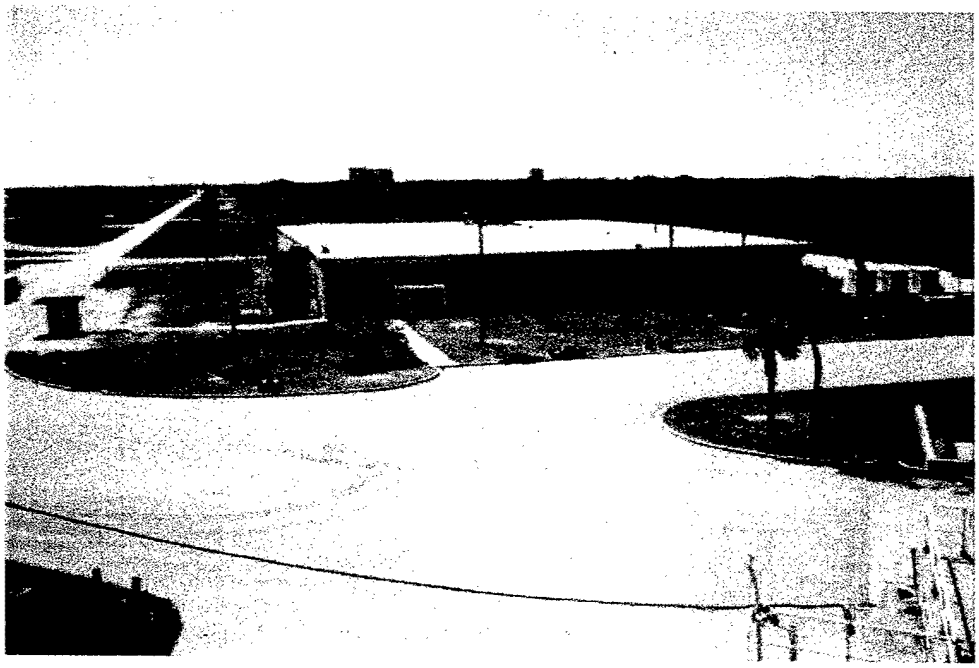
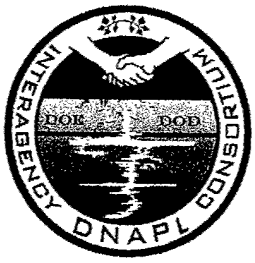
Demonstration of ISCO Treatment of a DNAPL Source Zone at Launch Complex 34 in Cape Canaveral Air Station

Final Innovative Technology Evaluation Report



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Dense, Nonaqueous-Phase Liquid (DNAPL) Source Zone at Launch Complex 34 in Cape Canaveral Air Force Station

Demonstration of ISCO Treatment

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Dense, nonaqueous-phase liquid contaminants are a challenge to characterize and remediate at many sites where such contaminants have entered the aquifer due to past use of disposal practices. Chlorinated solvents are common DNPL contaminates at sites where operations, such as aircraft maintenance, dry cleaning, and metal finishing have historically occurred. In the past, because of the difficulty in identifying the DNAPL source zone, most remediation efforts focused on controlling the migration of the dissolved chlorinated volatile organic compounds plume. Recently, many sites owners have had success in locating DNAPL sources. DNAPL source remediation is beneficial because once the source has been significantly mitigated; the strength and duration of the resulting plume can potentially be lowered. The goal of the project is to evaluate the technical and cost performance of chemical oxidation technology for remediation of DNAPL source zones. This innovative technology is based on the ability of strong oxidants to react with and destroy several types of DNAPL contaminants. Treatment of chlorinated volatile organic compounds with oxidants has been used historically for drinking water and wastewater treatment, but the in situ use of these oxidants for DNAPL source treatment is relatively new. The chemical oxidation demonstration is part of a larger demonstration of three different DNAPL remediation technologies being conducted.

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Executive Summary

Dense, nonaqueous-phase liquid (DNAPL) contaminants are a challenge to characterize and remediate at many sites where such contaminants have entered the subsurface due to past use or disposal practices. Chlorinated solvents, comprised of chlorinated volatile organic compounds (CVOCs), such as trichloroethylene (TCE) and perchloroethylene (PCE), are common DNAPL contaminants at sites where operations, such as aircraft maintenance, dry cleaning, metal finishing, and electronics manufacturing have historically occurred. In the past, because of the difficulty in identifying the DNAPL source zone, most remediation efforts focused on controlling the migration of the dissolved CVOC plume. In recent years, many site owners have had success in locating DNAPL sources. DNAPL source remediation may be beneficial because once the source has been significantly mitigated, the strength and duration of the resulting plume can potentially be lowered in the long term, and sometimes in the short term as well.

The Interagency DNAPL Consortium

The Interagency DNAPL Consortium (IDC) was formally established in 1999 by the U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (U.S. EPA), Department of Defense (DoD), and National Aeronautics and Space Administration as a vehicle for marshalling the resources required to test innovative technologies that promise technical and economic advantages in DNAPL remediation. The IDC is advised by a Technical Advisory Group comprised of experts drawn from academia, industry, and government. The IDC and other supporting organizations facilitate technology transfer to site owners/managers though dissemination of the demonstration plans and results, presentations at public forums, a website, and visitor days at the site.

Demonstration Site and Technology

In 1998, after preliminary site characterization conducted by Westinghouse Savannah River Company indicated the presence of a sizable DNAPL source at Launch Complex 34 in Cape Canaveral, Florida, the IDC selected this site for demonstrating three DNAPL remediation technologies. The surficial aquifer at this site lies approximately between 5 to 45 ft bgs. This aquifer can be subdivided into three stratigraphic units — the Upper Sand Unit, the Middle Fine-Grained Unit, and the Lower Sand Unit. Although the Middle Fine-Grained Unit is a conspicuous hydraulic barrier, a Lower Clay Unit underlying the surficial aquifer is considered to be the aquitard that prevents downward migration of the DNAPL source. The Lower Clay Unit appears to be pervasive throughout the demonstration area, although it is only 1.5 to 3 ft thick. The hydraulic gradient in the surficial aquifer is relatively flat. The native aquifer is anaerobic and neutral in pH. Also the aquifer contains relatively high levels of chloride and total dissolved solids (TDS).

The source zone was divided into three test plots, 75 ft × 50 ft each in size, for testing three technologies — in situ chemical oxidation (ISCO), resistive heating, and steam injection. About 15 ft of each plot was under the Engineering Support Building. ISCO and resistive heating were tested concurrently between September 1999 and April/June 2000 in the two outer plots, separated by about 80 ft. Steam injection was subsequently tested in the middle plot, beginning June 2001. The IDC contracted MSE Technology Applications, Inc., to conduct vendor selection and subcontracting for the three technology demonstrations, and to track costs for each demonstration. IT Corporation was the vendor selected for implementing ISCO (using potassium permanganate) at Launch Complex 34. Potassium permanganate was selected due to the fact that the oxidation reaction with permanganate is relatively pH insensitive and proceeds acceptably under alkaline conditions. The reaction is not subject to inhibition by free-radical scavengers like carbonates, both of which (i.e., high pH and radical scavengers) are a challenge for other oxidants, such as Fenton's reagent. In addition, it is a strong oxidant, relatively easy to handle, commonly available and inexpensive, does not generate strong exothermic reactions in the aquifer, and persists long enough in the environment to enable efficient distribution in the aquifer.

Performance Assessment

The IDC contracted Battelle in 1998 to plan and conduct the technical and economic performance assessment of the three technologies. The EPA Superfund Innovative Technology Evaluation (SITE) Program and its contractor TetraTech EM, Inc., provided Quality Assurance (QA) oversight and field support for the performance assessment. Before the ISCO field application, Battelle prepared a Quality Assurance Project Plan (QAPP) or test plan that was reviewed by all the project stakeholders. This report describes the results of the performance assessment of the ISCO technology. The objectives of the performance assessment were to:

- Estimate the TCE/DNAPL mass removal
- Evaluate changes in aquifer quality
- Evaluate the fate of the TCE/DNAPL removed from the ISCO plot
- Verify ISCO operating requirements and costs.

Estimating the TCE/DNAPL mass removal due to the ISCO application was the primary objective of the demonstration in terms of resources expended for planning, data gathering, and interpretation; the other three were secondary, but important, objectives.

In February 1999, Battelle conducted the preliminary characterization of the DNAPL source region on the north side of the Engineering Support Building. This characterization provided preliminary DNAPL mass estimates and aquifer data to support the vendor's design of the technology application. It also provided data on the spatial variability of the TCE/DNAPL that supported the design of a more detailed characterization of each test plot before the demonstration. In June 1999, a detailed predemonstration characterization of the ISCO plot was conducted to initiate the performance assessment of the ISCO technology. From September 1999 to April 2000, when the ISCO field application was conducted, Battelle collected subsurface data to monitor the progress of the demonstration; the vendor collected additional data to aid in the operation of the technology. In May 2000, the postdemonstration assessment of the ISCO plot was conducted, followed by an extended monitoring event in February 2001.

TCE/DNAPL Mass Removal

Detailed soil sampling was used as the main tool for determining TCE/DNAPL mass removal. The spatial distribution data from the preliminary characterization were used

to determine a statistically significant number and location of soil samples required to obtain good coverage of the ISCO plot. A systematic unaligned sampling scheme was used to conduct pre- and postdemonstration soil coring at 12 locations in a 4 × 3 grid in the test plot. Continuous soil samples were collected at every 2-ft vertical interval in each core, resulting in nearly 300 soil samples in the ISCO plot during each event. A vertical section (approximately 200 g of wet soil) from each 2-ft interval was collected and extracted with methanol in the field; the methanol extract was sent to an off-site laboratory for analysis. In this manner, the entire soil column was analyzed from ground surface to aquitard, at each coring location. Evaluation of this extraction method with Launch Complex 34 soil showed between 84 and 113% recovery (92% average) of the spiked surrogate compound (trichloroethane).

The TCE concentrations (mg/kg of dry soil) obtained by this method were considered "total TCE." Total TCE includes TCE in the dissolved and adsorbed phases, as well as in the free phase (DNAPL). The portion of the total TCE that exceeded a threshold concentration of 300 mg/kg was considered "DNAPL." This threshold was calculated based on properties of the TCE and the subsurface media at Launch Complex 34, and is determined as the maximum TCE concentration in the dissolved and adsorbed phases; any TCE concentration exceeding this threshold would be DNAPL.

The results of the TCE/DNAPL mass removal evaluation by soil sampling show the following:

- Linear interpolation of TCE concentrations between sampled points indicated that there was 6,122 kg of total TCE in the ISCO plot before the demonstration; approximately 5,039 kg of this TCE mass was DNAPL. Approximately 77% of the total TCE mass and 76% of the DNAPL mass was removed from the plot due to the ISCO application. This predicted removal is less than the 90% DNAPL removal target proposed at the beginning of the demonstration, but is still a significant achievement for the technology.
- A statistical evaluation of the pre- and postdemonstration TCE concentrations confirmed these results. Kriging, a geostatistical tool that takes the spatial variability of the TCE distribution into account, indicated that between 6,217 and 9,182 kg of total TCE was present in the test plot before the demonstration. Kriging of the pre- and postdemonstration TCE data indicated that between 62 and 84% of the total TCE was removed from the test plot by the technology application. When the predemonstration and extended monitoring event TCE mass estimates were compared, kriging indicated that between 49 and 68% of the TCE was removed from the plot. The extended monitoring event was conducted nine months after the end of the oxidant injections. The slightly lower removal estimates during the extended monitoring event are due to an isolated DNAPL pocket found on the north end of the test plot. These statistics are significant at the 80% confidence level specified before the demonstration. In summary, it can be said that at least half the initial TCE mass in the test plot was removed by the ISCO treatment.
- The highest TCE/DNAPL mass removal was obtained in the Upper Sand Unit, followed by the Lower Sand Unit. The Middle Fine-Grained Unit showed the least removal. This shows that the oxidant distribution was most effective in the coarser soils. The level of TCE/DNAPL removal was not as high under the building as outside it, indicating that these regions could not be efficiently accessed from outside the building. The general radius of influence of the potassium permanganate appeared to be less than 15 ft around the injection points, although preferential flowpaths sometimes transported the oxidant to more distant locations.

Changes in Aquifer Quality

Application of the ISCO technology caused the following short-term changes in the treated aquifer:

- Dissolved TCE levels declined sharply in several monitoring wells in the ISCO plot, with some wells showing postdemonstration concentrations of less than 5 µg/L, the federal drinking water standard. Achievement of the State of Florida groundwater target cleanup level of 3 µg/L could not be determined because excessive permanganate in several of the postdemonstration groundwater samples caused analytical interference and required dilution. In some wells within the ISCO plot, TCE levels declined, but stayed above 5 µg/L. In one of the shallow wells, TCE levels rose through the demonstration, indicating that local heterogeneities (limited oxidant distribution) or redistribution of groundwater flow due to partial DNAPL removal may have affected dissolved TCE levels. *cis*-1,2-DCE levels in all monitoring wells declined to below 70 µg/L. Vinyl chloride levels in some wells declined to less than 1 µg/L, the State of Florida target; in some wells, higher TCE levels elevated the detection limits of vinyl chloride. This indicated that ISCO considerably improved groundwater quality in the short term. There are some signs of a rebound in TCE and *cis*-1,2-DCE concentrations in the test plot during the extended monitoring that was conducted nine months after the end of the injections. Although TCE and *cis*-1,2-DCE levels rebounded to some extent in the nine months following the demonstration, they were still considerably below the predemonstration levels in most wells. In any case, DNAPL mass removal is expected to lead to eventual and earlier disappearance of the plume over the long term. There is also the possibility that even in the medium term, as normal groundwater flow is reestablished, a weakened plume may be generated and the resulting CVOC levels may be amenable to natural attenuation.
- Groundwater pH and dissolved oxygen levels remained stable, but oxidation-reduction potential (ORP), chloride, alkalinity, and TDS levels rose following the demonstration. TDS levels were above the secondary drinking water standard of 500 mg/L both before and after the demonstration, classifying the aquifer as brackish. Dissolved manganese levels rose above the 50 µg/L secondary drinking water standard; the dissolved manganese is expected to be mostly Mn^{7+}, while there still is excess permanganate in the plot. More manganese dioxide solids and Mn^{2+}, a reduced form of dissolved manganese, may be generated as the oxidant is depleted and the aquifer reverts to reducing conditions. The reduced manganese can cause discoloration of water when it exceeds 50 µg/L. Downgradient concentrations of manganese may have to be monitored over the next few years. However, manganese levels dropped considerably with distance from the test plot.
- Biological oxidation demand and total organic carbon (TOC) levels in the groundwater generally increased. TOC in soil remained relatively constant through the demonstration. These parameters were expected to decrease following oxidation. Dissolved iron levels remained relatively constant, and sulfate levels increased. The anomalous behavior of these parameters indicates that the oxidant-contaminant-aquifer reactions are complex and may result in a wider variety of byproducts.
- The postdemonstration groundwater levels of three trace metals—chromium, nickel, and thallium—showed a short-term increase above State of Florida standards. These metals are present in the aquifer at levels that are too high to be explained solely by their presence in the industrial-grade permanganate injected. Possible sources for some of these metals could be the native aquifer solids or the stainless steel monitoring wells in the plot; although stainless steel

is relatively resistant to oxidation, high levels of oxidant and chloride could have caused corrosion. Nine months after the end of the oxidant injections, the levels of these metals in the test plot were still elevated. The elevated levels of these trace metals are expected to subside over time, as flow is re-established. The levels of these metals decline significantly as the water reaches the monitoring wells surrounding the plot, probably due to adsorption on the aquifer solids and on the newly generated manganese dioxide.

- Slug tests conducted in the ISCO plot before and after the demonstration did not indicate any noticeable changes in the hydraulic conductivity of the aquifer; any manganese dioxide accumulation in the aquifer did not appear to have affected its hydraulic properties. Also, it is possible that the porosity loss due to formation of manganese dioxide solids is offset by the dissolution of native calcium carbonate solids in the aquifer.

Fate of TCE/DNAPL Removed

The TCE/DNAPL removed from the plot could have taken several pathways, including destruction by oxidation, migration to surrounding aquifer, or migration to vadose zone/atmosphere.

- The sharp rise in chloride levels in all three stratigraphic units is the strongest indicator that destruction by oxidation contributed significantly to TCE/DNAPL mass removal in the plot. The rise in chloride levels was conspicuous, despite the relatively high level of native chloride in the groundwater and despite dilution from the hydrant water used to make up the permanganate solution.
- The large increase in aquifer alkalinity, a sign of carbon dioxide generation, is a strong indicator of oxidation in the aquifer, although not of TCE alone. Native organic matter may also account for some of the oxidant consumption and carbon dioxide generation. One research need for this technology is determining the possible generation and potential toxicity of any organic byproducts of incomplete oxidation of TCE and native organic matter.
- Some DNAPL movement occurred in the saturated zone after the start of the ISCO and resistive heating demonstrations. However, because the DNAPL appeared in monitoring wells between the two test plots, it is difficult to attribute the cause of the DNAPL movement to one of the two technologies. If the strong hydraulic gradient created by the oxidant injection caused DNAPL to migrate, the DNAPL would have to have been present in mobile, and not residual, form. A limited number of additional soil cores collected around the ISCO plot did not show any signs of DNAPL accumulation. Monitoring of the vadose zone soil and surface atmosphere did not indicate any TCE/DNAPL migration in the upward direction, as could have happened had exothermic reactions taken place in the aquifer. Monitoring was conducted below the Lower Clay Unit only after the demonstration because of NASA's initial concerns over breaching the aquitard. The three semi-confined aquifer wells were installed after the demonstration. The one well below the aquitard in the ISCO plot did not show soil or groundwater TCE levels reflective of DNAPL. None of the data indicate that downward migration of DNAPL was a significant pathway for the TCE in the test plot.
- Surface emission tests before, during, and after the demonstration did not show any elevated levels of TCE emanating from the ISCO plot. Unlike other strong oxidants, permanganate does not generate exothermic reactions that could cause VOCs to vaporize and escape to the vadose zone and atmosphere. The

top portion of the soil cores in the vadose zone did not show any elevated TCE concentrations either.

Verifying Operating Requirements

The vendor injected a total of 842,985 gal of permanganate solution (or 66,956 kg of solid potassium permanganate) in three injection cycles over an 8-month period. In the first injection cycle, the vendor injected the oxidant (1 to 2% solution of industrial-grade potassium permanganate from Carus® Chemical Company, Inc.) through 11 more-or-less equally spaced locations. At each location, the vendor advanced a specially designed injection tip in 2-ft intervals, using a Geoprobe®. The amount of permanganate injected at each location and depth was based on prior knowledge of the TCE/DNAPL distribution from the site characterization.

The injection pressure, flowrate, and period of injection were used to control the radius of influence of the permanganate around the injection point. The vendor estimates that 10 to 12 ft or less radius of influence was achieved at some injection points. However, local heterogeneities, DNAPL content, and native organic matter content limited oxidant distribution at some points, as indicated by the varying injection flowrates achieved. For example, whereas one injection point would permit 2 to 3 gpm of flow, another point only one horizontal foot away would permit less than 0.1 gpm of flow. Both groundwater and soil samples indicated (visually and analytically) that oxidant distribution varied in different parts of the plot. The portion of the aquifer underneath the building also appeared to have received insufficient oxidant; the plot extended 15 ft inside the building, whereas all injections were conducted outside.

Both the vendor and Battelle conducted additional monitoring in the periods between each injection cycle. During the second and third injection cycles, the vendor focused on only those portions of the plot that the interim monitoring showed had not received sufficient oxidant during the previous cycle.

Use of heavy equipment and handling of a strong oxidant were the primary hazards during the operation. The operators donned Level D protection at most times, except when a respirator had to be worn in order for the operator to protect against spray and dust generated while handling the dry potassium permanganate oxidant. A solution consisting of vinegar and hydrogen peroxide was kept on site to neutralize any exposure to potassium permanganate solution due to spills or hose leaks. The permanganate delivery system was automated so that it would shut off if any excessive pressure (clogging) or loss of pressure (leaks) was experienced in the system.

Economics

The vendor incurred a total cost of approximately $1 million for the field application of ISCO process. This includes the design, procurement, mobilization/demobilization, oxidant injection, and process monitoring. The vendor estimated that approximately 15% of this cost was incurred due to the fact that this was a technology demonstration, not a full-scale clean-up treatment. In addition, NASA incurred site preparation costs of $2,800. No aboveground wastes were generated from the injections. Waste disposal costs were minimal and were limited to nonhazardous solid waste disposal of materials generated during mobilization and operation.

A comparison of the cost of ISCO treatment of the DNAPL source the size of the ISCO plot and an equivalent (2 gpm) pump-and-treat system for plume control over the next 30 years was conducted to evaluate the long-term economic impact of the

technology. The ISCO application cost was found to be less than the present value (PV) of a 30-year pump-and-treat application. This comparison assumes that natural attenuation would be sufficient to address any residual source. Also, in the absence of source treatment, the plume emanating from this relatively large DNAPL source may be expected to last much more than 30 years. ISCO and natural attenuation require none of the aboveground structures, recurring operational costs, and maintenance that pump-and-treat systems require. Anecdotal evidence indicates that, at many sites, pump-and-treat systems are operational only about 50% of the time. The impact of this downtime and the associated maintenance costs should also be considered. In general, the economics favor DNAPL source treatment, and ISCO (non-extraction mode) in particular, over a pump-and-treat system at this site.

Site characterization costs were not included in the cost comparison because a good design of a source treatment or plume control remedial action is assumed to require approximately the same degree of characterization. The site characterization conducted by Battelle in February 1999 is typical of the characterization effort that may be required for delineating a 75-ft × 50-ft × 45-ft DNAPL source; the cost of this effort was $255,000, which included a work plan, 12 continuous soil cores to 45 ft bgs, installation of 36 monitoring wells, field sampling, laboratory analysis of samples, field parameter measurements, hydraulic testing, and data analysis and report.

Summary of Conclusions and Recommendations

As described above, the following conclusions were drawn from the ISCO demonstration:

- At least half (49% to 84%) of the initial total TCE mass and possibly 76% of the DNAPL mass in the source zone were removed by ISCO.
- Much of this removal can be attributed to destruction of TCE by oxidation, as indicated by the chloride buildup in the plot. The sharp increase in carbon dioxide and, consequently, alkalinity levels in the groundwater, is another sign of considerable oxidation of TCE and natural organic matter occurring in the aquifer.
- Dissolved TCE levels declined considerably in most parts of the test plot in the short term, immediately following the demonstration. The federal drinking water standard for TCE (5 µg/L) was met in several monitoring wells during postdemonstration monitoring. Achievement of the lower State of Florida standard (3 µg/L) could not be determined due to analytical interference from the permanganate. Postdemonstration sampling indicated that *cis*-1,2-DCE and vinyl chloride levels in the many parts of the plot declined considerably as well. Some rebound in concentrations is evident in the extended monitoring event conducted nine months after the demonstration, after some re-equilibration occurred between the remaining DNAPL and dissolved TCE concentrations. However, the rebounded levels of these contaminants were still considerably below the predemonstration levels.
- It is possible to achieve a relatively good distribution of permanganate oxidant in sandy soils. Distribution of oxidant is more difficult in finer-grained soils. A radius of influence of 10 to 12 ft around the injection point was achieved at several locations. However, at some locations, resistance to oxidant flow was considerable, and the radius of influence was much smaller. Local geologic heterogeneities and native organic matter content of the aquifer may limit oxidant distribution in some regions. These factors may have also limited the reach of the oxidant under the building, from the injection points located outside.

- Elevated levels of some trace metals, such as chromium, nickel, and thallium, may occur in the short term. The source of these trace metals is partly the industrial-grade permanganate used and partly the native aquifer solids or stainless steel monitoring wells. Levels of dissolved manganese, a species subject to secondary drinking water standards, may be elevated in the short term as well. The concentrations of the trace metals and other dissolved species were found to mitigate quickly with distance from the treatment area. Elevated levels of even potassium ion, a relatively conservative species, subsided by the time the groundwater moved about 80 to 100 ft from the plot. This indicates that permanganate oxidation, even in an injection-only mode, can be applied at many sites at locations that are relatively close to receptors or property boundaries.
- Some DNAPL appeared in monitoring wells located between the two test plots, where ISCO and resistive heating technologies were being applied concurrently. It is difficult to attribute the DNAPL migration to one of the two technologies. The strong hydraulic gradient generated by the oxidant injection is unlikely to cause DNAPL migration, unless some DNAPL is already present in mobile form. When permanganate is used as the oxidant, there are no strong exothermic reactions involved and the potential for migration of DNAPL to the vadose zone or atmosphere is minimal.
- The cost of the ISCO application was approximately $1 million, including the design, oxidant purchase, equipment procurement and installation, operation, and limited monitoring costs. The vendor estimated that approximately 15% of these costs were for the demonstration specific rather than a full-scale. A comparison of the DNAPL source treatment with ISCO cost with the life cycle cost of an equivalent pump-and-treat system at the site showed that the ISCO treatment was more economical in the long term.

Based on the lessons learned during the demonstration, the following recommendations can be made for future applications:

- It is imperative to delineate the boundaries of the DNAPL source zone. A treatment such as oxidation also requires knowledge of the distribution of the DNAPL in the source region. The ISCO treatment can be better targeted and injections can be arranged suitably to mitigate any potential for DNAPL migration. A combination of monitoring well clusters with discrete screened intervals and strategically located continuous soil cores are a good way of delineating the source, in preparation for remedial design and treatment.
- If the DNAPL source boundaries can be identified with a fair degree of confidence, an injection-only scheme should be applied in such a way that the oxidant is first injected around the perimeter of the source, and then applied progressively to inner regions. This will minimize the potential for DNAPL migration. Alternatively, extraction wells can be used for better hydraulic control, but this will involve additional costs for aboveground treatment and reinjection/disposal of extracted fluids.
- For the portion of a DNAPL source that is under a building, the oxidant can be more effectively distributed by locating injection points inside the building (in this demonstration, this was not performed). This may create administrative difficulties if the building is in use, but will lead to more effective source removal. Alternatively, angled injection points or injection-extraction schemes with injection at one end of the building and extraction at another end could be considered.
- The native hydraulic gradient at this site is relatively flat, but the high injection pressures that were used here and that were required to achieve a reasonable radius of influence indicate that the native groundwater flow is not likely to play a significant role in oxidant distribution on the localized scale of most DNAPL

zones. For schemes that rely on lower injection pressures, injection points would have to be much more closely spaced and injections would have to start much further upgradient to take advantage of the natural gradient and obtain good coverage of the plot.

- One way of lowering oxidant injection pressures, if desirable at a site, may be to inject lower concentrations of oxidant for a longer period of time. This will mitigate the potential for elevated trace metal levels in the groundwater during the application, but may lead to higher operational costs.
- Sodium permanganate, which is commercially available as a concentrated solution, may be used to ease the difficulties associated with the handling of a solid oxidant (potassium permanganate).
- Additional research is required to elucidate the geochemistry of the oxidant-aquifer-contaminant interactions, particularly the effects of the oxidant on native organic matter and the effects of excessive chloride generation on underground structures, such as monitoring wells or buildings. Additional research also is required to evaluate further rebound of dissolved CVOC concentrations in the long term and to evaluate the survival and regrowth of microbial populations in the plot. These factors are important for natural attenuation of any residual contamination following ISCO treatment.

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Acronyms and Abbreviations

3-D	three-dimensional
ACL	alternative concentration limits
AFRL	Air Force Research Laboratory
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
BOD	biological oxygen demand
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CES	Current Environmental Solutions
CFU	colony forming units
CMT	Core Management Team
CVOC	chlorinated volatile organic compound
CWA	Clean Water Act
DCE	dichloroethylene
DNAPL	dense, nonaqueous-phase liquid
DO	dissolved oxygen
DoD	(U.S.) Department of Defense
DOE	(U.S.) Department of Energy
EM50	Environmental Management 50 (Program)
FDEP	(State of) Florida Department of Environmental Protection
f_{oc}	fraction organic carbon
FSU	Florida State University
gpm	gallon(s) per minute
HDPE	high-density polyethylene
HSWA	Hazardous and Solid Waste Amendments
IDC	Interagency DNAPL Consortium
ISCO	in situ chemical oxidation
ITRC	Interstate Technology Regulatory Council
K_{oc}	organic carbon partitioning coefficient
LCS	laboratory control spikes
LCSD	laboratory control spike duplicates
LRPCD	Land Remediation and Pollution Control Division

MCL	maximum contaminant level
MS	matrix spikes
MSD	matrix spike duplicates
msl	mean sea level
MSE	MSE Technology Applications, Inc.
MTBE	methyl-*tert*-butyl ether
mV	millivolts
MYA	million years ago
NA	not applicable/not available
N/A	not analyzed
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
ND	not detected
NFESC	Naval Facilities Engineering Service Center
NPDES	National Pollutant Discharge Elimination System
O&M	operation and maintenance
ORD	Office of Research and Development
ORNL	Oak Ridge National Laboratory
ORP	oxidation-reduction potential
OSHA	Occupational Safety and Health Administration
PID	photoionization detector
POTW	publicly owned treatment works
ppb	parts per billion
psig	pounds per square inch gage
PV	present value
PVC	polyvinyl chloride
PVDF	polyvinylidene fluoride
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RI/FS	Remedial Investigation/Feasibility Study
RPD	relative percent difference
RSKERC	R.S. Kerr Environmental Research Center (of the U.S. EPA)
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SIP	State Implementation Plan
SITE	Superfund Innovative Technology Evaluation (Program)
STL	STL Environmental Services, Inc.
TCA	trichloroethane
TCE	trichloroethylene
TDS	total dissolved solids
TOC	total organic carbon
UIC	Underground Injection Control (permit)
U.S. EPA	United States Environmental Protection Agency
VOA	volatile organic analysis
WSRC	Westinghouse Savannah River Company

1. Introduction

This section introduces the project demonstration of in situ chemical oxidation (ISCO) technology for remediation of a dense, nonaqueous-phase liquid (DNAPL) source zone at Launch Complex 34, Cape Canaveral Air Station, FL. The section also summarizes the structure of this report.

1.1 Project Background

The goal of the project is to evaluate the technical and cost performances of ISCO technology for remediation of DNAPL source zones. The chlorinated volatile organic compound (CVOC) trichloroethylene (TCE) is present in the aquifer as a DNAPL source at Launch Complex 34. Smaller amounts of dissolved *cis*-1,2-dichloroethylene (*cis*-1,2-DCE) and vinyl chloride also are present in the groundwater. The field demonstration of ISCO technology started at Launch Complex 34 in September 1999 and ended in April 2000. Performance assessment activities were conducted before, during, and after the field demonstration.

1.1.1 The Interagency DNAPL Consortium

The ISCO demonstration is part of a larger demonstration of three different DNAPL remediation technologies being conducted at Launch Complex 34 with the combined resources of several U.S. government agencies. The government agencies participating in this effort have formed the Interagency DNAPL Consortium (IDC). The IDC is composed primarily of the following agencies, which are providing most of the funding for the demonstration:

- U.S. Department of Energy (DOE), Environmental Management 50 (EM50) Program
- U.S. Environmental Protection Agency (U.S. EPA), Superfund Innovative Technology Evaluation (SITE) Program
- U.S. Department of Defense (DoD), Naval Facilities Engineering Service Center (NFESC)
- National Aeronautics and Space Administration (NASA).

In the initial stages of the project, until January 2000, the Air Force Research Laboratory (AFRL) was the DoD representative on this consortium and provided significant funding. NFESC replaced AFRL in March 2000. In addition, the following organizations are participating in the demonstration by reviewing project plans and data documents, funding specific tasks, and/or promoting technology transfer:

- Patrick Air Force Base
- U.S. EPA Technology Innovation Office and U.S. EPA R.S. Kerr Environmental Research Center (RSKERC)
- Interstate Technology Regulatory Council (ITRC).

Key representatives of the various agencies constituting the IDC formed a Core Management Team (CMT), which guided the progress of the demonstration. An independent Technical Advisory Group was formed to advise the Core Management Team on the technical aspects of the site characterization and selection, remediation technology selection and demonstration, and performance assessment of the technologies. The Technical Advisory Group consisted of experts drawn from industry, academia, and government.

The IDC contracted MSE Technology Applications, Inc. (MSE), to conduct technology vendor selection, procure the services of the three selected technology vendors, and conduct the cost evaluation of the three technologies. The IT Corporation is the selected vendor for implementing the ISCO technology at Launch Complex 34. Current Environmental Solutions and Integrated Water Resources, Inc., are the vendors for the resistive heating and steam injection technologies, respectively. In addition, the IDC also contracted Westinghouse Savannah River Company (WSRC) to conduct the preliminary site

characterization for site selection, and Florida State University (FSU) to coordinate site preparation and other field arrangements for the demonstration. Figure 1-1 summarizes the project organization for the IDC demonstration.

1.1.2 Performance Assessment

The IDC contracted Battelle to plan and conduct the detailed site characterization and an independent performance assessment for the demonstration of the three technologies. U.S. EPA and its contractor, TetraTech EM, Inc., provided quality assurance (QA) oversight and field support for the performance assessment activities. Before the field demonstration, Battelle prepared a Quality Assurance Project Plan (QAPP) that was reviewed by all the project stakeholders. This QAPP was based on the general guidelines provided by the U.S. EPA's SITE Program for test plan preparation, quality assurance, and data analysis (Battelle, 1999d). Once the demonstration started, Battelle prepared six interim reports (Battelle 1999e, and f; Battelle 2000a, b, c, and d) for the IDC.

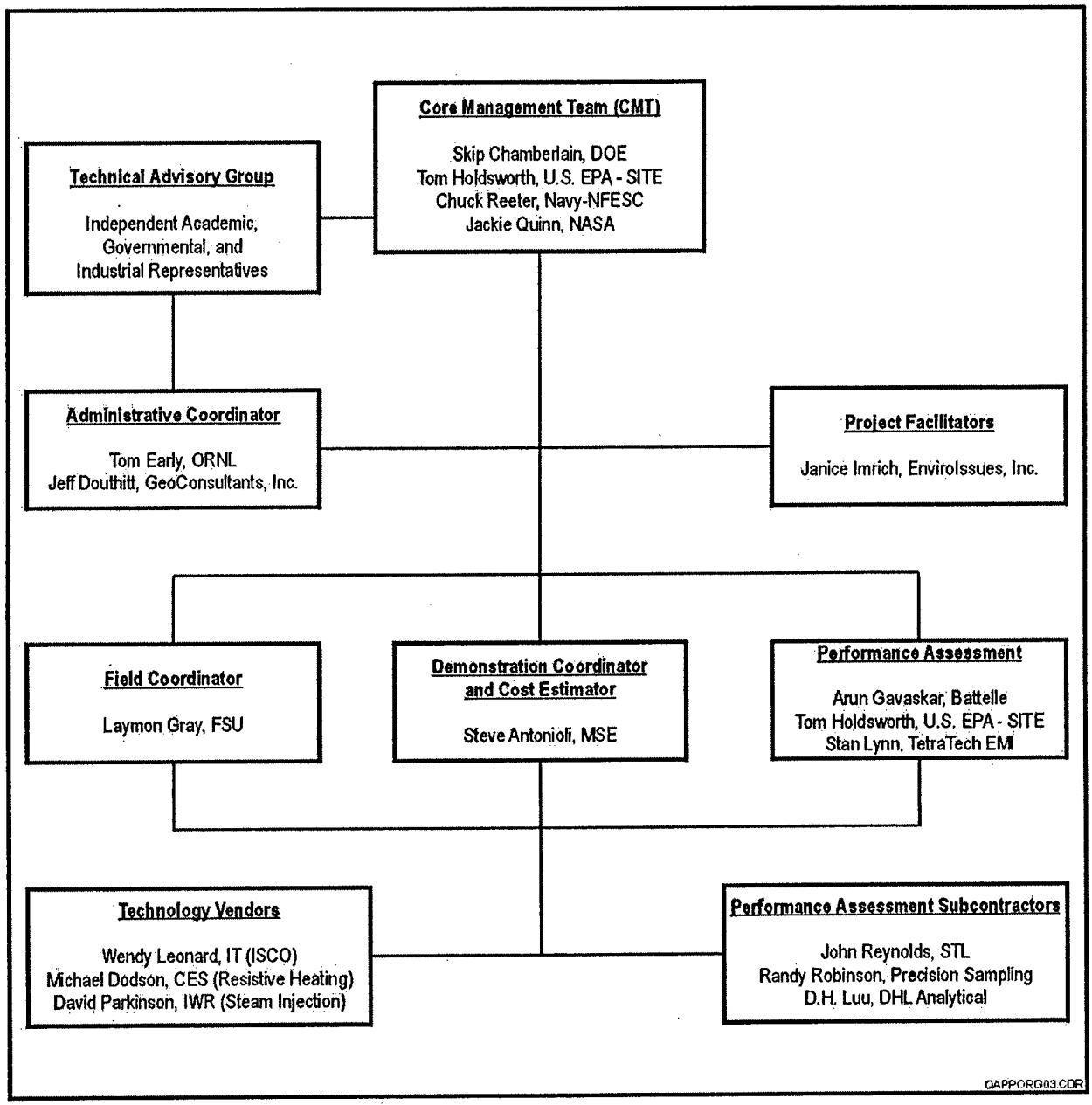


Figure 1-1. Project Organization for the IDC Demonstration at Launch Complex 34

1.1.3 The SITE Program

The performance assessment planning, field implementation, and data analysis and reporting for the ISCO demonstration followed the general guidance provided by the U.S. EPA's SITE Program. The SITE Program was established by U.S. EPA's Office of Solid Waste and Emergency Response and the Office of Research and Development (ORD) in response to the 1986 Superfund Amendments and Reauthorization Act, which recognized a need for an "Alternative or Innovative Treatment Technology Research and Demonstration Program." ORD's National Risk Management Research Laboratory in the Land Remediation and Pollution Control Division (LRPCD), headquartered in Cincinnati, OH, administers the SITE Program. The SITE Program encourages the development and implementation of (1) innovative treatment technologies for hazardous waste site remediation, and (2) innovative monitoring and measurement tools.

In the SITE Program, a field demonstration is used to gather engineering and cost data on the innovative technology so that potential users can assess the technology's applicability to a particular site. Data collected during the field demonstration are used to assess the performance of the technology, the potential need for pre- and postprocessing of the waste, applicable types of wastes and waste matrices, potential operating problems, and approximate capital and operating costs.

U.S. EPA provides guidelines on the preparation of an Innovative Technology Evaluation Report at the end of the field demonstration. These reports evaluate all available information on the technology and analyze its overall applicability to other site characteristics, waste types, and waste matrices. Testing procedures, performance and cost data, and quality assurance and quality standards also are presented. This IDC report on the ISCO technology demonstration at Launch Complex 34 is based on these general guidelines.

1.2 The DNAPL Problem

Figure 1-2 illustrates the formation of a DNAPL source at a chlorinated solvent release site. When solvent is released into the ground due to previous use or disposal practices, it travels downward through the vadose zone to the water table. Because many chlorinated solvents are denser than water, the solvent continues its downward migration through the saturated zone (assuming sufficient volume of solvent is involved) until it encounters a low-permeability layer or aquitard, on which it may form a pool. During its downward migration, the solvent leaves a trace of residual solvent in the soil pores. Many chlorinated solvents are only sparingly soluble in water; therefore, they can persist as a separate phase for several

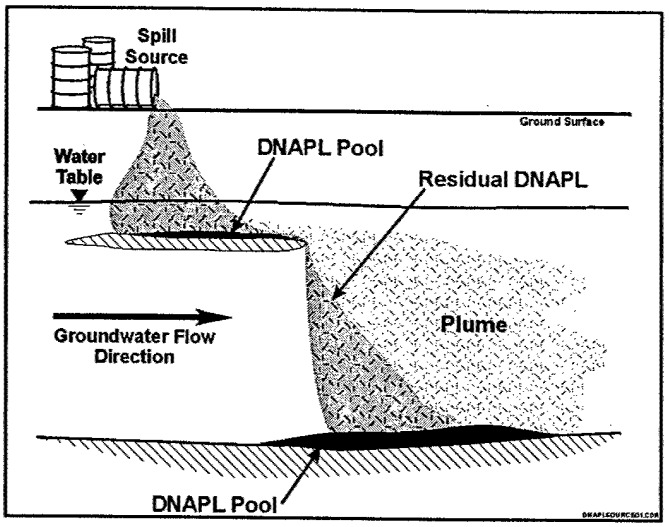


Figure 1-2. Simplified Depiction of the Formation of a DNAPL Source Zone in the Subsurface

years (or decades). This free-phase solvent is called DNAPL.

DNAPL in pools often can be mobilized towards extraction wells when a strong hydraulic gradient is imposed; this solvent is called mobile DNAPL. Residual DNAPL can be DNAPL that can be trapped in pores and cannot be mobilized towards extraction wells, regardless of how strong the applied gradient. DNAPL pools may dissolve in the groundwater flow over time, leaving behind residual DNAPL. At most sites, DNAPL pools are rare, as DNAPL is often present in residual form.

As long as DNAPL is present in the aquifer, a plume of dissolved solvent is generated. DNAPL therefore constitutes a secondary source that keeps replenishing the plume long after the primary source (leaking aboveground or buried drums, drain pipes, vadose zone soil, etc.) has been removed. Because DNAPL persists for many decades or centuries, the resulting plume also persists for many years. As recently as five years ago, DNAPL sources were difficult to find and most remedial approaches focused on plume treatment or plume control. In recent years, many chlorinated solvent-contaminated sites have been successful in identifying DNAPL sources, or at least identifying enough indicators of DNAPL. The focus is now shifting from plume control to DNAPL source removal or treatment.

Pump-and-treat systems have been the conventional treatment approach at DNAPL sites and these systems have proved useful as an interim remedy to control the progress of the *plume* beyond a property boundary or other compliance point. However, pump-and-treat systems are not economical for *DNAPL* remediation. Pools

of DNAPL, which can be pumped and treated above ground, are rare. Residual DNAPL is immobile and does not migrate towards extraction wells. As with plume control, the effectiveness and cost of DNAPL remediation with pump and treat is governed by the time (decades) required for slow dissolution of the DNAPL source in the groundwater flow. An innovative approach is required to address the DNAPL problem.

1.3 The ISCO Technology

Figure 1-3 illustrates the in situ application of a chemical oxidant for remediation of a DNAPL source zone. This innovative technology is based on the ability of strong oxidants to react with and destroy several types of DNAPL contaminants. Common chemicals with high oxidation potential that have been used to treat DNAPL zones are Fenton's reagent and potassium permanganate (Watts et al., 1990; Vella et al., 1990; Gates et al., 1995; Siegrist et al., 2001). Notably, the DNAPL constituents most susceptible to oxidation by potassium permanganate are Cl-alkenes. Treatment of CVOCs with oxidants has been used historically for drinking water and wastewater treatment, but the in situ use of these oxidants for DNAPL source treatment is relatively new. Equation 1-1 illustrates how a common contaminant, TCE, would react with (and be destroyed by) potassium permanganate.

$$2KMnO_4 + C_2HCl_3 \rightarrow 2CO_2 + 2MnO_2\,(s) + 2K^+ + H^+ + 3Cl^- \quad (1\text{-}1)$$

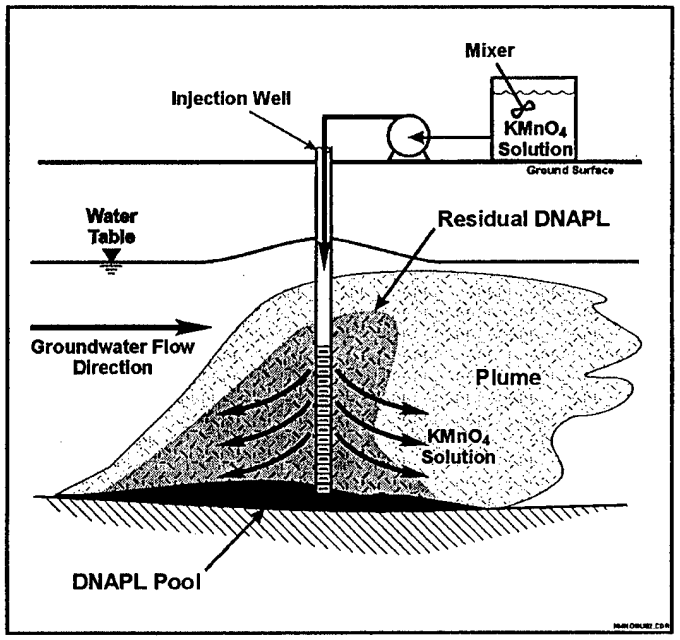


Figure 1-3. In Situ Chemical Oxidation of a DNAPL Source Zone

TCE is oxidized to potentially nontoxic byproducts, such as carbon dioxide, manganese dioxide (solid), and chloride. In the absence of other organic matter, the reaction is second order and the rate is governed by the concentrations of both TCE and MnO_4^- ion.

In an aquifer setting, permanganate also reacts with other reduced species, including native organic matter. The natural organic matter in an aquifer competes with the contaminant for consuming the oxidant. Therefore, the amount of oxidant required to sweep an aquifer depends on the characteristics of both the contaminants and the aquifer. Also, geologic heterogeneities may limit the degree of contact achievable between the oxidant and the contaminant. In this respect, a longer-lived oxidant, such as permanganate, has some advantage over a short-lived oxidant, such as the hydroxyl free radical created from Fenton's reagent. Because permanganate does not degrade as quickly as the hydroxyl free radical, it can potentially sweep longer distances around the injection point and persist long enough to diffuse slowly into more isolated pores. In addition, $KMnO_4$ oxidation is a redox reaction that is relatively effective over a wide pH range, thus making it suitable for the alkaline subsurface conditions in the Launch Complex 34 aquifer. Therefore, potassium permanganate was selected as the oxidant in the IDC demonstration.

When permanganate is applied in an injection-only mode, as was done in this demonstration, extraction of the injected fluids and their subsequent treatment and disposal/reinjection is not required. Therefore, ISCO has a potential advantage over technologies that rely on enhanced mobilization, capture, and aboveground treatment of DNAPL contaminants. One concern with in situ application of permanganate has been related to the generation of manganese dioxide, a solid that could build up in the aquifer and potentially cause plugging of pores. Another concern has been the spread of dissolved manganese (Mn^{2+}), a reduced species that is generated from manganese (Mn^{4+}) dioxide, if and when the oxidative environment reverts to a reducing environment. Dissolved manganese is subject to a secondary (nonhealth-based) drinking water standard. A third concern relates to the potential for release of regulated metals from the aquifer formation under strong oxidizing conditions. These concerns were evaluated during the demonstration.

1.4 The Demonstration Site

Launch Complex 34, the site selected for this demonstration, is located at Cape Canaveral Air Station, FL (see Figure 1-4). Launch Complex 34 was used as a launch site for Saturn rockets from 1960 to 1968. Historical

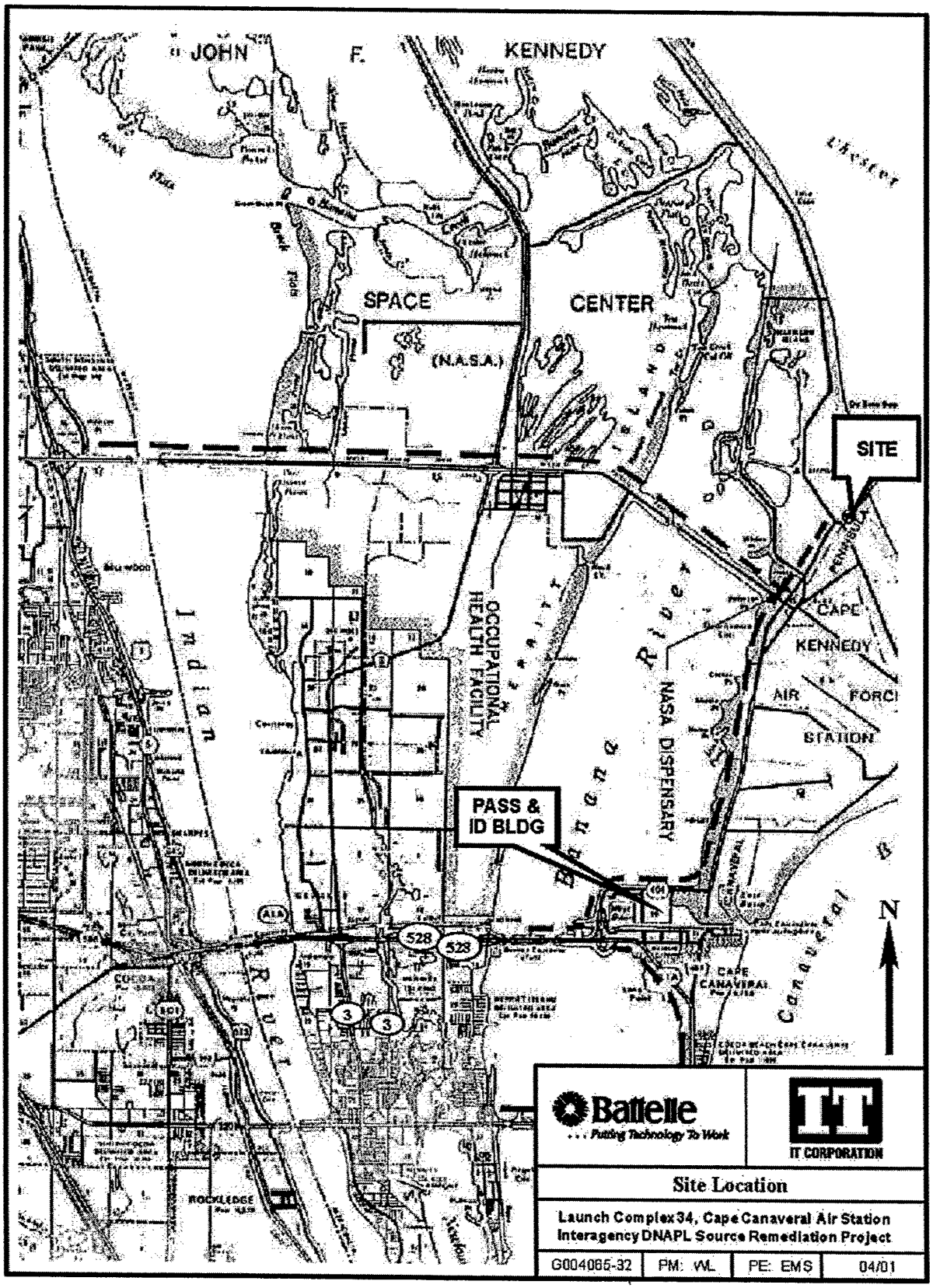


Figure 1-4. Demonstration Site Location

records and worker accounts suggest that rocket engines were cleaned on the launch pad with chlorinated organic solvents such as TCE. Other rocket parts were cleaned on racks at the western portion of the Engineering Support Building and inside the building. Some of the solvents ran off to the surface or discharged into drainage pits. The site was abandoned in 1968 and since that time much of the site has been overgrown by vegetation, although several on-site buildings remain operational.

Preliminary site characterization efforts suggested that approximately 20,600 kg (Battelle, 1999a) to 40,000 kg (Eddy-Dilek et al., 1998) of solvent could be present in the subsurface near the Engineering Support Building at Launch Complex 34. Figure 1-5 is a map of the Launch Complex 34 site at Cape Canaveral that shows the target DNAPL source area, located in the northern vicinity of the Engineering Support Building. The DNAPL source zone was large enough that the IDC and the Technical Advisory Group could assign three separate test plots encompassing different parts of this source zone. Figure 1-5 also shows the layout of the three test plots along the northern edge of the Engineering Support Building at Launch Complex 34. The ISCO plot is the easternmost of these plots. Figure 1-6 is a photograph looking southward towards the three test plots and the Engineering Support Building. All three test plots lie partly under the Engineering Support Building in order to encompass the portion of the DNAPL source under the building.

1.5 Technology Evaluation Report Structure

The ISCO technology evaluation report starts with an introduction to the project organization, the DNAPL problem, the technology demonstrated, and the demonstration site (Section 1). The rest of the report is organized as follows:

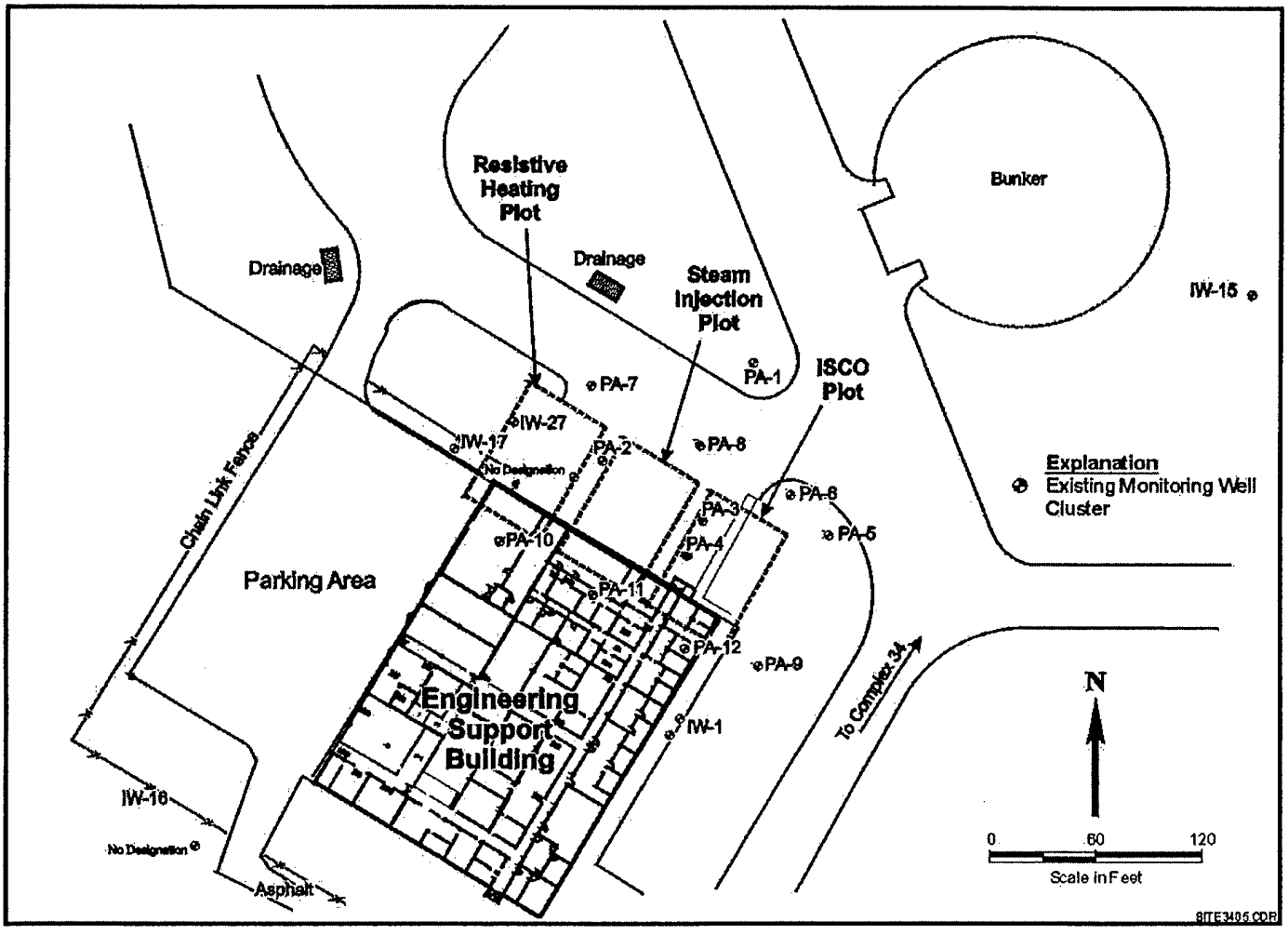


Figure 1-5. Location Map of Launch Complex 34 Site at Cape Canaveral Air Station

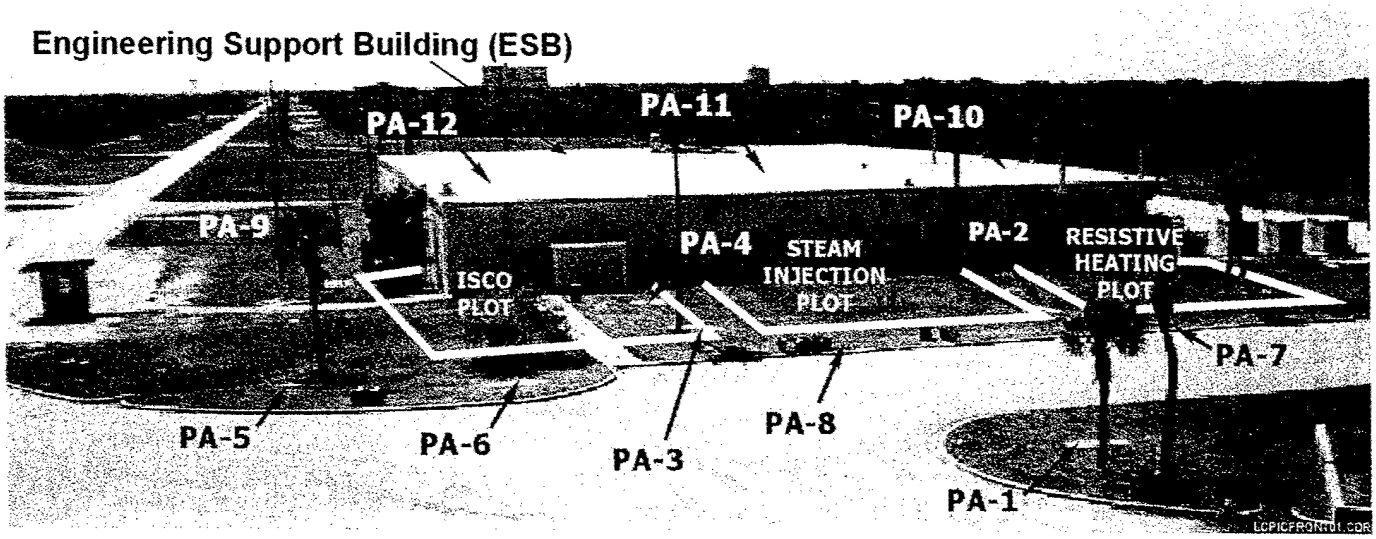


Figure 1-6. View Looking South towards Launch Complex 34, the Engineering Support Building, and the Three Test Plots

- Site Characterization (Section 2)
- Technology Operation (Section 3)
- Performance Assessment Methodology (Section 4)
- Performance Assessment Results and Conclusions (Section 5)
- Quality Assurance (Section 6)
- Economic Analysis (Section 7)
- Technology Applications Analysis (Section 8)
- References (Section 9).

