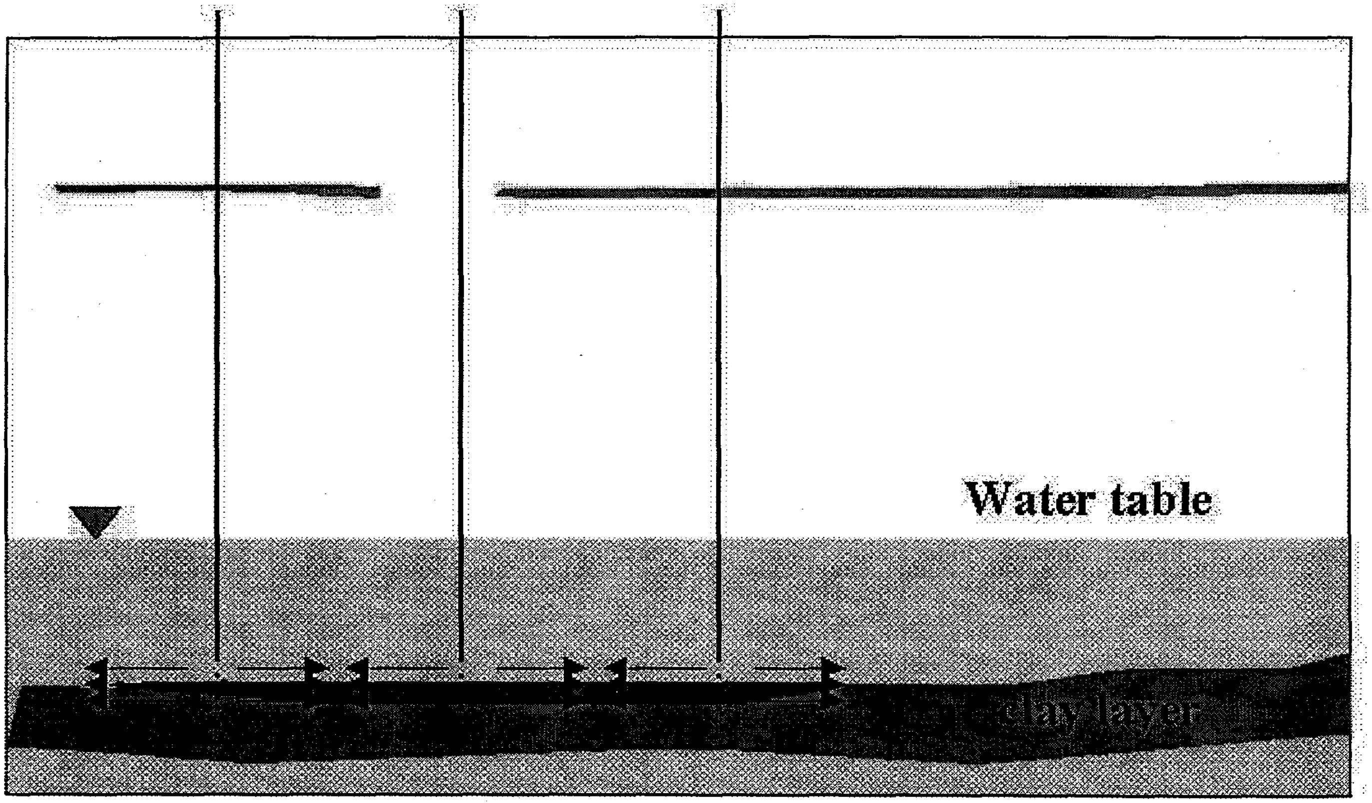
WSRC-TR-97-00283
September 19, 1997
Rev. 0

Final Report
for
Demonstration of In Situ Oxidation of DNAPL
Using the Geo-Cleanse® Technology



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Demonstration of In Situ Oxidation of DNAPL

Using the Geo-Cleanse® Technology

U.S Department of Energy Office of Technology Development
U.S. Department of Energy Savannah River Operations

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ACRONYM LIST

bgs	below ground surface
cfm	cubic feet per minute
DNAPL	Dense Non-Aqueous Phase Liquid
ECD	Electron Capture Detector
FID	Flame Ionization Detector
ft	feet
GC	Gas Chromatograph
GC-MS	Gas Chrmatograph - Mass Spectrometer
gm	gram
µgm	microgram
lb	pound
LNAPL	Light Non-Aqueous Phase Liquid
mg/L	milligrams/liter
MOX and MSB	Well identifier series
msl	mean sea level
NAPL	Non-Aqueous Phase Liquid
PCB	Polychlorinated Bi-Phenyl
PCE	Perchloroethylene or tetrachloroethylene
ppm	parts per million
ppmv	parts per million vapor
RCRA	Resource Conservation and Recovery Act
SRS	Savannah River Site
SVE	Soil Vapor Extraction
TCE	Trichloroethylene

Chemicals

CO_2	carbon dioxide
Cl	chloride ion
Fe+2	ferrous iron
Fe+3	ferric iron
H_2O_2	hydrogen peroxide
OH- or OH*	hydroxyl radical
H_2O	water

1.0 SUMMARY

At large industrial sites like the A/M Area of the Savannah River Site (SRS), undissolved dense non-aqueous phase liquid (DNAPL) in soil and groundwater is the most significant barrier to successful clean up. DNAPL acts as a reservoir that will continue to generate contaminant levels far above remediation concentration goals well into the future. In an effort to achieve remediation goals and reduce future costs, the SRS DNAPL program is evaluating technologies which will recycle or destroy DNAPL. In situ oxidation is one class of DNAPL destruction technologies. A demonstration of this technology was conducted at SRS in the spring of 1997. This demonstration involved treating a small DNAPL plume in the A/M Area over a 6 day period. A destruction efficiency of 94 % was achieved in this small scale test. As part of the test evaluation, a unit cost per pound of DNAPL was determined for different depths to DNAPL and for varying volumes of DNAPL. Comparison was made to pump and treat (air stripping) which is considered a baseline technology for DNAPL contaminated groundwater. This information will provide a basis to determine which DNAPL contaminated waste units will be remediated in a more cost effective manner by using in situ oxidation. For the A/M Area, a DNAPL pool of approximately 11,000 pounds or more is required for this technology to be more cost efficient than pump and treat.

The in situ oxidation of DNAPL demonstration deployed a technology based on Fenton's chemistry to destroy DNAPL below the water table. This demonstration was a cooperative venture between Westinghouse Savannah River Company and Geo-Cleanse International, Inc. The site selected for the demonstration is a 50 ft by 50 ft area adjacent to the M-Area Seepage Basin, a known source of DNAPL. The site is located along an area of DNAPL migration in the subsurface. DNAPL is located at approximately 140 ft below surface at the demonstration site (approximately 20 ft below the top of the water table). The treatment zone consisted of a 64,000 ft^3 volume of soil containing approximately 600 pounds of DNAPL. Four injector wells, three monitoring wells and three vadose zone piezometers were installed for this test. The demonstration occurred in three stages: pre-test characterization, technology test, and post-test characterization.

Characterization efforts conducted throughout the demonstration were used to evaluate the effectiveness of the technology. Pre- and post-test characterization activities consisted primarily of soil core sampling to determine the soil concentration of TCE and PCE in the treatment zone. Groundwater sampling was conducted throughout all three phases of the demonstration to provide information on TCE and PCE concentrations, chloride concentrations, pH and temperature. Indicators of destruction include increase in chloride concentration in groundwater during the treatment period and decreases in TCE and PCE concentration in both groundwater and soil from pre-test to post-test.

Field activities were initiated January 8, 1997 with the start of pre-test characterization of the demonstration site. These activities lasted for five weeks. Infrastructure support activities were completed and the demonstration test was initiated on April 15, 1997. The six day treatment period ended on April 21, 1997. The treatment period lasted for six days. Post-test characterization activities began April 24, 1997 and were completed July 23, 1997.

Several observations made during the treatment period have led to a proposal for follow-on work. Increased groundwater temperature, inoperable groundwater monitoring pumps during operation (due to release of gases from reaction) and audible bubbling sounds from the monitoring wells indicated a vigorous chemical reaction occurred. This raised questions on what happens in the treatment zone from a geo-chemical and biological perspective.

2.0 INTRODUCTION

The in situ oxidation of DNAPL demonstration deployed a technology based on Fenton's chemistry to destroy DNAPL below the water table. This demonstration, sponsored by the Department of Energy, is a cooperative venture between Westinghouse Savannah River Company and Geo-Cleanse International, Inc. (referred to as Geo-Cleanse through the remainder of this document). The purpose of this demonstration is to evaluate a technology in the general class of DNAPL destruction technologies. The site selected for the demonstration is a 50 ft by 50 ft area adjacent to the M-Area Seepage Basin, a known source of DNAPL. The site is located along an area of DNAPL migration in the subsurface. DNAPL is located at in a thin zone at approximately 140 feet below surface (and in discrete lenses associated with other clay layers at the site) at the demonstration site. Four injector wells, three monitoring wells and three vadose zone piezometers were installed for this test. The demonstration occurred in three stages: pre-test characterization, technology test, and post-test characterization. The following report documents results and conclusions of this demonstration.

Field activities were initiated January 8, 1997 with the start of pre-test characterization of the demonstration site. These activities lasted for five weeks. Infrastructure support activities were completed and the demonstration test was initiated on April 15, 1997 with completion on April 21, 1997. The treatment period lasted for six days. Post-test characterization activities began April 24, 1997 and were completed July 23, 1997.

3.0 BACKGROUND

The M-Area of Savannah River Site was a fuel and target fabrication facility. The mission of this area was processing uranium, lithium, aluminum and other materials into fuel elements and targets for use in the nuclear production reactors. The processes were primarily metallurgical and mechanical, such as casting, extrusion, plating, hot-die-sizing, welding and magneforming. Solvent cleaning and acid/caustic etching were used to prepare the materials.

The M-Area Settling Basin and associated areas (the overflow ditch, Lost Lake, the seepage area, and the inlet process sewer line), designated as the M-Area Hazardous Waste Management Facility, received process effluent from 1958 until 1985. VOC contamination of soils and groundwater occurred in M-Area as a result of breaks in the old process-sewer line and disposal to the basin. In 1985, pump and treat was employed, followed by soil vapor extraction (SVE) in 1995. The M-Area Settling Basin, capped in 1988 and closed under RCRA, is a certified closure as a landfill. These activities have been performed under a RCRA Post Closure Care Part B Permit. This demonstration of an in situ oxidation technology to destroy DNAPL supports the phased remediation of the 1500 acre plume.

A wide range of research and development activities have been performed in support of the A/M -Area groundwater corrective action. These various activities have been designated the Integrated Demonstration and include use of horizontal wells for remediation, an in situ air stripping test, in situ bioremediation test, off gas treatment technology tests, a radio frequency heating test, and an ohmic heating test. Development and demonstration of characterization tools have also been an integral part of the program in the A/M area.

During routine sampling using a bottom filling bailer, a separate, dense phase was identified in monitoring wells MSB-3D and MSB-22 sumps. These wells are located approximately 20 feet from the M-Area Settling Basin. The relatively thick vadose zone, approximately 130 ft, beneath A/M-Area tends to limit the downward flux of DNAPL and capture some DNAPL in layered clays. As expected, DNAPL below the water table has been observed where solvent release exceeded the capacity of the vadose zone to moderate the flux of the pure phase to the groundwater. The clearest evidence of DNAPL below the water table was found at the Settling Basin, where a separate phase was identified in the sumps of wells MSB-3D and MSB-22. Data collected at separate times suggest that DNAPL below the water table occurs as relatively diffuse ganglia and/or a thin layer on the top of aquitards, and that DNAPL collects in well sumps as a result of dynamic processes. One such process is accumulation of dense ganglia in the well sump as the well is actively purged and sampled (similar to accumulation of sediments in the sump).

The cone penetrometer, in conjunction with conventional coring, allowed refinement of the delineation of an important clay zone (the "green clay") beneath the water table. Undulations and other structural variations on top of this layer serve to control movement of a dense phase below the water table. Based on cone penetrometer results, structure controlled pathways for density-dominated transport below the water table were discerned. Two potential pathways were identified. The primary potential pathway of contaminant migration begins near the Settling Basin, where DNAPL was found in monitoring wells MSB-3D and MSB-22, Figure 3.1. The contour grades toward the west and then north toward MSB-76, where high dissolved constituent concentrations (> 1000μg/L) are reported.

Phase I of the DNAPL characterization provided significant insight into the nature and location of DNAPL in the SRS subsurface. In particular, data indicate a substantial amount of DNAPL has been trapped in clays and silts in the vadose zone above the water table. Phase I characterization data also suggest DNAPL below the water table in A/M-Area is present as disconnected ganglia, rather than as a large, solvent-saturated layer. DNAPL present below the water table is composed of approximately 95% TCE, 5% PCE and a very small but measurable amount of PCBs. Objectives of Phase 2 of the DNAPL remediation focus on: (1) pure phase DNAPL, (2) recycle of DNAPL, and (3) on site destruction of DNAPL.

The in situ oxidation of DNAPL demonstration is an important element of the Phase 2 remediation activities. This demonstration involves in situ oxidative destruction of the DNAPL plume using Fenton's chemistry. Demonstration activities were conducted within one quarter mile of the M-Area Settling Basin. Figure 3.1 shows the selected location for this demonstration, the area of review, all monitoring wells, surface bodies of water, roads, and other cultural features. Because "treatment" of pure phase non-aqueous phase liquid (NAPL) is the key to a successful and timely cleanup, in situ oxidation technologies are promising sys
tems for destruction of both aqueous and pure phase NAPL in the subsurface.

4.0 TECHNICAL BASIS

4.1 Fenton's Chemistry

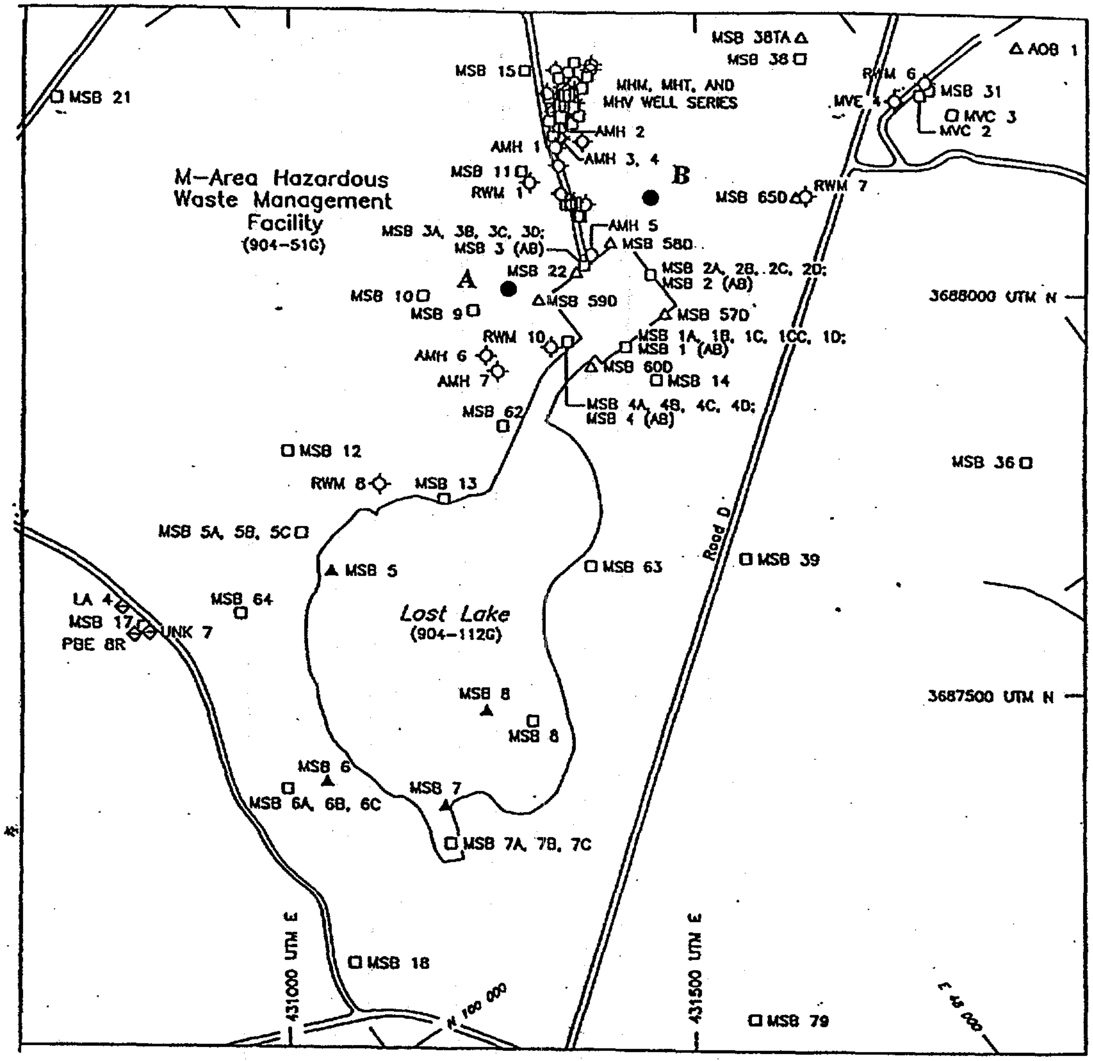
The Geo-Cleanse® process is an in situ oxidative reduction process based on Fenton's chemistry.

H. J. H. Fenton developed a chemistry which oxidized malic acid through use of hydrogen peroxide and iron salts in the 1890s. This chemistry has been, and is still widely used by the waste water industry for treatment of organic wastes. Hydrogen peroxide is the active ingredient in oxidation of organic compounds by this methodology. The hydroxyl radical is the reactive species in this process.

The chemistry of Fenton's reagent (1) is well documented as a method for producing hydroxyl radicals by reaction of hydrogen peroxide and ferrous iron (Fe+2). Hydroxyl radicals are very powerful, effective and nonspecific oxidizing agents, approximately 10^6 to 10^9 times more powerful than oxygen or ozone alone.

$$H_2O_2 + Fe^{2+} \Rightarrow Fe^{3+} + OH^- + OH^\bullet \qquad (1)$$

With the Geo-Cleanse® process, iron salts in the form of ferrous sulfate (Fe+2) and hydrogen peroxide are injected with a patented process, Patents #5,525,008 and #5,611,642, to generate hydroxyl radicals. Proprietary mixtures of non-hazardous metallic salts are used to control the reaction. During the optimum reaction sequence and when the catalyst is iron, ferrous iron (Fe+2) is converted to ferric iron (Fe+3). Ferrous iron is soluble in water at the target pH and is necessary for generation of the hydroxyl radical, but ferric iron will not generate the hydroxyl radical and is less soluble at the target pH range (pH 5 to 6). However, under properly controlled and buffered conditions, ferric iron can be regenerated back to ferrous iron by a subsequent reaction with another molecule of hydrogen peroxide (2).



A and **B** were proposed locations for demonstration.

A is location of In Situ Oxidation Demonstration.

Figure 3.1 Area Map of In Situ Oxidation Demonstration Site, Located Adjacent to the M-Area Hazardous Waste Management Facility

$$H_2O_2 + Fe^{3+} \Longleftrightarrow Fe^{2+} + H^+ + HO_2^{\bullet} \quad (2)$$

In this case, the iron will remain available in ferrous form as long as pH is properly buffered and there is sufficient hydrogen peroxide. As hydrogen peroxide is consumed, some iron will precipitate out as ferric iron (if pH is moderate). The Geo-Cleanse® process has been widely used for light non-aqueous phase liquids (LNAPLs), and adverse impacts due to precipitation of iron have not been observed.

There are many reactions that occur during the oxidation of a contaminant, but as shown by equation (3) a contaminant (RHX), hydrogen peroxide, and ferric iron, as a catalyst, are consumed to produce water and carbon dioxide. RHX represents an organic compound and X represent a halide (such as chloride). If the compound is non-halogenated (no X), then the hydrogen ion and halide anion are not formed in the *overall* reaction. Thus compounds such as BTEX are converted to carbon dioxide and water, whereas trichloroethylene and tetrachloroethylene are converted to carbon dioxide, water, hydrogen and chloride ions, which are all non-toxic at the levels they will be produced.

$$RHX + \overset{Fe+2}{H_2O_2} \Longleftrightarrow H_2O + CO_2 + H^+ + X^- \quad (3)$$

4.2 Description of Geo-Cleanse® Technology

Geo-Cleanse® technology, an in situ destruction technique, utilizes Fenton's reagent (ferrous iron and hydrogen peroxide) to convert organic contaminants to water and carbon dioxide. Hydrogen peroxide and catalyst (ferrous sulfate and/or sulfuric acid) are injected into the groundwater zone where DNAPL contamination is located. A patented injection process is used to inject hydrogen peroxide and catalyst.

After initial characterization of the site and installation of injectors in the zone of contamination, the treatment process is initiated. The number of injectors installed and volume of injectate is based on the source area size. Injection of catalyst solution with 2 to 4 cfm of air to sparge the catalyst away from the injector into the formation is the initial step in treatment. This adjusts the groundwater pH to between 4 and 6, where metals, specifically iron, will be at the optimal electron state, +2. This is followed by the simultaneous injection of hydrogen peroxide and catalyst. Mixing of catalyst and hydrogen peroxide in the subsurface will generate heat as the reaction with organic contaminants progresses. Monitoring is conducted during the treatment phase for water vapor; carbon dioxide gas, hydrogen peroxide, the contaminants to be destroyed, pH, conductivity, and dissolved oxygen. Catalyst solution may be added throughout the injection process to maintain groundwater pH within the range of 4 to 6.

A key part of this technology is the injection process. The injection process is proprietary and Patents #5,525,008 and #5,611,642 have been issued. The injector contains a mixing head which is utilized for mixing reagents and has components to stimulate circulation of groundwater to promote rapid reagent diffusion and dispersion. Thus, all reagents are injected into the subsurface through the injectors. Upon start of the injection process, air with catalyst solution is injected to ensure the injector is open to the formation prior to injection of peroxide and catalyst solution. When an acceptable flow has been established, peroxide and catalyst will be injected simultaneously. This ensures that catalyst and peroxide will not mix together in the sealed system. The injector is designed with a check valve and constant pressure delivery system which prevents mixing of the chemicals before they have reached the zone of contamination/treatment. Thus, the chance of reaction within the wellbore is eliminated.

