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September 29, 1993

Mr. Homer Lin
Office of the State Architect
400 P Street, 5th Floor
Sacramento, CA 95814

Subject: Letter report presenting the cost of additional drilling, results of the feasibility study, and options for the existing diesel tank at the Department of the Military's Organizational Maintenance Shop No. 35 (OMS #35) in San Lorenzo, CA.
Contract UT 048R, work Order MAR 112, Assignment 1.

TC-9409

Dear Mr. Lin:

This report provides a cost estimate for drilling three additional borings at the San Lorenzo site, presents the results of the feasibility study for remediation of the soil and ground water contaminated with gasoline, and presents and discusses options to allow the existing 5,000 gallon diesel tank to remain in place and be permitted by Alameda County.

PART 1: COST ESTIMATE FOR DRILLING THREE ADDITIONAL BORINGS

Three additional soil borings were recommended in the final report. The purpose of these borings is to provide samples of the soil and ground water to help complete the definition of the extent of ground water contamination. One to two borings were to be located west of monitoring well MW-3 and the truck repair rack and one to the northeast of well MW-3 (Figs 2 and 5). The total cost of drilling three additional borings is approximately $9,000. The costs are distributed across various tasks as follows:

Task 1:	Site Planning and Permitting		
		Work Plan	833
		Health and Safety Plan	385
		Permitting	480

			Subtotal	$1698
Task 2:	Drilling of Borings			
	Labor		1520	
	Drilling		1735	
		Task 2	Subtotal	$3255
Task 3:	Sample Analyses			
	Mobile Lab, 1 day			$2275
Task 4:	Data Reduction & Interpretation and Report			$1625
				=====
			Total	$8853

These costs presume the borings will be 20 feet deep, four soil samples and a grab water sample will be collected from each boring, and that the water sample and one or more of the soil samples will be analyzed for TPH-D, TPH-G, and BTEX. Additional soil borings, if needed, will cost approximately $800 each if they can be drilled and the samples analyzed the same day as the three proposed borings.

Additional costs may be incurred if access to San Lorenzo High School land is required so the soil borings west of the truck repair rack may be drilled (Fig. 5[1]). According to OMS personnel, moving the temporary storage buildings presently located between the truck repair rack and the west fence would be very difficult. If it is infeasible to move these buildings to allow drilling of the borings between the repair rack and the west fence, then the borings would have to be drilled west of the storage buildings, either on San Lorenzo High School land or on State-owned land between the temporary buildings and the fence. In either case, permission to cross and work on the school land would have to be obtained. Cost of obtaining such permission (labor) is estimated to be less than $750.

Installation of a monitoring well in one of the borings, surveying in and sampling the well, and analyzing the water sample as above would cost an additional $1,500.

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[1] Figures and Tables from the final report are attached at the end of this report for reference.

PART 2: FEASIBILITY STUDY FOR REMEDIATION OF THE SOIL AND GROUND WATER

This study is concerned with the remediation of contaminated soil and ground water that is still in place at the site. It does not address remediation of the soil excavated during the removal of the 2,000 gallon gasoline tank.

CONTAMINATED SOIL

The objective of soil remediation is to minimize further contamination of the ground water by reducing the source of the contamination near the former tank. Although the gasoline tank and its contaminated backfill was removed in April 1993, the contaminated soil adjacent to the tank pit was not excavated.

Because of the relatively small volume of soil near the former tank pit that requires remediation, the following soil remedial options are available:

- No action
- Excavation and offsite disposal or treatment
- Excavation and onsite treatment
- In situ vapor extraction

Option 1: No action. This is the least expensive option. However, because ground water occurs at such shallow depths (7-11 ft), contaminated soil near the tank pit will continue to be a source of ground water contamination. Remediation of the source of contamination will almost surely be required by the regulatory agencies.

Option 2: Excavation and offsite disposal and remediation. Excavation of the soil removes the source of contamination from contact with the ground water. Offsite disposal or remediation of the soil allows rapid removal of the soil from the site and eliminates the need for onsite space that would be required for onsite remediation.

If the soil is transported to another site for remediation or if the soil characterized for disposal using the analytical results from soil samples collected from existing soil borings, the soil can be loaded directly into trucks following excavation and removed from the site. In many cases where the soil is sent for disposal, the soil is stockpiled temporarily following excavation while composite samples of the stockpiled soil are analyzed to profile the soil for the landfill. Temporary stockpiling may be advantageous because the TPH concentrations of the composite samples are usually lower than the maximum concentrations from the soil borings, and may result in lower disposal costs for the stockpiled soil.

If the soil is to be remediated offsite, the soil must be transported to an area with sufficient space for remediation. Remediation using passive aeration or bioremediation can take weeks to months. These remediation methods are described in detail in Appendix A.

Total volume of the soil to be excavated cannot be definitely determined until excavation takes place and the extent of excavatable contamination is revealed. During Tetra Tech's July 1993 site investigation, the open pit resulting from the removal of the gasoline tank made it unsafe to attempt drilling a soil boring between the open pit and the diesel tank 6-7 ft south. The tank pit has recently been backfilled with aggregate and capped with a cement slab. Tetra Tech recommends drilling an additional soil boring between the diesel tank and the recently filled pit prior to excavating to test the native soil between. If the soil samples come up sufficiently clean, excavation south of the tank pit may not be necessary.

However, for the purpose of estimating the volume of soil to be removed, we assume that the excavation would be 9 ft deep and rectangular and that its maximum boundaries would be the edge of the concrete pad over diesel tank to the south, the truck repair rack on the west, boring B-3 on the north, and halfway to boring B-7 on the east (see Fig. 5, attached). The dimensions of the resulting excavation would be approximately 25' X 23' X 9', and the volume of soil removed from such an excavation would be approximately 200 cubic yards. Clean soil, such as material used to backfill the tank pit (about 35 cy), or that above the contaminated soil, will be separated where possible and stockpiled for potential reuse in backfilling the pit. The stockpile of "clean" soil would be sampled and its lack of contamination verified prior to its use as backfill.

Although the total volume of excavated soil is not expected to exceed 200 cy, larger volumes are possible if thick zones of contamination extend significantly north of boring B-3. The maximum likely soil volume should not exceed 300 cy.

Excavation of the soil, backfilling of the pit, and paving of the excavated area would take about three days. Excavation would require that the north half of the dispenser island and the northwest corner of the cement pad on the east side of the island be removed. After the backfill is emplaced, the area must be paved with asphaltic concrete. Total cost for excavation of 200 cy of soil, backfilling, and paving, would be about $16,000, plus $4550 for the mobile lab (two days), and Tetra Tech labor.

Disposal of the soil would most likely be at the Class II landfill operated by Forward, Inc., near Stockton, CA. The Forward facility is the nearest landfill that will accept soil from Alameda County contaminated with more than 100 mg/kg TPH-G. Disposal costs at this site for such soil would be $47.25/cy. Assuming that 150 cubic yards of the contaminated soil are disposed of at the Forward facility, the total cost for transportation and disposal would be about $11,000. Disposal costs would be reduced to $21/cy if composite soil samples from stockpiled soil contained less than 100 mg/kg TPH-G.

Offsite remediation would require that OSA have available a relatively nearby site of 1 acre or more, to allow room for spreading of the soil for remediation. Remediation would take weeks to 2-3 months. Once TPH levels are reduced to 10 mg/kg or less, remediation would be complete and the soil may be used for as fill or otherwise disposed of. Remediation costs would be $2.50-$15/cy for volatilization and $40-100/cy for bioremediation, plus transportation to the remediation site and disposal costs.

The major advantages of excavation of the contaminated soil are that the contamination source the ground water is permanently removed, it is quick, and it is less expensive for such small volumes of soil than *in situ* remediation methods. Disadvantages are that small lenses of contamination overlain by thick overburden cannot be economically excavated and that the excavated soil is still contaminated and must be dealt with.

Advantages of disposal are that the contaminated soil is permanently removed from the site and that no space and on-going expense is needed for subsequent remediation. Disadvantages are that disposal may be costly for highly contaminated soil, the soil is not available for reuse, and the generator still has long-term liability for the contaminated soil.

Advantages of offsite remediation are that the soil will be available for reuse, that long-term liability is not a concern, and remediation may be less expensive than disposal for certain types of highly contaminated soils. Disadvantages are that the soil must be transported to the remediation site, significant amounts of space will be encumbered at the remediation site for a time period that could be months in extent, and following remediation, the soil must be used or disposed of.

Option 3: Excavation and onsite remediation. This option is similar to the previous option, except that space must be made available on the site for remediation that may take weeks to months to accomplish. The site is presently used as a parking lot for National Guard vehicles and is filled to capacity. Onsite remediation would require that a substantial number of the vehicles would have to be removed from the site and parked at another location.

Costs would be similar to those for excavation and offsite remediation, except that no offsite transportation costs would be incurred.

The advantages of this option over Option 2 are that no transportation costs are incurred because the soil is remediated on site, and another site does not have to be made available for remediation. Disadvantages are similar to those for offsite remediation except that offsite transportation is not necessary.

Option 4: In situ vapor extraction. Soil vapor extraction (SVE) is a process in which volatile gasoline is removed from the soil by pulling a vacuum in one or more vapor extraction wells. Gasoline is ideally suited for SVE in that it is composed of volatile compounds. A detailed description of SVE is presented in Appendix A.

SVE at the San Lorenzo site would entail a pilot study to determine if SVE is feasible. If SVE were shown to be practical, then computer modelling would be used to determine the location and number of vapor extraction wells. Away from the immediate vicinity of the former tank pit, the contaminated permeable units are thin sand beds at depths of more than 8 feet. Soil vapors from these beds might best be removed using a horizontal vapor extraction well, perhaps installed in a trench filled to depth of 7.5 feet with permeable sediment such as sand or gravel. The permeable material containing the horizontal well screen is then covered with impermeable sediments so air from the surface above cannot be drawn down along the walls of the trench and "short circuit" the SVE process. Final design would depend upon the results of the pilot study.

If the SVE is appropriate for a site, it can be quite effective. Levels of VOCs in soil can routinely be lowered to the single digit level, and, because the contaminant is removed from the soil, the process is permanent. Removal rates depend upon the soil and contaminant conditions.

SVE has relatively low capital and operations and maintenance (O&M) costs. Pilot level testing for applicability of SVE costs approximately $10,000 and takes approximately one week. System costs for a small site would range from $35,000 to $50,000. A large site would range from $75,000 to $125, 000. This figure includes all the SVE system equipment and installation. However, it does not include the well installation nor the treatment technology to treat off-gassed volatiles.

Monitoring makes up the majority of the O&M costs. Monthly maintenance would cost between $1,000 and $1,500 per month. This does not include component replacement, or carbon replacement (if activated carbon is used to adsorb TPH vapors from the soil gas) or regeneration. In general, clean-up costs have been reported to range between $10.00 and $40.00 per cubic yard.

Advantages are: the soil does not have to be excavated and remediated on or off site or disposed, and SVE can remediate the thin permeable sand beds underlying the uncontaminated overburden. An additional advantage of SVE is that the movement of air towards the well(s) helps dry the soil, resulting in easier volatilization of the gasoline compounds, and oxygen in the incoming air promotes bioremediation of the hydrocarbons by indigenous microorganisms in the soil. Disadvantages are: it may take years to remediate the site to satisfactorily low TPH concentrations; for a small site like OMS #35, SVE is likely to be more expensive than excavation, i.e., the per yard remediation costs would be larger than those cited above; and, once removed from the ground, the soil vapor must still be remediated. Hydrocarbons would be removed from the soil gases by thermal incineration, catalytic oxidation, or granular activated charcoal.

Recommendations. Tetra Tech recommends excavation and offsite disposal as the most cost effective and permanent option. The contaminated soil adjacent to the tank pit should be excavated down to the water table as soon as feasible. Tracking the extent of contamination can be accomplished with a Photo Ionization Detector (PID), aided by use of an on-site mobile laboratory to analyze confirmation soil samples.

Any contamination that occurs in very thin (< 0.5 ft thick) lenses of contamination underlying 8 ft or more of clean soil will probably not be excavated because of the cost of removal of the clean overburden. The pit resulting from excavation will be backfilled with clean fill and paved so onsite activities are not obstructed. Remediation of contaminated soil below the water table will be accomplished as part of the ground water remediation, discussed below.

Tetra Tech recommends disposal of the contaminated soil rather than remediation because of the time and space required for remediation of the excavated soil. Disposal is quick, and no remediation space is required.

REMEDIATION OF GROUND WATER

The estimated contamination plume for ground water is shown in Figure 6. This plume is unconstrained west and northeast of monitoring well B-3 and boring B-17. Definition of the horizontal extent of the ground water plume is needed before any of the proposed remediation methods can be unequivocally chosen.

The upper aquifer, which contains the contaminated ground water, is composed of thin sand beds within in a predominately fine-grained matrix of silty clay and clayey silt. The sand beds occur at different depths, as indicated by varying depths at which groundwater was encountered. However, the sands appear to be hydraulically connected because water levels in all borings rose to an approximate common elevation. Tetra Tech believes that the soil and ground water contamination observed away from the immediate vicinity of the former tank pit results from lateral transportation of the gasoline on and in ground water flowing through the sand beds. Several options for remediation of the ground water are reviewed and compared. These include (1) No action, (2) Limited action, (3) Pump and treat, and (4) *In situ* bioremediation.

<u>No action.</u> This is the least expensive option. However, because the ground water has been shown to be contaminated, the "no action" option is unlikely to be approved by the San Francisco Bay Regional Water Quality Control Board (RWQCB).

<u>Limited action.</u> This option is to not treat the ground water, but instead monitor it, usually on a quarterly basis, to determine how the water quality varies with time and to determine how the plume is moving. This would require definition of the plume extent and installation of at least one monitoring well down gradient of the plume. All down-gradient and one or more of the up-gradient wells would then be monitored on a quarterly basis until the TPH-G concentrations declined to values that were acceptable to the RWQCB. Because the major source has been removed, the contamination eventually would be mitigated by natural processes that include volatilization and bioremediation by microorganisms native to the soil.

The advantages to limited action is that no additional capital costs are needed for this option except for the installation of 1-3 monitoring wells. The disadvantages to limited action are: it may take tens of years for the ground water contamination to degrade without enhancement, during which the plume could migrate well beyond its present extent, requiring more wells to adequately monitor it; OSA would incur additional costs for monitoring wells, and for long-term ground water monitoring, including sample collection, analysis, and reporting costs.

<u>Pump and treat.</u> In this method, contaminated ground water is removed from the ground, treated, and either returned to the aquifer or dumped into the sanitary sewer. The ground water may be remediated by a variety of methods, including activated carbon adsorption, air stripping, and bioremediation. The process continues until sufficient contaminant has been removed to bring the hydrocarbon concentrations down to acceptable levels.

Contaminated ground water is removed from the aquifer with a ground water extraction system. Such a system consists of one or more extraction wells that are positioned and pumped in such a manner that flow of contaminated water is toward the well(s) and no contaminated water flows past the downgradient well(s). One or more monitoring wells must be located downgradient from the extraction wells to demonstrate that contaminated ground water is not bypassing the extraction system.