Supporting data and other information are presented in the appendices to the report. The appendices are organized as follows:

- Performance Assessment Methods (Appendix A)
- Hydrogeologic Measurements (Appendix B)
- CVOC Measurements (Appendix C)
- Inorganic and Other Aquifer Parameters (Appendix D)
- Microbiological Assessment (Appendix E)
- Surface Emissions Testing (Appendix F)
- Quality Assurance/Quality Control (QA/QC) Information (Appendix G)
- Economic Analysis Information (Appendix H)
- Technical Information for $KMnO_4$ Used for the ISCO Demonstration (Appendix I).

2. Site Characterization

This section provides a summary of the hydrogeology and chemistry of the site based on the data compilation report (Battelle, 1999a), the additional site characterization report (Battelle, 1999b), and the predemonstration characterization report (Battelle, 1999c).

2.1 Hydrogeology of the Site

A surficial aquifer and a semi-confined aquifer comprise the major aquifers in the Launch Complex 34 area, as described in Table 2-1. The surficial aquifer extends from the water table to approximately 45 ft below ground surface (bgs) in the Launch Complex 34 area. A clay semi-confining unit separates the surficial aquifer from the underlying confined aquifer.

Figures 2-1 and 2-2 are geologic cross sections, one along the northwest-southeast (NW-SE) direction across the middle of the three test plots and the other along the southwest-northeast (SW-NE) direction across the middle of the ISCO plot. As seen in these figures, the surficial aquifer is subclassified as having an Upper Sand Unit, a Middle Fine-Grained Unit, and a Lower Sand Unit. The Upper Sand Unit extends from ground surface to approximately 20 to 26 ft bgs and consists of unconsolidated, gray fine sand and shell fragments. The Middle Fine-Grained Unit is a layer of gray, fine-grained silty/clayey sand that exists between about 26 and 36 ft bgs. In general, this unit contains soil that is finer-grained than the Upper Sand Unit and Lower Sand Unit, and varies in thickness from about 10 to 15 ft. The Middle Fine-Grained Unit is thicker in the northern portions of the test plots and appears to become thinner in the southern and western portions of the test area (under the Engineering Support Building and in the resistive heating plot). Below the Middle Fine-Grained Unit is the Lower Sand Unit, which consists of gray fine to medium-sized sand and shell fragments. The unit contains isolated fine-grained lenses of silt and/or clay. Figure 2-2 shows a stratigraphic cross section through the demonstration area. The lithologies of thin, very coarse, shell zones were encountered in several units. These zones probably are important as reservoirs for DNAPL.

A 1.5- to 3-ft-thick semi-confining layer exists at approximately 45 ft bgs in the Launch Complex 34 area. The layer consists of greenish-gray sandy clay. The semi-confining unit (i.e., the Lower Clay Unit) was encountered in all borings across the Launch Complex 34 site, and it appears to be a pervasive unit. However, the clay unit is fairly thin (around 1.5 ft thick) in some areas, especially under the resistive heating plot. Site characterization data (Battelle, 1999a and b; Eddy-Dilek et al., 1998) suggest that the surfaces of the Middle Fine-Grained Unit and the Lower Clay Unit are somewhat uneven (see Figures 2-3 to 2-5). The Lower Clay Unit slopes downward toward the southern part of all three test plots and toward the center plot and the building (Battelle, 2001).

Table 2-1. Local Hydrostratigraphy at the Launch Complex 34 Site

Hydrostratigraphic Unit		Thickness (ft)	Sediment Description	Aquifer Unit Description
Surficial Aquifer	Upper Sand Unit	20-26	Gray fine sand and shell fragments	Unconfined, direct recharge from surface
	Middle Fine-Grained Unit	10-15	Gray, fine-grained silty/clayey sand	Low-permeability, semi-confining layer
	Lower Sand Unit	15-20	Gray fine to medium-sized sand and shell fragments	Semi-confined
Lower Clay Unit (Semi-Confining Unit)		1.5-3	Greenish-gray sandy clay	Thin low-permeability semi-confining unit
Semi-Confined Aquifer		>40	Gray fine to medium-sized sand, clay, and shell fragments	Semi-confined, brackish

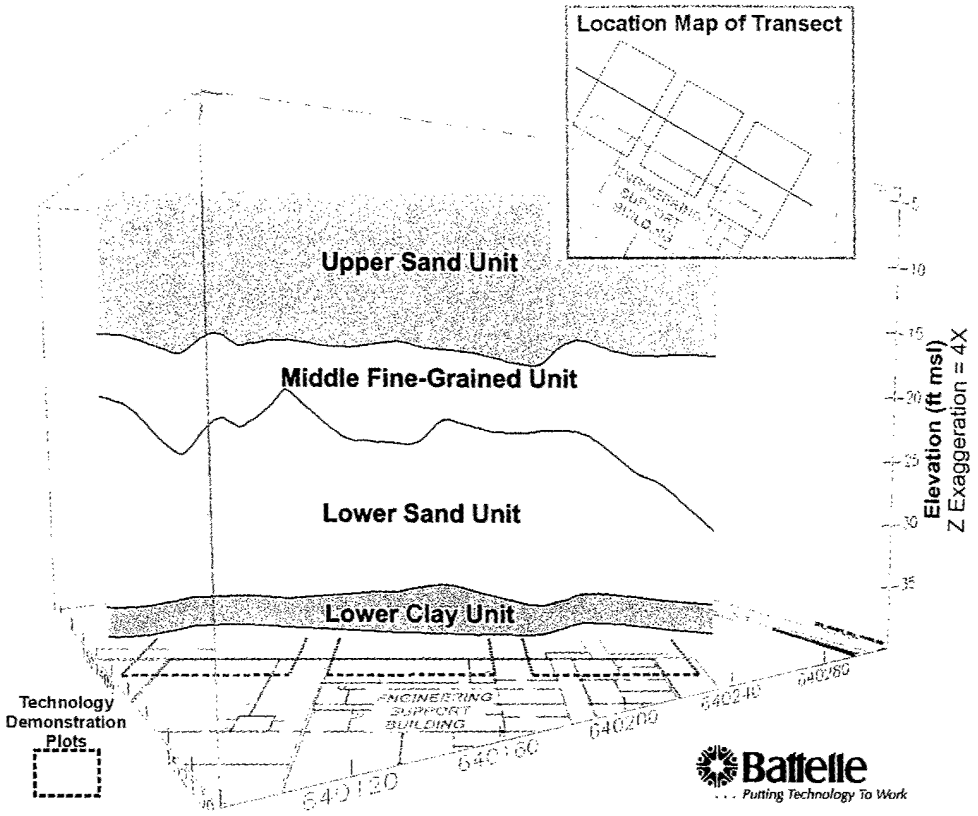


Figure 2-1. NW-SE Geologic Cross Section through the Three Test Plots

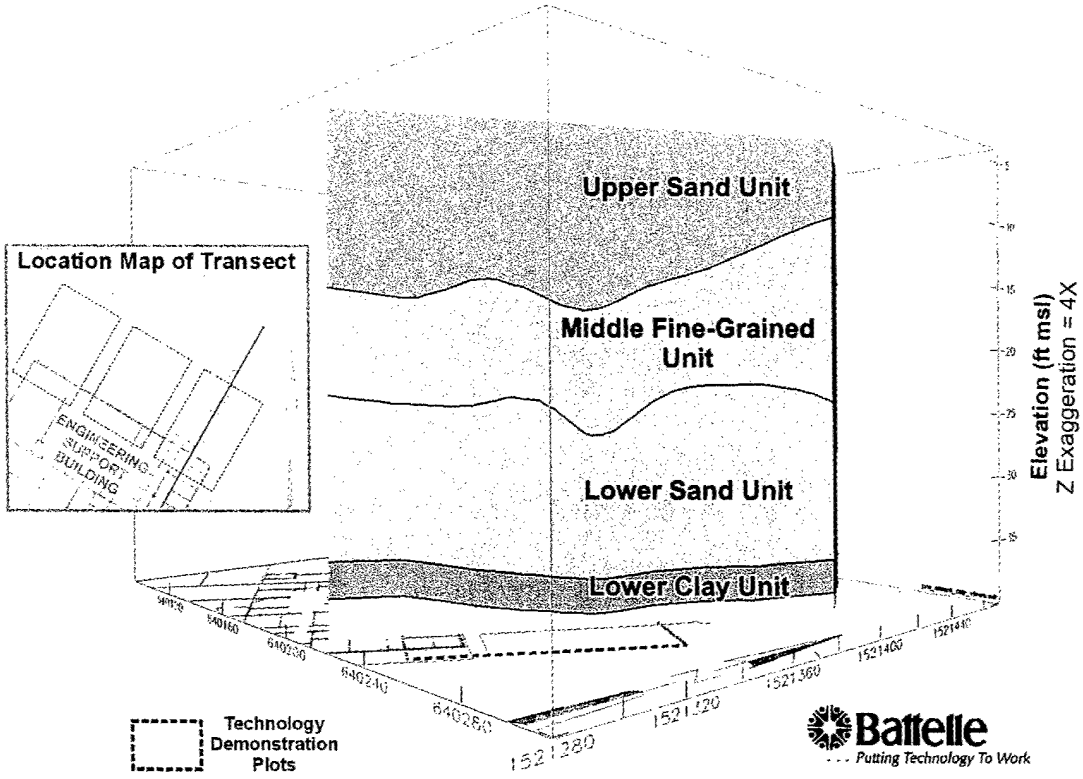


Figure 2-2. SW-NE Geologic Cross Section through ISCO Plot

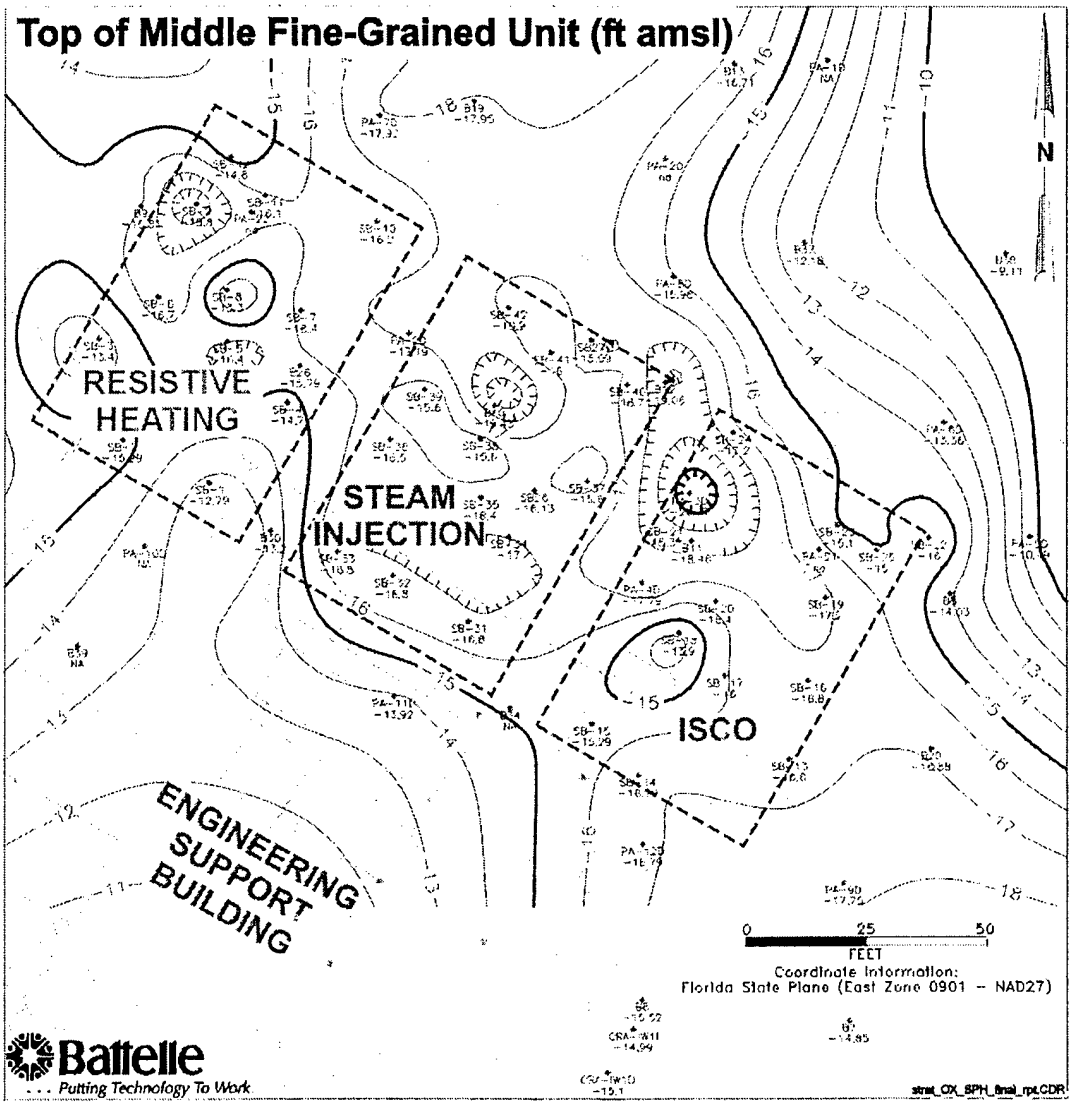


Figure 2-3. Topography of Top of Middle Fine-Grained Unit

The semi-confined aquifer underlies the Lower Clay Unit. The aquifer consists of gray fine to medium-sized sand, clay, and shell fragments during the investigation to the aquifer below the Lower Clay Unit (Battelle 2001). Water levels from wells in the aquifer were measured at approximately 4 to 5 ft bgs. Few cores were advanced below the semi-confined aquifer. The thickness of the semi-confined aquifer is between 40 ft and 120 ft.

Water-level surveys were performed in the surficial aquifer in May 1997, December 1997, June 1998, October 1998, and March 1999. Water table elevations in the surficial aquifer were between about 1 and 5 ft mean sea level (msl). In general, the surveys suggest that water levels form a radial pattern with highest elevations near the Engineering Support Building. Figure 2-6 shows a water-table map of June 1998. The gradient and flow directions vary over time at the site. Table 2-2 summarizes the hydraulic gradients and their directions near the Engineering Support Building. The gradient ranged from 0.00009 to 0.0007 ft/ft. The flow direction varied from north-northeast to south-southwest.

Predemonstration water-level measurements in all three surficial aquifer zones — Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit — indicate a relatively flat hydraulic gradient in the localized setting of the three test plots, as seen in Figures 2-7 to 2-9 (Battelle, 1999c). On a regional scale, mounding of water levels near the Engineering Support Building generates a radial gradient; the regional gradient across the test plots is weak and appears to be toward the northeast (see Figure 2-6). Probable discharge points for the aquifer include wetland areas, the Atlantic Ocean, and/or the

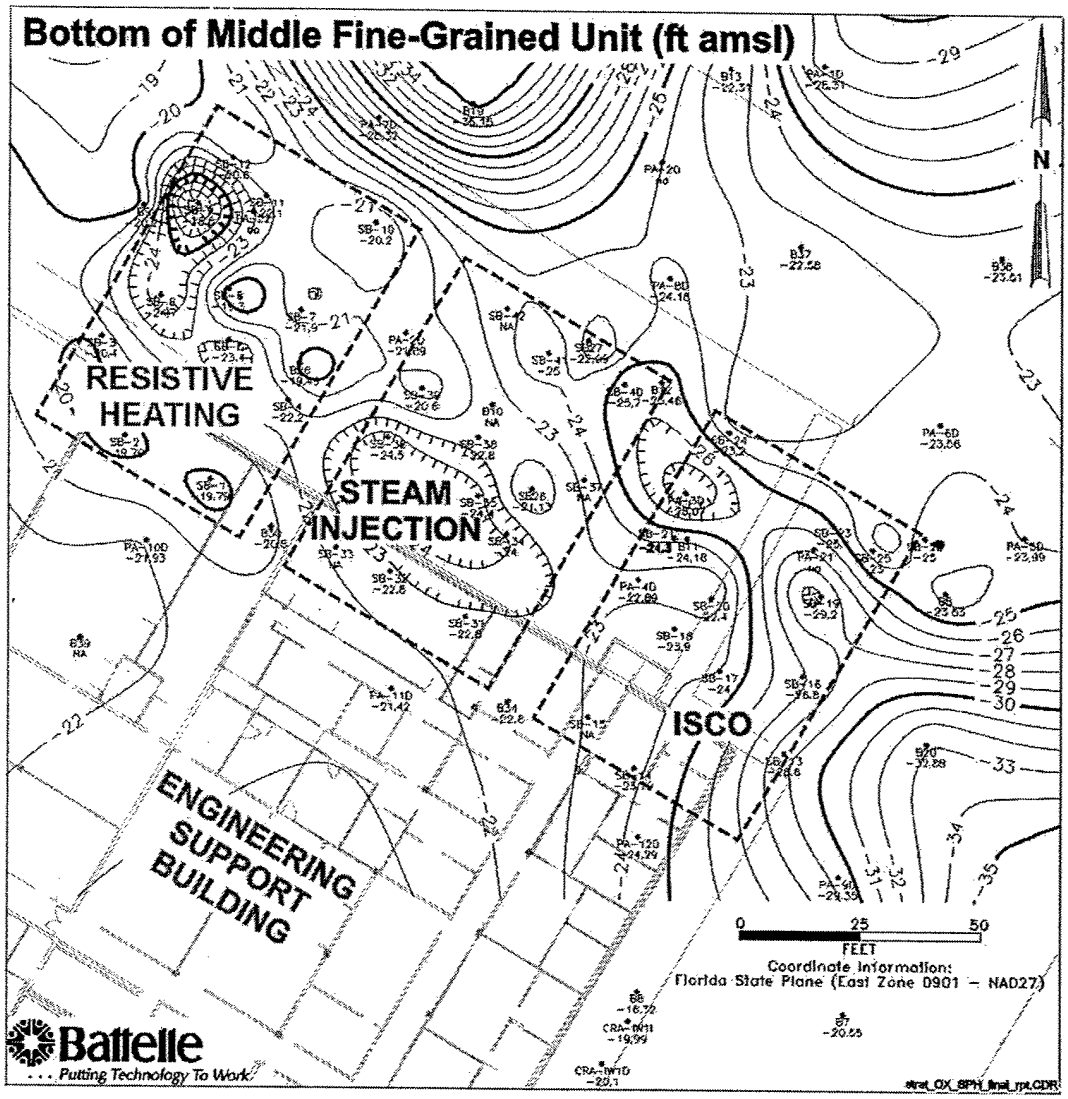


Figure 2-4. Topography of Bottom of Middle Fine-Grained Unit

Banana River. Water levels from wells screened in the Lower Sand Unit usually are slightly higher than the water levels from the Upper Sand Unit and/or the Middle Fine-Grained Unit. The flow system may be influenced by local recharge events, resulting in the variation in the gradients. Recharge to the surficial aquifer is from infiltration of precipitation through surface soils to the aquifer.

In general, predemonstration slug tests show that the Upper Sand Unit is more permeable than the underlying units, with hydraulic conductivity ranging from 4.0 to 5.1 ft/day in the shallow wells at the site (Battelle, 1999c). The hydraulic conductivity of the Middle Fine-Grained Unit ranges from 1.4 to 6.4 ft/day in the intermediate wells; measured conductivities probably are higher than the actual conductivity of the unit because the well screens include portions of the Upper Sand Unit. The hydraulic conductivity of the Lower Sand Unit ranged from 1.3 to 2.3 ft/day. Porosity averaged 0.26 in the Upper Sand Unit, 0.34 in the Middle Fine-Grained Unit, 0.29 in the Lower Sand Unit, and 0.44 in the Lower Clay Unit. The bulk density of the aquifer materials averaged 1.59 g/cm^3 (Battelle, 1999b). Groundwater temperatures ranged from 22.4 to 25.7°C during a March 1999 survey.

Water level surveys in the semi-confined aquifer were performed in December 1997, June 1998, and October 1998. Water table elevations were measured at approximately 1 to 5 ft msl, and formed a pattern similar to the pattern formed by surficial aquifer water levels. Groundwater elevations in the semi-confined aquifer are above the semi-confining unit. The gradient in the semi-confined

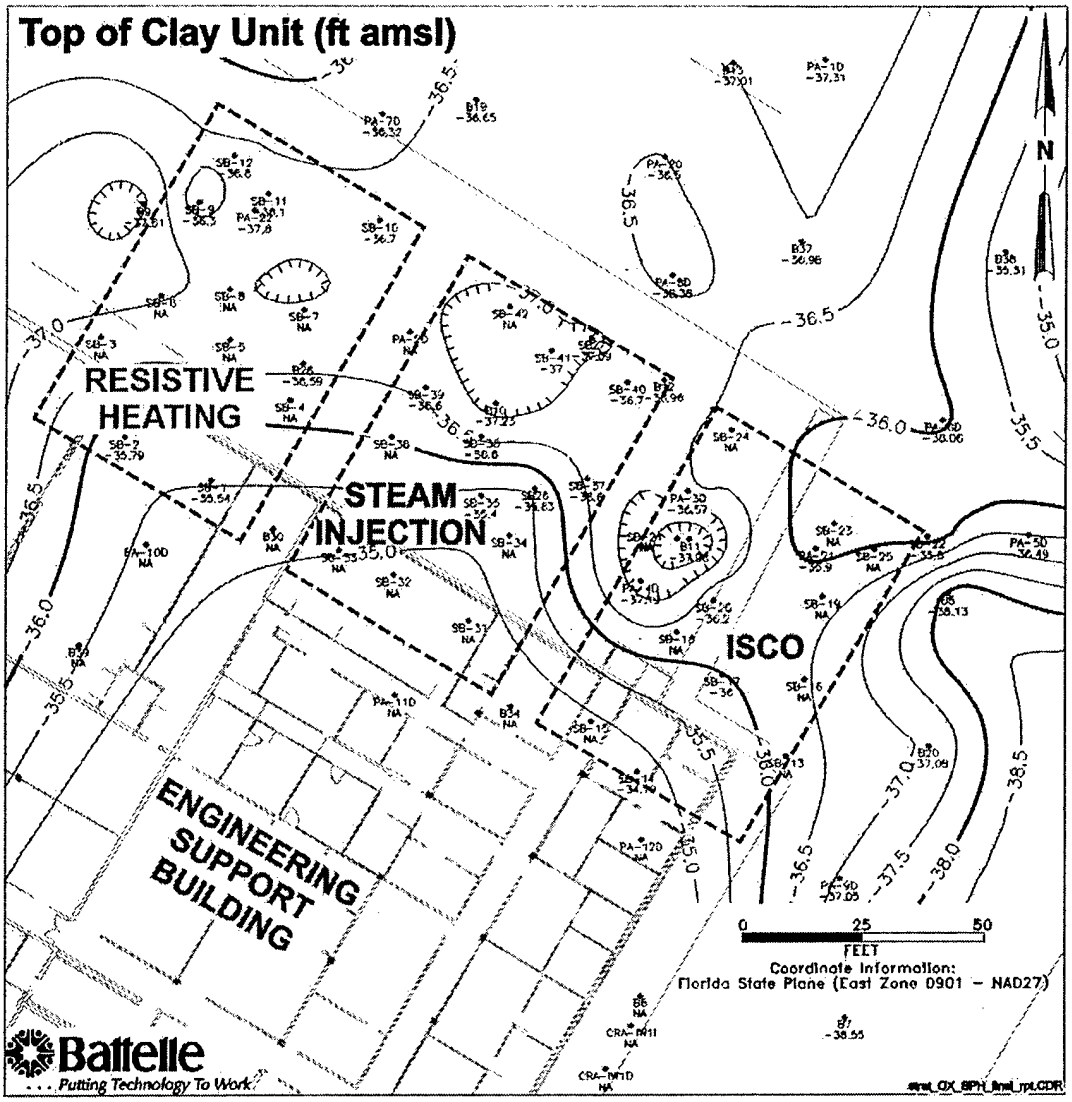


Figure 2-5. Topography of Top of Lower Clay Unit

aquifer is positioned in a similar direction to the surficial aquifer. The flow direction varies from east to south-southwest. In general, water levels in the aquifer below the Lower Clay Unit are higher than those in the surficial aquifer, suggesting an upward vertical gradient. Recharge to the aquifer may occur by downward leakage from overlying aquifers or from direct infiltration inland where the aquifer is unconfined. Schmalzer and Hinkle (1990) suggest that saltwater intrusion may occur in intermediate aquifers such as the semi-confined aquifer.

Other notable hydrologic influences at the site include drainage and recharge. Paved areas, vegetation, and topography affect drainage in the area. No streams exist in the site area. Engineered drainage at the site consists of ditches that lead to the Atlantic Ocean or swampy areas. Permeable soils exist from the ground surface to the water table and drainage is excellent. Water infiltrates directly to the water table.

2.2 Surface Water Bodies at the Site

The major surface water body in the area is the Atlantic Ocean, located to the east of Launch Complex 34. To determine the effects of surface water bodies on the groundwater system, water levels were monitored in 12 piezometers over 50 hours for a tidal influence study during Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) activities (G&E Engineering, Inc., 1996). All the piezometers used in the study were screened in the surficial aquifer. No detectable effects from the tidal cycles were measured, suggesting that the surficial aquifer and the Atlantic Ocean are not well connected hydraulically. However, the Atlantic Ocean

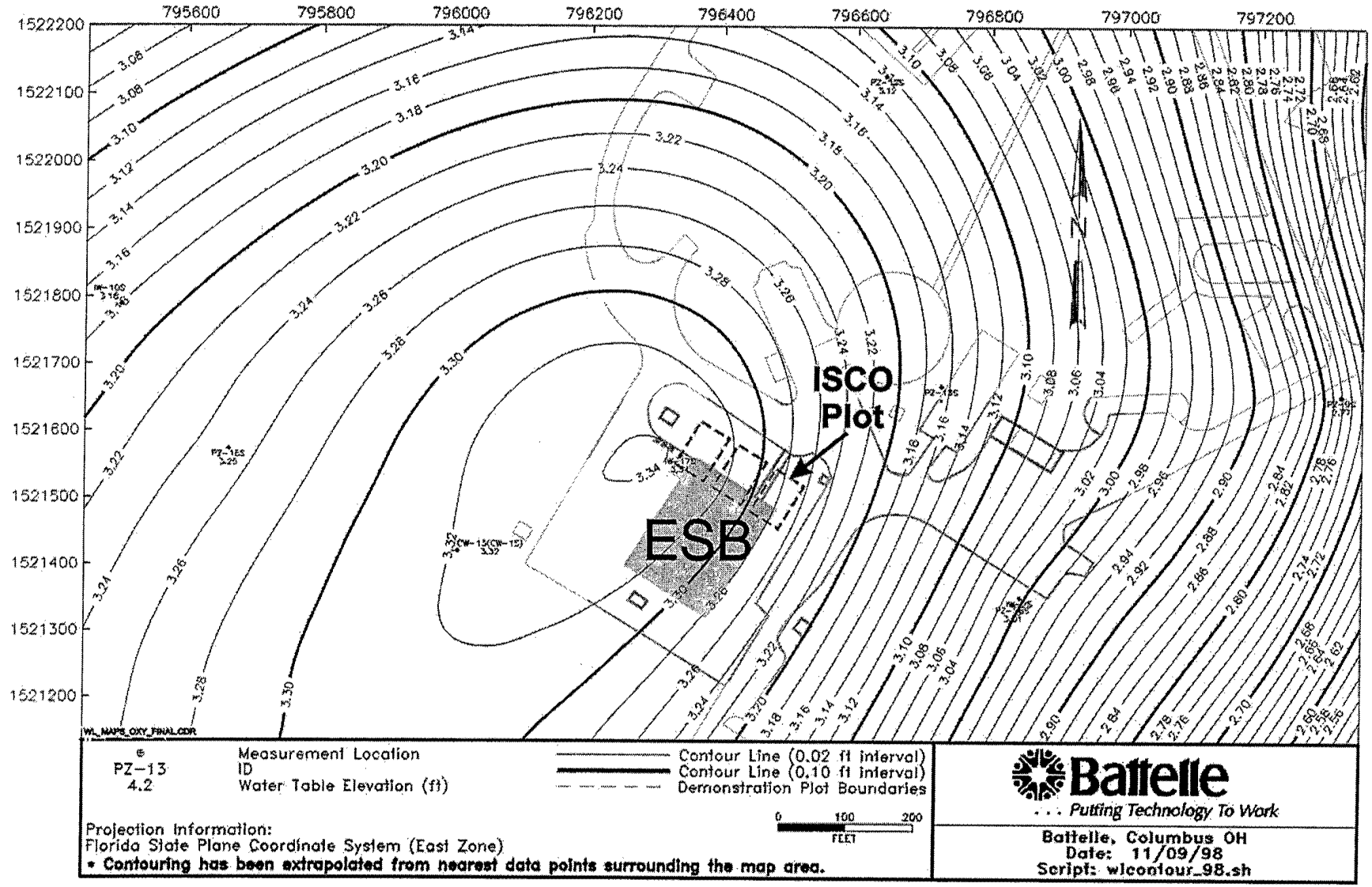


Figure 2-6. Water Table Elevation Map for Surficial Aquifer from June 1998

Table 2-2. Hydraulic Gradients and Directions in the Surficial and Semi-Confined Aquifers

Hydrostratigraphic Unit	Sampling Date	Hydraulic Gradient	Gradient Direction
Surficial Aquifer	May 1997	0.00009	SW
	December 1997	0.0001	SSW
	June 1998	0.0006	WNW
	October 1998	0.0007	NNE
	March 1999	undefined	undefined
Semi-Confined Aquifer	December 1997	0.0008	S
	June 1998	0.0005	E
	October 1998	0.00005	SSW

and the Banana River seem to act as hydraulic barriers or sinks, as groundwater likely flows toward these surface water bodies and discharges into them.

2.3 TCE/DNAPL Contamination in the ISCO Plot and Vicinity

Figures 2-10 to 2-12 show representative predemonstration distributions of TCE, the primary contaminant at Launch Complex 34, in the shallow, intermediate, and deep wells, installed during the site characterization, to correspond with the hydrostratigraphic units: Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit (Battelle, 1999c), respectively. No free-phase solvent was observed in any of the wells during the predemonstration sampling; however, groundwater analysis in many wells shows TCE at levels near or above its solubility, indicating the presence of DNAPL at the site. Lower levels of *cis*-1,2-DCE and vinyl chloride are also present in the aquifer, indicating some historical natural attenuation of TCE. Groundwater sampling indicates that the highest levels of TCE are in the Lower Sand Unit (deep wells) and closer to the Engineering Support Building.

Figures 2-13 to 2-15 show representative predemonstration horizontal distributions of TCE in soil from the Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit, respectively (Battelle, 1999c). TCE levels are highest in the Lower Sand Unit and concentrations indicative of DNAPL extend under the building. As seen in the vertical cross section in Figure 2-16, much of the DNAPL is present in the Middle Fine-Grained Unit and the Lower Sand Unit.

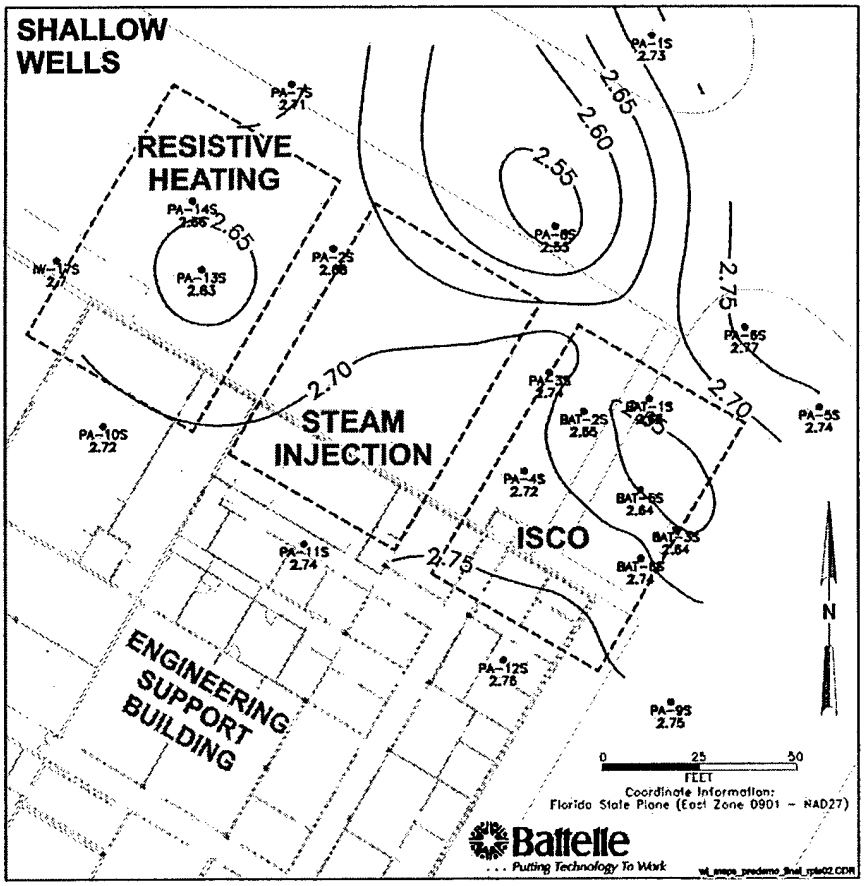


Figure 2-7. Predemonstration Water Levels (as Elevations msl) in Shallow Wells at Launch Complex 34 (September 1999)

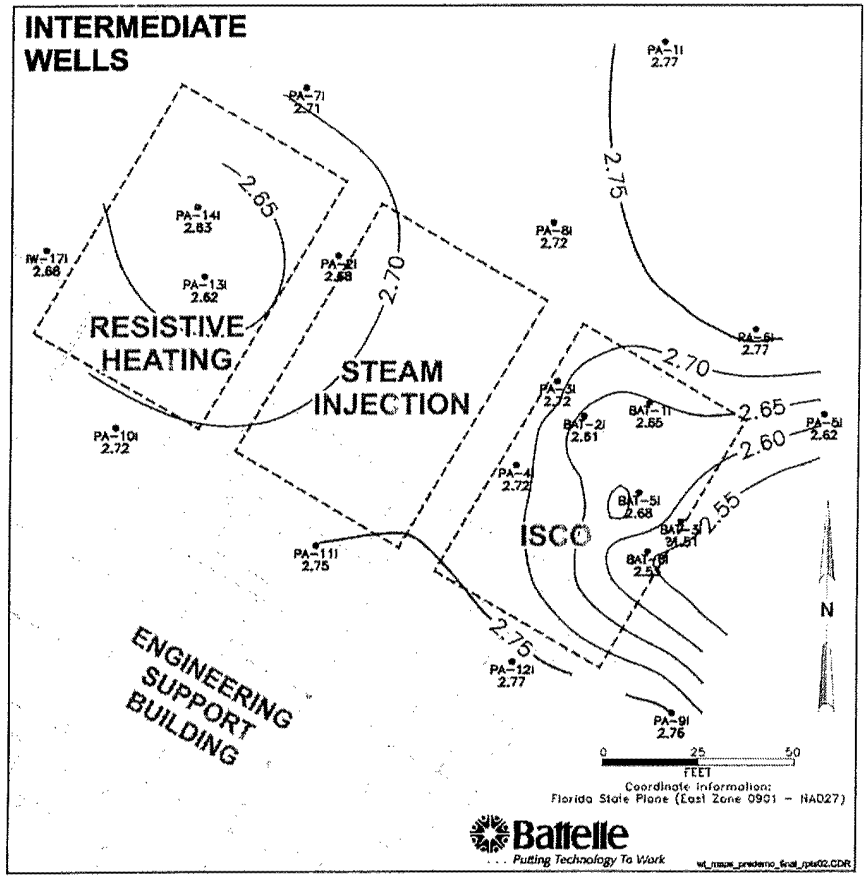


Figure 2-8. Predemonstration Water Levels (as Elevations msl) in Intermediate Wells at Launch Complex 34 (September 1999)

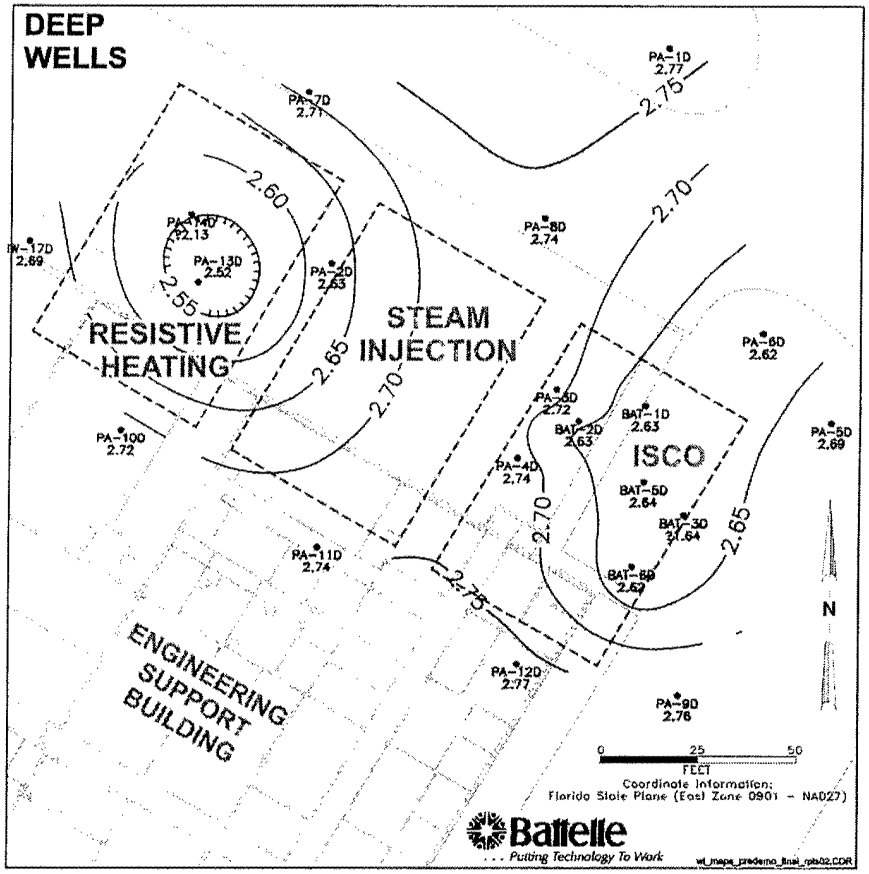


Figure 2-9. Predemonstration Water Levels (as Elevations msl) in Deep Wells at Launch Complex 34 (September 1999)

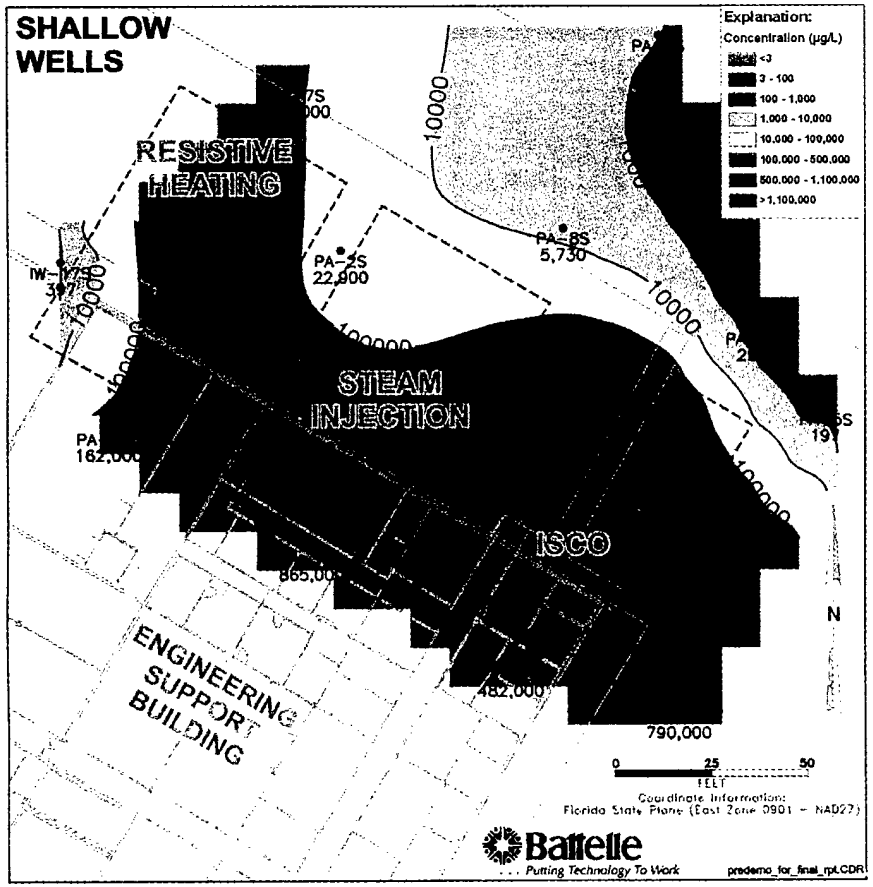


Figure 2-10. Predemonstration Dissolved TCE Concentrations (µg/L) in Shallow Wells at Launch Complex 34 (September 1999)

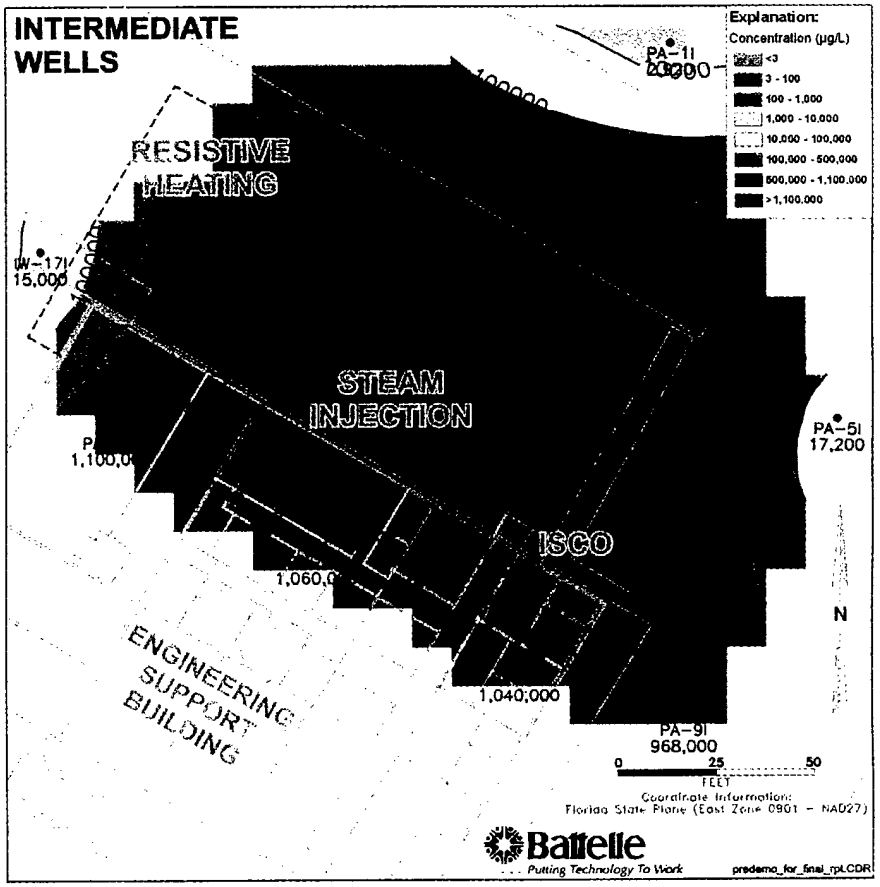


Figure 2-11. Predemonstration Dissolved TCE Concentrations (µg/L) in Intermediate Wells at Launch Complex 34 (September 1999)

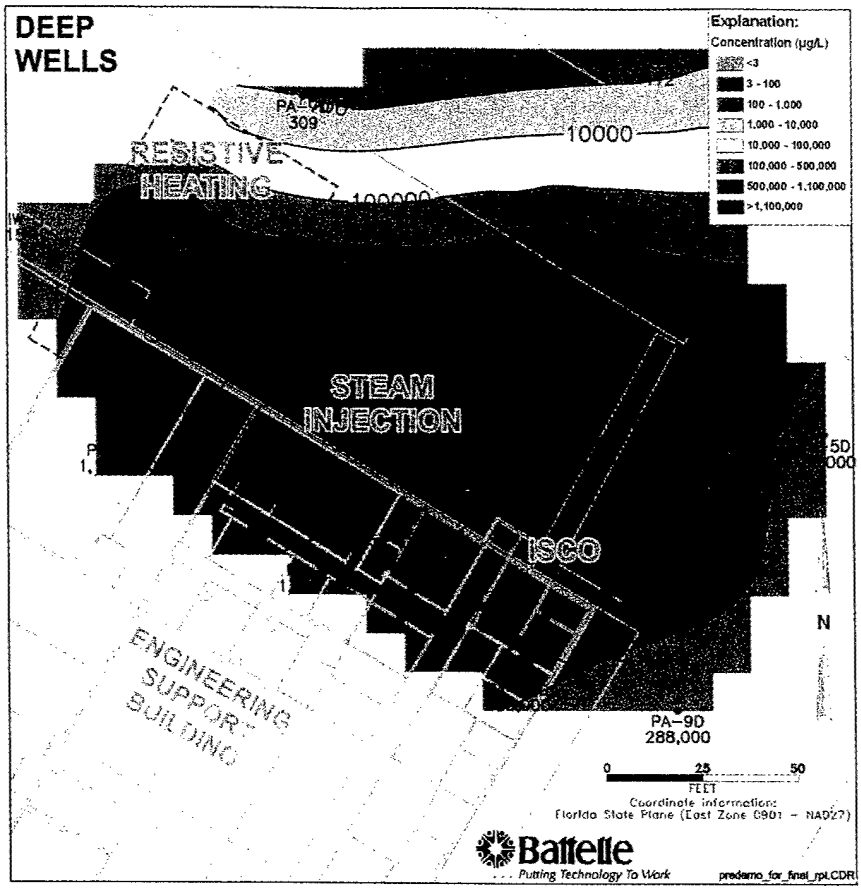


Figure 2-12. Predemonstration Dissolved TCE Concentrations (µg/L) in Deep Wells at Launch Complex 34 (September 1999)

The predemonstration soil sampling indicated that between 6,217 and 9,182 kg of TCE was present in the ISCO plot before the demonstration (see Section 5.1.3). Approximately 5,039 kg of this TCE may occur as DNAPL, based on a threshold TCE concentration of about 300 mg/kg in the soil (see Section 5.1.2). This threshold is determined as the maximum TCE concentration in the dissolved and adsorbed phases in the Launch Complex 34 soil; it was calculated based on properties of the TCE and the subsurface media (the porosity, organic matter content of the soil, etc.) as follows:

$$C_{sat} = \frac{C_{water}\,(K_d \rho_b + n)}{\rho_b} \qquad (2\text{-}1)$$

where C_{sat} = maximum TCE concentration in the dissolved and adsorbed phases (mg/kg)
C_{water} = TCE solubility (mg/L) = 1,100
ρ_b = bulk density of soil (g/cm^3) = 1.59
n = porosity (unitless) = 0.3
K_d = partitioning coefficient of TCE in soil [(mg/kg)/(mg/L)], equal to ($f_{oc} \cdot K_{oc}$)
f_{oc} = fraction organic carbon (unitless)
K_{oc} = organic carbon partition coefficient [(mg/kg)/(mg/L)].

TCE with concentrations below the threshold value of 300 mg/kg was considered dissolved phase; at or above this threshold, the TCE was considered to be DNAPL. The 300-mg/kg figure is a conservative estimate and takes into account the minor variability in the aquifer characteristics, such as porosity, bulk density, and organic carbon content. The native organic carbon content of the Launch Complex 34 soil is relatively low and the threshold TCE concentration is driven by the solubility of TCE in the porewater.

In Figures 2-13 to 2-16, the colors yellow to red indicate presence of DNAPL. As described in Section 4.1.1, contouring software from EarthVision™ was used to divide the plot into isoconcentration shells. A total TCE mass was obtained from multiplying the TCE concentration in each shell by: (1) the volume of the shell; and (2) the

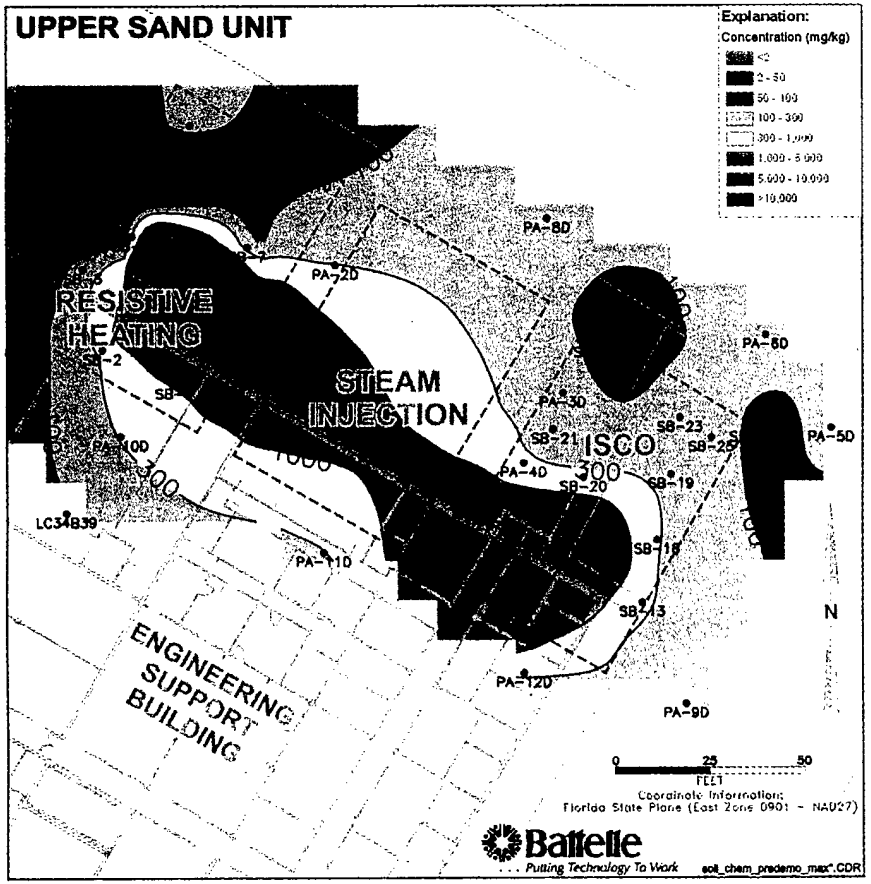


Figure 2-13. Predemonstration TCE Concentrations (mg/kg) in the Upper Sand Unit [-15±2.5 ft msl] Soil at Launch Complex 34 (September 1999)

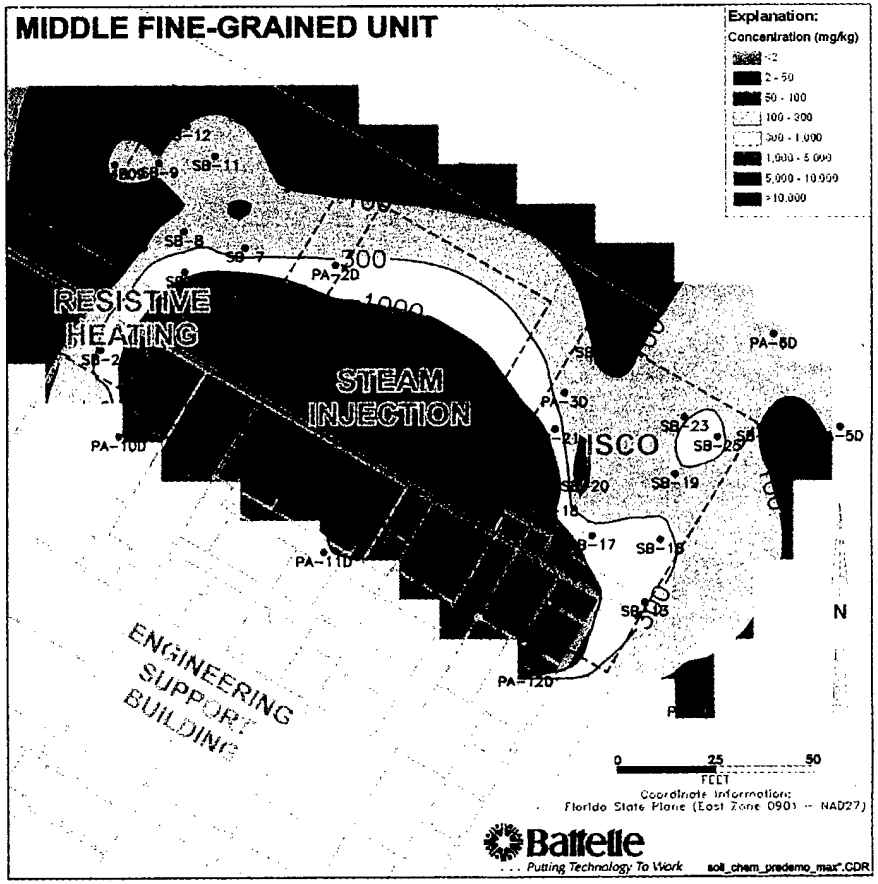


Figure 2-14. Predemonstration TCE Concentrations (mg/kg) in the Middle Fine-Grained Unit [-20±2.5 ft msl] Soil at Launch Complex 34 (September 1999)

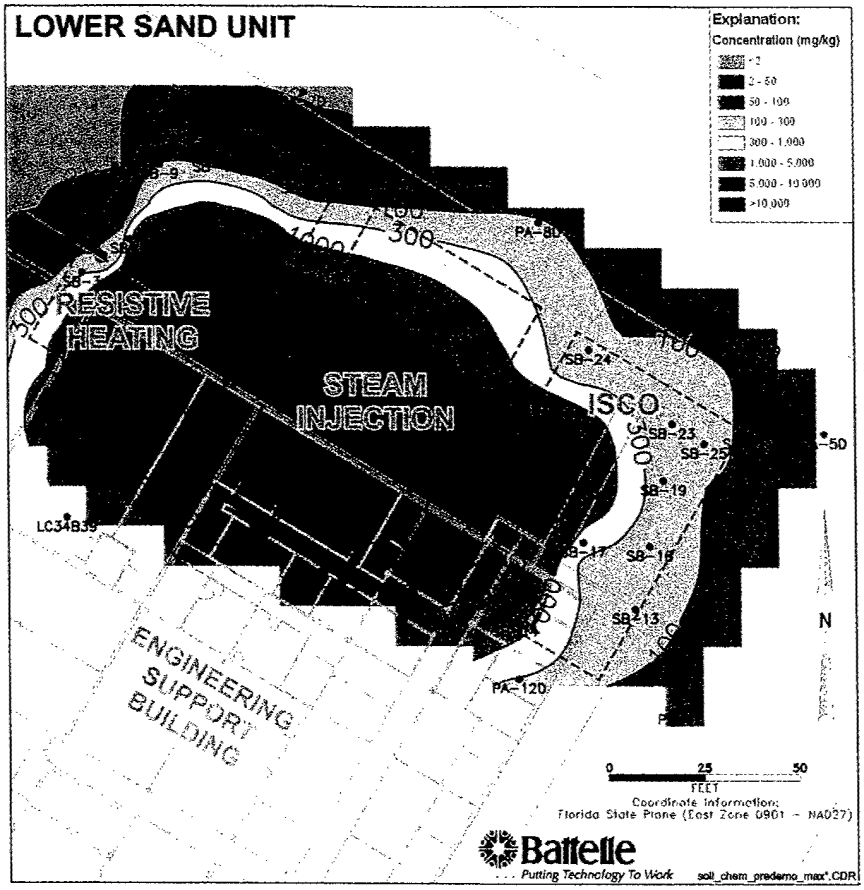


Figure 2-15. Predemonstration TCE Concentrations (mg/kg) in the Lower Sand Unit Unit [–35 ±2.5 ft msl] Soil at Launch Complex 34 (September 1999)

bulk density of the soil. To determine the DNAPL mass in the plot, the TCE mass in the shells containing concentrations greater than 300 mg/kg was used. Section 5.1 contains a more detailed description of the TCE/ DNAPL mass estimation procedures for the ISCO plot.