4.3 Green Clay Integrity in the Vicinity of the M-Area Basin

Typical of the Atlantic Coastal Plain, sediments beneath A/M-Area are interbedded sands, silts and clays deposited during periods of fluctuation in sea level and modified by erosion during intervening times. Clay rich confining, or restrictive, intervals are interspersed with more transmissive, sandier intervals. In A/M-Area, there are several clay rich intervals above the water table (with elevations of about 325 feet msl, 305 feet msl, and 270 feet msl). Ground surface in central A/M-Area is about 365 feet msl, and the water table is approximately 135 feet deep (elevation 235 feet msl). DNAPL below the water table (target contamination for this in situ oxidation test) accumulates in sandy layers on top of fine grain (clay and silt) layers. The uppermost significant clay beneath the water table is termed the "Green Clay." This confining zone is at an elevation of approximately 200 feet msl (or about 35 feet below the water table). The structural contour of this layer was carefully delineated in previous characterization work (WSRC, 1992). Delineation indicated the Green Clay is generally present in the vicinity of the M-Area Settling Basin. The uppermost surface of the Green Clay is not flat, but has structural features, undulating or irregular features forming local depressional or trough-like areas that control migration of DNAPL near the basin. Data from A/M-Area indicate discontinuities, in the form of compositional changes, present in the Green Clay. Note, however, that the scale and pattern of DNAPL migration (in a narrow structural feature located between the M-Area Settling Basin and well cluster MSB 76) indicate DNAPL accumulated above the Green Clay; this is a target of opportunity for in situ destruction technologies. Figure 4.1 is a representation of the surface contour of the Green Clay in the vicinity of the M-Area Settling Basin. It is based on cone penetrometer data and hydrostratigraphic core information collected in the general vicinity of the M-Area Settling Basin and Integrated Demonstration Site.

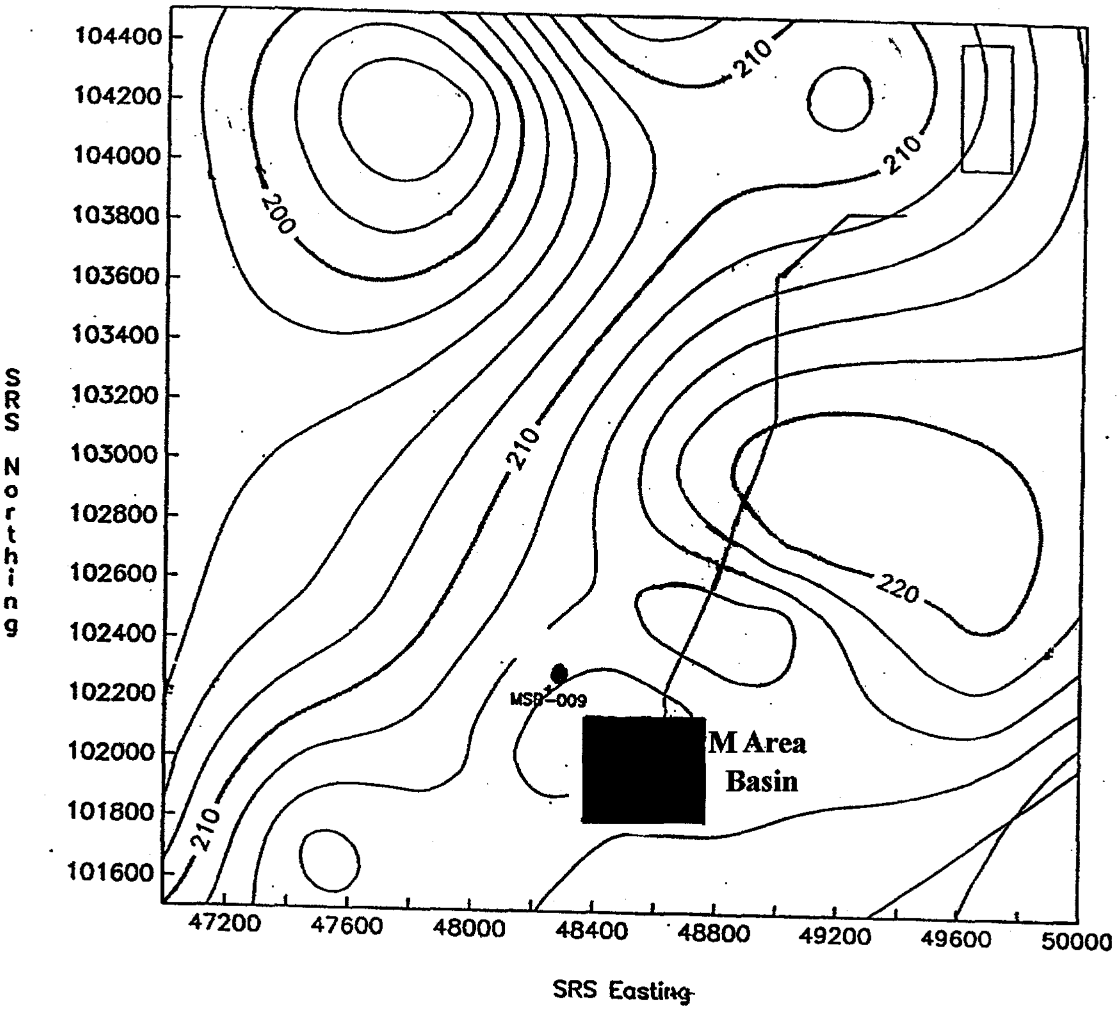
4.4 Selection of Demonstration Location

Two locations of suspected DNAPL accumulation were identified adjacent to the closed M-Area Settling Basin, see Figure 3.1. Location A, the location chosen for the demonstration, is approximately 50 yards off the western corner of the basin. This location is in a bowl shaped surface depression approximately 50 feet square. It is located within a suspected subsurface trough in the Green Clay along which DNAPL is migrating. The second location is off the eastern corner of the basin, location B in Figure 3.1. Soil sample data showed no DNAPL, TCE and PCE below the water table at location B.. TCE and PCE were detected at a single depth in the vadose zone at location B. Concentrations of 0.98 μg TCE/gm of soil and 4.5 μg PCE/gm of soil were detected an approximate depth of 90 feet below ground surface.

Initial field work for this demonstration involved continuously coring and collecting samples in both locations to determine the preferred site. One boring was drilled at each location. The location with the greatest concentration of TCE and PCE was selected for this demonstration. Site A was the chosen location. The estimated pre-tested volume of DNAPL at this location was approximately 600 pounds.

5.0 DESCRIPTION OF DEMONSTRATION

This demonstration was conducted in three phases: pre-test characterization, technology test (or treatment phase), post-test characterization. Pre-test characterization was used to identify the location of the demonstration, the zone below the water table to be targeted for treatment, and initial TCE and PCE concentrations. Pre-test drilling consisted of 2 initial borings, located off the west corner and off the east corner of the basin, followed by 6 borings at the site selected for the demonstration. The locations of the pre-test borings at the selected test site are identified as MOX-1 through MOX-8, as shown in Figure 5.1. These locations were all cored and samples collected and analyzed for TCE and PCE concentrations. MOX-1 through MOX-4 were completed as injection wells and MOX-5 through MOX-8 were completed as monitoring wells. (MOX-6 is the identifier of the second of the two initial borings drilled to select the demonstration location.) In addition, 4 vadose zone piezometers, identified as MOX-1V through MOX-4V, were installed. No characterization data was collected during the installation of the piezometers. The treatment phase involved injection of the chemicals required for the destruction reaction to occur.



• Location of In Situ Oxidation Demonstration

Figure 4.1 Map of Surface of the Green Clay in Vicinity of the In Situ Oxidation Demonstration Site

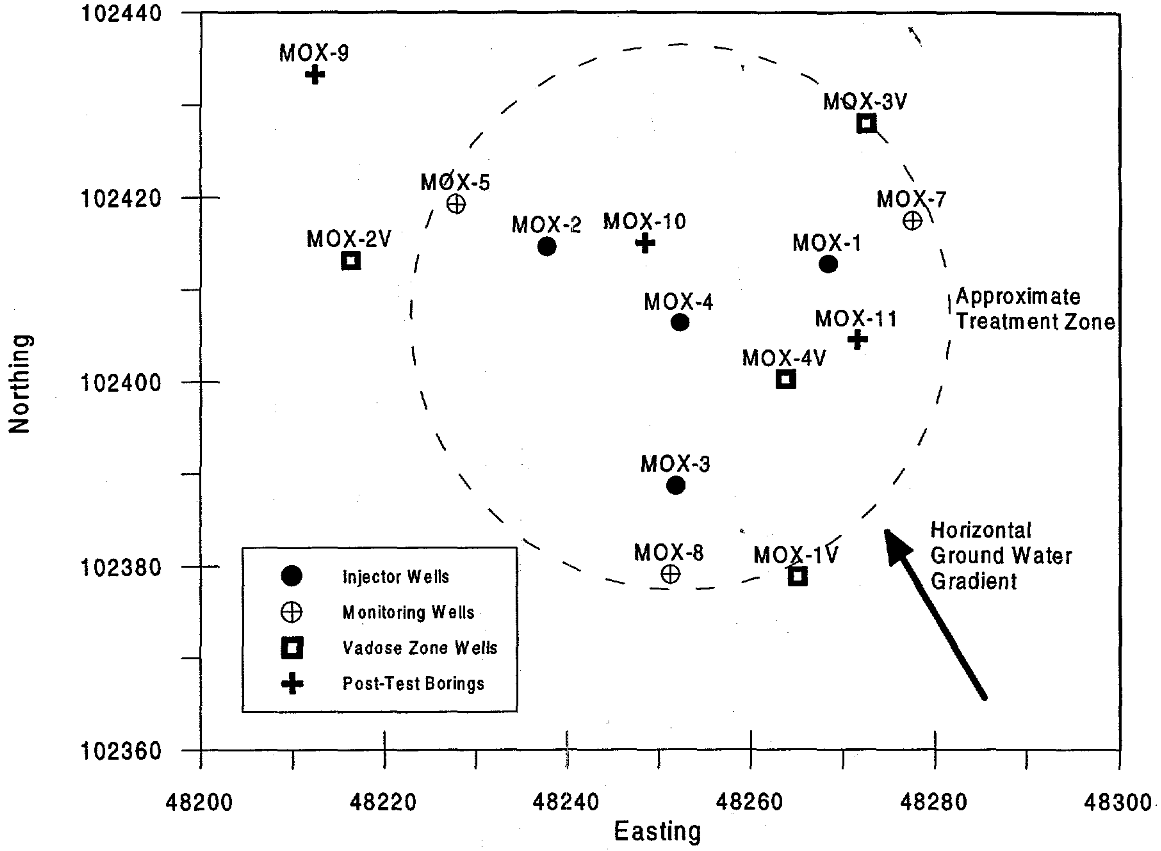


Figure 5.1 Schematic of In Situ Oxidation Field Demonstration Site Layout (coordinates are a local grid in feet)

Injection occurred over a six day period, in a batch process mode of approximately 6 hours per day, completing one batch per day. The process was initiated each day by injection of the catalyst solution. This was followed by injecting peroxide and additional catalyst, simultaneously, in volumes varying from 500 to 1000 gallons per batch. Monitoring of off-gases from monitoring wells was conducted throughout the injection process. Due to the violent nature of this reaction, it was not possible to collect water samples from the monitoring wells during injection. Monitoring wells were sampled daily before the injection process began. Post-test characterization encompassed post-test drilling to verify soil concentrations of TCE and PCE in the treatment zone and sampling and analysis of monitoring wells for a several month period after the injection process had been completed. Sampling of monitoring wells continued until TCE and PCE concentrations stopped increasing, a period of approximately 3 months. Post-test drilling involved 3 soil borings located on a transect running through the test area and within 3 feet of the center of the test zone, with one boring being approximately 10 feet outside the outermost monitoring well. Specific details of the test are addressed below.

In designing this demonstration, decisions had to be made concerning location of the demonstration site, volume of DNAPL to be treated, volume of peroxide and catalyst to be injected, and verification of destruction of DNAPL. Two potential locations for the demonstration were selected based on previous data indicating a high probability of finding DNAPL. Upon drilling both locations, one area was found to contain no indication of DNAPL, while the second area showed soil concentrations of 10 to 150 µg/g of PCE. Highest concentrations were found in a zone at approximately 140 feet below surface, at location A (Figure 3.1).

Five foot screens were used for all installed wells (both monitoring and injector) with the screen zone set from 138 ft to 143 ft below surface. A circular pattern was chosen for the system layout with an injector in the center, ringed by 3 injectors with 3 monitoring wells in a third outer ring. Injectors were set on 17 foot centers with monitoring wells on 27 foot centers. Three vadose zone piezometers were also installed within the treatment area. Figure 5.1 shows a schematic of the system layout. Upon completing pre-test drilling, it was determined that approximately 600 pounds of DNAPL was located within the treatment zone (see Appendix A for equation). The treatment zone was defined as being from the water table to the top of the Green Clay, a zone approximately 30 feet in depth. Testing of the Geo-Cleanse® process occurred over a 6 day period. Injection was conducted in batch mode with one batch injected per day. The injectate was composed of a catalyst of 100 ppm ferrous sulfate which was pH adjusted with concentrated sulfuric acid and the hydrogen peroxide. Three days after the last injection, post-test drilling was initiated to verify destruction of DNAPL. In addition, post-test sampling of monitoring wells was initiated on a weekly basis.

6.0 ANALYSIS AND EVALUATION OF PRE-TEST CHARACTERIZATION SAMPLES

Samples for these tests were analyzed by headspace analysis using a gas chromatograph (GC) with a flame ionization detector (FID) and electron capture detector (ECD) for TCE and PCE. Duplicates were collected for all samples with triplicates collected of samples used in selecting the treatment zone. These triplicate samples were analyzed immediately upon collection by a gas chromatograph with mass-spectrometer (GC-MS) with direct injection of the sample. This allowed for rapid turn around of the sample results leading to rapid decisionmaking on screen zone depth; thus, minimizing down time during the well installation process. (The original and duplicates were analyzed as per standard protocol.) Standards were prepared and run with each batch of samples analyzed. Standard curves were generated and concentrations determined for each analyzed sample. This methodology was followed for all samples analyzed for TCE and PCE throughout the demonstration (treatment test, and post-test).

All pre-test data is provided in Appendix A. Based on analysis of samples from MOX-5 and MOX-6 (first borings at locations A and B, respectively), location A was selected for the demonstration. These two holes were drilled to depths of approximately 155 ft bgs with samples collected continuously from surface to total depth. Sampling to 155 ft ensured sampling to the top of the Green Clay. Sampling intervals were every 10 feet at the surface and decreased to every foot for the bottom 30 feet of each hole (depth from water table to total depth). Small sampling intervals near the bottom of the holes enabled identification of discrete DNAPL zones to the extent possible (remember that DNAPL exists as ganglia below the water table). Data from MOX-5, at location A, showed the presence of TCE and PCE below the water table at a depth of approximately 140 feet bgs. TCE and PCE were present in MOX-6, location B, in the vadose zone only (approximately 90 feet bgs). For this demonstration, the selected site must have DNAPL below the water table. Thus, location A, which is located approximately 50 yards to the west of the closed M-Area Basin, was selected.

Using the data from MOX-5, the well screen depths were selected. MOX-4 and MOX-8 which were drilled to 155 and 165 ft bgs total depth, respectively, confirmed the findings of MOX-5. The remaining 4 wells for the demonstration were drilled to a total depth of 144 ft bgs. All seven wells at the demonstration site were screened from 138 ft to 143 ft bgs. These holes were sampled from above the water table (approximately 125 ft bgs) to total depth at intervals every 2 feet for the first 5 to 10 feet then at intervals of 1 foot until reaching total depth.

The majority of the DNAPL at location A was detected in a zone from 138 ft bgs to 144 ft bgs, collected on a clay stringer approximately 10 ft above the Green Clay. Small quantities of PCE and TCE were detected below the Green Clay, a leaky aquitard that separates the water table zone (M Area Aquifer) from a semiconfined zone (Lost Lake Aquifer). Volume of DNAPL in the target treatment zone was calculated using all pre-test characterization data at Location A (see Appendix A for calculation). The treatment zone extended vertically from the water table to the top of the Green Clay (approximately 30 ft thick) and laterally a circular area of radius 27 feet from the center injector. Volumes of DNAPL present were calculated over 1 foot increments by averaging the soil core data within each increment. The volumes were added and a total volume of 593 pounds of DNAPL was calculated.

Pre-test data, collected from MOX-5, MOX-7 and MOX-8, included average PCE and TCE water concentrations of 119.49 mg/L and 21.3 mg/L, respectively. Average baseline pH, temperature and chloride readings were 5.71 pH units, 19.2° C and 3.61 mg/L, respectively.

7.0 ANALYSIS AND EVALUATION OF TREATMENT TEST SAMPLES

During the six day treatment test, water samples were collected from the monitoring wells (MOX-5, 7 and 8) and analyzed for PCE, TCE, pH, temperature, and chloride ion. Water samples were collected in the morning before the batch injections. Water sampling was limited due to poor pump performance caused by gases entrained in the groundwater during and immediately following injection. Bubbling was heard emanating from the monitoring wells during operation, corroborating the hypothesis that entrained gases were the cause of the poor performance of the pumps. Average contaminant concentrations in the treatment area groundwater were 119.49 mg/L PCE and 21.31 mg/L TCE before treatment and were reduced to 0.65 mg/L PCE and 0.07 mg/L TCE at completion of treatment. Average pH before treatment was 5.71 and 2.44 at completion of treatment. Reduction in pH was due to addition of acid to reduce pH for optimal oxidation and, to some extent, reduction of pH due to increase in CO_2 from the destruction process. Average baseline groundwater temperature in the treatment zone was 19.2° C and was raised to a maximum of 34.7° C by the oxidation process. Average baseline chloride concentration was 3.61 mg/L and reached a maximum of 24.33 mg/L at the completion of the treatment process. The increase in chloride concentration verifies breakdown (oxidation) of PCE and TCE which was contacted by the peroxide. Hydrogen peroxide (H_2O_2) concentrations in the monitoring wells ranged from approximately 2 to 5 ppm. Data from the in situ oxidation treatment period is shown in Figure 7.1. A time history of the hydrogen peroxide batch injections, PCE and TCE, and chloride concentrations is illustrated in these charts.

Three vadose zone wells, screened approximately 10 ft above the water table, were monitored for increases in CO_2 and TCE and PCE volatilizing from the groundwater. Increases in concentrations of these three parameters were not observed. This may be accounted for by the distance of the piezometers above the treatment zone and interbedded sand and clay between the piezometers and treatment zone acting as barriers to upward migration.

Gaseous headspace from the monitoring wells was monitored for CO_2, PCE, and TCE during the injection process. Gases were escaping from water in the monitoring wells during injection due to the violent oxidation process. Carbon dioxide levels from gases escaping from the monitoring wells rose to over 3,500 ppmv (ambient CO_2 levels are approximately 300-400 ppmv). Elevated CO_2 levels verify DNAPL oxidation in the subsurface to H_2O, CO_2, and Cl- based on stoichiometry presented in equation 3 (Section 4.1). PCE and TCE were evident in the gas and can be attributed to sparging of water in the wells. PCE and TCE gas concentrations from the headspace of the monitoring wells during the oxidation process ranged from 0 to 190 ppmv PCE and 0 to 80 ppmv TCE.

8.0 ANALYSIS AND EVALUATION OF POST-TEST CHARACTERIZATION SAMPLES

Three post test soil borings were conducted to obtain sediment samples for VOC analysis to determine effectiveness of the treatment process. A significant decrease in PCE and TCE concentration was observed in post-test sediment samples. Post-test borings were located on a transect running through the test area and within 3 feet of the center of the test zone (MOX-10 and 11), with one boring being approximately 10 feet outside the outermost monitoring well (MOX-9). The outermost boring, MOX-9, was outside the expected treatment zone and was used to verify the DNAPL had not been moved out of the treatment zone. See Figure 5.1.

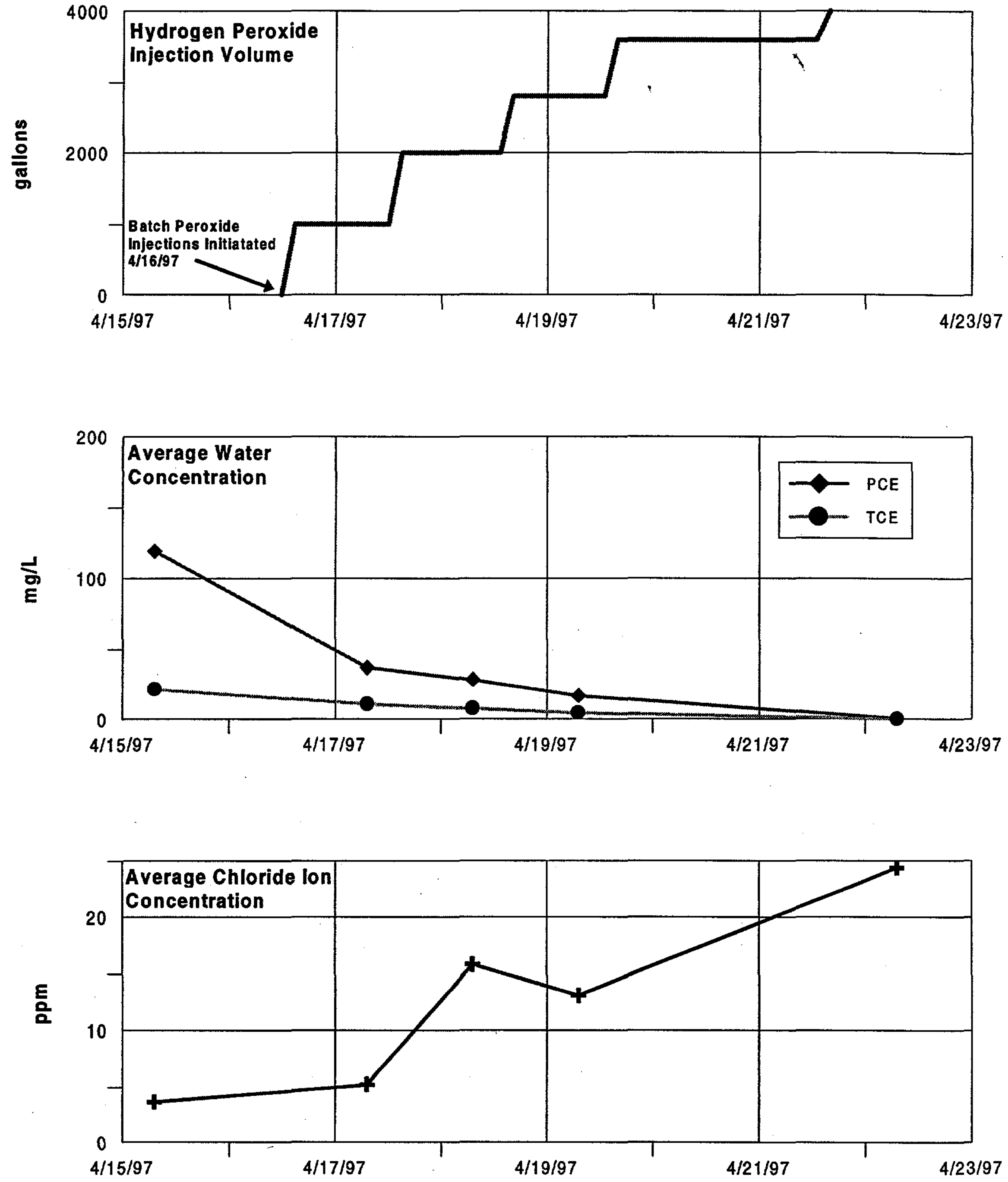


Figure 7.1 - In Situ Oxidation Treatment Period Data

Samples for these tests were analyzed by headspace analysis using a gas chromatograph (GC) with a flame ionization detector (FID) and electron capture detector (ECD) for TCE and PCE, Appendix B. Duplicates were collected for all samples. Standards were prepared and run with each batch of samples analyzed. Standard curves were generated, and concentrations determined for each analyzed sample.

