Gen-Tech Environmental

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San Jose, CA 95124
Contractor's Lic. #615869

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TRANSMITTAL

Read 12/8/94
B Chan

DATE: 12/8/94

TO: Barney Chan

COMPANY: Alameda County Health Care Services

ADDRESS: 1131 Harbor Bay Parkway
Alameda, CA 94502

Tel.#: 510-567-6700

FROM: Stuart Solomon

RE: DiSalvo Trucking Company
4919 Tidewater Ave.
Oakland, CA

NO. PAGES: 35

MESSAGE:

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November 28, 1994

Alameda County Health Care Services
Department of Environmental Health
Hazardous Materials Division
1131 Harbor Bay Parkway, Second Floor
Alameda, CA 94502

Attn: Barney M. Chan - Haz. Mat. Specialist

In behalf of:

Charles Lawlor
DiSalvo Trucking Company
859 Harrison Street
San Francisco, CA 94107

#3687

Subject: Proposed Work Plan for Contaminate Migration Control at: 4919 Tidewater Ave., Oakland, CA 94612

INTRODUCTION

During the removal of four underground fuel storage tanks from the DiSalvo Trucking property at the subject site in Oakland, CA, diesel fuel contaminated soil and ground water was encountered. A considerable quantity of floating free product was pumped out and removed from the excavation area directly following the removal of the underground tanks. Also removed contiguous to the excavation of the tanks was a system of hydrant lines networked between the truck loading docks and fuel pumping station. Specific data concerning the tank and hydrant line removals can be found in reports generated by Geo-Environmental Technology (GET) dated April 27, 1989 and June 15, 1989. Upon removal of the tanks, free product was discovered in the excavation areas. Samples collected from the excavation area revealed that the contaminate was diesel fuel. Approximately 20,000 gallons of free product and 20,000 gallons of water were pumped out of the tank pits by GET. This was followed by the excavation of approximately 1800 cubic yards of diesel contaminated soil. The contaminated soil was stockpiled on site and successfully biologically treated by GET. A report of this process can be found in a submittal by GET

dated February 28, 1991. The decontaminated soil was used for fill material at the northern and eastern portions of the lot. Following the tank and hydrant removal, a subsurface investigation was conducted at the site by GET. This investigation involved installing 19 bore holes concentrating on the areas where the hydrant piping had been previously located. Results of this initial subsurface investigation can be found in a submittal by GET dated June 15, 1989. A product recovery sump/well was constructed and installed at the northwestern corner of the excavation area. This well was equipped with a skimming system designed to remove the floating hydrocarbon product from the water. A product recovery pumping system was constructed by Clean Environment Engineers of Emeryville, CA and installed to handle the free product removal from the product recovery sump. This system was operational for a period of time from approximately April 1989 to August 1989 after which the system was shut down and has not since been employed. The excavation area was backfilled, compacted and resurfaced with asphalt.

In the summer of 1991, Gen-Tech Environmental (GTE) installed a shallow interceptor trench system to aid in facilitating the capture and removal of the remaining free product on the groundwater. This trench was installed in accordance with GTE's March 12, 1991 work plan, with modifications as discussed in GTE's supplemental report of July 12, 1994.

Under the direction of the Alameda County Department of Environmental Health, GTE performed additional soil and groundwater investigation in April 1994. During this investigation, GTE installed fourteen exploratory borings, of which three were converted to groundwater monitoring wells. Details on this investigation can be found in GTE's "Soil and Groundwater Investigation" report of May 17, 1994. GTE's study concluded that a plume of diesel contamination exists and is located almost entirely within the site boundaries except for the eastern edge of the plume which appears to have migrated just off-site under Tidewater Avenue. GTE recommended that the existing product recovery well and trench be re-activated, and that the wells be tested on a quarterly schedule.

The property owner is currently suing Chevron (Standard Oil) as a PRP in the site clean-up. Chevron apparently installed the tanks using inferior product piping, which the client is contending contributed to the early demise of the pipe integrity. Early corrosion is apparently what caused the pipe to fail. This law suit is currently scheduled to be heard in November 1994. The ACDEH is requiring that site remediation be initiated immediately. The client has already spent nearly $250,000 on the initial steps necessary for source removal, initial free product removal, soil treatment, and investigation activities.

In evaluating remediation alternatives, these factors were considered:

1. *Groundwater in the immediate area occurs at between 3 ft. and 4 ft. below grade surface.*

2. *The plume of groundwater contamination appears to be located primarily in an area free from building structures.*

3. *There is sufficient space available for on-site soil treatment.*

4. *There is currently an existing business operating on site. Rent from this business provides the client with cash flow which can help to supplement the costs of site remediation. The recommended approach was designed to permit the business to continue with as little disruption as possible.*

20,000 per S. Salmon Conversation 12/8/94

5. *There is an existing 10,000 gallon above ground diesel tank located at the site that can be used to store and treat groundwater.*

Proposed Remediation Plan

The purpose of this phase of work will be to remove the remaining free product from the affected areas and to initiate dissolved product removal from groundwater. The proposed system involves; A) installing a 20,000 gallon groundwater holding/treatment tank in the immediate area of the existing recovery sump/well to create a holding facility for biological treatment of the groundwater; B) installing an additional product recovery trench in the areas of remaining free product concentrations in order to collect and pump free product and contaminated water to the treatment tank; C) using the holding tank to inoculate, treat, and decontaminate the groundwater in batch cycles; D) pumping the treated groundwater from the bio-treatment tank into the existing 10,000 gallon tank diesel fuel tank for final "polishing" and cleaning of the water to acceptable standards for beneficial-purpose discharge; E) discharging the clean water in batches on-site for dust control and irrigation purposes (under a discharge waiver issued by the Regional Water Quality Control Board).

In addition to the above remediation measures, this phase of work will include; F) performing a "pump test" on the existing recovery trench to help determine the draw-down potential of the trenching system; G) installing one additional groundwater monitoring well as requested by the Alameda County Department of Environmental Health; H) additional soil sampling along the remote dispenser line on the west side of the building, and; I) quarterly sampling of the four groundwater monitoring wells on site.

3 existing + 1 new

A) Subsurface Bio-Treatment Tank

1. A 10,000 gallon treatment tank will be placed in the immediate area of the existing recovery sump (designated "Treatment Area" on **Figure 1**. This tank will be used for the first stage of biological treatment of contaminated groundwater. A second smaller tank (500 gallons) will be installed in the same and designated as the "free product holding tank". This tank will be used to store free diesel product that is anticipated to separate from the groundwater in the treatment process.

2. The treatment area will be surrounded by a chain link fence for security, bermed on the perimeter to approximately 2 ft. above grade, and lined with a plastic liner.

B) Install Additional Trenches and Discharge Piping

1. Additional product/groundwater collection trenches will be installed in the areas depicted on **Figure 1**. The trenching detail will be as shown on the drawing. The collection trench (trench #2) will be excavated to a depth of approximately six feet below grade surface and into the underlying bay mud. The trench will be backfilled with 3/4 to 1 inch drain rock from the bottom of the trench to approximately one foot below grade surface so as to permit free flowing of the contaminated water into the trench zone.

2. An 8 inch diameter extraction well with a wire wrap will be installed in the center of Trench #2 to extract groundwater from the trench and send it to the treatment area. The extracted water will be pumped through a buried 2 inch PVC piping system into the existing trench recovery well. Rigid conduit piping will be used to house the electrical wiring necessary for the extraction pump. The PVC and rigid conduit piping will be buried at 24 inches below grade, bedded, and surrounded in sand. A six to eight inch Class II base rock cap will be compacted over the sand fill.

3. A narrow piping trench will be installed between the bio-treatment area and the existing 10,000 gallon diesel tank. This trench will house a 2 inch PVC discharge line to transfer treated groundwater from the first stage bio-treatment tank to the 10,000 gallon holding tank. In addition, the trench will contain the electrical conduit which will provide power to the treatment area. The PVC and rigid conduit piping will be buried at 24 inches below grade, bedded, and surrounded in sand. A six to eight inch Class II base rock cap will be compacted over the sand fill.

4. An 8 inch layer of class II base rock will be compacted over the drain rock within trench #2. All trenches will be resurfaced with asphalt to grade.

C) Aquifer Trench Pump Test

1. The extraction well in the new trench will be pumped to ascertain the yield and to estimate trench capture extent. Since the low permeability sediment underlies the site, it is anticipated that the trench extract water from predominately the upper five to six feet of aquifer. While a "traditional" aquifer analytical solution cannot be calculated, estimates of transmissivity will be made from measurements collected in the existing monitoring wells. The trench and well system will be allowed to operate for a 2 week period to allow for water removal from the trench to equilibrate with aquifer recharge.