2.4 Aquifer Quality/Geochemistry

Appendix A.3 lists the various aquifer parameters measured and the standard methods used to analyze them. Appendix D contains the results of the predemonstration groundwater analysis. Predemonstration groundwater field parameters were measured in several wells in the demonstration area in August 1999 (Battelle, 1999c). The pH was relatively constant with depth, and ranged from 7.0 to 7.6. Measured dissolved oxygen (DO) levels were mostly less than 1 mg/L in deep wells, indicating that the aquifer was anaerobic. Oxidation-reduction potential (ORP) from all the sampled wells ranged from –165 to –22 millivolts (mV). Total organic carbon (TOC) concentrations in soil samples ranged from 0.9 to 1.7% dry weight basis; some of this TOC might be attributed to DNAPL, as the samples were collected from the DNAPL source region.

Inorganic groundwater parameters were tested in August 1999 in selected wells to determine the predemonstration quality of the groundwater in the target area (Battelle, 1999c). Inorganic parameters of the groundwater in the surficial aquifer at Launch Complex 34 are summarized as follows:

- Total dissolved solids (TDS) concentrations increased sharply with depth, suggesting that the water becomes more brackish with depth. The TDS levels ranged from 387 to 1,550 mg/L. Chloride concentrations ranged from 38 to 752 mg/L and increased sharply with depth, indicating some saltwater intrusion in the deeper layers. These high levels of chloride made a chloride mass balance difficult during the performance assessment.
- Alkalinity levels ranged from 204 to 323 mg/L and showed little trend with depth or distance.

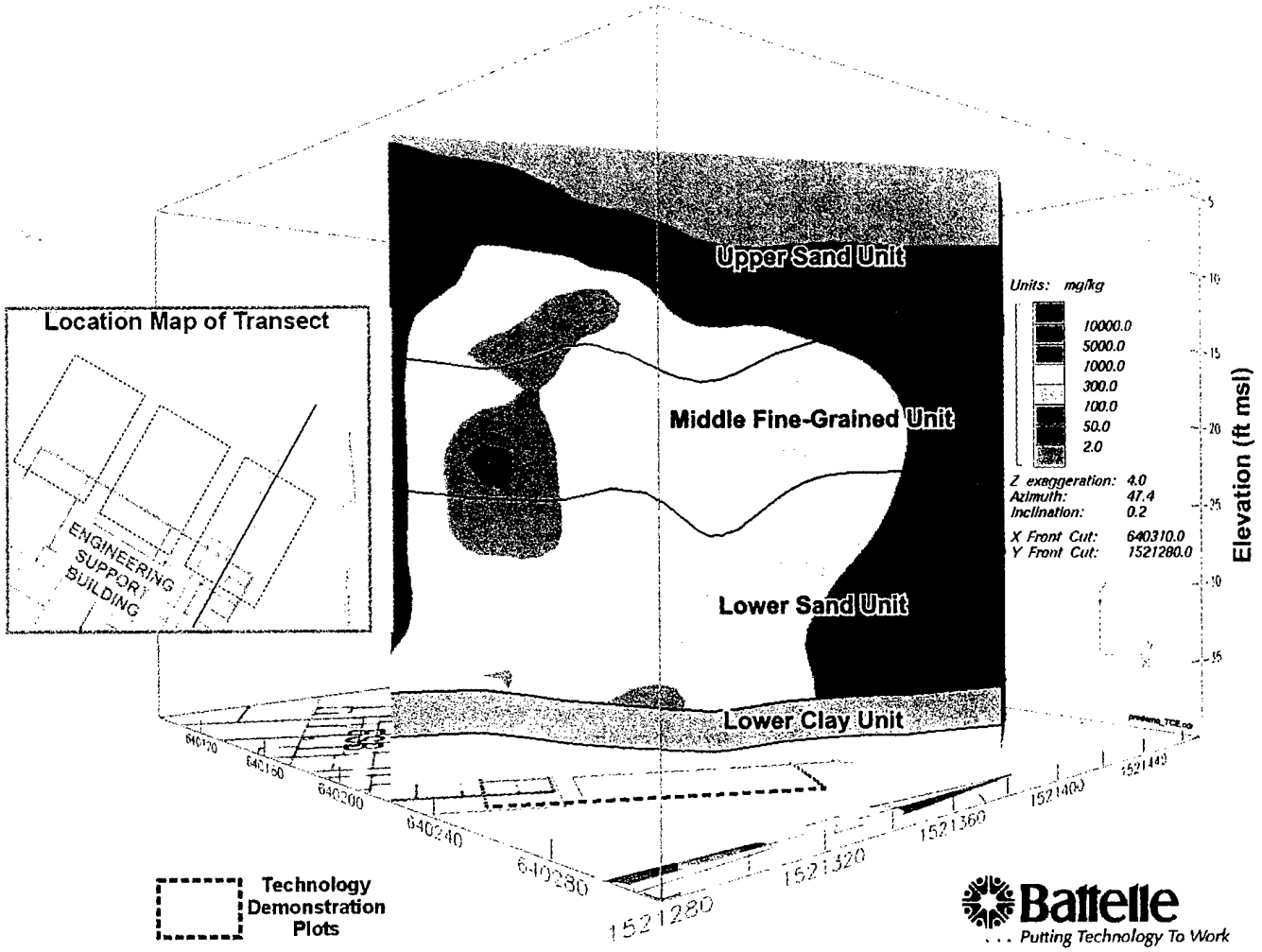


Figure 2-16. Vertical Cross Section through ISCO Plot Showing TCE Soil Concentrations (mg/kg) in the Subsurface

- Iron concentrations ranged from <0.05 to 2.5 mg/L in the groundwater, and manganese concentrations ranged from <0.015 to 1.1 mg/L with little vertical or lateral trend.
- Calcium concentrations ranged from 41 to 88 mg/L and magnesium concentrations ranged from 53 to 84 mg/L.
- Sulfate concentrations were between 29 and 138 mg/L and showed no discernable trends. Nitrate concentrations were below detection.

2.5 Aquifer Microbiology

A separate exploratory microbiological study was conducted in the predemonstration, postdemonstration, and one-year after the demonstration in the ISCO plot under a Work Plan prepared by Battelle and Lawrence Berkeley National Laboratory (Hazen et al., 2000). The approach and results of this study are presented in Appendix E.

3. Technology Operation

This section describes how ISCO technology was implemented at Launch Complex 34.

3.1 ISCO Concept

In an in situ application (see Figure 1-3 and Section 1.3), a chemical oxidant is injected in the subsurface, where it contacts target contaminants and oxidizes them. The main advantage of this technology is that, in many cases, target contaminants can be oxidized to potentially nontoxic products in the ground itself. The benefits of chemical oxidation have been known in the drinking water and wastewater treatment industry for many years. ISCO technology has emerged as a promising option for in situ treatment of contaminated aquifers, especially DNAPL source zones. The oxidant used during the demonstration at Launch Complex 34 was industrial-grade potassium permanganate. The stoichiometric reaction of permanganate with TCE, the primary contaminant at the site, is shown in Equation 3-1.

$$2KMnO_4 + C_2HCl_3 \rightarrow 2CO_2 + 2MnO_2 + 2K^+ + H^+ + 3Cl^- \quad (3\text{-}1)$$

3.2 Regulatory Requirements

Prior to the injection of chemical oxidants such as $KMnO_4$ into the subsurface, an Underground Injection Control (UIC) permit is required, as the potassium permanganate injection may generate byproducts that temporarily exceed drinking water standards. Elevated levels of trace metals were expected in the treated aquifer, given the fact that these metals were present as minor components in the industrial-grade potassium permanganate. For the permanganate demonstration at Launch Complex 34, a variance was obtained from the State of Florida Department of Environmental Protection.

3.3 Application of ISCO Technology at Launch Complex 34

In the IDC demonstration, potassium permanganate was used for in situ oxidation of a DNAPL source zone consisting primarily of TCE. Lesser amounts of *cis*-1,2-DCE are also present in the aquifer at Launch Complex 34. For the purpose of the demonstration, the relatively large source zone was divided into three test plots for three different technology applications. The 75-ft × 50-ft test plot assigned to the ISCO technology is shown in Figure 3-1 and is referred to as the ISCO plot. The ISCO and resistive heating technology demonstrations were conducted concurrently in the two outer plots, which are separated by about 80 ft. The steam injection demonstration will be conducted later.

In their final report (IT Corporation, 2000) on the IDC demonstration, the vendor provided a detailed description of their ISCO equipment, injection methodology, and process measurements. A summary description of the ISCO process implemented by the vendor at Launch Complex 34 follows in this section. Table 3-1 includes a chronology of events constituting the ISCO demonstration and an inventory of the volume of 1 to 2% potassium permanganate solution injected and the mass of $KMnO_4$ consumed. The industrial-grade $KMnO_4$ contains less than 1% of minor impurities (see Appendix I).

The field application of the technology was conducted over a period of 8 months from September 8, 1999 to April 17, 2000. The vendor conducted the field application relatively efficiently, without significant downtime. Because the field system did not involve any complex equipment, maintenance requirements were minimal. This period includes an unexpected interruption from September 13 to 20 due to hurricanes. Other than the hurricanes, the main interruptions were the time intervals between the three series of oxidant injections; these time intervals were used by the vendor to monitor the effectiveness of the oxidant distribution within the plot and by Battelle and the vendor to monitor the degree of interim TCE removal from the plot. The vendor used these breaks to plan each successive series of oxidant injections.

little or no flow; this part of the plot also had the highest DNAPL mass. On the other hand, other regions of high-DNAPL mass in the plot were more conducive to flow.

The vendor estimates that hydraulic displacement from several injection points exceeded 30 ft. However, the radius of permanganate distribution around each injection point was probably less than 10 ft, and varied based on the hydraulic conductivity and TCE/organic matter content of the surrounding aquifer. Such variations were unpredictable, with instances where an injection point would permit only 0 to 0.1 gpm of flow within one horizontal foot of a point that permitted 2 to 3 gpm. Permanganate was injected for durations of up to 4 days at each given injection point. Between 8 to 20 points were injected simultaneously. Between oxidant injections, water was kept flowing through the injection tips to maintain sufficient static head to prevent fine sands and silt from fouling the tips.

During the treatment, the vendor injected a total of 842,985 gal of permanganate solution into the ISCO plot aquifer (see Table 3-1), which corresponds to 66,956 kg (150,653 lb) of $KMnO_4$ mass. On average, the oxidant loading equates to 2.5 kg of $KMnO_4$ per kilogram of soil in the test plot. Not all of the injected permanganate stayed in the test plot; some may have migrated to the surrounding aquifer. The vendor initially based the desired oxidant loading on the results of treatability tests, and the amount and distribution of TCE in the test plot. However, as the treatment progressed, the vendor adjusted the amount of oxidant injected at each location and at each depth based on field indicators, such as visual observation and analysis of groundwater from neighboring monitoring wells.

The hydrant water used for preparing the solution contained 3.8 mg/L of TOC, which adds up to 27 lb of TOC that could have consumed approximately 107 lb of permanganate (assuming a 4:1 potassium permanganate-to-TOC ratio). Approximately 22 drums or 9,300 lb of sludge was generated during the filtration of the injected liquid. After accounting for the sand (about 1,500 lb or 1% by weight of the potassium permanganate stock) that was present in the delivered solid potassium permanganate and some amount of MnO_2 generated, the vendor estimates that most of these solids were undissolved permanganate. This indicates that the mixing tank (50 gal) may have been sized too small. The permanganate supplier indicated that one option in the future to reduce the level of undissolved solids would be to use sodium permanganate, which is available as a solution, instead of solid potassium permanganate (Lowe et al., 2002).

3.4 Health and Safety Issues

Use of heavy equipment (hopper, GeoProbe®, mixer, pumps, and forklift) and a strong oxidant (potassium permanganate) were the main hazards encountered during the demonstration. The vendor's personnel wore Level D personal protective equipment during the demonstration. Steel-toed shoes and hard hats were worn when dealing with heavy equipment. Safety glasses were worn when dealing with the oxidant. Sometimes, operators wore Tyvek® suits when handling the oxidant injection apparatus. A solution consisting of vinegar, hydrogen peroxide, and water was kept handy in a spray bottle and used for neutralizing any oxidant spills on the ground or on clothing. This solution was used whenever a hose burst or oxidant surged up into a monitoring well vault adjacent to an injection point.

The vendor reported an incidental airborne release of $KMnO_4$ while filling the silo with dry permanganate. The release abated when the hatch was sealed tighter. Fugitive dust from the cycle bin feeder in the equipment enclosure had to be abated periodically by spraying the enclosure with the neutralizing solution while wearing respiratory protection. The only incident that caused a slight concern occurred during demobilization, when the hopper used for storage of potassium permanganate solids toppled over as the permanganate supplier was dismounting it and loading it on a truck. There were no injuries during the demonstration.

4. Performance Assessment Methodology

Battelle, in conjunction with the U.S. EPA SITE Program and TetraTech EM, Inc., conducted an independent performance assessment of the ISCO demonstration at Launch Complex 34 (see Figure 4-1). The objectives and methodology for the performance assessment were outlined in a QAPP prepared before the field demonstration and reviewed by all stakeholders (Battelle, 1999d). The objectives of the performance assessment were:

- Estimating the TCE/DNAPL mass removal
- Evaluating changes in aquifer quality due to the treatment
- Evaluating the fate of TCE/DNAPL removed from the ISCO plot
- Verifying ISCO operating requirements and costs.

The first objective, estimating the TCE/DNAPL mass removal percentage, was the primary objective. The rest were secondary objectives in terms of demonstration focus and resources expended. Table 4-1 summarizes the four objectives of the performance assessment and the methodologies used to achieve them.

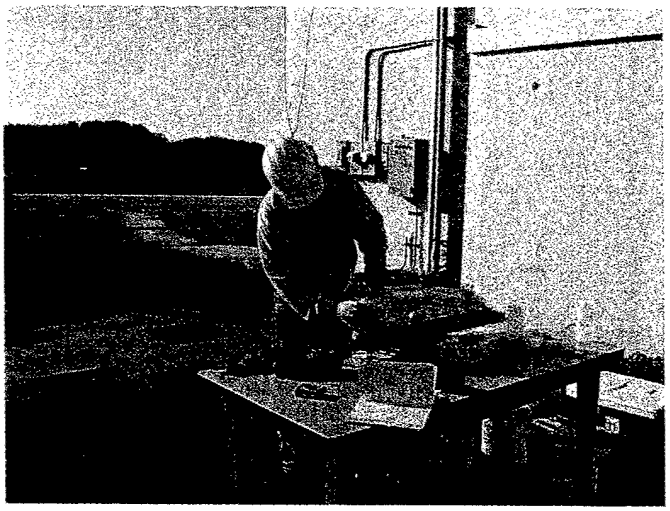


Figure 4-1. Sampling for Performance Assessment at Launch Complex 34

4.1 Estimating TCE/DNAPL Mass Removal

The primary objective of the performance assessment was to estimate the mass removal of total TCE and DNAPL. Total TCE includes both dissolved- and free-phase TCE present in the aquifer soil matrix. DNAPL refers to free-phase TCE only and is defined by the threshold TCE concentration of 300 mg/kg described in Section 2.3. The method used for estimating TCE/DNAPL mass removal was soil sampling in the ISCO plot before and after the demonstration.

At the outset of the demonstration, the Technical Advisory Group, formed by a group of independent academic, government, and industrial representatives, proposed 90% DNAPL mass removal as a target for the three remedial technologies being demonstrated. This target represented an aggressive treatment goal for the technology vendors. Soil sampling was the method selected in the QAPP for determining percent TCE/DNAPL removal at this site. Previous soil coring, sampling, and analysis at Launch Complex 34 (Battelle, 1999b; Eddy-Dilek, 1998) had shown that this was a viable technique for identifying the boundaries of the DNAPL source zone and estimating the DNAPL mass. The advantage of soil sampling was that relatively intensive horizontal and vertical coverage of the ISCO plot, as well as of the dissolved-phase TCE and DNAPL distribution, could be achieved with a reasonable number of soil samples and without DNAPL access being limited to preferential flowpaths in the aquifer. Soil sampling was conducted before (predemonstration event), immediately after (postdemonstration event), and nine months after (extended monitoring event) the ISCO application.

Although the primary focus of the performance assessment was on TCE, *cis*-1,2-DCE and vinyl chloride, contaminants that could be oxidized by permanganate also were measured in the soil samples; however, high TCE

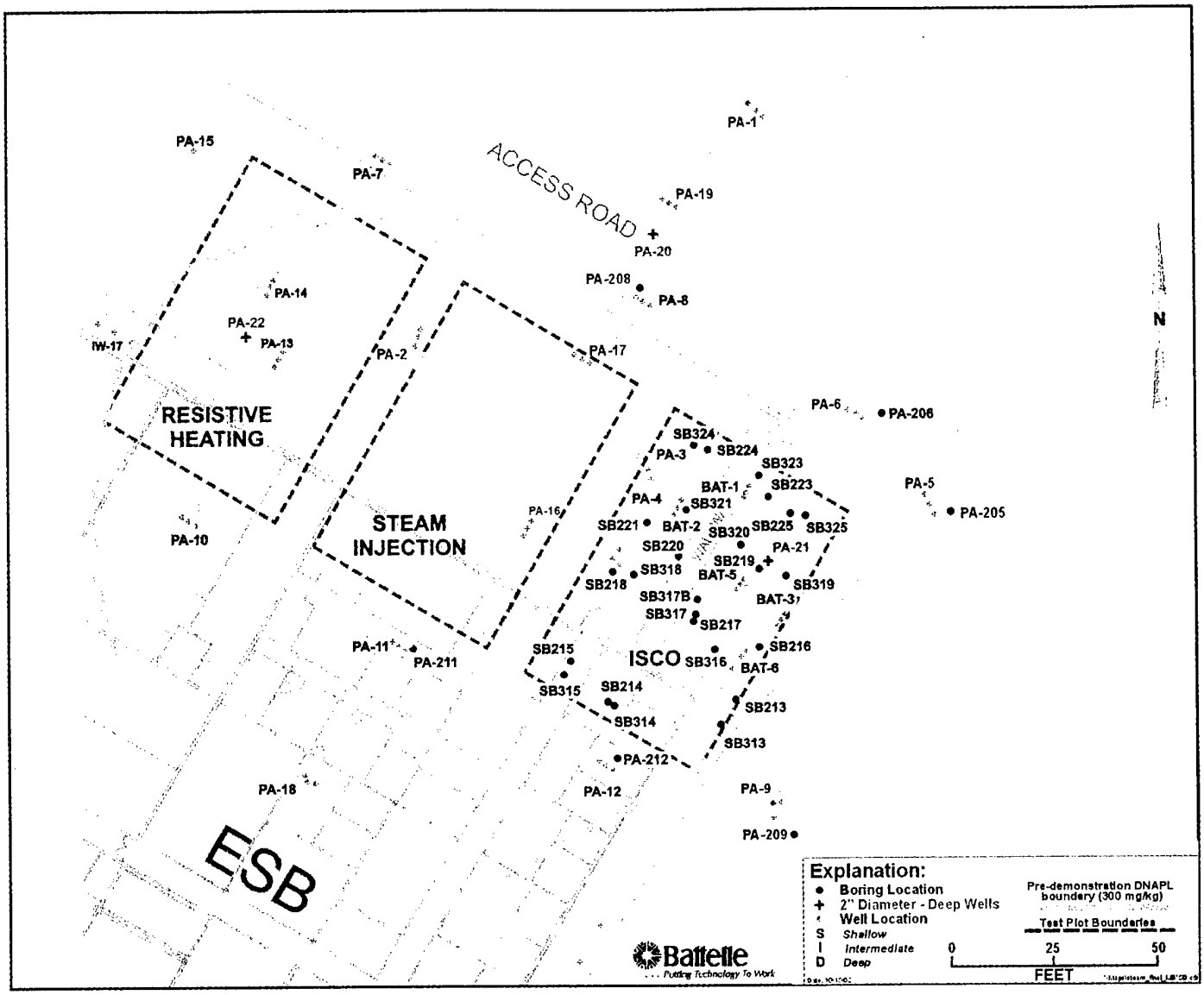


Figure 4-3. Postdemonstration Soil Coring Locations SB-213 to SB-224 in the Test Plot (May 2000) (the corresponding extended monitoring soil coring locations are similarly numbered SB-313 to SB-324 [February 2001])

4.1.1 Linear Interpolation

Linear interpolation is the more straightforward and intuitive method for estimating TCE concentration or mass in the entire plot, based on a limited number of sampled points. TCE concentrations are assumed to be linearly distributed between sampled points. A software program, such as EarthVision™, has an edge over manual calculations in that it is easier to conduct the linear interpolation in three dimensions. In contouring, the only way to address the spatial variability of the TCE distribution is to collect as large a number of samples as is practical so that good coverage of the plot is obtained; the higher the sampling density, the smaller the distances over which the data need to be interpolated.

For linear interpolation, input parameters must be adjusted to accommodate various references such as geology and sample size. Nearly 300 soil samples were collected from the 12 coring locations in the plot during each event (predemonstration and postdemonstration), which was the highest number practical within the resources of this project. Appendix A (Section A.1.1) describes how the number and distribution of these sampling points were determined to obtain good coverage of the plot.

The contouring software EarthVision™ uses the same methodology that is used for drawing water level contour maps based on water level measurements at discrete locations in a region. The only difference with this software is that the TCE concentrations are mapped in three

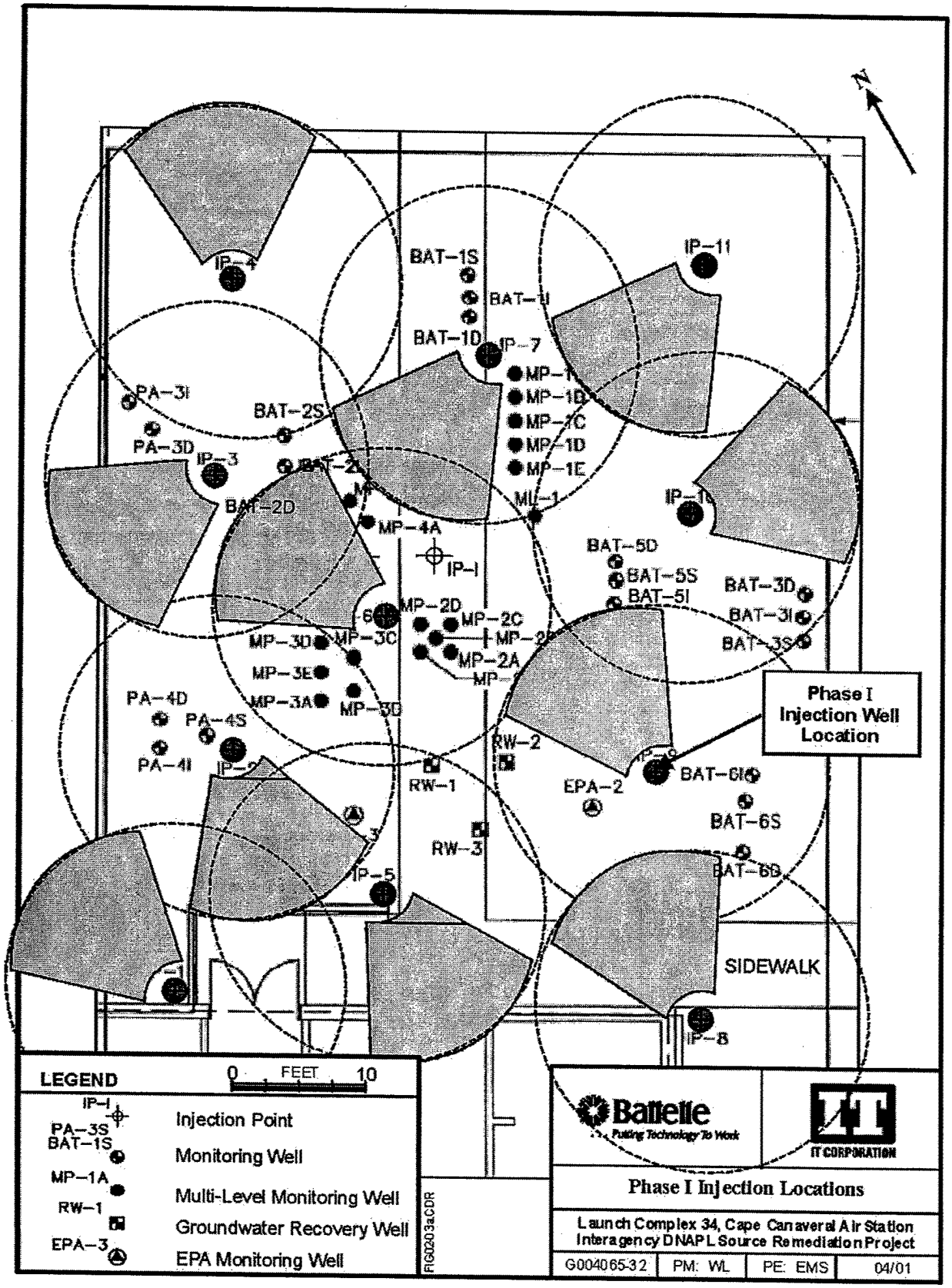


Figure 3-6. Phase 1 Injection Locations and Radii of Influence of the Injected Oxidant

little or no flow; this part of the plot also had the highest DNAPL mass. On the other hand, other regions of high-DNAPL mass in the plot were more conducive to flow.

The vendor estimates that hydraulic displacement from several injection points exceeded 30 ft. However, the radius of permanganate distribution around each injection point was probably less than 10 ft, and varied based on the hydraulic conductivity and TCE/organic matter content of the surrounding aquifer. Such variations were unpredictable, with instances where an injection point would permit only 0 to 0.1 gpm of flow within one horizontal foot of a point that permitted 2 to 3 gpm. Permanganate was injected for durations of up to 4 days at each given injection point. Between 8 to 20 points were injected simultaneously. Between oxidant injections, water was kept flowing through the injection tips to maintain sufficient static head to prevent fine sands and silt from fouling the tips.

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- Estimating the TCE/DNAPL mass removal
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The first objective, estimating the TCE/DNAPL mass removal percentage, was the primary objective. The rest were secondary objectives in terms of demonstration focus and resources expended. Table 4-1 summarizes the four objectives of the performance assessment and the methodologies used to achieve them.



Figure 4-1. Sampling for Performance Assessment at Launch Complex 34

4.1 Estimating TCE/DNAPL Mass Removal

The primary objective of the performance assessment was to estimate the mass removal of total TCE and DNAPL. Total TCE includes both dissolved- and free-phase TCE present in the aquifer soil matrix. DNAPL refers to free-phase TCE only and is defined by the threshold TCE concentration of 300 mg/kg described in Section 2.3. The method used for estimating TCE/DNAPL mass removal was soil sampling in the ISCO plot before and after the demonstration.

At the outset of the demonstration, the Technical Advisory Group, formed by a group of independent academic, government, and industrial representatives, proposed 90% DNAPL mass removal as a target for the three remedial technologies being demonstrated. This target represented an aggressive treatment goal for the technology vendors. Soil sampling was the method selected in the QAPP for determining percent TCE/DNAPL removal at this site. Previous soil coring, sampling, and analysis at Launch Complex 34 (Battelle, 1999b; Eddy-Dilek, 1998) had shown that this was a viable technique for identifying the boundaries of the DNAPL source zone and estimating the DNAPL mass. The advantage of soil sampling was that relatively intensive horizontal and vertical coverage of the ISCO plot, as well as of the dissolved-phase TCE and DNAPL distribution, could be achieved with a reasonable number of soil samples and without DNAPL access being limited to preferential flowpaths in the aquifer. Soil sampling was conducted before (predemonstration event), immediately after (postdemonstration event), and nine months after (extended monitoring event) the ISCO application.

Although the primary focus of the performance assessment was on TCE, *cis*-1,2-DCE and vinyl chloride, contaminants that could be oxidized by permanganate also were measured in the soil samples; however, high TCE

Table 4-1. Summary of Performance Assessment Objectives and Associated Measurements

Objective	Measurements	Sampling Locations[a]
Estimating TCE/ DNAPL mass removal	CVOCs in soil; once before and twice after treatment	12 horizontal locations, every 2-ft depth interval
Evaluating changes in aquifer quality	CVOCs in groundwater; before, during, and after treatment	Primarily well clusters BAT-2 and BAT-5; other plot wells (BAT-1, BAT-3, BAT-6, and PA-4) sampled to guide oxidant injections
	Field parameters in groundwater; before, during, and after treatment	Primarily well clusters BAT-2 and BAT-5; perimeter wells[b] for verifying spread
	Inorganic parameters in groundwater (cations, anions, including alkalinity); before and after treatment	Primarily well clusters BAT-2 and BAT-5; perimeter wells[b] for verifying spread
	Trace metals in groundwater; before, during, and after treatment	Primarily well clusters BAT-2 and BAT-5; perimeter wells[b] for verifying spread
	TOC in soil; before and after treatment	Two locations, three depths inside plot
	TDS and BOD; before and after treatment	Primarily well clusters BAT-2 and BAT-5
	Hydraulic conductivity; before and after treatment	BAT-5S, BAT-6S, BAT-3I, BAT-5I, BAT-6I, BAT-3D, and BAT-6D
Evaluating fate of TCE/DNAPL	Chloride in groundwater	Primarily well clusters BAT-2 and BAT-5; perimeter wells[b]
	Alkalinity in groundwater	Primarily well clusters BAT-2 and BAT-5
	Hydraulic gradients	All wells
	Potassium ion in groundwater	Primarily well clusters BAT-2 and BAT-5; perimeter wells[b]
	Potassium permanganate in groundwater	Primarily well clusters BAT-2 and BAT-5; perimeter wells[b]
	Surface emissions; primarily during oxidant injection	Three locations inside plot; 3 background locations
Verifying operating requirements and cost	Field observations; tracking materials consumption and costs	Field observations by vendor and Battelle; materials consumption and costs reported by vendor to MSE

(a) Monitoring well locations inside and outside the ISCO plot are shown in Figure 3-1. Soil coring locations are shown in Figures 4-2 (predemonstration) and 4-3 (postdemonstration).
(b) Perimeter wells are PA-3, PA-5, PA-9, and PA-12. Distant wells PA-1, PA-8, and PA-11, as well as other wells in the vicinity, were sampled for various parameters, based on ongoing data acquisition and interpretation during the demonstration.

levels often masked the other two compounds and made their detection difficult.

The statistical basis for determining the number of soil coring locations and number of soil samples required to be collected in the ISCO plot is described in Appendix A.1. Based on the horizontal and vertical variability observed in the TCE concentrations in soil cores collected during preliminary site characterization in February 1999, a systematic unaligned sampling approach was used to divide the plot into a 4 × 3 grid and collect one soil core in each grid cell for a total of 12 soil cores (soil cores SB-13 to SB-24 shown in Figure 4-2). The resulting 12 cores provided good spatial coverage of the 75-ft × 50-ft ISCO plot and included two cores inside the Engineering Support Building. For each soil core, the entire soil column from ground surface to aquitard (approximately 45 ft bgs) was sampled and analyzed in 2-ft sections. Sets of 12 cores each were similarly collected after the demonstration (SB-213 to SB-224) and nine months after the demonstration (SB-313 to SB-324 in corresponding locations), as shown in Figure 4-3. Each sampling event, therefore, consisted of nearly 300 soil samples (12 cores, 23 two-foot intervals per core, plus duplicates). The thicker dashed lines in Figures 4-2 and 4-3 represent the predemonstration DNAPL source boundary. This boundary includes all the soil coring locations where at least one of the soil samples (depth intervals) showed TCE levels above 300 mg/kg.

Soil coring, sampling, and extraction methods are described in Appendix A.2 and summarized in this section. Figures 4-4 and 4-5 show the outdoor and indoor rigs used for soil coring outside and inside the Engineering Support Building. A direct-push rig with a 2-inch diameter, 4-ft-long sample barrel was used for coring. As soon as the sample barrel was retrieved, the 2-ft section of core was split vertically and approximately one-quarter of the core (approximately 200 g of wet soil) was deposited into a predetermined volume (250 mL) of methanol for extraction in the field. The methanol extract was transferred into 20-mL volatile organic analysis (VOA) vials, which were shipped to a certified laboratory for analysis. The sampling and extraction technique used at this site provided better coverage of a heterogeneously distributed contaminant distribution as compared to the more conventional method of collecting and analyzing small soil samples at discrete depths, because

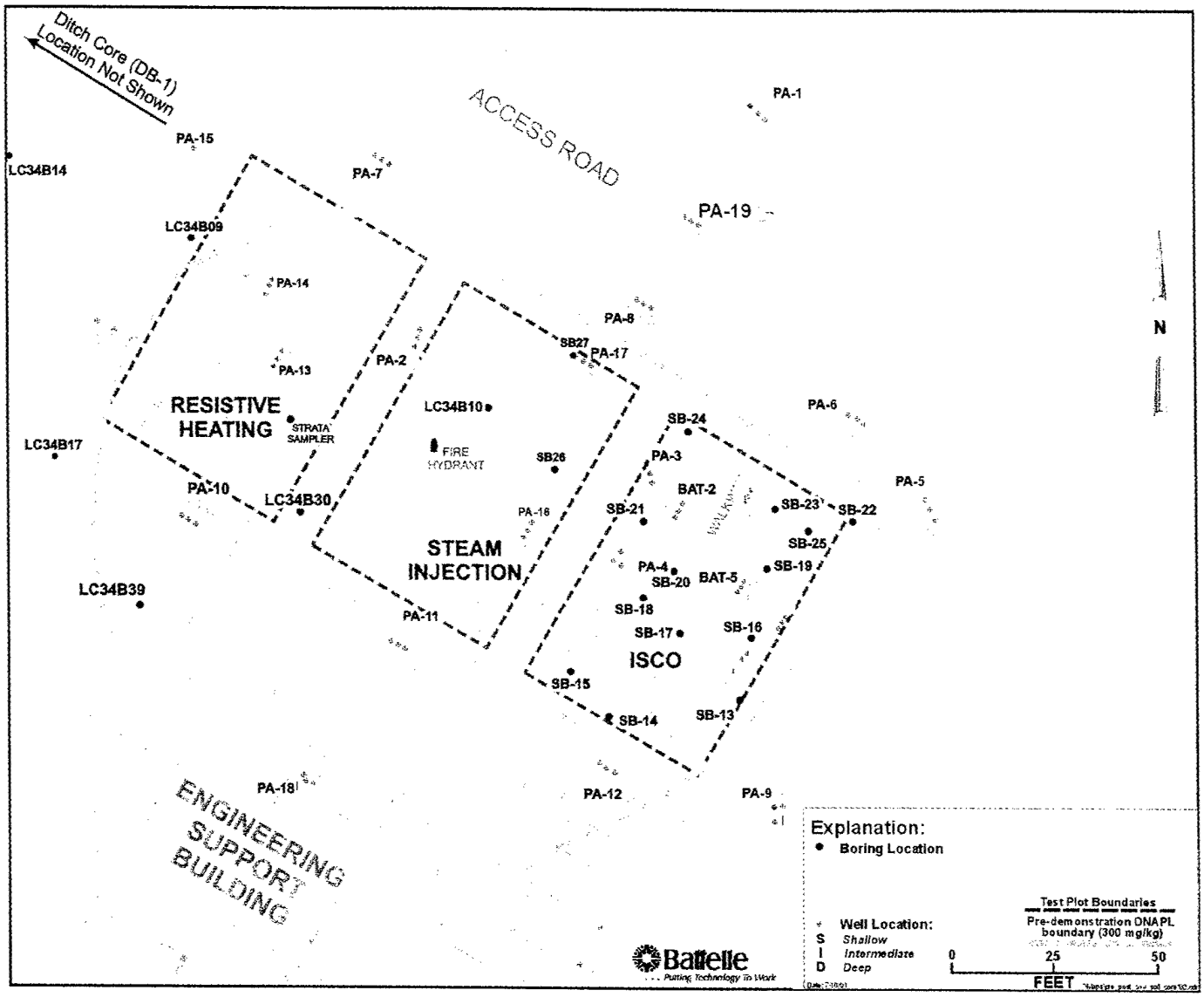


Figure 4-2. Predemonstration Soil Coring Locations (SB-13 to SB-24) in ISCO Plot (June 1999)

the entire vertical depth of the soil column at the coring location could be analyzed. Preliminary site characterization had showed that the vertical variability of the TCE distribution was greater than the horizontal variability, and this sampling and extraction method allowed continuous vertical coverage of the soil column. The efficiency of TCE recovery by this method (modified EPA Method 5035; see Appendix A.2) was evaluated through a series of tests conducted for the demonstration (see Appendix G). In these tests, a surrogate compound (trichloroethane [TCA]) was spiked into soil cores from the Launch Complex 34 aquifer, extracted, and analyzed. Replicate extractions and analysis of a spiked surrogate (TCA) indicated a CVOC recovery efficiency between 84 and 113% (with an average recovery of 92%), which was considered sufficiently accurate for the demonstration.

Two data evaluation methods were used for estimating TCE/DNAPL mass removal in the ISCO plot: linear interpolation or contouring, and kriging. The spatial variability or spread of the TCE distribution in a DNAPL source zone typically is high, the reason being that small pockets of residual solvent may be distributed unevenly across the source region. The two methods address this spatial variability in different ways, and therefore the resulting mass removal estimates differ slightly. Because it is impractical to sample every single point in the ISCO plot and obtain a true TCE mass estimate for the plot, both methods basically address the practical difficulty of estimating the TCE concentrations at unsampled points by interpolating (estimating) between sampled points. The objective in both methods is to use the information from a limited sample set to make an inference about the entire population (the entire plot or a stratigraphic unit).

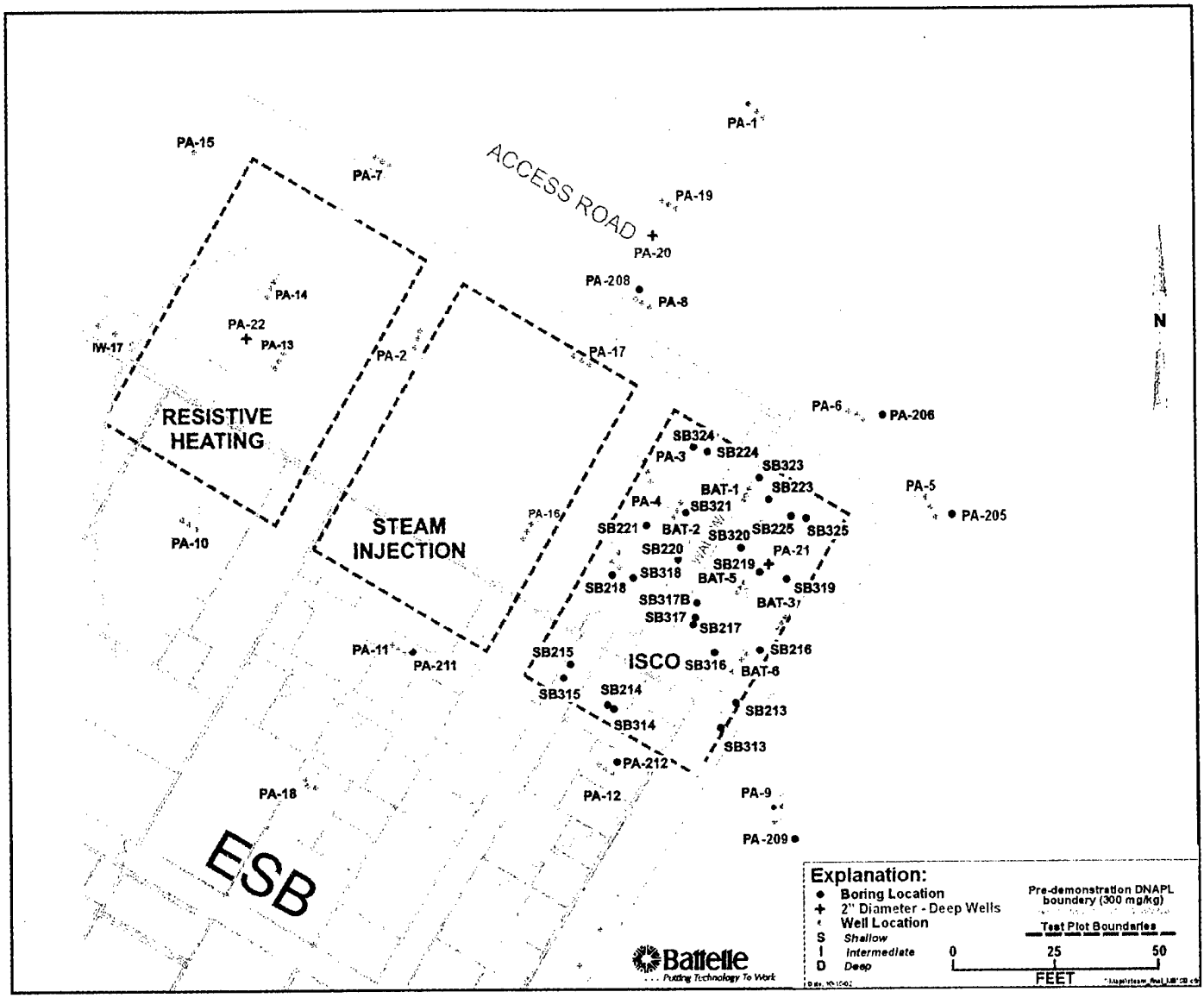


Figure 4-3. Postdemonstration Soil Coring Locations SB-213 to SB-224 in the Test Plot (May 2000) (the corresponding extended monitoring soil coring locations are similarly numbered SB-313 to SB-324 [February 2001])

4.1.1 Linear Interpolation

Linear interpolation is the more straightforward and intuitive method for estimating TCE concentration or mass in the entire plot, based on a limited number of sampled points. TCE concentrations are assumed to be linearly distributed between sampled points. A software program, such as EarthVision™, has an edge over manual calculations in that it is easier to conduct the linear interpolation in three dimensions. In contouring, the only way to address the spatial variability of the TCE distribution is to collect as large a number of samples as is practical so that good coverage of the plot is obtained; the higher the sampling density, the smaller the distances over which the data need to be interpolated.

For linear interpolation, input parameters must be adjusted to accommodate various references such as geology and sample size. Nearly 300 soil samples were collected from the 12 coring locations in the plot during each event (predemonstration and postdemonstration), which was the highest number practical within the resources of this project. Appendix A (Section A.1.1) describes how the number and distribution of these sampling points were determined to obtain good coverage of the plot.

The contouring software EarthVision™ uses the same methodology that is used for drawing water level contour maps based on water level measurements at discrete locations in a region. The only difference with this software is that the TCE concentrations are mapped in three



Figure 4-4. Outdoor Cone Penetrometer Test Rig for Soil Coring at Launch Complex 34

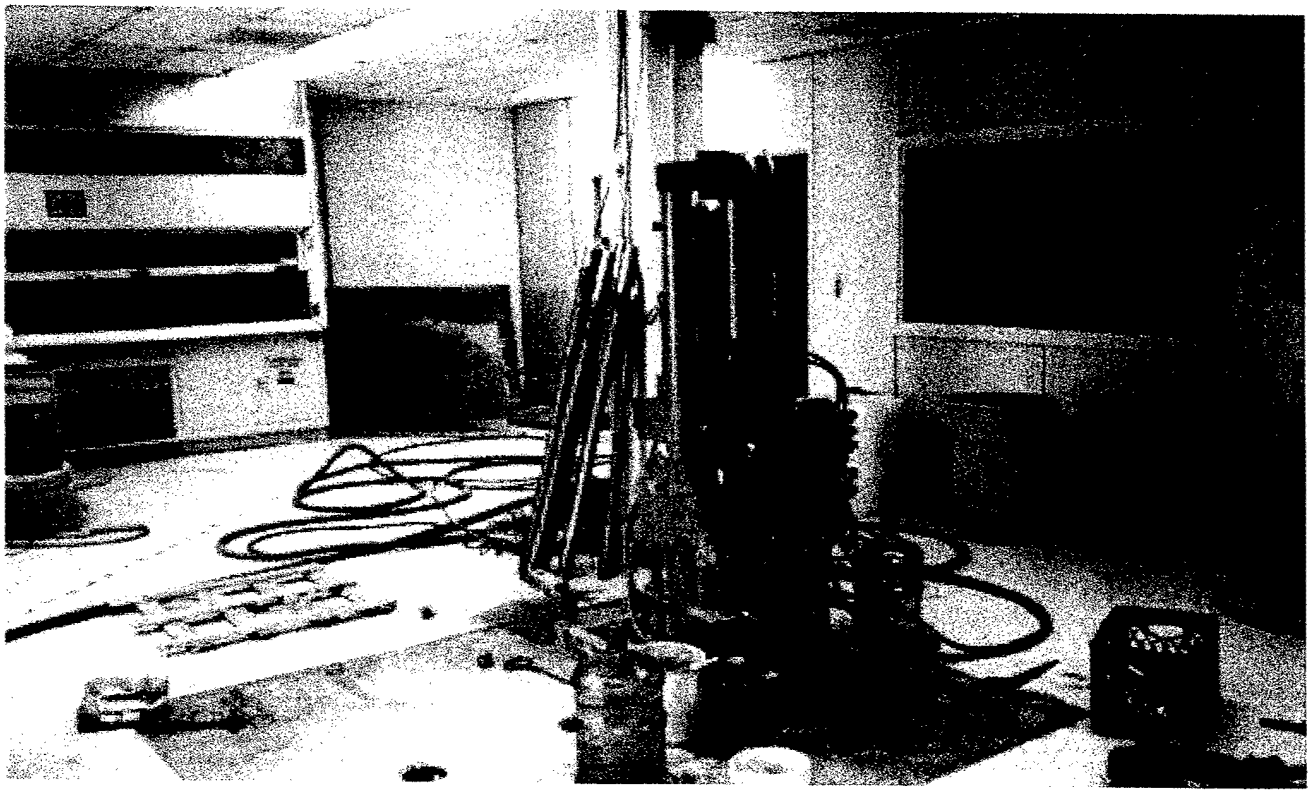


Figure 4-5. Indoor Vibra-Push Rig (LD Geoprobe® Series) Used in the Engineering Support Building

dimensions to generate iso-concentration shells (i.e., volumes of soil that fall within a specified concentration range). The average TCE concentration of each shell is multiplied by the volume of the shell (as estimated by the volumetric package in the software) and the bulk density of the soil (1.59 g/cm^3, estimated during preliminary site characterization) to estimate a TCE mass for each shell. The TCE mass in each region of interest (Upper Sand Unit, Middle-Fine-Grained Unit, Lower Sand Unit, and the entire plot) is obtained by adding up the portion of the shells contained in that region. The DNAPL mass is obtained by adding up the masses in only those shells that have TCE concentrations above 300 mg/kg. Contouring provides a single mass estimate for the region of interest.

4.1.2 Kriging

Kriging is a geostatistical interpolation tool that takes into consideration the spatial correlations among the TCE data in making inferences about the TCE concentrations at unsampled points. Spatial correlation analysis determines the extent to which TCE concentrations at various points in the plot are similar or different. Generally, the degree to which TCE concentrations are similar or different is a function of distance and direction. Based on these correlations, kriging determines how the TCE concentrations at sampled points can be optimally weighted to infer the TCE concentrations/masses at unsampled points in the plot or the TCE mass in an entire region of interest (entire plot or stratigraphic unit). Kriging accounts for the uncertainty in each point estimate by calculating a standard error for the estimate. Therefore a range of TCE mass estimates is obtained instead of a single estimate; this range is defined by an average and a standard error or by a confidence interval. The confidence or level of significance required by the project objectives determines the width of this range. A level of significance of 0.2 (or 80% confidence) was determined as necessary at the beginning of the demonstration (Battelle, 1999d).

4.1.3 Interpreting the Results of the Two Mass Removal Estimation Methods

The two data evaluation methods address the spatial variability of the TCE distribution in different ways and, therefore, the resulting mass removal estimates differ slightly between the two methods. This section discusses the implication of these differences.

In both contouring and kriging, TCE mass removal is accounted for on an absolute basis; higher mass removal in a few high-TCE concentration portions of the plot can offset low mass removal in other portions of the plot, to infer a high level of mass removal. Kriging probably provides a more informed inference of the TCE mass removal than contouring because it takes into account the spatial correlations in the TCE distribution and the uncertainties (error) associated with the estimates. At the same time, because a large number of soil samples were collected during each event, the results in Section 5.1 show that contouring was able to overcome the spatial variability to a considerable extent and provide mass estimates that were generally in agreement with the ranges provided by kriging.

4.2 Evaluating Changes in Aquifer Quality

A secondary objective of the performance assessment was to evaluate any short-term changes in aquifer quality due to the treatment. ISCO affects both the contaminant and the native aquifer characteristics. Pre- and postdemonstration measurements conducted to evaluate the short-term impacts of the technology application on the aquifer included:

- CVOC measurements in the groundwater inside the ISCO plot
- Field parameter measurements (pH, Eh, DO, ORP, temperature, and conductivity) in the groundwater
- Inorganic measurements (common cations and anions) in the groundwater
- Selected trace metals
- TDS and 5-day biological oxygen demand (BOD)
- TOC measurements in the soil
- Hydraulic conductivity of the aquifer
- Microbial populations in the aquifer (see Figure 4-6 and Appendix E).

These measurements were conducted primarily in monitoring wells within the plot, but some measurements also were made in the perimeter and distant wells.

4.3 Evaluating the Fate of the TCE/DNAPL Mass Removed

Another secondary objective was to evaluate the fate of the TCE removed from the plot by ISCO treatment. Possible pathways (or processes) for the TCE removed from the plot include oxidation (destruction of TCE) and migration from the ISCO plot (to the surrounding regions). These pathways were evaluated by the following measurements:



Figure 4-6. Collecting and Processing Groundwater Samples for Microbiological Analysis

- Chloride in groundwater (mineralization of CVOCs leads to formation of chloride) and other inorganic constituent in groundwater
- Alkalinity in groundwater (oxidation of CVOCs and native organic matter leads to formation of CO_2 which, in a closed system, forms carbonate)
- Hydraulic gradients (injection of oxidant solution creates gradients indicative of groundwater movement)
- Potassium ion in the ISCO plot and surrounding wells (potassium ion from potassium permanganate addition acts as a semi-conservative tracer for tracking movement of injected solution)
- $KMnO_4$ in groundwater (presence of excess $KMnO_4$ indicates completeness of oxidation in the vicinity of the sample)
- Surface emission tests were conducted as described in Appendix F to evaluate the potential for CVOC losses to the vadose zone and atmosphere (see Figure 4-7)
- CVOC concentration in the semi-confined aquifer below the test plot.

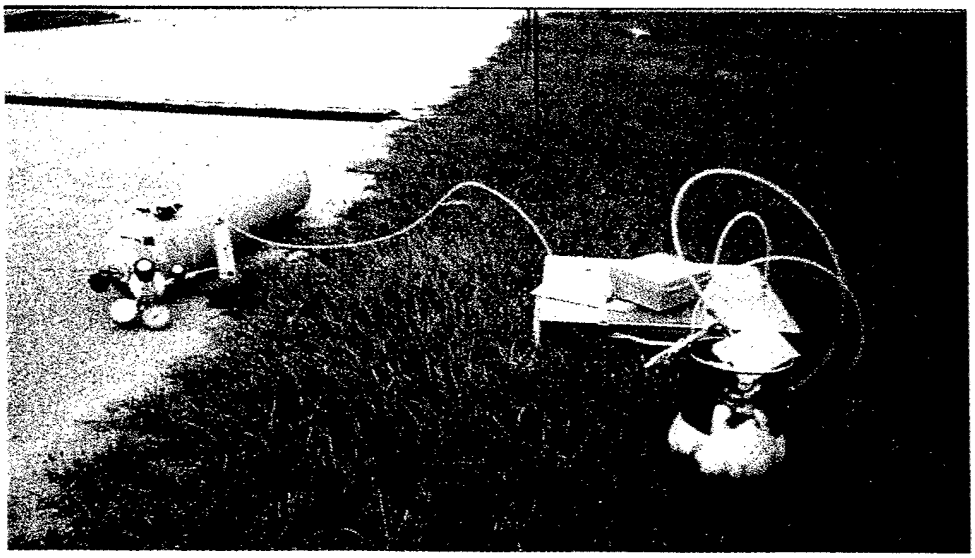


Figure 4-7. Surface Emissions Testing at Launch Complex 34

Potential for Migration to the Semi-Confined Aquifer

During the week of April 2, 2001, Battelle installed three wells into the semi-confined aquifer with a two-stage (dual-casing) drilling and completion process with a mud rotary drill rig provided by Environmental Drilling Services, Inc., from Ocala, Florida. Figure 4-8 shows the location of these wells (PA-20, PA-21, and PA-22). The objective of installing these deeper wells was to evaluate the potential presence of CVOC contamination in the confined aquifer and to assess any effect of the DNAPL remediation demonstration on the confined aquifer.