All post-test data is provided in Appendix A. Sediment sampling began at 117 ft bgs at an interval of every foot for the bottom 30 ft of each hole, approximately. MOX-9 was completed to 152 ft, MOX-10 to 153 ft, and MOX-11 to 156 ft bgs. MOX-11 was sampled through the Green Clay confining zone to determine if any DNAPL had been pushed through the unit. The Green Clay formation is located at approximately 152 ft bgs. Small sampling intervals near the bottom of the holes enabled identification of DNAPL zones to the extent possible.

A dramatic decrease in VOC sediment concentrations was observed compared to pre-test borings indicating destruction of DNAPL in the treatment zone. These findings will be discussed in Section 9.0.

9.0 EVALUATION OF DEMONSTRATION SUCCESS

Success of the demonstration is based on destruction of DNAPL in the treatment zone. The best measure of destruction success is based on measurement of DNAPL globules in the sediment before and after the treatment process. Destruction was measured by conducting pre- and post-test soil borings and measuring the amount of PCE and TCE in the sediment. A comparison of sediment concentrations for PCE and TCE from boring MOX-1 (pre-test) and MOX-11 (post-test) is presented in Figure 9.1 (Appendix A contains the profiles for the remaining borings and wells). A significant decrease in sediment concentrations is evident. The estimated pre-test mass of DNAPL in the treatment zone was 593 lbs, and the estimated post-test mass of DNAPL was 36 lbs. This results in a 94% destruction rate estimated for the treatment zone. The treatment zone is defined as the vertical distance between the water table (124 ft bgs) and the Green Clay (152 ft bgs) and a 27 ft radius around the center injector. The estimated mass of DNAPL in the treatment zone before and after the test is presented in Table 9.1. Mass of contaminants was estimated by averaging sediment concentrations at one foot depth intervals and assuming a treatment zone of 64,000 ft^3. Estimation of the PCE and TCE destruction using chloride ion concentration changes during the test will are planned.

Table 9.1 Calculated Pre- and Post-Test DNAPL Mass and Destruction for the In Situ Oxidation Demonstration

	Pre-Test, lbs			Post-Test, lbs			Destruction		
Location	PCE	TCE	Total	PCE	TCE	Total	PCE	TCE	Total
Above Green Clay	528.53	64.56	593.09	28.24	7.95	36.19	94.7%	87.7%	93.9%
Below Green Clay	36.23	13.07	49.30	26.96	9.98	36.94	25.6%	23.6%	24.5%

PCE and TCE water concentrations in the monitoring wells were judged to not provide a representative measure of destruction. The basis for this being 1) groundwater will come into equilibrium with contaminants not destroyed; and 2) the zone is subject to migration of contaminated water from up gradient. A graphical depiction of the total pounds of DNAPL by one foot intervals in the treatment zone is shown in Figure 9.2. The location of the injection zone (5 ft injector screen lengths) and the location of the Green Clay is shown. The Green Clay acts as a semi-confining unit, which is indicated in part by the higher DNAPL mass and destruction efficiency above the Green Clay than below it. The semi-confining nature of the Green Clay is also supported by hydrologic and geologic data. A total destruction of all DNAPL was not achieved and can be attributed to the process not contacting all DNAPL globules in the fine grained sediments. Injected hydrogen peroxide will take the path of least resistance through areas of higher permeability, which in this case will be through sandy regions of the treatment zone.

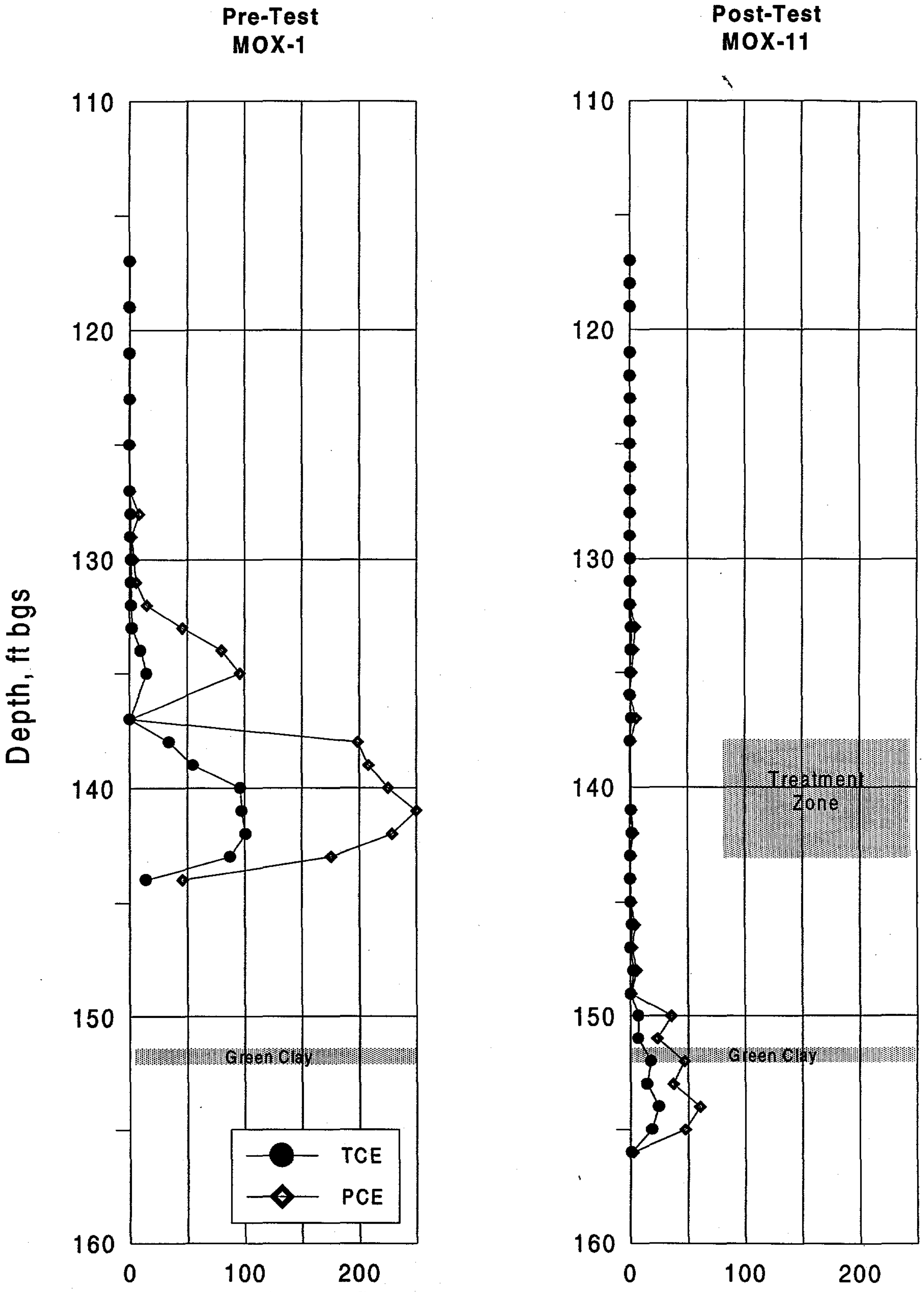


Figure 9.1 - Pre and Post-Test Sediment Concentrations

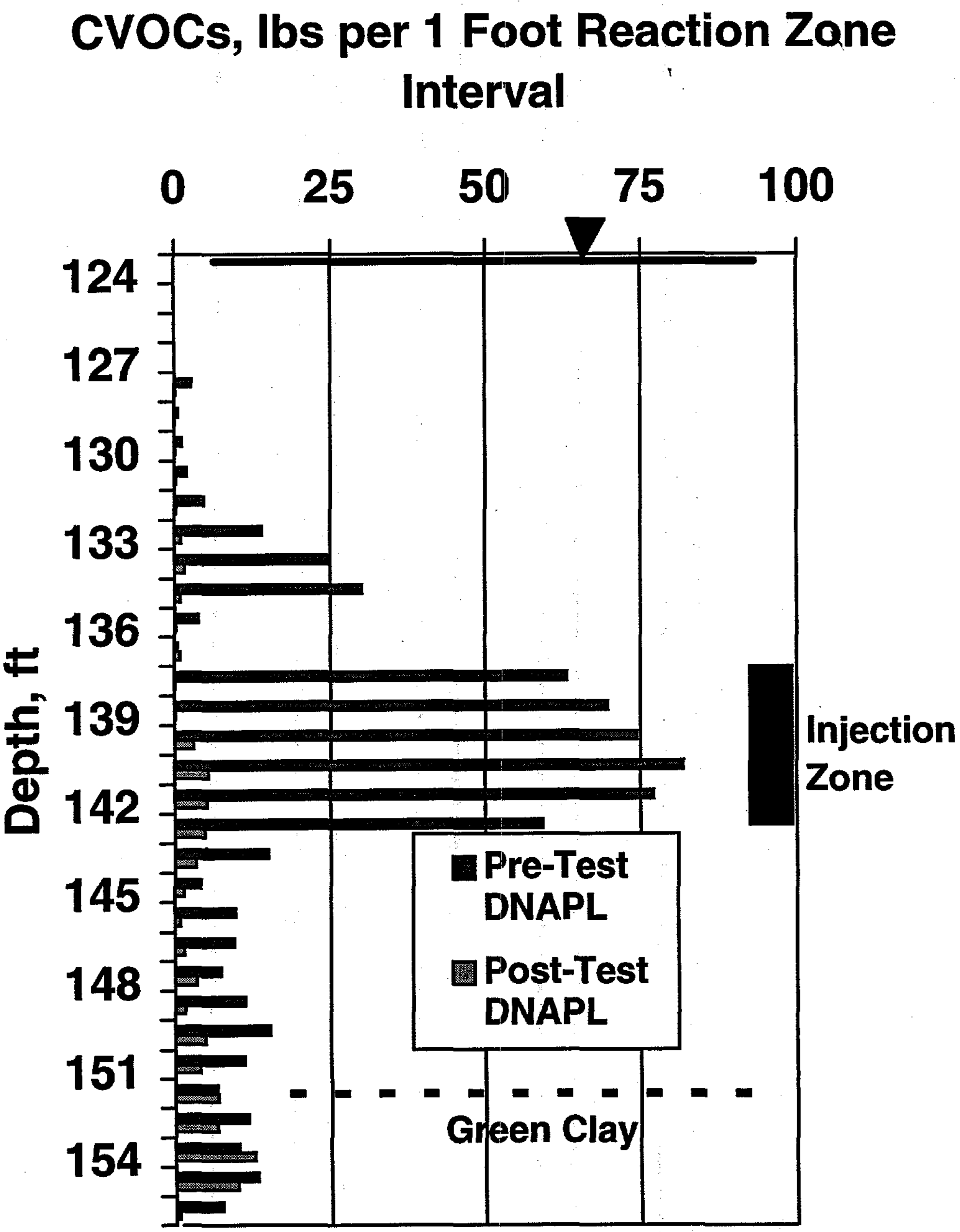


Figure 9.2 - Pre and Post Test DNAPL Mass for the In Situ Oxidation Demonstration

Groundwater concentrations began rebounding in the monitoring wells after treatment was completed. Rebound in the treatment zone can be attributed to groundwater coming into equilibrium with small DNAPL globules not treated. Some of the small DNAPL globules in the fine grained sediments were probably not contacted by the hydrogen peroxide and were therefore not oxidized. Concentration data from the three monitoring wells is shown in Figure 9.3. Groundwater concentration in MOX-8 is rebounding faster than MOX-5 and 7 and can be attributed to direction of groundwater flow in the area. Groundwater is flowing approximately across the site from MOX-8 to MOX-5 (see Figure 5.1) at an estimated velocity of a few inches per day. DNAPL is expected to be in the subsurface between the treatment site and the M-Area Settling Basin, source of DNAPL contamination. Chloride ion concentration increased significantly during the injection process and then leveled off at a higher concentration than the baseline. Chloride ion is a product of the oxidation of PCE and TCE. Post-treatment chloride concentrations in monitoring well MOX-5 are slightly elevated compared to MOX-7 and MOX-8 and can be attributed to groundwater flow from the treatment zone towards MOX-5. A time history of the chloride concentration is shown in Figure 9.4.

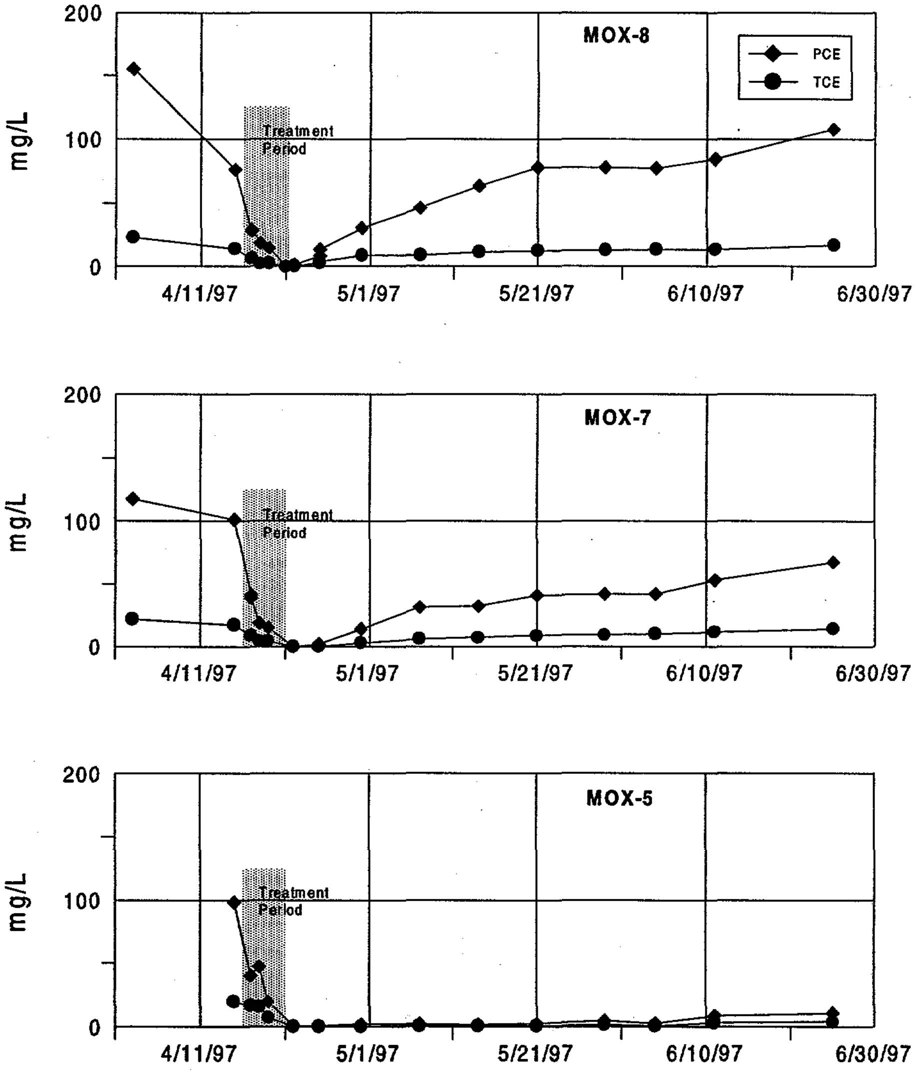


Figure 9.3 - Monitoring Well Concentrations Showing Rebound of Contaminant Concentration for In Situ Oxidation Demonstration

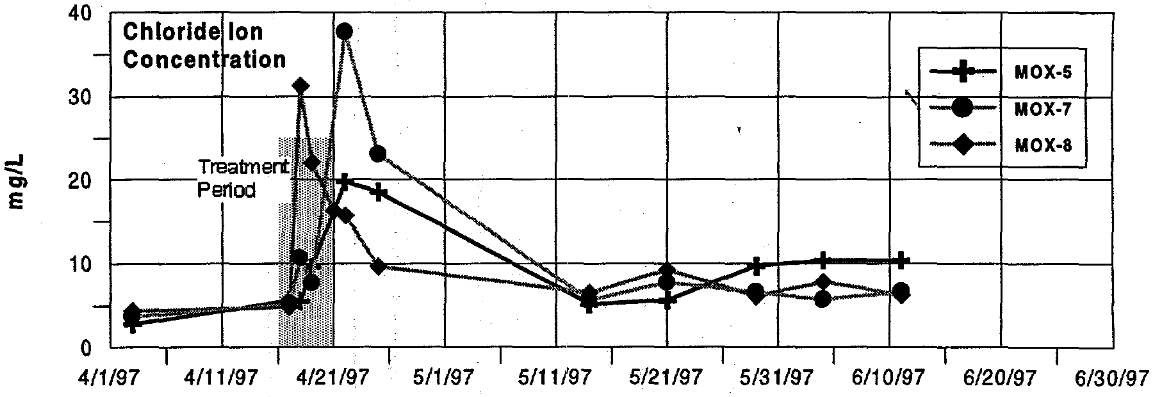


Figure 9.4 - Chloride Ion Concentration for In Situ Oxidation Demonstration

10.0 COST EVALUATION OF DEMONSTRATION

This cost evaluation will examine the costs of this demonstration from two perspectives. First, the overall cost of the demonstration will be discussed in relationship to the influence of each component of the demonstration (i.e. drilling costs, chemicals, documentation). Second, cost on a per pound of DNAPL removed basis will be determined and compared to the cost per pound of DNAPL removed for the baseline system of pump and treat using air stripping.

10.1 Overall Cost of Demonstration in Relationship to Sensitivity to each Component of Demonstration

Demonstration activities were placed in one of six categories: site preparation, pre-test drilling and characterization, technology test, post-test drilling and characterization, demobilization, and documentation/project management. Table 10.1 presents costs for each of these categories.

Table 10.1 Costs for In Situ Oxidation Using Fenton's Chemistry Demonstration Identified by Activity Category

Activity Categories	Cost
Site Preparation	$ 60,422
Pre-test drilling and characterization	$150,738
Technology Test	$183,539
Post-test drilling and characterization	$ 49,477
Post-test demobilization	$ 6,934
Documentation and Project Management	$ 60,005
TOTAL	*$511,115*

The majority of the costs are related to the technology test and the pre-test drilling and characterization. Table 10.2 provides a list of tasks for each activity category. In order to identify which tasks are sensitive to variations in site conditions, an understanding of each task is needed. Below the tasks are discussed in association with their respective activity categories.

Table 10.2 Costs for In Situ Oxidation Using Fenton's Chemistry Demonstration Identified by Task

CATEGORY/TASK	COST	CATEGORY/TASK	COST
Site Preparation and Operation Activities		**Post-test Drilling and Characterization**	
Construct Secondary Containments	$10,425	Drilling Subcontract	$22,000
Generator Rental	$6,456	Oversight and Sampling	$20,888
Electrical Hookup	$12,411	Analysis	$6,589
Signs	$5,098	**Post-test Demobilization**	
Tanks Setup	$11,081	Disconnect Electrical Hookups	$2,677
Water Supply	$4,320	Tear down secondary containments	$2,764
Clearing/Grubbing	$10,631	Remove generators	$1,493
Pre-test Drilling and Characterization		**Documentation and Project Management**	
Drilling Subcontract	$85,000	Documents	$36,003
Oversight and Sampling (provided by WSRC)	$44,070	Project Management (provided by WSRC)	$24,002
Analysis	$19,229		
Sampling Supplies	$2,439		
Technology Test			
Oversight	$14,627		
Peroxide	$20,412		
Operation	$148,500		

- Tasks associated with site preparation are essentially constant. Implementation of this technology does not require permanent infrastructure such as a permanent power source, permanent water and chemical tanks, etc. Temporary power is required for operation of the system. This is much less expensive for the short duration of operation, typically less than 1 month and in many instances 1 to 2 weeks. Also required is a constant supply of water for process, as well as emergency, purposes. For remote sites where a distribution line with potable water is not available tanks for water storage are appropriate. For this demonstration, tanks were obtained from the material excess yard located at SRS; thus, not incurring additional costs to the project. Use of existing tanks is acceptable, as long as they have been cleaned (rinsing the inside of the tanks and draining several times with potable water should be sufficient). During the demonstration, approximately 1000 gallons of water per day was used for a 6 day period.

- Pre-test drilling and characterization costs will vary according to site characteristics. In the A/M-Area, the core holes were drilled to total depths ranging from 144 ft bgs to 155 ft bgs. All pre-test holes were completed as wells. The cost per well was approximately $10,500 or $70/ft. These costs include drilling, setting the well, all well materials, well development, and well finishing (posts and pads). Thus, depth to contamination will have a large effect on the cost of the drilling activities

  Sampling and analyses costs will vary linearly with depth to contamination. Most sampling activities for this demonstration were concentrated below the water table. This will be required regardless of overall depth. Because of the nature of DNAPL (thin ganglia below the water table), it is necessary to sample at small intervals to identify discrete DNAPL zone(s). Preliminary characterization, which would lead to choosing this technology, should help to identify the approximate zone in which DNAPL would be present. However, discrete sampling will be required to "pinpoint" the location for setting screen zones of injectors and for providing an accurate estimate of the quantity of DNAPL to be destroyed.

- Costs for the technology treatment ($148,500) are the largest component of the treatment operation. The majority of these costs are labor and use of equipment. Thus, they are based on duration of the work. Peroxide costs were $20,412 for 42,000 pounds of peroxide, use of an ISO tank capable of holding 45,000 pounds of peroxide, and a dosing unit for transfer from the tank to the Geo-Cleanse® process equipment. Thus, peroxide costs are approximately $0.50/pound. For this demonstration, the treatment zone was a circular area with a 27 foot diameter and a depth of approximately 30 feet for a total volume of 68,702 ft^3. The controlling factor is the amount of contaminant present at the site. At the demonstration site, the estimated volume of DNAPL based on pre-test characterization is approximately 600 pounds. The third component of the technology costs is oversight. These costs are dependent on duration of treatment.

