified



CLIENT SHOULD PROVIDE 100 GAL OF SURGE CAPACITY ABOVE HIGH LEVEL PUMP SWITCH FOR FILTRATE SURGE AFTER STARTING FILTER CYCLE

REV. NO.	REV. DATE	REVISION	REV. BY:	APPR. BY:
△	8/28/90	ORIGINAL DRAFT	DSR	

DR: DSR
DSGN: LWB
CK:
DATE: 8/28/90
SCALE: NONE
PROJ: 1329
SKID:

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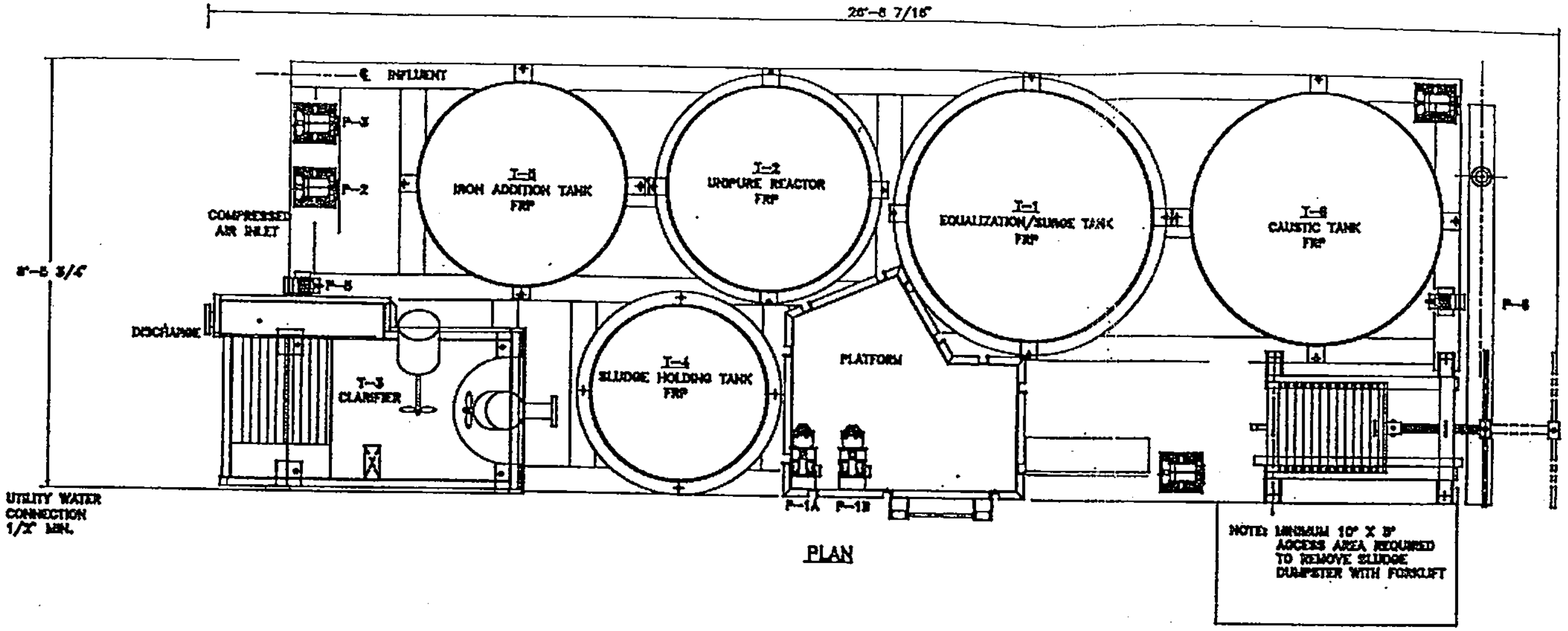
UNOCAL