These wells were first proposed in 1999, but the IDC and Battelle decided to forgo their construction because of NASA's concerns over breaching the relatively thin aquitard (i.e., the Lower Clay Unit). Subsequently, nonintrusive geophysical tests indicated the possibility of DNAPL in the semi-confined aquifer (Resolution Resources, 2000). It was not clear whether any DNAPL in the semi-confined aquifer (approximately 50 to 120 ft bgs) would be related to the demonstration activities. However, the IDC and Battelle decided that there were enough questions about the status of this aquifer that it would be worthwhile taking the risk to characterize the deeper aquifer. Suitable precautions would be taken to mitigate any risk of downward migration of contamination during the well installation.

Westinghouse Savannah River Company (WSRC) sent an observer to monitor the field installation of the wells. The observer verified that the wells were installed properly and that no drag-down of contaminants was created during their installation.

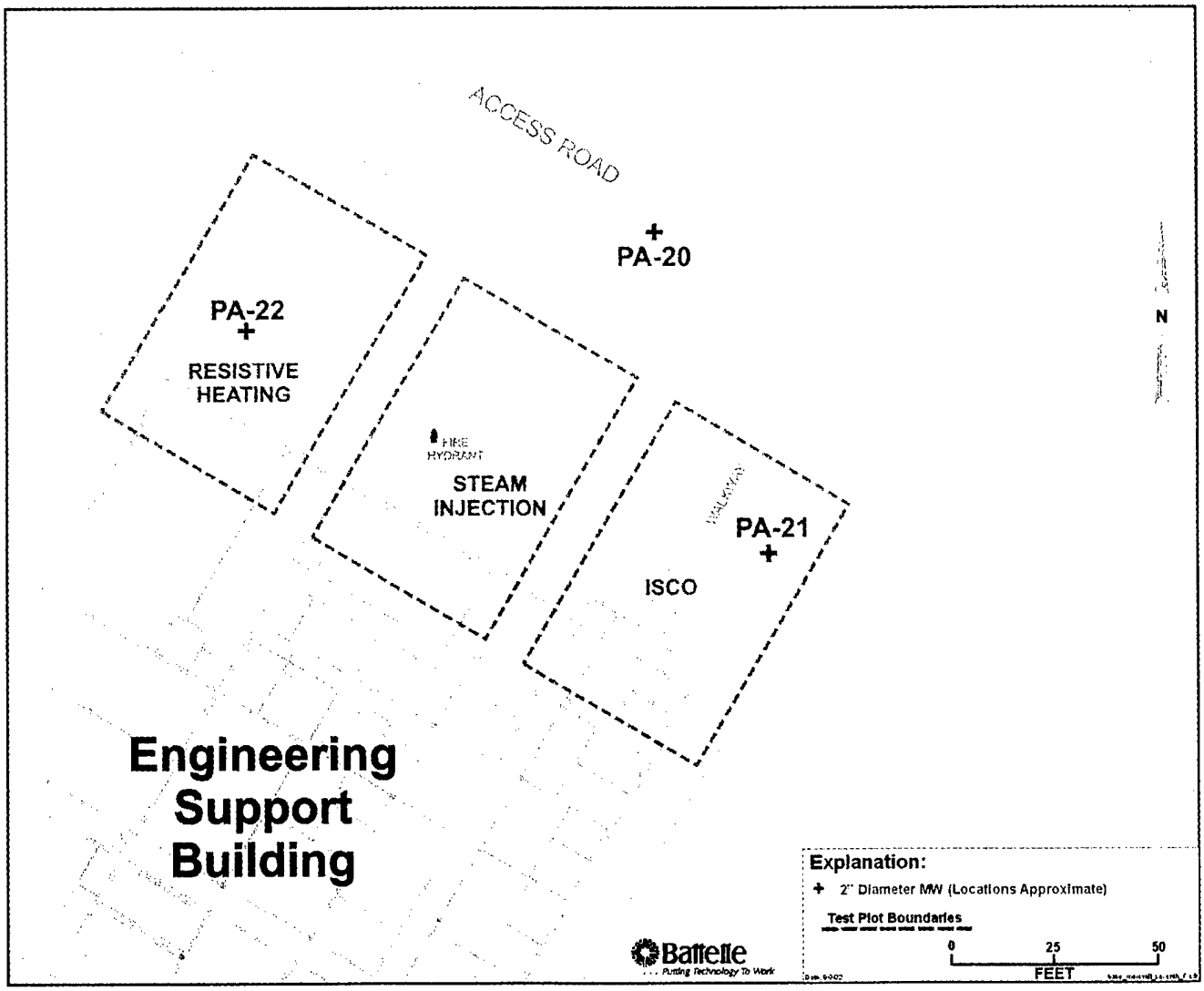


Figure 4-8. Location Map of Semi-Confined Aquifer Wells at Launch Complex 34

4.3.1 Geologic Background at Launch Complex 34

Several aquifers are present at the Launch Complex 34 area, reflecting a barrier island complex overlying coastal sediments (Figure 4-9). The surficial aquifer is comprised of layers of silty sand and shells. It extends down to about 45 ft bgs, where the Lower Clay Unit (aquitard) is encountered. Previous logging suggested that the Lower Clay Unit is 3 ft thick and consists of gray clay with low to medium plasticity. A 40- to 50-ft-thick semi-confined aquifer (Caloosahatchee Marl formation or equivalent) resides under the Lower Clay Unit and is composed of silty to clayey sand and shells. The semi-confined aquifer is confined in the Launch Complex 34 area. Underlying the semi-confined aquifer is the Hawthorne formation, a clayey sand-confining layer. The limestone Floridan Aquifer underlies the Hawthorne formation and is a major source of drinking water for much of Florida. Table 4-2 summarizes the character and water-bearing properties of the hydrostratigraphic units in the area.

4.3.2 Semi-Confined Aquifer Well Installation Method

Figure 4-10 shows the well completion diagram for the three semi-confined aquifer wells. In the first stage of well installation, a 10-inch borehole was advanced to about 45 ft bgs and completed with 6-inch blank stainless steel casing. The surface casing was advanced until it established a key between the "surface" casing and the confining unit (Lower Clay Unit). The borehole was grouted around the surface casing. Once the grout around the 6-inch surface casing had set, in the second stage, a 5⅞-inch borehole was drilled through the inside of the surface casing to a depth of 61 ft bgs. A 2-inch casing with screen was advanced through the deeper borehole to set the well. This borehole also was grouted around the 2-inch casing. These measures were undertaken to prevent any DNAPL from migrating to the confined aquifer. Figure 4-11 shows the surface casing and inner (screened well) casing for the dual-casing wells installed at Launch Complex 34. The detailed installation method for these wells is described in the following paragraphs.

To verify the depth of the confining unit at each well location, a 3⅞-inch pilot hole first was installed to a depth of 40 ft using a tricone roller bit. After this pilot hole was drilled, split-spoon samples were collected in 2-ft (or 1-ft) intervals as soils were observed and logged in search of the top interface of the clay confining unit or aquitard. Upon retrieval of a 2-ft split-spoon sample, the borehole then was deepened to the bottom of the previously spooned interval. Once the previously spooned interval was drilled, the drilling rods and bit were pulled

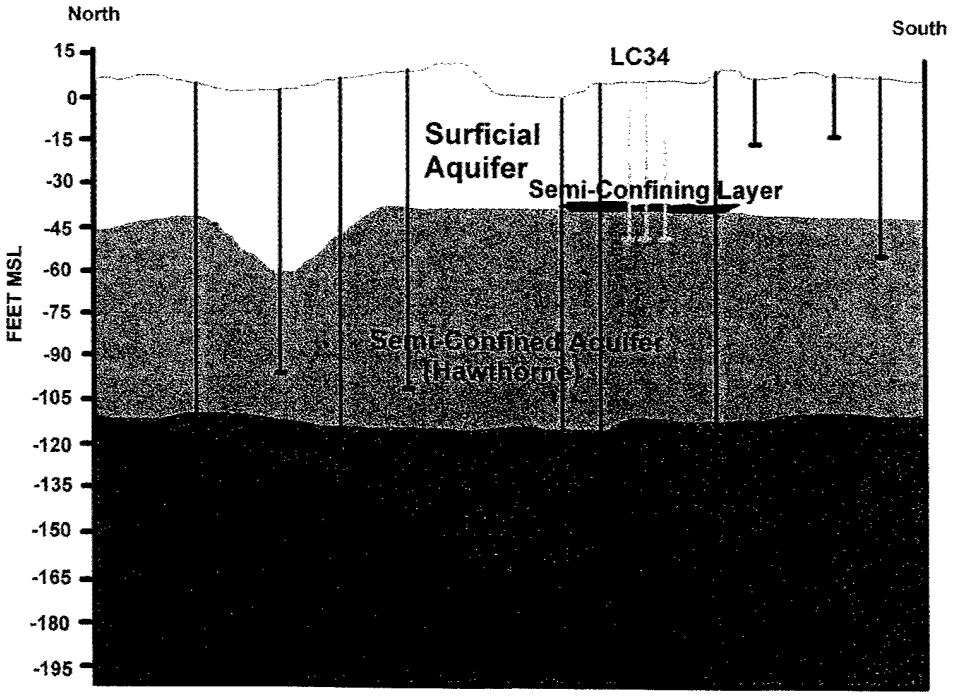


Figure 4-9. Regional Hydrogeologic Cross Section through the Kennedy Space Center Area (after Schmalzer and Hinkle, 1990)

Table 4-2. Hydrostratigraphic Units of Brevard Country, Florida[a]

Geologic Age	Stratigraphic Unit		Approximate Thickness (ft)	General Lithologic Character	Water-Bearing Properties
Recent (0.1 MYA-present) Pleistocene (1.8-0.1 MYA)	Pleistocene and Recent Deposits		0-110	Fine to medium sand, coquina and sandy shell marl.	Permeability low due to small grain size, yields small quantities of water to shallow wells, principal source of water for domestic uses not supplied by municipal water systems.
Pliocene (1.8-5 MYA)	Upper Miocene and Pliocene Deposits (Caloosahatchee Marl)		20-90	Gray to greenish gray sandy shell marl, green clay, fine sand, and silty shell.	Permeability very low, acts as confining bed to artesian aquifer, produces small amount of water to wells tapping shell beds.
Miocene (5-24 MYA)	Hawthorne Formation		10-300	Light green to greenish gray sandy marl, streaks of greenish clay, phosphatic radiolarian clay, black and brown phosphorite, thin beds of phosphatic sandy limestone.	Permeability generally low, may yield small quantities of fresh water in recharge areas, generally permeated with water from the artesian zone. Contains relatively impermeable beds that prevent or retard upward movement of water from the underlying artesian aquifer. Basal permeable beds are considered part of the Floridan aquifer.
Eocene (37-58 MYA)	Ocala Group	Crystal River Formation	0-100	White to cream, friable, porous coquina in a soft, chalky, marine limestone.	Floridan aquifer: Permeability generally very high, yields large quantities of artesian water. Chemical quality of the water varies from one area to another and is the dominant factor controlling utilization. A large percentage of the groundwater used in Brevard County is from the artesian aquifer. The Crystal River Formation will produce large quantities of artesian water. The Inglis Formation is expected to yield more than the Williston Formation. Local dense, indurate zones in the lower part of the Avon Park Limestone restrict permeability but in general the formation will yield large quantities of water.
		Williston Formation	10-50	Light cream, soft, granular marine limestone, generally finer grained than the Inglis Formation, highly fossiliferous.	
		Inglis Formation	70+	Cream to creamy white, coarse granular limestone, contains abundant echinoid fragments.	
	Avon Park Limestone		285+	White to cream, purple tinted, soft, dense chalky limestone. Localized zones of altered to light brown or ashen gray, hard, porous, crystalline dolomite.	

(a) Source: Schmalzer and Hinkle (1990).
MYA = million years ago.

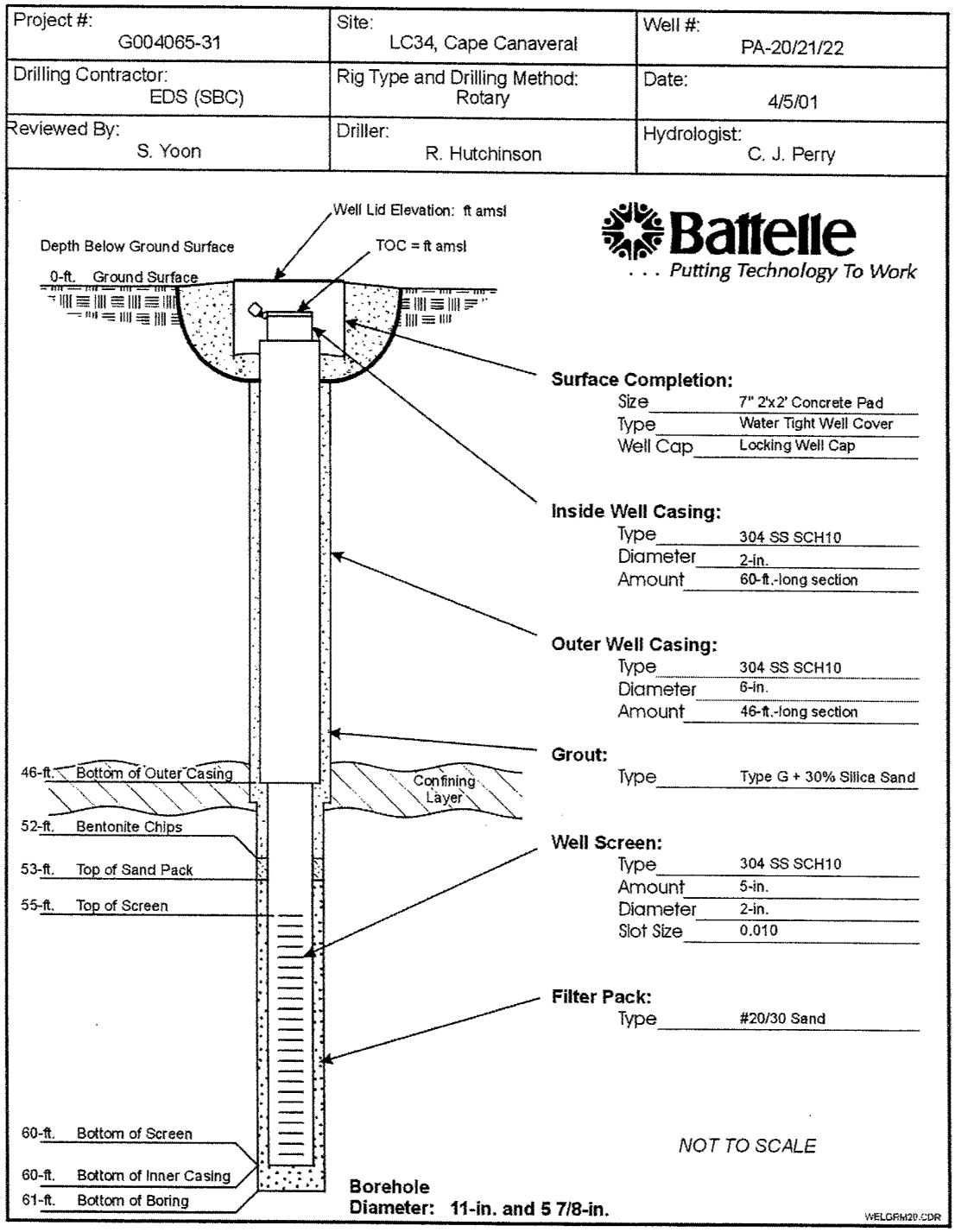


Figure 4-10. Well Completion Detail for Semi-Confined Aquifer Wells

out of the hole and replaced with a new split spoon that was driven another 2 ft ahead of the borehole. Standard penetration tests (i.e., blow counts) were conducted and logged during each split-spoon advance. The blow counts were useful in identifying the soil types that are penetrated during spooning. They also were useful in helping to determine the exact interval of soil recovered from spoons that lacked total recovery. The split-spoon soil samples were logged. The soils were visually logged for soil type and description, photoionization detector (PID) scans were run, and at least one soil sample per 2-ft spoon interval was collected for methanol extraction and analysis.

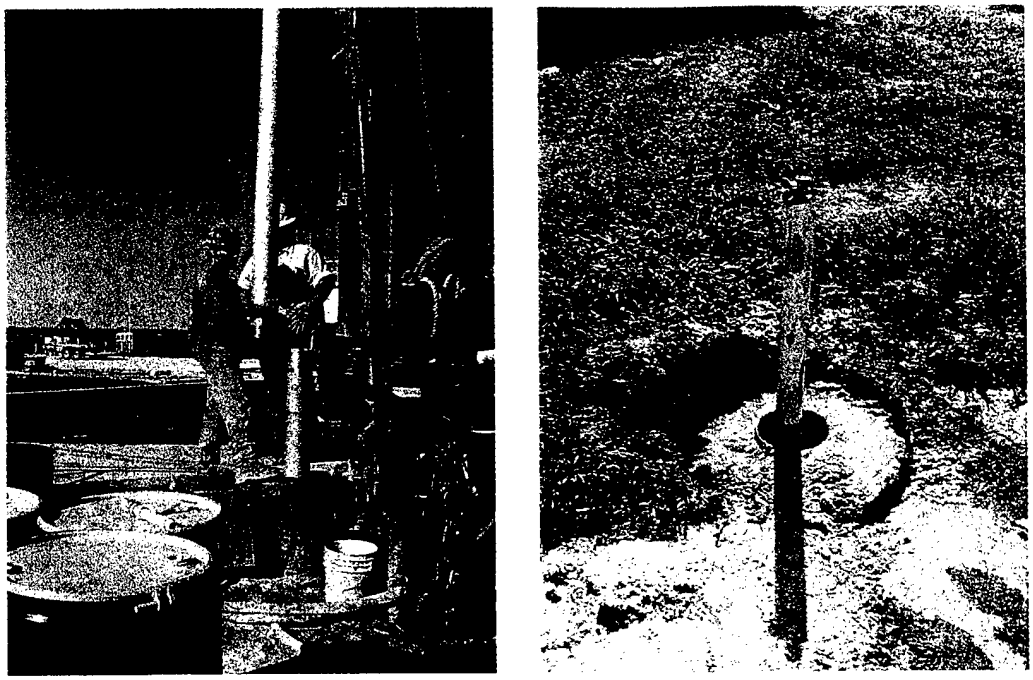


Figure 4-11. Pictures Showing (a) Installation of the Surface Casing and (b) the Completed Dual-Casing Well

Once the top portion (approximately the first 1.5 ft) of the confining unit was retrieved by split spoons in each borehole, the spoon and rods were pulled out of the borehole and the hole was reamed with a 10-inch tricone rotary drill bit to the depth of the lowest spooned interval. Before the 6-inch diameter casing was set in the hole, a PVC slipcap was placed on the bottom of the casing to keep it free of drilling mud and soil. Use of slip caps was an added precaution to prevent any possibility of downward contamination. As the casing was lowered in the hole, it was filled with clean water to prevent it from becoming buoyant. When the casing was set to the drilled depth of about 45 ft, it was grouted in place.

After the grout was allowed to set for at least 24 hours, the slipcap was drilled through with a 5⅞-inch roller bit. Then split-spoon sampling progressed through the remainder of the confining unit and into the confined aquifer. Split-spoon samples were collected totaling 4 ft of lifts before the hole was reamed with the 5⅞-inch bit as fresh drilling mud was circulated in the hole. Split-spooning progressed to a depth of 60 ft. Each hole was reamed an extra foot, to 61 ft, before the screen and casing were set. A sand pack was tremied into place from total depth to 2 ft above the top of the well screen (about 53 ft bgs). A bentonite seal (placed as a slurry) then was tremied in about the sand pack before the remainder of the casing was tremie-grouted into place with a Type G cement and silica flour slurry.

Once the split-spoon samples showed that the Lower Clay Unit had been reached, the 6-inch-diameter surface casing was set and grouted into place with a Type G (heat-resistant) cement and silica flour grout slurry. The drilling mud used for advancing the boreholes consisted of a product called "Super Gel-X bentonite." This powdered clay material was mixed with clean water in a mud pit that was set and sealed to the borehole beneath the drilling platform. The drilling mud was mixed to a density and viscosity that is greater than both groundwater and the bulk density of soil. This mud was pumped down through the drill pipe, out through the drill bit, and then pushed upward (circulated) through the borehole annulus into the mud pit (open space between the drilling rods and borehole wall). Use of the mud stabilizes the borehole, even in sandy soils, enabling advancement of the borehole in depths well below the water table without heaving or caving. The mud seals the borehole walls, preventing the borehole from being invaded by groundwater and contaminants. The mud also lifts all of the cuttings created by the drill bit as the hole is advanced. Once the drilling mud rose to the top of the annulus, it was captured in the mud pit where cuttings were removed by a series of baffles through which the mud was circulated.

The mud pit was monitored with a PID throughout the drilling process. At no time did the PID detect VOCs in the drilling mud, indicating that no significant levels of

contamination were entering the borehole and being carried downward into cleaner aquifer intervals as the drilling advanced.

After each well was installed, it was developed using a 3-ft-long stainless steel bailer and a small submersible pump. Bailing was done to surge each well and lift the coarsest sediments. The submersible pump then was used to lift more fines that entered the well as development progressed. A total of at least three well volumes (approximately 27 gal) were lifted from each well. Groundwater sampling was performed following well development. Standard water quality parameters were measured during sampling, and groundwater samples were collected after these parameters became stable.

4.4 Verifying Operating Requirements and Costs

Another secondary objective of the demonstration was to verify the vendor's operating requirements and cost for the technology application. The vendor prepared a detailed report describing the operating requirements and costs of the ISCO application (IT Corporation, 2000). An operating summary based on this report is provided in Section 3.2. Costs of the technology application also were tracked by MSE, the DOE contractor who subcontracted the ISCO vendor. Site characterization costs were estimated by Battelle and TetraTech EM, Inc.

5. Performance Assessment Results and Conclusions

The results of the performance assessment methodology outlined in Section 4 are described in this section.

5.1 Estimating TCE/DNAPL Mass Removal

Sections 2.3 and 4.1 describe the methodology used to estimate the masses of total TCE and DNAPL removed from the plot due to the application of ISCO technology at Launch Complex 34. Intensive soil sampling was the primary tool for estimating total TCE and DNAPL mass removal. Total TCE refers to both dissolved-phase and DNAPL TCE. DNAPL refers to that portion of total TCE in a soil sample that exceeds the threshold concentration of 300 mg/kg (see Section 2.3). Pre- and postdemonstration concentrations of TCE at 12 soil coring locations (nearly 300 soil samples) inside the ISCO plot were tabulated and graphed to *qualitatively* identify changes in TCE/DNAPL mass distribution and efficiency of the ISCO application in different parts of the plot (Section 5.1.1). In addition, TCE/DNAPL mass removal was *quantified* by two methods:

- Contouring (Section 5.1.2)
- Kriging (Section 5.1.3)

These quantitative techniques for estimating TCE/DNAPL mass removal due to the ISCO application are described in Section 4.1; the results are described in Sections 5.1.2 through 5.1.3.

5.1.1 Qualitative Evaluation of Changes in TCE/DNAPL Distribution

Figure 5-1 charts the concentrations of TCE in the soil samples from the 12 coring locations in the ISCO plot, as measured during the predemonstration, postdemonstration, and extended monitoring events (nine months after end of demonstration). This chart allows a simple comparison of the pre- and postdemonstration (or extended monitoring) TCE concentrations at paired locations. The colors in the chart indicate the color observed in each soil sample at 2-ft intervals. The gray and tan colors are the natural colors of the Launch Complex 34 soil. The orange color indicates mildly oxidizing conditions, when the first trace of oxidant reaches the soil and native iron precipitates out as ferric compounds. The brown color probably indicates moderately oxidizing conditions where MnO_2, a byproduct of TCE and native organic matter oxidation, has formed. The purple color indicates an excess of permanganate.

These visual indicators of $KMnO_4$ were not always representative of the level of TCE oxidation/removal observed in the corresponding soil samples. However, the colors (such as purple or brown) did provide preliminary guidance on the extent of oxidant distribution at different points in the plot. Based on the colors, oxidant distribution appeared to be best in the Upper Sand Unit, followed by the Lower Sand Unit. The Middle Fine-Grained Unit showed less penetration of the oxidant than the other two stratigraphic units. Based on the pervasiveness of purple color, the soil core SB-220 in the center of the plot showed the best oxidant distribution at all depths. The predominance of native colors at soil core SB-215, located under the Engineering Support Building, indicated that the soil core sustained less penetration of oxidant than other parts of the plot. In general, access under the building and local geologic heterogeneities appear to have played a considerable role in the efficiency of oxidant distribution.

The chart in Figure 5-1 shows that TCE concentrations were reduced considerably in all three units at several locations in the plot. The thicker horizontal lines in the chart indicate the depths at which the Middle Fine-Grained Unit was encountered at each location. The colors in this figure are indicative of the colors observed visually during sampling. As seen in Figure 5-1, the highest predemonstration contamination detected was 30,056 mg/kg of TCE in SB-14, the soil core located under the Engineering Support Building along the southern edge of the plot, where the contamination was the highest. This hot spot was present at the interface between the Middle Fine-Grained Unit and the Lower

Top Depth	Bottom Depth	Pre-Demo SB-13	Post-Demo SB-213	Ext. Mon. SB-313	Pre-Demo SB-16	Post-Demo SB-216	Ext. Mon SB-316	Pre-Demo SB-19	Post-Demo SB-219	Ext. Mon SB-319	Pre-Demo SB-25	Post-Demo SB-225	Ext. Mon SB-325
0	2	0.4	ND	0.11 J	ND	ND	ND	0.4	ND	ND	0.3	ND	ND
2	4	0.2	ND	1.33	ND	ND	ND	0.5	ND	ND	0.2	ND	ND
4	6	0.2	2.3	ND	ND	ND	0.08 J	0.7	ND	ND	0.3	ND	ND
6	8	0.4	ND	0.07 J	0.3	ND	0.23	2.9	2.4	ND	0.4	ND	ND
8	10	0.5	ND	0.71	0.2	ND	1.11	7.4	57.3	0.23	NA	NA	1.23
10	12	0.5	ND	5.44	0.3		0.29	0.6	42.7	0.88	0.6		1.64
12	14	0.4		18.55	0.2		0.25	8.7	23.4	1.22	0.5		2.18
14	16	0.8		24.46	ND		ND	0.4	25.0	5.69	0.5		2.41
16	18	6.5		0.47	2.6		0.16 J	1.1	19.3	20.33	1.6		0.55
18	20	21.9		0.21	14.5		ND	2.5	14.7	0.14 J	7.7		0.27
20	22	105.9	ND	ND	19.1		1.16	11.6	1.4	0.20	14.8		0.83
22	24	234.6	ND	0.15 J	176.5	ND	0.77	115.4	1.0	ND	194.6	2.4	0.36
24	26	304.2	ND	ND	272.4		0.18 J	210.9	NA	NA	250.0	6.7	5.60
26	28	318.4	ND	ND	307.9	10.0	0.87	280.4	8.3	NA	432.6	15.2	12.77
28	30	NA	ND	0.22	397.9	1.4	10.97	185.0	43.3	5.80	398.8	13.0	16.66
30	32	66.8	7.1	0.16	331.6	4.9	10.86	125.1	12.9	2.95	19.5	0.6	2.21
32	34	23.4	2.8	0.19 J	202.0	0.6	3.25	88.4	NA	8.27	253.4		0.78
34	36	7.3		ND	227.0	ND	0.98	131.1	13.1	2.65	95.5		6.69
36	38	13.2	ND	0.31	292.3	ND	0.36	117.5		5.03	237.4		2.30
38	40	19.9	2.2	0.43	85.2	4.1	ND	198.9		2.24	82.8		0.27
40	42	6.8	5.7	0.71	225.1	3.6	37.21	71.7		40.69	109.9		0.37
42	44	41.0	ND	0.90	288.4	1.7	108.59	116.4		100.59	165.8		21.54
44	46	180.5		NA	48.9		NA	153.1	614.4	NA	262.5	218.8	NA

Figure 5-1. Distribution of TCE Concentrations (mg/kg) During Predemonstration, Postdemonstration, and Nine Months after the Demonstration in the ISCO Plot Soil (page 1 of 3)

Top Depth	Bottom Depth	Pre-Demo SB-14	Post-Demo SB-214	Ext. Mon. SB-314	Pre-Demo SB-17	Post-Demo SB-217	Post-Demo SB-317	Ext. Mon. SB-317B	Pre-Demo SB-20	Post-Demo SB-220	Ext. Mon SB-320	Pre-Demo SB-23	Post-Demo SB-223	Ext. Mon SB-323
0	2	0.2	ND	0.11 J	0.1	ND	ND	2.98	4.7	ND	ND	ND	ND	ND
2	4	0.3	ND	0.08 J	ND	ND	ND	[illegible]	1.0	ND	[illegible]	1.8	ND	[illegible]
4	6	0.2	ND	ND	0.4	ND	ND	[illegible]	7.8	ND	[illegible]	1.9	[illegible]	[illegible]
6	8	0.3	ND	[illegible]	ND	ND	[illegible]	ND	0.2	[illegible]	[illegible]	ND	5.3	[illegible]
8	10	0.3	[illegible]	[illegible]	ND	ND	[illegible]	[illegible]	ND	[illegible]	[illegible]	ND	[illegible]	[illegible]
10	12	0.5	[illegible]	[illegible]	ND	[illegible]	[illegible]	[illegible]	ND	[illegible]	[illegible]	ND	[illegible]	[illegible]
12	14	1.6	[illegible]	[illegible]	0.4	[illegible]	[illegible]	[illegible]	ND	[illegible]	[illegible]	0.3	[illegible]	[illegible]
14	16	0.4	[illegible]	[illegible]	1.2	[illegible]	[illegible]	[illegible]	0.3	[illegible]	[illegible]	ND	[illegible]	[illegible]
16	18	3.8	[illegible]	[illegible]	0.4	[illegible]	[illegible]	[illegible]	1.8	[illegible]	[illegible]	0.7	[illegible]	[illegible]
18	20	28.5	[illegible]	[illegible]	14.1	[illegible]	[illegible]	[illegible]	11.4	[illegible]	[illegible]	1.3	[illegible]	[illegible]
20	22	114.3	[illegible]	[illegible]	46.1	[illegible]	[illegible]	[illegible]	75.7	[illegible]	[illegible]	59.8	[illegible]	[illegible]
22	24	236	[illegible]	[illegible]	4,412.4	0.6	[illegible]	[illegible]	161.2	[illegible]	ND	157.5	[illegible]	[illegible]
24	26	226	ND	11.67	215.1	1.8	[illegible]	0.86	179.8	[illegible]	ND	172.8	4.0	[illegible]
26	28	3,798	ND	0.67	210.5	17.6	4.4	13.12	534.3	[illegible]	[illegible]	272.0	7.2	0.29
28	30	447	NA	56.53	339.8	36.1	44.9	132.87	260.5	[illegible]	0.39	331.1	11.7	0.22
30	32	2,261	31.2	43.72	360.5	6.8	1.8	102.73	209.2	[illegible]	0.55	310.0	3.2	7.63
32	34	30,056	[illegible]	20.75	191.4	[illegible]	8.5	28.01	196.4	[illegible]	7.35	146.9	[illegible]	3.20
34	36	8,859	[illegible]	[illegible]	215.2	[illegible]	[illegible]	[illegible]	171.3	[illegible]	5.61	102.0	[illegible]	657.33
36	38	15,113	97.5	1,261.5	258.7	20.7	[illegible]	[illegible]	187.1	[illegible]	5.30	267.6	71.8	93.2
38	40	853.3	832.0	46.33	188.2	134.5	194.1	[illegible]	153.8	[illegible]	4.59	222.5	21.7	416.82
40	42	NA	330.3	82.61	156.5	32.5	11.9	[illegible]	NA	[illegible]	69.6	144.5	5.6	103.24
42	44	1,264.5	15.5	4.95	138.0	[illegible]	[illegible]	[illegible]	245.8	[illegible]	7,533.6	132.2	92.9	993.09
44	46	1,896.4	211.4	NA	245.4	[illegible]	[illegible]	NA	8,349	10.8	NA	149.5	NA	26,310.3

Figure 5-1. Distribution of TCE Concentrations (mg/kg) During Predemonstration, Postdemonstration, and Nine Months after the Demonstration in the ISCO Plot Soil (page 2 of 3)

Top Depth	Bottom Depth	Pre-Demo SB-15	Post-Demo SB-215	Ext. Mon. SB-315	Pre-Demo SB-18	Post-Demo SB-218	Ext. Mon. SB-318	Pre-Demo SB-21	Post-Demo SB-221	Ext. Mon SB-321	Pre-Demo SB-24	Post-Demo SB-224	Ext. Mon SB-324
0	2	ND	0.4	ND	0.4	ND	ND	0.3	ND	ND	0.5	ND	ND
2	4	0.2	0.4	ND	0.2	ND	ND	0.7	ND	ND	0.3	ND	ND
4	6	0.4	0.6	0.77	0.3	ND	ND	0.2	ND	ND	ND	ND	ND
6	8	0.4	ND	0.15	6.7		ND	ND		ND	ND	ND	ND
8	10	0.8		ND	0.3		0.12 J	0.3		1.29	8.6	ND	
10	12	1.6		ND	0.5		0.16	0.4		0.96	7.4		
12	14	4.8		ND	0.4		8.87	0.7		0.36	4.2		
14	16	0.5		ND	0.2		28.40	0.5		1.24	5.4		
16	18	2.1		981.89	5.9		5.23	1.1		ND	5.1		
18	20	1.3		313.81	35.1		3.32	3.4		ND	10.0		ND
20	22	28.1		44.77	110.1		0.13 J	51.4			34.5		ND
22	24	240.8	246.7	4,555.70	59.5		ND	NA			NA		ND
24	26	3,033.8	2,261.9	179.79	6,898.9		0.46	65.1			59.3		
26	28	13,323.6	9,726.8	145.19	1,416.2		ND	226.2		ND	191.6		51.08
28	30	17,029.5	390.9	925.3	441.9		0.19 J	NA		1.41	137.3		59.22
30	32	490.0	3,391.8	2,383.5	586.8		ND	189.0		0.85	84.8		106.19
32	34	664.2	3,722.9	3597.7	321.9		0.30	97.9		0.03	62.3		61.06
34	36	NA	3,279.6	1,251.1	1,767.3		9.48	7,881.2		0.14	154.7		8.94
36	38	17,686.5	4,132.9	1,398.3	3,201.6		2.38	7,391.4		0.91	439.7		14.80
38	40	11,322.8	8,313.7	482	8,374.1		3.09	7,397.8		0.24	101.7	124.7	30.49
40	42	2,750.7	834.8	729.84	778.2		5.25	5,913.6		0.25	43.0		52.74
42	44	4,334.1	NA	NA	334.6		8.92	10,456.1		0.36	113.9		2,424.6
44	46	6,649.0	NA	NA	8,919.7		NA	NA	NA	NA	NA	NA	39,904.9

NA: Not available.
ND: Not detected.
Solid horizontal lines demarcate MFGU.

Figure 5-1. Distribution of TCE Concentrations (mg/kg) During Predemonstration, Postdemonstration, and Nine Months after the Demonstration in the ISCO Plot Soil (page 3 of 3)

Sand Unit; concentrations in the vicinity of this hot spot were reduced considerably by the ISCO application, as seen in the postdemonstration core SB-214. The highest postdemonstration TCE concentration was 9,727 mg/kg, found in soil core SB-215. This high residual contamination was present in the Middle Fine-Grained Unit at a location under the building, probably the region that presented the most geologic and operational difficulty for oxidation treatment through injection points outside the building. The highest TCE concentration found during the extended monitoring event was 39,905 mg/kg, found in soil core SB-324 on the northern edge of the test plot, at a depth right above the clay aquitard. The postdemonstration groundwater concentration in monitoring well BAT-1D, the well closest to soil boring SB-324, shows persistently high levels of TCE (see Appendix C); therefore, the soil and groundwater data are in agreement in this region. During postdemonstration sampling of this location (SB-224), the soil recovery in the sample at this depth was poor and the sample could not be analyzed. This high a level of TCE in SB-324 indicates a DNAPL pocket remaining right above the aquitard after treatment. The color of the soil at this depth in SB-324 is its natural color and visually it does not appear that much permanganate reached this spot. As apparent in Figure 5-1, the TCE concentration was relatively low (52 mg/kg) 2 ft above this DNAPL pocket, where the soil shows discoloration due to permanganate. Except for this one soil boring location (corresponding to the group SB-24, SB-224, and SB-324), the TCE distribution in the rest of the test plot during the three events (predemonstration, postdemonstration, and extended monitoring) was consistent with expectations.

Figures 5-2 to 5-4 show representative pre- and postdemonstration distributions of TCE in soil from the Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit, respectively, in the ISCO plot and surrounding aquifer. A graphical representation of the TCE data illustrates the horizontal and vertical extent of the oxidant distribution and the changes in TCE concentrations. The colors yellow to red indicate DNAPL (TCE >300 mg/kg). In general, the portions of the aquifer under the building (SB-14 and SB-15) and along the western boundary of the ISCO plot (SB-18 and SB-21) had the highest predemonstration contamination, especially in the Middle Fine-Grained Unit and Lower Sand Unit. The postdemonstration coring showed that the ISCO process had caused a considerable decline in TCE concentrations throughout the ISCO plot. Postdemonstration soil cores SB-218 and SB-221, along the western edge of the plot, showed the sharpest declines in TCE/DNAPL concentrations. On the other hand, cores SB-214 and SB-215, collected under the building, contained considerable postdemonstration concentrations of both total TCE and DNAPL. These results indicate that distribution of oxidant under the building was not as efficient as in the rest of the plot.

Figure 5-5 depicts three-dimensional (3-D) DNAPL distributions identified during the pre- and postdemonstration sampling in the ISCO plot. This figure shows that DNAPL was removed from large regions of the test plot. A few pockets of DNAPL remain, primarily under the building and near the northern edge of the test plot, at locations where the permanganate probably experienced difficulty penetrating.

Figures 5-6 to 5-8 show the distribution of potassium permanganate in the shallow, intermediate, and deep wells, respectively, in the Launch Complex 34 aquifer, as measured by spectrophotometry in May 2000, soon after the end of the oxidant injection process. The permanganate levels in the monitoring wells are probably a measure of the excess oxidant in the aquifer; that is, the permanganate left over after the TCE and native organic matter in the vicinity had been oxidized. These figures show that some excess potassium permanganate was present in most parts of the ISCO plot and surrounding aquifer, although some regions seemed to have received a higher oxidant dose than others. Monitoring wells BAT-5S and BAT-5D seemed to have barely measurable levels of permanganate, indicating that preferential pathways may have guided the oxidant flow away from this region. In fact, BAT-5S was the only well inside the ISCO plot that showed an increase in TCE concentration throughout the demonstration (see Section 5.2.1). TCE increased in some of the perimeter wells as described in Section 5.3.2.

5.1.2 TCE/DNAPL Mass Removal Estimation by Linear Interpolation

Section 4.1.1 describes the use of linear interpolation to estimate pre- and postdemonstration TCE/DNAPL masses and calculate TCE/DNAPL mass removal. In this method, EarthVision™, a three-dimensional contouring software, is used to group the TCE concentration distribution in the ISCO plot into three-dimensional shells (or bands) of equal concentration. The concentration in each shell is multiplied by the volume of the shell and the bulk density of the soil to arrive at the TCE mass in that shell. The masses in the individual shells are added up to arrive at a TCE mass for the entire plot; this process is conducted separately for the pre- and postdemonstration TCE distributions in the ISCO plot. The predemonstration TCE/DNAPL mass in the entire plot then can be compared with the postdemonstration mass in the entire plot to estimate TCE/DNAPL removal. The results of this evaluation are described in this section.

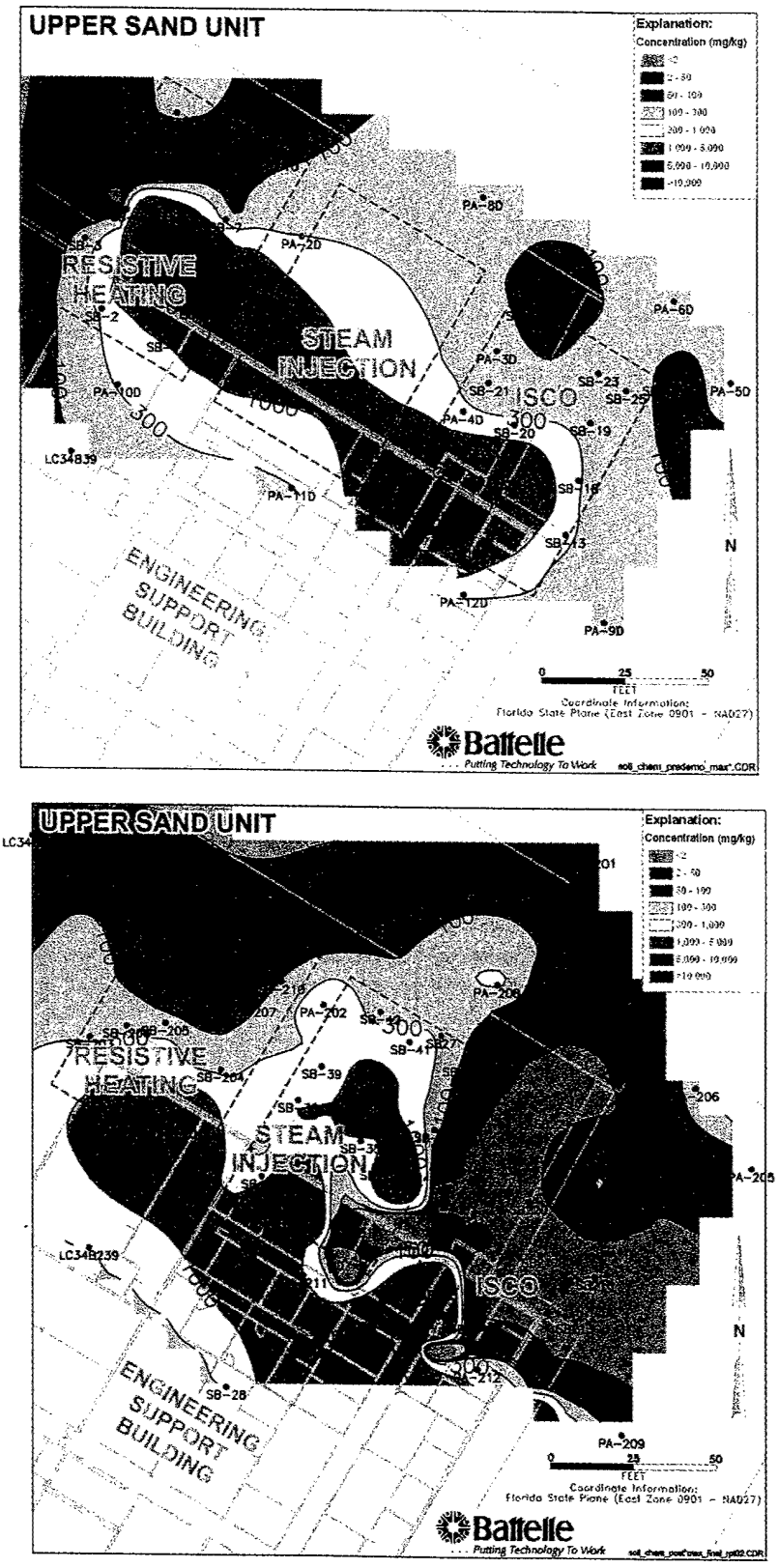
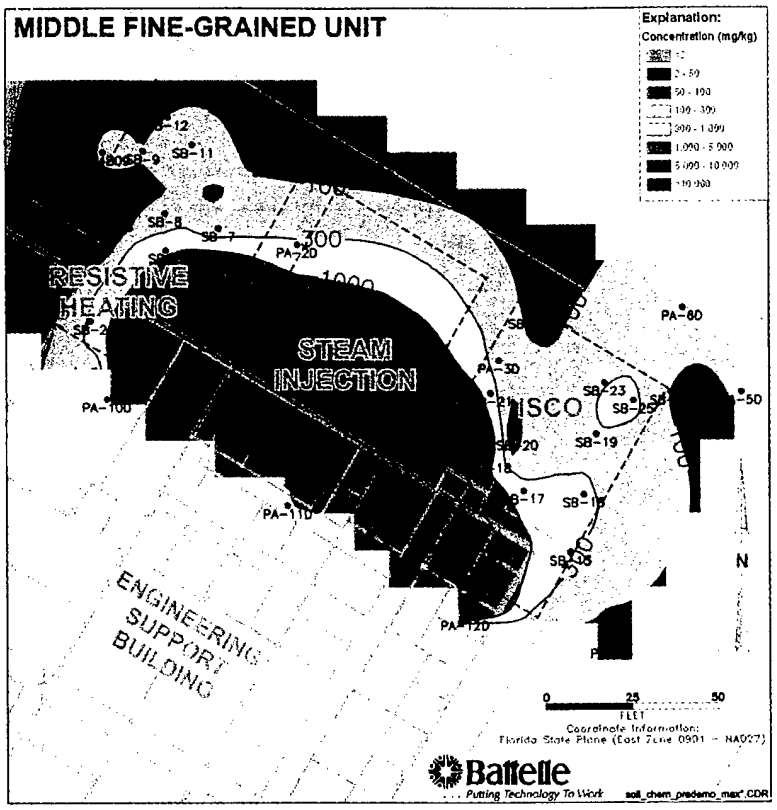
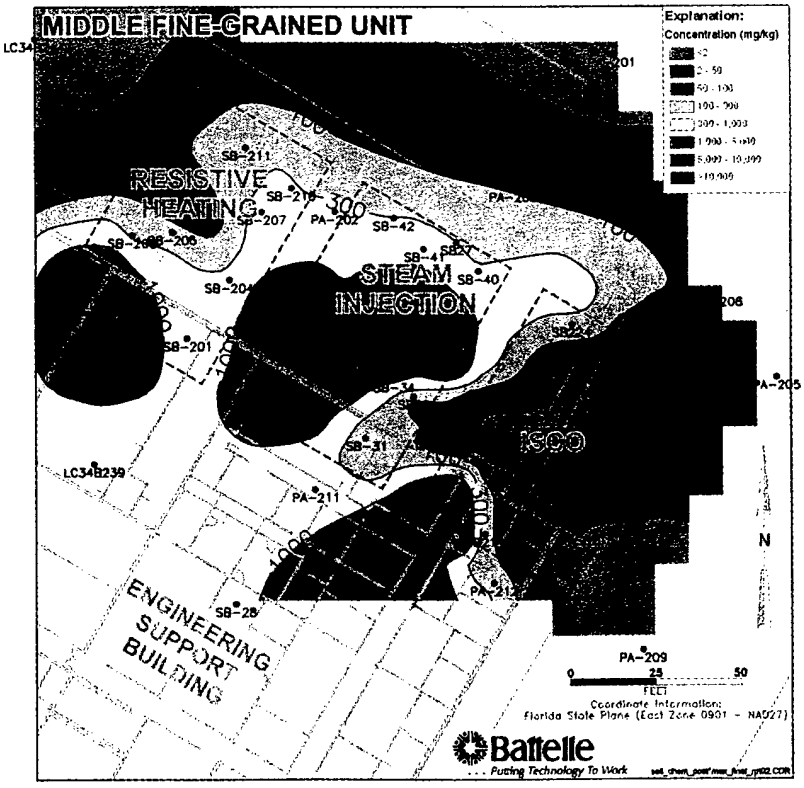


Figure 5-2. Representative (a) Predemonstration (June 1999) and (b) Postdemonstration (May 2000) Horizontal Cross Sections of TCE (mg/kg) in the Upper Sand Unit Soil

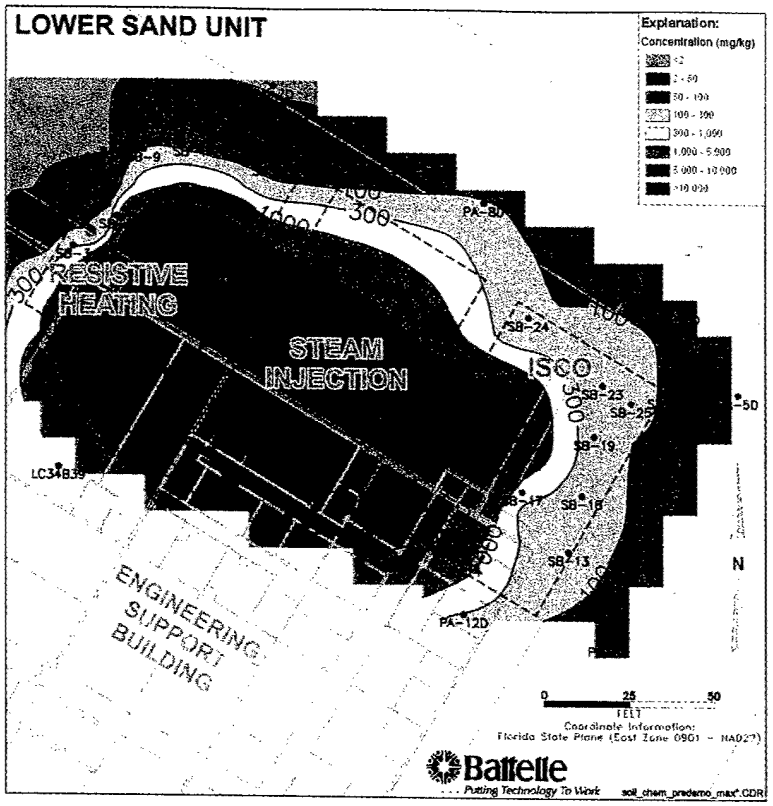


(a)

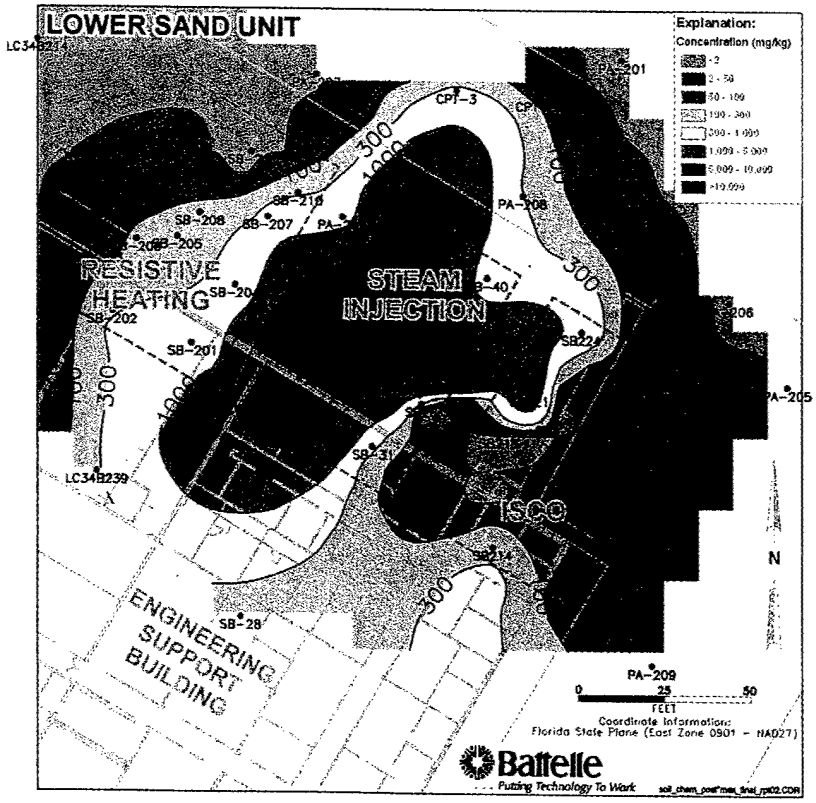


(b)

Figure 5-3. Representative (a) Predemonstration (June 1999) and (b) Postdemonstration (May 2000) Horizontal Cross Sections of TCE (mg/kg) in the Middle Fine-Grained Unit Soil



(a)



(b)

Figure 5-4. Representative (a) Predemonstration (June 1999) and (b) Postdemonstration (May 2000) Horizontal Cross Sections of TCE (mg/kg) in the Lower Sand Unit Soil

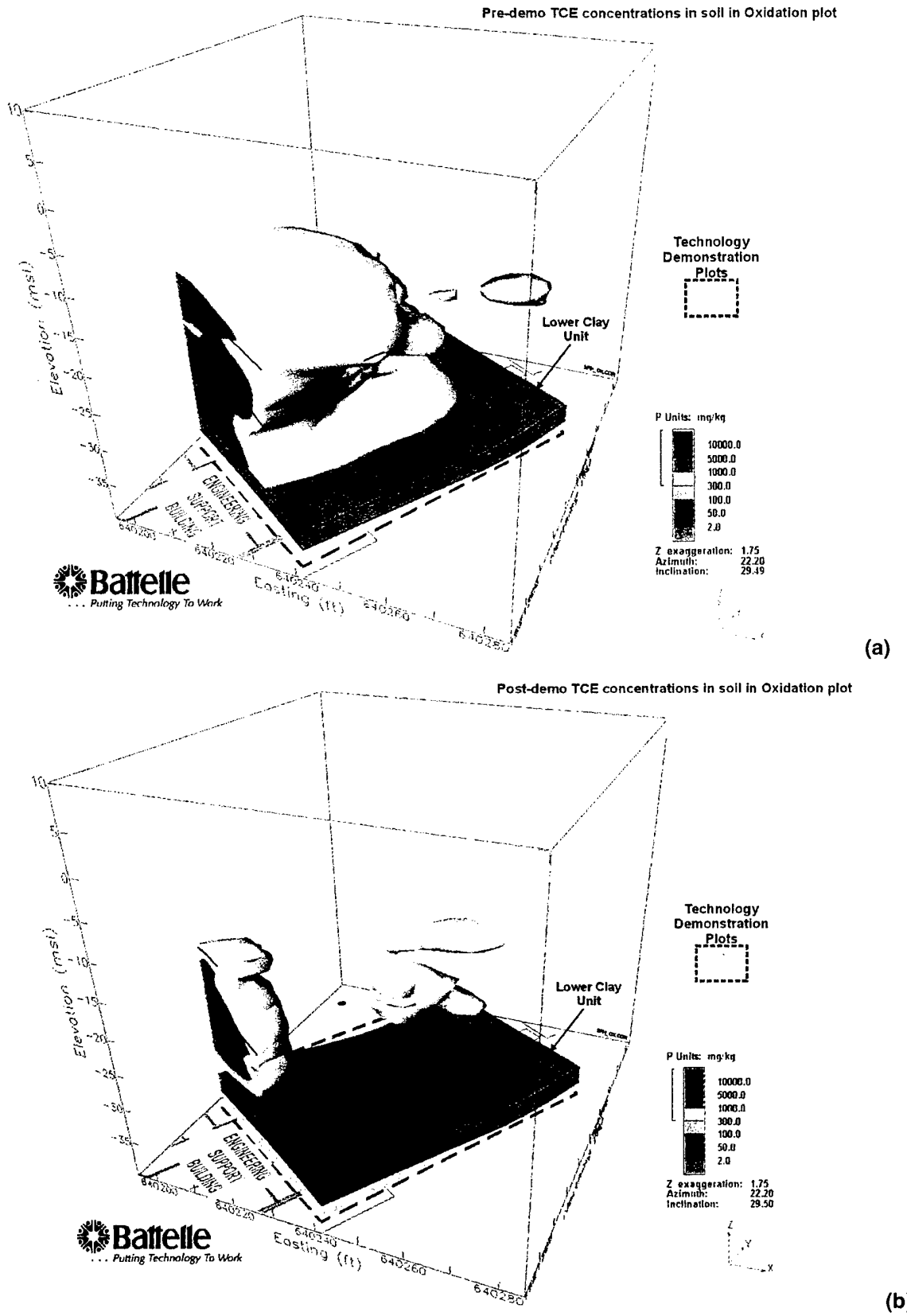


Figure 5-5. Three-Dimensional Distribution of DNAPL in the ISCO Plot Based on (a) Predemonstration (June 1999) and (b) Postdemonstration (May 2000) (mg/kg) Soil Sampling Events

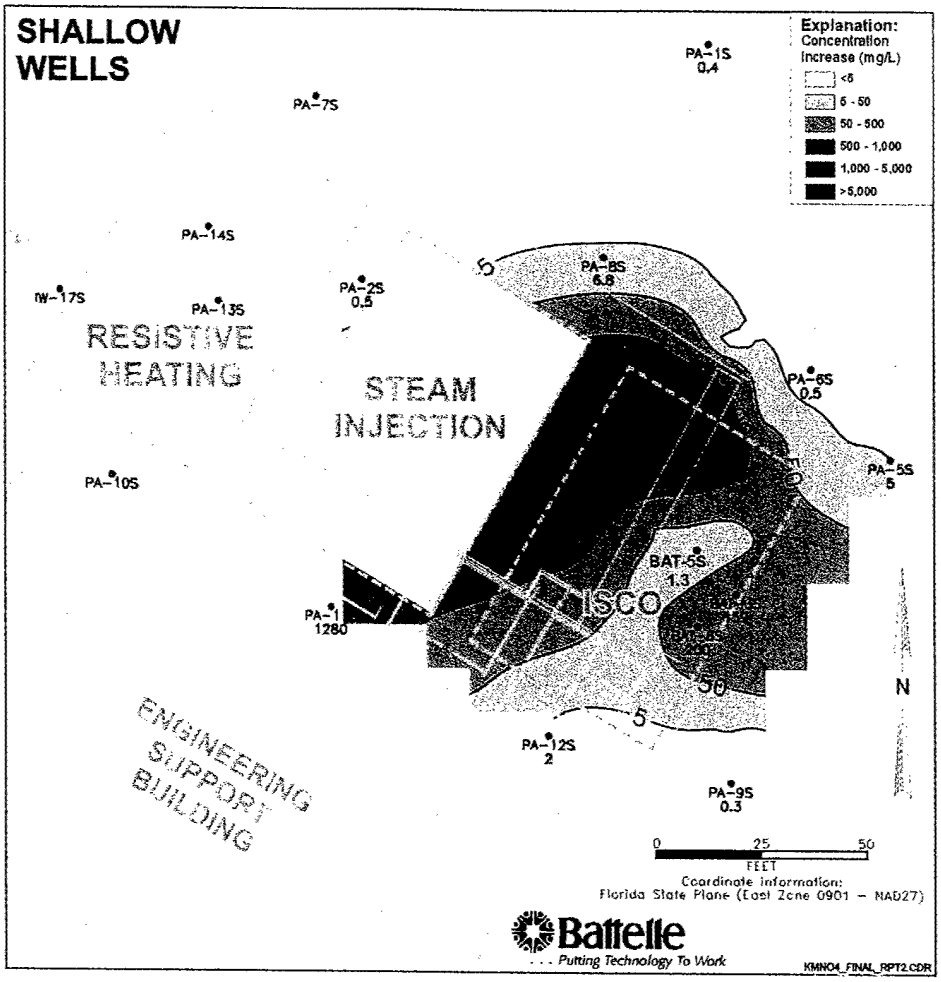


Figure 5-6. Distribution of Potassium Permanganate ($KMnO_4$) in Shallow Wells near the Engineering Support Building at Launch Complex 34 (May 2000)

Table 5-1 presents the estimated masses of total TCE and DNAPL in the ISCO plot and the three individual stratigraphic units. Under predemonstration conditions, soil sampling indicated the presence of 6,122 kg of total TCE (dissolved and free phase), approximately 5,039 kg of which was DNAPL. Following the demonstration, soil sampling indicated that 1,100 kg of total TCE remained in the plot; approximately 810 kg of this remnant TCE was DNAPL. Based on these estimates, 5,022 kg of total TCE, including 4,229 kg of DNAPL, was removed from the plot. Therefore, linear interpolation indicates that the overall mass removal effected by the ISCO process was 82% of total TCE and 84% of DNAPL.