- Post-test drilling and characterization costs, as with pre-test characterization costs will be dependent on depth. For this demonstration three post-test holes were drilled to a total depth of 155 ft. and samples collected from the water table to total depth. As stated above, sampling and analysis costs should vary linearly with depth.

- Post-test demobilization costs are a small fraction of the entire project costs. They include removal of water tanks, disconnecting the power supply, removal of the generator, and disassembly of secondary containments.

- Documentation and project management costs are approximately 12 percent of the demonstration, with 5 percent of total costs going to project management activities and 7 percent of total costs attributed to documentation activities. Documentation includes a test plan, all regulatory documents for drilling and underground injection, scopes of work for drilling services and other materials, and a test report documenting the results of the demonstration.

After reviewing each specific activity, costs, and factors affecting costs, two items stand out. These are costs of drilling activities and cost of peroxide. Drilling costs are approximately $70/ft. This includes drilling charges, well installation, well materials, and well completion charges. Peroxide costs $0.50/pound. Peroxide usage is based on 42 pounds of peroxide per pound of DNAPL. Thus, the cost of peroxide per pound of DNAPL present is $21. For a small site (i.e. 2,000 pounds of DNAPL), peroxide costs will not be a significant portion of the entire remediation costs, less than 10%. For a large site (i.e. 15,000 pounds of DNAPL), the peroxide costs can be a significant portion of the total remediation costs, 20% and greater. Thus, depth to contamination and amount of DNAPL present will be driving factors in determining costs for use of this technology.

10.2 Unit Cost of In Situ Oxidation Technology

In an effort to determine the cost effectiveness of this technology, a unit cost based on a pound of DNAPL treated or destroyed was determined and compared to the unit cost of the baseline technology. For A/M-Area, the baseline technology is pump and treat using airstripping. The baseline cost is $87/pound DNAPL treated. Appendix C provides the basis for the baseline cost for the pump and treat system. DNAPL in A/M-Area is detected above the Green Clay, located at an approximate depth of 155 ft below surface. For that depth, approximately 9,500 pounds of DNAPL must be present to have a unit cost for in situ oxidation equal to the baseline cost for pump and treat. For DNAPL contamination at a depth of approximately 60 ft below surface, 6,500 pounds of DNAPL will yield the equivalent unit cost.

In reviewing costs of each component of this demonstration, items which are essentially fixed costs were identified along with those which are dependent on site conditions. Mobilization, site setup, demobilization, and document preparation were assumed to be fixed costs. Materials and equipment mobilized for injection are independent of site size. Size of the site will effect duration of operation rather than sizing of equipment. Document preparation requires well construction approval forms and an Underground Injection Control Permit. A test plan is also a valuable document to submit to the regulator agencies to provide information on why and how the work will be completed. For CERCLA sites, a Proposed Plan and Record of Decision would be required, but costs for these documents should be fixed.

Site conditions affecting costs are pounds of DNAPL present and depth to contamination. Depth to contamination in this context refers to the major volume of the plume and not the shallowest depth at which measurable concentrations are detected. Site conditions influence days of operating the treatment system, days for drilling, days for oversight, and number of analyses. As depth to contamination increases, days of drilling and oversight and number of analyses will increase. As DNAPL contamination increases, days of operating the treatment system will increase.

In order to calculate a unit cost of treatment per pound of DNAPL destroyed, an equation was created based on activities required to complete remediation. The general equation is listed below with the detailed equation provided in Appendix D. Because this treatment technique is of a short duration, the operations equipment is portable. Thus no permanent structures nor longterm maintenance activities are included.

Unit Cost = (Mobilization/Setup + Pre-test Characterization + Treatment System
Operation + Peroxide + Demobilization + Document Preparation +
Post-test Characterization + Project Management)/Pound of DNAPL

Table 10.3 presents data used to determine the break even unit cost with the pump and treat unit cost. This data is represented by Figures 10.1 and 10.2. These figures represent the same data. Figure 10.1 provides a complete look at the data with Figure 10.2 showing the data near the break even point. The break even point is dependent on depth to contamination, as seen in Figures 10.1 and 10.2. This occurs at volumes ranging from 6,500 pounds to 9,500 pounds of DNAPL as depth to contamination increases from 60 ft to 155 ft, as seen in Figure 10.2. Unit cost of in situ oxidation at sites with small volumes of DNAPL, less than 4000 pounds, is greater than \$100/pound of DNAPL, as seen in Figure 10.1. Unit costs escalate to greater than \$700/pound of DNAPL for sites with approximately 1000 pounds of DNAPL. The unit cost for pump and treat using airstripping is currently \$87/pound of DNAPL (note that this is related to groundwater concentration, and the unit cost will increase over time as the concentrations decrease).

Unit costs for remediation technologies are often compared on a $\$/ft^3$ of soil treated. The $\$/ft^3$ of soil treated was calculated at the \$/lb DNAPL breakeven point between in situ oxidation and pump and treat for the three depths evaluated. The calculation is presented in Appendix D. The unit costs on a $\$/ft^3$ basis are $\$8.84/ft^3$, $\$9.95/ft^3$ and $\$13.03/ft^3$ for depths of 60 ft, 100 ft and 155 ft to DNAPL contamination, respectively.

Table 10.3 Unit Cost/Pound of DNAPL Destroyed for Implementation of In Situ Oxidation for Destruction of DNAPL as a Function of Depth to Contamination

	UNIT COSTS ($/lb DNAPL)		
DNAPL (lbs)	*60 ft depth*	*100 ft depth*	*155 ft depth*
500	708	816	917
1,000	365	419	469
2,000	194	221	246
5,000	105	116	126
6,000	92	101	109
6,750	84	92	99
7,500	78	85	92
9,000	79	85	90
10,000	73	78	83
11,000	68	73	78
12,000	65	69	73

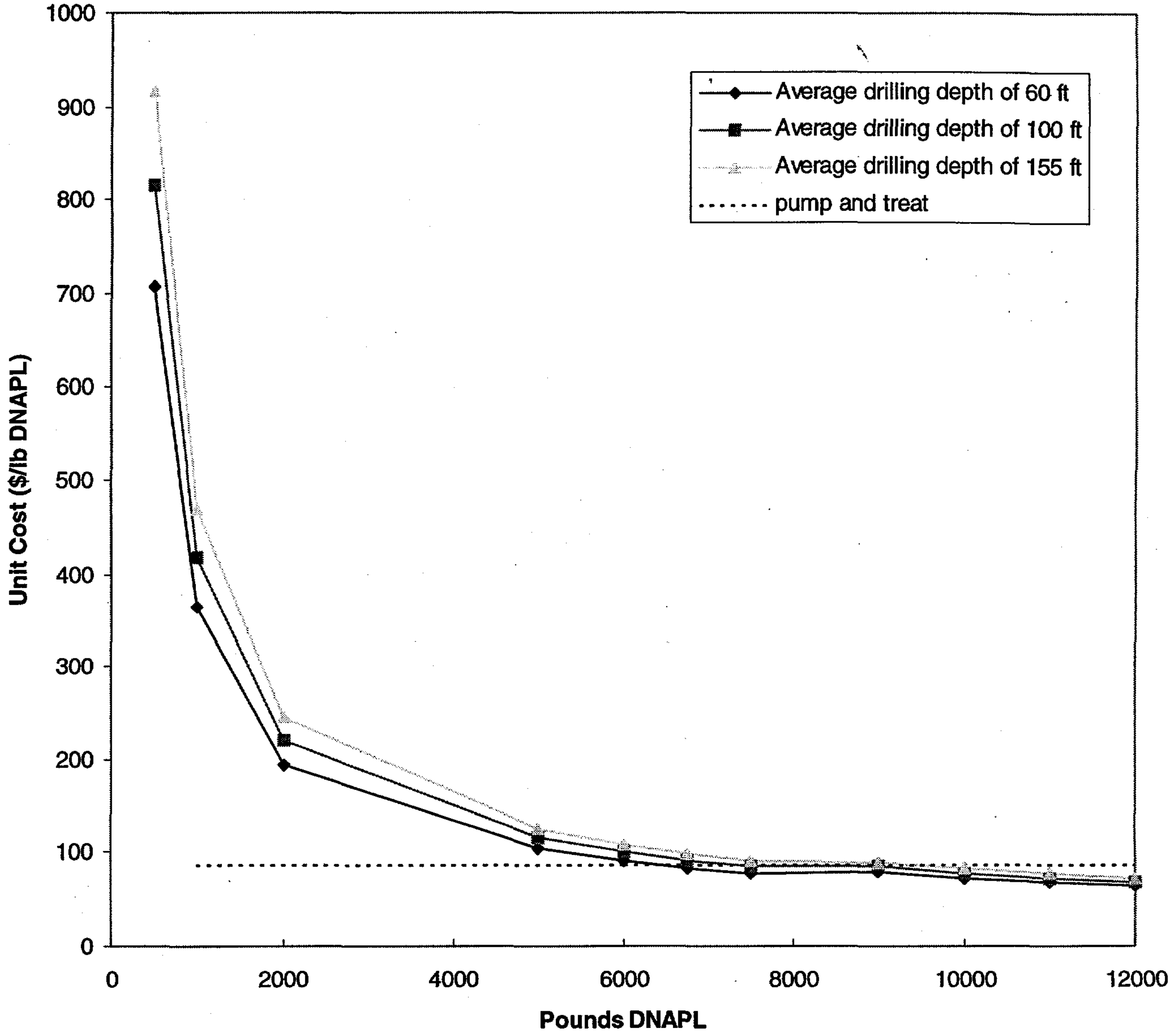


Figure 10.1 Full Scale Representation of Unit Cost/Pound of DNAPL Destroyed for Implementation of In Situ Oxidation for Destruction of DNAPL as a function of depth to Contamination

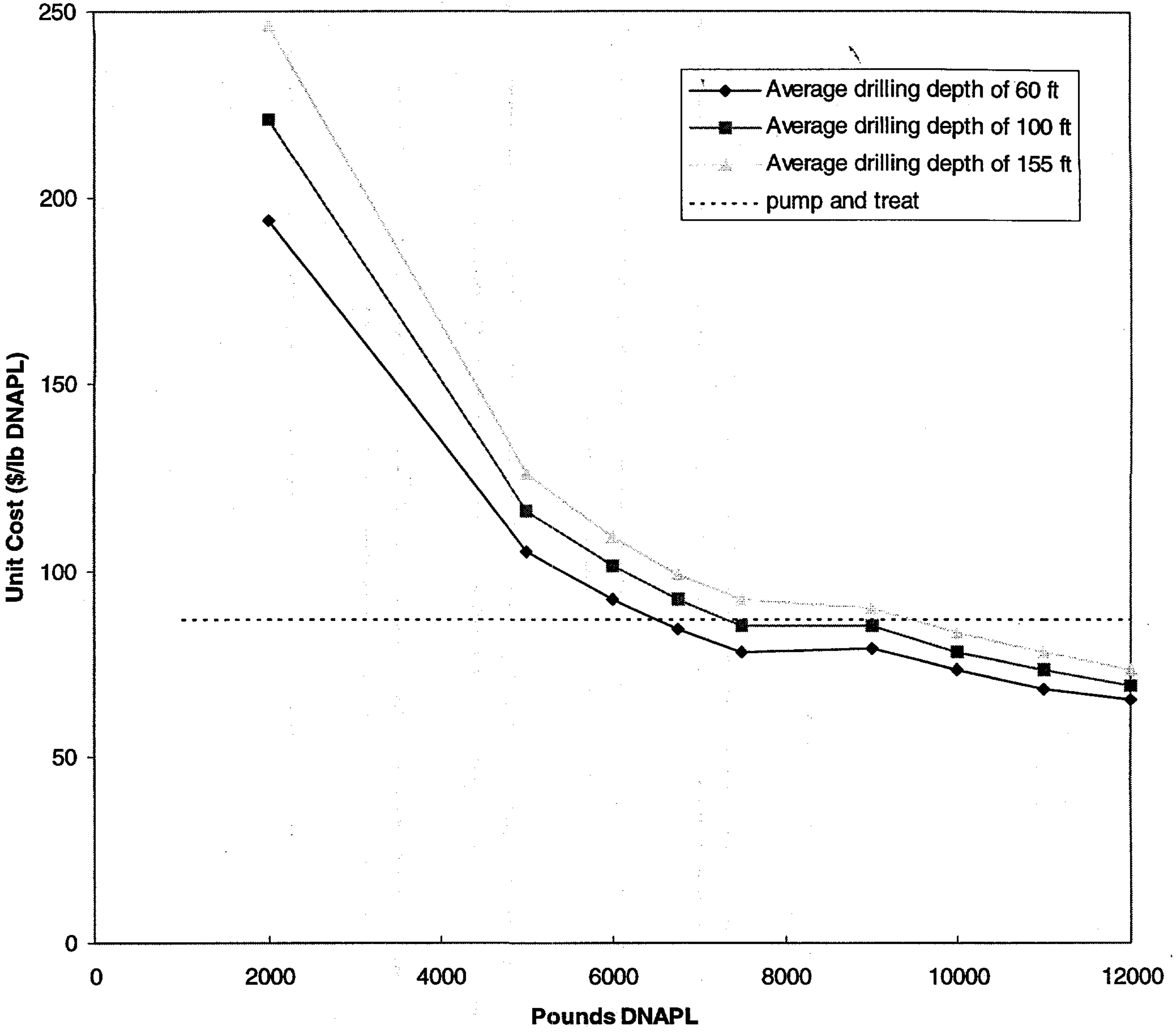


Figure 10.2 Unit Cost/Pound of DNAPL Destroyed for Implementation of In Situ Oxidation for Destruction of DNAPL as a Function of Depth to Contamination

11.0 DISCUSSION OF RESULTS

During this demonstration approximately 600 pounds of DNAPL was destroyed in a six day operating period, leaving a residual of 40 pounds of DNAPL in the target zone. This is a 94% destruction efficiency. In situ oxidation using Fenton's chemistry was the process evaluated during this demonstration. The cost of the demonstration was approximately $500,000. On a unit cost basis, this technology becomes cost competitive with pump and treat using airstripping ($87/pound DNAPL) for a DNAPL pool of approximately 9,500 pounds at a depth of 155 ft bgs. Depth is a major contributor to the overall costs when this technology is employed. For a DNAPL pool of volume V, as depth to the DNAPL pool increases the costs for remediation will increase. Thus, both the size of the DNAPL pool and the depth to the DNAPL pool must be considered in determining when this technology becomes cost competitive with pump and treat using airstripping.

Other factors contributing to the decision to use this technology include duration of treatment, volume of DNAPL, and end products of treatment. Ninety-four percent of a 600 pound plume were destroyed in a six day period during this demonstration. Injection was in a circular area with radius 27 feet and operation was approximately 6 hours per day using 4 injectors. Duration of operation is not a linear function of volume of DNAPL. Factors effecting the duration of the treatment would include: other compounds which may be oxidized under similar conditions, geochemical makeup of treatment zone, and tightness of treatment zone (i.e., access to DNAPL), The site of the demonstration was not completely saturated with DNAPL. In preparing the Test Plan, an estimated volume at this site (assuming a two foot zone had been fully saturated) was 50,000 pounds of DNAPL. The vendor, Geo-Cleanse International, Inc.estimated a 10 day duration for treatment of the demonstration site with a 50,000 pound volume of DNAPL. The evaluation of unit costs, identified that depth to DNAPL is inversely related to volume of DNAPL in the treatment zone. However, at least 6,000 pounds of DNAPL is required at a site with the DNAPL pool at a depth of 60 feet to make this treatment cost competitive with pump and treat systems. With this in mind, an appropriate site for using in situ oxidation would be the DNAPL source.

The end products of in situ oxidation are very appealing. No waste is generated from the treatment process, and no material is brought to the surface. The end products of this process are carbon dioxide, water, and chloride ions. All of these compounds are considered innocuous materials.

Additional questions were raised as the demonstration progressed and data was collected. Many of the questions concerned the geochemistry and microbiology in the treatment zone. Because in situ oxidation is a very robust chemical reaction, a reasonable assumption is that most microbial activity was destroyed during the reaction. The type of microbial activity that will return to the area and to what extent is not known. We also saw the pH drop dramatically from an average pH of 5.7 before treatment to 2.4 at completion of treatment. Post-test treatment has shown a very slow rebound of the groundwater pH. Three months after completion of the test, the groundwater pH remains at approximately 3.5. It is not known as to whether this is due to changes in the geochemistry. Work is proposed for FY98 to conduct additional post-test studies to answer these and other questions.

REFERENCES

Westinghouse Savannah River Company. *Assessing DNAPL Contamination, A/M-Area, Savannah River Site: Phase I Results (U)*, WSRC-RP-92-1302, December 1992. Prepared for the U.S. Department of Energy under Contract No. DE-AC09-89SR18035.

Westinghouse Savannah River Company. *Test Plan for Geo-Cleanse Demonstration (In Situ Destruction of Dense Non-Aqueous Phase Liquid (DNAPL))*, WSRC-RP-96-441, September 1996. Prepared for the U. S. Department of Energy under Contract No. DE-AC09-89SR18035.

APPENDIX A

RAW DATA AND SOIL CONCENTRATION DEPTH PROFILES FOR IN SITU OXIDATION DEMONSTRATION

Well and Boring Coordinates with Ground Surface Elevation

ID	Description	SRS Site Coordinates		Elevation ft msl
		Northing	Easting	
MOX-1	Injector	102412.627	48268.202	353.649
MOX-2	Injector	102414.600	48237.618	352.960
MOX-3	Injector	102388.561	48251.611	353.412
MOX-4	Injector	102406.310	48252.180	353.109
MOX-5	Monitoring Well	102419.057	48227.797	352.979
MOX-6	Monitoring Well	102212.283	48830.626	355.520
MOX-7	Monitoring Well	102417.415	48277.433	354.392
MOX-8	Monitoring Well	102379.281	48250.906	353.784
MOX-10	Post Test Boring	102415.125	48248.511	352.917
MOX-11	Post Test Boring	102404.620	48271.597	353.794
MOX-9	Post Test Boring	102433.337	48212.416	353.557
MOX-1V	Vadose Well	102378.881	48265.261	354.485
MOX-2V	Vadose Well	102412.528	48215.546	353.114
MOX-3V	Vadose Well	102428.040	48272.590	353.684
MOX-4V	Vadose Well	102400.446	48263.701	353.753

Concentration Data for MOX-1 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0100	117	236.6	4.17	0	0	0.0008	0.0009
MOX0100	117	236.6	3.78	0	0	0.0000	0.0000
MOX0101	119	234.6	3.97		0	0.0000	0.0005
MOX0101	119	234.6	4.59	0	0	0.0000	0.0000
MOX0102	121	232.6	3.68	44	0	0.0905	0.0004
MOX0102	121	232.6	3.48	0	0	0.0000	0.0000
MOX0103	123	230.6	3.75		0	0.0000	0.0006
MOX0103	123	230.6	3.99	0	0	0.0000	0.0000
MOX0104	125	228.6	3.61	2	2	0.0090	0.0085
MOX0104	125	228.6	3.49	0	0	0.0000	0.0000
MOX0105	127	226.6	3.97	5	3	0.0172	0.0100
MOX0105	127	226.6	3.58	0	0	0.0000	0.0000
MOX0106	128	225.6	4.41	309	2461	1.0522	8.3717
MOX0106	128	225.6	4.61	37	158	0.1111	0.4805
MOX0107	129	224.6	3.78	168	364	0.6649	1.4436
MOX0107	129	224.6	3.88	166	620	0.5992	2.2372
MOX0108	130	223.6	3.55	263	747	1.1103	3.1577
MOX0108	130	223.6	3.82	108	412	0.3959	1.5122
MOX0109	131	222.6	3.94	350	1484	1.2458	5.2761
MOX0110	132	221.6	3.90	344	3863	1.3231	14.8591
MOX0110	132	221.6	3.91	179	703	0.6423	2.5177
MOX0111	133	220.6	3.43	426	10444	1.8622	45.6716
MOX0111	133	220.6	3.87	583	3285	2.1100	11.8901
MOX0112	134	219.6	4.08	2562	21711	9.4181	79.8210
MOX0112	134	219.6	3.68	599	3547	2.2800	13.5028
MOX0113	135	218.6	4.56	4546	29109	14.9531	95.7525
MOX0113	135	218.6	4.49	819	4768	2.5544	14.8737
MOX0114	137	216.6	4.18	24	86	0.0861	0.3077
MOX0114	137	216.6	3.27	0	17	0.0000	0.0709
MOX0115	138	215.6	4.31	9863	57121	34.3270	198.7972
MOX0115	138	215.6	3.66	1398	9029	5.3514	34.5603
MOX0116	139	214.6	4.11	15113	57043	55.1564	208.1865
MOX0117	140	213.6	3.93	25196	58949	96.1668	224.9973
MOX0118	141	212.6	4.93	32015	82110	97.4099	249.8272
MOX0119	142	211.6	4.39	29548	66929	100.9605	228.6853
MOX0120	143	210.6	4.99	28989	58187	87.1402	174.9121
MOX0121	144	209.6	3.73	3424	11404	13.7710	45.8599

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-2 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0200	119	235.79	3.71	3		0.0061	0.0000
MOX0200	119	235.79	4.01		0	0.0000	0.0004
MOX0201	120	234.79	3.84	60	42	0.1175	0.0818
MOX0201	120	234.79	4.44		0	0.0000	0.0005
MOX0202	122	232.79	4.51	12		0.0206	0.0000
MOX0202	122	232.79	4.55		0	0.0000	0.0005
MOX0203	124	230.79	3.99	0	1	0.0012	0.0020
MOX0203	124	230.79	4.03	0	0	0.0009	0.0009
MOX0204	126	228.79	4.07	3	2	0.0096	0.0090
MOX0204	126	228.79	3.42	1	1	0.0040	0.0028
MOX0205	130	224.79	3.70	71	168	0.2885	0.6818
MOX0205	130	224.79	3.46	76	169	0.3307	0.7345
MOX0206	131	223.79	3.57	97	270	0.4070	1.1348
MOX0206	131	223.79	3.31	85	214	0.3840	0.9715
MOX0207	132	222.79	3.85	115	265	0.4478	1.0306
MOX0207	132	222.79	3.70		402		1.6315
MOX0208	133	221.79	3.31	206	579	0.9318	2.6243
MOX0208	133	221.79	3.68	2	1	0.0089	0.0030
MOX0209	134	220.79	3.99	296	1085	1.1113	4.0773
MOX0209	134	220.79	3.67		679		2.7748
MOX0210	135	219.79	4.14	846	3396	3.0660	12.3051
MOX0210	135	219.79	3.65	812	4904	3.3365	20.1527
MOX0211	136	218.79	3.12	414	2144	1.9912	10.3065
MOX0211	136	218.79	3.52	555	3709	2.3647	15.8066
MOX0212	137	217.79	4.25	661	3567	2.3312	12.5905
MOX0212	137	217.79	3.31	716	4825	3.2426	21.8657
MOX0213	140	214.79	4.53	263	440	0.8717	1.4571
MOX0213	140	214.79	3.41	491	2034	2.1618	8.9463
MOX0214	141	213.79	3.74	300	222	1.2032	0.8884
MOX0214	141	213.79	3.19	254	89	1.1929	0.4191
MOX0215	142	212.79	4.32	5342	12479	18.5470	43.3310
MOX0215	142	212.79	3.45	3019	6618	13.1245	28.7730
MOX0216	143	211.79	3.30	3513	9466	15.9696	43.0255
MOX0216	143	211.79	3.98	3249	7968	12.2455	30.0309
MOX0217	144	210.79	3.53	306	842	1.3011	3.5765
MOX0217	144	210.79	2.70		463		2.5738