2. Extracted water will be treated as proposed in this workplan.

3. Groundwater contour maps of trench system drawdown and area of influence will be prepared and submitted with quarterly reports.

D) Bio-tank Batch Treatment of Groundwater

1. Groundwater will be pumped from Trench #2 into the existing collection sump/well via a float actuated extraction pump. A float actuated sump pump will be installed within the collection well. This pump will extract water from the bottom of the well and send it into the groundwater holding tank for primary bio-treatment. By depressing the level of groundwater in the extraction sump, water from Trench #1 (the existing trench system which is currently connected to the extraction sump/well) will also be allowed to flow into the sump area.

2. A free product skimmer will be employed within the collection sump to remove free product from the water accumulating within the sump. The skimmed free product will be pumped into the 500 gallon holding tank located in the treatment area. When the holding tank has reached capacity, the waste product will be pumped from the tank by a licensed waste oil hauler, and disposed of at a waste oil recycling facility.

3. The groundwater treatment tank will be equipped with two float-actuated capacity fill switches (the second switch as a back-up to the primary). When the tank has been filled to its specified capacity (approximately 9,000 gallons), both pumping systems (the trench #2 pump and the collection sump pump) will be automatically shut down.

4. A water aerator will be anchored in the center of the primary treatment tank and run continuously during the treatment process. A compressed air pump will recirculate water in the tank, which will help to oxygenate the water.

5. The water within the tank will be inoculated with Solmar® Formula L-104 biocultures by the exact specifications of the manufacturer (please refer to **Appendix 1** for details on this product). Periodic testing of the water will be conducted to check nutrient and PH balance. Appropriate nutrients (nitrogen and phosphate fertilizers) will be added as needed to maintain optimum growth conditions.

6. The aeration system will operate continuously during the decontamination process. Each primary decontamination cycle is estimated to take approximately 7 to 10 days.

7. Field tests (using the Nu-Hanby Colormetric Field Test for Volatile Organic Compounds) will be made periodically during the treatment cycles to determine the effectiveness of the process. When field testing has determined that the level of diesel contaminates in the water have reduced to less than 1 PPM, the water within the pond will be pumped from the pond into the 10,000 gallon "polishing" tank located as shown on **Figure 1**.

8. The pumps will be reactivated, and the batch treatment process will be repeated as in 1 through 7 above.

E) Groundwater "Polishing" Treatment

1. Approximately 9,000 gallons of partially treated groundwater from the primary treatment tank will have been pumped into the 10,000 gallon "polishing" tank. This "polishing" process will be used to remove low concentrations of residual contaminates. The tank will be equipped with two air diffusers ("bubblers") located at either end of the tank (please refer to the **Figure 1** detail attached hereto). These units will operate on filtered compressed air, which will constantly force oxygen into the water within the tank, with constant water agitation.

2. Additional Solmar® microbes (and nutrients if necessary) will be introduced, and the system allowed to operate for about 7 days. A representative sample of the water within the tank will be taken to a State Certified Laboratory and tested for TPHd and BTEX. Assuming that the sample results are within the RWQCB's discharge waiver requirements, the water will now be proposed for beneficial use discharge.

E) Treated Groundwater Discharge

1. A discharge waiver will be obtained from the RWQCB - allowing the treated groundwater to be used for the specific beneficial purposes outlined in the permit.

2. Each batch of the "polished" groundwater from the treatment tank will be pumped through a fire hose system and sprayed throughout the facility for the purposes of dust control and irrigation.

F) Installation of an Additional Groundwater Monitoring Well

1. An additional 2 inch groundwater monitoring well will be permitted and installed as located on **Figure 1** attached hereto. This well will be permitted through the Alameda County Department of Environmental Health, and will be installed, developed, and sampled in accordance with the GTE Drilling, Sealing, Well Construction, and Sampling Protocol attached as **Appendix 2**.

2. A groundwater well installation report will be prepared and submitted to the Alameda County Department of Environmental Health.

G) Additional Soil Sampling

1. Soils borings will be installed at 20 ft. intervals along the remote dispenser lines on the west side of the building. Soil samples will be collected from the soil/groundwater interface zone (currently at about 3 to 4 ft. BGS). Collection of the samples will be in accordance with the GTE Drilling, Sealing, Well Construction, and Sampling Protocol in **Appendix 2** attached hereto.

2. Each of the samples will be tested at a State Certified Laboratory for THPd and BTEX.

H) Quarterly Sampling of the Groundwater Wells

1. Each of the four groundwater wells will be sampled quarterly in accordance with GTE's Drilling, Sealing, Well Construction, and Sampling Protocol in **Appendix 2**.

I) Interim Activities Reports

1. Interim site remediation activities reports will be written and submitted to the ACDEH each quarter. These reports will include descriptions and accounting of free product removal, groundwater treatment, and well sampling events.

If you have any questions regarding this work plan, please do not hesitate to call the undersigned.

Respectfully submitted,

Stuart G. Solomon
Principal

Christopher M. Palmer
C.E.G. No. 1262

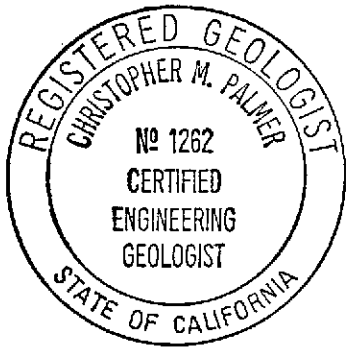
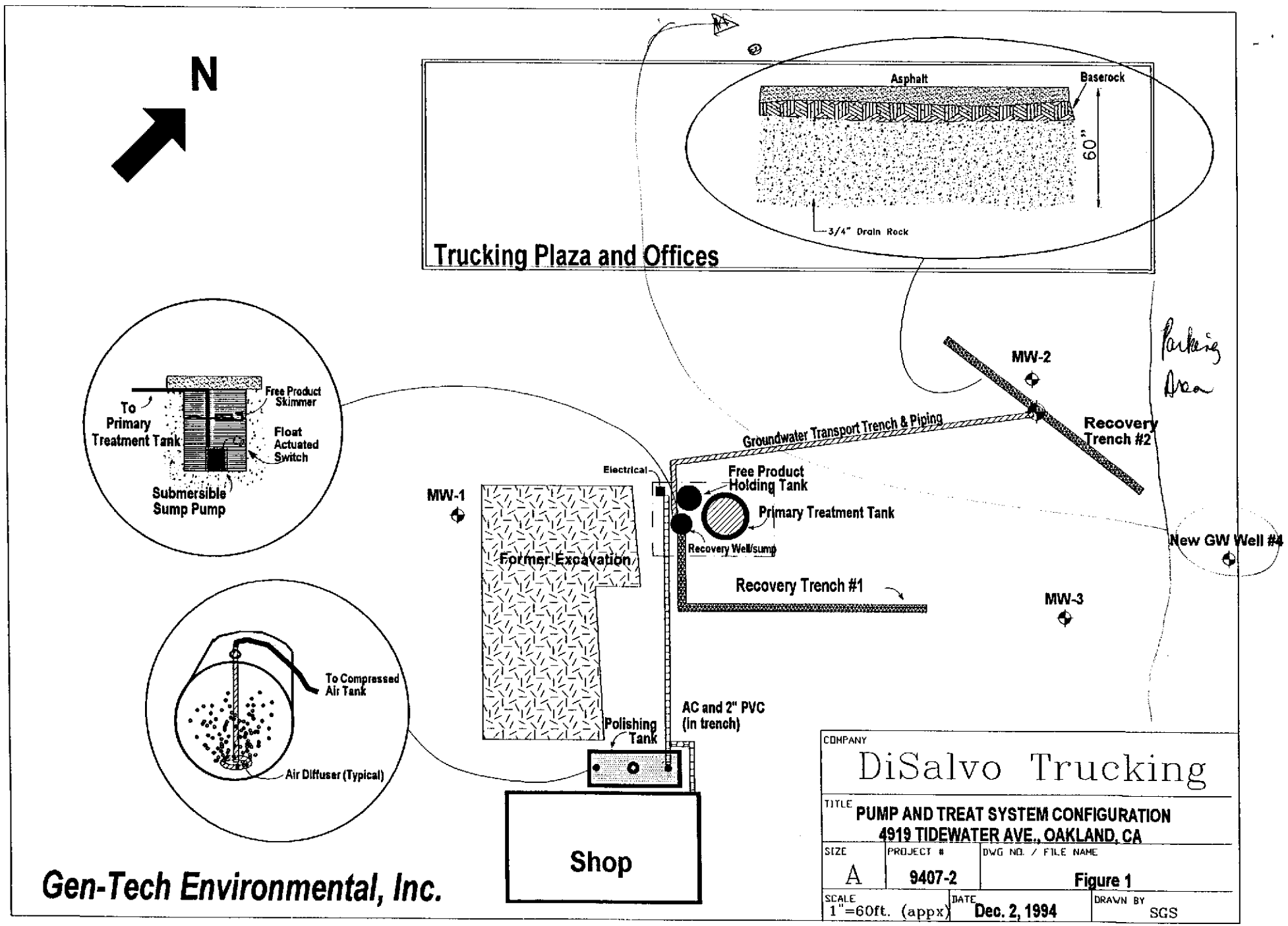