The aquifer and extent of contamination must be well characterized to provide the information needed to design the extraction well network. Pump tests are necessary to determine the hydraulic conductivity and other parameters, the hydraulic gradient must be determined, and the stratigraphy understood. Once the necessary information has been gathered, computer models are used to determine the optimal number and location of extraction wells, and the rate at which water should be extracted. Once this has been calculated, the optimal type of remedial system and its capacity will be determined. The optimal remedial method depends in part upon the concentration of contaminants in the ground water that is extracted.

In real systems, sorption reduces the amount of a contaminant in solution at any given moment. This means that more ground water must be pumped to remove the same amount of a contaminant that would be removed if it were all dissolved. In addition, residual product may continue to be a source of dissolved contaminants in ground water. A relatively small volume of product can contaminate a very large volume of ground water. Experience has shown that ground water extraction alone often requires many years to reduce dissolved contaminant concentrations to meet the very low drinking water standards typically applied to ground water cleanup. However, although remediation times may be long, properly designed ground water extraction well systems are quite effective at preventing the further migration of the contaminants.

Radius of capture of the extraction system must be verified through the use of observation wells or piezometers, since water levels in the extraction wells do not provide any indication of the extent of the capture zone. Observation wells are small-diameter wells used to measure ground water elevations and collect ground water samples. The number of observation wells required depends on the level of detail required at the site, and the degree of complexity of the aquifer system. A minimum of three observation wells, such as are already installed at the site, are required for determination of the horizontal hydraulic gradient.

The cost of an extraction system for contaminant capture depends on the size and depth of the plume and on the aquifer parameters. Cost elements include:

- Design,
- Extraction well and observation well installation,
- Pumps, piping, and power supply,
- Oil/water separation and other above-ground treatment,
- Verification monitoring, and
- Operation and Maintenance.

Cost and design of a ground water extraction and remediation system for the San Lorenzo OMS site cannot be determined until the extent of the plume has been defined and the aquifer characterized.

<u>*In situ* bioremediation.</u> *In situ* bioremediation is the biological treatment of contaminated soils and ground water without excavation of the soil or removal of the water from the aquifer. Bioremediation involves the chemical transformation, through a biologic process, of one chemical species to other

chemical products. The objective of bioremediation is detoxification of the parent contaminant compound(s) into products which are not hazardous to human health or the environment. The products of complete aerobic biodegradation (degradation in the presence of excess oxygen) are carbon dioxide, water, inorganic compounds, and cell protein (See Appendix A for a general discussion of bioremediation).

Treatability studies may be needed to determine biodegradation potential. Treatability studies should provide an estimate of time required for cleanup, level of cleanup attainable, and the cost of cleanup.

In-situ bioremediation has gained an increased level of acceptance by regulators in recent years, but is still considered to be an innovative technique. Advantages of in-situ ground water bioremediation include:

- It is applicable in otherwise inaccessible areas;
- It is a permanent treatment method; and
- It is lower in cost than many other remediation methods;

Among the disadvantages of in-situ bioremediation are:

- It requires detailed characterization of subsurface conditions;
- It may require several years to complete; and
- It may be difficult to demonstrate completion.

The physical, chemical, and biological conditions in the subsurface of a site must be evaluated to determine whether in-situ bioremediation is a feasible option at the site. These include:

- Geologic characterization, including determination of the stratigraphy, geologic structure, particle size distribution, porosity, and moisture content of stratigraphic units;
- Hydrologic characterization, including depth to ground water, permeabilities of stratigraphic units, and identification of perched aquifers;
- Geochemical characterization, including determination of biotoxic inorganic constituents, identification of mineral constituents which produce undesirable reactions with nutrients or oxygen (such as calcium, magnesium or iron), oxidation-reduction potential, pH, temperature, and characterization of the magnitude, identities, and extent of contaminants; and
- Microbial enumeration, to identify existing degraders or cometabolizers, microbial densities, and competitive species.

Hydrogeologic control of the addition of nutrients and oxygen is essential for ensuring that contaminants are economically treated. Fine-grained materials decrease the rate of biodegradation.

Temperature, pH, and redox potential are the major limiting environmental factors to in-situ bioremediation. Ground water temperatures remain relatively constant throughout the year. pH and redox potential are relatively constant under natural conditions, but can change as a result of microbial activity. The constancy of pH depends on the degree of buffering, which can be reduced by the presence of contaminants. Reducing environments may be sinks for oxygen.

Recommendations. Tetra Tech recommends that pump and treat, bioremediation, or a combination of the two, be used to remediate the ground water at the San Lorenzo site. At present, pump and treat methods are the methods most likely to be approved by Alameda County. However, pump and treat is a slow means of remediation because it depends upon the rate of diffusion of contaminants from the soil into the ground water and can only remediate what is dissolved in the water. Bioremediation actually reduces the concentrations of hydrocarbons in both the water and the soil in contact with the water, and therefore should remediate the site more quickly than pump and treat. Bioremediation is recommended if Alameda County will approve it.

PART 3: TANK OPTIONS REPORT

The purpose of this report is to present options whereby the existing 5,000 gallon diesel tank can remain in place at the San Lorenzo OMS #35 and be permitted by Alameda County.

Permitting the tank. I have discussed the diesel tank with the Alameda County Regulators. I initially spoke with Pamela J. Evans, Senior Hazardous Materials Specialist at the Hazardous Materials Division of the Alameda County Department of Environmental Health. She referred me to her letter of October 7, 1992, sent to the Office of the Adjutant General in Sacramento (se Exhibit A, Appendix B). She indicates in the letter that the following items are required:

- Written routine tank monitoring procedure for interstitial space and piping.
- Written leak response plan
- Completed UST permit application (Forms A and B)
- More recent (1993?) tightness test for the tank — Most recent test results she had as of October 7, 1992, were for April 1991. The most recent test information showed to me at the OMS was dated June 10, 1991.

In this letter Ms. Evans refers to several forms and regulations. I have made copies of the relevant regulations from Title 23 of the California Code of Regulations (See Exhibit B, Appendix B). I also called her office and asked about the various forms referred to in the letter. Because Ms. Evans was out of the office, I spoke with her associate, Robert Weston. He sent me a complete package of forms (see Exhibit C, Appendix B). We have only one original set of the forms and are sending them to you, along with several copies of the material. Additional sets of forms may be requested from Ms. Evans or Mr. Weston at (510) 271-4320.

In addition to the items from Ms. Evans letter listed above, an apparent misunderstanding regarding the type of tank that is in the ground should be resolved. In Ms. Evans' letter (Attachment A), she refers in Item 1 to the diesel tank as a ". . single walled tank with a pit liner. . .". This perception is based upon blue prints she was supplied. I reviewed what were probably the same blue prints at the OMS #35 on September 27, 1993. These blue prints do indeed show such an arrangement for the diesel tank but are the pre-installation blueprints dated 8/5/88. The particular figures are figures 6a and 6b, sheet M2, which show the "Leak Detection Detail" and are footnoted as "This detail is the minimum acceptable monitoring system and are (sic) subject to change without notice. Comply in all respects with the current Alameda County Standard for new tank only. . .". Sgt. Burns at the OMS insists that the diesel tank is a double-walled fiberglass tank; reports filed by Ms. Evans during her inspections of 7/3/91 and 8/14/91 both state that the tank is double walled. Further, Section 13 of the Bidding Requirements manual for the OMS Modifications and Additions (August, 1988) specify the installation of a double-wall tank. Although adequate documentation was available at the OMS for all other parts of the fuel delivery and monitoring systems, no information was available that actually described the tank that was installed. Inquiries directed to the engineering company that installed the system, R.S. Eagan and Co., Concord, CA, revealed that their phone has been disconnected and that they are no longer listed in the phone book.

Tetra Tech suggests that documents (as-built blue-prints??, records from R.S. Eagan and Co.?)) showing the kind of tank that was installed be located and submitted to Alameda County. A request has also been made to Ms. Evans at Alameda County to review her files to see if she has information from the installation that will clarify this discrepancy.

Lastly, the existing leak detection system for the Diesel tank is out of order. The wires were disturbed (cut?) during removal of the gasoline tank and the monitoring system hasn't worked since. It is likely that Alameda county will not issue a permit for the tank until the monitoring system is repaired.

Allowing the new tank to remain in place. Neither the regulators nor the correspondence indicate or suggest that the diesel tank should be removed. My understanding is that this concern was raised by OSA because of the possibility that the backfill around the diesel tank might be contaminated with gasoline. I specifically asked Mr. Weston if this situation would affect the permitting; he indicated that it would not. Tetra Tech sees no reason the tank should be moved even if the soil adjacent to the tank was shown to be contaminated and had to be excavated; the contaminated soil could immediately be replaced with clean backfill. And to date, no contamination of the soil adjacent to the diesel tank has been demonstrated (see borings B-1 and B-5, Final Report, Tetra Tech, 1993).

Should you have any questions regarding this report, or if we may otherwise be of assistance, please feel free to contact us at (415) 974-1221.

Very truly yours,

Mike Wopat, RG
Senior Geologist

cc: Mike Golden, OSA

TC-9409, 9410

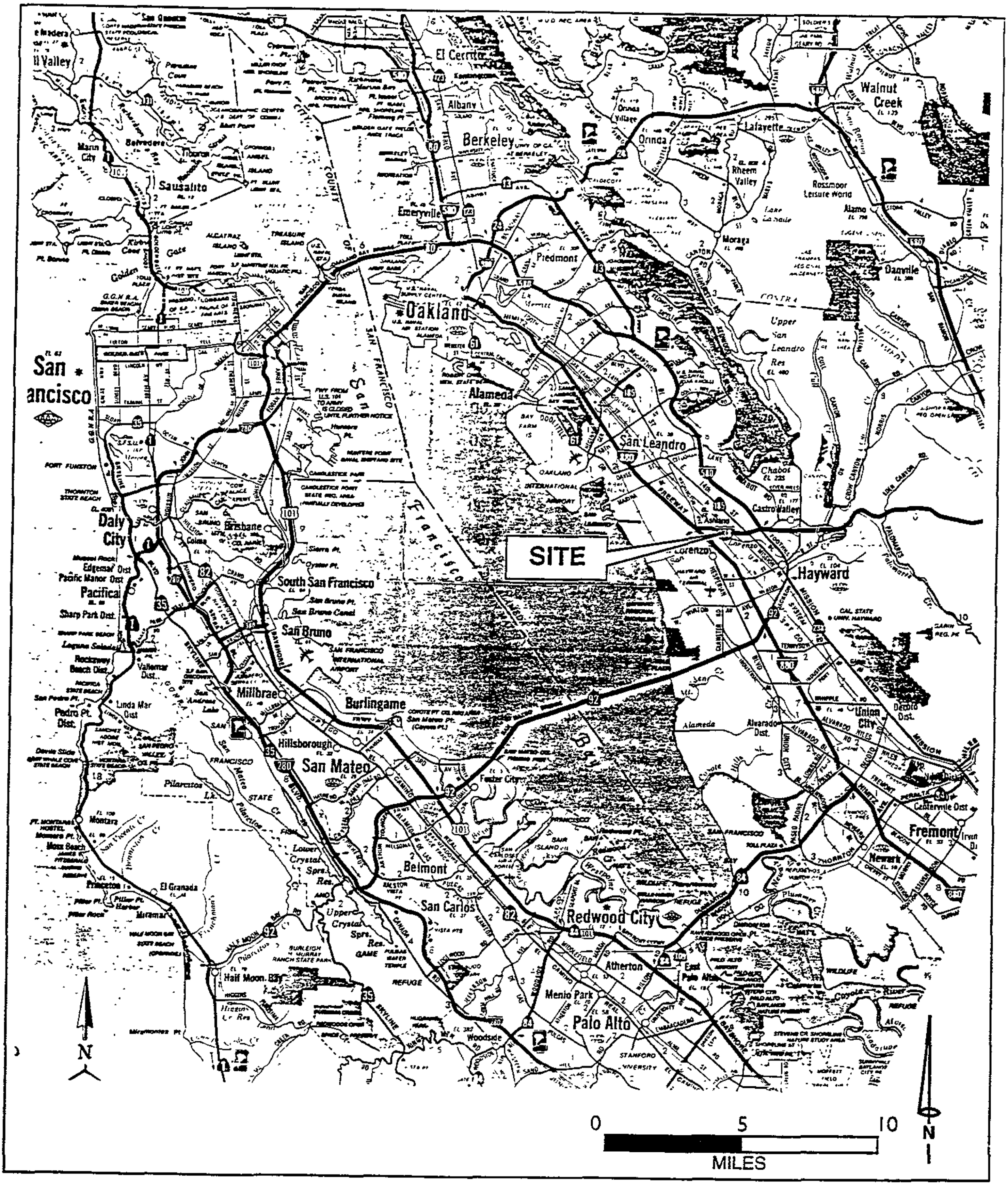


Figure 1A Regional Site Location Map

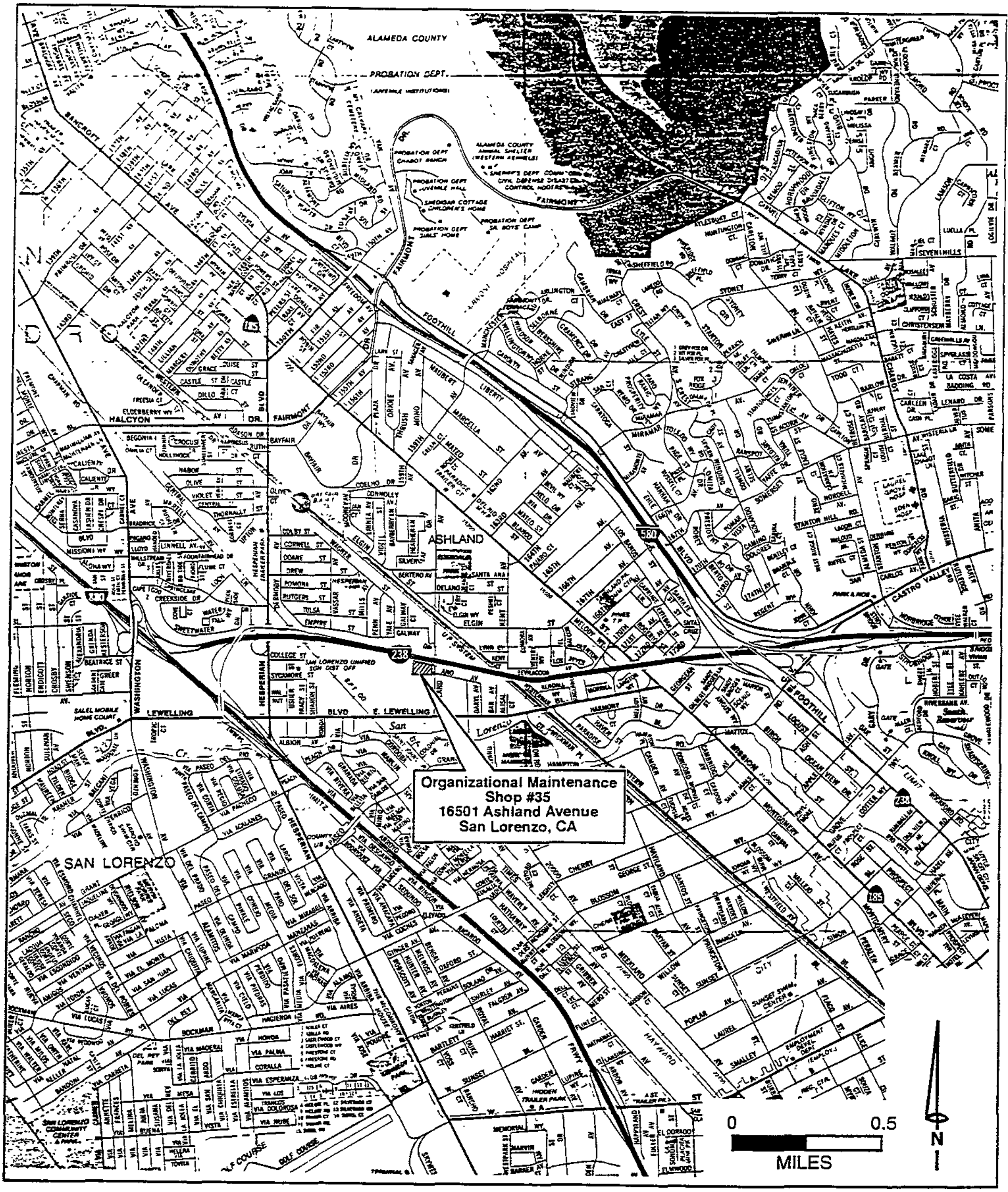


Figure 1B **Site Location Map**

Table 1
Analytical Results for Ground Water and Soil Samples Collected April 22, 1993 from the Tank Removal Excavation at OMS #35
16501 Ashland Avenue, San Lorenzo, CA