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-3 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0300	117	236.47	4.74	0	0	0.0006	0.0008
MOX0300	117	236.47	4.74	0		0.0005	0.0000
MOX0301	119	234.47	3.53	0	0	0.0006	0.0006
MOX0301	119	234.47	4.26	0		0.0008	0.0000
MOX0302	121	232.47	3.62	3	0	0.0056	0.0005
MOX0302	121	232.47	4.15	2		0.0044	0.0000
MOX0303	123	230.47	3.91	2	1	0.0033	0.0025
MOX0303	123	230.47	3.82	1		0.0021	0.0000
MOX0304	125	228.47	3.69	0	0	0.0013	0.0020
MOX0304	125	228.47	3.67	0		0.0010	
MOX0305	127	226.47	3.89	36	50	0.1373	0.1944
MOX0305	127	226.47	3.46	2		0.0106	
MOX0306	129	224.47	4.77	95	285	0.2993	0.8959
MOX0306	129	224.47	4.08	33	228	0.1210	0.8394
MOX0307	131	222.47	3.89	440	1695	1.6959	6.5363
MOX0307	131	222.47	3.34	177	757	0.7944	3.3983
MOX0308	132	221.47	4.28	720	2306	2.5249	8.0825
MOX0308	132	221.47	4.14	323	945	1.1714	3.4225
MOX0309	133	220.47	4.04	487	1512	1.8065	5.6155
MOX0309	133	220.47	2.83	203	577	1.0747	3.0604
MOX0310	134	219.47	3.46	546	2366	2.3675	10.2580
MOX0310	134	219.47	3.68	377	1848	1.5364	7.5314
MOX0311	135	218.47	4.14	1707	9985	6.1853	36.1765
MOX0311	135	218.47	4.09	567	3123	2.0784	11.4530
MOX0312	136	217.47	4.71	2104	13030	6.7014	41.4977
MOX0312	136	217.47	3.44	879	5892	3.8347	25.6927
MOX0313	139	214.47	3.33	4237	15654	19.0861	70.5113
MOX0313	139	214.47	4.29	367	1356	1.2828	4.7413
MOX0314	140	213.47	3.96		0		0.0006
MOX0314	140	213.47	3.85	2825	6950	11.0074	27.0787
MOX0315	141	212.47	4.26	5242	13733	18.4590	48.3551
MOX0315	141	212.47	2.81	2500	6229	13.3478	33.2517
MOX0316	142	211.47	4.02	4004	8008	14.9421	29.8822
MOX0316	142	211.47	3.72		70		0.2840
MOX0317	143	210.47	4.01	179	28	0.6704	0.1043
MOX0318	144	209.47	4.16	2056	3426	7.4139	12.3539
MOX0318	144	209.47	3.87	1178	1661	4.5667	6.4375

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-4 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0400	88	266.34	3.78	0	0	0.0000	0.0000
MOX0401	97	257.34	4.25	51	25	0.0909	0.0447
MOX0401	97	257.34	3.84	28	25	0.0509	0.0458
MOX0402	110	244.34	3.07	2	0	0.0049	0.0004
MOX0402	110	244.34	5.24	0	0	0.0000	0.0000
MOX0403	114	240.34	3.71	2	1	0.0036	0.0019
MOX0403	114	240.34	3.68	0	0	0.0000	0.0000
MOX0404	117	237.34	2.08	2	0	0.0079	0.0003
MOX0404	117	237.34	4.11	0	0	0.0000	0.0000
MOX0405	119	235.34	3.94	3		0.0055	0.0000
MOX0405	119	235.34	4.25	0	0	0.0000	0.0000
MOX0406	121	233.34	4.85	0	0	0.0000	0.0000
MOX0407	128	226.34	4.23	7	44	0.0238	0.1577
MOX0407	128	226.34	4.18	10	45	0.0328	0.1509
MOX0408	130	224.34	3.84	10	37	0.0393	0.1431
MOX0408	130	224.34	3.63	0	0	0.0000	0.0000
MOX0409	132	222.34	4.21	43	168	0.1438	0.5581
MOX0410	133	221.34	3.96	7	53	0.0257	0.2005
MOX0410	133	221.34	4.01	10	61	0.0361	0.2143
MOX0411	134	220.34	3.91	215	1072	0.8230	4.1128
MOX0411	134	220.34	3.87	357	1849	1.2938	6.6947
MOX0412	135	219.34	4.22	814	4513	2.8949	16.0411
MOX0412	135	219.34	4.01	708	3366	2.4719	11.7603
MOX0413	136	218.34	3.86	1130	6397	4.3929	24.8594
MOX0413	136	218.34	4.06	1224	7139	4.2246	24.6311
MOX0414	136.5	217.84	4.10	554	2215	2.0268	8.1041
MOX0414	136.5	217.84	3.75	588	3344	2.1957	12.4941
MOX0415	137	217.34	4.37	1117	6421	3.5792	20.5808
MOX0416	137.5	216.84	4.45	32	166	0.1088	0.5602
MOX0416	137.5	216.84	3.85	715	4388	2.6022	15.9669
MOX0417	138	216.34	4.56	2971	11465	9.7741	37.7154
MOX0417	138	216.34	4.15	2491	9425	8.4099	31.8134
MOX0418	139	215.34	4.05	4139	10790	15.3279	39.9628
MOX0418	139	215.34	4.21	4072	10504	13.5478	34.9500
MOX0419	140	214.34	3.88	4323	10595	16.7143	40.9595
MOX0419	140	214.34	4.48	4122	10362	12.8887	32.3998
MOX0420	141	213.34	3.94	3072	8309	11.6950	31.6320
MOX0421	142	212.34	3.79	3279	9472	12.9795	37.4896
MOX0422	143	211.34	4.25	4630	11896	16.3397	41.9851
MOX0423	144	210.34	3.25	917	2042	4.2316	9.4224

Concentration Data for MOX-4 Soil Boring Samples (continued)

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. In Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0423	144	210.34	3.72	830	1932	3.1243	7.2750
MOX0424	145	209.34	3.68	1504	3597	6.1297	14.6609
MOX0424	145	209.34	4.00	2308	6217	8.0835	21.7732
MOX0425	146	208.34	4.49	1594	5049	5.3262	16.8686
MOX0425	146	208.34	4.01	1037	3750	3.6210	13.1019
MOX0426	147	207.34	3.65	2555	8091	10.5011	33.2493
MOX0436	147	207.34	3.76	979	2315	3.9046	9.2341
MOX0426	147	207.34	3.58	2238	7119	8.7577	27.8598
MOX0436	148	206.34	5.55	1943	4527	4.9044	11.4256
MOX0427	148	206.34	4.70	2629	9399	7.8345	28.0111
MOX0428	149	205.34	2.79	1379	5364	7.4166	28.8364
MOX0428	149	205.34	3.26	1057	4215	4.5435	18.1166
MOX0429	150	204.34	4.31	7426	18166	25.8439	63.2225
MOX0429	150	204.34	3.96	6245	15011	22.0934	53.1016
MOX0430	151	203.34	5.31	7360	15326	20.7923	43.2930
MOX0430	151	203.34	4.36	6873	14071	22.0826	45.2077
MOX0431	152	202.34	3.96	3575	6237	13.5402	23.6257
MOX0431	152	202.34	5.11	6915	14380	18.9545	39.4151
MOX0432	153	201.34	5.06	6773	14141	20.0778	41.9186
MOX0432	153	201.34	3.62	0	10870	0.0000	42.0681
MOX0433	154	200.34	4.33	5983	12398	20.7256	42.9496
MOX0433	154	200.34	4.45	4907	9888	15.4451	31.1256
MOX0434	155	199.34	4.07	2555	5104	9.4166	18.8113
MOX0434	155	199.34	4.50	3910	8091	12.1714	25.1865
MOX0435	156	198.34	4.63	2731	6859	8.2626	20.7514

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-5 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0517	130	222.42	3.76	138	411	0.5127	1.5300
MOX0518	132	220.42	3.43	8	20	0.0311	0.0815
MOX0519	134	218.42	4.38	10	10	0.0315	0.0313
MOX0520	136	216.42	3.63	0	0	0.0000	0.0000
MOX0521	138	214.42	5.35	3592	12351	9.4040	32.3361
MOX0522	140	212.42	4.01	320	921	1.1178	3.2159
MOX0523	142	210.42	4.96	1994	5004	5.6317	14.1320
MOX0524	144	208.42	4.01	0	3569	0.0000	12.4683
MOX0525	146	206.42	3.76	3023	8350	11.2648	31.1124
MOX0526	147	205.42	2.88	12	94	0.0565	0.4550
MOX0527	148	204.42	4.14	10	69	0.0332	0.2345
MOX0528	151	201.42	4.12	57	337	0.1951	1.1454
MOX0529	152	200.42	4.46	644	3415	2.0237	10.7261
MOX0530	153	199.42	4.04	1548	9003	5.3686	31.2187
MOX0531	154	198.42	3.80	1559	7664	5.7490	28.2537

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-6 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0600	10	338.64	3.59	0	0	0.0000	0.0000
MOX0601	20	328.64	4.10	0	0	0.0000	0.0000
MOX0602	30	318.64	4.88	0	0	0.0000	0.0000
MOX0603	40	308.64	4.12	0	0	0.0000	0.0000
MOX0604	50	298.64	4.23	1	10	0.0024	0.0180
MOX0604	50	298.64	4.14	0	15	0.0000	0.0254
MOX0605	60	288.64	3.68	13	76	0.0272	0.1551
MOX0605	60	288.64	4.00	30	190	0.0527	0.3331
MOX0606	70	278.64	3.82	2	8	0.0037	0.0148
MOX0606	70	278.64	3.61	0	8	0.0000	0.0161
MOX0607	80	268.64	4.32	11	54	0.0181	0.0869
MOX0608	90	258.64	3.93	551	2515	0.9817	4.4823
MOX0609	94	254.64	3.16	10	11	0.0215	0.0234
MOX0610	104	244.64	4.70	0	23	0.0000	0.0344
MOX0611	110	238.64	4.47	0	0	0.0000	0.0000
MOX0612	120	228.64	3.74	0	0	0.001312	0.001797
MOX0612	120	228.64	3.68	0	0	0	0
MOX0613	126	222.64	5.44	34	2	0.0939	0.0045
MOX0613	126	222.64	5.41	33	0	0.0858	0.0000
MOX0614	130	218.64	3.67	76	0	0.3121	0.0010
MOX0614	130	218.64	4.20	82	0	0.2744	0.0000
MOX0615	140	208.64	3.69	12	4	0.0481	0.0154
MOX0615	140	208.64	4.09	13	0	0.0430	0.0000
MOX0620	141	207.64	3.91	14	24	0.0538	0.0902
MOX0620	141	207.64	6.28	45	0	0.1009	0.0000
MOX0619	141.5	207.14	4.49	36	5	0.1216	0.0183
MOX0619	141.5	207.14	4.13	30	0	0.1014	0.0000
MOX0616	145	203.64	4.27	30	3	0.1055	0.0113
MOX0616	145	203.64	4.63	39	0	0.1191	0.0000
MOX0617	150	198.64	4.67	43	89	0.1391	0.2866
MOX0617	150	198.64	3.94	32	69	0.1134	0.2451
MOX0618	154	194.64	3.57	6	3	0.0269	0.0120
MOX0618	154	194.64	3.80	10	0	0.0362	0.0000

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (118 ft below surface)

Concentration Data for MOX-7 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0700	117	237.34	3.78		0	0.0000	0.0003
MOX0700	117	237.34	3.66	2	0	0.0043	0.0003
MOX0701	119	235.34	4.05	0	0	0.0009	0.0008
MOX0701	119	235.34	4.16	1	0	0.0013	0.0009
MOX0702	121	233.34	3.03		0	0.0000	0.0003
MOX0702	121	233.34	3.41	0	0	0.0000	0.0000
MOX0703	123	231.34	3.81	1	0	0.0012	0.0009
MOX0704	125	229.34	4.57	3	2	0.0094	0.0053
MOX0704	125	229.34	3.82	1	1	0.0028	0.0020
MOX0705	127	227.34	4.17	56	132	0.2024	0.4764
MOX0705	127	227.34	3.70	83	152	0.3380	0.6155
MOX0706	127.5	226.84	4.28	2	10	0.0085	0.0368
MOX0706	127.5	226.84	4.14	3	14	0.0098	0.0507
MOX0707	128	226.34	4.21	221	830	0.7862	2.9576
MOX0707	128	226.34	3.55	220	811	0.9310	3.4285
MOX0708	129	225.34	4.08	376	1431	1.3831	5.2613
MOX0708	129	225.34	3.80	624	2327	2.4638	9.1849
MOX0709	130	224.34	3.91	570	2322	2.1881	8.9069
MOX0709	130	224.34	4.03	294	1169	1.0929	4.3520
MOX0710	131	223.34	3.70	226	946	0.9151	3.8342
MOX0710	131	223.34	3.71	312	992	1.2628	4.0104
MOX0711	132	222.34	3.70	342	1740	1.3845	7.0539
MOX0711	132	222.34	3.90	306	1516	1.1751	5.8312
MOX0712	133	221.34	3.60	443	2040	1.8444	8.4990
MOX0712	133	221.34	3.88	497	2519	1.9228	9.7396
MOX0713	134	220.34	4.95	509	2890	1.5435	8.7572
MOX0713	134	220.34	4.34	485	2836	1.6769	9.8019
MOX0715	135	219.34	3.94	2	19	0.0076	0.0713
MOX0716	137	217.34	4.29	878	5038	3.0701	17.6140
MOX0716	137	217.34	3.85	690	4317	2.6865	16.8189
MOX0717	138	216.34	4.45	1254	5557	4.2259	18.7301
MOX0717	138	216.34	4.49	1318	5706	4.4017	19.0624
MOX0718	139	215.34	4.43	2196	12195	7.4367	41.2915
MOX0718	139	215.34	4.25	1969	11151	6.9479	39.3579
MOX0719	140	214.34	3.80	2795	13444	11.0339	53.0681
MOX0719	140	214.34	4.51	3108	15689	10.3362	52.1798
MOX0720	141	213.34	4.30	2807	7282	9.7927	25.4013
MOX0720	141	213.34	4.22	3140	12977	11.1609	46.1283
MOX0721	142	212.34	3.83	4213	11052	16.4989	43.2849
MOX0721	142	212.34	4.40	4681	12759	15.9593	43.4950
MOX0722	143	211.34	5.10	4106	10054	12.0778	29.5716

Concentration Data for MOX-7 Soil Boring Samples (continued)

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0722	143	211.34	4.55	3677	9574	12.1236	31.5611
MOX0723	144	210.34	3.82	445	1165	1.7475	4.5730
MOX0723	144	210.34	4.05	2037	5215	7.5443	19.3133

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-8 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0800	130	223.69	4.50		29		0.0977
MOX0800	130	223.69	4.94	11	76	0.0338	0.2296
MOX0801	131	222.69	3.63		0		0.0013
MOX0801	131	222.69	3.59	3	0	0.0117	0.0004
MOX0802	132	221.69	3.65	1	1	0.0030	0.0028
MOX0802	132	221.69	3.74	1	1	0.0027	0.0020
MOX0803	133	220.69	4.45	2	2	0.0084	0.0070
MOX0803	133	220.69	4.31	2	1	0.0056	0.0050
MOX0804	134	219.69	3.85	1	1	0.0054	0.0038
MOX0804	134	219.69	4.15	2	2	0.0085	0.0062
MOX0805	135	218.69	3.47	3	2	0.0112	0.0108
MOX0805	135	218.69	3.97	2	1	0.0058	0.0043
MOX0806	136	217.69	4.39	1	1	0.0047	0.0049
MOX0806	136	217.69	4.47	2	1	0.0055	0.0045
MOX0807	137	216.69	3.70	8	8	0.0341	0.0312
MOX0807	137	216.69	4.20	8	5	0.0274	0.0187
MOX0808	138	215.69	3.59	1	2	0.0035	0.0080
MOX0808	138	215.69	4.10	1	2	0.0032	0.0064
MOX0809	139	214.69	3.26	8	22	0.0361	0.1032
MOX0809	139	214.69	4.11	9	19	0.0315	0.0710
MOX0810	140	213.69	4.74	82	272	0.2588	0.8599
MOX0810	140	213.69	4.49	89	194	0.2967	0.6478
MOX0811	141	212.69	3.50	105	433	0.4490	1.8573
MOX0811	141	212.69	3.80	122	461	0.4827	1.8196
MOX0812	142	211.69	3.87	162	555	0.6289	2.1513
MOX0812	142	211.69	3.60	253	1066	1.0532	4.4400
MOX0813	143	210.69	3.67	217	1018	0.8876	4.1591
MOX0813	143	210.69	3.18	66	217	0.3119	1.0258
MOX0814	144	209.69	4.11	274	1283	1.0015	4.6836
MOX0814	144	209.69	3.89	130	376	0.4994	1.4490
MOX0815	145	208.69	4.73	318	1706	1.0070	5.4116
MOX0815	145	208.69	4.13	234	1123	0.8504	4.0799
MOX0816	147	206.69	4.67	3640	12019	11.6919	38.6042
MOX0816	147	206.69	4.87	3237	10228	9.9698	31.5031
MOX0817	148	205.69	4.39	3248	9717	11.0965	33.2012
MOX0817	148	205.69	4.64	2913	8487	9.4158	27.4378
MOX0818	149	204.69	4.34	3095	8002	10.6957	27.6554
MOX0818	149	204.69	3.99	644	1465	2.4210	5.5071
MOX0819	150	203.69	3.80	1151	2141	4.5444	8.4503
MOX0820	151	202.69	4.59	4927	8949	16.1029	29.2451
MOX0820	151	202.69	4.55	1861	3875	6.1361	12.7758

Concentration Data for MOX-8 Soil Boring Samples (continued)

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0821	152	201.69	4.15	2086	2529	7.5408	9.1415
MOX0821	152	201.69	5.02	1595	1903	4.7659	5.6860
MOX0822	153	200.69	5.24	2082	4462	5.9605	12.7728
MOX0822	153	200.69	5.39	1285	2761	3.5758	7.6848
MOX0823	154	199.69	4.04	373	883	1.3845	3.2792
MOX0823	154	199.69	4.36	128	519	0.4393	1.7868
MOX0824	155	198.69	3.82	2515	12654	9.8755	49.6877
MOX0824	155	198.69	3.64	381	2016	1.5705	8.3082
MOX0825	156	197.69	3.62	1112	3936	4.6091	16.3077
MOX0825	156	197.69	3.57	304	764	1.2776	3.2107
MOX0826	157	196.69	4.00	1038	5023	3.8927	18.8363
MOX0826	157	196.69	4.21	410	2029	1.4619	7.2284
MOX0827	158	195.69	4.01	13980	31597	52.2950	118.1933
MOX0827	158	195.69	5.48	7007	13786	19.1801	37.7366
MOX0828	159	194.69	4.36	10697	27260	36.8002	93.7854
MOX0828	159	194.69	4.33	6046	18886	20.9443	65.4252
MOX0829	160	193.69	4.28	3535	8298	12.3895	29.0821
MOX0829	160	193.69	4.44	1034	5967	3.4937	20.1601
MOX0830	161	192.69	4.57	12753	31477	41.8574	103.3173
MOX0830	161	192.69	5.00	6363	17015	19.0896	51.0444
MOX0831	162	191.69	5.23	11148	26495	31.9720	75.9885
MOX0831	162	191.69	4.38	4175	11769	14.2972	40.3038
MOX0832	163	190.69	5.19	17016	40899	49.1793	118.2044
MOX0832	163	190.69	5.86	1857	2396	4.7543	6.1330
MOX0833	164	189.69	4.01	7082	20556	26.4903	76.8940
MOX0833	164	189.69	3.08	0	0	0.0000	0.0005
MOX0834	165	188.69	3.99	8855	21982	33.2905	82.6383
MOX0834	165	188.69	4.19	4563	13202	16.3364	47.2613

Note: Soil concentrations have been corrected by a multiplier of 2. Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-9 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0900	117	237	3.92	0	0	0.0000	0.0002
MOX0900 DUP	117	237	3.8	0	0	0.0000	0.0000
MOX0901	119	235	4.31	0	10	0.0000	0.0182
MOX0901 DUP	119	235	3.67	0	0	0.0000	0.0000
MOX0902	121	233	4.13	0	9	0.0000	0.0167
MOX0902 DUP	121	233	3.97	0	0	0.0000	0.0000
MOX0903	123	231	3.29	0	0	0.0000	0.0000
MOX0903 DUP	123	231	3.01	0	0	0.0000	0.0003
MOX0904	125	229	4	0	0	0.0000	0.0000
MOX0904 DUP	125	229	2.96	0	0	0.0000	0.0005
MOX0905	127	227	4	8	88	0.0315	0.3317
MOX0905 DUP	127	227	4.2	8	88	0.0298	0.3132
MOX0906	128	226	3.97	76	351	0.2883	1.3244
MOX0906 DUP	128	226	4.22	58	242	0.2079	0.8593
MOX0907	129	225	4.09	97	341	0.3557	1.2512
MOX0907 DUP	129	225	3.61	50	152	0.2063	0.6303
MOX0908	130	224	2.84	92	268	0.4857	1.4162
MOX0908 DUP	130	224	3.45	63	154	0.2735	0.6705
MOX0909	131	223	3.5	123	241	0.5292	1.0346
MOX0909 DUP	131	223	3.44	75	131	0.3284	0.5703
MOX0910	132	222	3.57	252	421	1.0576	1.7690
MOX0910 DUP	132	222	3.85	148	182	0.5783	0.7076
MOX0911	133	221	3.48	292	677	1.2576	2.9176
MOX0911 DUP	133	221	3.41	164	353	0.7194	1.5540
MOX0912	134	220	3.69	631	1888	2.5652	7.6754
MOX0912 DUP	134	220	3.71	770	2475	3.1130	10.0076
MOX0913	135	219	4.12	554	1329	2.0174	4.8373
MOX0913 DUP	135	219	3.9	332	728	1.2784	2.8018
MOX0914	136	218	3.3	253	530	1.1496	2.4071
MOX0914 DUP	136	218	4.24	445	1218	1.5752	4.3078
MOX0915	137	217	4.12	403	1004	1.4689	3.6537
MOX0915 DUP	137	217	4.06	237	647	0.8756	2.3891
MOX0916	137.5	216.5	4.18	340	962	1.2186	3.4535
MOX0916 DUP	137.5	216.5	3.91	239	830	0.9169	3.1850
MOX0917 DUP	138	216	4.35	117	285	0.4047	0.9819
MOX0918 DUP	139	215	3.93	284	1409	1.0853	5.3777
MOX0919	143	211	4.19	1174	5521	4.2037	19.7659
MOX0919 DUP	143	211	4.38	1389	7240	4.7552	24.7938
MOX0920	143.5	210.5	4.55	1363	6686	4.4924	22.0427
MOX0920 DUP	143.5	210.5	5.02	1237	5647	3.6967	16.8727
MOX0921	144	210	4.16	1217	5778	4.3876	20.8340