FIGURE 1

SITE MAP WITH SYSTEM CONFIGURATIONS


N
Asphalt
Baserock
60"
3/4" Drain Rock
Trucking Plaza and Offices
Parking Area
MW-2
Recovery Trench #2
Groundwater Transport Trench & Piping
To Primary Treatment Tank
Free Product Skimmer
Float Actuated Switch
Submersible Sump Pump
Electrical
Free Product Holding Tank
Primary Treatment Tank
Recovery Well/sump
MW-1
Former Excavation
Recovery Trench #1
MW-3
New GW Well #4
To Compressed Air Tank
Air Diffuser (Typical)
AC and 2" PVC (in trench)
Polishing Tank
Shop
Gen-Tech Environmental, Inc.
COMPANY
DiSalvo Trucking
TITLE
PUMP AND TREAT SYSTEM CONFIGURATION
4919 TIDEWATER AVE., OAKLAND, CA
SIZE
A
PROJECT #
9407-2
DWG NO. / FILE NAME
Figure 1
SCALE
1"=60ft. (appx)
DATE
Dec. 2, 1994
DRAWN BY
SGS

APPENDIX 1

SOLMAR BIOCULTURES

BIOREMEDIATION OF PETROLEUM CONTAMINATED SOILS USING A MICROBIAL CONSORTIA AS INOCULUM

B.A. MOLNAA and R.B. GRUBBS, SOLMAR CORP.

ABSTRACT

Bioremediation is becoming an attractive alternative for cleaning up soil systems contaminated with petroleum and other hydrocarbons. Due to time constraints and unknown quality of results, certain projects have not had bioremediation as an option. A process has been developed in which a consortia of microorganisms is introduced into the soil system to facilitate the bioremediation process and ensure consistency of results.

Techniques to enhance the activity of the organisms and thus ensure the success of such programs are described.

Several successful projects are described along with potential roadblocks to bioremediation and how one can work around such roadblocks. Degradation parameters for these projects are discussed.

INTRODUCTION

In the past few years, as landfills have become more and more scarce and concomitantly more and more cost prohibitive, interest in biological methods to treat organic wastes has increased. One area, in particular, that has received increased attention is the biological treatment of petroleum contaminated soils.

The term bioremediation has been given to describe the process by which the use of living organisms (in conjunction with or independent from other technologies) is employed to effectively decontaminate a polluted system. In most cases the organisms employed are bacteria, however, work is being conducted using fungi and plants. Water hyacinths have been utilized in water systems to effectively remove trace organics and trace metals.

There are two techniques for utilizing bacteria to degrade petroleum in the soil. One method uses the bacteria that can already be found in the soil. These bacteria are stimulated to grow by introducing nutrients into the soil and thereby enhancing the biodegradation process. This process is known as biostimulation. The other method involves culturing the bacteria independently and adding them to the site. This process is known as bioaugmentation(8).

One advantage of bioremediation is that the process can be done on site with a minimum amount of space and equipment. By treating on site, costs and liability are greatly reduced while extending the life of our current landfills by reducing the amount of waste they would normally receive.

On site treatment may involve excavation of the contaminated soil and construction of a lined treatment cell. If excavation

is impractical the treatment may be conducted without disturbing the contaminated site by using a recirculating injection well system. This process is considered in situ treatment(5,8).

Both on site and in situ treatment have their advantages and disadvantages and the decision to use one method of treatment or the other is often dictated by various factors at the site.

ON SITE VERSUS IN SITU TREATMENT

On site treatment, whereby the contaminated soil is excavated and placed into a lined treatment cell, has some distinct advantages. It allows for better control of the system by enabling the engineering firm to dictate the depth of soil as well as the exposed surface area. By controlling the depth and exposed surface area of the soil one is able to better control the temperature, nutrient concentration, moisture content and oxygen availability(8). The presence of the liner is an added benefit, since the liner prevents the migration of the contaminants there is no possibility of contaminating the groundwater. After treatment the liner is picked up and properly disposed of generally by incineration.

On site treatment has an added benefit in that it is much easier to demonstrate the site is clean than in an in situ clean up. By isolating the contaminated soil in the treatment cell it is possible to sample the site in a more thorough and therefore representative manner. This may prove a necessity if the regulating agency or the customer desire to optimize the reliability of sampling and analysis.

The excavation of the contaminated soil adds to the cost of a bioremediation project as does the liner and the landfarming equipment. In addition to these costs it is necessary to find enough space to treat the excavated soil on site. In some states areas are now being set aside to provide the needed space to treat these soils.

In situ treatment is advantageous in instances where the excavation of the contaminated soil is cost prohibitive or impossible. The method of in situ treatment generally involves establishing a hydrostatic gradient through the area of contamination. Water is placed on the site so that it will flow through the area of contamination, carrying nutrients and possibly organisms to the contaminants. Once the water has passed through the site, it is pumped up through wells and returned to the beginning of the system. This continuous recirculation is carried on until the site has been determined to be clean (Figure 1).

Recovery of the percolating water is the most difficult aspect of this treatment method. Sites may contain a natural clay or rock barrier which collects the percolating water, in which case extraction wells can be placed in this collection zone. Other sites may require the construction of collection trenches or numerous recovery wells at the bottom of the contaminated soil horizon. Given the various geologic/hydraulic

conditions that exist at a site, the application of this technology may be limited and would depend on whether regulatory agencies would consider this to be an appropriate and feasible alternative.

The most effective means of implementing these principles depends on the geology/hydrology of the subsurface area, the extent of the contaminated area, and the nature (type) of the contamination. In general, this method is effective only when the subsurface soils are highly permeable, the soil horizon to be treated is within 20 - 30 feet of grade, and shallow ground water is present, i.e., at 30 feet or less below grade.

As was briefly mentioned above, determining whether or not an in situ remediation process is complete can be a difficult task. If the recirculating water is monitored to check if contaminant has disappeared then it becomes necessary to somehow correlate the recirculating water to that of the contaminated soil. If monitoring wells are to be used to assess the site then a preponderance of wells may be necessary to satisfy that the entire site is clean. Due to the poor mixing in these types of systems it becomes necessary to treat for very long periods of time to ensure that all the pockets of contamination have been treated.

The average time frame for an on site bioremediation project is from sixty to ninety days depending on contamination levels. The average time frame for an in situ bioremediation project can be on the order of twelve to twenty-four months depending on contamination levels and depth of contamination.

The depth of contamination plays an important role in determining whether or not an in situ bioremediation project should be employed. If the contamination is near the groundwater but the groundwater is not yet contaminated then it would be unwise to set up a hydrostatic system and further the migration of the contaminant. It would be safer to excavate the soil and treat away from the groundwater by using an on site method of treatment.

BIOSTIMULATION VS. BIOAUGMENTATION

Along with deciding whether or not a site should be remediated using on site treatment or in situ treatment, it is necessary to decide how one is going to bioremediate the site. As stated above, there are two methods of employing microorganisms to bioremediate a site. Biostimulation involves the stimulation of indigenous microorganisms to degrade the contaminant. Bioaugmentation involves adding preselected organisms to the site to degrade the contaminant.

A biostimulation project requires that adjustments be made to the soil to enhance the microbial populations already present. These include adding a nitrogen source, a phosphorous source, and a myriad of trace minerals and making appropriate pH adjustments. For an on site treatment the nutrients are spread over the site and worked into the soil. For an in situ treatment

the nutrients are added to the water upstream in the hydrostatic gradient.

Biostimulation assumes that every organism needed to accomplish the desired treatment results are, in fact, present. Therefore, all that is required to achieve effective biodegradation is to provide (or enhance) an ideal environment for these ubiquitous microorganisms to live and work(8).

There are numerous shortcomings with this hypothesis. For example, how can we be certain that those organisms present are the most suitable to degrade all materials present? Secondly, what if the only organisms stimulated are those that eliminate the primary substrate, but do not cometabolize the specifically targeted substrates? At any given site, many of the problem substrates may not be able to be biodegraded directly. If they are the only food source available, the microbes may not be able to degrade these targeted organics, since they do not serve as primary food sources on which the microbes feed.