Sample No.	Sample type and location	Depth (ft)	TPH-g (ppm)[1]	Benzene (ppb)[2]	Ethyl benzene (ppb)[2]	Toluene (ppb)[2]	Xylenes (ppb)[2]
SL-1	stockpiled soil	N/A	297	450	5,790	6,420	35,800
SL-2	ground water in the excavation	~7.0	51.4	7,210	2,680	13,500	12,000
SL-3	soil, E sidewall	~5.0	73	438	1,700	3,410	10,400
SL-4	soil, W sidewall	~6.5	ND<1.0	ND<5	ND<5	ND<5	ND<15
SL-5	soil, W sidewall	–7.0	ND<1.0	ND<5	ND<5	ND<5	23

(1) ppm = parts per million = mg/l for water, mg/kg for soil
(2) ppb = parts per billion = µg/l for water, µg/kg for soil
(3) N/A = Not Applicable
(4) ND = Not Detectable at indicated detection limit.

Source: ATR Enterprises, personal communication

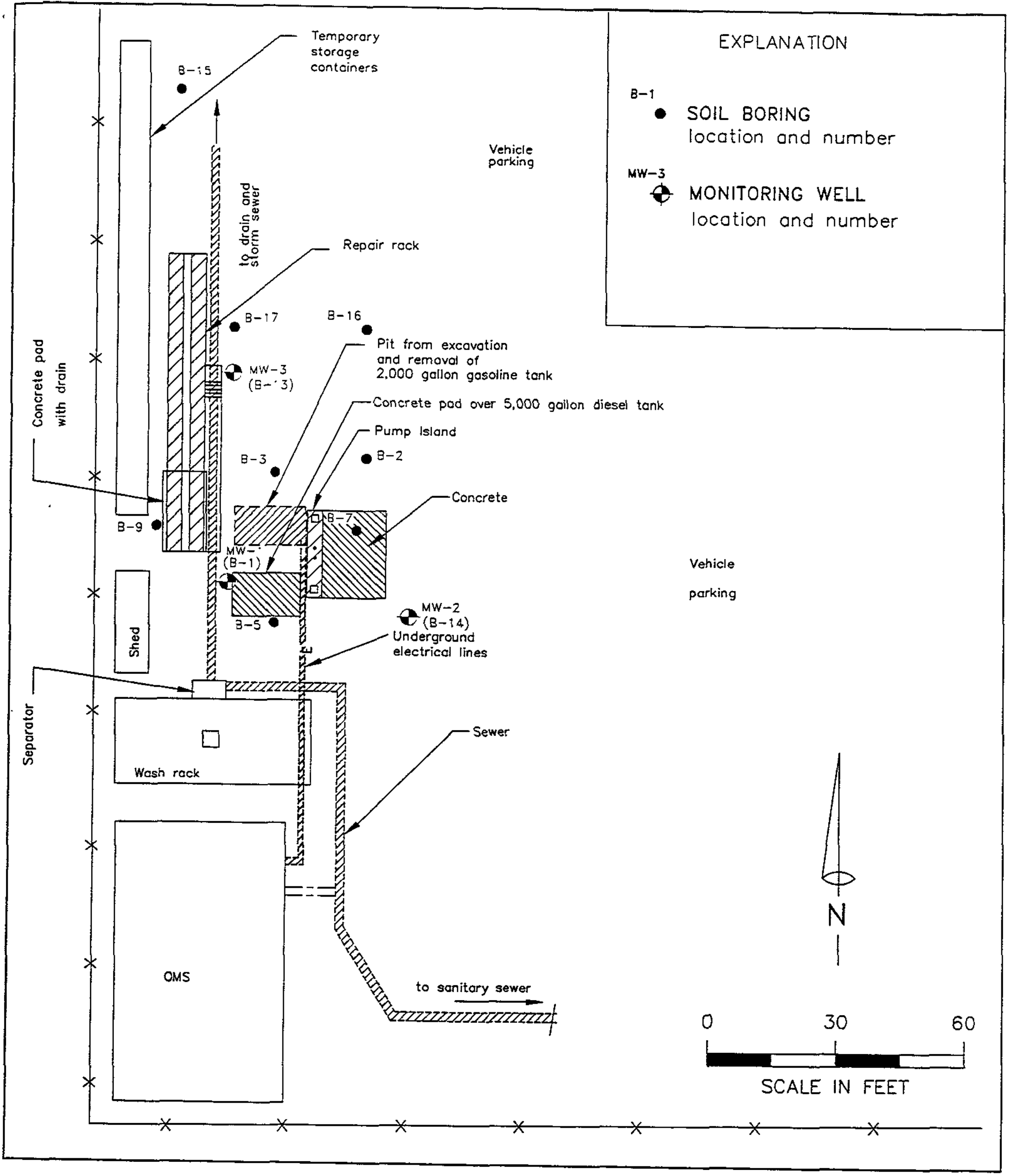


Figure 2 Site Plan with Soil Boring and Monitoring Well Locations

PROJECT NO.9410-01 DRAWN BY EH DATE 7/23/93 FILE NO. SITEPLAN

Table 2
Analytical Results for Petroleum Hydrocarbons and Lead in Soil Samples Collected From Soil Borings Drilled July 7, 8, and 9, 1993 at San Lorenzo, OMS #35

Sample Number	Depth (ft)	TRPH (418.1) (mg/kg)	TPH - D (8015mod) (mg/kg)	TPH - G (8015mod) (mg/kg)	Organic Pb (22 CAC) (mg/kg)	Total Pb (7420) (mg/kg)	Benzene (8020) (mg/kg)	Toluene (8020) (mg/kg)	Ethylbenzene (8020) (mg/kg)	Xylene (8020) (mg/kg)	PID (ppm)
B1-5	5.0 - 5.5	ND	ND	ND	na	na	ND	ND	ND	ND	0.6
B1-9.5&10	9.5 - 10.5	ND	ND	ND	ND	17	ND	ND	ND	ND	0.3
B1-15	15.0 - 15.5	ND	ND	ND	na	na	ND	ND	ND	ND	0.4
B1-20	20.0 - 20.5	ND	ND	ND	na	na	ND	ND	ND	ND	0.4
B2-5	5.0 - 5.5	ND	ND	ND	na	na	ND	ND	ND	ND	0.3
B2-9.5&10	9.5 - 10.5	ND	ND	ND	ND	10	ND	ND	ND	ND	0.6
B2-15	15.0 - 15.5	ND	ND	ND	na	na	ND	ND	ND	ND	0.6
B3-5	5.0 - 5.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
B3-9.5&10	9.5 - 10.5	82	17	**450**	ND	13	2.4	11	8	8	151
B3-15	15.0 - 15.5	19	ND	7	na	na	0.066	0.32	0.2	0.75	54
B3-20	20.0 - 20.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
B5-5	5.0 - 5.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
B5-10	10.0 - 10.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
B5-15	15.0 - 15.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
B7-5	5.0 - 5.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
B7-10	10.0 - 10.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
B7-15	15.0 - 15.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
B9-5	5.0 - 5.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
B9-10	10.0 - 10.5	ND	na	ND	na	na	ND	ND	ND	ND	0
B13-9.5&10	9.5 - 10.5	ND	ND	5.9	ND	17	0.19	0.006	0.04	0.31	6.4
B13-15	15.0 - 15.5	ND	ND	ND	na	na	ND	ND	ND	0.008	2.8
B14-10	10.0 - 10.5	ND	na	ND	na	na	ND	ND	ND	ND	0
B14-15	15.0 - 15.5	ND	na	ND	na	na	ND	ND	ND	ND	0
B15-5	5.0 - 5.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
B15-10	10.0 - 10.5	ND	na	ND	na	na	ND	ND	ND	ND	0
B15-15	15.0 - 15.5	ND	na	ND	na	na	ND	ND	ND	ND	0
B16-5	5.0 - 5.5	ND	na	ND	na	na	ND	ND	ND	ND	0
B16-10	10.0 - 10.5	ND	na	ND	na	na	ND	ND	ND	ND	0
B16-15	15.0 - 15.5	ND	na	ND	na	na	ND	ND	ND	ND	0
B17-25	25.0 - 25.5	ND	ND	ND	na	na	ND	ND	ND	ND	0
Detection Limit:		10	5	1	1	1	0.005	0.005	0.005	0.005	---
Average		3.37	0.77	15.43	ND	14.25	0.09	0.38	0.27	0.30	7.20
Maximum		82	17	450	ND	17	2.4	11	8	8	151
Minimum		ND	ND	ND	ND	10	ND	ND	ND	ND	0

Note: Only soil samples which had detectable concentrations of TPHg were analyzed for lead
na = not analyzed for this analyte
ND = not detected at or above detection limit
Bold = TPH-G > 100 mg/kg
Averages are computed assuming that ND = 0 mg/kg.

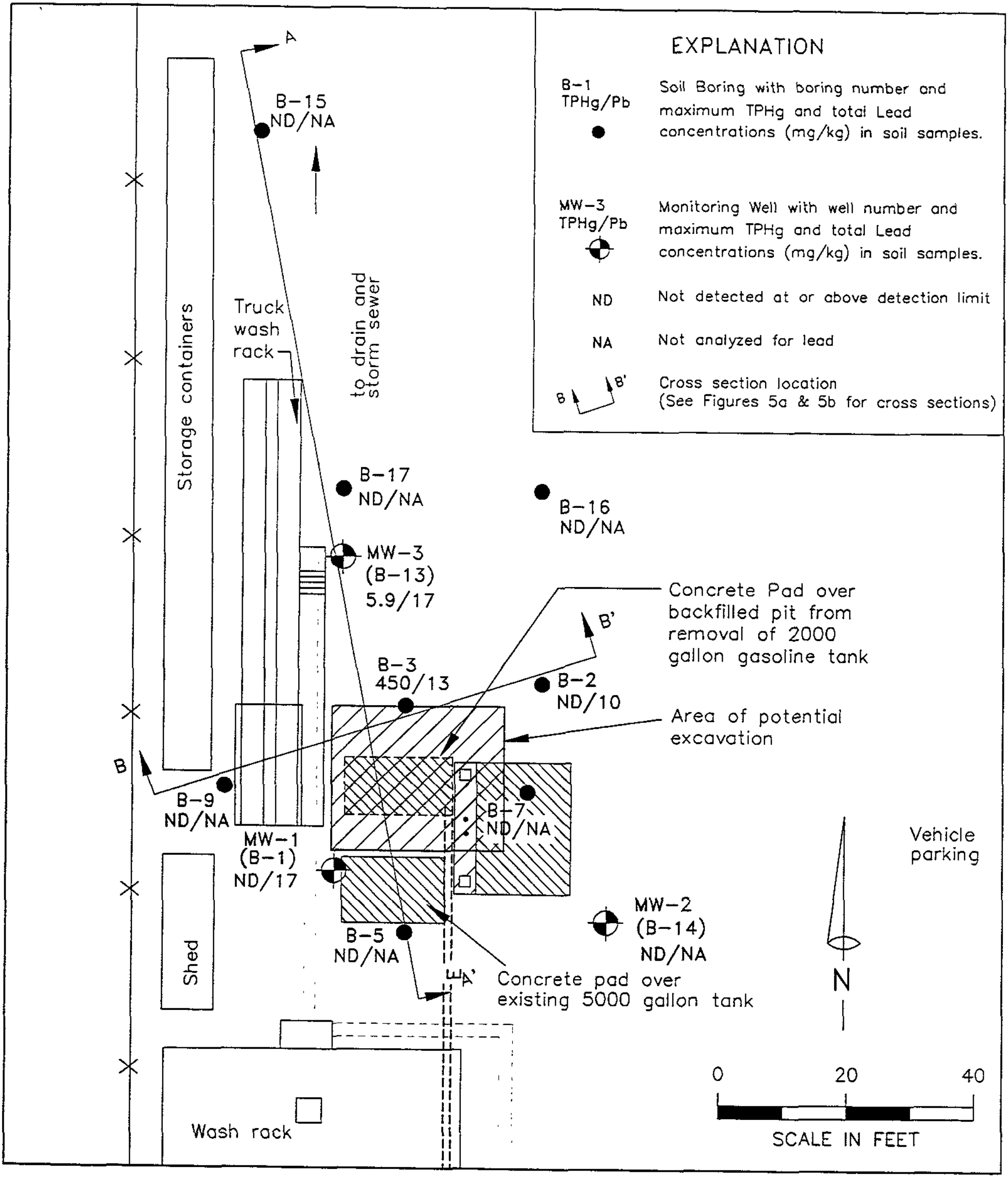
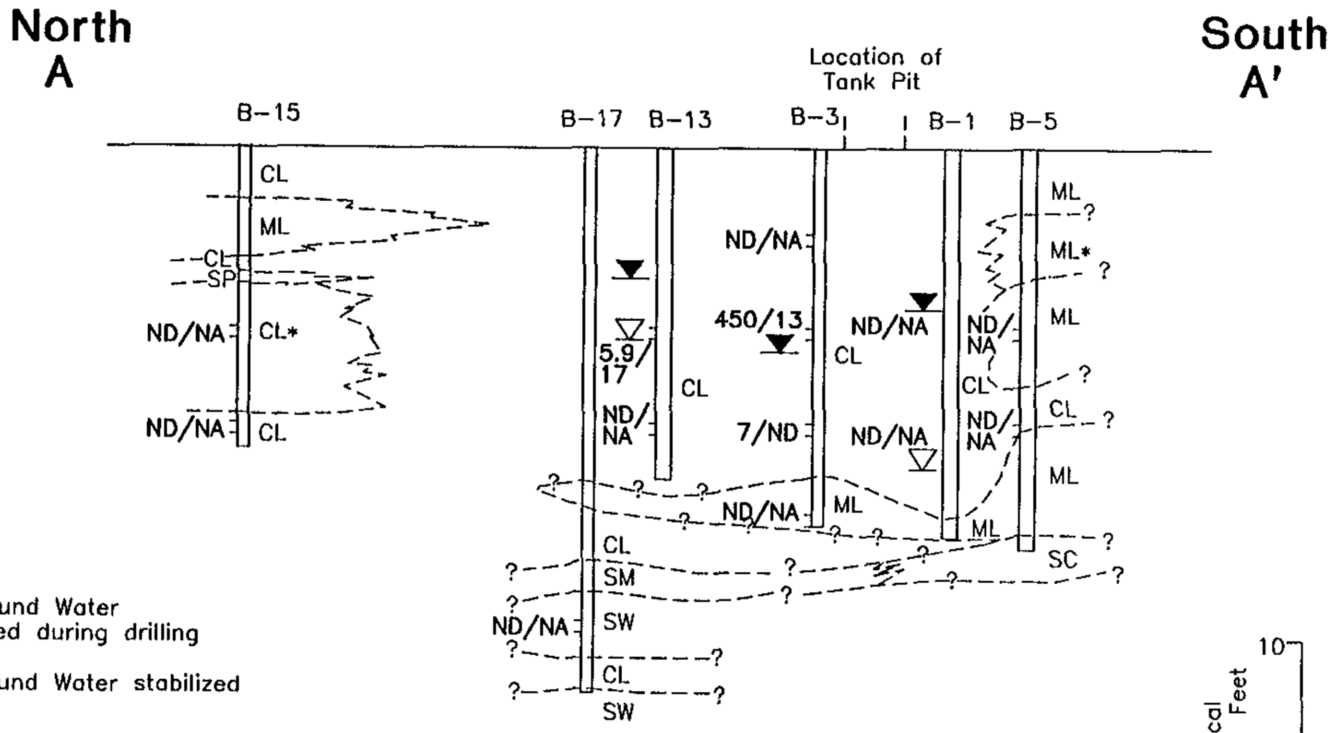
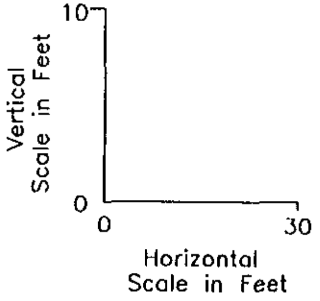