Table 5-1 indicates that the highest mass removal (97% of total TCE and 98% of DNAPL) was achieved in the Upper Sand Unit, followed by the Lower Sand Unit. Substantial TCE/DNAPL mass was removed in the Middle Fine-Grained Unit as well, but the removal efficiency in this finer-grained unit was not as high as in the two sandy units.

When the predemonstration and extended monitoring TCE concentrations are compared, the estimated mass removal is 77% of total TCE and 76% of DNAPL. The lower estimated mass removal during the extended monitoring event is due to an isolated pocket of DNAPL found in soil core SB-323.

5.1.3 TCE Mass Removal Estimation by Kriging

Section 4.1.2 describes the use of kriging to estimate the pre- and postdemonstration TCE masses in the aquifer. Whereas the contouring method linearly interpolates the TCE measurements at discrete sampling points to estimate TCE concentrations at unsampled points in the plot, kriging takes into account the spatial variability and uncertainty of the TCE distribution when estimating TCE concentrations (or masses) at unsampled points. Consequently, kriging provides a range of probable values rather than single TCE concentration estimates. Kriging

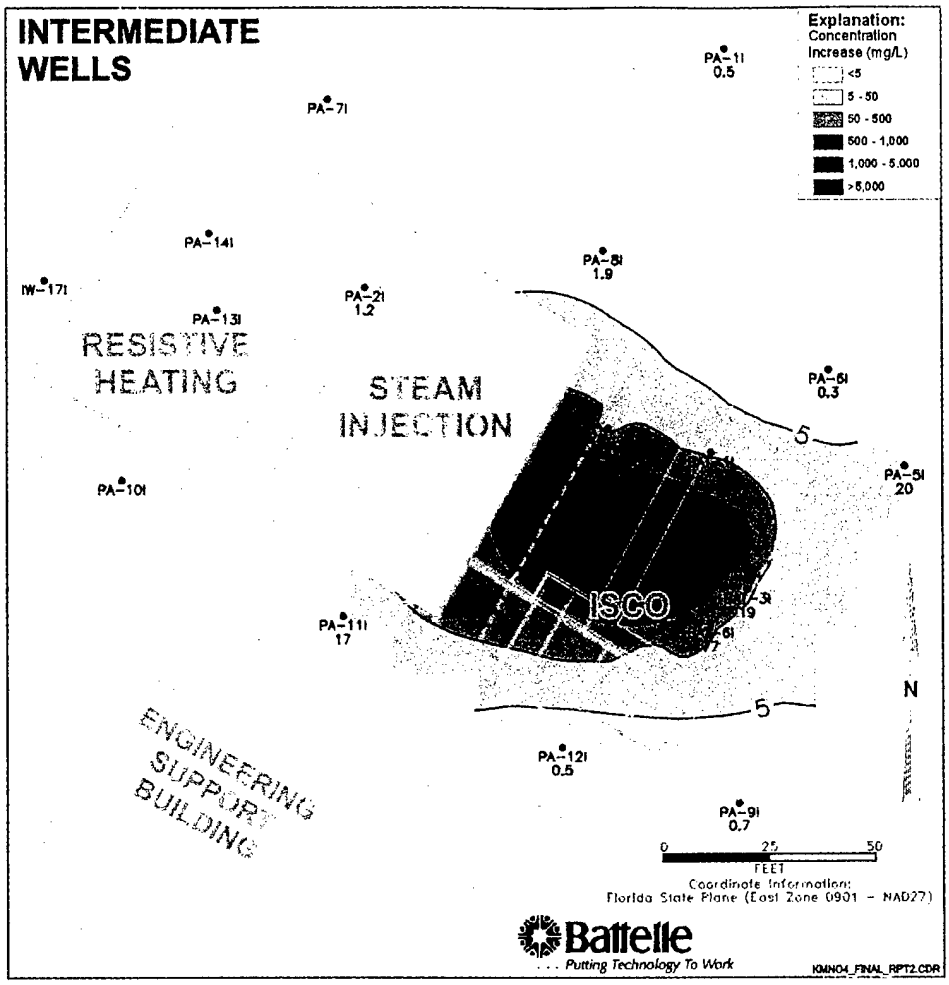


Figure 5-7. Distribution of Potassium Permanganate ($KMnO_4$) in Intermediate Wells near the Engineering Support Building at Launch Complex 34 (May 2000)

is a good way of obtaining a global estimate (estimate for one of the three stratigraphic units or the entire plot) for the parameters of interest (such as pre- and postdemonstration TCE masses), when the parameter is heterogeneously distributed.

Appendix A.1.2 contains a description of the application and results of kriging the TCE distribution in the ISCO plot. Table 5-2 summarizes the total TCE mass estimates obtained from kriging. This table contains an average and range (80% confidence interval) for each global estimate (Upper Sand Unit, Middle Fine-Grained Unit, Lower Sand Unit, and the entire plot). Limiting the evaluation to DNAPL instead of total TCE limits the number of usable data points to those with TCE concentrations greater than 300 mg/kg. To avoid using too small a number of data points (especially for the postdemonstration DNAPL mass estimates), kriging was conducted on total TCE values only.

The pre- and postdemonstration total TCE masses estimated from kriging match the total TCE obtained from linear interpolation relatively well, probably because the high sampling density (almost 300 soil samples in the plot per event) allows linear interpolation to capture much of the variability of the TCE distribution in the plot. Kriging shows that between 62 and 84% (75% on average) of the predemonstration TCE mass was removed from the plot due to the application of ISCO technology. TCE mass removal was highest in the Upper Sand Unit, followed by the Lower Sand Unit. TCE mass removal was lowest in the Middle Fine-Grained Unit. An interesting observation from Table 5-2 is that the estimated ranges for the pre- and postdemonstration TCE masses do not overlap, either for the entire plot or for any of the three stratigraphic units; this indicates that the mass removal due to the ISCO application is significant at the 80% confidence level. The initial 90% DNAPL removal goal set for the demonstration probably was not met due

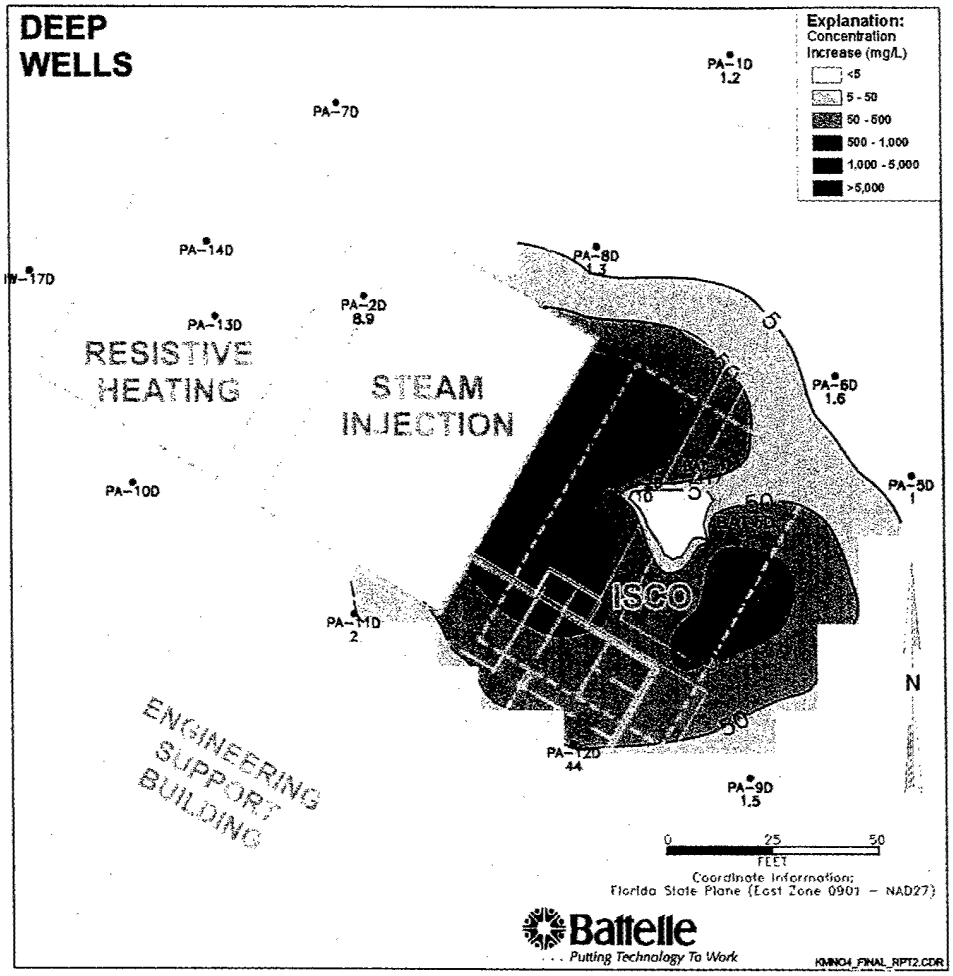


Figure 5-8. Distribution of Potassium Permanganate ($KMnO_4$) in Deep Wells near the Engineering Support Building at Launch Complex 34 (May 2000)

Table 5-1. Linear Interpolation Estimates for the ISCO Demonstration

	Predemonstration		Postdemonstration		Mass Removal	
Stratigraphic Unit	Total TCE (kg)	DNAPL[(a)] (kg)	Total TCE (kg)	DNAPL[(a)] (kg)	Total TCE (%)	DNAPL (%)
Upper Sand Unit	846	601	23	10	97	98
Middle Fine-Grained Unit	1,048	749	233	163	78	78
Lower Sand Unit	4,228	3,689	844	637	80	83
Total (Entire Plot)	6,122	5,039	1,100	810	82	84

	Predemonstration		Extended Monitoring		Mass Removal	
Stratigraphic Unit	Total TCE (kg)	DNAPL[(a)] (kg)	Total TCE (kg)	DNAPL[(a)] (kg)	Total TCE (%)	DNAPL (%)
Upper Sand Unit	846	601	82	57	90	91
Middle Fine-Grained Unit	1,048	749	160	126	85	93
Lower Sand Unit	4,228	3,689	1,172	1,036	72	72
Total (Entire Plot)	6,122	5,039	1,415	1,219	77	76

(a) The DNAPL estimates include only TCE concentrations estimated to be above 300 mg/kg of soil.

Table 5-2. Kriging Estimates for the ISCO Demonstration

Stratigraphic Unit	Predemonstration Total TCE[a] Average (kg)	Predemonstration Total TCE[a] Lower Bound (kg)	Predemonstration Total TCE[a] Upper Bound (kg)	Postdemonstration Total TCE[a] Average (kg)	Postdemonstration Total TCE[a] Lower Bound (kg)	Postdemonstration Total TCE[a] Upper Bound (kg)	Total TCE Mass Removal[a] Average (%)	Total TCE Mass Removal[a] Lower Bound (%)	Total TCE Mass Removal[a] Upper Bound (%)
Upper Sand Unit	454	250	659	26	18	34	94	87	97
Middle Fine-Grained Unit	2,836	1,668	4,005	872	532	1,211	69	27	87
Lower Sand Unit	4,408	3,519	5,298	1,030	788	1,272	77	64	85
Entire Plot[b]	7,699	6,217	9,182	1,928	1,511	2,345	75	62	84

Stratigraphic Unit	Predemonstration Total TCE[a] Average (kg)	Predemonstration Total TCE[a] Lower Bound (kg)	Predemonstration Total TCE[a] Upper Bound (kg)	Extended Monitoring Total TCE[a] Average (kg)	Extended Monitoring Total TCE[a] Lower Bound (kg)	Extended Monitoring Total TCE[a] Upper Bound (kg)	Total TCE Mass Removal[a] Average (%)	Total TCE Mass Removal[a] Lower Bound (%)	Total TCE Mass Removal[a] Upper Bound (%)
Upper Sand Unit	454	250	659	246	238	254	46	0	64
Middle Fine-Grained Unit	2,836	1,668	4,005	152	140	164	95	90	97
Lower Sand Unit	4,408	3,519	5,298	2,683	2,583	2,782	39	21	51
Entire Plot[b]	7,699	6,217	9,182	3,081	2,980	3,182	60	49	68

(a) Average and 80% confidence intervals (bounds).
(b) The standard error for the entire plot is different from the standard error for the individual stratigraphic units. Therefore, the estimated range of TCE levels in the entire plot are different from the sum total of the TCE estimates in the individual units.

to the limited access to the DNAPL under the building and the limited distribution of oxidant in the Middle Fine-Grained Unit.

When the predemonstration and extended monitoring TCE mass estimates are compared, the total TCE mass removal ranges from 49 to 68%, with an average removal of 60%. The lower removal estimates during the extended monitoring event are due to the isolated pocket of DNAPL discovered in the northern part of the test plot.

5.1.4 TCE/DNAPL Mass Removal Summary

In summary, the evaluation of TCE concentrations in soil indicates the following:

- In the horizontal plane, the highest predemonstration DNAPL contamination was under the Engineering Support Building and along the western boundary of the ISCO plot.
- In the vertical plane, the highest predemonstration DNAPL contamination was associated with the Lower Sand Unit.
- Kriging indicated that between 6,217 and 9,182 kg of total TCE was present in the test plot before the demonstration; and that between 62 and 84% of the total TCE was removed from the test plot by the technology application. When the predemonstration and extended monitoring event TCE mass estimates were compared, kriging indicated that between 49 and 68% of the TCE was removed from the plot. The extended monitoring event was conducted nine months after the end of the oxidant injections. The slightly lower removal estimates during the extended monitoring event are due to an isolated pocket of DNAPL found on the north end of the test plot during extended monitoring. These statistics are significant at the 80% confidence level specified before the demonstration. In summary, it can be said that at about half (at least 49%) of the initial TCE mass in the test plot was removed by the ISCO treatment.
- Linear interpolation of the predemonstration, postdemonstration, and extended monitoring TCE/DNAPL soil concentrations shows that approximately 76% of the estimated predemonstration DNAPL mass in the ISCO plot was removed due to the ISCO application.
- Oxidant was injected at relatively high pressures at several locations and depths within the ISCO plot and this improved the overall TCE/DNAPL mass removal. However, despite the high injection pressures and spatially intensive injection scheme, localized aquifer heterogeneities played a significant role in the eventual oxidant distribution and TCE/DNAPL removal.

- TCE/DNAPL removal efficiency was highest in the Upper Sand Unit, indicating that oxidant was effectively distributed in the more permeable, coarse-grained soil.
- TCE/DNAPL removal efficiency was lowest in the Middle Fine-Grained Unit, indicating that oxidant distribution was difficult in the tighter, fine-grained soil.
- Accessing the 15 ft of plot underneath the Engineering Support Building from oxidant injection points located outside the building proved difficult and resulted in low TCE/DNAPL removal efficiency under the building. This indicates that the radius of influence of the oxidant around the injection points was less than 15 ft.

5.2 Evaluating Changes in Aquifer Quality

This section describes the changes (between the predemonstration and postdemonstration sampling events) in aquifer characteristics created by the ISCO application at Launch Complex 34, as measured by monitoring conducted before, during, and after the demonstration. The affected aquifer characteristics are grouped into four subsections:

- Changes in CVOC levels (see Appendix C for detailed results)
- Changes in aquifer geochemistry (see Appendix D for detailed results)
- Changes in the hydraulic properties of the aquifer (see Appendix B for detailed results)
- Changes in the aquifer microbiology (see Appendix E for detailed results).

Table 5-3 lists selected CVOC concentrations in groundwater at the ISCO plot, and Table 5-4 lists levels of various groundwater parameters that indicate aquifer quality and the impact of the ISCO treatment. The tables summarize the levels from predemonstration, postdemonstration, and one year after the demonstration. Other important organic and inorganic aquifer parameters are discussed in this subsection. A separate microbiological evaluation of the aquifer is described in Appendix E.

5.2.1 Changes in CVOC Levels in Groundwater

The fact that considerable DNAPL mass was removed was expected to reduce CVOC levels in groundwater, at least in the short term. Although influx from surrounding contamination is possible, it was not expected to contribute significantly to the postdemonstration sampling in the short term because through most of the demonstration, hydraulic gradients radiated outward from the plot due to the injection pressures inside the plot. Also, the natural gradient at the site is relatively flat, so any influx of contaminated groundwater into the plot between oxidant injection and postdemonstration sampling was expected to be minimal. Lastly, excess permanganate in many parts of the plot would help control CVOC influx. Therefore, CVOC levels were measured in the ISCO plot wells before, during, and after the demonstration to evaluate changes in CVOC levels in the groundwater.

Table 5-3 shows the changes of TCE and *cis*-1,2-DCE in the ISCO performance monitoring wells. Appendix C tabulates the levels of TCE, *cis*-1,2-DCE and vinyl chloride in the groundwater in the ISCO plot wells. Figures 5-9 to 5-11 show dissolved TCE concentrations in the shallow, intermediate, and deep wells, respectively, in the ISCO plot and perimeter. Before the demonstration, several of the shallow, intermediate, and deep wells in the plot had concentrations close to the solubility of TCE (1,100 mg/L). Immediately after the demonstration, TCE concentrations in several of these wells (e.g., BAT-1S, BAT-2S, BAT-2I, and BAT-6D) declined by 99% or more. The only anomalous well was the Upper Sand Unit Well BAT-5S. Both during and after the demonstration, BAT-5S showed increased TCE concentrations, at times approaching saturation levels. SB-219, the soil core closest to BAT-5S (the only monitoring well that showed an increase in TCE concentrations throughout the demonstration) did not indicate any substantial amounts of DNAPL (see Figure 5-1). These results suggest the following possibilities:

Table 5-3. CVOC Concentrations in Groundwater from the ISCO Plot

	TCE (µg/L)			*cis*-1,2-DCE (µg/L)		
Well ID	Predemonstration	Postdemonstration	Extended Monitoring	Predemonstration	Postdemonstration	Extended Monitoring
BAT-2S	1,110,000	<5	19 J	4,900J	<5	<20
BAT-2I	970,000	880	937 D	4,700J	<77	7
BAT-2D	1,160,000	220,000	388,000 D	NA	<10,000	7,770
BAT-5S	298,000	410,000	13,300 D	12,500	<17,000	5,300 D
BAT-5S-DUP	240,000	NA	11,100 D	9,100J	NA	5,020 D
BAT-5I	868,000	<10	356,000 D	5,220	<10	540 J
BAT-5D	1,140,000	52,000	436,000 D	NA	<1,700	1,090

Table 5-4. Predemonstration, Postdemonstration, and Extended Monitoring Levels of Groundwater Parameters Indicative of Aquifer Quality

Groundwater Parameter (applicable groundwater standard, if any) (mg/L)	Aquifer Depth	Predemonstration (mg/L)[a]	Postdemonstration (mg/L)[a]	Extended Monitoring (mg/L)[a]
TCE (0.003)	Shallow	298 to 1,140	<0.005 to 630	0.019J to 13.3
	Intermediate	868 to 1,190	<0.005 to 360	0.937 to 356
	Deep	752 to 1,160	<0.005 to 220	388 to 436
DCE (0.070)	Shallow	3.9 to 12.5	<0.005 to 52.0	<0.02 to 5.3
	Intermediate	4.1 to 21.3	<0.005 to 0.015	0.007 to 0.54J
	Deep	9.18 to 44.5	<0.005 to <17.0	1.09 to 7.77
Vinyl chloride (0.001)	Shallow	<5.0	<0.010 to <33.0	<0.02
	Intermediate	<5.0	<0.010 to <33.0	<0.001 to <0.1
	Deep	<5.0	<0.010 to <20.0	<1
pH	Shallow	7.0 to 7.4	7.2	7.5
	Intermediate	7.3 to 7.6	6.6	6.8 to 7.7
	Deep	7.4 to 7.5	6.4	5.5 to 7.0
ORP[b]	Shallow	−149 to −25 mV	−2 mV	−40 to 469 mV
	Intermediate	−165 to −38 mV	−97 to 384 mV	−103 to −29 mV
	Deep	−150 to −22 mV	−84 mV	−171 to 166 mV
DO	Shallow	<0.5 to 2.7	<0.5	0.92
	Intermediate	0.50 to 0.9	<0.5 to 3.1	0.72
	Deep	<0.5 to 0.9	0.7	0.06 to 0.92
Calcium	Shallow	70	4 to 70	1 to 7
	Intermediate	41	4 to 49	24 to 85
	Deep	84 to 88	210 to 349	71 to 1,020
Magnesium	Shallow	53	2 to 111	0.3 to 23
	Intermediate	59	3 to 19	32 to 45
	Deep	82 to 84	53 to 203	83 to 201
Alkalinity as $CaCO_3$	Shallow	269 to 316	1,060 to 1,500	1,700 to 2,010
	Intermediate	291 to 323	1,280	1,060 to 1,860
	Deep	204 to 208	1,300 to 2,140	359 to 1,610
Chloride (250)	Shallow	38 to 53	236 to 237	126 to 531
	Intermediate	57 to 181	238 to 582	186 to 452
	Deep	722 to 752	1,360 to 1,730	1,010 to 5,070
Manganese (0.05)	Shallow	0.016 to 1.1	2 to 235	0.25 to 33
	Intermediate	<0.015 to 0.018	98 to 516	1.46 to 7.41
	Deep	0.015 to 0.025	9 to 10	3.47 to 488
Iron (0.3)	Shallow	0.3 to 2.5	<0.05	<0.1 to 0.263
	Intermediate	<0.05 to 0.5	<0.1	<0.1 to 4.06
	Deep	0.1 to 0.3	<0.05 to 1.1	2.84 to 35.6
Sulfate in mg SO_4/L	Shallow	29 to 46	483	778 to 1,330
	Intermediate	49 to 138	1,380	618 to 1,810
	Deep	67 to 103	379 to 535	517 to 781
TDS (500)	Shallow	387 to 499	2,860 to 6,790	5,170 to 5,980
	Intermediate	517 to 760	5,280 to 13,000	3,640 to 4,750
	Deep	1,490 to 1,550	5,990 to 6,410	5,250 to 8,280
BOD	Shallow	<3	<3 to 112	<2 to 18
	Intermediate	<3 to 16	<3	8.6 to >74
	Deep	13	16 to 108	15 to >74
TOC	Shallow	4 to 6	157 to 422	51 to 95
	Intermediate	6 to 16	86 to 2,110	24 to 109
	Deep	10 to 11	10 to 131	32 to 233

(a) All reported quantities are in mg/L, except for pH, which is in log units, and ORP, which is in mV.
(b) ORP (469 mV) measured in the shallow well during the extended monitoring period may have been affected by interference from $KMnO_4$.

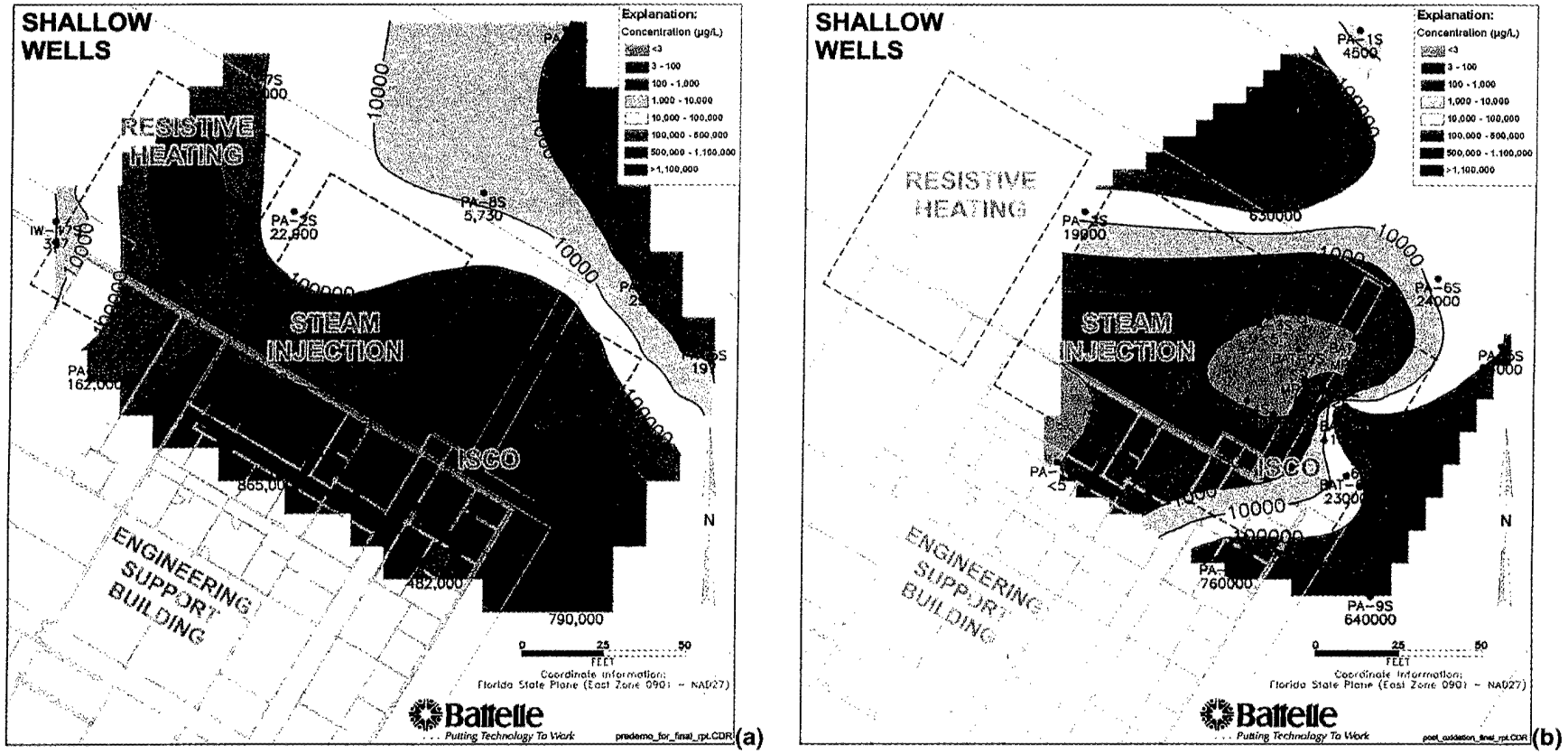


Figure 5-9. Dissolved TCE Concentrations (µg/L) during (a) Predemonstration (August 1999) and (b) Postdemonstration (May 2000) Sampling of Shallow Wells

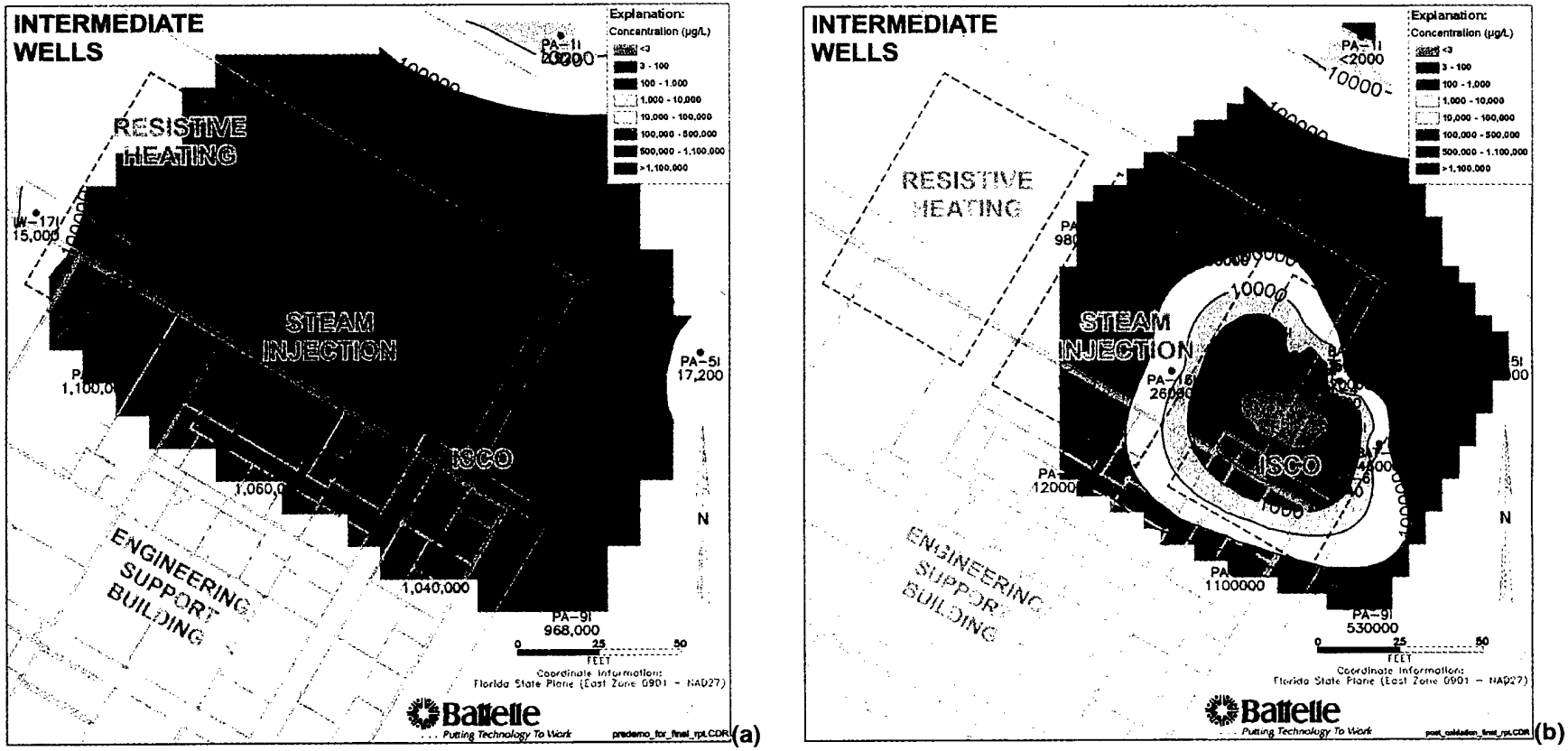


Figure 5-10. Dissolved TCE Concentrations (µg/L) during (a) Predemonstration (August 1999) and (b) Postdemonstration (May 2000) Sampling of Intermediate Wells

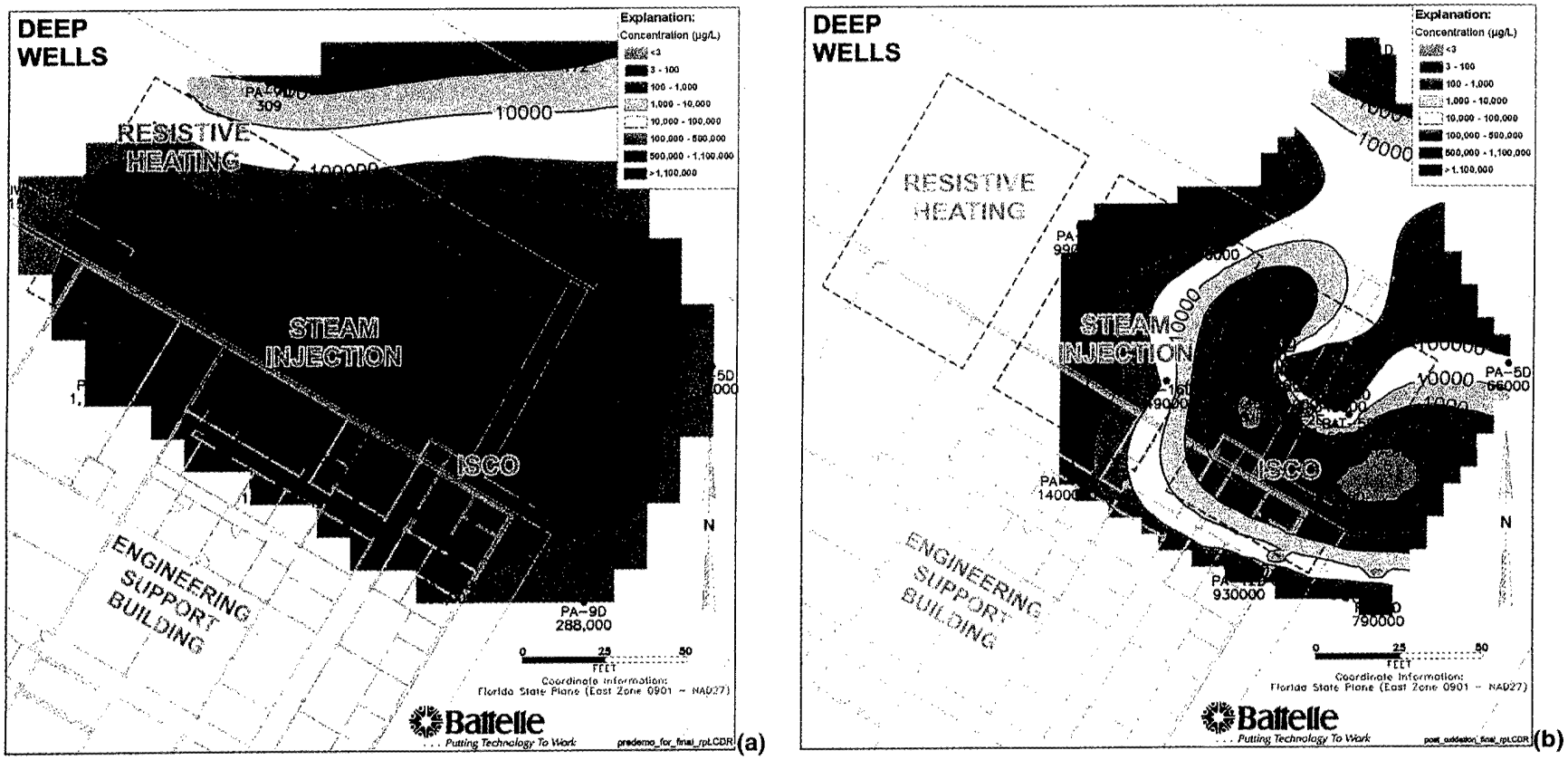


Figure 5-11. Dissolved TCE Concentrations (µg/L) during (a) Predemonstration (August 1999) and (b) Postdemonstration (May 2000) Sampling of Deep Wells

- Local heterogeneities near BAT-5S may have prevented sufficient oxidant from reaching this region, as well as perhaps other regions in the plot. In many wells inside the ISCO plot, the water turned purple during the demonstration, indicating excess permanganate and good oxidant distribution. However, in some wells in the plot (such as BAT-5, which is relatively close to one of the injection points), the water never turned purple, indicating that preferential pathways dominated flow and oxidant distribution on the scale of the plot. Local heterogeneities may limit the amount of oxidant encountered through advective flow in certain regions of the plot; some of these regions may be relatively close to oxidant injection points. Another possibility is that the injected oxidant encountered so much DNAPL and natural organic matter that it was depleted prior to reaching a neighboring monitoring well. Over time, it is possible that permanganate may persist in the vicinity long enough to penetrate into such difficult spots by diffusion. In fact, during the extended monitoring event (see Table 5-3), there were signs that TCE levels in BAT-55 were beginning to decline.
- Redistribution of residual DNAPL within the plot due to hydraulic gradients is unlikely; residual DNAPL does not move out of pores by hydraulic gradient alone. On the other hand, some mobile DNAPL in the plot may have migrated into the BAT-5S well early during the injection and subsequently created elevated TCE levels in the well.
- Another possibility is that the sharp increase in TCE in BAT-5S and some perimeter wells (see Section 5.2.2) is due to the increased groundwater flow through previously less permeable regions of the DNAPL source zone. Partial removal of DNAPL by oxidation increases the permeability of the DNAPL source regions to groundwater flow (Pankow and Cherry, 1996). Therefore, DNAPL mass removal, if it is not 100%, can initially elevate dissolved TCE concentrations, although reduced dissolved-TCE levels will result over subsequent years.

The concentration of *cis*-1,2-DCE declined considerably in several wells (e.g., BAT-1S, BAT-2S, BAT-3D, BAT-6D, PA-4S, and PA-4I) within the plot. Vinyl chloride was not detected in several wells both before and after the demonstration, primarily because of the analytical limitations associated with samples containing higher levels of TCE.

5.2.2 Changes in Aquifer Geochemistry

Among the field parameter measurements (tabulated in Table 5-4 and Appendix D) conducted in the affected aquifer before, during, and after the demonstration, the following trends were observed:

- Groundwater *temperature* ranged from 26 to 29°C before the demonstration to 27 to 29°C after the demonstration (relatively unchanged). This was expected as there is no exothermic reaction involved with permanganate, as with some other oxidants.
- Groundwater *pH* ranged from 7.0 to 7.6 before the demonstration to 6.4 to 7.7 after the demonstration, with some fluctuation during the demonstration. A pH drop would be expected in an unbuffered system as the oxidation reaction produces hydrogen ions and CO_2. However, as discussed in Section 5.3.1, the native groundwater alkalinity and carbonate shell materials provide a buffer, and limit any change in pH.
- *ORP* increased from –22 to –165 mV before the demonstration to –171 to 469 mV after the demonstration, with some fluctuation during the demonstration. The higher ORP is indicative of the oxidizing conditions created in the plot.
- *DO* ranged from <0.5 to 2.7 mg/L before the demonstration to <0.5 to 3.1 mg/L after the demonstration, with some fluctuation during the demonstration. Some DO may have been introduced into the aquifer through the hydrant water used to make up the permanganate solution. Due to the limitations of measuring DO with a flowthrough cell, groundwater with DO levels below 1.0 is considered anaerobic. Except for the shallower regions, the aquifer was mostly anaerobic through the demonstration.
- *Conductivity* increased from 0.5 to 2.7 mS/cm before the demonstration to 6.7 to 14.6 mS/cm after the demonstration (see Appendix D-1). The increase is attributed to a buildup of dissolved ions formed from the mineralization of organic matter and CVOCs. Also, this possibly resulted from residual permanganate in solution.

Other groundwater measurements indicative of aquifer quality included inorganic ions, BOD, and TOC. The results of these measurements are as follows:

- *Calcium* and *magnesium* levels remained relatively unchanged in the shallow and intermediate wells, but increased in the deep wells. In the deep wells, predemonstration levels of calcium (84 to 88 mg/L) and magnesium (82 to 84 mg/L) rose to postdemonstration levels of 210 to 349 mg/L (calcium) and 53 to 203 mg/L (magnesium). Calcium levels further increased to 1,020 mg/L during the extended monitoring, nine months after the demonstration.

Groundwater *alkalinity* increased from 204 to 323 mg/L before the demonstration to 1,060 to 2,140 mg/L after the demonstration. The sharp changes in calcium, magnesium, and alkalinity can be attributed to the oxidation of organic matter and CVOCs that leads to CO_2 generation in the aquifer, and the interaction of this CO_2 with shell material and groundwater in open (shallow aquifer) and closed (deep aquifer) systems, as described in Section 5.3.1.

- *Chloride* levels were already relatively high in the aquifer due to saltwater intrusion, especially in the deeper units. Despite relatively high native chloride levels in the aquifer and despite the dilution effect of hydrant water containing 94 mg/L that was used to make up the permanganate injection solution, chloride concentrations increased noticeably in the three stratigraphic units. In the shallow wells, chloride increased from 38 to 53 mg/L before the demonstration to 126 to 531 mg/L after the demonstration. In the deep wells, chloride levels increased from 722 to 752 mg/L before the demonstration to 1,360 to 1,730 mg/L after the demonstration. Nine months after the demonstration, chloride levels in the deep wells had increased to as high as 5,070 mg/L. These increased chloride levels are a primary indicator of CVOC destruction due to ISCO. The secondary drinking water limit for chloride is 250 mg/L.

- *Manganese* levels in the plot rose from <0.015 to 1.1 mg/L before the demonstration to as high as 516 mg/L in BAT-5I after the demonstration; manganese has a secondary drinking water limit of 0.05 mg/L, which was exceeded during and after the demonstration. Perimeter wells also showed elevated levels of manganese. Dissolved manganese consists of the species Mn^{7+} (from excess permanganate ion) and Mn^{2+} (generated when MnO_2 is reduced by native organic matter). Mn^{7+} levels are expected to subside over time, as excess permanganate precipitates out as MnO_2 and normal groundwater flow re-establishes in the plot. Mn^{2+} is generated when MnO_2 enters a reducing environment. Mn^{2+} is not a health hazard, but it can cause discoloration of the water above 0.05 mg/L. As the water enters a more aerobic environment (as may be present outside the CVOC plume), Mn^{2+} will precipitate out as MnO_2. Manganese levels declined considerably with distance from the plot (see Table D-2 in Appendix D).

- *Iron* levels in the ISCO plot remained relatively unchanged at levels of <0.05 to 2.5 mg/L in the native groundwater and <0.05 to 1.1 mg/L in the postdemonstration water. In the extended monitoring, iron levels had increased to as high as 35.6 mg/L in one well. The secondary drinking water limit for iron is 0.3 mg/L, which was exceeded during and after the demonstration. Precipitation of ferric iron on soil was visually noted (as orange color) and the expectation was that dissolved iron levels would decrease. Some dissolution of iron from underground materials could have occurred that replenished dissolved iron. The monitoring wells are made of stainless steel and are fairly resistant to the oxidant; however, chloride may corrode stainless steel and dissolve some iron and, perhaps, chromium and nickel.

- *Sulfate* levels increased sharply from 29 to 138 mg/L before the demonstration to 379 to 1,380 mg/L in postdemonstration water. In the extended monitoring, sulfate levels increased to 1,810 mg/L in one well. This increase in sulfate may be due to oxidation of reduced sulfur species in the native soil.

- *TDS* levels increased considerably in all three units. In the shallow wells, TDS levels rose from 387 to 499 mg/L before the demonstration to 2,860 to 6,790 mg/L after the demonstration; in the intermediate wells, TDS rose from 517 to 760 mg/L before to 3,640 to 13,000 mg/L after the demonstration; in the deep wells, TDS rose from 1,490 to 1,550 mg/L before to 5,250 to 8,280 mg/L after the demonstration. During extended monitoring, TDS levels remained high. The secondary drinking water limit for TDS is 500 mg/L, which was exceeded both before and after the demonstration.

- Table 5-5 shows the groundwater cleanup target levels issued by the State of Florida for 12 *trace metals*. The primary drinking water limits for chromium, nickel, and thallium were exceeded in some of the ISCO plot wells during and after the demonstration. Chromium (PA-3S, PA-5S, and PA-12D) and nickel (PA-5S and PA-12 cluster) limits were also exceeded in some of the perimeter wells. The secondary drinking water standard for aluminum was exceeded on one occasion during the demonstration, but subsided after the demonstration.

  Metals of concern that are minor ingredients in the industrial-grade $KMnO_4$ batch used at Launch Complex 34 are listed in Table 5-6 (see Appendix I for the technical specification sheet from the manufacturer). This table also shows the expected concentrations in the groundwater, if the metals entering the aquifer stay within the test plot (a worst case scenario). When the expected concentrations are compared with the actual concentrations in the groundwater before and after ISCO treatment, the increases in concentrations of chromium and nickel are difficult to attribute to the injected permanganate

Table 5-5. Postdemonstration Concentrations of Trace Metals in Groundwater at Launch Complex 34 versus the State of Florida Standards (issued May 26, 1999)

Trace Metal	Maximum Concentration Measured in Treated Aquifer (µg/L)	State of Florida Drinking Water Limit (µg/L)	Standard
Aluminum	<200	200	Secondary
Antimony	<6	6	Primary
Arsenic	21	50[a]	Primary
Barium	<200	2,000	Primary
Beryllium	<10	4	Primary
Chromium	193,000	100	Primary
Copper	<25	1,000	Secondary
Lead	12	15	Primary
Nickel	10,600	100	Primary
Silver	38	100	Secondary
Thallium	20	2	Primary
Zinc	56	5,000	Secondary

(a) The federal arsenic standard for drinking water standard was recently lowered to 10 µg/L.
Shading denotes the metals that are exceeding the State of Florida drinking water standard.

Table 5-6. Contribution from the Industrial-Grade $KMnO_4$ to Elevated Levels of Trace Metals in the ISCO Plot

Metals	Metal Concentration in the Industrial-Grade $KMnO_4$ Used (mg/kg)	Expected Metal Concentration in Aquifer[a] (mg/L)	Maximum Concentration in Untreated Aquifer (mg/L)	Maximum Concentration Measured in Treated Aquifer (mg/L)
Aluminum	61.6	1.17	<0.2	<0.2
Antimony	0.8	0.02	<0.006	<0.006
Arsenic	3.3	0.06	1.11	0.021
Barium	11.1	0.21	<0.1	<0.2
Beryllium	<0.8	0.01	<0.005	<0.01
Chromium	10	0.19	<0.01	193
Copper	25.3	0.48	<0.025	<0.25
Iron	24.7	0.47	1.1	35.6
Lead	1.4	0.03	<0.003	0.012
Nickel	4.2	0.08	0.066	10.6
Silver	<0.8	0.01	<0.01	0.038
Thallium	3.4	0.06	<0.01	0.02
Zinc	3.8	0.07	<0.02	0.056

(a) The expected metal concentration due to $KMnO_4$ was calculated based on the volume (1,274,265 L) of porewater in the ISCO plot (porosity of 0.3) and the mass (66,956 kg) of $KMnO_4$ used for the ISCO demonstration.

chemical. Other possible sources of chromium and nickel could be the aquifer itself (metals extracted from the soil particles by the action of the strong oxidant) or the stainless steel (Fe-Ni-Cr alloy) monitoring wells. Iron levels increased sharply in some wells, too.

On the other hand, actual thallium levels in the posttreatment aquifer are of the same approximate order as the expected levels. Given the fact that some injected thallium would migrate outside the test plot, the elevated thallium concentrations in the test plot could be attributed to the injected permanganate. Elevated levels of trace metals in the treated aquifer are expected to eventually subside by advection and diffusion over time. To a certain extent, the manganese dioxide formed when permanganate reacts with organic matter, can itself adsorb some of the trace metals released. Elevated levels of trace metals are an issue that needs further investigation in the context of industrial-grade potassium permanganate application to the subsurface.

- *TOC and BOD* data were difficult to interpret. TOC in groundwater ranged from 4 to 16 mg/L before the demonstration and from 10 to 2,110 mg/L after the demonstration. BOD declined in some wells, increased in other wells, and remained unchanged in some wells, indicating the variations in the efficiency of oxidant distribution in different regions of the plot. BOD increased sharply in BAT-5S and BAT-5D, from <3 to 13 mg/L before the demonstration to <2 to 112 mg/L after the demonstration. The increase in groundwater TOC and BOD may indicate greater dissolution of native organic species in the groundwater due to oxidation. TOC levels measured in soil remained relatively unchanged, ranging from 0.9 to 1.8% before the demonstration and from 0.8 to 1.8% after the demonstration.

In addition to measuring inorganic parameters in the ISCO plot wells, they also were measured in the perimeter wells surrounding the plot and selected distant wells to see how far the influence of the ISCO would progress. In addition to the geochemistry, the effect of the ISCO treatment on the aquifer microbiology was evaluated in a separate study as described in Appendix E.

5.2.3 *Changes in the Hydraulic Properties of the Aquifer*

Table 5-7 summarizes the results (see Appendix B) of slug tests conducted in the ISCO plot before and after the demonstration. Hydraulic conductivity of the aquifer ranged from 1.3 to 6.4 ft/day before the demonstration to 1.4 to 5.0 ft/day after the demonstration. There was no noticeable difference in the hydraulic conductivity due to

Table 5-7. Pre- and Postdemonstration Hydraulic Conductivity at ISCO Plot Aquifer

Well	Hydraulic Conductivity (ft/day)	
	Predemonstration	Postdemonstration
BAT-5S	4.0	5.0
BAT-6S	5.1	Poor response
BAT-3I	1.6	2.4
BAT-5I	6.4	1.5
BAT-6I	1.4	3.7
BAT-3D	1.3	Poor response
BAT-6D	2.3	1.4

the ISCO treatment. Any buildup of MnO_2 or other solids due to the chemical oxidation process does not seem to have affected the hydraulic properties of the aquifer. It is possible that the lack of change in hydraulic conductivity is due to the fact that any porosity loss caused by generation of MnO_2 solids is offset by the porosity gain from calcium carbonate solids that go into solution because of the CO_2 generated in the oxidation process. Also, if the MnO_2 solids are small enough, they could have been transported out of the test plot with the groundwater flow.

5.2.4 *Changes in Microbiology of ISCO Plot*

Microbiological analysis of soil and groundwater samples was conducted to evaluate the effect of the ISCO application on the microbial community (see Appendix E for details). Samples were collected before, six months after (as postdemonstration monitoring), and nine months after the ISCO technology demonstration. For each monitoring event, soil samples were collected from five locations in the plot and five locations in a control (unaffected) area. At each location, four depths were sampled—capillary fringe, Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit. The results are presented in Appendix E.

Table 5-8 summarizes the soil analysis results. The geometric mean typically is the mean of the five samples collected in each stratigraphic unit in the plot. Because microbial counts can be highly variable, only order-of-magnitude changes in counts were considered significant. Figure 5-12 illustrates the live/dead stain analysis of soil samples (see Appendix E for detailed data).

In the Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit, aerobic microbial populations decreased immediately following the demonstration. In the capillary fringe, aerobic counts increased. Anaerobic microbial populations decreased in the Upper Sand Unit, but increased in the Lower Sand Unit. In other stratigraphic units, the populations appeared to be relatively constant. The postdemonstration microbial counts indicate that microbial populations may have declined during the ISCO treatment. In some parts of the plot, both aerobic and anaerobic counts declined to below detection, immediately after the oxidant injections. The live/dead stain analysis (Appendix E) also appears to indicate a decline in the percentage of live cells immediately after the demonstration, although the variability in the results is quite high. However, the microbial counts during the extended monitoring event indicate that microbial populations rebound quickly and re-establish in all parts of the plot.

Table 5-8. Geometric Mean of Microbial Counts in the ISCO Plot (Full Range of Replicate Sample Analyses Given in Parentheses)

ISCO Plot	Pre-demonstration Aerobic Heterotrophic Counts (CFU/g)	Post-demonstration Aerobic Heterotrophic Counts (6 months after) (CFU/g)	Extended Monitoring Aerobic Heterotrophic Counts (9 months after) (CFU/g)	Pre-demonstration Anaerobic Heterotrophic Counts (cells/g)	Post-demonstration Anaerobic Heterotrophic Counts (6 months after) (cells/g)	Extended Monitoring Anaerobic Heterotrophic Counts (9 months after) (cells/g)
Capillary Fringe	66,069 (3,981 to 1,584,893)	11,220,184 (3,162,278 to 100,000,00)	1,096,478 (19,952 to 63,095.7)	57,543 (5,012 to 1,584,893)	1,584,893 (1,584,893 to >1,584,893)	3,019,952 (251,188.6 to >31,622,776.6)
Upper Sand Unit	39,810.7 (1,259 to 100,000)	420.9 (<316.2 to 7,943)	478,630 (7,943 to 7,943,282)	85,770 (2,512 to 316,228)	8 (<1.78 to 6,310)	1,737,800 (199,526 to 19,952,623)
Middle Fine-Grained Unit	14,125 (501 to 125,893)	15,841 (<316.2 to 1,584,893)	316,227 (15,848.9 to 1,258,925)	7,499 (794 to 79,432.8)	12,879 (<1.78 to 1,584,893	457,088 (7,943 to 3,162,277)
Lower Sand Unit	6,309.6 (316 to 316,228)	218,776 (7,943 to 7,943,282)	114,815 (19,952 to 316,227.8)	4,365 (251 to 63,096)	239,883 (1,259 to >1,584.9)	416,869 (50,118.7 to 3,981,071)

CFU = colony-forming unit.