To ensure that the necessary organisms are present it is generally necessary to conduct a feasibility study on the soil from the site before any biostimulation project is undertaken. The cost of such a study can range from $5000 to $40000 depending on the extent of contamination and the characteristics of the contaminants.

Bioaugmentation is the controlled addition of specially formulated biocultures to assist those found naturally in the soil. It is done in conjunction with the development and monitoring of an ideal growth environment in which these selected bacteria can live and work.

In most cases, the targeted organic contaminants either serve as the food source or are cometabolized. Essential elements are added to the "food source" to provide the required nutrient levels, and water provides the media in which the bacteria function.

The mere addition of bacteria will not, in itself, solve the problem. Studies conducted in 1979 by Dibble and Bartha clearly demonstrated that sewage sludge actually inhibited hydrocarbon biodegradation in soil, and the use of yeast extract had no effects whatsoever(2). The selected microorganisms must be carefully matched to the waste contamination present in the soil, as well as the metabolites formed. They must favorably compete with the ubiquitous organisms found in the expected environmental conditions.

Bioaugmentation allows one to control the nature of the biomass. It provides an element, heretofore not available, that of predictability. Bioaugmentation ensures that the proper team of microorganisms is present in the soil in sufficient type, number, and compatability to effectively and efficiently attack the waste constituents and break them down into their most basic compounds.

One objection to bioremediation has been that it takes an inordinate amount of time for the process to work. In the case of biostimulation this is true. However, the addition of

specially selected microbial consortia allows one to control the biomass of the contaminated site. The additional control of the biomass enables one to increase the kinetic rates of removal from the contaminated site by selecting a more efficient consortia of microorganisms than might be present at the site.

By increasing the kinetic rates it has been possible to remediate sites in sixty to ninety days using the addition of a selected consortia of microorganisms.

By selecting the microbial consortia beforehand it is possible to select for organisms that will not produce nuisance odors such as hydrogen sulfide. Petroleum degradation can create anaerobic conditions within the soil. Once anaerobic conditions are present it becomes possible to generate phytotoxic compounds such as hydrogen sulfide(1). If one augments the soil with organisms that do not possess the ability to generate these phytotoxic compounds a potential hazard to on site petroleum degradation can be averted.

The cost of the selected microorganisms has been mentioned as a disadvantage in treating contaminated soils. However, if one considers the cost of a feasibility study to ensure that a biostimulation project will work, the cost is considerably less for the bioaugmentation products.

THE PROCESS

There is far more involved with bioremediation projects than simply adding microorganisms. Various factors need to be considered to ensure the success of these programs. The proper engineering to facilitate biological growth is a crucial step in the process of bioremediating a site.

An electron acceptor is required for breakdown of hydrocarbons. Oxygen, nitrate and sulfate are the most common. In a bioremediation project the presence of oxygen is one of the most crucial factors to the rate of reaction. This is especially true early on in a project before any oxygenated intermediates are formed. Sporadic reports of anaerobic degradation in vitro remain controversial, and convincing proof of significant anaerobic hydrocarbon biodegradation is still outstanding(1). Sulfates are a potential electron acceptor, but are not abundant in soils. Nitrate is not energetically favorable for this purpose in soils(6).

In soils aeration depends on the total amount of air filled pore space. Elimination of air filled pore space by waterlogging or compaction reduces oxygen transfer. Large amounts of biodegradable organics in the top layers will deplete oxygen reserves in the soil and slow down oxygen diffusion rates to the deeper layers.

Oxygen can become a limiting factor in all types of petroleum degradation, so aeration is required in most applications. In aqueous systems aeration and agitation also provide more surface area of hydrocarbons to the bacteria which live only in the aqueous phase of the system and work at the oil

to water interface.

Another essential parameter in a bioremediation process is moisture. Bacteria rely on water to exchange everything through the cell. At 100% saturation of moisture in soils, however, all pore spaces are filled with water. At only 10% saturation of moisture level osmotic and matrix forces reduce metabolic activity to marginal levels. Moisture levels in the range of 20% to 80% of saturation generally allow suitable biodegradation in soils(1).

The addition of large quantities of hydrocarbons in a system usually creates a nutritional imbalance which needs to be corrected by the application of inorganic fertilizers containing nitrogen and phosphorous. Biosludges from refinery and petrochemical treatment facilities normally contain enough nitrogen and phosphorous.

For landfarming operations the American Petroleum Institute recommends a C:N ratio of 160:1. Laboratory experiments by Dibble and Bartha showed a C:N ratio 60:1 and a C:P ratio of 800:1 to be optimum(1). The expense of fertilizer and the potential for groundwater contamination encourage more conservative application rates. Most agricultural fertilizers contain excessive P and K for microbial use. Urea and ammonium compounds can be added to such fertilizer to bring up the nitrogen levels. Nitrates can pose leaching problems and encourage denitrification under anaerobic conditions. The ammonium ion being positively charged binds to the negatively charged soil particles. But in well aerated soils with neutral pH values, above 50° F the ammonium ion is nitrified to nitrates in one to two weeks after application(12).

In clean up situations one frequently cannot do a mass balance of pollutants. Sufficient nitrogen and phosphorous must be present to start off microbial activity and must be monitored continually to assure that they don't become too low due to assimilation into cell mass, leaching, nitrification, or volatilization. We recommend maintaining nitrogen levels in excess of 5 ppm at all times and phosphorous levels of 1 ppm or more. These levels will ensure that microbial activity is not lost.

Temperature affects the rates of microbial metabolism as well as the physical state of hydrocarbons. It also affects the solubility of the substrates. Some small alkanes are more soluble at 0° C than at 25° C(10). Elevated temperatures can influence nonbiological losses, mainly evaporation. In some cases the decreased evaporation of toxic components at lower temperatures has been reported to have inhibited degradation(3). In general most mesophilic bacteria perform best at about 35° C, but their performance can be affected by these other factors. Consequently researchers have reported different optimums and considerable variance in activity at different temperatures, little change in activity over given temperature ranges and other superficial contradictions. Huddleston and Cresswell (1976) reported petroleum degradation in soils as low as -1.1 ° C

as long as the soil solution remained liquid(7). Degradation rates were quite slow. In natural habitats shifts in microbial populations due to temperature changes have been reported(14). As one might suspect from such shifts, as well as changes in solubilities, there are reports showing the types of hydrocarbons being degraded may vary with temperature.

While the pH of the marine environment is uniform, steady, and alkaline, the pH of various soils covers a wide range. The marine environment is well buffered. In soils and poorly buffered treatment situations, organic acids and mineral acids from the various metabolic processes can significantly lower the pH. The overall biodegradation rate of hydrocarbons generally is higher under slightly alkaline conditions. So appropriate monitoring and adjustments should be made to keep such systems in the 7.0 to 7.5 pH range. Variations or swings in pH in treatment systems can have a very deleterious effect on the performance of the biomass.

Since oils and most petroleum hydrocarbons are only sparingly soluble in water, the relatively small interfacial area of oil in contact with water can limit the microbial degradation of oil. Microbes colonize the surfaces of oil droplets and the undersides of slicks. Many hydrocarbon using microorganisms produce emulsifying agents which greatly enhances their effectiveness in handling the oil. It is widely held that emulsifiers can be involved in the entry of hydrocarbons into the cells, but degradation can occur without emulsification. Emulsifiers have proven useful in some clean up operations, but various sources indicate that not all dispersants enhance biodegradation(9,12).

Most of the parameters that need to be monitored in a bioremediation project are a function of good environmental application. Once the environment has been made conducive to bacterial growth, and a satisfactory monitoring system has been established, the programs are not very labor or capital intensive.

SUCCESSFUL BIOREMEDIATION PROGRAMS

Several innovative and successful bioremediation programs have been conducted by Solmar Corp. in conjunction with various environmental engineering firms and remediation contractors.

CASE #1: Bioremediation was selected as the method of choice to clean up an abandoned refinery site in southern California. The thirty-two acre site was located in a prime industrial area and the goal was to clean the site to a low enough level that commercial buildings could be built.

The initial contamination levels for the site ranged from a low of 1500 ppm to a high of 30,000 ppm. The site was sectioned off into several treatment zones, and a bioremediation program was begun using a consortia of microorganisms supplied by Solmar Corp. of Orange, CA. Since the site had been contaminated on and off for a period of forty years with little or no sign of

decontamination by indigenous organisms it was concluded that a bioaugmentation program could accelerate the remediation process.

The treatment was conducted over a period of six months. While areas were being treated other areas were being taken out of service until the entire tank farm was dismantled. As areas were taken out of service treatment was begun to remediate those sections of the property.