Concentration Data for MOX-9 Soil Boring Samples (continued)

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX0921 DUP	144	210	4.21	1316	5349	4.6886	19.0593
MOX0922	145	209	3.88	460	994	1.7784	3.8432
MOX0922 DUP	145	209	4.33	642	1425	2.2238	4.9349
MOX0923 DUP	146	208	3.92	98	149	0.3748	0.5704
MOX0924	147	207	3.89	65	187	0.2515	0.7199
MOX0924 DUP	147	207	3.58	96	200	0.4028	0.8385
MOX0925	148	206	3.87	350	1025	1.3572	3.9725
MOX0925 DUP	148	206	3.95	176	524	0.6675	1.9901
MOX0926	149	205	3.76	243	761	0.9714	3.0364
MOX0926 DUP	149	205	3.78	173	470	0.6875	1.8658
MOX0927	150	204	3.57	1081	4496	4.5415	18.8889
MOX0927 DUP	150	204	3.25	573	2153	2.6424	9.9360
MOX0928	151	203	3.45	701	2503	3.0464	10.8817
MOX0928 DUP	151	203	3.98	1246	5068	4.6947	19.0990
MOX0929	152	202	4.24	2164	8095	7.6567	28.6395
MOX0929 DUP	152	202	4.26	1673	6908	5.8894	24.3250

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-10 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX1000	117	236	3.74	0	0	0.0000	0.0004
MOX1000 DUP	117	236	3.42	0	0	0.0000	0.0007
MOX1001	118	235	4.06	35	20	0.0642	0.0362
MOX1001 DUP	118	235	3.92	0	0	0.0000	0.0003
MOX1002	119	234	3.51	0	15	0.0000	0.0326
MOX1002 DUP	119	234	4.07	0	0	0.0000	0.0000
MOX1003	120	233	3.87	0	16	0.0000	0.0305
MOX1003 DUP	120	233	3.73	0	0	0.0000	0.0000
MOX1004	121	232	3.67	0	0	0.0000	0.0000
MOX1004 DUP	121	232	4	0	0	0.0000	0.0003
MOX1005	122	231	3.37	6	1	0.0124	0.0027
MOX1005 DUP	122	231	3.42	0	0	0.0000	0.0011
MOX1006	123	230	4.05	2	4	0.0044	0.0068
MOX1006 DUP	123	230	3.83	3	5	0.0050	0.0106
MOX1007	124	229	3.32	0	2	0.0018	0.0069
MOX1007 DUP	124	229	2.8	1	4	0.0041	0.0206
MOX1008	125	228	3.98	1	5	0.0020	0.0172
MOX1008 DUP	125	228	3.44	0	1	0.0016	0.0053
MOX1009	126	227	3.5	3	41	0.0127	0.1776
MOX1009 DUP	126	227	3.33	2	19	0.0070	0.0859
MOX1010	127	226	4.02	14	61	0.0538	0.2287
MOX1010 DUP.	127	226	3.98	19	62	0.0701	0.2325
MOX1011	128	225	3.81	51	164	0.1999	0.6446
MOX1011 DUP.	128	225	3.42	12	17	0.0513	0.0728
MOX1012	129	224	2.95	17	45	0.0889	0.2279
MOX1012 DUP	129	224	3.57	13	18	0.0530	0.0744
MOX1013	130	223	3.65	8	11	0.0338	0.0457
MOX1013 DUP.	130	223	3.75	13	9	0.0534	0.0360
MOX1014	131	222	4.21	55	102	0.1975	0.3619
MOX1014 DUP	131	222	3.75	10	9	0.0398	0.0377
MOX1015	136	217	3.28	9	6	0.0394	0.0258
MOX1015 DUP	136	217	3.33	4	6	0.0172	0.0259
MOX1016	137	216	3.36	17	25	0.0737	0.1138
MOX1016 DUP.	137	216	3.19	4	11	0.0200	0.0527
MOX1017	138	215	4.51	26	62	0.0870	0.2057
MOX1017 DUP.	138	215	4.16	0	0	0.0000	0.0000
MOX1018	139	214	4.11	30	110	0.1105	0.4014
MOX1018 DUP.	139	214	3.87	18	50	0.0684	0.1928
MOX1019	140	213	4.43	1256	2944	4.2544	9.9667
MOX1019 DUP.	140	213	4.11	892	1908	3.2548	6.9653
MOX1020	141	212	4.42	2670	10185	9.0602	34.5644

Concentration Data for MOX-10 Soil Boring Samples (continued)

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX1020 DUP.	141	212	4.31	2904	7439	10.1053	25.8892
MOX1021	142	211	4.13	2248	8783	8.1659	31.9002
MOX1021 DUP.	142	211	4.38	1628	2815	5.5767	9.6392
MOX1022	143	210	4.65	1709	6588	5.5125	21.2504
MOX1022 DUP,	143	210	3.99	284	342	1.0669	1.2851
MOX1023	144	209	4.01	1308	3375	4.8930	12.6242
MOX1023 DUP.	144	209	4.41	958	1240	3.2583	4.2184
MOX1024	145	208	4.55	1824	5046	6.0140	16.6350
MOX1024 DUP.	145	208	3.95	1110	2287	4.2137	8.6851
MOX1025	146	207	3.79	458	1133	1.8131	4.4823
MOX1025 DUP.	146	207	3.84	342	689	1.3355	2.6895
MOX1026	147	206	3.7	1227	5294	4.9741	21.4603
MOX1026 DUP,	147	206	4.01	1661	3320	6.2125	12.4177
MOX1027	148	205	3.44	2800	10097	12.2079	44.0267
MOX1027 DUP.	148	205	3.61	553	912	2.2983	3.7877
MOX1028	149	204	3.36	656	5121	2.9302	22.8617
MOX1028 DUP.	149	204	3.41	547	2643	2.4047	11.6269
MOX1029 DUP.	150	203	3.72	649	2018	2.6155	8.1367
MOX1030	151	202	4.08	1627	8208	5.9811	30.1755
MOX1030 DUP.	151	202	3.78	1247	5872	4.9473	23.3034
MOX1031	152	201	3.52	1518	7013	6.4685	29.8830
MOX1031 DUP.	152	201	3.72	742	2598	2.9900	10.4758
MOX1032	153	200	4.55	2329	9226	7.6766	30.4164
MOX1032 DUP.	153	200	4.52	1999	7657	6.6325	25.4094

Note: Soil concentrations have been corrected by a multiplier of 2. Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-11 Soil Boring Samples

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX01100	117	237	4.45	0	0	0.0006	0.0006
MOX01100 DUP	117	237	3.26	0	0	0.0000	0.0007
MOX01101	118	236	3.67	0	0	0.0000	0.0008
MOX01101 DUP	118	236	3.3	0	1	0.0000	0.0012
MOX01102	119	235	3.93	0	1	0.0005	0.0015
MOX01102 DUP	119	235	3.29	0	0	0.0000	0.0003
MOX01103	121	233	4.33	0	0	0.0000	0.0003
MOX01103 DUP	121	233	3.59	0	1	0.0000	0.0016
MOX01104	122	232	3.36	0	0	0.0000	0.0002
MOX01104 DUP	122	232	3.19	0	0	0.0000	0.0006
MOX01105	123	231	3.02	0	0	0.0000	0.0002
MOX01105 DUP	123	231	4.01	0	0	0.0000	0.0004
MOX01106	124	230	3.07	0	0	0.0000	0.0004
MOX01106 DUP	124	230	3.38	0	0	0.0000	0.0009
MOX01107	125	229	3.49	0	0	0.0000	0.0005
MOX01107 DUP	125	229	3.25	0	0	0.0000	0.0000
MOX01108	126	228	3.27	0	0	0.0000	0.0006
MOX01108 DUP.	126	228	3.24	0	0	0.0000	0.0006
MOX01109	127	227	3.24	1	1	0.0043	0.0057
MOX01109 DUP.	127	227	3.44	0	0	0.0000	0.0007
MOX01110	128	226	3.4	0	0	0.0000	0.0020
MOX01110 DUP.	128	226	3.36	0	0	0.0000	0.0007
MOX01111	129	225	3.75	0	1	0.0012	0.0030
MOX01111 DUP.	129	225	3.72	0	1	0.0018	0.0029
MOX01112	130	224	3.7	6	16	0.0260	0.0648
MOX01112 DUP.	130	224	3.75	3	6	0.0102	0.0245
MOX01113	131	223	2.36	21	79	0.1364	0.5005
MOX01113 DUP..	131	223	3.47	11	38	0.0496	0.1658
MOX01114	132	222	3.31	42	158	0.1895	0.7141
MOX01114 DUP.	132	222	3.39	21	46	0.0929	0.2037
MOX01115	133	221	3.19	212	949	0.9966	4.4642
MOX01115 DUP.	133	221	3.34	121	514	0.5416	2.3064
MOX01116	134	220	3.56	183	668	0.7706	2.8141
MOX01116 DUP.	134	220	3.51	52	107	0.2240	0.4576
MOX01117	135	219	3.84	135	400	0.5261	1.5634
MOX01117 DUP.	135	219	4.28	48	81	0.1668	0.2824
MOX01118	136	218	3.11	0	0	0.0000	0.0000
MOX01118 DUP.	136	218	3.26	179	736	0.8221	3.3859
MOX01119	137	217	3.36	260	1157	1.1615	5.1644
MOX01119 DUP.	137	217	3.55	121	301	0.5123	1.2712
MOX01120	138	216	3.95	84	229	0.3194	0.8710

Concentration Data for MOX-11 Soil Boring Samples (continued)

Sample	Depth	Elev. (msl)	Soil wt (grams)	Aqueous Conc. (PPB)		Conc. in Soil (ug/g)	
				TCE	PCE	TCE	PCE
MOX01120 DUP.	138	216	4.13	85	247	0.3103	0.8988
MOX01121	141	213	3.27	197	275	0.9042	1.2632
MOX01121 DUP.	141	213	3.29	260	375	1.1863	1.7080
MOX01122	142	212	4.2	555	845	1.9834	3.0196
MOX01122 DUP.	142	212	3.52	221	219	0.9431	0.9336
MOX01123	143	211	3.34	52	130	0.2347	0.5839
MOX01123 DUP.	143	211	3.45	30	36	0.1317	0.1585
MOX01124	144	210	3.99	32	74	0.1184	0.2786
MOX01124 DUP;	144	210	5.06	32	37	0.0940	0.1098
MOX01125	145	209	4.33	184	287	0.6360	0.9933
MOX01125 DUP.	145	209	3.73	69	73	0.2781	0.2918
MOX01126	146	208	3.32	404	958	1.8242	4.3281
MOX01126 DUP.	146	208	3.43	212	322	0.9279	1.4077
MOX01127	147	207	3.64	111	383	0.4575	1.5792
MOX01127 DUP.	147	207	3.52	83	243	0.3542	1.0346
MOX01128	148	206	3.51	701	1363	2.9958	5.8248
MOX01128 DUP..	148	206	3.27	422	434	1.9339	1.9929
MOX01129	149	205	2.7	126	186	0.6977	1.0328
MOX01129 DUP.	149	205	2.44	72	91	0.4431	0.5589
MOX01130	150	204	3.34	1578	7850	7.0882	35.2550
MOX01130 DUP.	150	204	3.15	1298	5957	6.1796	28.3678
MOX01131	151	203	3.63	1678	5628	6.9336	23.2543
MOX01131 DUP.	151	203	3.44	1221	3046	5.3252	13.2810
MOX01132	152	202	3.32	4005	10418	18.0957	47.0699
MOX01132 DUP.	152	202	3.47	3418	7184	14.7733	31.0545
MOX01133	153	201	3.37	3254	8347	14.4819	37.1522
MOX01133 DUP.	153	201	3.28	2809	4160	12.8456	19.0244
MOX01134	154	200	3.19	5237	12837	24.6236	60.3606
MOX01134 DUP.	154	200	3.3	3407	5922	15.4884	26.9184
MOX01135	155	199	3.6	4506	11455	18.7738	47.7305
MOX01135 DUP.	155	199	3.01	2825	6387	14.0763	31.8273
MOX01136	156	198	3.1	274	545	1.3252	2.6366
MOX01136 DUP.	156	198	3.08	1111	2583	5.4088	12.5804

Note: Soil concentrations have been corrected by a multiplier of 2. Only corrected those below water table (124 ft below surface)

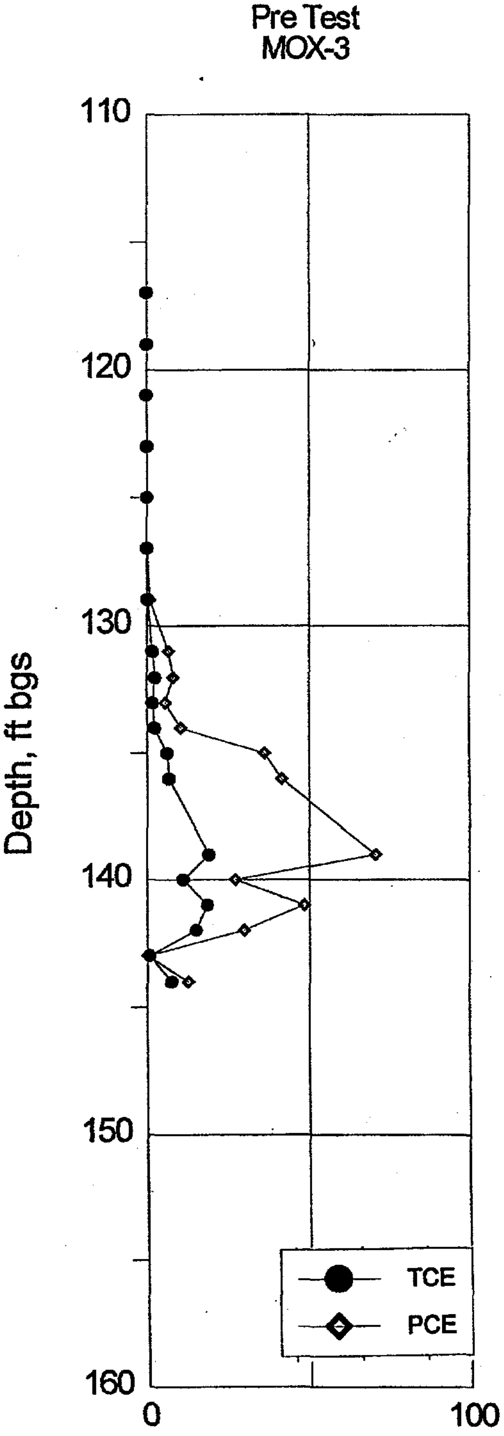
Monitoring Well Water Concentrations

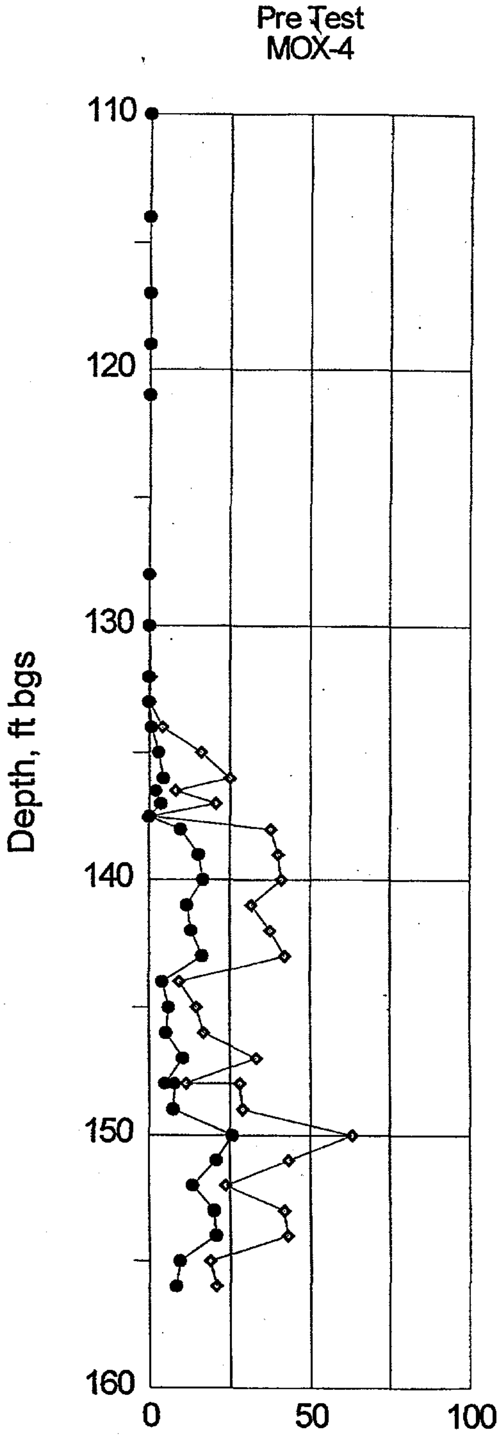
Sample Date	MOX-5, mg/L		MOX-7, mg/L		MOX-8, mg/L	
	PCE	TCE	PCE	TCE	PCE	TCE
03/01/97	142.52	27.84	151.19	24.81	159.71	25.30
03/20/97	106.28	21.73	117.34	21.67	155.15	23.18
04/15/97	98.11	19.84	101.13	17.07	76.57	14.16
04/17/97	40.33	16.68	38.93	8.78	29.41	7.05
04/18/97	47.41	15.81	18.46	4.28	18.43	2.52
04/19/97	19.94	6.97	15.13	4.21	14.60	2.62
04/21/97					0.01	0.00
04/22/97	0.35	0.01	0.00	0.00	1.59	0.19
04/25/97	0.48	0.02	1.46	0.04	13.32	4.01
04/30/97	1.84	0.17	13.88	2.82	30.53	8.75
05/07/97	2.19	0.56	31.07	6.04	46.15	8.79
05/14/97	1.74	0.47	32.04	7.30	63.48	11.24
05/21/97	2.33	0.63	40.97	8.73	78.42	12.28
05/29/97	4.67	1.42	42.05	9.24	78.29	12.84
06/04/97	2.61	0.66	42.10	9.92	77.95	13.47
06/11/97	8.71	2.93	53.20	11.78	84.79	13.66
06/25/97	10.87	3.85	67.44	14.24	108.16	17.09
07/09/97	11.99	4.46	52.99	12.24	87.82	15.25

Monitoring Well Chloride and Nitrate Data

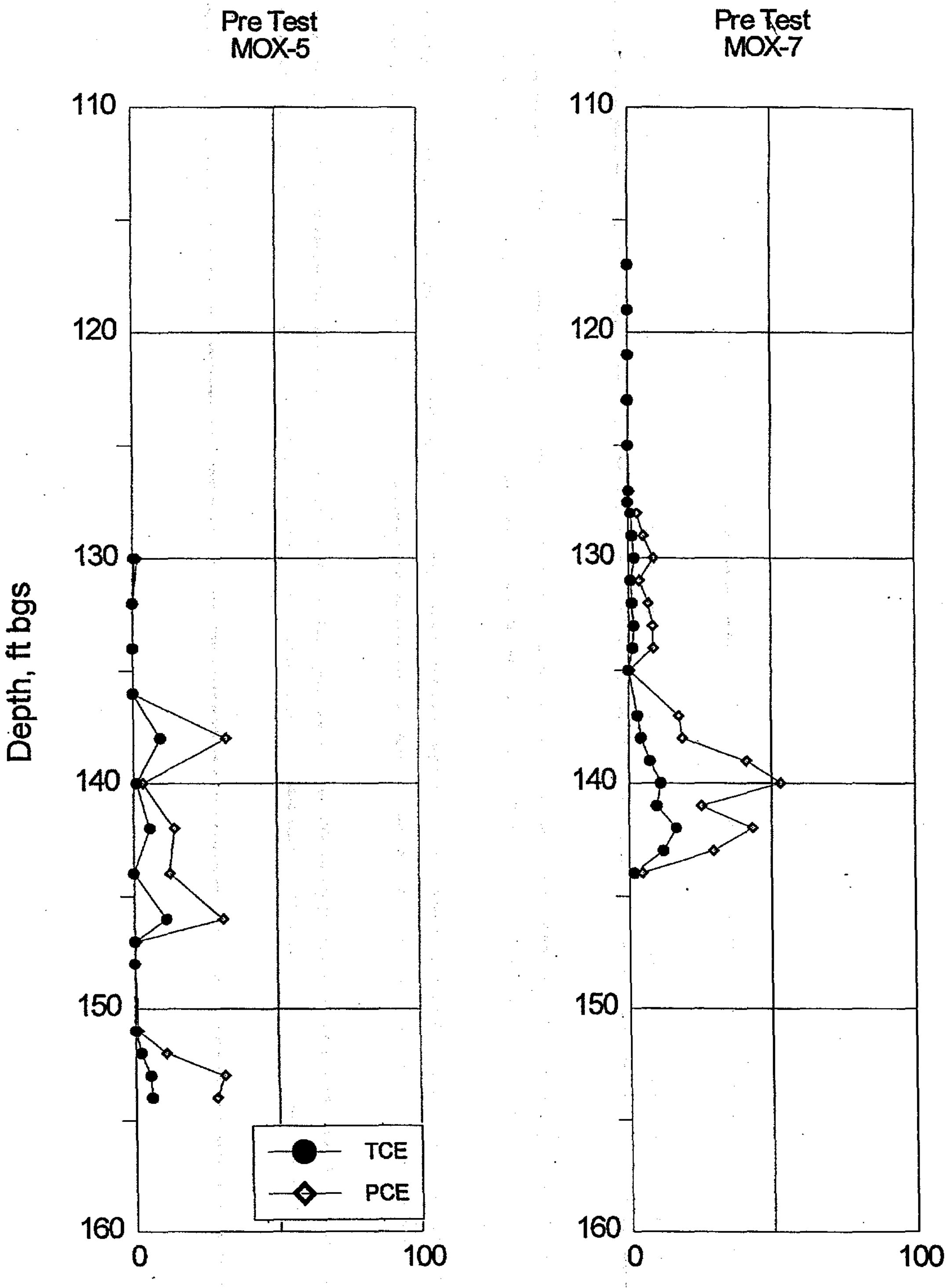
Sample Date	MOX-5, mg/L		MOX-7, mg/L		MOX-8, mg/L	
	Chloride	Nitrate	Chloride	Nitrate	Chloride	Nitrate
4/3/97	2.75	19.99	3.69	12.89	4.40	19.85
4/17/97	5.56	48.50	5.20	28.47	4.85	32.10
4/18/97	5.54	50.62	10.61	32.93	31.30	37.60
4/19/97	9.57	65.67	7.67	38.14	22.05	32.76
4/21/97					16.29	36.65
4/22/97	19.69	49.87	37.61	41.57	15.70	32.16
4/25/97	18.54	41.46	23.02	32.31	9.67	30.71
5/14/97	5.09	43.17	5.61	14.87	6.40	21.90
5/21/97	5.57	36.41	7.64	14.36	9.16	20.99
5/29/97	9.60	34.48	6.49	13.71	6.01	21.73
6/4/97	10.36	30.90	5.67	13.39	7.76	20.89