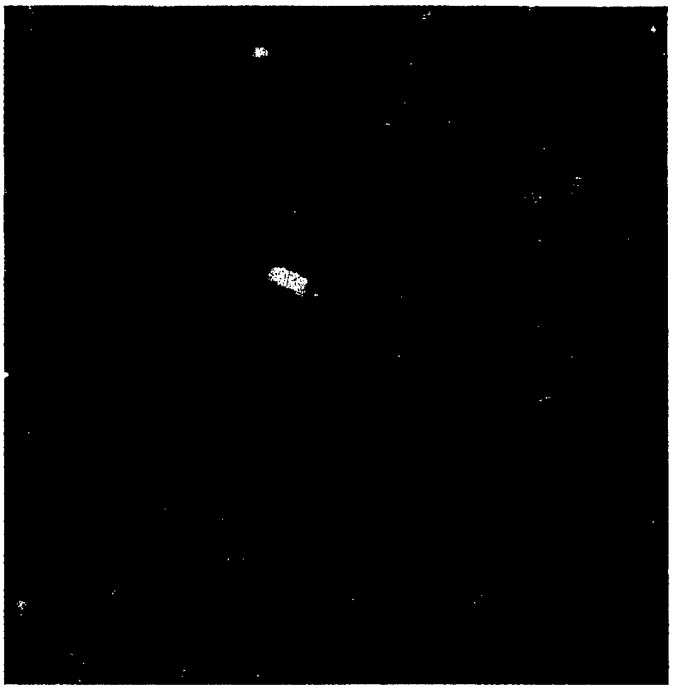


Figure 5-12. Representative Live/Dead Stain Analysis of Microorganisms in Soil (green indicating live, red indicating dead, and yellow indicating injured microorganisms)

5.2.5 Summary of Changes in Aquifer Quality

In summary, application of the ISCO technology created the following changes in the aquifer:

- Dissolved TCE levels declined sharply in several monitoring wells in the ISCO plot, with some wells showing postdemonstration concentrations of less than 5 µg/L, the federal drinking water standard. Achievement of the State of Florida groundwater target cleanup level of 3 µg/L could not be determined because excessive permanganate in several of the postdemonstration groundwater samples caused analytical interference and required dilution. In some wells within the ISCO plot, TCE levels declined, but stayed above 5 µg/L. In one of the shallow wells, TCE levels rose through the demonstration, indicating that local heterogeneities (limited oxidant distribution) or redistribution of groundwater flow due to partial DNAPL removal may have affected dissolved TCE levels. *cis*-1,2-DCE levels in all monitoring wells declined to below 70 µg/L. Vinyl chloride levels in some wells declined to less than 1 µg/L, the State of Florida target; in some wells, higher TCE levels elevated the detection limits of vinyl chloride. This indicated that ISCO considerably improved groundwater quality in the short term. There are some signs of a rebound in TCE and *cis*-1,2-DCE concentrations in the test plot during the extended monitoring that was conducted nine months after the end of the injections. Although TCE and *cis*-1,2-DCE levels rebounded to some extent in the nine months following the demonstration, they were still below the predemonstration levels in most wells. In any case, DNAPL mass removal is expected to lead to eventual and earlier disappearance of the plume over the long term. There is also the possibility that even in the medium term, as normal groundwater flow is reestablished, a weakened plume may be generated and the resulting CVOC levels may be amenable to natural attenuation.
- Temperature, pH, and DO remained relatively stable through the demonstration. ORP and conductivity of the groundwater increased, indicating oxidizing conditions and accumulation of dissolved ions.
- Calcium and magnesium levels rose in the deeper groundwater, indicating interactions with the shell material in the lower stratigraphic units (see Section 5.3.1).
- Alkalinity, chloride, and total dissolved solids levels rose sharply, indicating oxidation of TCE and native organic matter with carbon dioxide generation (see Section 5.3.1). High chloride and TDS levels both before and after the demonstration cause the groundwater to be classified as brackish.
- Dissolved manganese levels in the plot rose above secondary drinking water limits following the demonstration.
- Dissolved sulfate levels rose, indicating possible interactions between the oxidant and soil matter.
- Some trace metals, namely chromium, nickel, and thallium, exceeded State of Florida drinking water limits following the demonstration. The source of these metals is unclear. They could have been released from the soil matrix or the stainless steel monitoring wells. Some contribution from the industrial-grade permanganate is likely. Nine months after the end of the oxidant injections, the levels of these metals in the test plot were still elevated. The elevated levels of these trace metals are expected to subside over time, as flow is reestablished. The levels of these metals decline significantly as the water reaches the monitoring wells surrounding the plot, probably due to adsorption on the aquifer solids and on the newly generated manganese dioxide.
- The geochemical interactions between the oxidant and the aquifer are relatively complex, and not all of

the aquifer changes were easy to explain. The persistence of dissolved iron, the variability of 5-day BOD, the increase in sulfate, and the persistence of TOC in the postdemonstration aquifer are difficult to explain without further research.

5.3 Evaluating the Fate of the TCE/DNAPL Mass Removed

This part of the performance assessment was the most difficult because there are several pathways that the DNAPL could take when subjected to the ISCO treatment. These pathways were evaluated as follows:

5.3.1 DNAPL Destruction through Oxidation of TCE

As described in Equations 5-1 and 5-2, oxidation of TCE and other CVOCs by permanganate leads to the formation of chloride, carbon dioxide, hydrogen ion, and manganese dioxide. Any manganese dioxide generated is insoluble in water and is expected to deposit on the soil surfaces — the brown discoloration of soil observed in some soil samples indicates the formation of manganese dioxide. The soluble or partially soluble species — chloride, carbon dioxide, carbonate (alkalinity), and hydrogen ion (pH) — are more amenable to more direct measurement.

$$C_2HCl_3 + 2MnO_4^- \rightarrow 3Cl^- + 2CO_2 + H^+ + 2MnO_2\,(s) \quad (5\text{-}1)$$

$$C_2H_2Cl_2 + 2MnO_4^- \rightarrow 2Cl^- + 2CO_2 + 2H^+ + 2MnO_2\,(s) \quad (5\text{-}2)$$

Chloride is the strongest indicator of TCE oxidation, because it is directly traceable to TCE; because of the high injection pressures (and high water levels) in the ISCO plot during ISCO treatment, not much chloride intrusion is expected from tidal influence over the time period of the demonstration. Chloride generation due to oxidation would be expected to cause chloride levels to rise in the aquifer. Appendix D shows the pre- and postdemonstration chloride levels in the ISCO plot and surrounding aquifer. The increased chloride concentrations are noticeable in all three units — Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit — even though predemonstration chloride levels were high to begin with. Chloride levels in the aquifer increased to levels that were above the concentration level of water from the hydrant (94 mg/L chloride content) used to make up the oxidant solution.

Figures 5-13 to 5-15 show the distribution of excess chloride in the shallow, intermediate, and deep wells, respectively, as measured in May 2000, towards the end of the ISCO treatment. The chloride concentrations in these figures are the differences in chloride levels between the treated (postdemonstration) and native (predemonstration) levels of chloride. The strongest increase in chloride was observed in the deep wells (Lower Sand Unit), where the predemonstration DNAPL mass was highest. Most of the chloride increase in the test plot is attributable to oxidation of TCE by the permanganate. Because oxidation of TCE occurs in the aqueous phase, the treatment kinetics may be driven by the rate of dissolution of DNAPL, rather than the oxidation of dissolved TCE, which is a relatively fast process. There are reports that addition of permanganate increases the rate of dissolution of TCE by as much as a factor of 10 (Siegrist et al., 2001). There is very little possibility of chloride migrating into the ISCO plot from the resistive heating plot, because strong hydraulic gradients have been measured emanating radially outward from the ISCO plot during most of the ISCO application period. Some of the chloride formed probably migrated out of the ISCO plot under the strong hydraulic gradients created by the oxidant injection.

Carbon dioxide is an indicator of oxidation, although not of TCE alone. Native organic matter that is oxidized also releases carbon dioxide as indicated in Equation 5-3, which is a simplified illustration. However, TOC levels in the predemonstration groundwater and soil were relatively unchanged, or increased slightly (see Section 5.2.2), possibly due to the formation of new organic species from the complex native humic matter in the soil. Formation of carbon dioxide is an encouraging sign that TCE and native organic matter are being oxidized.

$$3C_{organic} + 4MnO_4^- + 4H^+ \rightarrow 3CO_2 + 4MnO_2\,(s) + 2H_2O \quad (5\text{-}3)$$

In an unbuffered system, the CO_2 generated may be expected to lower the *pH* of the aquifer. Dissolution of gaseous CO_2 in water can be expressed according to the following mass action equation:

$$CO_{2(g)} + H_2O \leftrightarrow H_2CO^*_{3(aq)} \quad (5\text{-}4)$$

where H_2CO_3* represents both dissolved CO_2 ($CO_{2(aq)}$) and carbonic acid (H_2CO_3). The predominant carbon species are H_2CO_3 below pH 6.3; HCO_3^- between pH 6.3 and 10.3, and CO_3^{-2} above pH 10.3. The presence of *carbonate* species in the Launch Complex 34 groundwater provides buffering capacity, which attenuates the effects of the accumulating acidic species (CO_2) in the water due to the oxidation treatment.

The other major factor in the geochemical scenario at Launch Complex 34 is the abundance of shell material in the aquifer soil. Carbonate rocks and biological shell

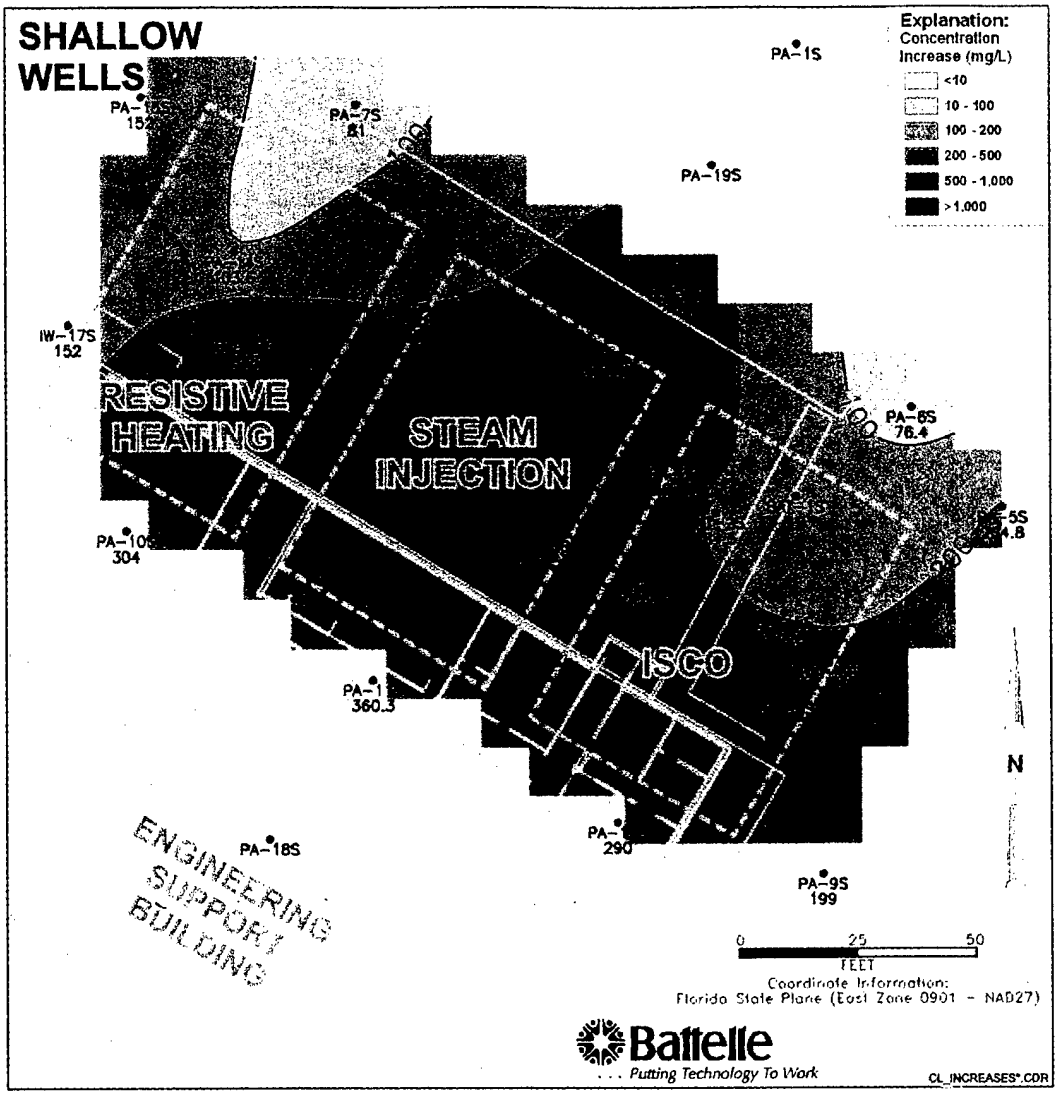


Figure 5-13. Distribution of Chloride Produced by ISCO Technology in Shallow Wells near the Engineering Support Building at Launch Complex 34 (May 2000)

material are composed primarily of calcium carbonate, and minor amounts of other metals, such as magnesium, iron, and manganese. Equilibrium between calcium carbonate (typically calcite or aragonite mineral forms) and water in the presence of CO_2 can be expressed as Equation 5-5 (Appelo and Postma, 1994).

$$CaCO_{3(solid)} + CO_{2(g)} + H_2O \leftrightarrow Ca^{2+} + 2HCO_3^- \qquad (5\text{-}5)$$

If a source of CO_2 is available, calcite will dissolve. Oxidation of organic matter by permanganate causes generation of CO_2. During the continuous oxidation, the partial pressure of CO_2 is probably high enough to cause a release of substantial amounts of calcium and bicarbonate ions into solution from the shell material. This could explain the sharp increase in alkalinity in all the ISCO plot wells, as well as the increase in dissolved *calcium* in some wells. Note that if calcite (shell material) were not available in the soil, the reaction in Equation 5-4 would apply, and the groundwater pH would have decreased accordingly. Therefore, despite the persistence of neutral pH and relatively low ORP in the posttreatment groundwater, the geochemistry indicates that a large amount of carbon dioxide was produced and a large portion of the organic matter (probably including the organic contaminants) was oxidized. The sharp increase in alkalinity and the substantial increase in inorganic chloride are encouraging signs that a significant proportion of the DNAPL removal was due to oxidation.

From a long-term perspective, it is important to note that after the CO_2 is exhausted, the system may not return to its original state, even though equilibrium is regained. In general, the aquifer environment is an open system, so

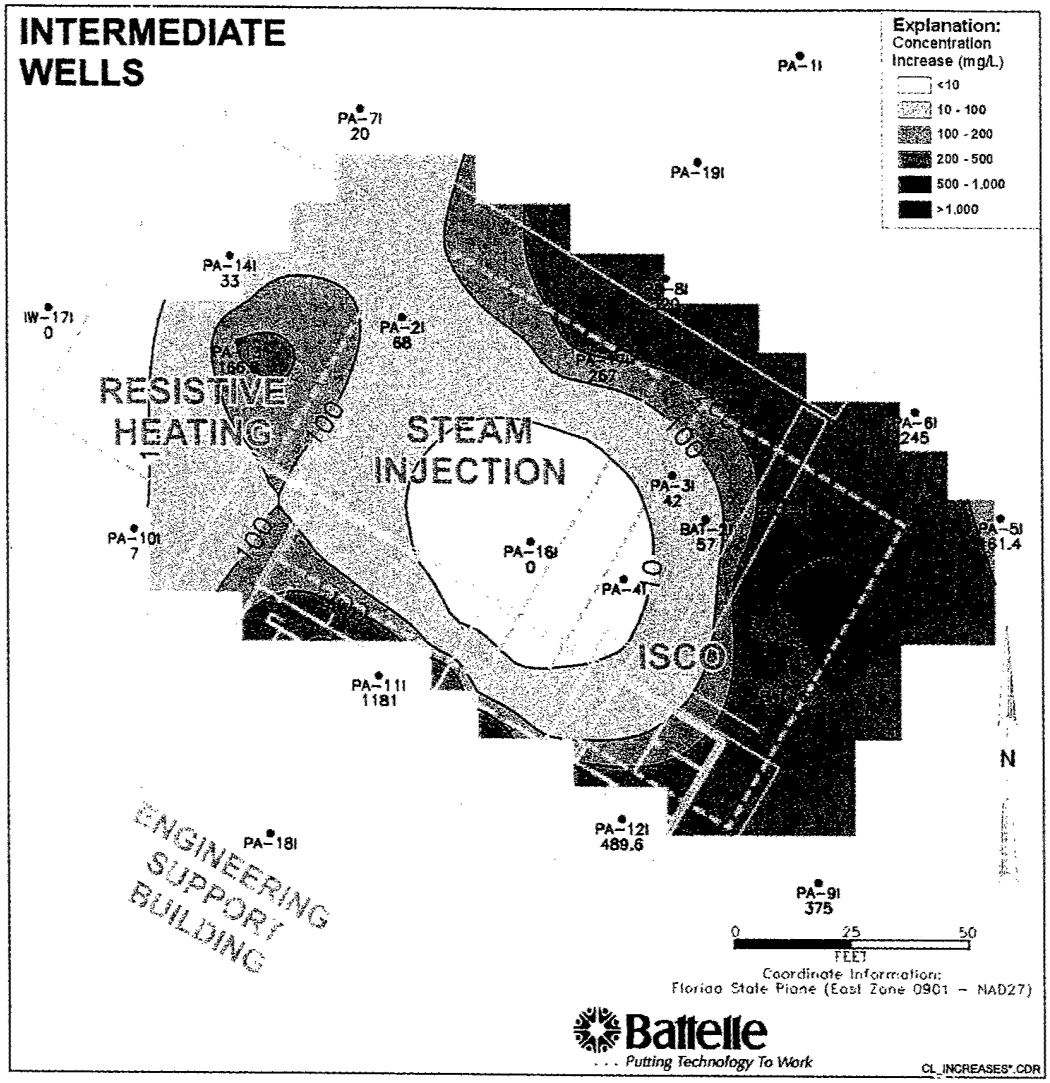


Figure 5-14. Distribution of Chloride Produced by ISCO Technology in Intermediate Wells near the Engineering Support Building at Launch Complex 34 (May 2000)

the partial pressure of CO_2 does return to its normal level after oxidation subsides. However, during the period when CO_2 is being produced, the HCO_3^- content increases logarithmically with pH, so that the final bicarbonate concentration at equilibrium is completely controlled by the initial partial pressure of CO_2 and the solubility of the calcite in the shell material. Therefore, the only way for the alkalinity and calcium levels in the groundwater to return to pretreatment levels is through dilution with the groundwater from the surrounding aquifer. In the relatively stagnant aquifer at Launch Complex 34, this could take a long time. Rainfall and recharge from the ground surface also could play a role in the rebound.

One aspect of the ISCO application that was not addressed during this demonstration is the formation of byproducts from incomplete oxidation of CVOCs and natural organic matter. This issue may best be addressed on a bench scale.

In summary, all the geochemical indicators examined point to oxidation as a pathway that contributed substantially to the removal of TCE/DNAPL from the ISCO plot. These geochemical indicators include:

- Considerable rise in chloride levels in the treated aquifer
- Considerable increase in groundwater alkalinity (as indicative of carbon dioxide generation)
- Rise in calcium levels in the deeper portions of the aquifer.

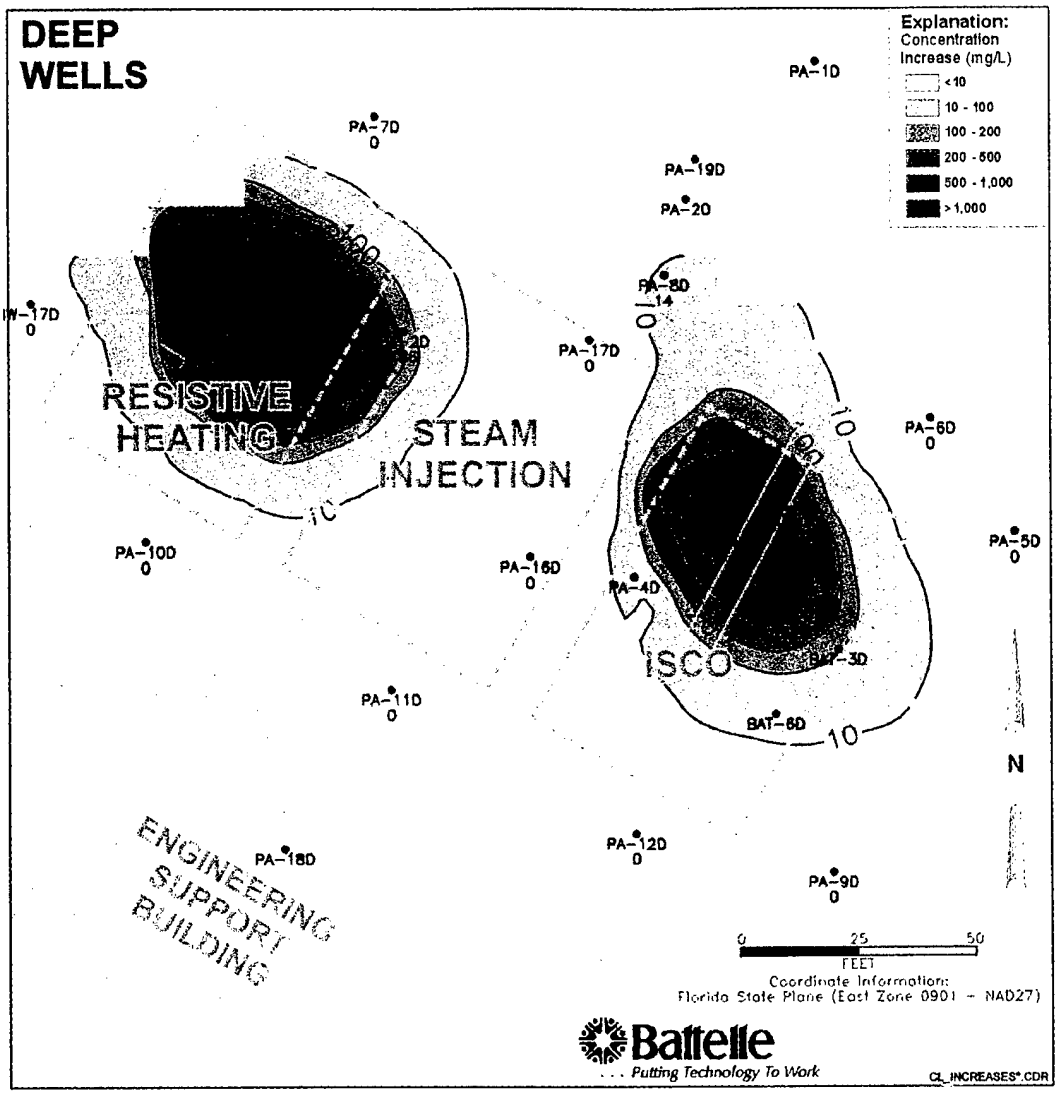


Figure 5-15. Distribution of Chloride Produced by ISCO Technology in Deep Wells near the Engineering Support Building at Launch Complex 34 (May 2000)

5.3.2 Potential for DNAPL Migration from the ISCO Plot

The six measurements conducted to evaluate the potential for migration of DNAPL, as well as dissolved vapor and nonaqueous phase, to the surrounding aquifer include:

- Hydraulic gradient in the aquifer
- Distribution of dissolved potassium in the aquifer
- TCE measurements in perimeter wells
- TCE concentrations in the surrounding aquifer soil cores
- TCE concentrations in the vadose zone soil cores
- TCE concentrations in surface emissions to the atmosphere.

As mentioned in Section 5.2, predemonstration *hydraulic gradients* in the Launch Complex 34 aquifer are relatively flat in all three stratigraphic units. During the demonstration, hydraulic gradients (see Figures 5-16 to 5-18) were measured in April 2000 in the shallow, intermediate, and deep wells, respectively, while the third and final oxidant injection was under way in the Lower Sand Unit. Water level measurements in the deep wells showed a sharp hydraulic gradient emanating radially from the ISCO plot because of the injection pressures. Interestingly, the gradient was not as strong in the shallow and intermediate wells while oxidant was being injected in the deeper layers, indicating that the Middle Fine-Grained Unit acts as a conspicuous hydraulic barrier.

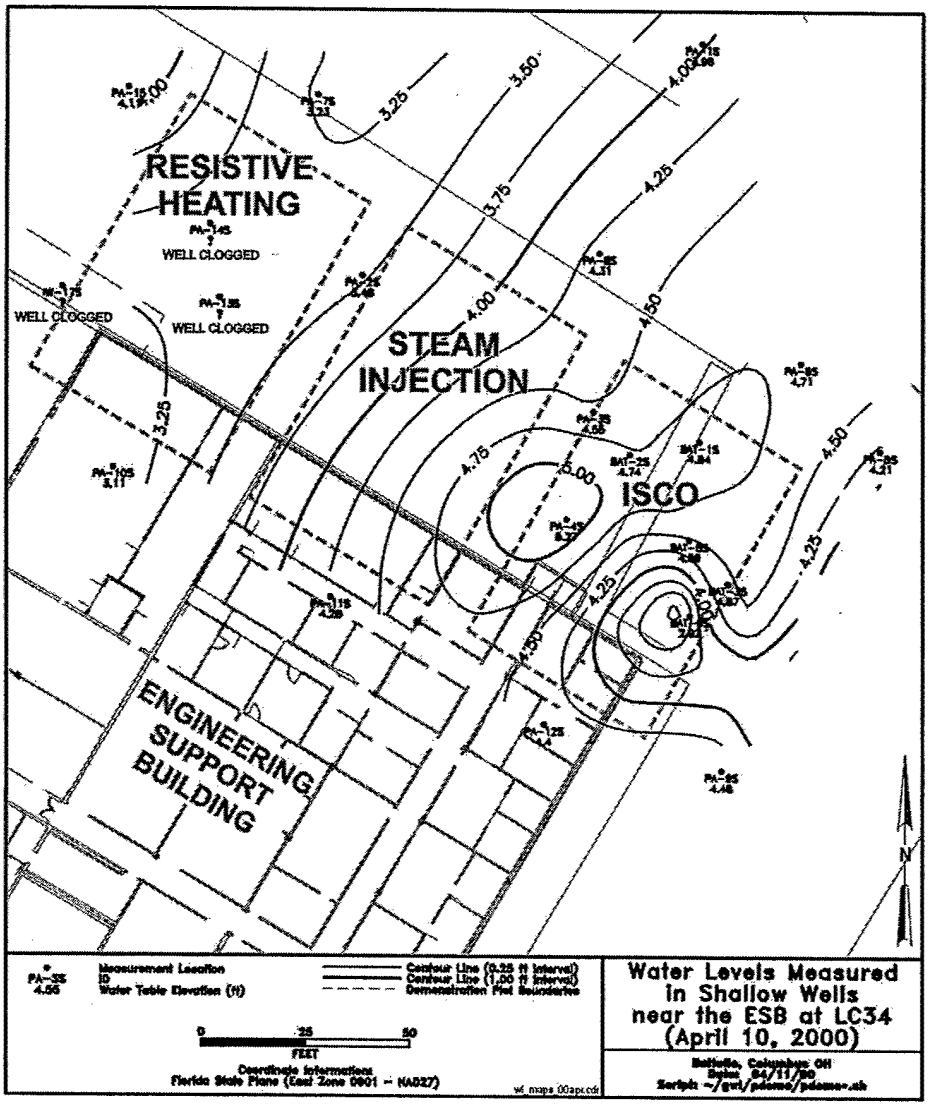


Figure 5-16. Water Levels Measured in Shallow Wells near the Engineering Support Building at Launch Complex 34 (April 2000)

Residual DNAPL cannot migrate due to hydraulic gradient alone, no matter how strong. However, if mobile DNAPL was present in the aquifer, strong injection pressures could have caused DNAPL movement from the plot.

Migration of groundwater and dissolved groundwater constituents from the ISCO plot are exemplified by the movement of *potassium ion* in the aquifer, as shown in Figures 5-19 to 5-21. Because there were no monitoring wells at the time in the steam injection plot, this area is blanked out in these figures to avoid interpolating over relatively large distances. Potassium, originating from the injected oxidant, acts as a semiconservative tracer for tracking groundwater movement. Figures 5-19 to 5-21 show the excess potassium (above predemonstration levels) in the groundwater at Launch Complex 34. The vapor extraction occurring in the resistive heating plot could have exacerbated the effect of the westward hydraulic gradient and increased the migration of water and ions from the ISCO plot. Also, vaporization of water in the resistive heating plot could have caused dissolved ion levels in the resistive heating plot and vicinity to increase. Because more monitoring wells are present on the western side of the ISCO plot, movement seems to be occurring to the west; however, similar groundwater transport probably occurred in all directions from the plot. This migration of groundwater and dissolved species from the ISCO plot is an important aspect of injecting oxidant without concomitant extraction or hydraulic control, and may need to be reviewed on a site-specific basis.

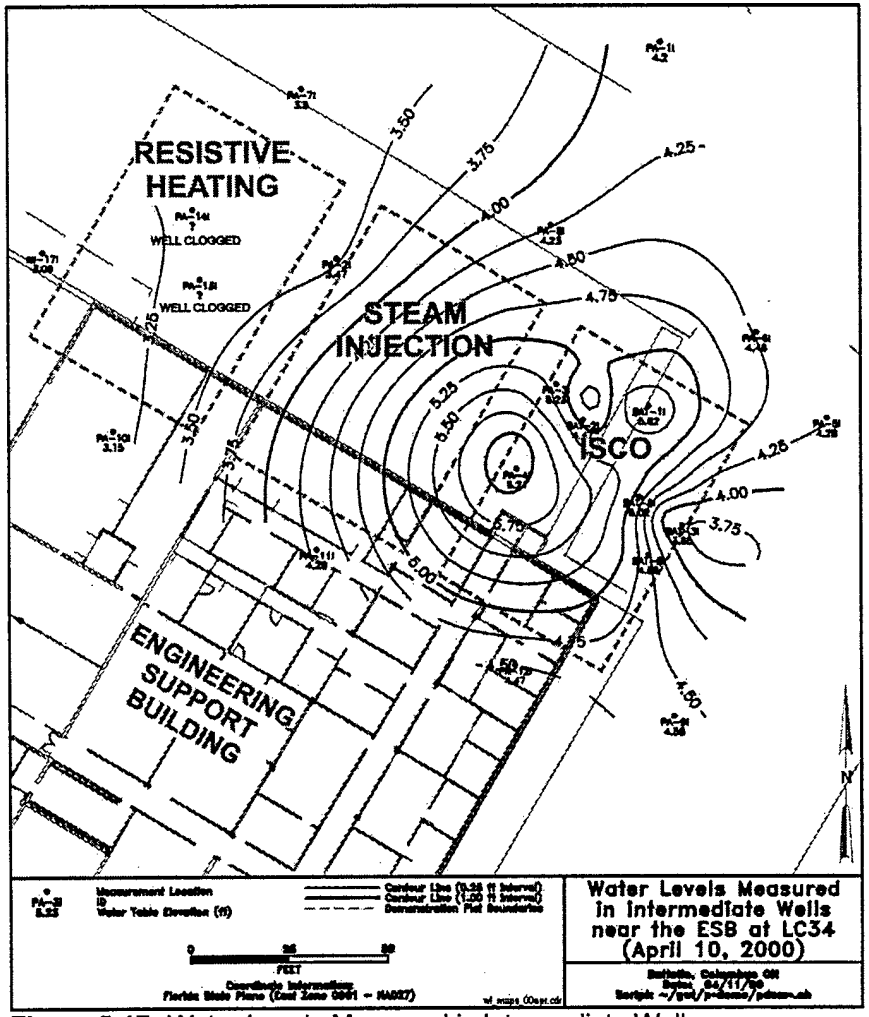


Figure 5-17. Water Levels Measured in Intermediate Wells near the Engineering Support Building at Launch Complex 34 (April 2000)

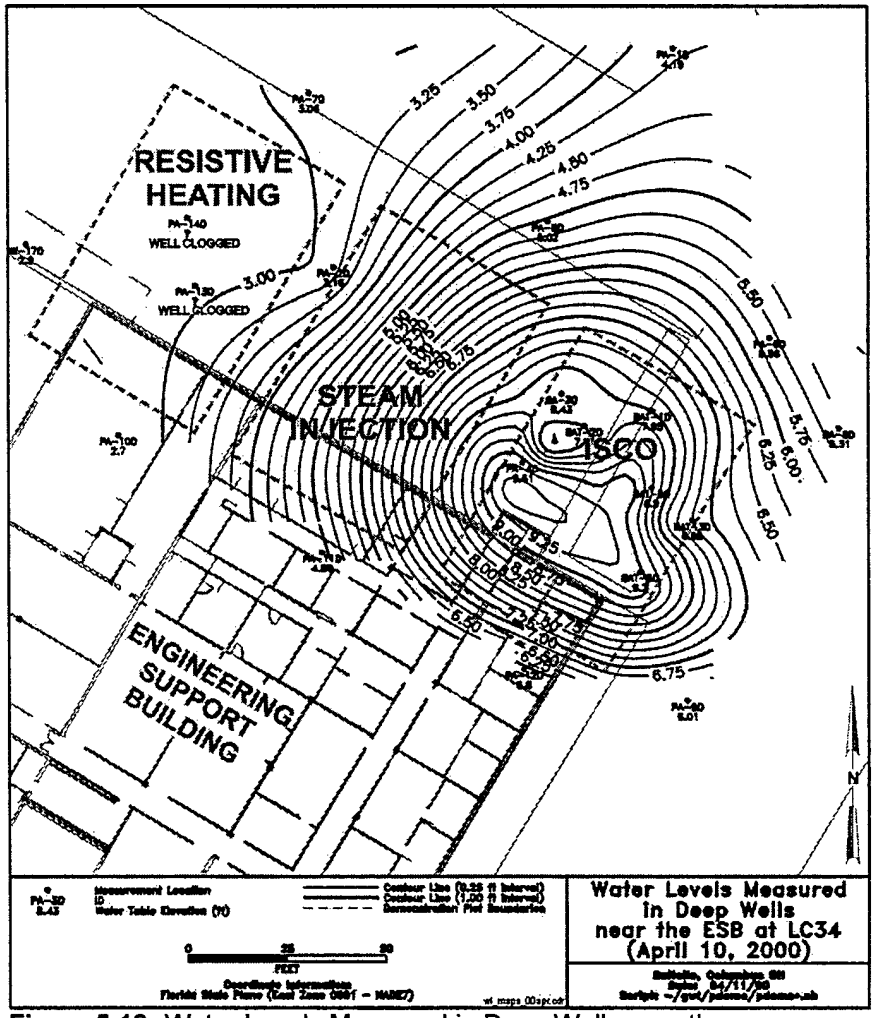


Figure 5-18. Water Levels Measured in Deep Wells near the Engineering Support Building at Launch Complex 34 (April 2000)

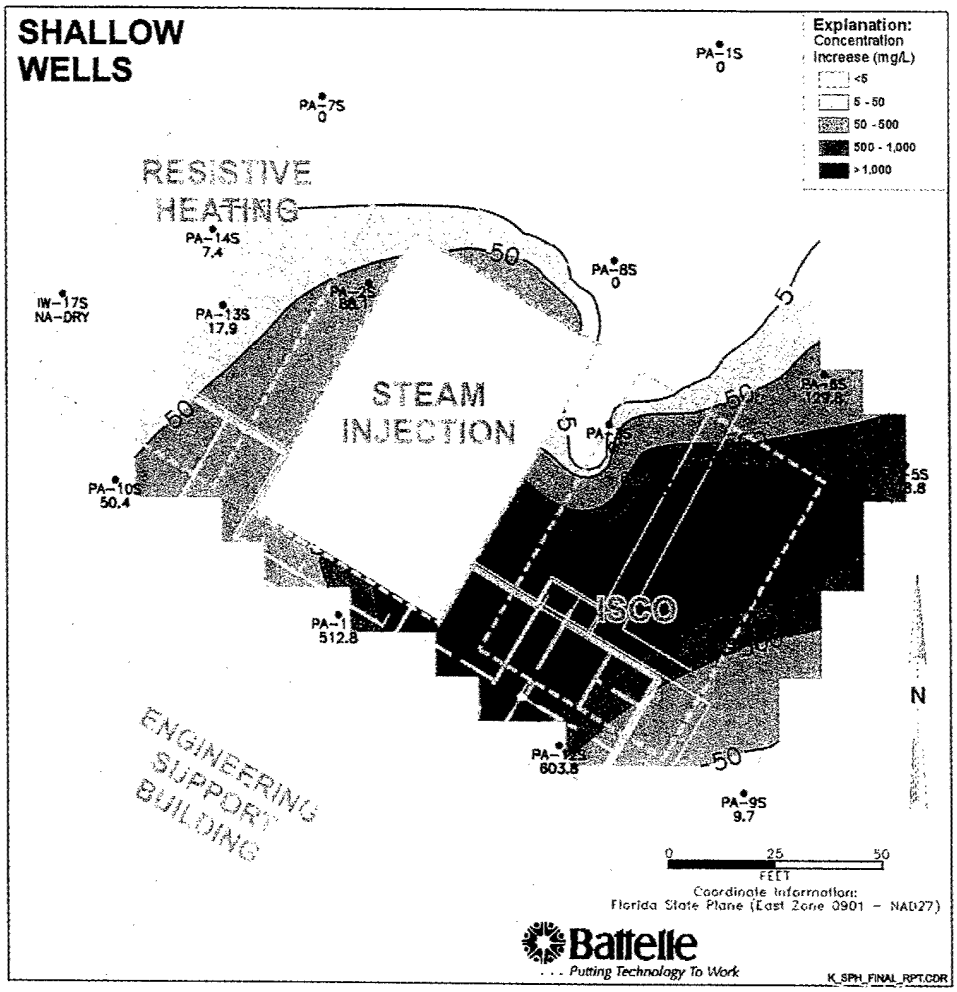


Figure 5-19. Distribution of Potassium (K) Produced by ISCO Technology in Shallow Wells near the Engineering Support Building at Launch Complex 34 (April 2000)

TCE and other CVOCs are among the dissolved species that migrated from the ISCO plot as indicated by the TCE measurements in perimeter and distant wells (see Appendix C). Figures 5-22 to 5-24 show the TCE trends observed in the *perimeter wells*. TCE levels in perimeter wells PA-5S, PA-5I, and PA-6S (on the northeast side of the ISCO plot) and in a somewhat distant well PA-8S (northwest of the ISCO plot) rose sharply when the oxidation treatment started and an increase of more than an order of magnitude was sustained through the end of the demonstration. In other perimeter wells, TCE levels either declined sharply or showed a mild increase. A sharp temporary increase in TCE concentrations in the monitoring wells would signify that dissolved-phase TCE has migrated. A sharp sustained increase may signify that DNAPL has redistributed within the plot or outside it. Another possibility, as mentioned in Section 5.2, is that the sharp increase in TCE in some ISCO plot and perimeter wells is due to the increased groundwater flow through previously less permeable regions of the DNAPL source zone; an increase in permeability can result in regions of the aquifer that experience partial removal of DNAPL.

Figure 5-25 shows the TCE trends observed in *distant well* clusters PA-8 and PA-1. PA-8 is closer to the ISCO plot on the northwest side. PA-1 is further away towards the north-northwest side. The PA-8 cluster showed a significant increase in TCE concentrations in the shallow and deep wells. After the ISCO and resistive heating demonstrations started, DNAPL was observed for the first time in distant wells PA-11D, PA-2I, and PA-2D, all of which are on the west side of the ISCO plot. DNAPL had not been previously found in any of the monitoring wells before the demonstration. This indicates that some free-phase TCE movement occurred in the aquifer due to the application of the two technologies. It is unclear which of the two technologies contributed to the DNAPL movement and whether or not this DNAPL was initially in mobile or residual form. Mobile DNAPL could have

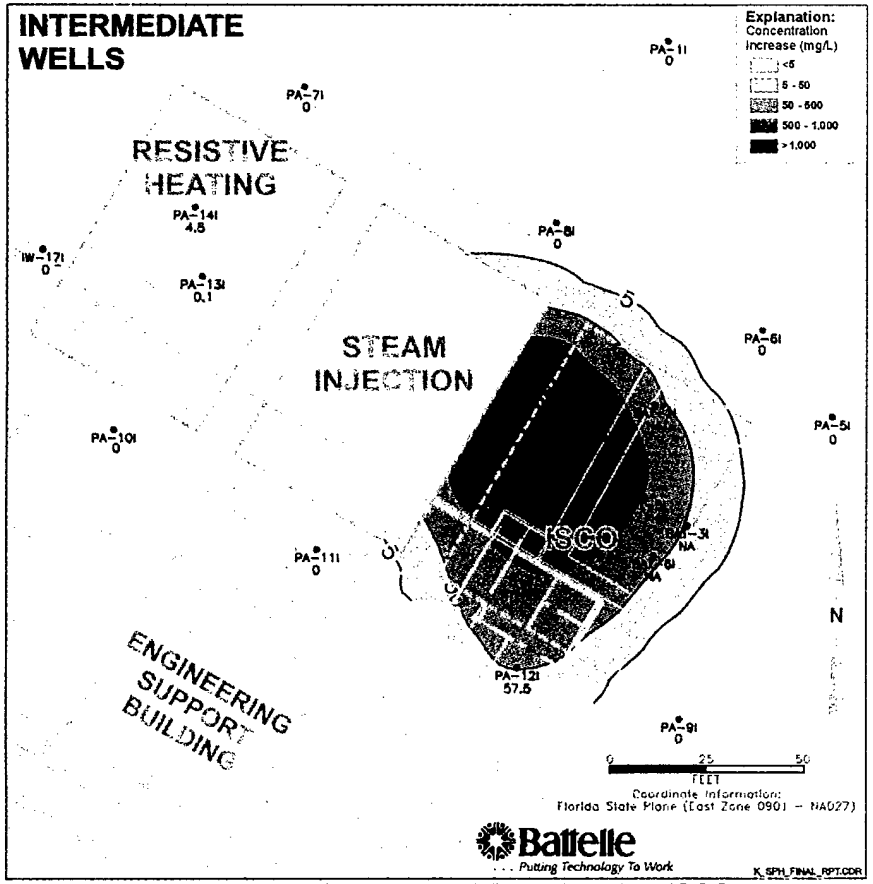


Figure 5-20. Distribution of Potassium (K) Produced by ISCO Technology in Intermediate Wells near the Engineering Support Building at Launch Complex 34 (April 2000)

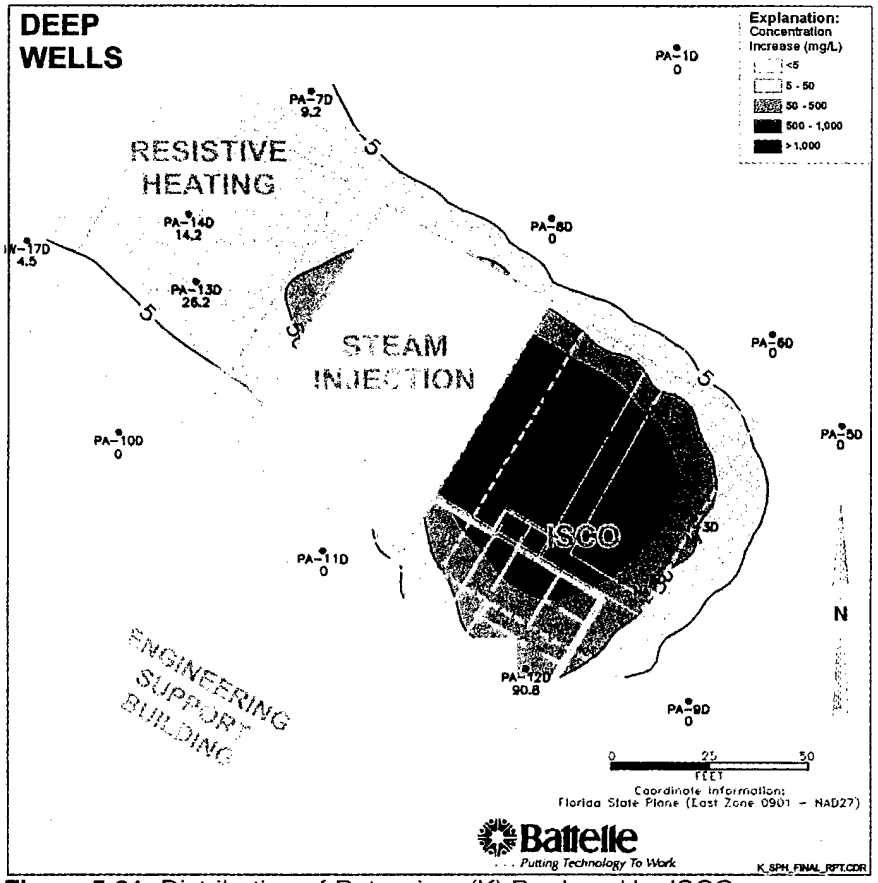


Figure 5-21. Distribution of Potassium (K) Produced by ISCO Technology in Deep Wells near the Engineering Support Building at Launch Complex 34 (April 2000)

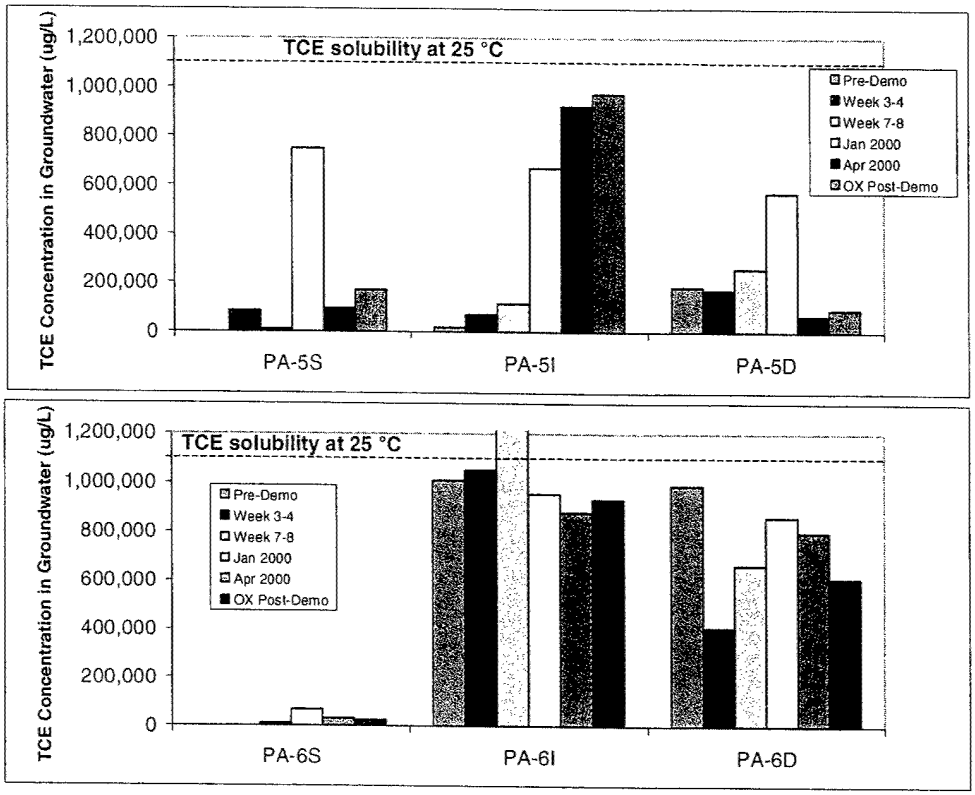


Figure 5-22. Dissolved TCE Levels (µg/L) in Perimeter Wells on the Northeastern Side of the ISCO Plot

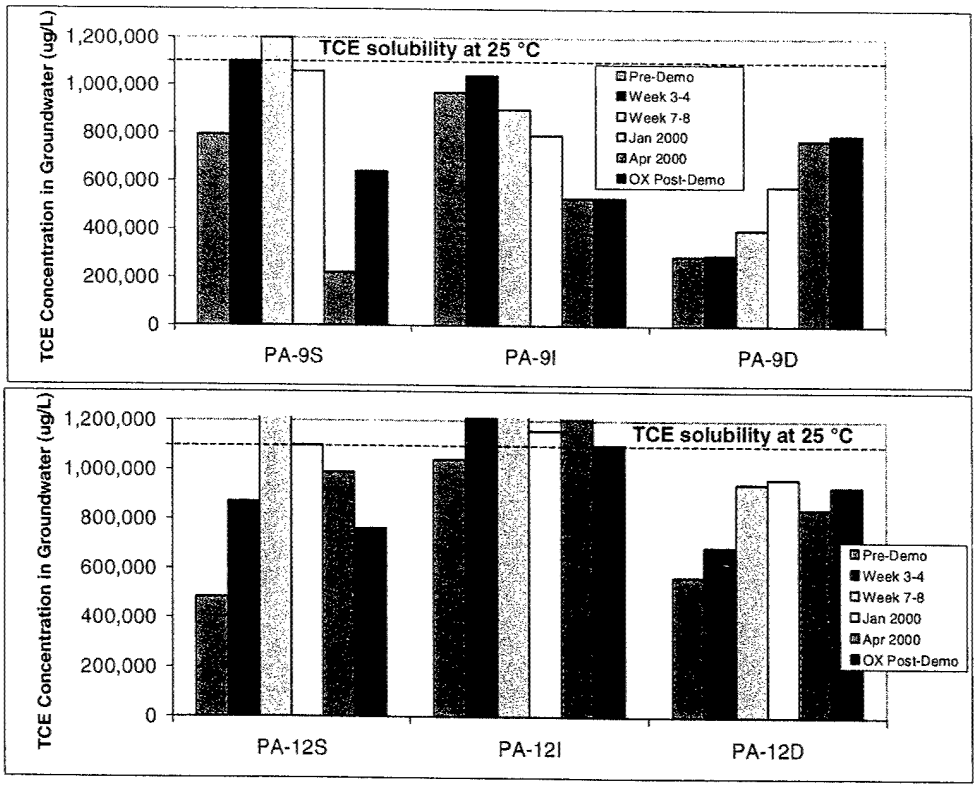


Figure 5-23. Dissolved TCE Levels (µg/L) in Perimeter Wells on the Southern Side of the ISCO Plot

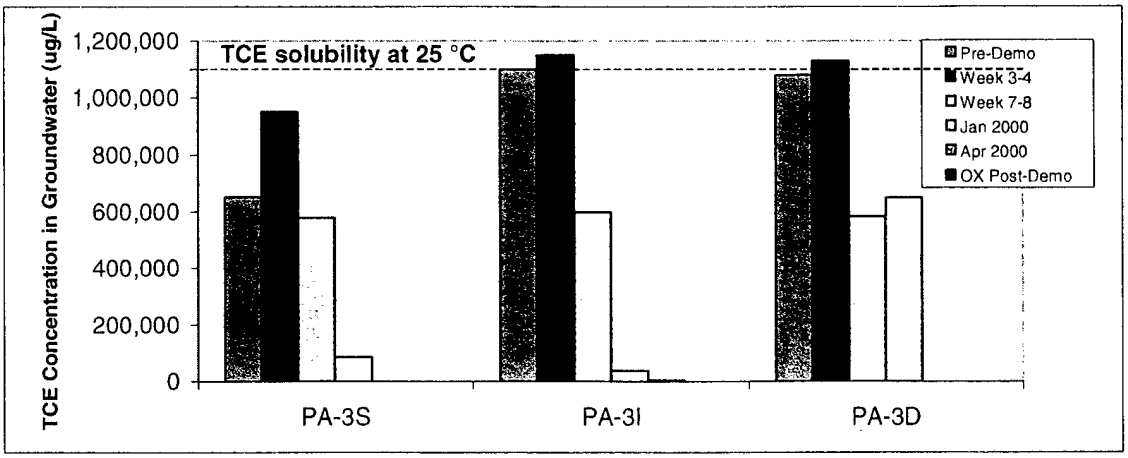


Figure 5-24. Dissolved TCE Levels (µg/L) in Perimeter Wells on the Western Side of the ISCO Plot

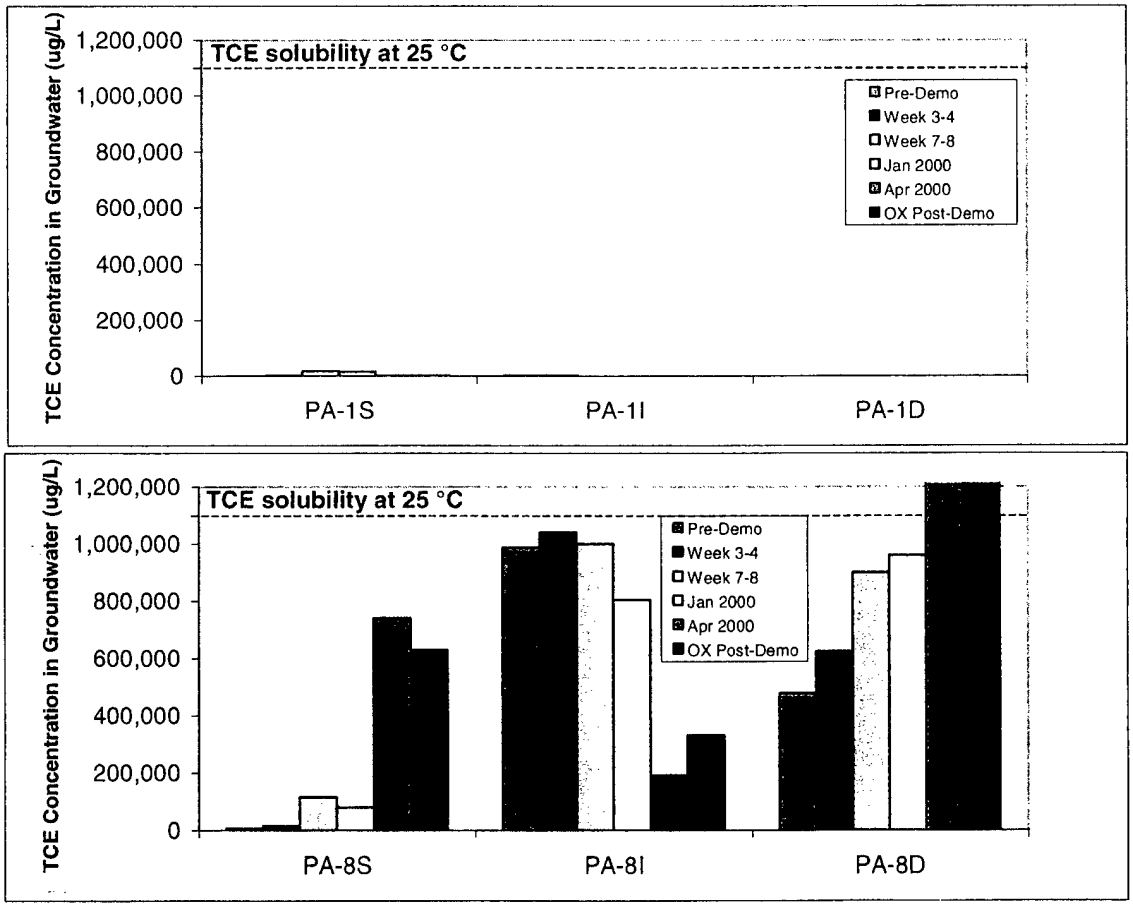


Figure 5-25. Dissolved TCE Levels (µg/L) in Distant Wells on the Northwestern Side of the ISCO Plot

moved under the influence of the sharp hydraulic gradient induced by the oxidant injection pressures. Residual DNAPL, by nature, would not be expected to move. PA-2I and PA-2D are closer to the resistive heating plot than to the ISCO plot and it is possible that the DNAPL migrated into these wells due to the resistive heating operation.

When the groundwater data indicated that DNAPL movement had occurred, additional postdemonstration *soil cores* were collected from areas surrounding the ISCO plot — at locations PA-206, PA-205, PA-209, PA-212, PA-211 and PA-208 (see Figure 4-3). These locations were selected because these were the only locations in the immediate vicinity of the ISCO plot where predemonstration soil core data were available for comparison. No noticeable increase in TCE or DNAPL concentration was found in any of these soil samples following the demonstration. The sampling density of the soil cores surrounding the plot is not as high as the sampling density inside the plot; therefore, the effort was more exploratory than definitive.