The twenty nine acres of the area was certified as clean within a period of one year. The balance, which has been used as the dumping area, is still being remediated.

CASE #2: The city of Carson, California decided to exercise its redevelopment powers and condemned a site that had been used as a petrochemical tank storage site and salvage operation. The site had been an eyesore. Rather than seal the contaminants at the site under buildings and parking lot, the city decided to get rid of the contaminants. The site had been earmarked as a park, and the city officials were concerned that if the contaminants were left in place they may endanger the health of the children using the park(13).

The price for hauling away the contaminated soil for proper disposal was estimated to be $2 million. The estimated amount of contaminated soil was approximately 10,000 cubic yards. A bioaugmentation program was proposed and adopted at the site.

The cost of the clean up was less than $132,000, and the city began seeking bids for its most elaborate recreation facility.

CASE #3: When the Sacramento Utilities District purchased a small parcel of land to expand their existing parking lot, they were unaware that the land had been previously contaminated with diesel fuel. Once the contamination had been detected the Utilities District decided to take it upon themselves to clean up the site.

The District realized that merely excavating and hauling the contaminated soil to a dump site was just transferring the problem to another site. In keeping with the Districts policy of concern with the environment, other alternatives to land disposal were sought.

Upon examination of treatment options the District decided to implement a bioremediation program using bioaugmentation as the source of organisms. The bioremediation of the 2000 cubic yards of contaminated soil reduced the Total Petroleum Hydrocarbon levels from 2800 ppm to less than 38 ppm (Figure 2) in approximately 74 treatment days(11). The cost of treatment was $360,000 less than the total price of disposal without the inherent liability.

CASE #4: Bioremediation was the method of treatment opted for to treat 1500 cubic yards of diesel contaminated soil at the former Kings Truck Stop in Sacramento, CA. The project reduced the diesel contaminant levels from 3000 ppm to less than 30 ppm in approximately 62 treatment days.

CASE #5: In situ bioremediation was necessary to clean up contamination from a ruptured transfer line that passed under a

railroad track. A jumbo tank car had been moving on the track as solvents were being pumped through the line. The resulting rupture led to a loss of 300 to 400 gallons of solvent at a depth of 38 inches beneath the surface along 120 feet of the track.

A continuously recirculating ground injection system was designed and installed to treat the contaminated soil (see Figure 1). Following a clean up program of nine months with the bioaugmented system, a 99.5% degradation of the contaminants was achieved (Table 1).

CASE #6: A bioremediation project involving 32,000 cubic yards of soil contaminated with various lubrication and form oils is currently ongoing. Preliminary results indicate that the contamination levels have been reduced from a high of 4800 ppm down to 125 ppm in the most contaminated cell (Figure 3). In a lesser contaminated cell the levels have been taken from 1400 ppm down to below the action level of 100 ppm (Figure 4).

COST OF TREATMENT

Cost effectiveness, it seems, plays only a small role in the agencies pursuit of the elusive Best Demonstrated Alternative Technology (BDAT). The facts are that economics do govern, and if cost effective ways of dealing with the problems can be found, then more sites will be cleaned up, and fewer generators will resort to legal delays in effecting clean ups.

Feasibility studies conducted on the previous projects discussed above found that bioremediation is a most cost effective means of dealing with contaminated soils. As with most technologies cost is directly related to the size of the site and extent of contamination. However, bioremedial approaches tend to have lower fixed costs and therefore are able to compete favorably with other technologies from a cost standpoint.

When looking at a bioaugmentation project, one must consider the cost of the cultures. Generally, the cost of the cultures is less than 2% of the total cost of the project. When one weighs the cost of the organisms versus the assurance of mind in knowing the correct organisms have been provided, this is a small price to pay.

Table 2 gives a breakdown of various technologies and their costs per ton.

FUTURE TRENDS

At the time of this writing California seems to be pushing for bioremediation of petroleum contaminated soils more than any other state. This is due in part to the stringent regulations within the state. Since California classifies all petroleum contaminated soil containing 1,000 ppm total petroleum hydrocarbons or more as hazardous, and requires it to be manifested and disposed of in a class one landfill, there are certain economic incentives in California that do not at this time exist in other states.

It will be a short time before other states set more stringent requirements for dealing with this contaminated soil. New Jersey's DEP is monitoring the effect of many of California's policies to enable them to prepare guidelines for soil treatment within their own state.

The technology of bioaugmentation has been around for over twenty years, but its use in bioremediation could still be considered in the formative stage. Treatment of "simple" wastes such as waste oil are fairly straight forward, and other more complex wastes are being treated everyday. Our firm is currently looking at being able to handle several troublesome substrates that had not been considered as candidates for bioremediation in the past. Concurrently, we are also assessing the possibility of selective removal of contaminants. There is some evidence that it may be possible to selectively remove PNAs from a site before removing the other contaminants. It would then be possible to delist certain contaminated sites by removing the characteristic that made them hazardous in the first place.

Regulatory obstacles to bioremediation are becoming fewer and fewer. In certain regions of California it is now required that a site must explore the possibility of bioremediation before any other technology can be adopted. We see this as a trend that will continue to grow as landfill alternatives and economic constraints limit the number of viable alternatives for hazardous waste disposal.

BIBLIOGRAPHY

1) Bossert, I. and Bartha, R. Chapter 10, "The Fate of Petroleum in Soil Ecosystems," in Petroleum Microbiology, Ed. by Atlas, R.M., MacMillan Publishing Company, New York, NY 1984.

2) Dibble, J.T. and Bartha, R., "Effects of Environmental Parameters on the Biodegradation of Oil Sludge," Applied and Environmental Microbiology, 37:729-739, 1979.

3) Floodgate, G.D. "The Fate of Petroleum in Marine Ecosystems," in Petroleum Microbiology, Ed. by Atlas, R.M., MacMillan Publishing Company, New York, NY 1984.

4) Grubbs, R.B. "Enhanced Biodegradation of Aliphatic and Aromatic Hydrocarbons through Bioaugmentation," presented at the 4th annual Hazardous Materials Management Conference/Exhibit, Atlantic City, NJ 1986.

5) Grubbs, R.B. and Molnaa, Barry A., "In Situ Biological Treatment of Troublesome Organics," presented at the 1st annual CWPCA Industrial and Hazardous Waste Information Exchange, Fresno, CA 1987.

6) Hansen, R.W. and Kallio, R.E., "Inability of Nitrate to

Serve as a Terminal Oxidant for Hydrocarbons," Science, 125:1198, 1957.

7) Huddleston, R.L. and Cresswell, L.W., "Environmental and Nutritional Constraints of Microbial Hydrocarbon Utilization in the Soil," in Proceedings of 1975 Engineering Foundation Conference: The Role of Microorganisms in the Recovery of Oil, pp71 - 72, NSF/RANN, Washington, 1976.

8) Mathewson, Joseph R. and Grubbs, R.B., "Innovative Techniques for the Bioremediation of Contaminated Soils," presented at 2nd annual CWPCA Industrial and Hazardous Waste Information Exchange, Oakland, CA 1988.

9) Mulkin-Phillips, G.J., and Stewart, J.E., "Effect of Four Dispersant on Biodegradation of Growth of Bacteria on Crude Oil," Applied Microbiology 28:547-552, 1974.

10) Polak, J. and Lu, B.C., "Mutual Solubilities of Hydrocarbons and Waters at 0o and 25oC," Canadian Journal of Chemistry, 51:4018 - 4023, 1973.

11) Rittenhouse, R.C., "Quality--the Critical Element in Liquid Fuel Handling," Power Engineering, July , 1988.

12) Robichaux, T.J., and Myrick, N.H., "Chemical Enhancement of the Biodegradation of Crude Oil Pollutants," Journal of Petroleum Technology, 24:16 - 20, 1972.

13) Stein, G., "Oil-Gobbling Bacteria Clean Soil at Site of Park in Carson," Los Angeles Times, October 11, 1987.

14) Westlake, D.W.S., Jobson, A., Phillippe, R., and Cook, F.D., "Biodegradability and Crude Oil Composition," Canadian Journal of Microbiology, 20:915 - 928, 1974.