Figure 5

Site Map Showing Soil TPHg and Lead Concentrations and Area of Potential Excavation

PROJECT NO.9410-01 DRAWN BY EH DATE 9/28/93 FILE NO. FIG6





EXPLANATION

▽ Depth at which Ground Water was first encountered during drilling

▼ Depth at which Ground Water stabilized

┤ Location of Soil Sample in Boring

NOTES:

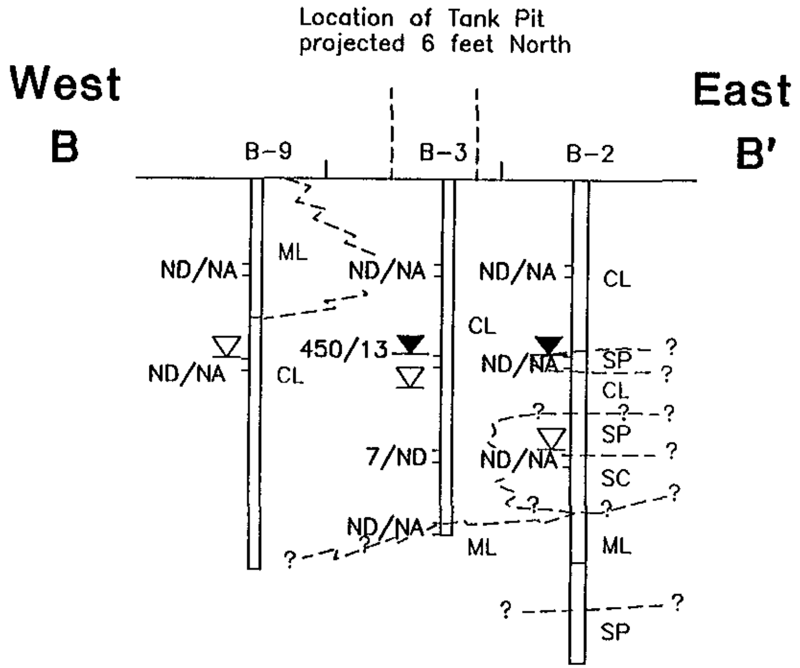
ND Not detected at or above detection limits
NA Not analyzed for this analyte

* Denotes presence of thin lenses of sand

Figure 5a

Cross-Section A-A' Showing TPHg and Total Lead ConcentrationS in Soil Samples

PROJECT NO. 9410-02 DRAWN BY EH DATE 8/17/93 FILE NO. FIG5A



EXPLANATION

▽ Depth at which Ground Water was first encountered during drilling

▼ Depth at which Ground Water stabilized

┤ Location of Soil Sample in Boring

NOTES:

ND Not detected at or above detection limit
NA Not analyzed for this analyte

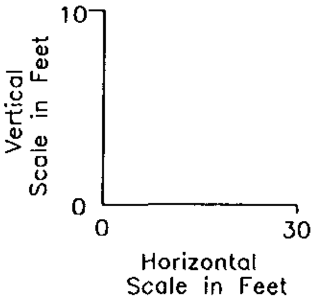


Figure 5b

Cross Section B–B' Showing TPHg and Total Lead Concentrations in Soil Samples

PROJECT NO. 9410-02 DRAWN BY eh DATE 8/17/93 FILE NO FIG5B

Table 3
Analytical Results for Petroleum Hydrocarbons and Lead in Grab Ground Water Samples Collected From Soil Borings Drilled July 7, 8, and 9, 1993 at San Lorenzo, OMS #35

Sample Number	TRPH (418.1) (mg/L)	TPH - D (8015mod) (ug/L)	TPH - G (8015mod) (ug/L)	Organic Pb (22 CAC) (mg/L)	Dissolved Pb EPA 7421 (mg/L)	Benzene (8020) (ug/L)	Toluene (8020) (ug/L)	Ethylbenzene (8020) (ug/L)	Xylenes (8020) (ug/L)
B1-W1	ND	ND	ND	na	na	ND	ND	ND	ND
B2-W1	ND	ND	61	ND	ND	0.6	2.1	62	0.8
B2-W2*	ND	ND	ND	na	na	ND	ND	ND	ND
B3-W1	3.3	ND	110000	ND	ND	3400	7600	2600	10000
B5-W1	ND	ND	ND	na	na	ND	ND	ND	ND
B7-W1	ND	ND	ND	na	na	ND	ND	ND	ND
B9-W1	ND	56	ND	na	na	ND	ND	ND	ND
B13-W1	Free Product	na	na	ND	ND	na	na	na	na
B14-W1	ND	na	ND	na	na	ND	ND	ND	ND
B15-W1	ND	ND	ND	na	na	ND	ND	ND	ND
B16-W1	ND	na	ND	na	na	ND	ND	ND	ND
B17-W1*	ND	ND	ND	na	na	ND	ND	1.7	ND
Detection Limit	1	50	50	0.05	0.005	0.5	0.5	0.5	0.5
Average	0.33	7.00	11000.00	ND	ND	340.06	760.21	266.37	1000.1
Maximum	3.3	56	110000	ND	ND	3400	7600	2600	10000
Minimum	ND	ND	ND	ND	ND	ND	ND	ND	ND
Maximum Contaminant Levels (MCLs) for Drinking Water									
EPA MCL	---	---	---	---	0.05	5	1,000	700	11,000
Cal DHS MCL	---	---	---	---	0.05	1	---	680	1,750

Note: Only water samples which had detectable concentrations of TPHg were analyzed for lead.
na = not analyzed for this analyte
ND = not detected at or above detection limit
Shading = TPH > 10 mg/L, BTEX > MCLs
Averages are computed assuming ND = 0.
* Sample B17-W1 is from the lower aquifer and sample B2-W2 is predominately composed of water from the lower aquifer (Tetra Tech, 1993, p. 25). All other samples are from the upper aquifer.

Table 4
Analytical Results for Petroleum Hydrocarbons and Lead in Ground Water Samples Collected July 14, 1993 at San Lorenzo, OMS #35

Sample Number	TRPH (418.1) (mg/L)	TPH - D (8015mod) (ug/L)	TPH - G (8015mod) (ug/L)	Benzene (8020) (ug/L)	Toluene (8020) (ug/L)	Ethylbenzene (8020) (ug/L)	Xylene (8020) (ug/L)
MW1	ND	ND	ND	ND	ND	ND	ND
MW2	ND	ND	ND	ND	ND	ND	ND
MW3	1.0	ND<200	4100	ND<5	ND<5	ND<5	640
Detection Limit	0.5	50	50	0.5	0.5	0.5	0.5
Average	0.33	ND	1366.67	ND	ND	ND	213.33
Maximum	1	ND	4100	ND	ND	ND	640
Minimum	ND	ND	ND	ND	ND	ND	ND
Maximum Contaminant Levels (MCLs) for Drinking Water							
EPA MCL	---	---	---	5	1,000	700	11,000
Cal DHS MCL	---	---	---	1	---	680	1,750

NA = not analyzed for this analyte
ND = not detected at or above detection limit
Averages are computed assuming ND = 0.

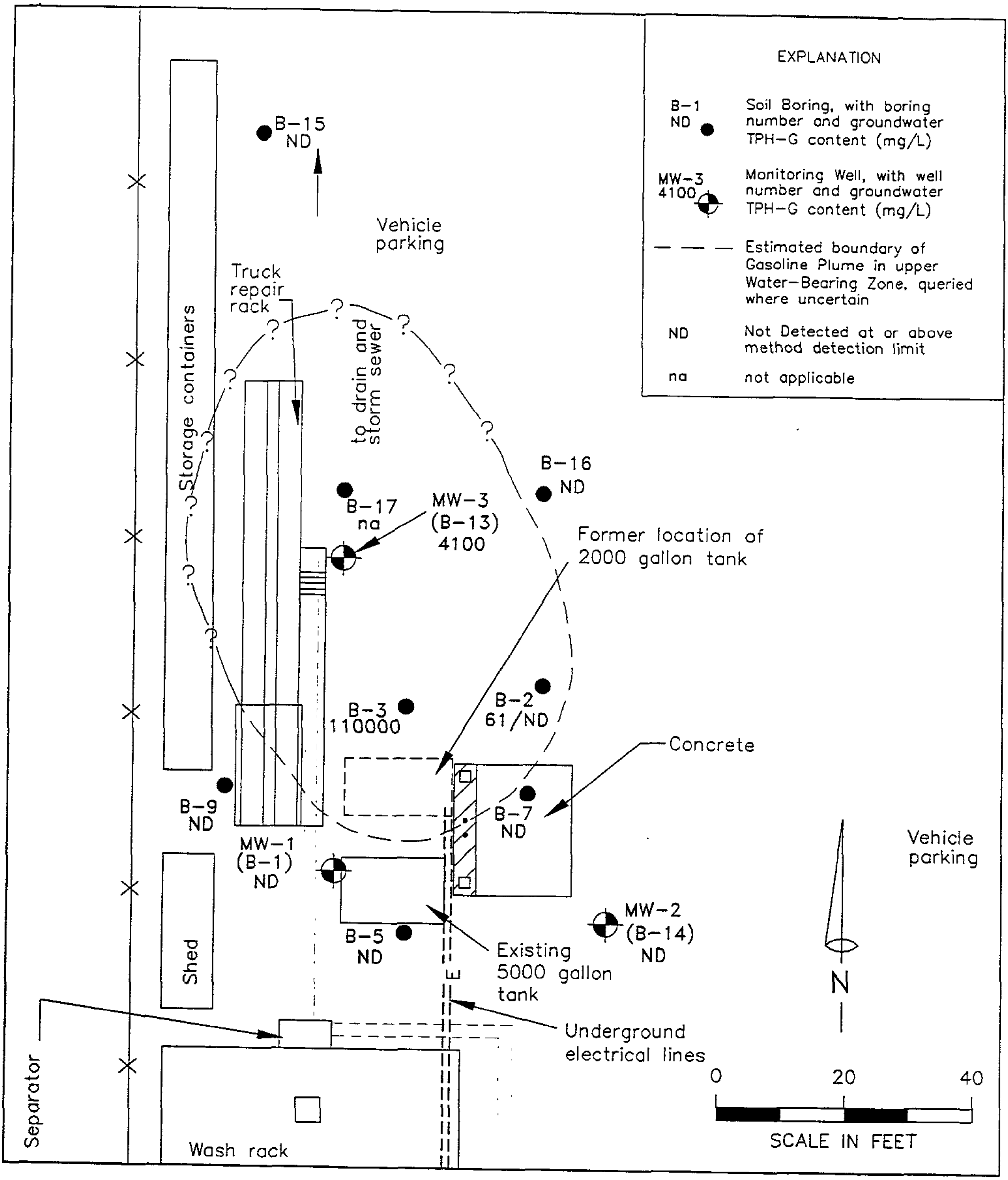


Figure 6 Map Showing Extent of Gasoline Plume in the Upper Water-Bearing Zone

PROJECT NO.9410-01 DRAWN BY EH DATE 9/28/93 FILE NO. FIG7

Table 5

Ground Water Elevations at San Lorenzo, OMS #35

Monitoring Well	Date Measured	Elevation at Top of Casing (feet MSL)	Depth to Water (feet)	Ground Water Elevation (feet MSL)
MW-1	7/14/93	35.53	8.05	27.48
	8/12/93		8.66	26.87
MW-2	7/14/93	36.32	8.86	27.46
	8/12/93		9.43	26.89
MW-3	7/14/93	34.54	7.34	27.20
	8/12/93		7.89	26.67