To evaluate the possibility of TCE/DNAPL migration to the *vadose zone*, all pre- and postdemonstration soil cores in the ISCO plot included soil samples collected at 2-ft intervals in the vadose zone. As seen in Figure 5-1, no noticeable deposition of TCE was found in vadose zone soils due to the ISCO treatment. *Surface emission* tests were conducted as described in Appendix F to evaluate the possibility of solvent losses to the atmosphere. As seen in Table 5-9, there was no noticeable difference in TCE concentrations between surface emission samples collected in the ISCO plot and at background locations at various times during and after the demonstration. Unlike some technologies that involve exothermic reactions or applied heating, permanganate oxidation does not cause volatilization of the targeted solvents and therefore there is very little probability of TCE losses to the vadose zone or atmosphere.

Because of NASA's concerns about breaching the relatively thin aquitard, no monitoring wells were installed before the demonstration into the Lower Clay Unit or in the aquifer below. After the resistive heating and ISCO demonstrations, the possibility of the historical presence of DNAPL under the Lower Clay Unit was revisited and specially designed wells with telescopic casing were designed and installed in the semi-confined aquifer below. Section 4.3 describes the installation and monitoring of these deeper wells. Figure 3-1 in Section 3.3.1 shows the locations of these three deeper wells (PA-20, PA-21, and PA-22) in the semi-confined aquifer. Tables 5-10 and 5-11 show the results of the analysis of soil and water samples from these wells. The soil samples were collected when these wells were being installed. At least in the soil and water samples in PA-21, the well

Table 5-9. Results for Surface Emission Tests

Sample ID	Sample Date	TCE (ppb [v/v])
	ISCO Plot	
OX-SE-1	9/30/1999	1.6
OX-SE-2	9/30/1999	2.4
OX-SE-3	10/1/1999	3.4
OX-SE-4	10/25/1999	0.68
OX-SE-5	10/25/1999	1.1
OX-SE-6	10/25/1999	1.4
OX-SE-7	1/17/2000	11
OX-SE-8	1/17/2000	7.6
OX-SE-9	1/17/2000	5.8
OX-SE-10	4/11/2000	2.6
OX-SE-11	4/11/2000	0.69
OX-SE-12	4/11/2000	1.7
	Background	
DW-SE-1	10/1/1999	<0.42
DW-SE-2	10/8/1999	<0.44
DW-SE-3	10/25/1999	0.44
DW-SE-4	10/22/1999	6,000[a]
DW-SE-5	1/17/2000	<0.38
DW-SE-6	4/11/2000	0.43
DW-SE-7	4/11/2000	0.86
DW-SE-8	4/11/2000	0.79
	Ambient Air at Shoulder Level[b]	
SPH-SE-14	5/9/2000	<0.39[c]
SPH-SE-15	5/9/2000	<0.39[c]
SPH-SE-C27	9/1/2000	<0.88
DW-C1	4/11/2000	2.1
DW-C2	5/9/2000	<0.39
DW-C3	5/9/2000	<0.39

(a) Background sample (10/22/99) was collected immediately after a sample was collected at the resistive heating plot that had an unexpectedly high concentration of 13,000 ppbv. This may indicate condensation of TCE in the emissions collection box at levels that could not be removed by the standard decontamination procedure of purging the box with air for two hours. In subsequent events (1/17/2000 background), special additional decontamination steps were taken to minimize carryover.
(b) A Summa canister was held at shoulder level to collect an ambient air sample to evaluate local background air quality.
(c) SPH-SE-14/15 samples were collected at an ambient elevation at the east and west edges of the resistive heating plot without using an air collection box.
ppb (v/v): parts per billion by volume.

directly under the ISCO plot, TCE levels do not indicate the presence of DNAPL. The absence of baseline (predemonstration) data in these wells makes interpretation difficult. However, most of the DNAPL-level TCE concentrations appear to be in the Lower Clay Unit and have not penetrated to the semi-confined aquifer below. Therefore, the data do not indicate that any migration of DNAPL occurred into the semi-confined aquifer portion below the ISCO plot, either before or during the ISCO demonstration.

5.3.3 Summary Evaluation of the Fate of TCE/DNAPL

In summary, the field measurements indicate that DNAPL movement has occurred in the Launch Complex 34

Table 5-10. Results of TCE Concentrations of Soil Analysis at Launch Complex 34

Approximate Depth (ft bgs)	TCE (mg/kg)[a]		
	SB-50 (PA-20)	SB-51 (PA-21)	SB-52 (PA-22)
39-40		66	
40-41			20
41-42	174	6,578	
42-43			21
43-44	72		
44-45		3,831	37
45-46	19	699	138
46-47	39	2,857	466
47-47.5			330
47.5-48			310
48-49	5	46	132
49-50			367
50-51	1	49	473
51-52			707
52-53	<1	3	
53-54			
54-55	<1	<1	8,496; 10,700
55-56			
56-57	2	<1	40,498
57-58			
58-59	<1	<1	122
59-60			

(a) Shaded cells represent the Lower Clay Unit.

Table 5-11. Results of CVOC Analysis in Groundwater from the Semi-Confined Aquifer

TCE

Well ID	Feb 2001	Apr 2001	May 2002	Jun 2001	Aug 2001	Nov 2001	Feb 2002
PA-20	67.1	447	111	350	19	15	181
PA-20-DUP	58.4	N/A	N/A	N/A	N/A	N/A	N/A
PA-21	7,840	15,700	6,400	5,030	790	1,640	416
PA-22	736,000	980,000	877,000	801,000	1,000,000	1,110,000	1,240,000
PA-22-DUP	N/A	N/A	939,000	N/A	1,000,000	N/A	N/A

cis-1,2-DCE

Well ID	Feb 2001	Apr 2001	May 2002	Jun 2001	Aug 2001	Nov 2001	Feb 2002
PA-20	21.7	199	37.4	145	10	52	66
PA-20-DUP	18.5	N/A	N/A	N/A	N/A	N/A	N/A
PA-21	1,190	5,790	1,490	1,080	330	5,140	315
PA-22	8,130	8,860	11,000	11,900	12,000 J	14,900	13,300
PA-22-DUP	N/A	N/A	10,700	N/A	12,000 J	N/A	N/A

trans-1,2-DCE

Well ID	Feb 2001	Apr 2001	May 2002	Jun 2001	Aug 2001	Nov 2001	Feb 2002
PA-20	<0.1	1.45	0.24J	0.38	<1.0	0.48J	0.3J
PA-20-DUP	<0.1	N/A	N/A	N/A	N/A	N/A	N/A
PA-21	<1	51.7	6 J	5	<33	<10	2
PA-22	<100	<1,000	<1,120	<100	<17,000	<100	<1,000
PA-22-DUP	N/A	N/A	<1,090	N/A	<17,000	N/A	N/A

Vinyl Chloride

Well ID	Feb 2001	Apr 2001	May 2002	Jun 2001	Aug 2001	Nov 2001	Feb 2002
PA-20	<0.1	0.36J	<1.08	<0.1	<2.0	<0.10	<1.0
PA-20-DUP	<0.1	N/A	N/A	N/A	N/A	N/A	N/A
PA-21	<1	4.22	<22.2	<1	<67	1,050	<1.0
PA-22	<100	<1,000	<1,120	<100	<33,000	<100	260J
PA-22-DUP	N/A	N/A	<1,090	N/A	<33,000	N/A	N/A

N/A: Not analyzed.
J: Estimated value, below reporting limit.

aquifer due to the demonstrations of resistive heating and ISCO technologies. It is unclear as to which of these two technologies caused this movement. It is also unclear as to whether the migrating DNAPL was initially present as mobile or residual form. If all the DNAPL was initially present in residual form, the strong hydraulic gradient created by the oxidant injection alone would not be sufficient to cause DNAPL to migrate. If some DNAPL was present in mobile form, the hydraulic gradient created by the injection pressures would cause it to migrate. In general, for future applications, the strong hydraulic gradients generated by the oxidant injection would necessitate that one of the following measures be implemented:

- The DNAPL source zone boundary should be delineated as accurately as possible so that oxidant injection can be applied without extraction or other hydraulic control.
- The oxidant injection pressures should be reduced in favor of higher injection point density and/or longer injection times.
- The oxidant should be injected from the outside in (injection in the perimeter of the DNAPL source zone, followed by injection in the interior of the source zone).

All of these measures pose their own challenges. In the first measure, a definitive identification of the DNAPL source boundary may be difficult or expensive to achieve. In the second measure, increasing the spatial density of injection points or using longer injection times may increase the cost of the application. Extraction of injected fluids may make the application more expensive due to the increased cost of extracting, treating, and disposing/reinjecting the recovered fluids. In the third option, some oxidant could be lost to surrounding regions. At Launch Complex 34, the vendor was constrained to some extent by the conditions of the demonstration, in which only a portion of the DNAPL source was targeted for treatment, as well as by regulatory/economic restraints against extraction/reinjection.

5.4 Verifying Operating Requirements and Cost

Section 3 contains a description of the ISCO field operations at Launch Complex 34. Section 7 contains the costs and economic analysis of the technology.

6. Quality Assurance

A QAPP (Battelle, 1999d) prepared before the demonstration outlined the performance assessment methodology and the QA measures to be taken during the demonstration. The results of the field and laboratory QA for the critical soil and groundwater CVOC (primary) measurements and groundwater field parameter (secondary) measurements are described in this section. The results of the QA associated with other groundwater quality (secondary) measurements are described in Appendix G. The focus of the QA measures is on the critical TCE measurement in soil and groundwater, for which, in some cases, special sampling and analytical methods were used. For other measurements (chloride, calcium, etc.), standard sampling and analytical methods were used to ensure data quality.

6.1 QA Measures

This section describes the data quality in terms of representativeness and completeness of the sampling and analysis conducted for technology performance assessment. Chain-of-custody procedures also are described.

6.1.1 Representativeness

Representativeness is a measure that evaluates how closely the sampling and analysis represents the true value of the measured parameters in the target matrices. The critical parameter in this demonstration is TCE concentration in soil. The following steps were taken to achieve representativeness of the soil samples:

- Statistical design for determining the number and distribution of soil samples in the 75-ft × 50-ft ISCO plot, based on the horizontal and vertical variability observed during a preliminary characterization event (see Section 4.1). Twelve locations (one in each cell of a 4 × 3 grid in the plot) were cored before and after the demonstration and a continuous core was collected and sampled in 2-ft sections from ground surface to aquitard at each coring location. At the 80% confidence level, the pre- and postdemonstration TCE mass estimates in the plot (see Section 5.1) were within relatively narrow intervals that enabled a good judgment of the mass removal achieved by the ISCO technology.
- Sampling and analysis of duplicate postdemonstration soil cores to determine TCE concentration variability within each grid cell. Two complete cores (SB-217 and SB-317) were collected within about 2 ft of each other in the postdemonstration ISCO plot, with soil sampling at every 2-ft interval (see Figure 5-1 for the TCE analysis of these cores). The resulting TCE concentrations showed a relatively close match (±30%) between the duplicate core TCE levels. This indicated that dividing the ISCO plot into 12 grid cells enabled a sampling design that was able to address the horizontal variability in TCE distribution.
- Continuous sampling of the soil column at each coring location enabled the sampling design to address the vertical variability in the TCE distribution. By extracting and analyzing the complete 2-ft depth in each sampled interval, essentially every vertical depth was sampled.
- Use of appropriate modifications to the standard methods for sampling and analysis of soil. To increase the representativeness of the soil sampling, the sampling and extraction procedures in EPA Method 5035 were modified so that an entire vertical section of each 2-ft core could be sampled and extracted, instead of the 5-g aliquots specified in the standard method (see Section 4.1). This was done to maximize the capture of TCE/DNAPL in the entire soil column at each coring location.

Steps taken to achieve representativeness of the groundwater samples included:

- Installation and sampling of six well clusters in the 75-ft × 50-ft ISCO plot. Each cluster consisted of three wells screened in the three stratigraphic

units—Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit.

- Use of standard methods for sampling and analysis. Disposable tubing was used to collect samples from all monitoring wells to avoid persistence of TCE in the sample tubing after sampling wells with high TCE (DNAPL) levels.

6.1.2 Completeness

All the regular samples planned in the QAPP were collected and analyzed, plus additional samples were collected when new requirements were identified as the demonstration progressed. Additional groundwater samples were collected from all ISCO plot and surrounding wells to better evaluate the generation and migration of chloride, potassium ion, and potassium permanganate. One additional soil core was collected during postdemonstration sampling to evaluate the variability within the same grid cell.

All the QC samples planned in the QAPP were collected and analyzed, except for the equipment rinsate blanks during soil coring. Equipment rinsate blanks were not planned in the draft QAPP and were not collected during the predemonstration soil coring event. These blanks were later added to the QAPP and were prepared during the postdemonstration soil coring event. Based on the preliminary speed of the soil coring, one rinsate blank per day was thought to be sufficient to obtain a ratio of one blank per 20 samples (5%). However, as the speed of the soil coring increased, this frequency was found to have fallen slightly short of the desired ratio of blanks to samples. The same rinsing procedure was maintained for the soil core barrel through the pre- and postdemonstration sampling. None of the blanks contained any elevated levels of CVOCs.

6.1.3 Chain of Custody

Chain-of-custody forms were used to track each batch of samples collected in the field and delivered either to the on-site mobile laboratory or to the off-site analytical laboratory. Copies of the chain-of-custody records can be found in Appendix G. Chain-of-custody seals were affixed to each shipment of samples to ensure that only laboratory personnel accessed the samples while in transit. Upon arrival at the laboratory, the laboratory verified that the samples were received in good condition and the temperature blank sample sent with each shipment was measured to ensure that the required temperature was maintained during transit. Each sample received was then checked against the chain-of-custody form, and any discrepancies were brought to the attention of field personnel.

6.2 Field QC Measures

The field QC checks included calibration of field instruments, field blanks (5% of regular samples), field duplicates (5% of regular samples), and trip blanks; the results of these checks are discussed in this section.

Table 6-1 summarizes the instruments used for field groundwater measurements (pH, ORP, DO, temperature, water levels, and conductivity) and the associated calibration criteria. Instruments were calibrated at the beginning and end of the sampling period on each day. The field instruments were always within the acceptance criteria during the demonstration. The DO membrane was the most sensitive, especially to extremely high (near saturation) levels of chlorinated solvent or permanganate in the groundwater and this membrane had to be changed more frequently. Because of interference with DO and other measurements, field parameter measurements in deeply purple (high permanganate level) samples were avoided, as noted in Appendix G.

6.2.1 Field QC for Soil Sampling

Soil extractions were conducted in the field and the extracts were sent to the off-site laboratory for CVOC analysis. A surrogate compound was initially planned on being spiked directly into a fraction of the soil samples collected, but the field surrogate addition was discontinued at the request of the off-site laboratory because of interference and overload of analytical instruments at the

Table 6-1. Instruments and Calibration Acceptance Criteria Used for Field Measurements

Instrument	Measurement	Acceptance Criteria
YSI Meter Model 6820	pH	3 point, ±20% difference
YSI Meter Model 6820	ORP	1 point, ±20% difference
YSI Meter Model 6820	Conductivity	1 point, ±20% difference
YSI Meter Model 6820	Dissolved Oxygen	1 point, ±20% difference
YSI Meter Model 6820	Temperature	1 point, ±20% difference
OHaus Weight Balance	Soil – Dry/Wet Weight	3 point, ±20% difference
Hermit Water Level Indicator	Water Levels	±0.01 ft

detection limits required. Surrogate addition was instead conducted by the analytical laboratory, which injected the surrogate compound into 5% of the methanol extracts prepared in the field. As an overall determination of the extraction and analytical efficiency of the soil sampling, the modified EPA Method 5035 methanol extraction procedure was evaluated before the demonstration by spiking a known amount of TCE into soil samples from the Launch Complex 34 aquifer. A more detailed evaluation of the soil extraction efficiency was conducted in the field by spiking a surrogate compound (1,1,1-TCA) directly into the intact soil cores retrieved in a sleeve. The injection volume of 1,1,1-TCA was approximately 10 µL. The spiked soil samples were handled in the same manner as the remaining soil samples during the extraction procedure. Of the 13 soil samples spiked with 1,1,1-TCA, 12 were within the acceptable range of precision for the postdemonstration soil sampling, calculated as the relative percent difference (RPD), where RPD is less than 30%. The results indicate that the methanol extraction procedure used in the field was suitable for recovering CVOCs. Extraction efficiencies ranged from 84 to 113% (92% average) (Tables G-1 and G-2 in Appendix G). For this evaluation, soil samples from the predemonstration soil core PA-4 were homogenized and spiked with pure TCE. Replicate samples from the spiked soil were extracted and analyzed; the results are listed in Appendix G (Table G-3). For the five replicate soil samples, the TCE spike recoveries were in the range of 72 to 86%, which fell within the acceptable range (70-130%) for quality assurance of the extraction and analysis procedure.

Duplicate soil samples were collected in the field and analyzed for TCE to evaluate sampling precision. Duplicate soil samples were collected by splitting each 2-ft soil core vertically in half and subsequently collecting approximately 250 g of soil into two separate containers, marked as SB#-Depth#-A and B. Appendix G (Table G-4) shows the result of the field soil duplicate analysis and the precision, calculated as the RPD for the duplicate soil cores, which were collected before and after the demonstration. The precision of the field duplicate samples was generally within the acceptable range (±30%) for the demonstration, indicating that the sampling procedure was representative of the soil column at the coring location. The RPD for three of the duplicate soil samples from the predemonstration sampling was greater than 30%, but less than 60%. This indicated that the repeatability of some of the predemonstration soil samples was outside targeted acceptance criteria, but within a reasonable range, given the heterogeneous nature of the contaminant distribution. The RPDs for six of the duplicate soil samples from the postdemonstration sampling were greater than 30%; five of the six samples had an RPD above 60%. This indicates that the ISCO treatment created greater variability in the contaminant distribution. Part of the reason for the higher RPD calculated in some postdemonstration soil samples is that TCE concentrations tended to be low (often near or below the detection limit). For example, the RPD between duplicate samples, one of which is below detection and the other is slightly above detection, tends to be high. In general, though, the variability in the two vertical halves of each 2-ft core was in a reasonable range, given the typically heterogeneous nature of the DNAPL distribution.

Field blanks for the soil sampling consisted of rinsate blank samples and methanol blank samples. The rinsate blank samples were collected once per drilling borehole (approximately 20 soil samples) to evaluate the decontamination efficiency of the sample barrel used for each soil boring. Decontamination between samples consisted of a three-step process where the core barrel was emptied, washed with soapy water, rinsed in distilled water to remove soap and debris, and then rinsed a second time with distilled water. The rinsate blank samples were collected by pouring distilled water through the sample barrel, after the barrel had been processed through the routine decontamination procedure. As seen in Appendix G (Table G-5), TCE levels in the rinsate blanks were always below detection (<5.0 µg/L), indicating that the decontamination procedure was helping control carryover of CVOCs between samples.

Methanol method blank samples (5%) were collected in the field to evaluate the soil extraction process. The results are listed in Appendix G (Table G-6). These samples were generally below the targeted detection limit of 1 mg/kg of TCE in dry soil. Detectable levels of TCE were present in methanol blanks sampled on 6/23/99 (1.8 mg/kg), 6/29/99 (8.0 mg/kg), and 7/16/99 (1.2 mg/kg) during the predemonstration phase of the project, but were still relatively low. The slightly elevated levels may be due to the fact that many of the soil samples extracted on these days were from high-DNAPL regions and contained extremely high TCE concentrations. The TCE concentrations in these blanks were below 10% of the concentrations in the associated batch of soil samples. All the postdemonstration methanol blanks were below detection.

6.2.2 *Field QC for Groundwater Sampling*

QC checks for groundwater sampling included field duplicates (5%), field blanks (5%), and trip blanks. Field duplicate samples were collected once every 20 wells sampled. Appendix G (Tables G-7 and G-8) contains the analysis of the field duplicate groundwater samples that were collected before, during, and after the demonstration. The RPD (precision) calculated for these samples always met the QA/QC target criteria of ±30%.

Decontamination of the sample tubing between groundwater samples initially consisted of a detergent rinse and two distilled water rinses. However, initial groundwater sampling results revealed that, despite the most thorough decontamination, rinsate blanks contained elevated levels of TCE, especially following the sampling of wells containing TCE levels near or greater than its solubility (1,100 mg/L); this indicated that some free-phase solvent may have been drawn into the tubing. When TCE levels in such rinsate blanks refused to go down, even when a methanol rinse was added to the decontamination procedure, a decision was made to switch to disposable Teflon® tubing. Each new piece of tubing was used only for sampling each well once and then discarded, despite the associated costs. Once disposable sample tubing was used, TCE levels in the rinsate blanks (Appendix G, Tables G-9 and G-10) were below the targeted detection limit (3.0 µg/L) throughout the demonstration. The only exception was one rinsate blank collected during the postdemonstration sampling event on May 20, 2000; this rinsate blank contained 11 µg/L of TCE, which was less than 10% of the TCE concentrations in the regular samples in this batch.

TCE levels in trip blank samples were always below 5 µg/L (Appendix G, Table G-11), indicating the integrity of the samples was maintained during shipment. In some batches of groundwater samples, especially when excess permanganate was present in the sample, detection limits were raised from 3 to 5 µg/L to avoid instrument interference.

6.3 Laboratory QC Measures

The on-site mobile and off-site analytical laboratories performed QA/QC checks consisting of 5% matrix spikes (MS) or laboratory control spikes (LCS), as well as the same number of matrix spike duplicates (MSD) or laboratory control spike duplicates (LCSD). The analytical laboratories generally conducted MS and MSD whenever the groundwater samples were clear, in order to determine accuracy. However, when excess permanganate was present in the samples, as with many postdemonstration samplers, LCS and LCSD were conducted. MS and MSD or LCS and LCSD were used to calculate analytical accuracy (percent recovery) and precision (RPD between MS and MSD or LCS and LCSD).

6.3.1 Analytical QC for Soil Sampling

Analytical accuracy for the soil samples (methanol extracts) analyzed were generally within acceptance limits (70-130%) for the predemonstration period (Appendix G, Table G-12). Matrix spike recoveries were outside this range for three of the MS/MSD samples conducted during the postdemonstration sampling period (Appendix G, Table G-13), but still within 50 to 150%; this indicates that although there may have been some matrix effects, the recoveries were still within a reasonable range, given the matrix interference from the permanganate. Matrix spike recovery was 179% for one of the matrix spike repetitions on 06/01/00. The precision between MS and MSD was always within acceptance limits (±25%). Laboratory control spike recoveries and precision were within the acceptance criteria (Appendix G, Tables G-14 and G-15).

The laboratories conducted surrogate spikes in 5% of the total number of methanol extracts prepared from the soil samples for CVOC analysis. Table 6-2 lists the surrogate and matrix spike compounds used by the on-site laboratory to perform the QA/QC checks. Table 6-3 lists the surrogate and matrix spike compounds used by the off-site laboratory to perform the QA/QC checks. Surrogate and matrix spike recoveries were always within the specified acceptance limits. Method blank samples were run at a frequency of at least one for every 20 samples analyzed in the pre- and postdemonstration periods

Table 6-2. List of Surrogate and Matrix Spike Compounds and Their Target Recoveries for Groundwater Analysis by the On-Site Laboratory

Surrogate Compound DHL	Matrix Spike Compound DHL
a,a,a-Trifluorotoluene (75-125%)	*cis*-1,2-DCE (70-130%)
	trans-1,2-DCE (70-130%)
	Vinyl chloride (65-135%)
	TCE (70-130%)

Table 6-3. List of Surrogate and Laboratory Control Sample Compounds and Their Target Recoveries for Soil and Groundwater Analysis by the Off-Site Laboratory

Surrogate Compound STL	Matrix Spike Compound STL
Dibromofluoromethane (66-137%)	Vinyl chloride (56-123%)
1,2-Dichloroethane – d4 (61-138%)	Carbon tetrachloride (60-136%)
Toluene – d8 (69-132%)	Benzene (70-122%)
Bromofluorobenzene (59-145%)	1,2-Dichloroethane (58-138%)
	TCE (70-130%)
	1,2-Dichloropropane (68-125%)
	1-1,2-Trichloroethane (63-123%)
	Tetrachloroethane (70-125%)
	1,2-Dibromoethane (66-126%)
	Bromoform (60-131%)
	1,4-Dichlorobenzene (70-120%)
	cis-1,3-Dichloropropane (65-132%)

(Appendix G, Tables G-16 and G-17). CVOC levels in the method blanks were always below detection.

6.3.2 Laboratory QC for Groundwater Sampling

Pre- and postdemonstration MS and MSD results for groundwater are listed in Appendix G (Table G-18). The MS and MSD recoveries (70 to 130%) and their precision (±25%) were generally within acceptance criteria. The only exceptions were the samples collected on 08/03/99 and 01/14/00 during the ongoing demonstration phase which had MS and MSD recoveries that were outside the range due to high initial TCE concentrations in the samples. Recoveries and RPDs for LCS and LCSD samples (Appendix G, Tables G-19 and G-20) were always within the acceptance range.

Method blanks (Appendix G, Tables G-21 and G-22) for the groundwater samples were always below the targeted 3-µg/L detection limit.

6.3.3 Analytical Detection Limits

Detection limits for TCE in soil (1 mg/kg) and groundwater (3 µg/L) generally were met. The only exceptions were samples that had to be diluted for analysis, either because one of the CVOC compounds (e.g., TCE) was at a relatively high concentration as compared to another VOC compound (e.g., *cis*-1,2-DCE) or because excessively high levels of permanganate in the sample necessitated dilution to protect instruments. The proportionately higher detection limits are reported in the CVOC tables in Appendix C. The detection limits most affected were those for *cis*-1,2-DCE and vinyl chloride, due to the masking effect of high levels of TCE. Additionally, the laboratories verified and reported that analytical instrumentation calibrations were within acceptable range on the days of the analyses.

6.4 QA/QC Summary

Given the challenges posed by the typically heterogeneous TCE distribution in a DNAPL source zone, the collected data were an acceptable representation of the TCE distribution in the Launch Complex 34 aquifer before, during, and after the demonstration.

- Sufficient number of locations (12) were sampled within the plot to adequately capture the horizontal variability in the TCE distribution. The continuous sampling of the soil at each coring location ensured that the vertical variability of the TCE distribution was captured. Sampling and analytical procedures were appropriately modified to address the expected variability. At the 80% confidence level, the soil sampling provided pre- and postdemonstration confidence intervals (range of TCE mass estimates) that were narrow enough to enable an acceptable judgment of the TCE and DNAPL mass removal achieved by the ISCO technology.
- Standard sampling and analysis methods were used for all other measurements to ensure that data were comparable between sampling events.
- Accuracy and precision of the soil and groundwater measurements were generally in the acceptable range for the field sampling and laboratory analysis. In the few instances that QC data were outside the targeted range, the reason was generally interference from excessive permanganate in the sample. In some cases, extremely low (near detection) or extremely high levels of TCE in the sample caused higher deviation in the precision (repeatability) of the data.
- The masking effect of high TCE levels on other CVOCs and the need for sample dilution because of the presence of excessive permanganate caused detection limits for TCE, in some cases, to rise to 5 µg/L (instead of 3 µg/L). However, postdemonstration levels of dissolved TCE in many of the monitoring wells in the ISCO plot were considerably higher than the 3-µg/L detection and regulatory target.
- Field blanks associated with the soil samples generally had acceptably low or undetected levels of TCE. After suitable modifications to account for the persistence of DNAPL in groundwater sampling tubing, TCE levels in field blanks were acceptably low or below detection.

7. Economic Analysis

The cost estimation for the ISCO technology application involves the following three major components:

- Treatment cost of ISCO at the demonstration site. Costs of the technology application at Launch Complex 34 were tracked by the ISCO vendor and by MSE, the DOE contractor who subcontracted the vendor.
- Site preparation costs incurred by the owner. NASA and MSE tracked the site preparation costs; that is, the costs incurred by the site owner.
- Site characterization and performance assessment costs. Battelle and TetraTech EM, Inc. estimated these costs based on the site characterization and performance assessment that was generally based on U.S. EPA's SITE Program guidelines.

An economic analysis for an innovative technology generally is based on a comparison of the cost of the innovative technology with a conventional alternative. In this section, the economic analysis involves a comparison of the ISCO cost with the cost of a conventional pump-and-treat system.

Table 7-1. ISCO Cost Summary Provided by Vendor

Item	Actual Cost
Final design and specifications	$ 48,301
Plans and permits	$ 23,367
Procurement	$ 15,696
Mobilization[a]	$ 410,412
Well installation	$ 46,675
Precharacterization sampling	$ 3,292
Tracer test	$ 48,846
Phase 1 injection and monitoring	$ 124,883
Phase 2 injection and monitoring	$ 38,737
Phase 3 injection and monitoring	$ 104,566
Process monitoring	$ 1,554
Cost reporting	$ 24,270
Design/cost modeling	$ 9,919
Final technical report	$ 49,161
Project management/proposal	$ 64,268
Total	$1,013,947

(a) Mobilization includes chemical costs for permanganate and major project equipment rentals and purchases. The total chemical cost is approximately $274,000.

Source: IT Corporation, 2000.

7.1 ISCO Treatment Costs

The costs of the ISCO technology were tracked and reported by both the vendor and MSE, the DOE contractor who subcontracted the vendor. Table 7-1 summarizes the major cost components for the application including the costs of chemicals at $274,000. The chemical cost consists of the purchase of 66,956 kg (150,653 lb) of potassium permanganate at an average price of $4/kg ($2/lb). The total cost of the ISCO demonstration was approximately $1 million. This total includes the design, permitting support, implementation, process monitoring, and reporting costs incurred by the vendor. The total does not include the costs of site characterization, which was conducted by other organizations (Remedial Investigation/Feasibility Study [RI/FS] study by NASA, preliminary characterization by WSRC, and detailed characterization by Battelle/TetraTech EM, Inc./U.S. EPA). The vendor estimated that approximately 15 to 20% of the total cost was demonstration-related and would not be incurred in an actual remediation application. The vendor documented that the demonstration cost was approximately $187/yd^3 for the total treatment plot soil volume (IT, 2000). A higher unit cost may be anticipated if greater DNAPL removal (percentage) is required.

A subsequent monitoring event indicated that some rebound in TCE concentrations occurred in the ISCO plot. Based on the DNAPL masses estimated during the predemonstration and extended monitoring events, the unit cost for the treatment was estimated by the DOE contractor at $109/lb of TCE removed (MSE, 2002).

7.2 Site Preparation Costs

Many of the site preparation costs were incurred by NASA and are not included in the treatment costs listed by the

vendor in Table 7-1. Site preparation costs for the ISCO technology were relatively minor, compared to the other two technologies demonstrated. For ISCO, site preparation involved the provision of power and water for the demonstration. NASA estimated the site preparation costs at $2,800. NASA did not incur any waste disposal costs associated with this technology because injected fluids did not have to be extracted. Except for the disposal of some mobilization- and operation-related nonhazardous solid wastes, there was no waste disposal requirement.

7.3 Site Characterization and Performance Assessment Costs

This section describes two categories of costs:

- **Site characterization costs.** These are the costs for the effort to bridge the gap between the general site information in an RI/FS or RFI report and the more detailed information required for DNAPL source delineation and remediation technology design. This cost component is perhaps the most reflective of the type of costs incurred when a site of the size and geology of Launch Complex 34 undergoes site characterization in preparation for remediation. Presuming that groundwater monitoring and plume delineation at a site indicates the presence of DNAPL, these site characterization costs are incurred in an effort to define the boundaries of the DNAPL source zone, obtain an order-of-magnitude estimate of the DNAPL mass present, and define the local hydrogeology and geochemistry of the DNAPL source zone.
- **Performance assessment costs.** These are primarily demonstration-related costs. Most of these costs were incurred in an effort to further delineate the portion of the DNAPL source contained in the ISCO plot and determine the TCE/DNAPL mass removal achieved by ISCO. Only a fraction of these costs would be incurred during full-scale deployment of this technology; depending on the site-specific regulatory requirements, only the costs related to determining compliance with cleanup criteria would be incurred in a full-scale deployment.

Table 7-2 summarizes the costs incurred by Battelle for the February 1999 site characterization. The February 1999 site characterization event was a suitable combination of soil coring and groundwater sampling, organic and inorganic analysis, and hydraulic testing (water levels and slug tests) that may be expected to bridge the gap between the RI/FS or RFI data usually available at a site and the typical data needs for DNAPL source delineation and remediation design.

Table 7-3 lists performance assessment costs incurred jointly by Battelle and TetraTech EM, Inc.

Table 7-2. Estimated Site Characterization Costs

Activity	Cost
Site Characterization Work Plan • Additional characterization to delineate DNAPL source • Collect hydrogeologic and geochemical data for technology design	$ 25,000
Site Characterization • Drilling – soil coring and well installation (12 continuous soil cores to 45 ft bgs; installation of 36 monitoring wells) • Soil and groundwater sampling (36 monitoring wells; 300 soil samples collection and field extraction) • Laboratory analysis (organic and inorganic analysis) • Field measurements (water quality; hydraulic testing)	$ 165,000
Data Analysis and Site Characterization Report	$ 65,000
Total	**$ 255,000**

Table 7-3. Estimated Performance Assessment Costs

Activity	Cost
Predemonstration Assessment • Drilling – 12 continuous soil cores, installation of 18 monitoring wells • Soil and groundwater sampling for TCE/DNAPL boundary and mass estimation (36 monitoring wells; 300 soil samples collection and field extraction) • Laboratory analysis (organic and inorganic analysis) • Field measurements (water quality; hydraulic testing)	$208,000
Demonstration Assessment • Groundwater sampling (ISCO plot and perimeter wells) • Laboratory analysis (organic and inorganic analysis) • Field measurements (water quality; hydraulic testing; ISCO plot and perimeter wells)	$240,000
Postdemonstration Assessment • Drilling – 12 continuous soil cores • Soil and groundwater sampling (36 monitoring wells; 300 soil samples collection and field extraction) • Laboratory analysis (organic and inorganic analysis) • Field measurements (water quality; hydraulic testing)	$215,000
Total	**$ 663,000**

7.4 Present Value Analysis of ISCO and Pump-and-Treat System Costs

DNAPL, especially of the magnitude present at Launch Complex 34, is likely to persist in the aquifer for several decades or centuries. The resulting groundwater contamination and plume also will persist for several decades. The conventional approach to this type of contamination has been the use of pump-and-treat systems that extract and treat the groundwater above ground. This conventional technology is basically a plume control technology and would have to be implemented as long as groundwater contamination exists. ISCO is an innovative in situ technology that seeks to replace the conventional pump-and-treat approach. The economic analysis therefore compares the costs of these two alternatives.

Because a pump-and-treat system would have to be operated for the next several decades, the life-cycle cost of this long-term treatment has to be calculated and compared with the cost of ISCO, a short-term treatment. The present value (PV) of a long-term pump-and-treat application is calculated as described in Appendix H. The PV analysis is conducted over a 30-year period, as is typical for long-term remediation programs at Superfund sites. Site characterization and performance (compliance) assessment costs are assumed to be similar for both alternatives and are not included in this analysis.

For the purpose of comparison, it is assumed that a pump-and-treat system would have to treat the plume emanating from a DNAPL source the size of the ISCO plot. Recent research (Pankow and Cherry, 1996) indicates that the most efficient pump-and-treat system for source containment would capture all the groundwater flowing through the DNAPL source region. For a 75-ft-long × 50-ft-wide × 40-ft-deep DNAPL source region at Launch Complex 34, a single well cluster (with two wells, one screened in the Upper Sand Unit and the other screened in the Lower Sand Unit) pumping at 2 gpm is assumed to be sufficient to contain the source in an aquifer where the hydraulic gradient (and therefore, the groundwater flow velocity) is extremely low. This type of minimal containment pumping ensures that the source is contained without having to extract and treat groundwater from cleaner surrounding regions, as would be the case in more aggressive conventional pump-and-treat systems. The extracted groundwater is treated with an air stripper and polishing carbon. The air effluent from the air stripper is treated with a catalytic oxidizer before discharge to the atmosphere.

As shown in Appendix H, the total capital investment for an equivalent pump-and-treat system would be approximately $167,000, and would be followed by an annual operation and maintenance (O&M) cost of $57,500 (including quarterly monitoring). Periodic maintenance requirements (replacements of pumps, etc.) would raise the O&M cost every five years to $70,000 and every 10 years to $99,000. A real discount rate of 2.9%, based on the current recommendation for government projects, was used to calculate the PV. The PV of the pump-and-treat costs over 30 years is estimated to be **$1,406,000**.

Based on the vendor's assessment that 15% of the total treatment cost for the ISCO plot was demonstration-related, an equivalent treatment cost for full-scale deployment of the ISCO technology would be approximately $850,000. This estimate is based on a total treatment and site preparation cost during the demonstration of approximately $1 million (from Table 7-1), less 15% of demonstration-related monitoring costs. Therefore, if the TCE remaining in the ISCO plot was allowed to attenuate naturally, the total treatment cost of ISCO would be around **$850,000**.

The economics of the ISCO technology compare favorably with the economics of an equivalent pump-and-treat system. As seen in Table H-3 in Appendix H, an investment in ISCO would be recovered in the 18th year, when the PV of a pump-and-treat system exceeds the cost of ISCO. In addition to lower PV or life-cycle costs, there may be other tangible and intangible economic benefits to using a source remediation technology that are not factored into the analysis. For example, the economic analysis in Appendix H assumes that the pump-and-treat system is operational all the time over the next 30 or more years, with most of the annual expense associated with operation and routine (scheduled) maintenance. Experience with pump-and-treat systems at several sites has shown that downtime associated with pump-and-treat systems is fairly high (as much as 50% downtime reported from some sites). This may negatively impact both maintenance requirements (tangible cost) and the integrity of plume containment (intangible cost) with the pump-and-treat alternative.

Another factor to consider is that, although the economic analysis for long-term remediation programs typically is conducted for a 30-year period, the DNAPL source (and therefore the pump-and-treat requirement) may persist for many more years or decades. This would lead to concomitantly higher remediation costs for plume containment (without source removal). Even if the limitations on the effectiveness of a source removal technology at some sites necessitate the use of pump-and-treat for the next few years, until the source (and plume) is further depleted, the cost of the pump-and-treat system and the time period over which it needs to be operated is likely to be considerably reduced.

8. Technology Applications Analysis

This section evaluates the general applicability of the ISCO technology to sites with contaminated groundwater and soil. The analysis is based on the results and lessons learned from the IDC demonstration, as well as general information available about the technology and its application at other sites.

8.1 Objectives

This section evaluates the ISCO technology against the nine evaluation criteria used for detailed analysis of remedial alternatives in feasibility studies under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Much of the discussion in this section applies to DNAPL source removal in general, and ISCO technology in particular. (For this section, "ISCO" refers to the mode in which this technology was applied at Launch Complex 34 — namely, by injection of industrial-grade potassium permanganate solution without concomitant extraction.)

8.1.1 Overall Protection of Human Health and the Environment

ISCO is protective of human health and environment in both the short and long term. At Launch Complex 34 for example, ISCO removed more than 4,000 kg of DNAPL contamination from the ISCO plot, with significant TCE mass destruction by oxidation. Because DNAPL acts as a secondary source that can contaminate an aquifer for decades or centuries, DNAPL source removal or mitigation considerably reduces the duration over which the source is active. Even if DNAPL mass removal is not 100%, the resulting long-term weakening of the plume and the reduced duration over which the DNAPL source contributes to the plume reduces the threat to potential receptors.

8.1.2 Compliance with ARARs

This section describes the technology performance versus applicable or relevant and appropriate requirements (ARARs). Compliance with chemical-, location-, and action-specific ARARs should be determined on a site-specific basis. Generally, location- and action-specific ARARs can be met with this technology, especially because of the following reasons:

- Injected oxidant solution is not reextracted or reinjected; therefore, there are no aboveground residuals that need treatment or disposal.
- When permanganate is used as the oxidant, there are no exothermic reactions that generate heat, and, therefore, no potential releases to the atmosphere.

Compliance with chemical-specific ARARs depends on the efficiency of the ISCO process at the site and the cleanup goals agreed on by various stakeholders. In general, reasonable DNAPL mass removal goals are more achievable and should lead to eventual and earlier compliance with long-term groundwater cleanup goals. Achieving short-term groundwater cleanup goals (e.g., federal or state maximum contaminant levels [MCLs]), especially in the DNAPL source zone, is more difficult because various studies (Pankow and Cherry, 1996) have shown that almost 100% DNAPL mass removal may be required before a significant change in groundwater concentrations is observed. However, removal of DNAPL, even if most of the removal takes place from the more accessible pores, probably would result in a weakened plume that may allow risk-based cleanup goals to be met in the downgradient aquifer.

The specific federal environmental regulations that are potentially impacted by remediation of a DNAPL source with ISCO are described below.

8.1.2.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA), provides for federal authority to respond to releases or potential releases of any hazardous substance into the environment, as well

as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or the environment. Remedial alternatives that significantly reduce the volume, toxicity, or mobility of hazardous materials and that provide long-term protection are preferred. Selected remedies must also be cost-effective and protective of human health and the environment. The ISCO technology meets several of these criteria relating to a preferred alternative. ISCO reduces the toxicity of oxidizable contaminants by converting them into potentially nontoxic forms. For example, at Launch Complex 34, as described in Section 5.3.1, the hazardous chlorinated solvent TCE was converted to carbon dioxide, chloride, and water, without generating any aboveground residuals. This elimination of solvent hazard is permanent and leads to a considerable reduction in the time it takes for the DNAPL source to deplete fully. Although aquifer heterogeneities and technology limitations often result in less than 100% removal of the contaminant and elevated levels of dissolved solvent may persist in the groundwater over the short term, there is faster and eventual elimination of groundwater contamination in the long term. Section 7.4 shows that ISCO is cost-effective compared with the conventional alternative of long-term pump and treat.

8.1.2.2 Resource Conservation and Recovery Act

RCRA, as amended by the Hazardous and Solid Waste Amendments (HSWA) of 1984, regulates management and disposal of municipal and industrial solid wastes. The U.S. EPA and RCRA-authorized states (listed in 40 CFR Part 272) implement and enforce RCRA and state regulations. Generally, RCRA does not apply to in situ groundwater treatment because the contaminated groundwater may not be considered hazardous waste while it is still in the aquifer. The contaminated groundwater becomes regulated if it is extracted from the ground, as would happen with the conventional alternative of pump and treat. At least in the injection-only (no extraction) mode implemented at Launch Complex 34, no aboveground waste streams that may be hazardous, as defined by RCRA, are generated. At some sites, where hydraulic control requirements necessitate extraction and reinjection or treatment/disposal of injected fluids, RCRA may be invoked.

8.1.2.3 Clean Water Act

The CWA is designed to restore and maintain the chemical, physical, and biological quality of navigable surface waters by establishing federal, state, and local discharge standards. In the injection-only mode adopted at Launch Complex 34, there was no extraction of groundwater and therefore no reinjection or treatment/disposal of water; in this mode, the CWA may not be triggered. If, however, groundwater extraction is conducted in conjunction with injection, and the resulting water stream needs to be treated and discharged to a surface water body or a publicly owned treatment works (POTW), the CWA may apply. On-site discharges to a surface water body must meet National Pollutant Discharge Elimination System (NPDES) requirements, but may not require an NPDES permit. Off-site discharges to a surface water body must meet NPDES limits and require an NPDES permit. Discharge to a POTW, even if it is through an on-site sewer, is considered an off-site activity. Sometimes, soil or groundwater monitoring may lead to small amounts of purge and decontamination water wastes that may be subject to CWA requirements. Micropurging was one measure implemented at Launch Complex 34 to minimize such wastes during site characterization and technology performance assessment.

8.1.2.4 Safe Drinking Water Act

The SDWA, as amended in 1986, requires U.S. EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorizes national drinking water standards and a joint federal-state system for ensuring compliance with these standards. The SDWA also regulates underground injection of fluids through the UIC program and includes sole-source aquifer and wellhead protection programs.

The National Primary Drinking Water Standards are found at 40 CFR Parts 141 through 149. The health-based SDWA primary standards (e.g., for TCE) are more critical to meet; SDWA secondary standards (e.g., for dissolved manganese) are based on other factors, such as aesthetics (discoloration) or odor. The MCLs based on these standards generally apply as cleanup standards for water that is, or potentially could be, used for drinking water supply. In some cases, such as when multiple contaminants are present, alternative concentration limits (ACLs) may be used. CERCLA and RCRA standards and guidance are used in establishing ACLs. In addition, some states may set more stringent standards for specific contaminants. For example, the federally mandated MCL for vinyl chloride is 2 µg/L, whereas the State of Florida drinking water standard is 1 µg/L. In such instances, the more stringent standard is usually the cleanup goal.

Although the long-term goal of DNAPL source zone treatment is meeting applicable drinking water standards or other risk-based groundwater cleanup goals agreed on between site owners and regulatory authorities, the short-term objective of ISCO and source remediation is DNAPL mass removal. Because technology, site, and economic limitations may limit DNAPL mass removal to less than 100%, it may not always be possible to meet groundwater cleanup targets in the source region in the

short term. Depending on other factors, such as the distance of the compliance point (e.g., property boundary, at which groundwater cleanup targets have to be met) from the source (as negotiated between the site owner and regulators), the degree of weakening of the plume due to DNAPL source treatment, and the degree of natural attenuation in the aquifer, it may be possible to meet groundwater cleanup targets at the compliance point in the short term. DNAPL mass removal will always lead to faster attainment of groundwater cleanup goals in the long term, as compared to the condition in which no source removal action is taken.

One aspect of using potassium permanganate solution as an oxidant for DNAPL source remediation is the presence of regulated trace metals in industrial-grade permanganate, the grade that is most commonly and economically available commercially. Depending on the concentration of permanganate used, levels of trace metals in the injected solution and/or the treated aquifer may temporarily exceed federal or state drinking water standards. At Launch Complex 34, injection of a 1 to 2% solution of permanganate resulted in elevated levels of some trace metals (chromium, nickel, and thallium) in the aquifer during and immediately after the demonstration (see Section 5.2.2). There is also the possibility that the strong oxidant may cause the release of other regulated metals (e.g., iron) from the aquifer formation or from other underground structures. Dissolved manganese originating from the oxidant is also subject to secondary drinking water standards. A UIC permit will be required for permanganate injection in many cases. At Launch Complex 34, a variance was obtained from the State of Florida Department of Environmental Protection to allow injection of the industrial-grade potassium permanganate for the ISCO demonstration.

Elevated levels of these metals of concern are expected to subside over time; the time period required for the metals to once again meet applicable drinking water standards will depend on the groundwater flux through the treated zone, once normal flow resumes. Many of the elevated metals are subject to secondary drinking water standards, which are somewhat less of a concern than target contamination (DNAPL) and metals subject to primary standards. One option for mitigating these concerns is to use the more expensive pharmaceutical-grade permanganate. Another option is to reduce the concentration of industrial-grade permanganate in the injected solution to a level where trace metal concentrations are compatible with regulatory standards applicable to the injected solution and/or the treated aquifer. The tradeoff between higher injected permanganate concentration (lower injection volumes and times) and lower injected permanganate (higher injection volumes and times) should be taken into consideration on a site-by-site basis.

One issue that has not been formally investigated in the field is generation and potential toxicity of organic byproducts from the incomplete oxidation of CVOCs and natural organic matter by the permanganate. This is a research need for the technology.

8.1.2.5 Clean Air Act

The CAA and the 1990 amendments establish primary and secondary ambient air quality standards for protection of public health, as well as emission limitations for certain hazardous pollutants. Permitting requirements under CAA are administered by each state as part of State Implementation Plans (SIPs) developed to bring each state in compliance with National Ambient Air Quality Standards (NAAQS).

Unlike pump-and-treat systems, which often generate air emissions (when an air stripper is used), and unlike other source removal technologies that use thermal energy (e.g., steam injection or resistive heating) or result in exothermic reactions (e.g., oxidation with Fenton's reagent), the potential for atmospheric releases by ISCO with potassium permanganate is absent. Surface emission tests conducted in the ISCO plot during and after the demonstration did not show any TCE emissions above background levels.

8.1.2.6 Occupational Safety and Health Administration

CERCLA remedial actions and RCRA corrective actions must be carried out in accordance with OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially Part 1910.120, which provide for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective action sites must be performed in accordance with Part 1926 of RCRA, which provides safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, also must be met.

The health and safety aspects of ISCO are minimal, and are described in Section 3.3, which describes the operation of this technology at Launch Complex 34. Level D personal protective equipment generally is sufficient during implementation. Operation of heavy equipment and handling of a strong oxidant are the main working hazards and are dealt with by using appropriate personal protective equipment and trained workers. All operating and sampling personnel are required to have completed the 40-hour Hazardous Waste Operations training course and 8-hour refresher courses.

8.1.3 Long-Term Effectiveness and Permanence

ISCO leads to destruction of DNAPL mass and therefore permanent removal of contamination from the aquifer. Although dissolved solvent concentrations may rebound in the short term when groundwater flow redistributes through the treated source zone containing DNAPL remnants, depletion of the source through dissolution will continue in the long term, and lead to eventual and earlier compliance with groundwater cleanup goals.

8.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

ISCO effects treatment by reducing the toxicity of the contamination. Hazardous chlorinated solvents or other target contaminants are oxidized to potentially nontoxic compounds, such as chloride, carbon dioxide, and water.

8.1.5 Short-Term Effectiveness

Short-term effectiveness of the ISCO technology depends on a number of factors. If the short-term goal is to remove as much DNAPL mass as possible, this goal is likely to be met. If the short-term goal is to reduce dissolved contaminant levels in the source zone, achievement of this goal will depend on the hydrogeology and DNAPL distribution in the treated region. As seen in Section 5.2.1, TCE levels declined sharply in some monitoring wells in the ISCO plot, but rose in one of the wells. Geologic heterogeneities, preferential flowpaths taken by the oxidant, and localized permeability changes that determine flow in the treated region may lead to such variability in posttreatment groundwater levels of contamination. As discussed in Section 8.1.2.4, the chances of DNAPL mass removal resulting in reduced contaminant levels at a compliance point downgradient from the source is more likely in the short term. In the long term, DNAPL mass removal will always shorten the time period required to bring the entire affected aquifer in compliance with applicable standards.

8.1.6 Implementability

As mentioned in Section 7.2, site preparation and access requirements for implementing ISCO are minimal. Firm ground for setup of the permanganate storage and mixing equipment is required. The equipment and chemicals involved are commercially available. Setup and shakedown times are relatively small. Overhead space available at open sites is generally sufficient for housing storage and GeoProbe® equipment, if required. Accessibility to the portion of the contamination under the Engineering Support Building at Launch Complex 34 was not particularly efficient with normal injection from the outside. The use of angled injection wells/drive points or the capability of conducting injection from inside the building may be required to remediate more of the contamination under the building.

Generally, 8 to 10 hours of operator attention each day is sufficient to keep the oxidant flowing through the injection points and 24-hour presence is not required, as long as the system is automated enough that it shuts off when any backpressure is sensed in the injection lines. Strong oxidant and byproduct colors make it easier to track the progress of the oxidant in the aquifer, although confirmatory groundwater and soil sampling is required. The strong oxidant is a chemical hazard, but one that can be handled through the use of basic personal protective equipment and a common neutralizing solution.

At least in the injection-only mode used at Launch Complex 34, ISCO did not generate any significant aboveground wastes that required treatment and reinjection/disposal. If additional hydraulic control is to be achieved through the use of strategic extraction wells, then the complexity of the operation may increase to some degree and waste generation and handling requirements may become significant.

8.1.7 Cost

As described in Section 7.4, the cost of the ISCO treatment is competitive with the life-cycle cost of pump and treat (over a 30-year period of comparison). The cost comparison becomes even more favorable for source remediation in general and ISCO in particular when other tangible and intangible factors are taken into account. For example, a DNAPL source, such as the one at Launch Complex 34, is likely to persist much longer than 30 years (the normal evaluation time for long-term remedies), thus necessitating continued costs for pump and treat into the distant future (perhaps 100 years or more). Annual O&M costs also do not take into account the nonroutine maintenance costs associated with the large amount of downtime typically experienced by site owners with pump-and-treat systems.

Factors that may increase the cost of the ISCO application are:

- Operating requirements associated with any contamination under a building
- Stringent regulatory requirements on elevated levels of trace metals in the treated aquifer that necessitate operating longer with lower permanganate concentrations or moving to a higher grade of oxidant.

- Need for additional hydraulic control (e.g., with extraction wells) and any associated need to treat and dispose/reinject extracted fluids.

8.1.8 State Acceptance

The ITRC, a consortium of several states in the United States, is participating in the IDC demonstration through reports review and attendance at key meetings. The ITRC plays a key role in innovative technology transfer by helping disseminate performance information and regulatory guidance to the states.

The IDC set up a partnering team consisting of representatives from NASA and Patrick Air Force Base (site owners), U.S. EPA, State of Florida Department of Environmental Protection (FDEP), and other stakeholders early on when the demonstration was being planned. The partnering team was and is being used as the mechanism to proactively obtain regulatory input in the design and implementation of the remediation/demonstration activities at Launch Complex 34. Because of the technical limitations and costs of conventional approaches to DNAPL remediation, state environmental agencies have shown growing acceptance of innovative technologies.

8.1.9 Community Acceptance

The ISCO technology's low profile, limited space requirements, absence of air emissions, absence of waste storage, handling, and off-site transportation requirements, low noise levels, and ability to reduce short- and long-term risks posed by DNAPL contamination are expected to promote local community acceptance.

8.2 Operability

Unlike a pump-and-treat system that may involve continuous long-term operation by trained operators for the next 30 or 100 years, a source remediation technology is a short-term application. The field application of ISCO in the 75-ft × 50-ft plot at Launch Complex 34 took about seven months to complete including two interim monitoring events. The remediation generally is done as a turnkey project by multiple vendors, who will design, build, and operate the oxidant delivery system. Site characterization, site preparation (utilities, etc.), monitoring, and any waste disposal often are done by the site owner. Although various organization has patented some aspects of the process, ISCO of dissolved contamination, in general, has been known for a long time and is commercially available through several vendors.

The chemical (permanganate) oxidation process is relatively easy to set up and operate using off-the-shelf equipment and generally proficient operators. Potassium permanganate handling requires moderate health and safety measures; however, other oxidants, such as Fenton's reagent or ozone, may require additional precautions.

8.3 Applicable Wastes

ISCO has primarily been applied to remediation of aquifers contaminated with chlorinated solvents. Source zones consisting of PCE and TCE in DNAPL form, as well as dissolved *cis*-1,2-DCE and vinyl chloride can be addressed. However, oxidation has a range of other potential applications. Permanganate, for example, is able to oxidize source zones containing naphthalene, phenanthrene, pyrene, and phenols. ISCO can be implemented in source zones present in saturated or vadose zones. The technology also has been contemplated for treating dissolved contaminant plumes of these compounds. Oxidants, such as Fenton's reagent, have been found to be capable of treating methyl-*tert*-butyl ether (MTBE) hot spots. In general, any contaminant that exists in a relatively reduced form that can be oxidized into potentially nontoxic products is amenable for treatment by ISCO.

8.4 Key Features

The following are some of the key features of chemical (permanganate) oxidation that makes it attractive for DNAPL source zone and groundwater treatment:

- In situ application
- Potential for injection-only mode at some sites that prevents the generation of aboveground wastes, which would need additional treatment or handling
- Potentially nontoxic products
- Uses relatively simple, commercially available equipment
- Relatively fast field application time
- Longer-lived oxidant (potassium permanganate) distributes in the aquifer through both advection and diffusion, thus achieving better contact with contaminants
- At many sites, a one-time application has the potential to reduce a DNAPL source to the point where either natural attenuation is sufficient to address a weakened plume or pump and treat needs to be applied for over a shorter duration in the future.

8.5 Availability/Transportability

ISCO is commercially available from multiple vendors or consulting organizations as a service on a contract basis.

In addition, potassium permanganate or sodium permanganate suppliers are familiar enough with the application that they can help design some of the front-end permanganate storage and delivery equipment. No stand-alone mobile ISCO plant has been built, but components are readily available and oxidant delivery systems can be assembled or disassembled on site relatively quickly.