TABLE 1

COMPONENT	09/24/84 (ppb)	10/31/84 (ppb)	04/04/84 (ppb)	% RED.
Benzene	N/A	96	31	67.7
Carbon Tet.	N/A	65	Nil	99.9
Chlorobenzene	9,050	227	37	99.6
1,1 DCE	N/A	508	341	32.9
Ethyl Benzene	154,000	1,119	382	99.8
Toluene	31,000	1,276	526	98.3
111 TCA	N/A	82	Nil	99.9
Xylene	1,249,000	16,825	1,979	99.8

N/A - not analyzed for

TABLE 2

TREATMENT PROCESS	COST PER TON
Landfill disposal fees:	$140 to $120/ton + Taxes + Transportation
Mobile Incineration:	$150 to $400/ton
Stabilization/fixation:	$100 to $200/ton
Bioremediation:	$15 to $70/ton

BIOTREATMENT SYSTEM SCHEMATIC

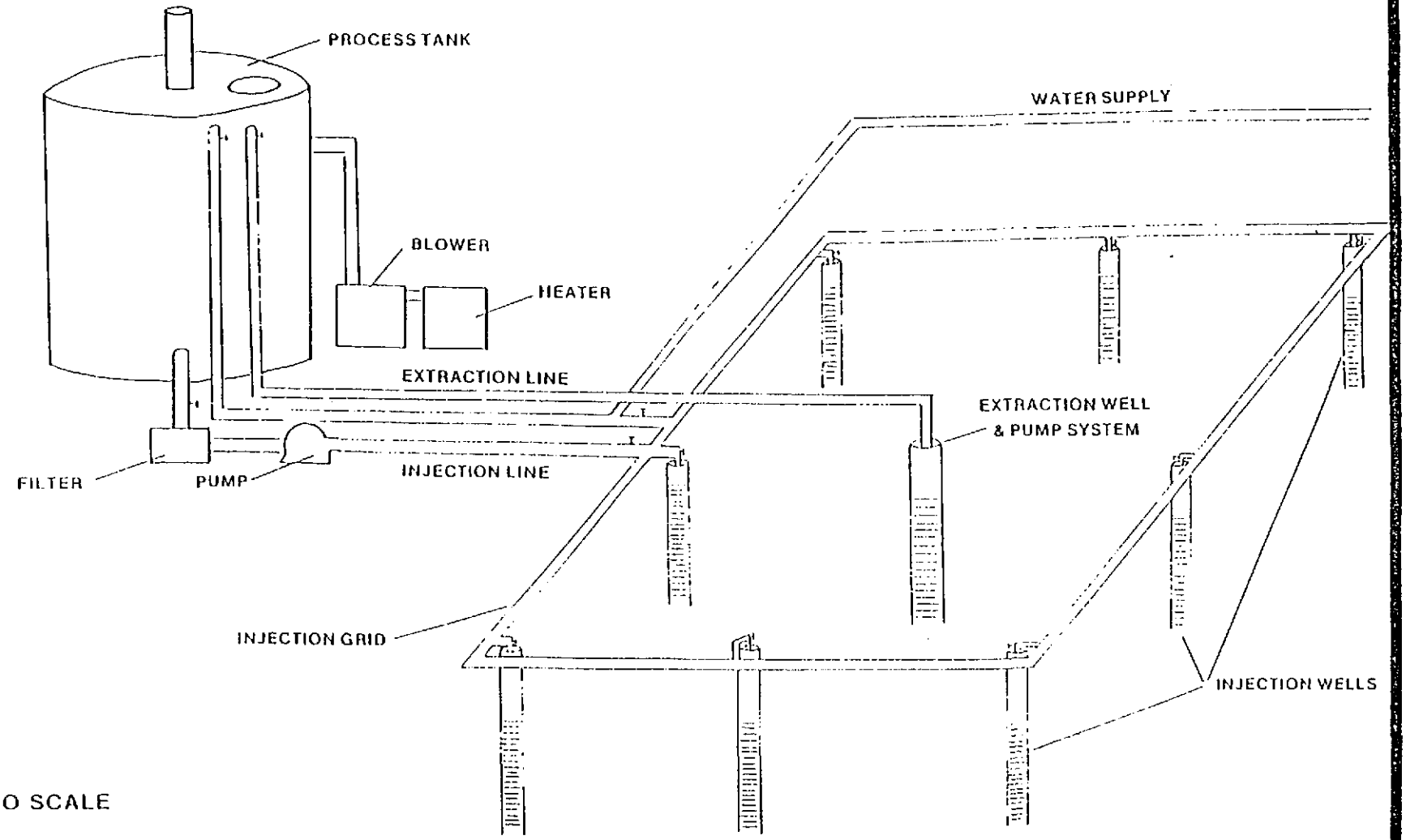


FIGURE 1

Compliments of California GEO

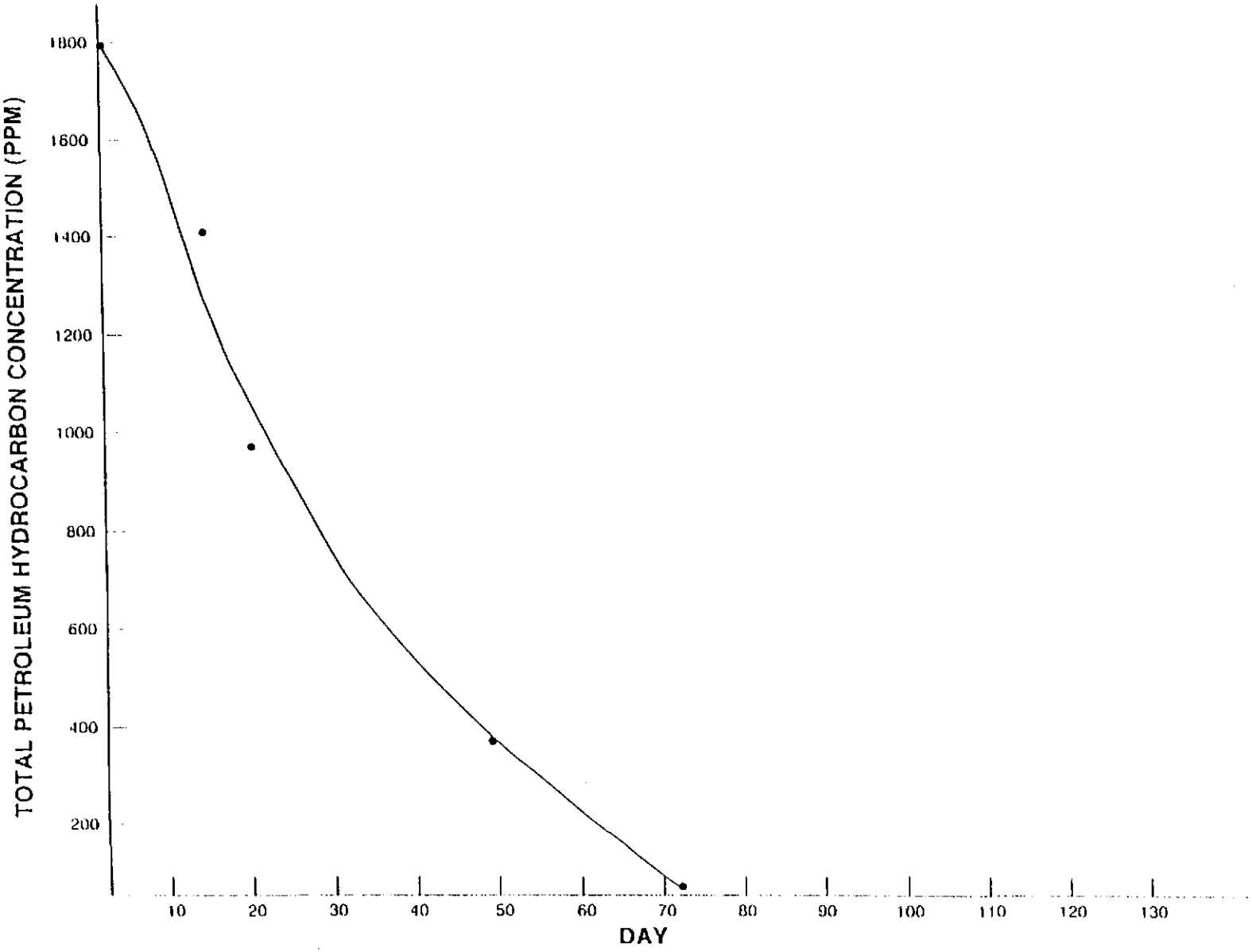
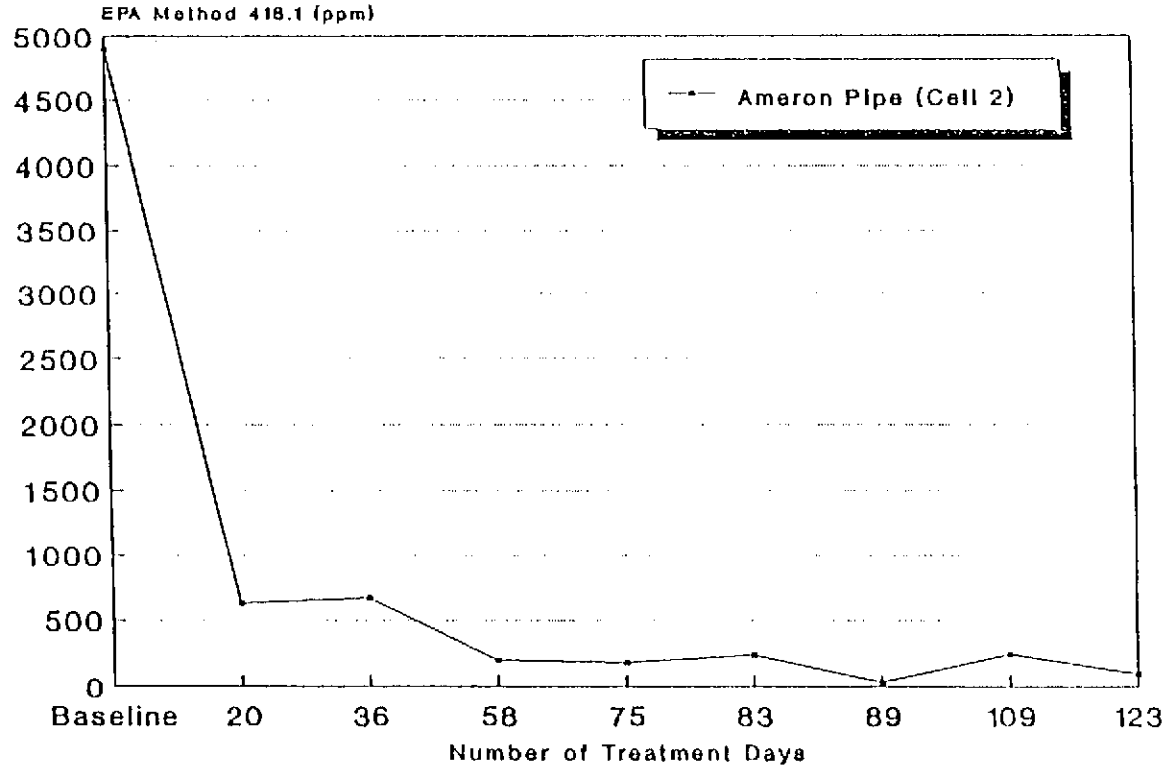