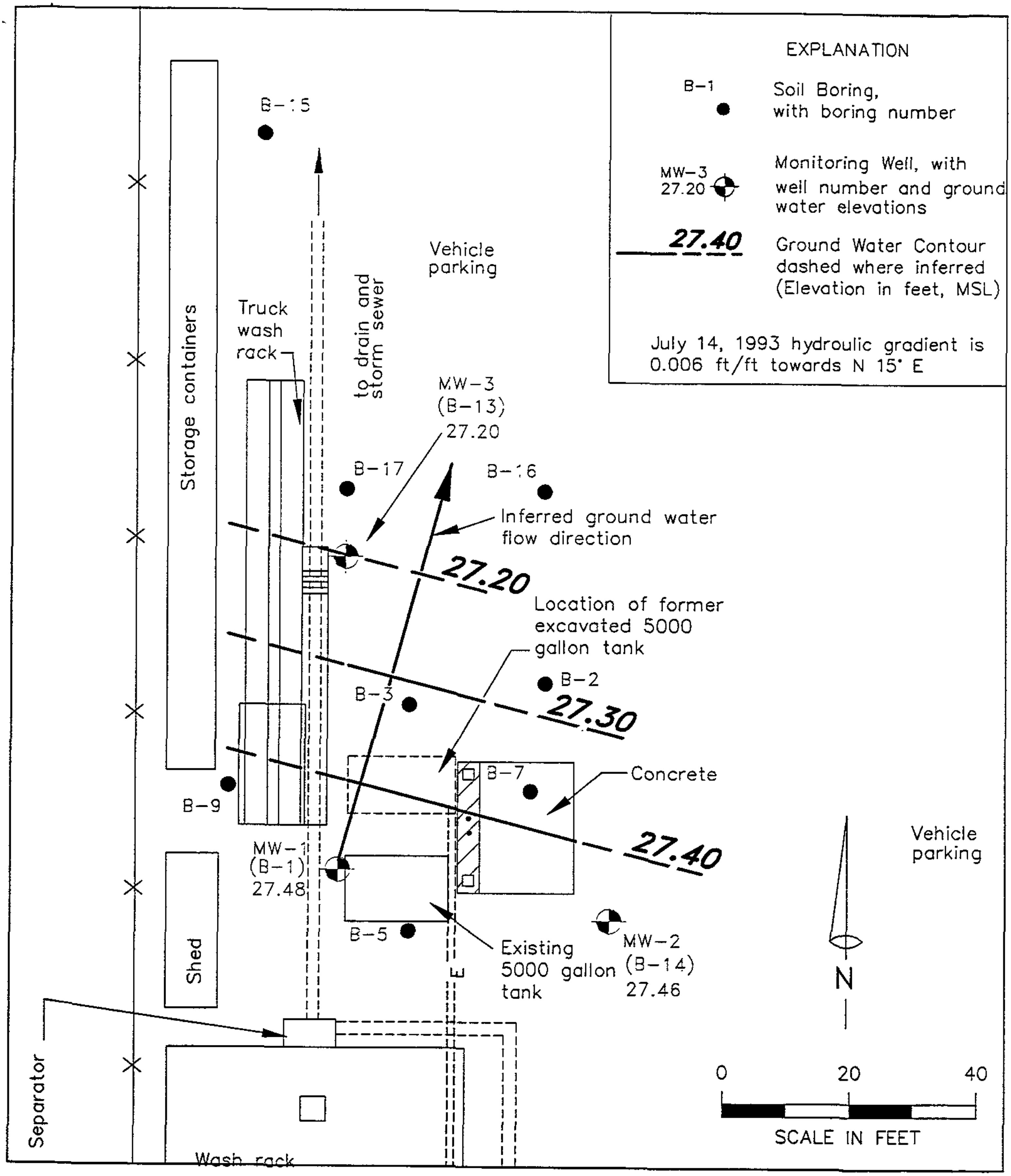
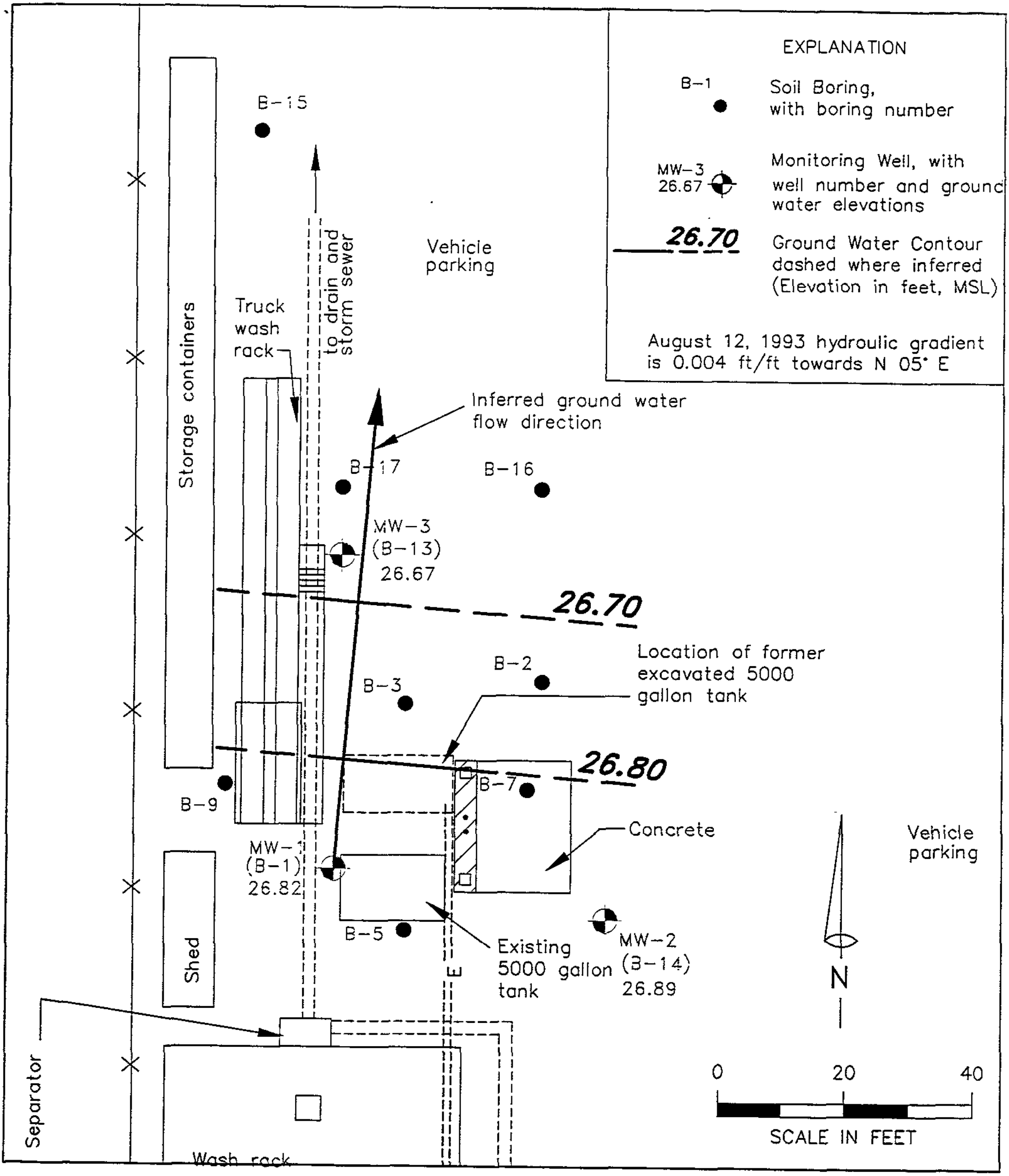


Figure 7

Water Table Contours and Hydraulic Gradient for July 14, 1993

PROJECT NO.9410-01 DRAWN BY EH DATE 8/2/93 FILE NO. FIG4



August 12, 1993 hydroulic gradient is 0.004 ft/ft towards N 05° E

Figure 8

Water Table Contours and Hydraulic Gradient for August 12, 1993

PROJECT NO.9410-01 DRAWN BY EH DATE 8/2/93 FILE NO. FIG8

APPENDIX A

REMEDIATION METHODS FOR SOIL

PASSIVE AERATION (VOLATILIZATION)

Volatilization refers to the removal of volatile contaminants from soil by evaporation. In this process, soil is spread in a thin layer, about 6 inches thick, on an impermeable surface and left uncovered ("uncontrolled" aeration) so the evaporating volatile contaminants can dissipate. The soil may be tilled periodically to make sure that clods of dirt are broken up and that most of the soil gets exposed to the air.

Only contaminants with sufficiently high vapor pressures can be remediated by volatilization. Of the contaminants which are considered in this study, only petroleum contaminants can be remediated by volatilization. Heavier hydrocarbons which make up diesel fuel, motor oil, or grease have too low a vapor pressure for this technique to be effective.

Volatilization works more effectively with the fresh gasoline which contains a greater percentage of volatile constituents compared to weathered gasoline (Table 4.2-1). Table 4.2-2 shows the boiling point and the vapor pressure measured at 20° C for selected gasoline compounds.

Because the gasoline compounds are removed from the soil through volatilization, the magnitude of residual risk associated with the soil is minimal and the effectiveness of the treatment is permanent.

This means of treatment reduces the total volume and the concentration of the petroleum hydrocarbons in the soil to concentrations below the detection limit for typical analytical methods (EPA Method 8015 modified; detection limit = 1 mg/kg). Soil sampling after volatilization treatment is recommended to insure that the concentration of hydrocarbon components in the soils has decreased.

In uncontrolled aeration, the volatilized gases are emitted to the atmosphere where they dissipate and are diluted. If there is a large volume of soil which is being aerated and/or if the gasoline is present in high concentrations, the amount of volatile material emitted may significantly impact the air-quality on the site and downwind of it. This could have deleterious effects upon the community and upon workers on the site. Periodic ambient and personal air monitoring for benzene during uncontrolled aeration is recommended.

TABLE 4.2-1
COMPOSITION (MASS FRACTIONS) OF FRESH AND WEATHERED GASOLINE

Compound Name	M_w (g)	Fresh Gasoline	Weathered Gasoline
Propane	44.1	0.0001	0.0000
Isobutane	58.1	0.0122	0.0000
n-Butane	58.1	0.0629	0.0000
Trans-2-Butene	56.1	0.0007	0.0000
Cis-2-Butene	56.1	0.0000	0.0000
3-Methyl-1-Butene	70.1	0.0006	0.0000
Isopentane	72.2	0.1049	0.0069
1-Pentene	70.1	0.0000	0.0005
2-Methyl-1-Butene	70.1	0.0000	0.0008
2-Methyl-1,3-Butadiene	68.1	0.0000	0.0000
n-Pentane	72.2	0.0586	0.0095
Trans-2-Pentene	70.1	0.0000	0.0017
2-Methyl-2-Butene	70.1	0.0044	0.0021
2-Methyl-2-Butadiene	68.1	0.0000	0.0010
3,3-Dimethyl-1-Butene	84.2	0.0049	0.0000
Cyclopentane	70.1	0.0000	0.0046
3-Methyl-1-Pentene	84.2	0.0000	0.0000
2,3-Dimethylbutane	86.2	0.0730	0.0044
2-Methylpentane	86.2	0.0273	0.0207
3-Methylpentane	86.2	0.0000	0.0186
n-Hexane	86.2	0.0283	0.0207
Methylcyclopentane	84.2	0.0083	0.0234
2,2-Dimethylpentane	100.2	0.0076	0.0064
Benzene	78.1	0.0076	0.0021
Cyclohexane	84.2	0.0000	0.0137
2,3-Dimethylpentane	100.2	0.0390	0.0000

TABLE 4.2-1
COMPOSITION (MASS FRACTIONS) OF FRESH AND WEATHERED GASOLINE

Compound Name	M_w (g)	Fresh Gasoline	Weathered Gasoline
3-Methylhexane	100.2	0.0000	0.0355
3-Ethylpentane	100.2	0.0000	0.0000
n-Heptane	100.2	0.0063	0.0447
2,2,4-Trimethylpentane	114.2	0.0121	0.0503
Methylcyclohexane	98.2	0.0000	0.0393
2,2-Dimethylhexane	114.2	0.0055	0.0207
Toluene	92.1	0.0550	0.0359
2,3,4-Trimethylpentane	114.2	0.0121	0.0000
3-Methylheptane	114.2	0.0000	0.0343
2-Methylheptane	114.2	0.0155	0.0324
n-Octane	114.2	0.0013	0.3000
2,4,4-Trimethylhexane	128.3	0.0087	0.0034
2,2-Dimethylheptane	128.3	0.0000	0.0226
Ethylbenzene	106.2	0.0000	0.0130
p-Xylene	106.2	0.0957	0.0151
m-Xylene	106.2	0.0000	0.0276
3,3,4-Trimethylhexane	128.3	0.0281	0.0056
o-Xylene	106.2	0.0000	0.0274
2,2,4-Trimethylheptane	142.3	0.0105	0.0012
n-Nonane	128.3	0.0000	0.0000
3,3,5-Trimethylheptane	142.3	0.0000	0.0000
n-Propylbenzene	120.2	0.0841	0.0117
2,3,4-Trimethylheptane	142.3	0.0000	0.0000
1,3,5-Trimethylbenzene	120.2	0.0411	0.0493
1,2-4-Trimethylbenzene	120.2	0.0213	0.0707
n-Decane	142.3	0.0000	0.0140

TABLE 4.2-1
COMPOSITION (MASS FRACTIONS) OF FRESH AND WEATHERED GASOLINE

Compound Name	M_w (g)	Fresh Gasoline	Weathered Gasoline
Methylpropylbenzene	134.2	0.0351	0.0170
Dimethylethylbenzene	134.2	0.0307	0.0289
n-Undecane	156.3	0.0000	0.0075
1,2,4,5-Tetramethylbenzene	134.2	0.0133	0.0056
1,2,3,4-Tetramethylbenzene	134.2	0.0129	0.0704
1,2,4-Trimethyl-5-Ethylbenzene	148.2	0.0405	0.0651
n-Dodecane	170.3	0.0230	0.0000
Napthalene	128.2	0.0045	0.0076
n-Hexylbenzene	162.3	0.0000	0.0147
Methylnapthalene	142.2	0.0023	0.0134
Total		1.0000	1.0000

Source: Johnson et. al., 1990

TABLE 4.2-2
SELECTED COMPOUNDS IN GASOLINE AND THEIR CHEMICAL PROPERTIES

Compound Name	M_w (g/mole)	T_b 1 atm (C)	P_v°20 C (atm)
n-Pentane	72.2	36	0.57
n-Hexane	86.2	69	0.16
Trichloroethane	133.4	75	0.132
Benzene	78.1	80	0.10
Cyclohexane	84.2	81	0.10
Trichloroethylene	131.5	87	0.026
n-Heptane	100.2	98	0.046
Toluene	92.1	111	0.029
Tetrachloroethylene	166	121	0.018
n-Octane	114.2	126	0.014
Chlorobenzene	113	132	0.012
p-Xylene	106.2	138	0.0086
Ethylbenzene	106.2	138	0.0092
m-Xylene	106.2	139	0.0080
o-Xylene	106.2	144	0.0066
Styrene	104.1	145	0.0066
n-Nonane	128.3	151	0.0042
n-Propylbenzene	120.2	159	0.0033
1,2,4 Trimethylbenzene	120.2	169	0.0019
n-Decane	142.3	173	0.0013
DBCP	263	196	0.0011
n-Undecane	156.3	196	0.0006
n-Dodecane	170.3	216	0.00015
Napthalene	128.2	218	0.00014
Tetraethyllead	323	dec.@200C	0.0002
Gasoline	95	-	0.34
Weathered Gasoline	111	-	0.049