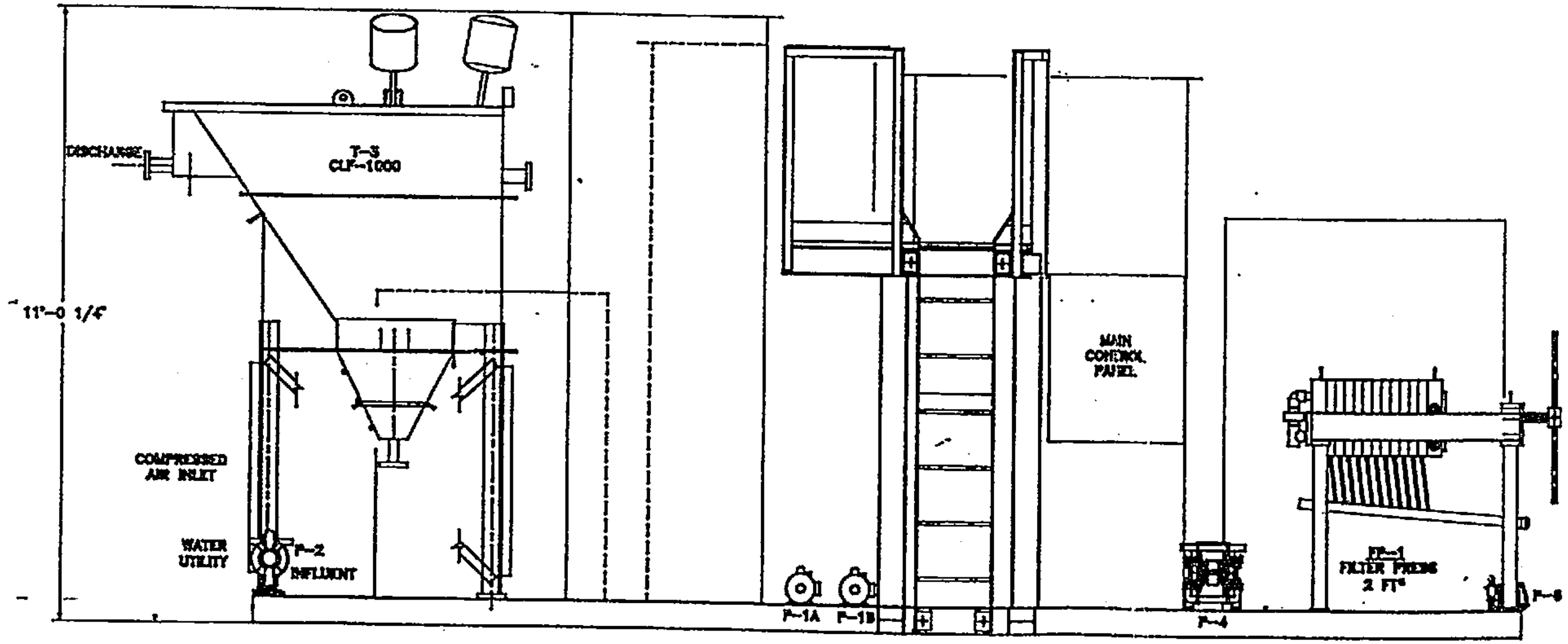
UNIPURE

TITLE: LEVINE – FRICKE
UNIPURE TREATMENT SYSTEM
PROCESS FLOW DIAGRAM

DWG.# 1329-B-F-1



PLAN



ELEVATION

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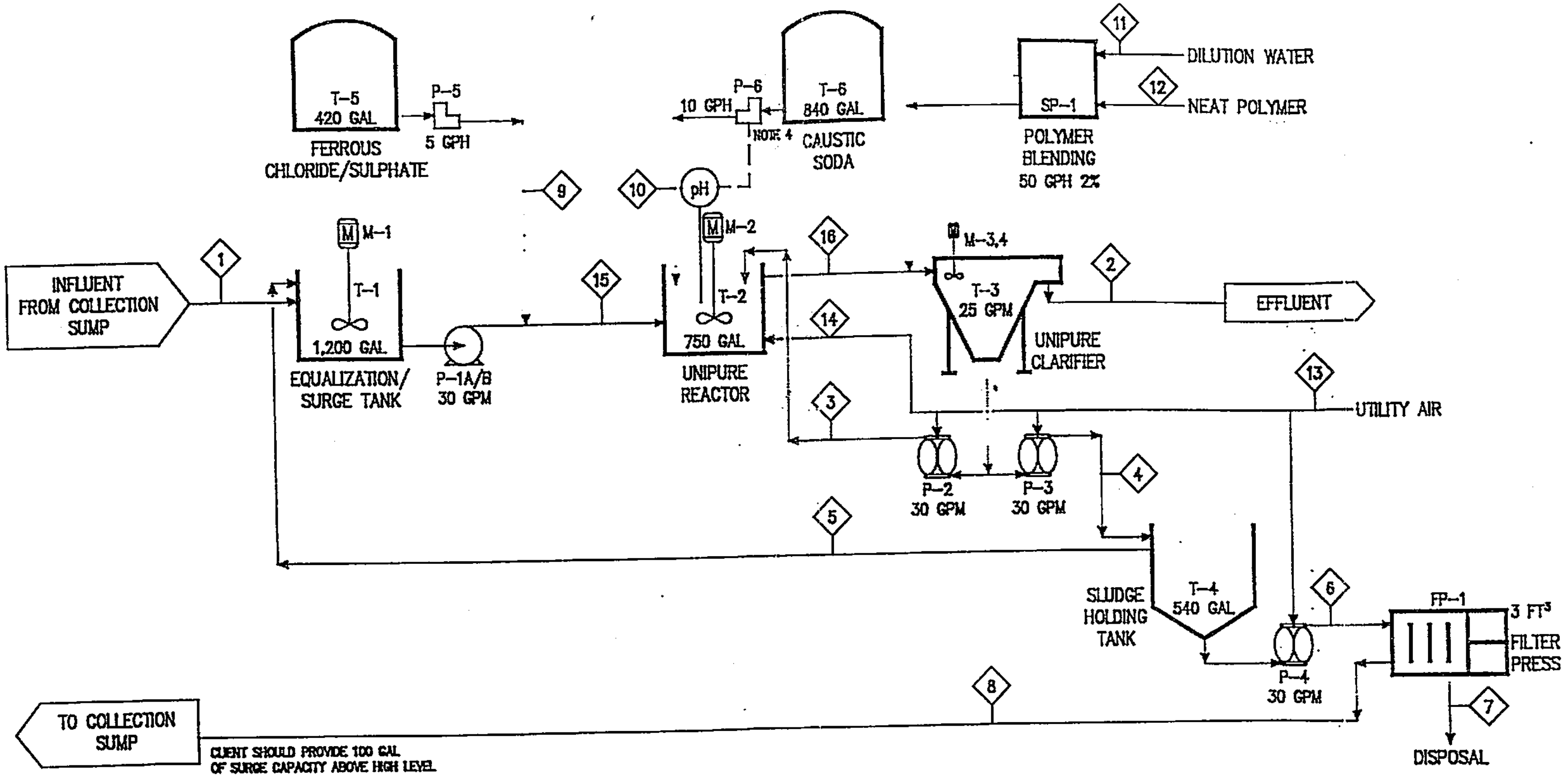
(800) 323-8647

UNOCAL 76
UNIPURE

DSR
DLM
RAK
3/4"=1'
7-20-89

SKID SYSTEM
GENERAL ARRANGEMENT

1195-D-G-1
1 OF 1
0



CLIENT SHOULD PROVIDE 100 GAL
OF SURGE CAPACITY ABOVE HIGH LEVEL
PUMP SWITCH FOR FILTRATE SURGE AFTER
STARTING FILTER CYCLE

REV. NO.	DATE	REVISED	CKD. BY
0	05-04-89	ISSUE FOR FABRICATION	

DRAWN BY SBK
CHKD BY JCM
APPD BY
SCALE

UNIPURE

15/25 GPM SKID
GENERIC DESIGN

SALES PROCESS FLOW DIAGRAM
UNIPURE TREATMENT SYSTEM

DATE	DRAWING NO.	SHEET	REV.
06-26-89	9003BF4	1 OF 1	0

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UNOCAL 76

Unipure

September 19, 1990

Mr. Bruce W. Page
Levine·Fricke
1900 Powell Street
Emeryville, California 94608

RE: Sherwin-Williams Facility

Dear Mr. Page:

As I promised in our meeting of September 12, I had our Technology and Engineering groups review the estimated operating costs for the treatment systems we had proposed.

The lab checked the titration curve for the samples we used and engineering ran a computer check using that data. The results showed a significant drop in the daily operating costs from those listed in my letter of September 6.

The daily operating costs for chemicals and power, per 24 hour day, now are approximately $ 115 for the 25 gpm single pass skid and $ 245 for the dual pass, modified skid system with pretreatment.

I also discussed with our Technology group, the effect the pre-removal of the organics would have on heavy metals treatability. The consensus of opinion is that we should see greatly improved results. Pilot studies have shown increased treatability where a the waste stream had limited pre-treated with peroxide, ozone and UV for organics removal.

If you wish, I can be available to answer questions during your meeting with Sherwin-Williams. I will need to know if that is desirable by this Friday to make the proper arrangements.

Sincerely yours,

John A. Schroth

John A. Schroth

cc: Al Peters, ABP Engineering
1329S1JS