Soil Concentration Depth Profiles for MOX-3 and MOX-4 Borings

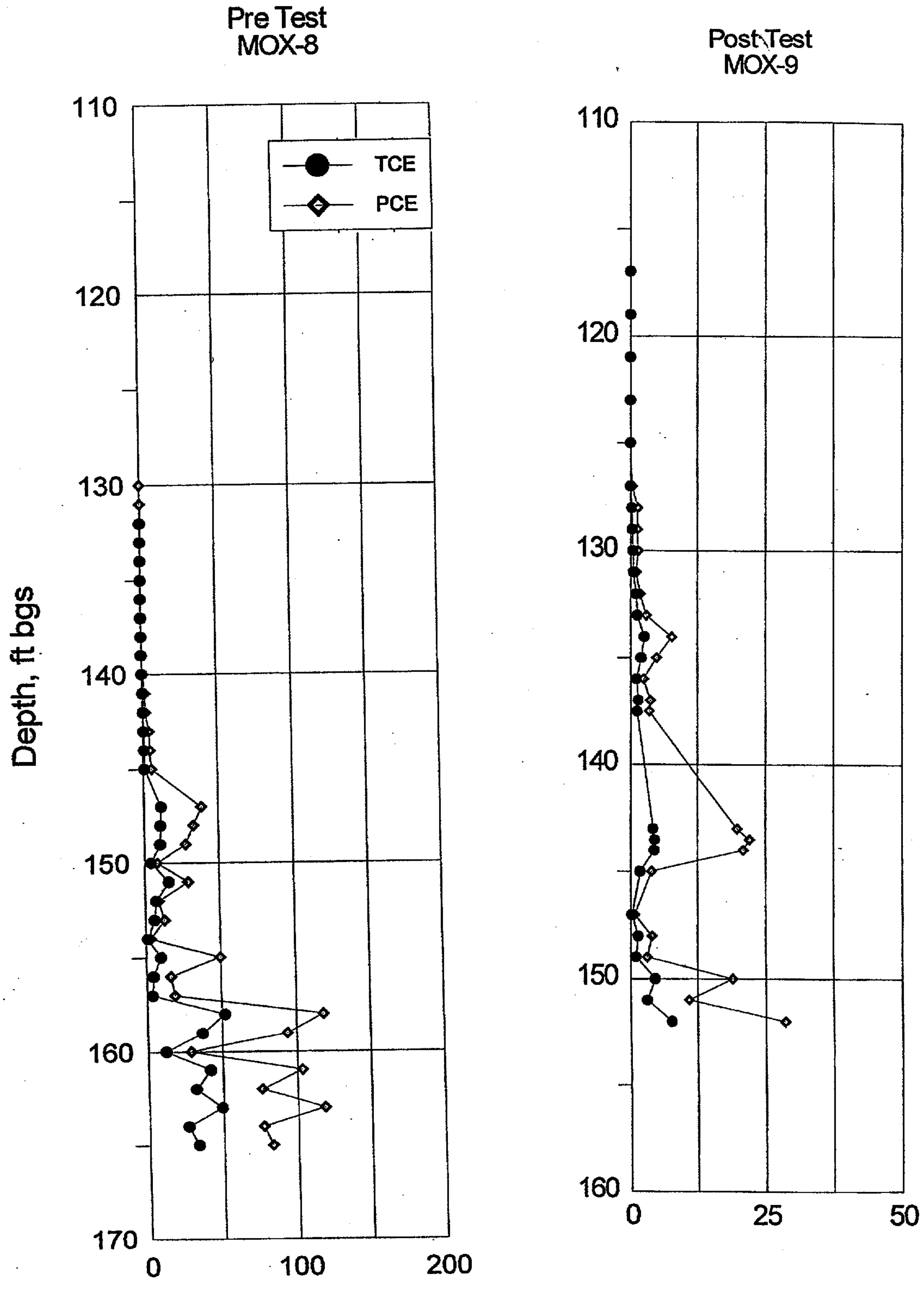




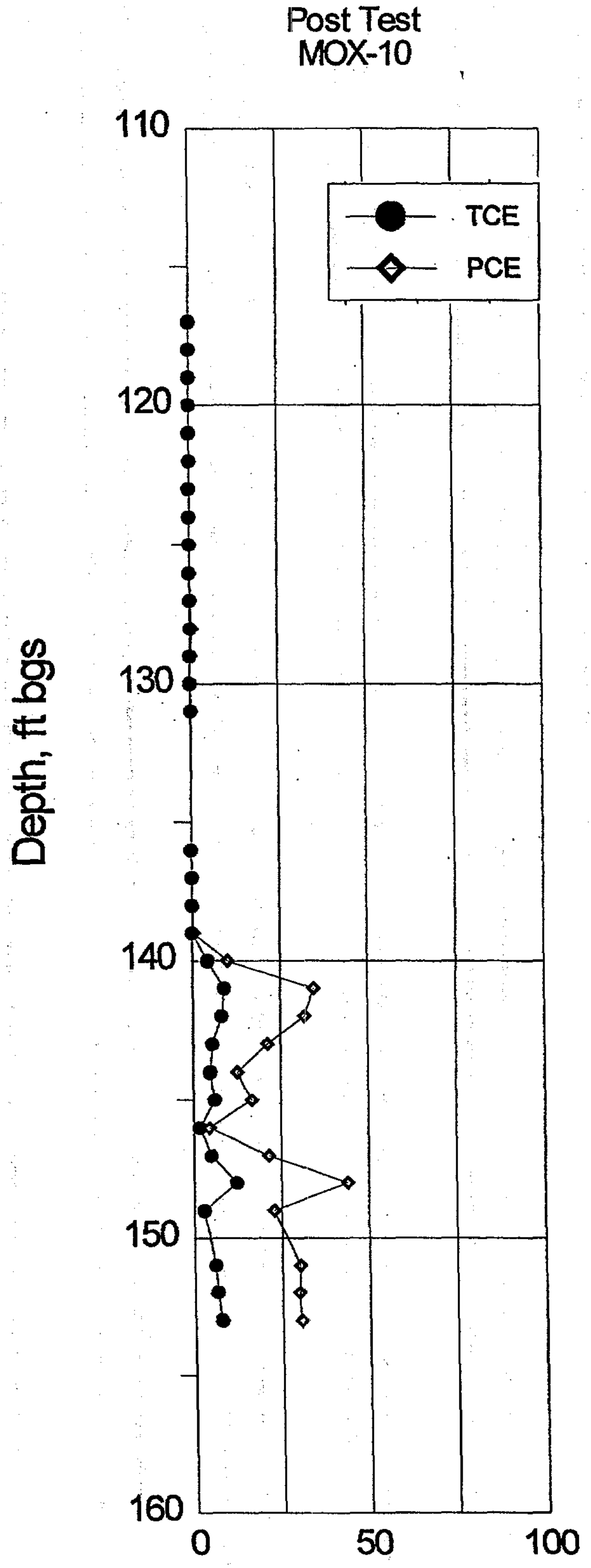
Soil Concentration Depth Profiles for MOX-5 and MOX-7 Borings



Soil Concentration Depth Profiles for MOX-8 and MOX-9 Borings



Soil Concentration Depth Profiles for MOX-10 Borings



Calculation of DNAPL Volume in Treatment Zone

Definitions:

Treatment zone area is circular with a radius, r, of 27 feet (824 cm) (distance from center injector to monitoring wells)

Treatment zone total height, h_T, is from the top of the Green Clay to the water table: Height (h_T) of 30 feet is based on average depth of water table at 125 ft bgs. and average depth of Green Clay at 155 ft bgs. h_i are the 1 foot (30.5 cm) increments from the Green Clay to the water table.

ρ = bulk soil density, in gm/cc = 2.1 gm/cc for soil at demonstration site
V_i = Volume over the depth interval i, in cubic centimeters (cc)
$C_{avg,i}$ = average concentration over the depth interval i, in µg of contaminant per gram of soil

$$\text{Total Volume in } \mu g = \quad V_T = \sum_{i=0}^{30} \rho V_i * (C_{TCE\,avg,i} + C_{PCE\,avg,i}) = \sum_{i=0}^{30} \rho \pi r^2 h_i * (C_{TCE\,avg,i} + C_{PCE\,avg,i})$$

Total Volume in pounds = Volume in µg * 10^{-9} kg/µg * 2.2 pounds/kg

Calculation of DNAPL Destroyed

DNAPL destroyed = $V_{T,\text{pre-test}} - V_{T,\text{post-test}}$

APPENDIX B

SAMPLING AND ANALYSIS METHODS

Sediment Samples

Once the core was brought to the surface, a 2 cc plug sample was collected using a modified plastic syringe. The plug was transferred to a 22 ml vial containing 5 ml of nano-pure water and the vial was sealed with a crimped septum top for later head space analysis. Duplicate samples were collected at each depth and all samples were stored at 4°C until analysis.

Each sample was weighed and then analyzed on the HP 5890 Series gas chromatograph using an automated head space sampler for equivalent water concentrations. Mass soil concentrations (ppb, µg/kg) were calculated based on an equal head space volume from 7.5 ml of water standards and approximately 7.5 ml of water/soil matrix and were corrected for the mass difference between the soil and water. The gas chromatograph was calibrated using certified solvent mixtures in methanol diluted to specific concentrations. The standard concentrations used for each head space sample run were 3, 5, 10, 50, 250, 500, and 1,000 ppb (µg/l). The samples were analyzed for Vinyl Chloride, Freon-11, Freon-113, 1,1-DCE, trans-DCE, cis-DCE, 1,1,1-TCA, CCl_4, TCE, and PCE.

Water Samples

The Savannah River Technology Center's technique used to sample and analyze water samples for VOC content is a modified version of EPA Method 3810 and has been studied and used successfully at SRS since 1991. A water level measurement was taken and minimum of 30 gallons of groundwater was purged from each well. Temperature and pH were measured using an electronic probe. 7.5 ml of groundwater was transferred from the well sample port to a 22 ml glass head space vial and the vial was sealed with a crimped Teflon-lined septum top for head space analysis. 40 ml plastic vials were filled for chloride ion analysis. Duplicate samples were collected at each well and all samples were stored at 4°C until analysis (maximum allowed storage time is 14 days).

Each VOC sample was analyzed on a HP 5890 Series II gas chromatograph (GC) using an automated head space sampler at 70°C for water contaminant concentrations. The GC is equipped with an electron capture detector (ECD) and flame ionization detector (FID) connected in parallel. The GC column is a Supelco - VOCOL megabore borosilicate glass (60m x 0.75 mm ID x 1.5 micron film thickness) specifically developed for volatile priority pollutants (EPA Methods 502, 602, and 8240). The GC is calibrated using certified solvent mixtures in methanol diluted to specific concentrations and two reagent blanks. The standard concentrations used for each head space sample run were 3, 5, 10, 50, 250, 500, and 1,000 ppb (µg/l). The samples were analyzed for Vinyl Chloride, Freon-11, Freon-113, 1,1-DCE, trans-DCE, cis-DCE, 1,1,1-TCA, CCl_4, TCE, and PCE.

Groundwater samples were analyzed for nutrients using a Dionex QIC 2 ion chromatograph. A FAST ANION (P/N 39590, 4x250mm) ion exchange column equipped with polymeric packing was used for separation of chloride, nitrite, nitrate, phosphate and sulfate. A conductivity detector measuring µS was used. The ions were eluted with a 200 mM Na_2CO_3 / 75 mM $NaHCO_3$ solution at a flow rate of 2 ml/min.

Standards were prepared using solutions of sodium chloride, sodium nitrate, sodium nitrite, potassium phosphate, and potassium sulfate. The standards were made at several different concentrations in order to generate an acceptable calibration curve. The calibration data was entered into the Dionex AI450 software package and configured to automatically calculate concentrations. The software was configured to automatically generate a report listing the component name, retention time, concentration in mg/l, area of response, and peak characteristics.

APPENDIX C

BASIS FOR UNIT COST FOR PUMP AND TREAT SYSTEM

Department of Energy
Savannah River Operations Office
P.O. Box A
Aiken, South Carolina 29802

SEP 0 3 1996

Mr. John L. Steele, Manager
Manager, Focus Area Programs Department
Westinghouse Savannah River Company
P. O. Box 616
Aiken, SC 29802

Dear Mr. Steele:

SUBJECT: Cost Savings Analyses for Soil Vapor Extraction (SVE) (U)

A second independent analysis of projected and actual costs for the subject activity was performed by this office as a result of the meeting held on August 21 between your staff and Terry Brennan of this office.

This analysis supports your claim for comparing the new technology, SVE, to the cost of removing the same amount of solvent with the baseline pump and treat technology, the M-1 Air Stripper. The resulting savings for the solvent extracted by the SVE during the first twelve months of operation is $ 4,380,000.

Questions from you or your staff may be directed to Terry Brennan at 725-4716.

Sincerely,

Karen L. Hooker, Director
Program Management and
Coordination Division

PM&CD:TJB:ap

OB-96-018

cc:
G. Hooker, WSRC, 773-41A
J. Iwert, WSRC, 773-41A

Westinghouse Savannah River Company

INTER-OFFICE MEMORANDUM

July 30, 1996 SRT-FAP-96-0173

To: J. L. Steele

From: G. J. Hooker
J. W. Iwert

ESTIMATED COST SAVINGS SOIL VAPOR EXTRACTION COMPARED TO PUMP AND TREAT AND IN WELL VAPOR STRIPPING COMPARED TO PUMP AND TREAT

SUMMARY

This document details FY1996 cost savings attributable to Soil Vapor Extraction ($4,380,000) and to In Well Vapor Stripping ($2,462,000). These savings are derived by comparing the new technology to the cost of removing the same amount of solvent with the baseline pump and treat technology, the M-1 air stripper. Soil Vapor Extraction (SVE) removes the solvent from the vadose zone before it has migrated to the groundwater and avoids the greater cost of removal by pump and treat. In Well Vapor Stripping (IWVS) is being applied in the Southern Sector of the A/M contaminant plume to remove solvent from groundwater at low solvent concentrations where the economic advantage of IWVS over Pump and Treat is most significant.

The capital and O & M cost estimates were provided by the WSRC Site Project Cost Estimating Department. Technical input and review was provided by Roger White of SRTC and by Chris Bergren and Michael Hartz of WSRC-ER.

DISCUSSION

Soil Vapor Extraction

Four Soil Vapor Extraction units with catalytic oxidation were started up in A/M Area in May 1995. Although this innovative technology was anticipated in the 1993 Baseline its first full year of operation was completed in April 1996. We are therefore submitting the cost savings attributable to SVE for the FY1996 Award Fee Item.

It is estimated that over 1 million pounds of the solvent contaminant in the A/M Area plume remains in the vadose zone where it will continue to recharge the the groundwater. Removal of the contaminant from the soil is less expensive than removal from the groundwater.

Exhibit I summarizes the full operating cost for removing 64,800 lbs of solvent ($18.90 per lb) with the SVE units during the most recent 12 months, the full operating cost for removing 13,209 lbs of solvent ($86.49 per lb) extracted by the M-1 air stripper for a similar period, and calculates the resulting savings for the solvent extracted by the SVE in this period, $4,380,000.

In Well Vapor Stripping
The scope for this project is detailed in "Southern Sector Vertical Recirculation Wells-Phases 2 and 3", G-TC-A-0006. As a substitute for pump and treat remediation, a line of 12 Vertical Recirculation wells is being installed at the southernmost extent of the A/M Area plume to terminate its further migration and to remove the contaminant from the plume as it moves past the line of wells. Exhibit II summarizes the full cost per pound of solvent removal by IWVS ($74.94 per lb), the adjusted cost per pound of solvent removal for the M-1 stripper operating in the low solvent concentration of the southern sector ($1210.86 per lb), and the cost savings per pound of solvent removed by the IWVS ($1135.92 per lb). The resulting FY1996 savings estimate is $2,462,000.

Exhibit III is the June ER solvent removal summary report from which solvent removal rates were taken.

Exhibit IV is the Estimate Detail Sheet for Capital and O&M costs for the M-1 Stripper, the Soil Vapor Extraction, and the In Well Vapor Stripping. These calculations are further supported in the following Exhibits.

Capital costs for the pump and treat operation were estimated from the following document by Stone and Webster (and approved by DOE), "Pump and Treat of Contaminated Groundwater at USDOE Savannah River Site, Aiken, SC, June 1994. Exhibit V is the information used. Note that because the M-1 stripper is being modified to treat the offgas at a cost of $449,000 this amount has been added to the final estimate for the M-1 stripper capital cost.

Exhibit VI is the final capitalized amount for the SVE operation.

Exhibit VII is the capital cost and other data provided for the IWVS cost estimate.

Exhibit VIII contains other miscellaneous notes and data sheets used in this estimate.

EXHIBIT I
ESTIMATED COST SAVINGS
SOIL VAPOR EXTRACTION COMPARED WITH PUMP AND TREAT

ANNUAL OPERATING COST FOR FOUR M AREA SVE UNITS:

Capital	$260,000
O & M	$964,000
Total	$1,224,600

SOLVENT REMOVED BY THESE SVE UNITS, 6/95 THRU 5/96..........64,800 lbs

SVE COST PER POUND EXTRACTED:
$1,224,600/64,800 lbs = $18.90

ANNUAL OPERATING COST FOR M-1 AIR STRIPPER:

Capital	$172,500
O & M	$970,000
Total	$1,142,500

SOLVENT REMOVED BY M-1 AIR STRIPPER, 5/95 THRU 4/96............13,209 lbs

M-1 COST PER POUND EXTRACTED:
$1,142,500/13209 lbs = $86.49

COST SAVINGS BY SVE:
($86.49 - $18.90) x 64,800 lbs = $67.59 x 64,800 lbs = $4,379,832
Rounding.......................... 168
$4,380,000

EXHIBIT II
ESTIMATED COST SAVINGS
INWELL VAPOR STRIPPING COMPARED WITH PUMP AND TREAT

ANNUAL OPERATING COST FOR INWELL VAPOR STRIPPING (IWVS):

Capital	$62,400
O & M	$100,000
Total	$162,400

ESTIMATED ANNUAL SOLVENT REMOVAL FOR IWVS:

0.0217 lbs/hr x 12 wells x 24 hrs/day x 365 days/year x 0.95 availability = 2167 lbs/year

COST PER POUND OF SOLVENT REMOVED BY IWVS:

$162,400/2167 lbs = $74.94 per lb

COST OF REMOVING SOLVENT FROM THE IWVS FEEDSTREAM WITH M-1 STRIPPER:

From Exhibit I the operating cost of M-1 Stripper	$86.49 per lb
Concentration of Solvent in M-1 Feedstream is	7 ppm
Concentration of Solvent in IWVS Feedstream is	0.5 ppm

Cost of Operating M-1 in the IWVS Feedstream:

(7 ppm/0.5ppm) x $86.49 = 14 x $86.49 = $1210.86 per lb

ESTIMATED COST SAVINGS FOR THE IWVS:

($1210.86 - $74.94) x 2167 lbs = $1135.92 x 2167 = $2,461,534

Rounding........................466

$2,462,000

Total pounds VOCs Removed per Month in A/M Area
FY 1995 and FY 1996

FY ' 95	Oct. '94	Nov. ' 94	Dec. ' 94	Jan. ' 95	Feb ' 95	Mar. ' 95	April ' 95	May ' 95	June ' 95	July ' 95	Aug. ' 95	Sept. ' 95	Total		
M-1 Stripper	1719	1444	823	785	596	1544	1174	1174	608	783	0	1893	12543		
A-1 Stripper	55	47	43	47	15	48	35	33	49	36	5	47	460		
IDU	445	0	0	345	0	0	0	22	296	1176	3355	506	6145		
SVEU 3M	0	0	0	0	0	0	0	1000	1600	700	3000	3200	9500		
SVEU 4M	0	0	0	0	0	0	0	1800	1600	600	700	600	5300		
SVEU 5M	0	0	0	0	0	0	0	1900	1300	1400	2200	1500	8300		
SVEU 6M	0	0	0	0	0	0	0	1400	200	0	600	1800	4000		
															74% target
									FY '95	Total pounds VOCs removed			46248		80472
FY ' 96	Oct. '95	Nov. ' 95	Dec. ' 95	Jan. ' 96	Feb ' 96	Mar. ' 96	April '96	May ' 96	June ' 96	July ' 96	Aug. ' 96	Sept. ' 96	Total		
M-1 Stripper	1200	1540	1307	1426	1156	702	1420						8751		
A-1 Stripper	43	43	40	28	7	6	48						215		
IDU	985	742	706	600	600	600	600						4833		
SVEU 3M	2200	1800	300	300	1000	2000	3100	1400					12100		
SVEU 4M	600	1200	1000	1500	700	1800	1500	500					8800		
SVEU 5M	1100	1200	1900	1600	700	1600	700	1200					10000		
SVEU 6M	800	1400	2000	1200	2600	2200	1600	1100					12900		
A-2 Stripper	0	0	0	0	0	0	0						0		
Other	170	165	170	170	160	170	165	170					1340		
Sum	7098	8090	7423	6824	6923	9078	9133	4370							% of goal
									FY '96	Total pounds VOCs removed			58939		73
% of	105.8	120.6	110.7	101.8	103.2	135.4	136.2	65.2							
monthly goal															current % of
															annual goal
															110

EXHIBIT IV
(3 pages)

WESTINGHOUSE SAVANNAH RIVER COMPANY

INTER-OFFICE MEMORANDUM

ENGINEERING & CONSTRUCTION SERVICES
SITE PROJECT ESTIMATING DEPARTMENT

ECS-SPE-96-0327

DATE: July 25, 1996

TO: G. J. HOOKER, 773-41A / 253

FROM: R. M. SIMPSON, 730-1B / 114

BY: C.B. JORDAN, 730-1B / 1066

COMPARATIVE COST FOR THE M-1 AIR STRIPPER, VALDOSE ZONE SOIL VAPOR EXTRACTION AND IN-WELL VAPOR STRIPPING (U)

Estimate Log No:96-06-07A and 96-07-11 Estimate Type: Comparative Cost

Attached is the capital costs and operation and maintenance cost for the above listed treatment technologies.