Source: Johnson et. al., 1990

TABLE 4.2-3
PHYSICAL AND CHEMICAL PROPERTIES OF TOXIC GASOLINE COMPOUNDS

	Mass %		Prevalence	Fate and Transport			Toxicity	
Compound	Volume in Gasoline %	Weight in Gasoline $	Gasolines Containing Chemical %	Water Solubility at 20 Degrees C (mg/L)	Vapor Pressure at 20 Degrees C (torr)	Degree of Biodegradability	Final RQ* (kg)	Confidence in data**
Benzene	1-2	0.81	>99	1,780	75.0	Some	4.54	+
Toluene	4.0	12.02	>99	515	22.0	Some	454.00	+
Xylene-M	5-8	3.83	>99	175	5.0	Some	454.00	+
Xylene-O	5-8	1.93	>99	162	6.0	Some	454.00	+
Xylene-P	5-8	1.58	>99	198	6.5	Some	454.00	+
Ethylbenzene	2-5	1.70	>99	152	7.0	Some	454.00	+
Napthalene	0.7	0.10	>90	31.1	1.0	Readily	45.40	+
Phenol	-	-	>90	66,667	0.5	Readily	454.00	+
EDB	0.01	0.024	<40	4,310	11.0	Some	4.54	0
EDC	0.01	<0.024	<40	8,690	61.0	Some	45.40	0
Tetraethyl Lead	-	-	<40	0.08	0.2	Some	4.54	0
Dimethylamine	-	-	-	1,000,000	1345	Readily	454.00	-
Cyclohexane	<0.7	.17	-	66.5	77.0	Some	454.00	-

* : the lower the RQ value, the more toxic the chemical is in pure form.
** : + = highly confident; 0 = somewhat confident; - = not confident
Source: EPA, 1988

TABLE 4.2-4
OCCUPATIONAL EXPOSURE LIMITS FOR LEAD-FREE GASOLINE AND BENZENE

Automotive gasoline, lead free		
1990 OSHA PELs 8-hr TWA: 300 ppm, 900 mg/m^3 15-min STEL: 500 ppm, 1500 mg/m^3	**1990-91 ACGIH TLVs** TWA: 300 ppm, 890 mg/m^3 STEL: 500 ppm, 1480 mg/m^3 **1990 NIOSH REL** None established	**1985-1986 Toxicity Data*** Man, inhalation TC_{Lo}: 900 ppm/1 hr; toxic effects include sense organs and special senses (conjuctive irritation), behavioral (hallucinations, distorted perceptions), lungs, thorax, or respiration (cough) Human, eye: 140 ppm/8hr; toxic effects include mild irritation Rat, inhalation, LC_{50}: 300 g/m^{3}5/min
Benzene, ca 100%**		
1989 OSHA PELs (29 CFR 1910.1000, Table Z-1-A) 8-hr TWA: 1 ppm, 3 mg/m^3 15-min STEL: 5 ppm, 15 mg/m^3 (29 CFR 1910.1000, Table Z-2) 8-hr TWA: 10 ppm Acceptable Ceiling concentration: 25 ppm Acceptable Maximum Peak: 50 ppm (10 min)	**1989-90 ACGIH** TLV-TWA: 10 ppm, 32 mg/m^3 **1988 NIOSH RELs** TWA: 0.1 ppm, 0.3 mg/m^3 Ceiling: 1 ppm, 3 mg/m^3	**1985-1986 Toxicity Data** Man, oral, LD_{Lo}: 50 mg/kg; no toxic effect noted Man, inhalation, TC_{Lo}: 150 ppm inhaled intermittently over 1 yr in a number of discrete, separate doses affect the blood (other changes) and nutritional and gross metabolism (body temperature increase) Rabbit, eye: 2 mg administered over 24 hr produces severe irritation

* A typical modern gasoline composition is 80% paraffins, 14% aromatics, and 6% olefins. The mean benzene content is approximately 1%. Other additives include sulfer, phosphorus, and MTBE.

** OSHA 29 CFR 1910.1000 Subpart Z, states that the final benzene standard in 29 CFR 1910.1028 applies to all occupational exposures to benzene except in some subsegments of industry where exposures are consistently under the action level (i.e., distribution and sale of fuels, sealed containers and pipelines, coke production, oil and gas drilling and production, natural gas processing, and the percentage exclusion for liquid mixtures); for the excepted subsegments, the benzene limits in Table Z-2 apply.

Acceptable maximum peak above the acceptable ceiling concentration for an 8-hr shift.

See NIOSH, RTECS (CY1400000), for additional irritative, mutative, reproductive, tumorigenic, and toxicity data.

Source: Genium Publishing Corp., 1990, 1991.

For simple open-air aeration, technology is usually not a limitation. The soils should be laid out on an impermeable surface to avoid contamination of the underlying soil. Such a substrate may be polyethylene sheeting or a solid impermeable surface such as concrete. The soil should be broken up into small pieces. This may be done with a rototiller or soil shredder.

Soil conditions can limit the effectiveness of volatilization. Soil with limited pore space due to compacted conditions or fine-grained texture could restrict the rate at which gasoline may diffuse through the soil. Rototilling the soil can increase the soil permeability.

Moisture content of the soil also affects the rate of volatilization. Liquid water in the pore spaces of wet soils will inhibit diffusion of the volatilized gasoline.

Adequate space must be available to thin-spread the soil for open-air aeration. Soil handling equipment is needed to move the soil, and till it. Also, the space in which the soil is remediated should be sufficiently removed from residences and places of work that any odor or fumes are not a nuisance.

Time to complete: The time it takes to remediate gasoline-contaminated soils by volatilization of the gasoline depends upon the concentration of gasoline in the soil; soil conditions such as permeability, composition, and moisture content; and temperature. For a permeable soil containing 50 mg/kg gasoline, remediation could be accomplished in a matter of a few days to three weeks, depending upon the temperature and how often the soil was tilled.

The major concern regarding volatilization is the impact upon air quality. In the San Francisco Bay area, the Bay Area Air Quality Management Distract (BAAQMD) regulates air quality in the nine contiguous counties which surround San Francisco Bay. BAAQMD's Regulation 8, Rule 40, specifically addresses aeration of soil containing more than 50 mg/kg of organic contaminants with boiling points of 302° F or higher. Table 4.2-5 shows the allowable rates of uncontrolled aeration.

BAAQMD should be notified whenever aeration of gasoline-contaminated soil is planned.

Costs for uncontrolled volatilization are quite low, ranging from \$2.50 to \$20 or more per cubic

TABLE 4.2-5
ALLOWABLE RATE OF UNCONTROLLABLE AERATION OF GASOLINE-CONTAMINATED SOIL

Gasoline Content mg/kg	Rate of Uncontrolled Aeration	
	m^3/day	yards^3/day
<50	Exempt	Exempt
50 - 99	459.0	600
100 - 499	91.8	120
500 - 999	45.9	60
1,000 - 1,999	22.9	30
2,000 - 2,999	11.5	15
3,000 - 3,999	7.6	10
4,000 - 4,999	5.7	8
>5,000	0.08	0.1

Source: BAAQMD, 1989

depending upon the soil volume and the amount of labor it takes to prepare and turn the soil.

BIOREMEDIATION

Bioremediation includes treatment methods which rely on a biological process to permanently decrease the toxicity the contaminants in the contaminated medium. Sometimes this involves the use of microorganisms, which chemically transform the contaminant molecules, deriving energy for cell processes from the degradation reaction. Some bioremediation designs rely on micro-organisms which transform contaminants without using them as an energy source, whereas other designs use enzymes instead of living micro-organisms. A specialized area of bioremediation involves the use of plants which remove contaminants from environmental media, concentrating them in the plant tissues, which can be harvested and disposed.

Four general categories of bioremediation are discussed in this section, including:

- In-situ bioremediation (including bioventing);
- Prepared bed bioremediation or landfarming (including composting), which involves excavation and ex-situ treatment of unsaturated soil;
- Bioreactor or bioslurry bioremediation, which includes aqueous, suspended growth techniques; and
- Bio-uptake techniques, which are usually, but not necessarily applied in-situ, and involve concentration of a contaminant in a biological substrate which can be physically separated from the contaminated medium.

Before discussing these bioremediation methods, it is necessary to briefly describe the bioremediation process. The chemical/biological processes involved in biodegradation are similar whether biodegradation occurs in-situ, ex situ, or in soil or ground water media. The choice of which treatment method to use may be influenced by site-specific constraints such as limitations on space or accessibility, regulatory constraints, cost constraints, and environmental conditions, which affect the feasibility and cost of bioremediation methods.

Biodegradation involves the chemical transformation, through a biologic process, of one chemical species to other chemical products. The objective of bioremediation is detoxification of the parent contaminant compound(s) into products which are not hazardous to human health or the environment. complete mineralization of contaminants is not necessarily an appropriate endpoint in bioremediation. The products of complete aerobic biodegradation (degradation in the presence of excess oxygen) are carbon dioxide, water, inorganic compounds, and cell protein. The products of anaerobic biodegradation (in the absence of oxygen), are incompletely oxidized intermediate substances such as organic acids, and other products, such as methane or hydrogen gas (Sims et al, 1990). Some of the intermediate substances may be as toxic or more toxic than the original contaminants.

Treatability studies may be needed to determine biodegradation potential. Treatability studies should provide an estimate of time required for cleanup, level of cleanup attainable, and the cost of cleanup. Measurements of bioremediation potential should be carefully evaluated, since they may be misleading. For example, high concentrations of natural organic matter in soils may mask hydrocarbon reductions if gravimetric methods are used to analyze soils before and after remediation. Bioremediation intermediates, which contain oxygen, increase in mass as they degrade, which also masks reductions. Photochemical and volatile losses may occur independently from biodegradation, resulting in an overestimate of biodegradation in test plots. Since decreasing toxicity is the objective of bioremediation, direct measurement of toxicity, through bioassay techniques, may be appropriate.

Metabolism vs Cometabolism

Micro-organisms produce enzymes to metabolize the substrate which supplies energy for cell growth. Enzymes are proteins which are selective biological catalysts. Without catalysts, the reactions which produce energy for cell growth would not occur at a fast enough rate to support the growth of the organism and the population will not increase. Metabolic degradation of a compound occurs when the micro-organism uses the compound as its sole source of carbon and energy. Figure 4.7-1 illustrates the principal metabolic degradation reactions.

Often, biotransformations of contaminants occur even though the energy released is not used by the cell or is not adequate to support cell growth. Such degradation is called cometabolism. Cometabolism occurs when an enzyme produced by an organism to degrade the substrate which serves as its energy source also incidentally degrades another substance.

Since many enzymes are not released by micro-organisms, contaminant molecules must be transported into the cells. Living cells are not necessary, however, for the enzyme-catalyzed reaction to occur, if the proper reaction conditions are present. Enzymes which catalyze a reaction which degrades a selected contaminant can be isolated or manufactured. One of the advantages of using enzymes, rather than living organisms to degrade contaminants, is that enzymes do not reproduce. Another advantage is that it is that many of the conditions which limit growth of a microbial population, such as biotoxicity, lack of nutrients, etc., are not limiting to enzyme activity. A disadvantage of using enzymes is that they cannot adapt, as living micro-organisms can, to the contaminant substrate.

Since enzymes are often highly compound-specific, bioremediation of a mixture of contaminants may require the presence of a mixture, or consortium, of microbes and/or enzymes. Some of the contaminants in a mixture may degrade through an aerobic pathway, while others may degrade anaerobically, or an anaerobic step may be required to reach a desired intermediate which is more readily degradable. In such cases, it may be desirable to change the environmental conditions. Such changes are difficult to control in-situ, are more controllable in a prepared bed system, and are most controllable in bioreactors.

Biostimulation vs. Bioaugmentation

Two approaches are available in bioremediation projects biostimulation and bioaugmentation. Biostimulation (or bioenhancement), is the approach by which indigeneous organisms are supplied with the nutrients and other conditions optimal for their growth. According to the U.S. EPA (1988), more than 200 soil microbial species have been identified which can assimilate hydrocarbon substrates. Among the indigenous soil bacterial species capable of degrading petroleum hydrocarbons are *Pseudomonas, Flavobacterium, Achromobacter, Arthrobacter, Micrococcus,* and *Acinetobactor.* Microbial counts of hydrocarbon degraders in fertile soils range from 10^5 to 10^6 per gram of dry soil, or about 1 to 0.1 per cent of the indigenous bacteria (Bossert and Bartha, 1984). There are few species available which can utilize chlorinated compounds as a carbon source. These man-made compounds have only recently been introduced into the environment, and microorganisms have not had time to evolve the capability of utilizing these substrates. Jansen, et al (1991) list twelve indigenous bacterial strains capable of degrading chlorinated compounds. A non-selective enzyme, methane monooxygenase (MMO), produced by aerobic bacteria which utilize methan as their carbon source (methanotrophs), has been shown to oxidize a number of halogenated compounds. The microorganisms do not use the halogenated hydrocarbons a substrate. Their growth is dependent on the availability of methane. The more highly substituted the compound (the more chlorines or bromine atoms in the molecule) the less reactive the compound is under aerobic conditions. Vinyl chloride is more degradable than dichloroethylene, which is more degradable than trichloroethylene. Tetrachloroethylene is not degradable under aerobic conditions.

Degradation of the more highly substituted compounds such as PCE, carbon tetrachloride and hexachloroethane proceeds more readily under anaerobic conditions than aerobically. The biochemical mechanisms for such reactions are complex, since the dehalogenation intermediate products are less reactive under anaerobic conditions. Since some are more toxic than the contaminants, anaerobic dehalogenation is not usually pursued in-situ. For example, dichloromethane, chloroform, 1,2-DCA, trans-1,2-DCE, cis-1,2-DCE, TCE, 1,2-DCP, and trans-1,3-dichloropropylene are degraded by MMO (Vanssen et al 1991).

Biostimulation is used primarily for in-situ applications, where introduction of an organism may be discouraged by regulators or the public, and in dealing with certain recalcitrant contaminants or mixtures. Research continues on identifying and isolating organisms capable of degrading or constablizing recalcitrant compounds.

Bioaugmentation differs from biostimulation in which pure cultures of microorganisms or mixtures (consortia) are introduced to the contaminated medium. Usually these organisms are cometabolizing, which may be more effluent or tolerant to contaminants than indigenous microorganisms. The introduced organisms must compete with existing organisms for the substrate. One approach is to introduce organisms which cometabolize the chemical(s) of concern and utilize a substrate which must be introduced. In this way, introduction of the substrate only stimulates the growth of the desired organisms, and removal of the substrate source causes the introduced organisms to die off.