TOTAL PETROLEUM HYDROCARBON CONCENTRATION (PPM)
1800
1600
1400
1200
1000
800
600
400
200
10
20
30
40
50
60
70
80
90
100
110
120
130
DAY

FIGURE 2

SOIL ANALYSIS RESULTS

BioAugmentation Program

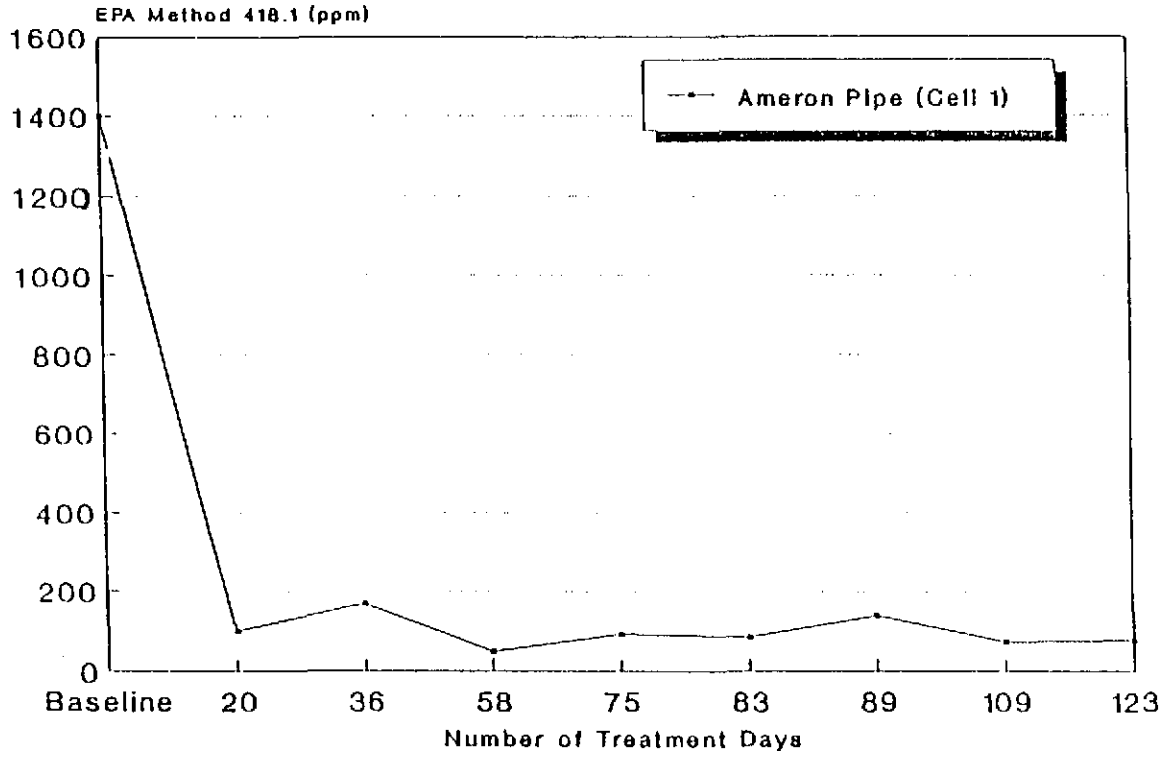


Courtesy of: ProTek Environmental, Inc.
Huntington Beach, CA (714)897-0781

Figure 3

TYPICAL DEGRADATION RESULTS

BioAugmentation Process



Courtesy of: ProTek Environmental, Inc.
Huntington Beach, CA (714)897-0781

Figure 4

APPENDIX 2

GEN-TECH DRILLING, SEALING,

WELL CONSTRUCTION AND SAMPLING PROTOCOL

Gen-Tech Environmental

1936 Camden Ave., Suite 1
San Jose, CA 95124
Contractor's Lic. #615869

Tel. (408) 559-1220 • Fax (408) 559-1228 • 1-800-499-1220

GEN TECH ENVIRONMENTAL, INC.
DRILLING, SEALING WELL CONSTRUCTION AND SAMPLING PROTOCOL

Last Rev. 4/5/93

Exploratory Boring Drilling and Sealing

Exploratory boring and well construction, and borehole sealing procedures follow guidelines recommended by the USEPA, California Regional Water Quality Control Board, and modified as required by City, local or water district agencies. Drilling is performed only under approved permits and boreholes are sealed upon completion.

Soil Sampling Procedures

1. Drive (or hydraulically push) soil sampling will commence at a depth of 5 feet below surface grade. The samples will be taken at 5 foot increments and at intervals of geologic interest or obvious contamination. Additional sampling and/or continuous coring may be done at the discretion of the supervising geologist. All logging will be done using the Unified Soil Classification System, together with pertinent geologic observations.

2. Soil sampling tools (split spoons, cores, etc.) will be disassembled, steam-cleaned or cleaned in soapy (TSP) water, rinsed with clean tap water and finally rinsed with or distilled water, and air-dried prior to taking each sample. The cleaned tools will then be reassembled with similarly cleaned, dry brass sample liners and carefully lowered into the hollow stem augers for the collection of the next sample. The drill rig will be decontaminated as needed and at the discretion of the logging geologist.

3. When sampling stockpile soils or during excavations, the soil sample will be collected by the following procedure; a clean brass liner will be pushed into the stockpile or soil in the excavator bucket. About two inches of soil will be brushed away and the liner pushed into the soil. The liner is then removed, sealed, labeled and logged onto chain-of-custody forms and packed in a chilled ice chest.

4. The soil samples in the lowermost of brass liners in the sampling tool (if in good condition) will be retained for chemical testing. The samples will be labeled and sealed in the field in their original liners. Sample liners ends will be sealed with aluminum foil, capped with clean cap plugs, and taped.

5. The remaining soil sample will be extruded from the other rings in the field and lithologically logged. Sampler shoe cuttings, drill rig response and bit penetration rate will also be logged. The cuttings and the soils samples not retained for chemical analysis will be placed in 55-gallon drums pending chemical analysis and off-site disposal.

6. All samples retained for chemical analysis will be stored on ice in a clean, covered cooler-box for transport to the Laboratory.

Reconnaissance Groundwater Sampling Procedures

1. Reconnaissance groundwater sample, handling, and storage will follow guidance documents of the Environmental Protection Agency and Regional Water Quality Control Board and local agency guidelines for the investigation.