COST BASIS:
The cost are based on previous life cycle costs and other information supplied by the ER Group.

ASSUMPTIONS:
The costs are in FY'96 Dollars. SRS Site mark-ups for subcontract work, construction management and projectsupport are not included.

MANAGEMENT RESERVE / CONTINGENCY:
No Management reserve or Contingency is included in the costs for this study.

ESTIMATE CLOSURE:
No response is required for this study.

DDH
cc: R. M. Simpson, 730-1B / 114
J. W. Iwert, 773-41A / 251
Estimate File

PROJECT NO : N/A
PROJ. NAME : Comparitive Technology Cost
LOG NO : 96-07-11

SITE PROJECT ESTIMATING

ESTIMATE DETAIL SHEET

EST'D BY : C.Jordan, D.Hanson
PHONE : 2-9540
LOC : 730-1B/1066

ITEM WBS	CSI	TWC	DESCRIPTION	QTY UNIT	UNIT COST	MHRS	CR	MHRS	LABOR RATE	LABOR	ENGR'D EQUIP.	BULK MAT'L	S/C	TOTAL DOLLARS
1.0			M-1 Air Stripper (ADS-516/1701)											
1.1			Capital Cost											
			Total Capital Cost (FY'90 $)		$4,552,000									
			(Assume 30 Yr. Life)											
			Cost Per Year											$151,700
			Escalation 1990 to 1996 @		13.70%									$20,800
			Total Yearly Capital Cost											$172,500
1.2			Operations & Maintenance											
			M-1 Stripper - RMET Avg. Yr.											$622,500
			ER Labor - Exempt											$307,700
			ER Labor - Non-Exempt											$12,300
			Power & Misc. O & M Costs											$27,500
			Total Yearly O & M Costs											$970,000
2.0			Vadose Zone (ADS - 516/1704)											
2.1			Capital Cost											
			Total Capital Cost (FY'95 $)		$3,810,000									
			(Assume 15 Yr. Life)											
			Cost Per Year											$254,000
			Escalation 1995 to 1996 @		2.60%									$6,600
			Total Yearly Capital Cost											$260,600
2.2			Operations & Maintenance											
			Vadose Zone - RMET - F											$501,000
			ER Labor - Exempt											$391,000
			ER Labor - Non-Exempt											$46,000
			Power & Misc. O & M Costs											$26,000
			Total Yearly O & M Costs											$964,000

PROJECT NO : N/A
PROJ. NAME : Comparitive Technology Cost
LOG NO : 96-07-11

SITE PROJECT ESTIMATING

ESTIMATE DETAIL SHEET

EST'D BY : C.Jordan, D.Hanson
PHONE : 2-9540
LOC : 730-1B/1066

ITEM WBS CSI TWC	DESCRIPTION	QTY UNIT	UNIT COST	MHRS	MHRS	LABOR RATE	LABOR	ENGR'D EQUIP.	BULK MAT'L	S/C	TOTAL DOLLARS
3.0	Southern Sector In-Well Vapor Stripping										
3.1	Capital Cost										
	Total Capital Cost (FY'96 $)		$1,873,000								
	(Assume 30 Yr. Life)										
	Cost Per Year										$62,400
	Total Yearly Capital Cost										$62,400
3.2	Operations & Maintenance										
	ER Labor										$41,000
	Inspection & Maintence										$47,000
	Power & Misc. O & M Costs										$12,000
	Total Yearly O & M Costs										$100,000

EXHIBIT V
(2 pages)

M-1 AIR STRIPPER - CAPTIAL COST

COST

- The production air stripper was designed and constructed in 1984-1985. The major capital cost elements associated are provided below. Annual operating costs based upon data from 1985 through 1990 are also listed. All information is based on an analysis performed in 1990 and all costs are in 1990 dollars.

- During 1985 to 1990, the average volume of water treated by the air stripper was 198 million gallons per year. Using the operating costs detailed below (in 1990 dollars), the total cost of operation and maintenance is $0.75 per 1000 gallons treated.

- An assessment of total cost and duration of operation for the pump and treat system to complete the cleanup is not possible due to the multi-phased approach to environmental restoration of the A/M Area. As detailed on page 6, the overall treatment plan for the site includes future identification and implementation of technologies to achieve cleanup goals. The extent to which the pump and treat system will be part of that effort has not yet been determined therefore projected costs to cleanup can not be estimated.

Capital Costs

Design	$420,000
Contracts (permitting, modeling, etc.)	368,000
Site Development	28,000
QA Engineering	16,000
Control Building	211,000
Electrical	877,000
Instrumentation	466,000
Piping/Construction	925,000
Tower Installation	132,000
Control System	230,000
Erect/Test Tower	428,000
Total	$4,103,000

Operating Costs

Electrical Power (@ $0.052/kwh)	$26,000
Maintenance	
Labor (@ $35/hr)	13,500
Equipment repair & replacement	13,000
Operation	
Operation & daily inspections	45,700
Well sampling & lab analysis	15,000
Engineering support	36,000
Total Annual Operating Cost	$149,200

ESCALATE to 96

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental
Technology & Services

245 Summer Street
Boston, MA 02210
Contact: Bruno Brodfeld (617) 589-2767

Assistance was provided by the
WESTINGHOUSE SAVANNAH RIVER COMPANY
which supplied key information and reviewed report drafts.

for:

HAZWRAP

HAZARDOUS WASTE REMEDIAL ACTIONS PROGRAM
Environmental Restoration and Waste Management Programs
Oak Ridge, Tennessee 37831-7606
managed by
MARTIN MARIETTA ENERGY SYSTEMS
for the
U.S. Department of Energy
under Contract DE-AC05-84OR-21400

This analysis was funded by:

U.S. Air Force
Headquarters USAF/CEVR

CERTIFICATION

This analysis accurately reflects the performance and costs of the remediation:

x	x G. E. Turner
C.L. Bergren	G.E. Turner
Westinghouse Savannah River Company	Department of Energy
Environmental Restoration Department	*Savannah River Operations Office*
Manager Northern Ground Water Facilities	Environmental Restoration Division
	Environmental Specialist

07/24/96 WED 09:51 FAX 8038444916 SWER DIVISION ☑002

1/24/96 WED 09:14 FAX 8036444519 CENTRE SOUTH ☑002

EXHIBIT VI

SR 22-265-W
CT

Westinghouse Savannah River Company
Closing Statement

January 31, 1996

Project Number	SR Number	Accrual Reserve Account	B & R Code	Supplementary Data	WBS Number	Fixed Asset Voucher Number
CS9-4817	4817	YES	EW2010202	EQU99ZZ	011201	952374

Project Title A/M AREA VADOSE ZONE REMEDIATION COST FUNDED

Building Number 730-2B

Original Appropriation $4,637,000.00

Appropriation Changes -$826,766.04

Expended Amount $3,810,233.96

Additional Information	Amount	Reference Number
CENTS ELIMINATION	$0.96	COST FUNDED

FIS Code	FIS Description	Amount
755	SHOP EQUIPMENT	$3,768,465.00
720	LABORATORY EQUIPMENT	$41,768.0(
	Total	$3,810,233

his is to advise that final costs for the work included in the above authorization have been recorded and the project has been nancially closed.

EXHIBIT VII

DATA FOR ESTIMATING COST SAVINGS OF VERTICAL RECIRCULATION WELLS

(Provided by Roger White, 7/16/96)

1.	Install 12(8" dia) wells: 12x170' = 2040 linear feet estimate $17,000 per well	$204,000
2.	Air Compressor, 30hp 12x$25,000 ea	$300,000
3.	Equipment enclosures: 12x$10,000	$120,000
4.	Vacuum System, 10hp 12x$10,000	$120,000
5.	Electrical Utilities: Run 13.8 etc.	$300,000
6.	Finishing Materials for Wells 12x$4000	$48,000
7.	Well Packers 12x$8000	$96,000
8.	PVC Casing & Screens 12x$5000	$60,000
9.	Monitoring Wells, 8: 8x$1200	$96,000
10.	Characterization 12x$4000	$48,000
11.	Installation for above ground components:	$50,000
12.	O&M Cost: Energy...assume 20hp continuous Inspection: 2 hrs per day Maintenance: $10,000 per year ER Exempt Labor: 1/4 FTE	
13.	Productivity of wells: 0.0217 lbs solvent per hour per well [This to be documented in formal calculation by SRTC] Estimated solvent concentration in Southern Sector groundwater is 500 parts per billion.	
14.	License fees to EG&G for use of patents	$128,000
15.	M-1 Stripper Feedstream: (per Michael Hartz) Solvent concentration (1995 annual average): TCE 4.1ppm PCE 2.9ppm Total 7.0ppm	

EXHIBIT VIII
(Misc. Notes)

147,755

M-1 AIR STRIPPER (1706)

OPERATIONS

FY96

CAPITAL COST

TOTAL CAP. COST	$4,103,000
OFF GAS SYS	449,000
S/T	$4552,000
PER YR COST	$151,733
ESCALATE '90-'96	

	FY XX-(AVG. 96-99)	622,506	RMET
50%	ER LABOR EXEMPT	307,655	EXEMPT
50%	" " NON-EXMP	12,295	NON EXEMPT
	SUBTOTAL	942,456	
	ELECT, EQ & MTL	26,000	
$154K	PROCESS MODS	968,456	
$295K	M-1 OFFGAS TREAT. SYS		
449			

VADOSE ZONE (1704) - ESCALATE CAPITAL 95 to 96

CAPITAL COST - ?	$3,810,000 +
PER YR COST @ 15 YRS	$254,000 / YR
OPERATIONS -	
VADOSE ZONE - RMET-F	501,000
ER LABOR - EXEMPT	391,000
ER LABOR - NON EXEMPT	46,000
SUBTOTAL OPERATIONS	938,000
ELECT, MAT'L & EQ	26,000
	964,000

SOUTHERN SECTOR (1703) - IN WELL VAPOR STRIPPING
12 WELLS

DESIGN	100,000
WELL INSTALL & EQUIP & PWR	1,453,000
SITEWORK PDS	150,000
MISC - PERMITS, CONSTR SITE QA	170,000
	1,873,000 ÷ 30 YR = $62,400

O & M

PWR	12,000
INSP & MAINT	47,000
ER LABOR 500 MHR	41,000
	100,000

Fri 26 Jan 1996

U.S. Department of Energy
PROJECT 16706T: A-1/H-1 AIR STRIPPER GW - ADS 516, REVISION FY96.02
A-1/H-1 AIR STRIPPER GROUNDWATER
** PROJECT DIRECT SUMMARY - LEVEL 3 **

TIME 15:14:06
SUMMARY PAGE 7

		QUANTITY UOM	LABOR	EQUIPMNT	MAT/SUPP	UNIT CST	TOTAL COST	UNIT COST
A	GROUNDWATER ASSESSMENT							
A.08	ADDITIONAL STUDIES							
A.08.02	A-1 SYS. CYCLING DEMO S/C FY97	67.00 HR	5,377	0	0	0	5,377	80.25
A.08.04	A-1 SYS. CYCLING DEMO SRTC FY97	150.00 HR	12,038	0	0	0	12,038	80.25
A.08.06	DEVELOP PROCEDURE - S/C FY97	67.00 HR	5,377	0	0	0	5,377	80.25
	ADDITIONAL STUDIES		22,791	0	0	0	22,791	
A.09	REGULATORY REQUIREMENTS							
A.09.02	INTGRD AIR PERM MOD SC FY99		0	0	0	21,400	21,400	
A.09.03	INTRGD AIR PERM MOD SC FY00-22		0	0	0	470,800	470,800	
A.09.04	A-1A OUTFALL NPDES RENWL SC FY99		0	0	0	32,100	32,100	
A.09.05	A-1A OUTFL NPDES RNWL SC FY00-22		0	0	0	706,200	706,200	
A.09.06	A-1 AIR PERMIT RENEWL SC FY99		0	0	0	21,400	21,400	
A.09.07	A-1 AIR PERMIT RENEWL SC FY00-22		0	0	0	470,800	470,800	
A.09.08	M-1 AIR PERMIT RENEWL SC FY97		0	0	0	32,100	32,100	
A.09.16	M-1 AIR PERMIT RENEWL SC FY99		0	0	0	21,400	21,400	
A.09.18	M-1 AIR PERMIT RENEWL SC FY00-22		0	0	0	470,800	470,800	
A.09.21	VADOSE ZONE RENEWAL FY99		0	0	0	64,200	64,200	
A.09.22	VADOSE ZONE RENEWAL FY00-22		0	0	0	256,800	256,800	
	REGULATORY REQUIREMENTS		0	0	0	2,568,000	2,568,000	
A.95	AOP - FISCAL YEAR 1995							
A.95.01	AOP - FISCAL YEAR 1995		635,688	0	0	1,439,150	2,074,838	
	AOP - FISCAL YEAR 1995		635,688	0	0	1,439,150	2,074,838	
	GROUNDWATER ASSESSMENT		658,479	0	0	4,007,150	4,665,629	
O	GROUNDWATER OPERATIONS							
O.14	OPERATIONS							
O.14.02	M-1 STRIPPER - RMET FY96		47,000	0	42,800	559,931	649,731	
O.14.04	M-1 STRIPPER - RMET FY97		0	0	0	565,281	565,281	AVG: 622,506
O.14.06	M-1 STRIPPER - RMET FY98		0	0	0	629,481	629,481	
O.14.08	M-1 STRIPPER - RMET FY99		0	0	0	645,531	645,531	
O.14.10	M-1 STRIPPER - RMET FY00 - 22	23.00 YR	0	0	0	15,413,243	15,413,243	670141.00
O.14.14	A-1 STRIPPER -RMET FY96		23,000	0	21,400	418,370	462,770	
O.14.16	A-1 STRIPPER -RMET FY97		0	0	0	365,405	365,405	
O.14.18	A-1 STRIPPER -RMET FY98		0	0	0	409,275	409,275	
O.14.20	A-1 STRIPPER -RMET FY99		0	0	0	419,975	419,975	

Fri 26 Jan 1996

U.S. Department of Energy
PROJECT 16706T: A-1/H-1 AIR STRIPPER GW - ADS 516, REVISION FY96.02
A-1/H-1 AIR STRIPPER GROUNDWATER
** PROJECT DIRECT SUMMARY - LEVEL 3 **

TIME 15:14:06
SUMMARY PAGE 8

		QUANTITY UOM	LABOR	EQUIPMNT	MAT/SUPP	UNIT CST	TOTAL COST	UNIT COST
0.14.22	A-1 STRIPPER -RMET FY00-22	23.00 YR	0	0	0	10,028,575	11,686,000 10,028,575	436025.00
0.14.24	LABOR FY96		880,134	0	0	0	880,134	
0.14.26	ER LABOR EXEMPT FY97	7461.00 HR	615,309	0	0	0	615,309	82.47
0.14.28	ER LABOR EXEMPT FY98	7461.00 HR	615,309	0	0	0	615,309	82.47
0.14.30	ER LABOR EXEMPT FY99	7461.00 HR	615,309	0	0	0	615,309	82.47
0.14.32	ER LABOR EXEMPT FY00 - 22	171603.00 HR	14,152,099	0	0	0	14,152,099	82.47
0.14.34	ER LABOR NONEXEMPT FY96	487.00 HR	24,589	0	0	0	24,589	50.49
0.14.36	ER LABOR NONEXEMPT FY98	487.00 HR	24,589	0	0	0	24,589	50.49
0.14.38	ER LABOR NONEXEMPT FY99	487.00 HR	24,589	0	0	0	24,589	50.49
0.14.40	ER LABOR NONEXEMPT FY00-22	11201.00 HR	565,538	0	0	0	565,538	50.49
0.14.51	PROCESS MODIFICATIONS		153,849	0	0	0	153,849	
0.14.55	H-1 OFF-GAS TREATMENT SYSTEM		144,907	5,350	75,669	69,336	295,262	
	OPERATIONS		17,886,219	5,350	139,869	29,524,403	47,555,841	
	GROUNDWATER OPERATIONS		17,886,219	5,350	139,869	29,524,403	47,555,841	
	A-1/H-1 AIR STRIPPER GW		18,544,698	5,350	139,869	33,531,553	52,221,470	

Fri 26 Jan 1996

U.S. Department of Energy
PROJECT 167040: VADOSE ZONE GW OPERATIONS - ADS 516, REVISION FY96.02
VADOSE ZONE GROUNDWATER
** PROJECT OWNER SUMMARY - LEVEL 3 **

TIME 15:13:35
SUMMARY PAGE 3

		QUANTITY UOM	CONTRACT COST	RZ/HZ	CAS	CN	PM/PC	TOTAL COST	UNIT COST
C	GROUNDWATER CLOSURE								
C.95	AOP - FISCAL YEAR 1995								
C.95.01	AOP - FISCAL YEAR 1995		119,908	0	0	0	0	119,908	
	AOP - FISCAL YEAR 1995		119,908	0	0	0	0	119,908	
	GROUNDWATER CLOSURE		119,908	0	0	0	0	119,908	
O	GROUNDWATER OPERATIONS								
O.14	OPERATIONS								
O.14.02	VADOSE ZONE (M-AREA) - RMET F		459,512	0	0	0	0	459,512	
O.14.04	VADOSE ZONE (M AREA) - RMET F		475,562	0	0	0	0	475,562	
O.14.06	VADOSE ZONE (M AREA) - RMET F		527,992	0	0	0	0	527,992	
O.14.08	VADOSE ZONE (M AREA) - RMET F		540,832	0	0	0	0	540,832	
O.14.20	VADOSE ZONE (M-AREA)RMET FY00	23.00 YR	12,906,715	0	0	0	0	12,906,715	561161.50
O.14.22	ER LABOR EXEMPT FY96	4740.00 HR	390,908	0	0	0	0	390,908	82.47
O.14.24	ER LABOR EXEMPT FY97	4740.00 HR	390,908	0	0	0	0	390,908	82.47
O.14.26	ER LABOR EXEMPT FY98	4740.00 HR	390,908	0	0	0	0	390,908	82.47
O.14.28	ER LABOR EXEMPT FY99	4740.00 HR	390,908	0	0	0	0	390,908	82.47
O.14.30	ER LABOR EXEMPT FY00 - 22	109020.00 HR	8,990,879	0	0	0	0	8,990,879	82.47
O.14.32	ER LABOR NONEXEMPT FY96	910.00 HR	45,946	0	0	0	0	45,946	50.49
O.14.34	ER LABOR NONEXEMPT FY97	910.00 HR	45,946	0	0	0	0	45,946	50.49
O.14.36	ER LABOR NONEXEMPT FY98	910.00 HR	45,946	0	0	0	0	45,946	50.49
O.14.38	ER LABOR NONEXEMPT FY99	910.00 HR	45,946	0	0	0	0	45,946	50.49
O.14.40	ER LABOR NONEXEMPT FY00 - 22	20930.00 HR	1,056,756	0	0	0	0	1,056,756	50.49
	OPERATIONS		26,705,660	0	0	0	0	26,705,660	
	GROUNDWATER OPERATIONS		26,705,660	0	0	0	0	26,705,660	
	VADOSE ZONE GW OPERATIONS		26,825,568	0	0	0	0	26,825,568	

Avg. 500,975

APPENDIX D

UNIT COST CALCULATION FOR IN SITU OXIDATION TECHNOLOGY

Equation for Calculating Unit Cost for In Situ Oxidation Technology

Unit Cost = (Mobilization/Setup + Pre-test Characterization + Treatment System Operation + Peroxide + Demobilization + Document Preparation + Post-test Characterization + Project Management)/Pound of DNAPL

Unit Cost = [mobilization and setup + (pre-test drilling + pre-test analysis + pre-test oversight) + (operation oversight + operation) + peroxide + demobilization + document preparation + (post-test drilling + post-test analysis + post-test oversight)]/pound of DNAPL

Total Cost = \$60,000 + ((\$70 per ft pre-test* ft pre-test) + (\$15 per ft pre-test* ft pre-test) + (\$2,800 per day pre-test * days of drilling pre-test)) + ((\$2,500 per day * days operation) + (\$15,000 per day * days operation)) + (\$21 per pound DNAPL * pounds DNAPL) + \$10,000 + \$40,000 + ((\$47 per ft post-test * ft post-test) + (\$15 per ft post-test* ft post-test) + (\$2,800 per day post-test * days of drilling post-test)) + 0.05* Total Cost

Total Cost = [(\$60,000 + \$10,000 + \$40,000) + ((\$70 per ft pre-test + \$15 per ft pre-test)* 0.73 * total footage drilled) + (\$2,800 per day * (days of pre-test drilling + days of post-test drilling)) + (\$17,500 per day * days operation) + (\$21 per pound DNAPL * pounds DNAPL) + ((\$47 per ft post-test + \$15 per ft post-test) * 0.27 * total footage drilled)]/0.95

Total Cost = [\$110,000 +(((\$85 * 0.73) + (\$62 * 0.27)) * total footage drilled) + (\$2,800 * total days drilling) + (\$17,500 * days operation) + (\$21 per pound DNAPL * pounds DNAPL)]/0.95

Total Cost = [\$110,000 + (\$78.8 * total footage drilled) + (\$2,800 * total days drilling) + (\$17,500 * days operation) + (\$21 per pound DNAPL * pounds DNAPL)/0.95

Unit Cost = Total Cost/pound of DNAPL

Calculation of Unit Cost based on a \$/ft^3 of soil treated.

This was calculated based on the amount of DNAPL required at depth X where an approximate cost of \$87/pound of DNAPL treated was determined (See Table 10.3).

The volume of soil to be treated is 64,000 pounds (based on size of demonstration site)

For example: at 60 ft depth, 6,750 pounds of DNAPL is needed to yield a \$84/pound of DNAPL treated cost.

Unit Cost (\$/ft^3) = Unit Cost (\$/pound DNAPL) * pounds of DNAPL/Volume of soil treated

Unit Cost (\$/ft^3) = \$84/pound DNAPL * 6750 pounds DNAPL/64,000 ft^3 of soil

Unit Cost (\$/ft^3) = \$8.84/ft^3