Critical Factors

Table 4.7-1 lists the optimal ranges of some of the critical factors in microbial activity. Moisture

TABLE 4.7-1
CRITICAL ENVIRONMENTAL FACTORS FOR MICROBIAL ACTIVITY

Environmental Factor	Optimum Levels
Available Soil Water	25-85% of water holding capacity; <0.01 MPa
Oxygen	Aerobic metabolism: Greater than 0.2 mg/l dissolved oxygen, minimum air-filled pore space of 10% by volume; Anaerobic metabolism: O_2 concentrations of less than 1% by volume
Redox Potential	Aerobes and facultative anaerobes: greater than 50 millivolts, pH 7-75; Anaerobes: less than 50 millivolts pH 5.5-8.5
Nutrients	Sufficient nitrogen, phosphorus, and other nutrients so not limiting to microbial growth (suggested C:N:P ratio of 120:10:1)
Temperature	15 - 45° C (Mesophiles)
Soil texture	Clay content low enough that oxygen diffusion is not restricted; organic matter not too high, since resultant microbial activity depletes oxygen.

Source: Sims, et. al., 1990

is the medium through which nutrients and organic constituents diffuse to the cell, and waste products are removed from the cell. Oxygen (and to a limited extent other electron acceptors such as sulfate and nitrate) is required for aerobic biodegradation of hydrocarbons. Redox potential is a measure of the ability of the system to accept electrons when molecular bonds are broken by oxidation reactions. Nutrients, particularly nitrogen and phosphorous, are used in microbial growth and must be supplied to enable microbial populations to increase. Extremes of temperature can inhibit microbial growth, and may affect the solubilities of contaminants, making them less degradable. Soil texture affects the moisture holding capacity and air permeability of soils, which in turn affects the rate of transfer of oxygen. Highly organic soils can stimulate microbial growth, resulting in depletion of oxygen.

Chemical Applicability

Biodegradation has been applied to a wide range of compounds, including, but not limited to petroleum hydrocarbons, halogenated volatiles, phenolic compounds, polynuclear aromatic hydrocarbons (PAHs), pesticides and herbicides, and PCBs. Petroleum hydrocarbons are among the most amenable to bioremediation. N-alkanes and n-alkylaromatics, in the C10 to C22 range (middle distillates, such as diesel, jet fuel, kerosene), are generally considered to be the least biotoxic and the most biodegradable, although double bonds resist complete degradation (Grubbs, 1986). Low molecular weight hydrocarbons tend to volatilize easily, and tend to be toxic to micro-organisms. Above C22, the low solubility of hydrocarbons tends to reduce their biodegradability. Branched compounds inhibit biodegradation. The hydrocarbons most resistant to biodegradation are the PAHs.

Interestingly, a recent California Department of Toxic Substances Demonstration Project (DHS 1990) successfully remediated diesel-contaminated soil by bioaugmented landfarming, from greater than 1000 mg/kg to less than 10 mg/kg in less than 3 months. But the control cell, which did not receive any nutrients, or proprietary inoculate, and was not vigorously aerated, showed reductions similar to the test cells. The reductions may have been a result of the presence of an active native microbial community in the control cell.

Some contaminants have not yet been found to be biodegradable. These include PCB congeners greater than 1248, PAHs with more than 5 rings, radiologic waste, asbestos, and metals. Changes in pH or organic content caused by microbial metabolism can affect the mobilities of metal complexes, causing them to mobilize or precipitate. At sites where metals are a concern, treatability studies should address the impacts on the mobilities of metals.

Process Description

Three types of bioremediation methods utilizing microbial populations and/or enzymes are available for ex situ soils. These include prepared bed bioremediation, or landfarming; composting, which is a subcategory of landfarming; and bioreactors. All three methods may rely on biostimulation, but in practice most ex situ applications use bioaugmentation to some degree, to increase the rate of degradation. In addition, certain plant species have been used to remove metals, which are not degradable by micro-organisms, from surficial soils (within the root zone of the plants). Plant uptake methods are considered to be an innovative technique.

Prepared Bed Bioremediation

Prepared bed bioremediation, or landfarming, is the most widely-used technique for remediation of petroleum hydrocarbons. It is relatively easy to implement and can be highly cost effective. It can be performed using readily obtainable equipment, although specialized equipment and techniques have been developed for application to large volumes of soil and recalcitrant chemicals or to overcome unfavorable conditions.

In landfarming excavated soil is placed in a treatment cell, and moisture, nutrients, and oxygen are supplied to encourage the growth of existing aerobic micro-organisms which are capable of metabolizing the contaminants in the soil to form carbon dioxide and water. Moisture may be supplied by a sprinkler system, nutrients may be added in the form of fertilizer and mulch, and oxygen is provided by tilling the soil. Figure 4.7-2 shows the layout of a typical landfarming system. Most landfarming relies on mesophilic (middle temperature) micro-organisms, which have an optimal temperature range of 15 to 45° C (59 to 113° F).

Landfarming cells are usually designed to facilitate aeration by tilling and overhead application of water and nutrients. Soils are typically placed in level beds, approximately 2 ft thick. The beds may be underlain by a liner, to collect leachate. Usually the beds are constructed in the open. Volatilization may

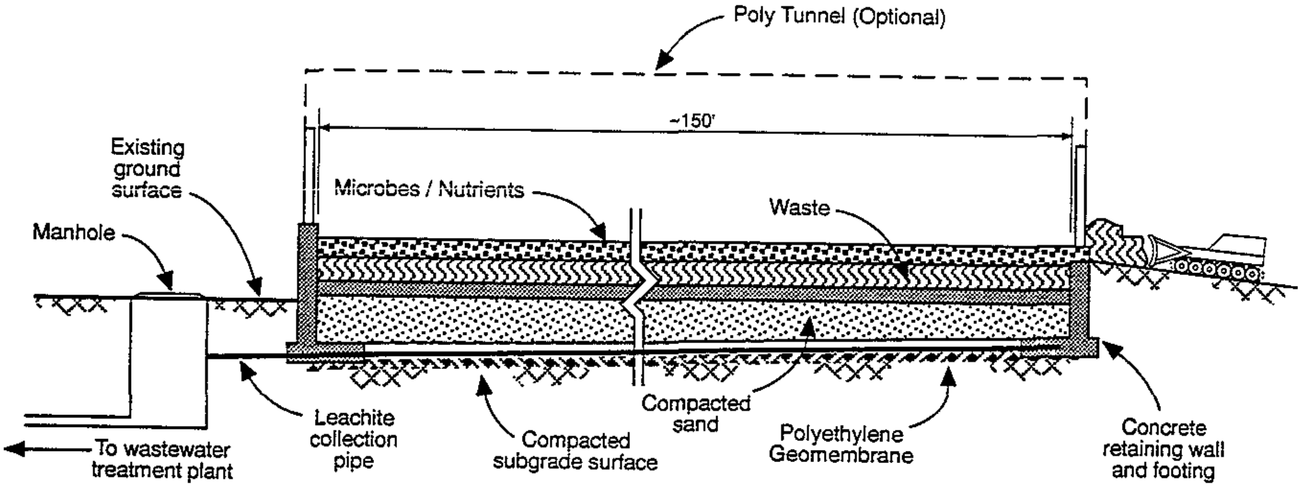


Figure 4.7-2 Typical Controlled Biological Land Treatment Unit

Source: TreaTek - CRA Company.

present an inhalation hazard for some contaminants, or may require permitting from air quality districts. More elaborate, commercially operated landfarming systems are available which include vapor containment systems. Other enhancements include automatic watering, aeration, and nutrient supply systems which minimize handling of the soil. Such systems can support thicker beds.

Composting

Composting is a specialized form of landfarming in which aerobic bacteria cometabolize contaminants in soil while digesting the compost substrate. Soil permeability is enhanced by addition of porous organic compost materials, such as straw, manure, shredded green matter, etc. Heat is generated during fermentation of the compost, supporting thermophilic bacteria during the active stage. Mesophilic bacteria and fungi prevail after cooling. Thermophilic metabolism is optimal in the range 45 to 55° C (113 to 131° F). Thermophilic bacteria can survive in temperatures up to about 70° C (158° F) (Wickham et al 1991). The shape and size of the compost pile is designed to retain heat. The physical characteristics of the compost pile must be maintained by frequent mixing and moistening, and are essential to maintaining the aerobic and thermophilic conditions necessary for cometabolism (Wickham et al, 1991). Moisture and oxygen can also be supplied to the piles by an internal network of piping. Elevated temperatures may result in an increased rate of contaminant degradation, partly as a result of increased solubility of high molecular weight compounds. Some of the reported rate enhancement may be a result of volatilization.

Wickham et al (1991) reported reductions in smudge-pot oil (tar) from an initial TPH concentration of 26,000 ppm to 790 ppm over a 10 week period. The compost medium consisted of 21.5 kg of smudge-pot oil, 50 kg of straw, 50 kg of chicken manure, and 400 kg of cow manure. Enzymes and a proprietary bacteria culture were added to the compost pipe at several times during the treatment period. Moisture content was maintained at about 53%. The temperature within the treatment pile reached 53° C (127° F). 550 cubic yards of gasoline- and diesel-contaminated soil were reportedly treated to non-detectable levels from initial concentrations in the range of 200 ppm of gasoline and 4000 ppm of diesel over a 6-month period. Samples indicated a highly heterogeneous distribution of contaminant concentrations.

4.7.2.3 Bioreactors

Bioreactors allow the highest level of control of the conditions which encourage biodegradation. Bioreactors are large open or closed containers in which soil is mixed with water to form a slurry. The slurry enables continuous mechanical mixing to homogeneously distribute nutrients. Temperature, pH, and oxygen content can be controlled. Bioreactors are batch systems. Figure 4.7-3 is a schematic representation of a bioreactor system. Since the conditions are carefully controlled, the reaction time can be closely predicted. Bioreactors offer the potential for designing highly specialized treatment trains for complex contaminants. Redox potential can be manipulated so that the slurry goes from aerobic to anaerobic at appropriate stages in treatment. Bioreactors are more likely to reproduce the conditions found to be optimal for treatment in bench-scale studies. Bioreactor systems can have relatively high throughput, but at high cost. They require frequent monitoring, and specialized equipment and training.

Plant Uptake

Plant uptake involves the cultivation of plant species which selectively concentrate metals in the plant tissue. This method is limited to the upper foot of soil. When the plants reach maturity, they whole plant or the foliage is harvested and disposed or treated. Water hyacinths have been successfully used to remove selenium from contaminated surface waters. Ragweed has been suggested for remediation of lead. Presumably, the metal species must be soluble in order to be removed from the soil. Precipitated species would not be removed. Removal efficiency would depend on root density, soil moisture, and the rate of plant transpiration. Like any crop, the plants would require supplemental nutrients and water to maintain optimal growth.

Applicable Contaminants

Long-Term Effectiveness and Permanence

Bioremediation is a permanent treatment method. Properly implemented, it permanently reduces the concentration of toxic substances. The degradation sequence followed by some contaminants depends on the conditions in the system. Anaerobic biodegradation of some chlorinated hydrocarbon parents may result in formation of more toxic products. These reactions can be identified in treatability studies.

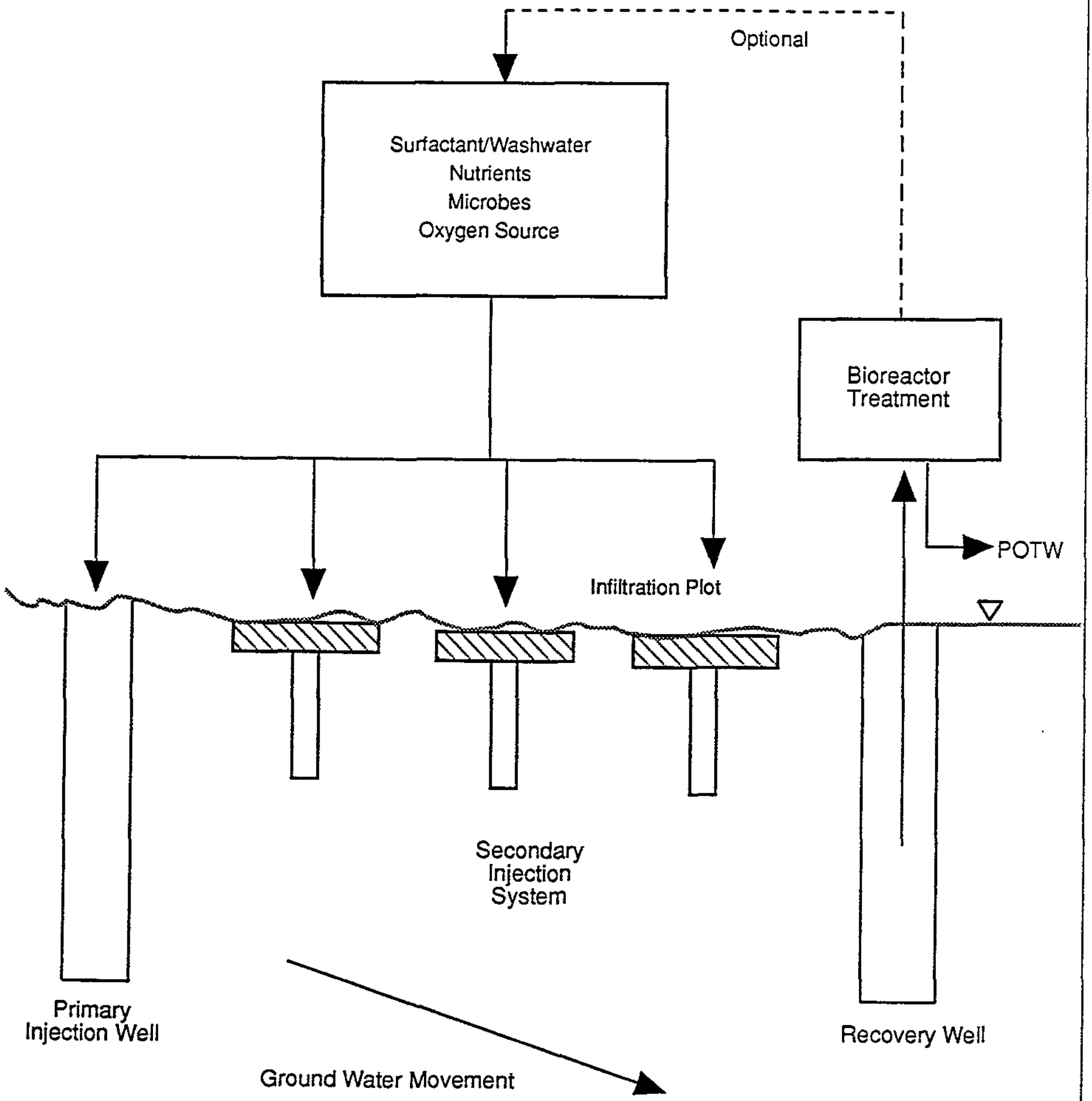


Figure 4.7-3 In-Situ Biological Treatment Schematic

Source: Trea Tek

Bioassays are one tool for measuring the change in toxicity following bioremediation. Decreasing the toxicity of the soil is the objective of bioremediation. Therefore, if toxicity cannot be reduced under the conditions of the site, then bioremediation should not be implemented at the site.