2. Reconnaissance groundwater samples will be collected in the field in temporarily cased exploratory boreholes using clean Teflon or disposal bailers. The samples will be collected from temporarily cased exploratory boreholes. All sample containers will be properly prepared, sealed, labeled, and identified. Label information will include the date, sampler name, sampling time, and identification number, and the project name and number.

3. The sample will be delivered to a State Certified Laboratory within two days of collection. Samples will be kept on ice and/or refrigerated continuously for shipment to the Laboratory.

4. The sealed sample will only be opened by Laboratory personnel who will perform the chemical analysis.

5. The samples will be analyzed according to the approved EPA Method and storage for the requested analysis.

6. Groundwater sampling will begin 24 hours following well development, following the procedures detailed below for monitoring well sampling. Depth to water measurements are made to the nearest 0.01 foot a surveyed datum (project or known) and wells are checked for separate phase product. Boreholes are sealed following water sampling.

Monitoring Well Construction

1. The proper permits will be obtained from the appropriate agency or Water District, using a Well Inspector as required to be present to witness the installation of the annular seal. The soils borings will be drilled with a continuous-flight hollow-stem auger of at least 3 inches Inside Diameter (ID) and 6 to 8 inches Outside Diameter (OD). All augers will be thoroughly steam-cleaned prior to visiting the site. The augers will be steamed cleaned between borings at a location well away from the proposed borings or adequate clean auger will be available to complete all of the wells without reusing auger sections.

2. A geologic drilling log will be made of the materials encountered and sample depth for each boring. The soils/sediment lithology will be logged using the Unified Soil Classification System. The log will include field descriptions of the soil lithologic variations, moisture conditions, geologic data, and any unusual characteristics which may indicate the presence of chemical contamination.

3. The borings will be advanced to a depth of 45 feet if a saturated zone is not encountered (in absence of other depth specifications). If a saturated zone is encountered, the boring will advance no further than 15 feet below first encountered groundwater or 5 feet into the underlying clay aquitard. A seal will be placed in the overdrilled portion of the aquitard.

4. During the drilling operations, 55-gallon drums will be on site to contain potentially contaminated soils and rinse water.

5. Where borings are completed as groundwater monitoring wells, 2-inch ID schedule 40 PVC blank pipe will be used. Usual well screen selection will be 2 inch ID Schedule 40 PVC pipe with 0.020 inch machine slot. Sections will be threaded and screwed together; glues will not be used. Screens will extend 3-5 feet above first encountered groundwater. The annulus of the perforated section will be packed with clean #3 or #4 Monterey Sand, or equivalent, to a point about 2-feet above the screen interval. Final well design will be adjusted in the field to site specific subsurface conditions, and will be placed so as not to interconnect two possible aquifers. Screens will extend a nominal length above first encountered groundwater for floating product detection. A 1-2 foot thick bentonite seal will be placed on top of the sandpack. A cement annular seal which extends to the surface will be placed by tremie line from the bottom to top of the remaining annular space above the bentonite.

6. The top of the well casing will be locked to prevent contamination and tampering. Above-grade or at-grade well completion will depend upon the final well location. Above-grade completion will require a 6 inch diameter locking, steel protective casing and a Christy, or equivalent, traffic box and concrete pad.

Monitoring Well Development

1. Wells will be developed until the water is free of fine-grained sediments and/or until field measurements of pH, and electrical conductivity have stabilized. Approximately 4 to 10 well volumes of water will be removed during development of the well. Duration of development will be specific for each well and continue until the water clears and sand content is minimal or ceases.

2. Equipment inserted into the well during development will be decontaminated by washing or steam cleaning prior to and after its use. Development water will be collected in drums.

Monitoring Well Sampling

1. Depth to groundwater will be measured to the nearest 0.01 foot, and the well checked for presence of separate phase product. If present, the apparent thickness of the product will be measured. The well will not be sampled if separate phase product is present.

2. The standing well volume calculated, and 4 to 10 well volumes will be purged from the well prior to sampling. Measurements of conductivity, temperature and the pH of the water will be taken until parameters have stabilized to indicate that aquifer water is entering the well.

3. The groundwater samples will be collected using a Teflon Bailer. A field log will record sampling measurements and observations. Aquifer parameters which will be measured are; pH, temperature and electrical conductivity. Aquifer water is assumed to be entering the well when these parameters are measured within a 10% range. The sample will be collected when the well recovers to within 80% of the original depth to water measurement.

4. The bailer will be thoroughly steam-cleaned or cleaned with soapy (TSP) water, rinsed with tap water, and finally rinsed with deionized or distilled water prior to the collection of each sample. A separate clean bailer will be used to sample each individual well.

5. All water retained for chemical analysis will be placed in clean, borosilicate, 40ml VOA vial with a teflon cap, or clean amber glass one-liter bottles and other sample containers as appropriate for water sampling purpose and test parameters. Each sample vial or bottle is topped-off to avoid air space, and will be inverted to check for air bubbles, and filled to minimum headspace. Samples will be placed on ice, blue ice, or refrigerated at 4 degrees Centigrade at all times.

6. Water samples blanks of distilled water will be poured through the sampling bailer and placed in clean sample collection bottles or vials. One water sample blank will be taken for each set of water samples collected from each boring or well.

7. All sampling equipment will be decontaminated following each sampling event, prior to use the next monitoring well.

Sample Records and Chain of Custody

1. Sample records for each sample will contain information on sample type and source; Gen-Tech Environmental project number, sampler name, sampling date, location, Laboratory name, sampling method, and any significant conditions that may affect the sampling.

2. A signature Chain-of-custody and transference documentation will be strictly maintained at all times.

3. A copy of the Laboratory sample results and the completed Chain of Custody will be provided with the technical report.

Quality Control and Quality Assurance Objectives

The sampling and analysis procedures employed by GTE for groundwater sampling and monitoring follow quality assurance and quality control (QA/QC) guidelines set out in Federal, State and local agencies guidance. Quality assurance objectives have been established to develop and implement procedures for obtaining and evaluating water quality and field data in an accurate, precise and complete manner. In this way, sampling procedures and field measurements provide information that is comparable and representative of actual field conditions. Quality control is maintained by site specific field protocols and requiring the analytical laboratory to preform internal and external QC checks. The goal is to provide data that are accurate, precise, complete comparable and representative.

The definitions as developed by overseeing federal, state, and local agency guidance documents for accuracy, precision, completeness, comparability and representativeness are:

- **Accuracy** - the degree of agreement of a measurement with an accepted reference or true value.

- **Precision** - a measure of agreement among individual measurements under similar conditions. Usually expressed in terms of standard deviation.

- **Completeness** - the amount of valid data obtained from a measurement system compared to the amount that was expected to meet the project data goals.

- **Comparability** - express the confidence with which one data set can be compared to another.

- **Representativeness** - a sample or group of samples that reflect the characteristics of the media at the sampling point. It also includes how well the sampling point represents the actual parameter variations which are under study.

Environmental
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STANDARD SYMBOLS

Legend

- Soil sample location
- Soil sample collected for laboratory analysis
- No soil recovery
- First encountered groundwater level
- Potentiometric groundwater level
- Disturbed or bag soil sample

2.5 YR 6/2 Soil color according to Munsell Soil Color Charts (1975 Edition)

Penetration

Sample drive hammer weight - 140 pounds falling 30 inches. Blows required to drive sampler 1 foot are indicated on the logs

Well Construction

- Annular seal
- Bentonite seal
- Sand pack
- Well riser section
- Well screen section

UNIFIED SOIL CLASSIFICATION SYSTEM

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES
COARSE-GRAINED SOILS More than half of material is larger than No. 200 sieve size	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size	Clean Gravels	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels, gravel-sand mixture, little or no fines
		Gravels with Fines	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS More than half of coarse fraction is smaller than No. 4 sieve size	Clean Sands	SW	Well-graded sands, gravelly sand, little or no fines
			SP	Poorly graded sands, gravelly sands, little or no fines
		Sands with Fines	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS More than half of material is smaller than No. 200 sieve size	SILTS AND CLAYS	Low Liquid Limit	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts, with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
		High Liquid Limit	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity, organic silts
			Pt	Peat and other highly organic soils

NOTES:

1. Boundary Classification: Soils possessing characteristics of two groups are designated by combinations of group symbols. For example, GW-GC, well-graded gravel-sand mixture with clay binder.
2. All sieve sizes on this chart are U.S. standard.
3. The terms "silt" and "clay" are used respectively to distinguish materials exhibiting lower plasticity from those with higher plasticity.
4. For a complete description of the Unified Soil Classification System, see "Technical Memorandum No. 3-357," prepared for Office, Chief of Engineers, by Waterways Equipment Station, Vicksburg, Mississippi, March 1953.