Short-Term Effectiveness

Short term effectiveness depends on the method. There is little chance that toxic intermediates will represent a significant short term threat for properly designed systems. Volatile losses during handling of soils containing volatiles may represent a significant short term hazard, particularly in landfarming. Many landfarming systems involve intensive handling and working of the soil. This may present short term hazards due to contact. Site-specific conditions may also result in short term hazards. These include operation of equipment and transport of soil to remote treatment sites. In general, however, short term hazards are low.

Implementibility

Landfarming is easily implementable, since it can be performed using readily available equipment, by personnel without specialized training, although more complex landfarming techniques, designed to address specific conditions, may require specialized equipment and training. Presence of volatiles in the soil may require mitigation of vapors to address ARARs, which may reduce implementibility. Treatability studies are performed to ensure that soils do not contain biotoxic substances which would limit the feasibility of a given remedial design, to estimate the rate and cost of biodegradation, and to design a treatment process which addresses the contaminant suite and the conditions which exist at the site.

Bioreactors are not as readily implementable as landfarming. Specialized training and equipment are required. Use of bioreactors implies a higher level of engineering design and treatability testing than is generally required for landfarming.

Regulatory and ARAR Compliance

ARARs which are most likely to impact ex situ bioremediation include air quality standards, use of best demonstrated available technology (BDAT) to mitigate vapor release, and leachate collection systems for landfarming. Similar ARARs may apply to bioreactor systems, if soil is stockpiled after excavation and before treatment. Soil cleanup standards are usually developed on a local or site-specific basis. The site-specific standards may not be possible to achieve by bioremediation. Again, treatability studies may be needed to demonstrate that the cleanup standards can be achieved.

Cost

The cost of enhanced bioremediation by landfarming of petroleum contaminated soils ranges between $30 to $60 per cubic yard (Cioffi et al, 1991); $60 to $125 per cubic yard (U.S. EPA, 1988). The cost is highly dependent on site-specific conditions.

The cost of bioreactor systems is in the same range as soil washing, $225 to $300 per cubic yard, including excavation.

SOIL VAPOR EXTRACTION

Process Description

In soils contaminated with volatile organic compounds (VOCs), a portion of the VOCs exist in a vapor phase which fills the soil's interstitial space. The process by which a contaminant volatilizes to the vapor phase is dependent upon the contaminant's Henry's Law constant, the temperature of the soil, the soil's moisture content and carbon content (*Pollution Engineering*, 1992).

SVE removes the VOCs by removing the soil vapor within the vadose zone. When the contaminated air is removed, clean air takes its place. A portion of the remaining VOCs will again volatilize into the interstitial pore space and be removed.

Vapor wells are emplaced within the contaminated zone and screened in the unsaturated zone. The wells are connected to a vacuum system which draws the contaminated air up through the pore space. The contaminated air is typically routed to a moisture separator. Water waste is generally routed through a carbon adsorption system and the vapor waste is generally destroyed by an afterburner. A typical soil vapor extraction system is presented as Figure 5.2-1.

SVE well grids are designed according to site conditions; however, two general well constructions exist: vertical extraction wells and horizontal extraction wells. Vertical wells are the most common method of employing SVE. Wells are placed into the contaminated soil zone but are screened in the unsaturated zone. The well casings are then connected to each other, and to a vacuum source.

In areas where the depth to ground water is low shallow, horizontal wells are occasionally used. Trenches are dug around and throughout the contaminated zone and slotted pipe is placed into the trenches. Low permeability soil is used to cover the pipe so that the force of the vacuum is directed downward. Riser pipes are then connected to the vacuum source and the treatment unit.

In some cases, it is possible to utilize SVE in soil stock piles. In this case piping is embedded

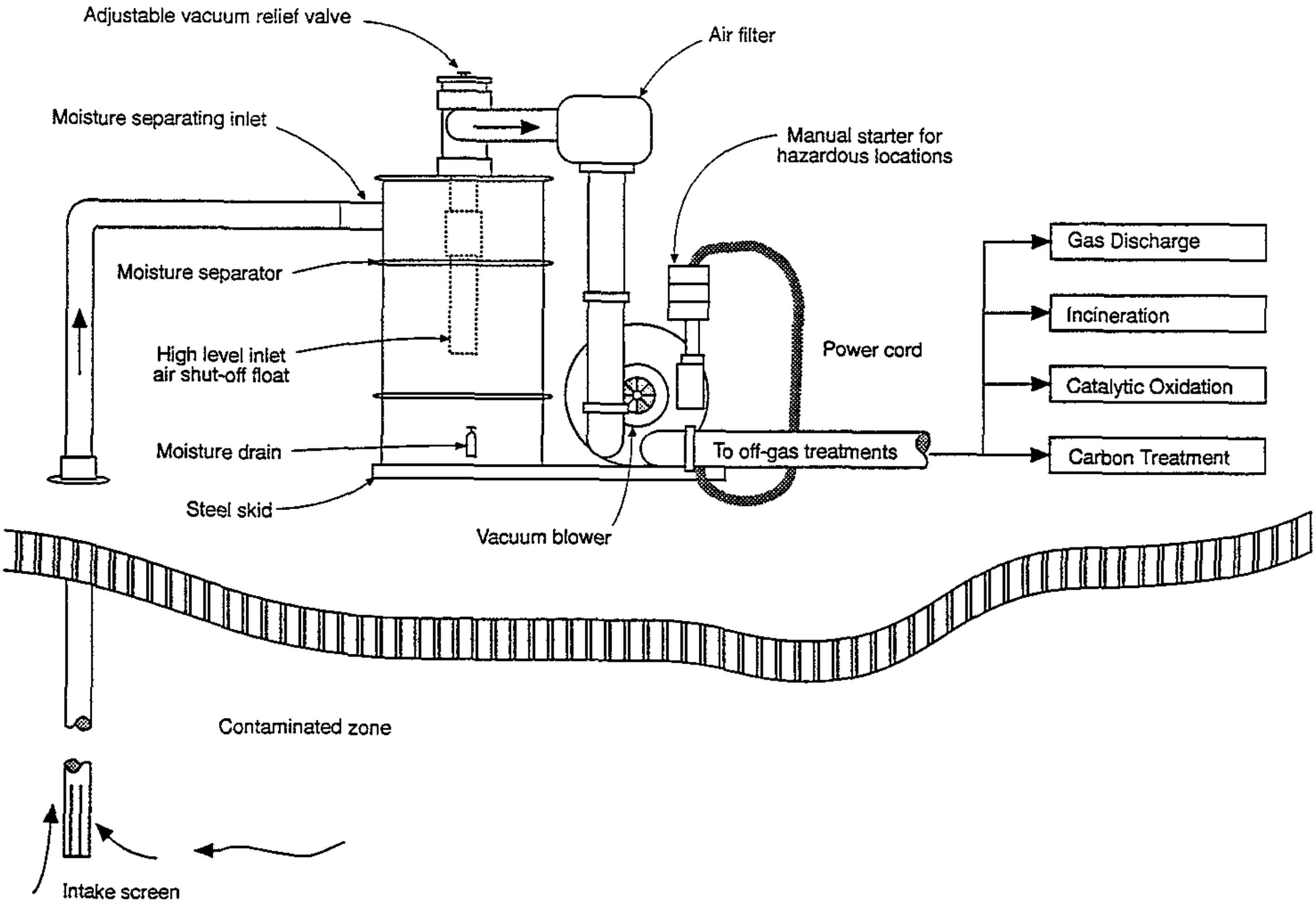


Figure 5.2-1 **Typical Vacuum Extraction System**

Source: U.S.A.F., 1992.

TABLE 5.2-1
SOIL VAPOR EXTRACTION SYSTEM VARIABLES

Site Conditions
- Distribution of VOCs
- Depth to ground water
- Infiltration rate
- Location of heterogeneities
- Temperature, humidity
- Atmospheric pressure
- Location of structures
- Rainfall
- Barometric pressure

Physical Properties
- Permeability (air and water)
- Porosity
- Organic carbon compound
- Soil structure
- Soil moisture characteristics
- Particle size distribution

Chemical Properties
- Henry's constant
- Solubility
- Adsorption equilibrium
- Diffusivity (air and water)
- Density
- Viscosity

Control Variables
- Air withdrawal rate
- Vent configuration
- Extraction vent spacing
- Vent spacing
- Ground surface covering
- Pumping duration
- Inlet air VOC concentration and moisture content

Response Variables
- Pressure gradients
- Final distribution of VOCs
- Final moisture content
- Extracted air concentration
- Extracted air temperature
- Power usage

Source: Tetra Tech 1993.

throughout the soil pile and the soil pile is covered with an impermeable liner to prevent volatilization to the atmosphere. SVE system variables are presented as Table 5.2-1.

Monitoring is very important to the remedial success of an SVE system. The following elements of an SVE system must be monitored:

- Vapor flow rates from extraction wells and into injection wells
- Pressure readings at each extraction and injection well
- Vapor concentrations and compositions
- Temperature of ambient atmosphere and soil
- Water table level
- Soil-gas vapor concentrations and compositions (GWMR, Spring, 1990)

Applicable Contaminants

SVE is only appropriate for removing VOCs with a Henry's Law constant of 0.01 or greater at 10° C (USAF, 1992). Table 5.2-2 provides Henry's Law constants for a number of contaminants. SVE has been demonstrated to remove benzene, toluene, xylene, ethylbenzene, hexane, chloroform, methylene chloride, tetrachloroethylene, trichloroethylene, dichloroethylene, ethyl acetate, cyclohexane, methyl ethyl ketone, methyl isobutyl ketone, chlorobenzene, dichlorobenzene, trichlorobenzene, and gasoline. SVE will not remove heavy oils, metals (with the possible exception of mercury), PCBs, or dioxins (USAF, 1992).

Long-Term Effectiveness and Permanence

The contaminant removal efficiency is a function of the air flow rate and the concentration of the

TABLE 5.2-2
DIMENSIONLESS HENRY'S LAW CONSTANTS FOR TYPICAL VOCs AT 10 DEGREES CELSIUS

Methyl Ethyl Ketone	0.0121
Ethylene Dibromide	0.0129
1,1,2,2-Tetrachloroethane	0.0142
Dibromochloromethane	0.0164
1,1,2-Trichloroethane	0.0168
Methyl Isobutyl Ketone	0.0284
Tetralin	0.0323
1,2-Dichloroethane	0.0504
1,2-Dichloropropane	0.0525
1,2,4-Trichlorobenzene	0.0555
Methylene Chloride	0.0603
1,2-Dichlorobenzene	0.0702
Chloroform	0.0740
1,4-Dichlorobenzene	0.0702
1,3-Dichlorobenzene	0.0951
Chlorobenzene	0.1050
Cis-1,2-Dichloroethylene	0.1162
o-Xylene	0.1227
Ethylbenzene	0.1403
Benzene	0.1420
Methyl Ethyl Benzene	0.1511
1,1-Dichlorethane	0.1584
Toluene	0.1640
1,3,5-Trimethylbenzene	0.1734
m-Xylene	0.1769
p-Xylene	0.1808
Trichloroethylene	0.2315
Propylbenzene	0.2445
Trans-1,2-Dichloroethylene	0.2539
Chloroethane	0.3267
2,4-Dimethylphenol	0.3568
Tetrachloroethylene	0.3641
1,1,1-Trichloroethane	0.4153
Carbon Tetrachloride	0.6370
Vinyl Chloride	0.6456
1,1-Dichloroethylene	0.6628
Methyl Cellosolve	1.8980
Trichlorofluoromethane	2.3068
Decalin	3.0127
Cyclohexane	4.4329
1,1,2-	6.6279
Trichlorotrifluoroethane	10.2430
N-Hexane	17.2152
Nonane	29.9975
2-Methylpentane	

contaminants. A year long study was undertaken to determine the effectiveness of SVE. After 227 days of soil vapor extraction, a 65.4% reduction in soil VOC content was reported [from what conc. to what?]. The level of VOC in soil is routinely lowered to the single digit ppm level (Personal Communication, Terra Vac, 1993). Because this process is a contaminant removal process, the effectiveness of this treatment alternative is permanent.

Reduction of Toxicity, Mobility, and Volume

The reduction of toxicity, mobility, and volume of this technology is a function of its removal efficiency. Because this technology is a removal technology, rather than a destruction technology, the toxicity, volume and mobility are reduced at the rate of removal. If 100% removal can be achieved, then this process can effectively eliminate the toxicity and mobility of the hazardous constituents from the soil. The volume, then, is reduced to the condensate which is collected during the process.

Short-Term Effectiveness

This process has no known risks associated with its application. The process is not immediately effective, however. Time is required to remove the contaminants. The removal rate is a function of the type of contaminant and the soil type.

Implementibility

Technical Feasibility: This technology is widely used and readily available. The technical feasibility is based on site-specific conditions determined by pilot testing. The pilot study evaluates the vacuum blower curve, the critical vacuum extraction flow rate, the zone of extraction influence, and the contaminant concentrations in the soil vapor. Pilot study components include extraction and observation wells, pressure gauges, the vacuum extraction system and the treatment unit.

Site Characteristics: Both the physiography and soil conditions are important in determining the proper scale and configuration of the soil vapor extraction system. Soil properties which factor into the effectiveness and feasibility of SVE include soil type, distribution and stratification, particle size, porosity, air permeability, and moisture content.

The range of influence is determined by the soil's permeability. A gravely soil with a permeability of 10^{-1} cm/sec may have a radius of influence as great at 75 to 200 feet, while a dense soil with a permeability of 10^{-7} may have a range of influence of only 20 to 30 feet (USAF, 1992). The permeability also affects the required vacuum strength. Soil heterogeneity affects the clean-up rate unless the vacuum strength is adjusted to account for uneven permeabilities which may be spread across the site.

Climatic Constraints: There are no known climatic constraints with respect to the implementibility of soil vapor extraction.

Logistical Constraints: The equipment required for soil vapor extraction is relatively small, and most of the equipment is concealed underground. A generator, or standard power source, sufficient to drive to the vacuum and the treatment unit is required. Well spacing typically ranges from 5 to 30 feet (USAF, 1992).

Regulatory Constraints

A local building permit is required for the construction of a SVE unit. The local fire department may also want to approve of the system piping and set-up. If releases of VOCs to the atmosphere were proposed, an air permit would be required from the local air quality control board. SVE is a demonstrated innovative technology through EPA's SITE program.

Costs

SVE has relatively low capital and operations and maintenance (O&M) costs. Costs for pilot level testing for soil contamination runs approximately $10,000 and takes approximately one week. System costs for a small site would range from $35,000 to $50,000. A large site would range from $75,000 to

$125, 000. This figure includes all the SVE system equipment and installation. However, it does not include the well installation as well as the treatment technology to treat off-gassed volatiles.

Monitoring makes up the majority of the O&M costs. Components of an SVE system monitoring program are presented in Section 5.3.1. Monthly maintenance would cost between $1,000 and $1,500 per month. This does not include component replacement, or carbon replacement where necessary. In general, clean-up costs have been reported to range between $10.00 and $40.00 per cubic yard.