8.6 Materials Handling Requirements

Potassium permanganate is typically available as a solid and requires solids handling and mixing equipment; however, sodium permanganate is available as a solution that can be diluted on site before the in situ application.

8.7 Ranges of Suitable Site Characteristics

The following factors should be considered when determining the suitability of a site for ISCO application:

- **Type of contaminants.** Contaminants should be amenable to oxidation with commonly available oxidants.
- **Site geology.** Oxidant can be distributed more effectively in sandy soils. Silts or clays can make the application more difficult. Aquifer heterogeneities and preferential flowpaths can make contact between the oxidant and the contaminants more difficult. DNAPL source zones in fractured bedrock also may pose a challenge.
- **Soil characteristics.** Soils with low organic carbon content require less oxidant and application is relatively quicker. Soils with higher organic content consume more oxidant and slow down the spread of the oxidation front.
- **Regulatory acceptance.** Although ISCO has long-term benefits in terms of a diminished DNAPL source, at least in the short term, use of industrial-grade permanganate can elevate the levels of trace metals in the treated aquifer. Regulatory acceptance is important for this application, and a UIC permit or variance may be required. In addition, hydraulic control requirements and economics at some sites may necessitate extraction, treatment, and reinjection of the oxidant solution. A reinjection permit will be required.
- **Site accessibility.** Sites that have no aboveground structures and fewer utilities are easier to remediate with ISCO. Presence of buildings or a network of utilities can make the application more difficult.

None of the factors mentioned above necessarily eliminate ISCO from consideration. Rather, these are factors that may make the application less or more economical.

8.8 Limitations

The ISCO technology has the following limitations:

- Not all types of contaminants are amenable to oxidative transformation. In addition, some cocontaminants, such as heavy metals, could be mobilized by oxidation.
- Byproducts of oxidation may make it unsuitable for application in a region very close to a receptor, even though some of these byproducts are subject to secondary (nonhealth-based) drinking water standards. Byproducts, such as manganese, chloride, and trace metals, require sufficient time and distance to dissipate (around 100 ft at Cape Canaveral).
- Aquifer heterogeneities can make the application more difficult, necessitating more complex application schemes, greater amounts of oxidant, and/or longer injection times.
- Some sites may require greater hydraulic control to minimize the spread of contaminants. This may necessitate the use of extraction, aboveground treatment, and disposal/reinjection.

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Appendix A

Performance Assessment Methods

A.1 Statistical Design and Data Analysis Methods
A.2 Sample Collection and Extraction Methods
A.3 List of Standard Sample Collection and Analytical Methods

A.1 Statistical Design and Data Analysis Methods

Estimating TCE/DNAPL mass removal due to the in situ chemical oxidation (ISCO) technology application was a critical objective of the IDC demonstration at Launch Complex 34. Analysis of TCE in soil samples collected in the ISCO plot before and after the demonstration was the main tool used to make a determination of the mass removal. Soil sampling was used to obtain pre- and postdemonstration data on the TCE distribution in the ISCO plot. Three data evaluation methods were used for estimating TCE/DNAPL masses in the ISCO plot before and after the demonstration:

- Linear interpolation by contouring
- Kriging

Section 4.1 (in Section 4.0 of the report) contains a general description of these two methods. Section 5.1 (in Section 5.0 of this report) summarizes the results.

The *contouring* method is the most straightforward and involves determining TCE concentrations at unsampled points in the plot by linear interpolation (estimation) of the TCE concentrations between sampled points. The contouring software EarthVision™ uses the same methodology that is used for drawing water level contour maps based on water level measurements at discrete locations in a region. The only difference with this software is that the TCE concentrations are mapped in three dimensions to generate iso-concentration shells. The TCE concentration in each shell is multiplied by the volume of the shell (as estimated by the software) and the bulk density of the soil (1.59 g/cc, estimated during preliminary site characterization) to estimate a mass for each shell. The TCE mass in each region of interest (Upper Sand Unit, Middle-Fine-Grained Unit, Lower Sand Unit, and the entire plot) is obtained by adding up the portion of the shells contained in that region. The DNAPL mass is obtained by adding up the masses in only those shells that have TCE concentrations above 300 mg/kg. Contouring provides a single mass estimate for the region of interest.

The contouring method relies on a high sampling density (collecting a large number of samples in the test plot) to account for any spatial variability in the TCE concentration distribution. By collecting around 300 samples in the plot during each event (before and after treatment) the expectation is that sufficient coverage of the plot has been obtained to make a reliable determination of the true TCE mass in the region of interest. Section A.1.1 of this appendix describes how the number of samples and appropriate sampling locations were determined to obtain good coverage of the 75 ft x 50 ft plot.

Kriging is a statistical technique that goes beyond the contouring method described above and addresses the spatial variability of the TCE distribution by taking into account the uncertainties associated with interpolating between sampled points. Unlike contouring, which provides a single mass estimate, Kriging provides a range of estimated values that take into account the uncertainties (variability) in the region of interest. Section A.1.2 describes the kriging approach and results

A.1.1 Sampling Design to Obtain Sufficient Coverage of the ISCO plot

Selection of the sampling plan for this particular test plot was based, in part, on the objectives of the study for which the samples were being collected. In this study, the objectives were:

- **Primary objective:** To determine the magnitude of the reduction in the levels of TCE across the entire test plot.

- **Secondary objectives:**

  - To determine whether remediation effectiveness differs by depth (or stratigraphic unit such as the upper sand unit [USU], middle fine-grained unit [MFGU], or lower sand unit [LSU]).
  - To determine whether the three remediation technologies demonstrated differ in their effectiveness at removing chlorinated volatile organic compounds (CVOCs).

Four alternative plans for selecting the number and location of sampling in the test plot were examined. These four plans were designated as simple random sampling (SRS), paired sampling, stratified sampling, and systematic sampling. Each plan is discussed in brief detail below.

Simple Random Sampling

The most basic statistical sampling plan is SRS, in which all locations within a given sampling region are equally likely to be chosen for sampling. For this study, using SRS would require developing separate SRS plans for each of the three test plots. In addition, because two sampling events were planned for the test plot, using SRS would involve determining two sets of unrelated sampling locations for the test plot.

The main benefit of using SRS is that the appropriate sample size can be determined easily based on the required power to detect a specific decrease in contaminant levels. In addition, SRS usually involves a reasonable number of samples. However, a key disadvantage of using SRS is that it would not guarantee complete coverage of the test plot; also, if contaminant levels are spatially correlated, SRS is not the most efficient sampling design available.

Paired Sampling

Paired sampling builds on SRS methods to generate one set of paired sampling locations for a given test plot rather than two separate sets. Instead of sampling from each of two separate random sample locations for pre- and post-remediation sampling, paired sampling involves the positioning of post-remediation sample locations near the locations of pre-remediation sampling. The number of samples required to meet specific power and difference requirements when using this design would be similar to the number of locations involved using SRS; the exact sample size cannot be determined because information is required about contaminant levels at collocated sites before and after remediation.

Paired sampling offers three significant benefits to this particular study. First, the work of determining the sampling locations is reduced in half. Second, the comparison of contaminant

levels before and after remediation is based on the differences in levels at collocated sites. Third, the variability of the difference should be less than the variability associated with the SRS, which would result in a more accurate test. The disadvantages of this sampling procedure are the same as with the SRS: there is no guarantee of complete coverage of the test plot, and the plan is inefficient for spatially correlated data.

Stratified Sampling

Stratified sampling guarantees better coverage of the plot than either SRS or paired sampling: to ensure complete coverage of a given test plot, it is divided into a regular grid of cells, and random samples are drawn from each of the grid cells. Samples then are selected within each grid cell either using SRS or paired sampling. The number of samples required to meet specific power and difference requirements would be slightly greater than that for SRS, although the difference would not be great. For this study, which involves test plots 50 × 75 ft in size, the most effective grid size would be 25 × 25 ft, which results in six grid cells per test plot.

Again, the main benefit of stratified sampling is that it guarantees more complete coverage of the test plot than SRS or paired sampling. Also, if any systematic differences in contaminant levels exist across the site, stratified sampling allows for separate inferences by sub-plot (i.e., grid cell). Disadvantages of stratified sampling are that the method requires a slightly larger number of samples than SRS or paired sampling methods, and that stratified sampling performs poorly when contaminant levels are spatially correlated.

Systematic Sampling

The samples for the ISCO techonology demonstration were collected using a systematic sampling plan. Systematic sampling is the term applied to plans where samples are located in a regular pattern. In geographic applications such as this study, the systematic sampling method involves the positioning of sampling locations at the nodes of a regular grid. The grid need not be square or rectangular; in fact, a grid of equilateral triangles is the most efficient grid design. (Regular hexagonal grids also have been used regularly and are nearly as efficient as triangles and squares.) The number of samples and the size of the area to be sampled determine the dimensions of the grid to be used. With systematic sampling, the selection of initial (e.g., pre-remediation) set of sampling locations requires the random location of only one grid node, because all other grid nodes will be determined based on the required size of the grid and the position of that first node. A second (e.g., post-remediation) set of sampling locations can be either chosen using a different random placement of the grid or collocated with the initial set of sampling locations.

One variation of the systematic sampling method worth consideration is *unaligned* sampling. Under this method, a given test plot is divided into a grid with an equal number of rows and columns. One sample per grid cell then is selected by:

- Assigning random horizontal coordinates for each row of the grid;
- Assigning random vertical coordinates for each column of the grid;
- Determining the sampling locations for a cell by using the horizontal and vertical coordinates selected for the corresponding row and column.

In other words, every cell in a row shares a horizontal coordinate, and every cell in a column shares a vertical coordinate. Figure A-1 illustrates the locations generated using unaligned systematic sampling with a 3 × 3 grid.

The major benefit of systematic sampling was that it is the most efficient design for spatially correlated data. In addition, coverage of the entire plot was guaranteed. One disadvantage of systematic sampling was that determining the required sample size was more difficult than the other three methods discussed in this appendix.

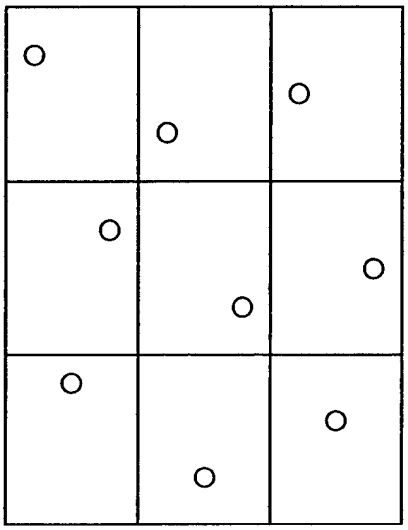


Figure A.1-1. Unaligned Systematic Sampling Design for a 3 × 3 Grid

A.1.2 Kriging Methods and Results

The geostatistical analysis approach was to utilize kriging, a statistical spatial interpolation procedure, to estimate the overall average TCE concentration in soil before and after remediation, and then determine if those concentrations were significantly different.

To meet the objectives of this study, it is sufficient to estimate the overall mean TCE concentration across an entire test plot, rather than estimating TCE concentrations at various spatial locations within a test plot. In geostatistical terms, this is known as global estimation. One approach, and in fact the simplest approach, for calculating a global mean estimate is to calculate the simple arithmetic average (i.e., the equally weighted average) across all available TCE concentrations measured within the plot. However, this approach is appropriate only in cases where no correlation is present in the measured data. Unfortunately, this is a rare situation in the environmental sciences.

A second approach, and the approach taken in this analysis, is to use a spatial statistical procedure called kriging to take account of spatial correlation when calculating the global average. Kriging is a statistical interpolation method for analyzing spatially varying data. It is used to estimate TCE concentrations (or any other important parameter) on a dense grid of spatial locations covering the region of interest, or as a global average across the entire region. At each location, two values are calculated with the kriging procedure: the estimate of TCE concentration (mg/kg), and the standard error of the estimate (also in mg/kg). The standard error can be used to calculate confidence intervals or confidence bounds for the estimates. It should be noted that this

calculation of confidence intervals and bounds also requires a serious distributional assumption, such as a normality assumption, which is typically more reasonable for global estimates than for local estimates.

The kriging approach includes two primary analysis steps:

1. Estimate and model spatial correlations in the available monitoring data using a semivariogram analysis.
2. Use the resulting semivariogram model and the available monitoring data to interpolate (i.e., estimate) TCE values at unsampled locations; calculate the statistical standard error associated with each estimated value.

A.1.2.1 Spatial Correlation Analysis

The objective of the spatial correlation analysis is to statistically determine the extent to which measurements taken at different locations are similar or different. Generally, the degree to which TCE measurements taken at two locations are different is a function of the distance and direction between the two sampling locations. Also, for the same separation distance between two sampling locations, the spatial correlation may vary as a function of the direction between the sampling locations. For example, values measured at each of two locations, a certain distance apart, are often more similar when the locations are at the same depth, than when they are at the same distance apart but at very different depths.

Spatial correlation is statistically assessed with the semivariogram function, (($\underline{h}$), which is defined as follows (Journel and Huijbregts, 1981):

$$2(\ (\underline{h}) = E\ \{[Z(\underline{x}) - Z(\underline{x} + \underline{h})]^2\}$$

where $Z(\underline{x})$ is the TCE measured at location $\underline{x}$, $\underline{h}$ is the vector of separation between locations $\underline{x}$ and $\underline{x} + \underline{h}$, and E represents the expected value or average over the region of interest. Note that the location $\underline{x}$ is typically defined by an easting, northing, and depth coordinate. The vector of separation is typically defined as a three-dimensional shift in space. The semivariogram is a measure of spatial differences, so that small semivariogram values correspond to high spatial correlation, and large semivariogram values correspond to low correlation.

As an initial hypothesis, it is always wise to assume that the strength of spatial correlation is a function of both distance and direction between the sampling locations. When the spatial correlation is found to depend on both separation distance and direction, it is said to be anisotropic. In contrast, when the spatial correlation is the same in all directions, and therefore depends only on separation distance, it is said to be isotropic.

The spatial correlation analysis is conducted in the following steps using the available measured TCE data:

- Experimental semivariogram curves are generated by organizing all pairs of data locations into various separation distance and direction classes (e.g., all pairs separated by 20-25 ft. in the east-west direction $\forall$ 22.5°), and then calculating within each class the average squared-difference between the TCE measurements taken at each pair of locations. The results of these calculations are plotted against separation distance and by separation direction.

Table A.1-4. Summary Statistics for Data Collected From ISCO Plot by Layer and Depth

Layer	Feet Above Sea Level (MSL)	Pre-Treatment					Post-Treatment				
		N	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)	Std. Dev. (mg/kg)	N	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)	Std. Dev. (mg/kg)
VADOSE	10 to 12	2	0.16	0.20	0.18	0.03	2	0.15	0.40	0.28	0.18
	8 to 10	4	0.13	0.37	0.26	0.11	13	0.15	0.55	0.35	0.14
	6 to 8	12	0.15	4.72	0.68	1.28	13	0.10	0.60	0.31	0.16
	4 to 6	12	0.17	1.81	0.52	0.47	13	0.15	2.30	0.50	0.57
	2 to 4	10	0.15	7.83	1.25	2.37	3	0.20	1.00	0.52	0.43
	0 to 2	1	0.38	0.38	0.38	.	.	.	.	.	.
	Total	41	0.13	7.83	0.70	1.38	44	0.10	2.30	0.39	0.35
USU	2 to 4	2	0.30	6.69	3.50	4.52	10	0.20	5.30	1.23	1.65
	0 to 2	11	0.15	2.94	0.65	0.86	12	0.20	57.30	6.28	16.24
	-2 to 0	11	0.18	8.56	2.27	3.13	13	0.15	42.70	10.49	15.72
	-4 to -2	13	0.20	7.40	0.94	1.95	13	0.15	44.80	5.59	13.39
	-6 to -4	12	0.21	8.71	1.89	2.57	13	0.15	39.30	5.13	12.34
	-8 to -6	12	0.25	28.48	3.71	8.05	13	0.15	83.60	8.55	23.19
	-10 to -8	13	0.74	114.31	16.49	31.41	14	0.15	14.70	1.75	4.05
	-12 to -10	14	1.33	240.81	70.76	93.31	13	0.20	246.70	26.03	70.59
	-14 to -12	12	11.63	4412.37	727.60	1563.26	12	0.20	31.00	3.06	8.82
	-16 to -14	10	57.93	3798.38	518.42	1153.89	7	0.15	1.80	0.72	0.76
	-18 to -16	6	59.30	304.19	201.89	85.59	.	.	.	.	.
	Total	116	0.15	4412.37	141.81	632.82	120	0.15	246.70	7.33	26.46
MFGU	-14 to -12	1	3033.83	3033.83	3033.83	.	1	2261.90	2261.90	2261.90	.
	-16 to -14	2	6898.91	13323.58	10111.24	4542.92	5	3.60	9726.77	1948.95	4347.93
	-18 to -16	7	65.10	17029.53	2798.69	6291.82	13	0.20	390.90	55.47	113.84
	-20 to -18	14	191.64	2261.17	488.48	520.49	15	0.20	4200.90	528.16	1335.90
	-22 to -20	10	137.28	30056.10	3288.71	9406.06	10	0.20	288.32	74.66	113.85
	-24 to -22	12	56.54	331.59	179.64	102.19	8	0.20	8.50	2.20	2.82
	-26 to -24	5	23.41	201.95	121.61	76.42	4	0.20	36.50	12.51	17.10
	-28 to -26	3	7.31	226.99	121.81	110.13	1	0.20	0.20	0.20	.
	-30 to -28	1	13.15	13.15	13.15	.	.	.	.	.	.
	Total	55	7.31	30056.10	1558.46	4916.03	57	0.20	9726.77	376.57	1471.04
LSU	-22 to -20	1	664.18	664.18	664.18	.	3	0.60	3887.58	2537.03	2198.15
	-24 to -22	2	19.52	8858.93	4439.23	6250.41	6	0.20	3279.60	798.48	1300.99
	-26 to -24	8	62.29	17686.46	4421.24	7446.19	10	0.20	4132.90	551.82	1301.99
	-28 to -26	10	95.48	11322.78	2479.58	3951.42	13	0.20	8313.75	976.92	2326.32
	-30 to -28	10	117.45	8374.13	2024.60	3194.20	14	0.30	1256.50	212.43	374.85
	-32 to -30	12	19.92	7397.80	1232.98	2289.02	13	0.20	583.10	63.21	157.71
	-34 to -32	13	6.75	8911.22	1883.02	3113.33	11	0.15	211.40	53.79	79.33
	-36 to -34	10	40.98	10456.12	2073.13	4030.31	9	0.20	857.60	189.68	323.49
	-38 to -36	6	48.87	8349.02	1521.04	3345.73	.	.	.	.	.
	Total	72	6.75	17686.46	2209.54	3943.33	79	0.15	8313.75	464.74	1260.41

The cores were drilled at least 44 feet deep; and the largest drill hole extends 48 feet. With few exceptions, TCE measurements were collected every two feet. Thus, approximately 20 to 25 two-foot core sections were analyzed from each drill hole. The vertical location of each core section was identified by the elevation of the midpoint of the section above sea level. At the time of data collection, the surface elevation at the location of the drill hole, as well as the top and bottom depths of each core section (rounded to the nearest half of a foot), were recorded. Hence, the elevation of each sample was calculated by the subtracting the average of the top and bottom depths from the surface elevation. For example, if a sample was collected from a core section that started and ended at 20 and 22 feet below a ground surface elevation of 5.2 feet, then the sample elevation equaled 5.2 - (20+22)/2=15.8 feet above sea level.

In some cases, field duplicate samples were collected by splitting an individual two-foot core section. In order to optimize the additional data, we used all measurements when evaluating spatial correlation with the semivariogram analysis, and when conducting the kriging analysis. However, to remain compatible with the kriging software, it was necessary to shift the location of the duplicate data slightly, by adding one-tenth of a foot to the easting coordinate. Table A.1-1 summarizes the number of two-foot sections from which more than one sample was collected.

Table A.1-1. Number of Field Duplicate Measurements Collected from the Resistive Heating and ISCO Plots

Plot	Pre/Post	Number of Two-Foot Sections From Which		Total
		1 Sample was Drawn	> 1 Sample was Drawn	
Resistive Heating	Pre	242	20	262
	Post	246	28	292
ISCO	Pre	251	16	267
	Post	276	12	288

There were also cases where the observed TCE concentration for a particular sample occurred below the analytical method detection limit (MDL). In such cases, the measurement that was included in our analyses equaled one-half of the given MDL. Table A.1-2 summarizes the number of observations that were below the MDL.

Table A.1-2. Number of Measurements (including Duplicates) Below the Minimum Detection Limit

Plot	Pre/Post	Number of Samples		Total
		Below MDL	Above MDL	
Resistive Heating	Pre	47	231	278
	Post	29	276	305
ISCO	Pre	20	266	286
	Post	156	144	300

When a two-foot section was removed from the core, the sample was identified by the easting, northing, and elevation coordinates. In addition, the geologic stratum, or soil type of the sample, was also documented. These strata and soil types included the vadose zone, upper sand unit (USU), middle fine-grained unit (MFGU), and lower sand unit (LSU). Note that the stratum of the sample was not solely determined by depth, but also by inspection by a geologist.

Table A.1-4. Summary Statistics for Data Collected From ISCO Plot by Layer and Depth

Layer	Feet Above Sea Level (MSL)	Pre-Treatment					Post-Treatment				
		N	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)	Std Dev (mg/kg)	N	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)	Std Dev (mg/kg)
VADOSE	10 to 12	2	0.16	0.20	0.18	0.03	2	0.15	0.40	0.28	0.18
	8 to 10	4	0.13	0.37	0.26	0.11	13	0.15	0.55	0.35	0.14
	6 to 8	12	0.15	4.72	0.68	1.28	13	0.10	0.60	0.31	0.16
	4 to 6	12	0.17	1.81	0.52	0.47	13	0.15	2.30	0.50	0.57
	2 to 4	10	0.15	7.83	1.25	2.37	3	0.20	1.00	0.52	0.43
	0 to 2	1	0.38	0.38	0.38	.	.	.	.	.	.
	Total	41	0.13	7.83	0.70	1.38	44	0.10	2.30	0.39	0.35
USU	2 to 4	2	0.30	6.69	3.50	4.52	10	0.20	5.30	1.23	1.65
	0 to 2	11	0.15	2.94	0.65	0.86	12	0.20	57.30	6.28	16.24
	-2 to 0	11	0.18	8.56	2.27	3.13	13	0.15	42.70	10.49	15.72
	-4 to -2	13	0.20	7.40	0.94	1.95	13	0.15	44.80	5.59	13.39
	-6 to -4	12	0.21	8.71	1.89	2.57	13	0.15	39.30	5.13	12.34
	-8 to -6	12	0.25	28.48	3.71	8.05	13	0.15	83.60	8.55	23.19
	-10 to -8	13	0.74	114.31	16.49	31.41	14	0.15	14.70	1.75	4.05
	-12 to -10	14	1.33	240.81	70.76	93.31	13	0.20	246.70	26.03	70.59
	-14 to -12	12	11.63	4412.37	727.60	1563.26	12	0.20	31.00	3.06	8.82
	-16 to -14	10	57.93	3798.38	518.42	1153.89	7	0.15	1.80	0.72	0.76
	-18 to -16	6	59.30	304.19	201.89	85.59	.	.	.	.	.
	Total	116	0.15	4412.37	141.81	632.82	120	0.15	246.70	7.33	26.46
MFGU	-14 to -12	1	3033.83	3033.83	3033.83	.	1	2261.90	2261.90	2261.90	.
	-16 to -14	2	6898.91	13323.58	10111.24	4542.92	5	3.60	9726.77	1948.95	4347.93
	-18 to -16	7	65.10	17029.53	2798.69	6291.82	13	0.20	390.90	55.47	113.84
	-20 to -18	14	191.64	2261.17	488.48	520.49	15	0.20	4200.90	528.16	1335.90
	-22 to -20	10	137.28	30056.10	3288.71	9406.06	10	0.20	288.32	74.66	113.85
	-24 to -22	12	56.54	331.59	179.64	102.19	8	0.20	8.50	2.20	2.82
	-26 to -24	5	23.41	201.95	121.61	76.42	4	0.20	36.50	12.51	17.10
	-28 to -26	3	7.31	226.99	121.81	110.13	1	0.20	0.20	0.20	.
	-30 to -28	1	13.15	13.15	13.15	.	.	.	.	.	.
	Total	55	7.31	30056.10	1558.46	4916.03	57	0.20	9726.77	376.57	1471.04
LSU	-22 to -20	1	664.18	664.18	664.18	.	3	0.60	3887.58	2537.03	2198.15
	-24 to -22	2	19.52	8858.93	4439.23	6250.41	6	0.20	3279.60	798.48	1300.99
	-26 to -24	8	62.29	17686.46	4421.24	7446.19	10	0.20	4132.90	551.82	1301.99
	-28 to -26	10	95.48	11322.78	2479.58	3951.42	13	0.20	8313.75	976.92	2326.32
	-30 to -28	10	117.45	8374.13	2024.60	3194.20	14	0.30	1256.50	212.43	374.85
	-32 to -30	12	19.92	7397.80	1232.98	2289.02	13	0.20	583.10	63.21	157.71
	-34 to -32	13	6.75	8911.22	1883.02	3113.33	11	0.15	211.40	53.79	79.33
	-36 to -34	10	40.98	10456.12	2073.13	4030.31	9	0.20	857.60	189.68	323.49
	-38 to -36	6	48.87	8349.02	1521.04	3345.73	.	.	.	.	.
	Total	72	6.75	17686.46	2209.54	3943.33	79	0.15	8313.75	464.74	1260.41

A.1.2.4 Semivariogram Results

In this study, the computer software used to perform the geostatistical calculations was Battelle's BATGAM software, which is based on the GSLIB Software written by the Department of Applied Earth Sciences at Stanford University, and documented and released by Prof. Andre Journel and Dr. Clayton Deutsch (Deutsch and Journel, 1998). The primary subroutine used to calculate experimental semivariograms was GAMV3, which is used for three-dimensional irregularly spaced data.

For the three-dimensional spatial analyses, horizontal separation distance classes were defined in increments of 5 ft. with a tolerance of 2.5 ft., while vertical distances were defined in increments of 2 ft. with a tolerance of 1 ft. Horizontal separation directions were defined, after rotation 30° west from North (see Figures A.1-2 and A.1-3), in the four primary directions of north, northeast, east, and southeast with a tolerance of 22.5°.

Data were analyzed separately for the Resistive Heating and ISCO plots, and vertically the data were considered separately by layer (i.e., USU, MFGU and LSU layers). Semivariogram and kriging analyses were not performed with the vadose data since the pre-remediation TCE concentrations were already relatively low and insignificant. Results from the semivariogram analyses are presented in Figures A.1-4 to A.1-15, as well as Table A.1-5. The key points indicated in the semivariogram analysis results are as follows:

(a) For all experimental semivariograms calculated with the TCE data, no horizontal directional differences (i.e., anisotropies) were observed; however, strong anisotropy for the horizontal versus vertical directions was often observed. Therefore, in Figures 3 through 14 the omni-directional horizontal semivariogram (experimental and model) is shown along with the vertical semivariogram (experimental and model).

(b) In all cases, the experimental semivariograms are relatively variable due to high data variability and modest sample sizes. As a result, the semivariogram model fitting is relatively uncertain, meaning that a relatively wide range of semivariogram models could adequately fit the experimental semivariogram points. This probably does not affect the TCE estimates (especially the global estimates), but could significantly affect the associated confidence bounds.

(c) The models shown in Figures 3 through 14 are all gaussian semivariogram models, chosen to be consistent with the experimental semivariogram shapes found for all twelve TCE data sets at this Cape Canaveral site. The fitted semivariograms model parameters are listed in Table 5.

Table A.1-5. Fitted Semivariogram Model Parameters for TCE at Cape Canaveral

	Data Set			Semivariogram				
Figure No.	Plot	Layer	Pre- or Post-Remediation	Gaussian Type	Nugget Var. $(mg/kg)^2$	Total Sill Var. $(mg/kg)^2$	Omni-Horizontal Range (ft.)	Vertical Range (ft.)
3	Resistive Heating	USU	PRE	Anisotropic	6.0×10^3	6.4×10^4	23	3
4	Resistive Heating	USU	POST	Anisotropic	2.0×10^4	1.9×10^5	35	3
5	Resistive Heating	MFGU	PRE	Anisotropic	1.0×10^6	2.0×10^7	35	5
6	Resistive Heating	MFGU	POST	Anisotropic	5.0×10^4	6.0×10^5	35	5
7	Resistive Heating	LSU	PRE	Isotropic	2.5×10^7	8.5×10^7	9	9
8	Resistive Heating	LSU	POST	Anisotropic	4.0×10^3	2.0×10^4	23	3
9	ISCO	USU	PRE	Anisotropic	5.0×10^4	3.0×10^5	12	3
10	ISCO	USU	POST	Isotropic	5.0×10^1	4.0×10^2	3	3
11	ISCO	MFGU	PRE	Anisotropic	2.5×10^6	2.0×10^7	35	3
12	ISCO	MFGU	POST	Anisotropic	2.0×10^5	1.4×10^6	52	3
13	ISCO	LSU	PRE	Anisotropic	1.0×10^6	1.0×10^7	23	3
14	ISCO	LSU	POST	Anisotropic	7.0×10^4	6.7×10^5	35	3

A.1.2.5 Kriging Results

The kriging analysis was performed using the BATGAM software and GSLIB subroutine KT3D. To conduct this analysis, each plot was defined as a set of vertical layers and sub-layers. Estimated mean TCE concentrations were then calculated via kriging for each sub-layer separately, as well as across the sub-layers. The vertical layering for kriging was consistent with the semivariogram modeling:

(a) Kriging the Resistive Heating plot was performed separately for the USU, MFGU and LSU layers. The USU layer was sub-divided into 11 two-foot sub-layers extending across elevations from –20 to +2 ft. The MFGU layer was sub-divided into 10 two-foot sub-layers extending across elevations from –32 to –12 ft. The LSU layer was sub-divided into 11 two-foot sub-layers from elevations of –40 to –18 ft.

(b) Kriging of the ISCO plot was also done separately for the USU, MFGU and LSU layers. The USU layer consisted of 11 two-foot sub-layers across elevations from –18 to +4 ft. The MFGU layer consisted of 9 sub-layers across elevations from –30 to –12 ft. The LSU layer consisted of 9 sub-layers across elevations from –38 to –20 ft.

(c) For kriging of the two-foot sub-layers, the data search was restricted to consider only three sub-layers, the current sub-layer and that immediately above and below. The data search was not restricted horizontally.

(d) For kriging of an entire layer (i.e., USU or MFGU or LSU separately), the data search considered all available data at all elevations. Note that by extending the data search radius to include all data within a plot, an implicit assumption is made that the semivariogram model holds true for distances up to about 100 ft., which are distances beyond those observable with this dataset in the experimental semivariograms. This assumption seems reasonable given the relatively short dimensions of the Resistive Heating and ISCO plots.

Results from the kriging analysis are presented in Tables A.1-6 and A.1-7 for the Resistive Heating and ISCO pre- and post-remediation data, and for each of USU, MFGU and LSU layers, as well as by sub-layer within each layer. Because of the shortcomings of using the ordinary kriging variance (discussed in Section 1.0) for local estimates, confidence bounds are only presented in Tables 6 and 7 for the global layer estimates (shaded rows). In cases where the upper confidence bound for the post-remediation average TCE concentration falls below the lower confidence bound for the pre-remediation average TCE concentration, the post-remediation TCE concentrations are statistically significantly lower than the pre-remediation TCE concentrations (denoted with a * in the tables). The estimated TCE reductions, expressed on a percentage basis, are also shown in Tables A.1-6 and A.1-7 and generally (with the exception of the TCE increase in the Resistive Heating USU layer) vary between 70% and 96%, based on the global estimates.

Table A.1-8 shows how the TCE concentration estimates (average, lower bound, and upper bound as determined in Table A.1-7) for ISCO plot are weighted and converted into TCE masses. The concentration estimates in the three stratigraphic units are multiplied by the number of grid cells sampled (N) in each stratigraphic unit and the mass of dry soil in each cell (26,831.25 kg). The mass of soil in each grid cell is the volume of each 18.75 ft x 16.67 ft x 2 ft grid cell (the area of the plot divided into a 4 x 3 grid; the thickness of each grid cell is 2 ft).

Table A.1-6. Kriging Results for TCE in the Resistive Heating Plot

Layer	Feet Above Sea Level (MSL)	Pre-Remediation TCE (mg/kg)	Post-Remediation TCE (mg/kg) / Percent Reduction
USU	0 to 2	3	32
	-2 to 0	2	21
	-4 to -2	2	18
	-6 to -4	1	32
	-8 to -6	14	46
	-10 to -8	31	297
	-12 to -10	124	325
	-14 to -12	118	122
	-16 to -14	182	78
	-18 to -16	245	61
	-20 to -18	88	41
	Total	64	112 / 75%
	95% C.I.	(19, 110)	(38, 186)
	90% C.I.	(26,103)	(49, 174)
	80% C.I.	(34, 94)	(63, 160)
MFGU	-14 to -12	.	1450
	-16 to -14	412	606
	-18 to -16	1375	635
	-20 to -18	2125	478
	-22 to -20	1765	181
	-24 to -22	1419	119
	-26 to -24	2809	54
	-28 to -26	1705	12
	-30 to -28	1	3
	-32 to -30	1	.
	Total	1655	408 / 75%
	95% C.I.	(251, 3059)	(165, 650)
	90% C.I.	(473, 2837)	(204, 612)
	80% C.I.	(731, 2579)	(248, 567)*
LSU	-20 to -18	.	512
	-22 to -20	140	204
	-24 to -22	151	166
	-26 to -24	207	180
	-28 to -26	2394	239
	-30 to -28	2462	189
	-32 to -30	2246	135
	-34 to -32	3190	153
	-36 to -34	7241	154
	-38 to -36	8225	118
	-40 to -38	5615	.
	Total	4092	183 / 96%
	95% C.I.	(1463, 6721)	(154, 212)*
	90% C.I.	(1879, 6305)	(159, 208)*
	80% C.I.	(2362, 5822)	(164, 202)*

* TCE reduction is statistically significant.

Table A.1-7. Kriging Results for TCE in the ISCO Plot

Layer	Feet Above Sea Level (MSL)	Pre-Remediation TCE (mg/kg)	Post-Remediation TCE (mg/kg) / Percent Reduction
USU	2 to 4	2	1
	0 to 2	1	5
	-2 to 0	1	6
	-4 to -2	2	7
	-6 to -4	3	9
	-8 to -6	9	5
	-10 to -8	31	12
	-12 to -10	53	16
	-14 to -12	613	6
	-16 to -14	760	4
	-18 to -16	167	.
	Total	146	8 / 95%
	95% C.I.	(45, 246)	(4, 11)*
	90% C.I.	(61, 230)	(4, 11)*
	80% C.I.	(80, 212)	(5, 10)*
MFGU	-14 to –12	7963	3593
	-16 to –14	9414	1501
	-18 to –16	2684	135
	-20 to -18	1508	619
	-22 to -20	2655	196
	-24 to -22	220	30
	-26 to -24	150	8
	-28 to -26	97	.
	-30 to -28	71	.
	Total	1922	570 / 70%
	95% C.I.	(712, 3133)	(230, 909)
	90% C.I.	(903, 2942)	(284, 856)*
	80% C.I.	(1126, 2719)	(346, 793)*
LSU	-22 to -20	4665	2021
	-24 to -22	10048	954
	-26 to -24	4796	846
	-28 to -26	2036	823
	-30 to -28	1876	245
	-32 to -30	1780	102
	-34 to -32	1453	73
	-36 to -34	1972	183
	-38 to -36	2491	.
	Total	2282	486 / 79%
	95% C.I.	(1578, 2986)	(311, 660)*
	90% C.I.	(1690, 2875)	(339, 632)*
	80% C.I.	(1819, 2746)	(371, 600)*

* TCE reduction is statistically significant.

Table A.1-8. Calculating Total TCE Masses based on TCE Average Concentrations and Upper and Lower Bounds

ISCO Plot Geology Units	Pre-Demonstration							Post-Demonstration						
		TCE Concentration			TCE Mass				TCE Concentration			TCE Mass		
	N	Average (mg/kg)	Lower Bound (mg/kg)	Upper Bound (mg/kg)	Average (kg)	Lower Bound (kg)	Upper Bound (kg)	N	Average (mg/kg)	Lower Bound (mg/kg)	Upper Bound (mg/kg)	Average (kg)	Lower Bound (kg)	Upper Bound (kg)
Upper Sand Unit	116	146	80	212	454	250	659	120	8	5	10	26	18	34
Middle Fine-Grained Unit	55	1,922	1,126	2,719	2,836	1,668	4,005	57	570	346	793	872	532	1,211
Lower Sand Unit	72	2,282	1,819	2,746	4,408	3,519	5,298	79	486	371	600	1,030	788	1,272
Total ISCO Plot	243	-	-	-	7,699	6,217	9,182	256	-	-	-	1,928	1,511	2,345

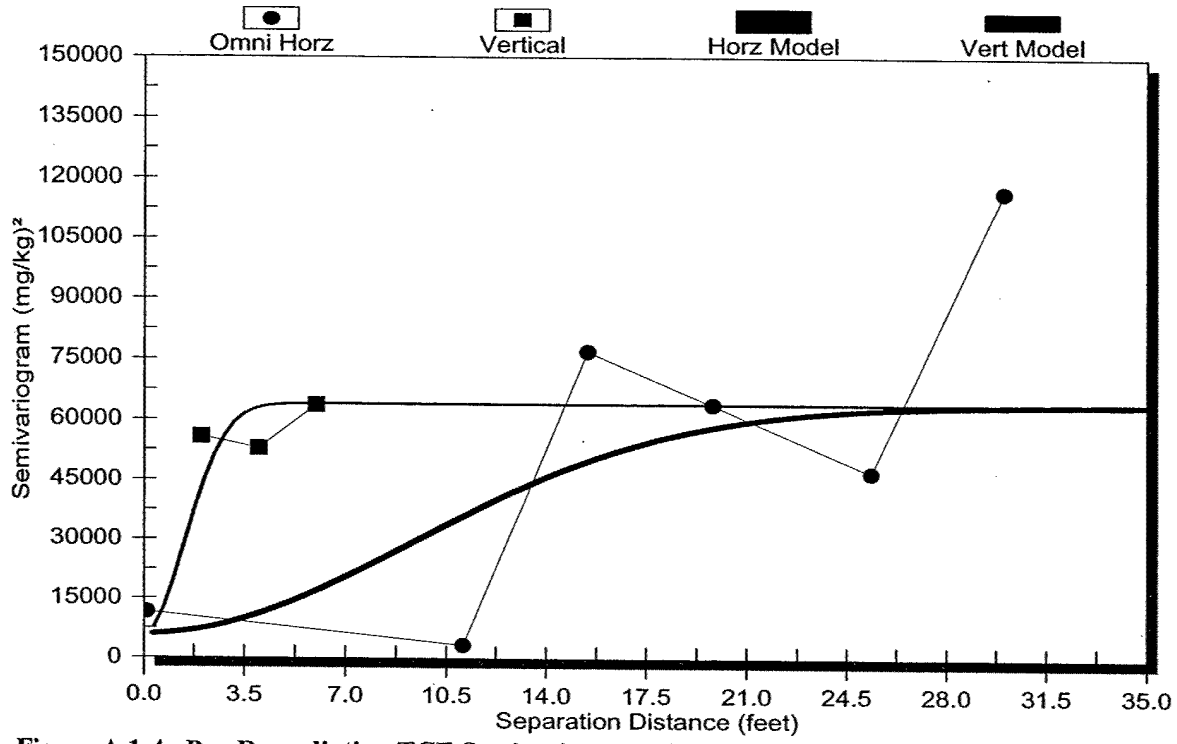


Figure A.1-4. Pre-Remediation TCE Semivariograms for Resistive Heating Plot and USU

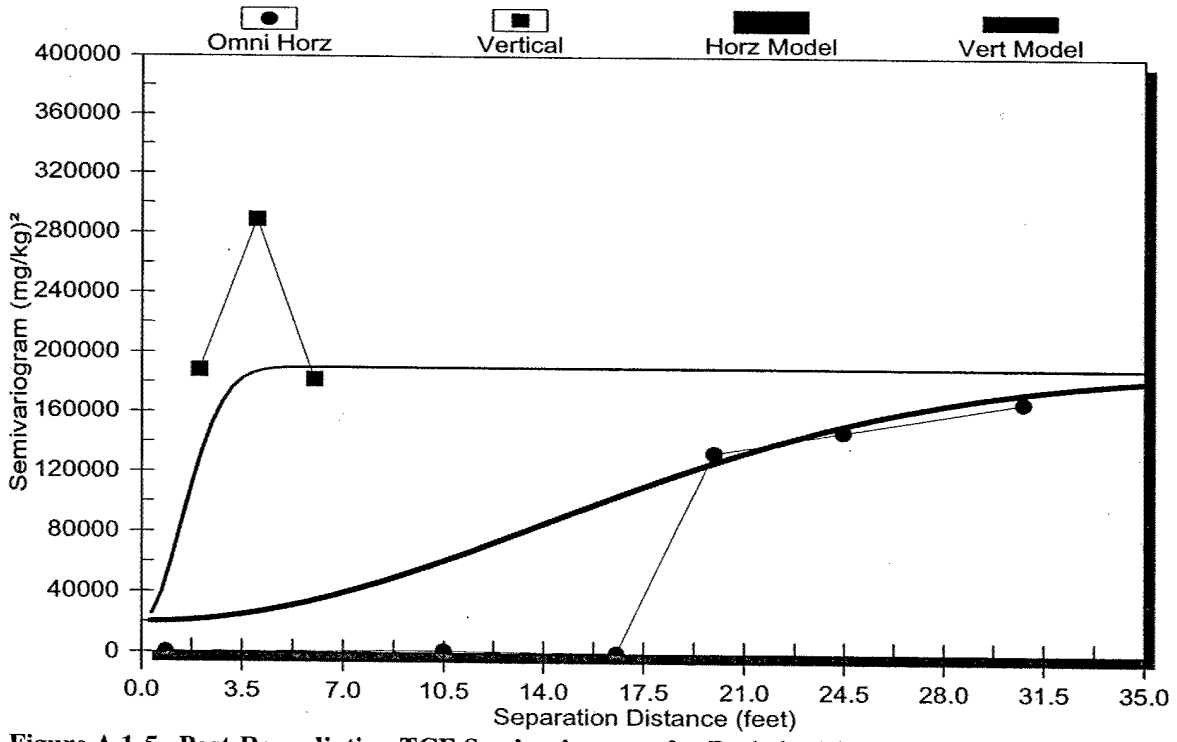


Figure A.1-5. Post-Remediation TCE Semivariograms for Resistive Heating Plot and USU

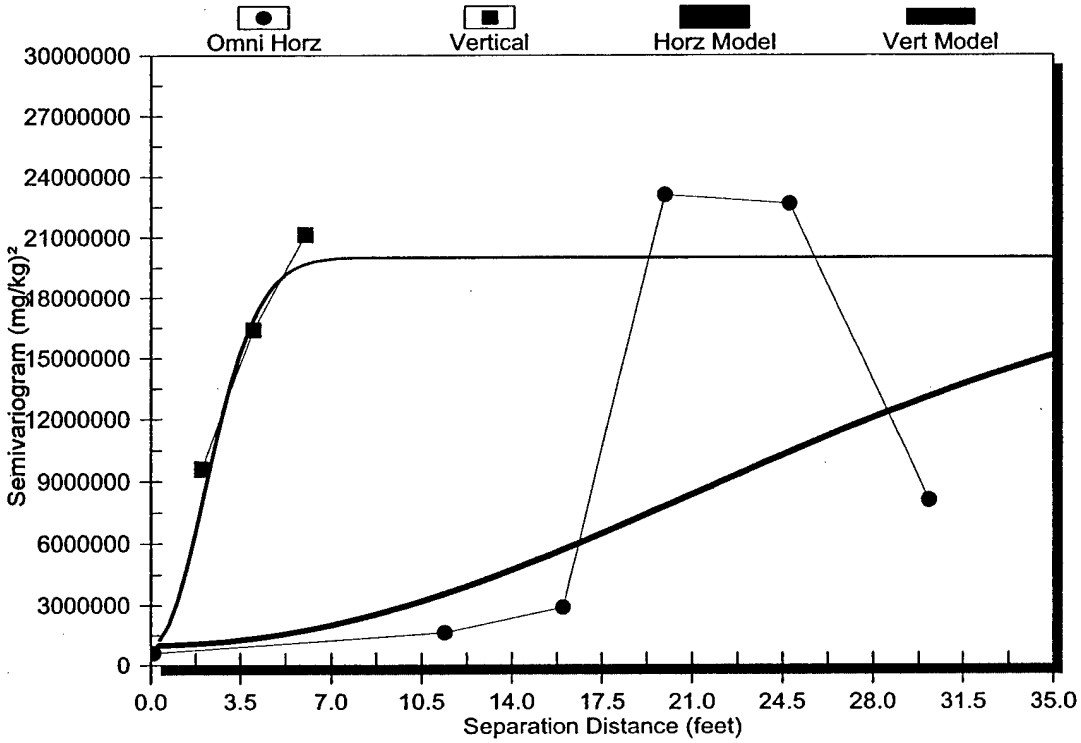


Figure A.1-6. Pre-Remediation TCE Semivariograms for Resistive Heating Plot and MFGU

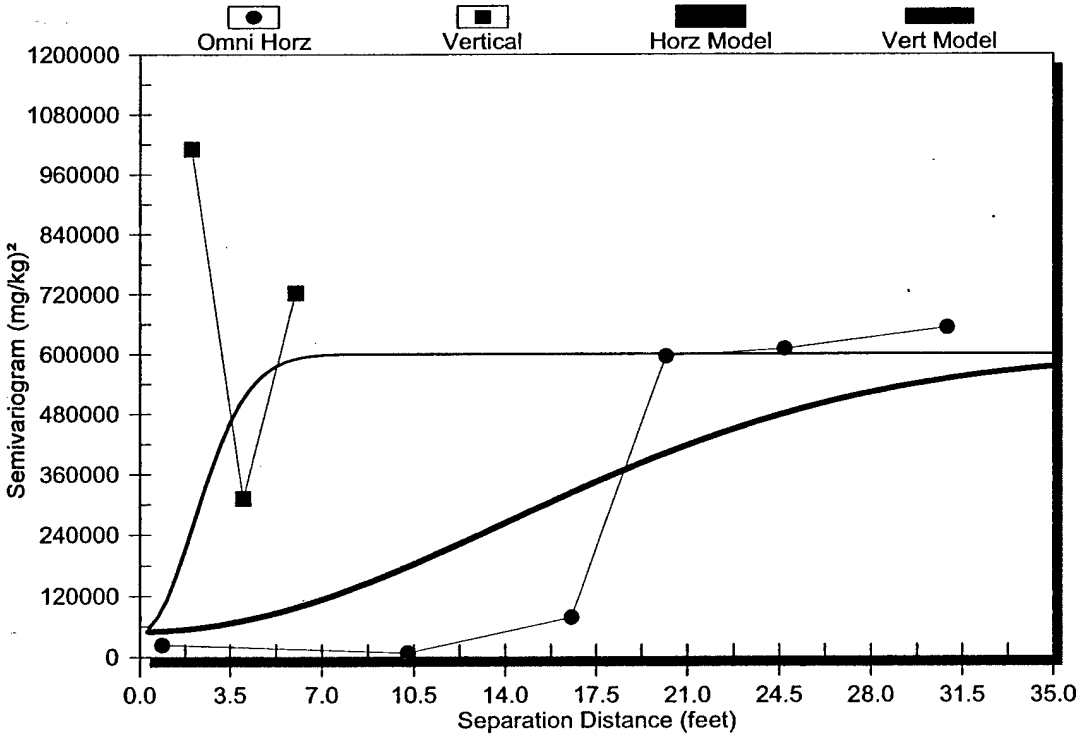


Figure A.1-7. Post-Remediation TCE Semivariograms for Resistive Heating Plot and MFGU

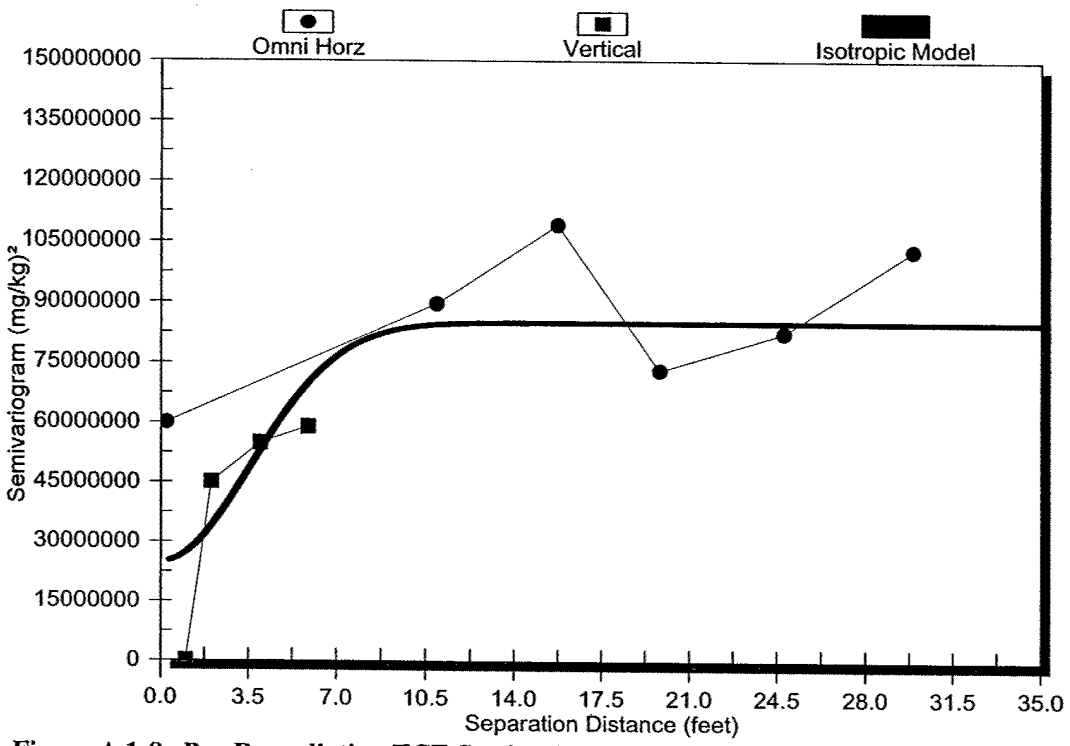


Figure A.1-8. Pre-Remediation TCE Semivariograms for Resistive Heating Plot and LSU

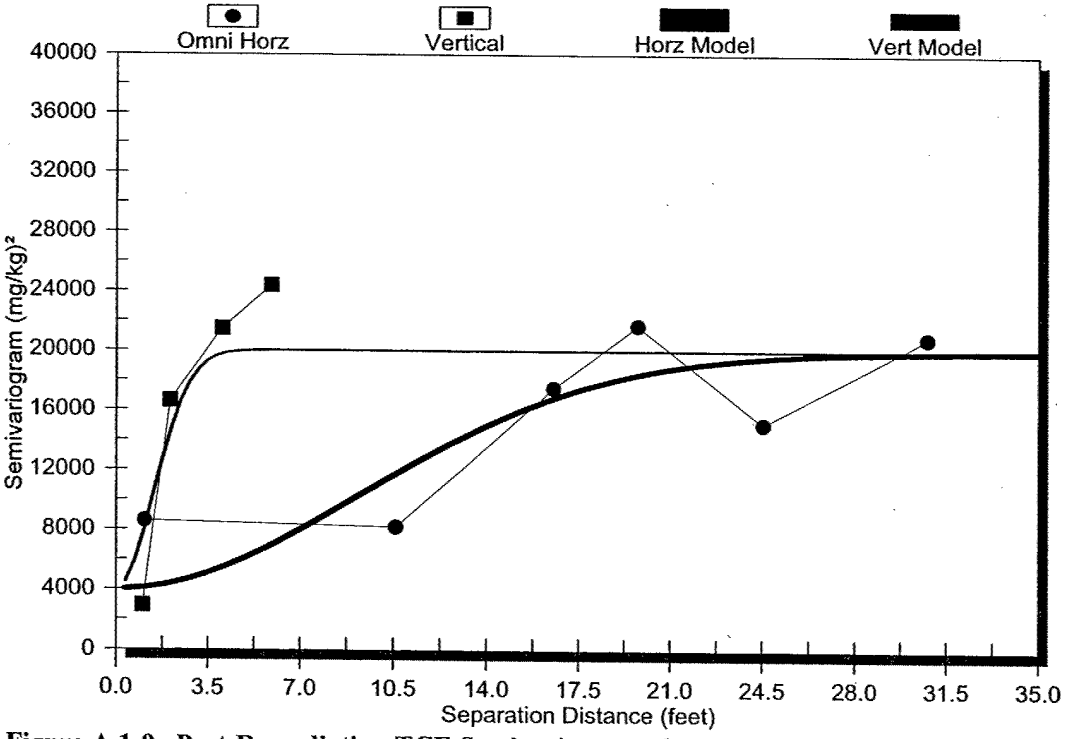


Figure A.1-9. Post-Remediation TCE Semivariograms for Resistive Heating Plot and LSU

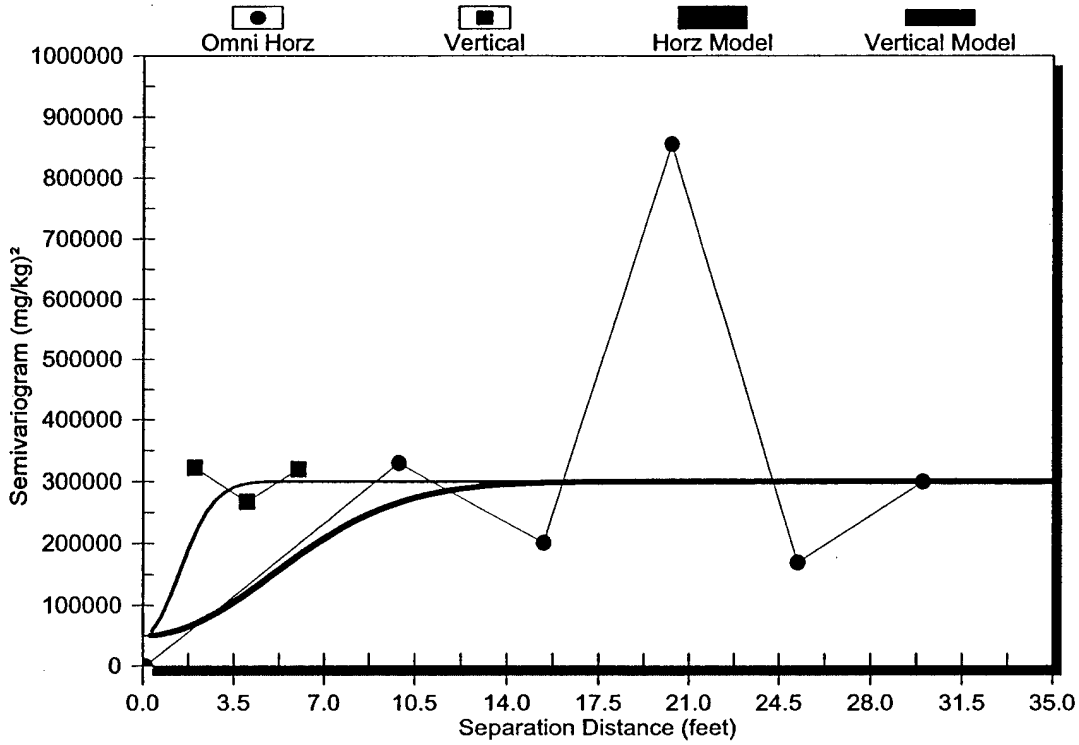


Figure A.1-10. Pre-Remediation TCE Semivariograms for ISCO Plot and USU

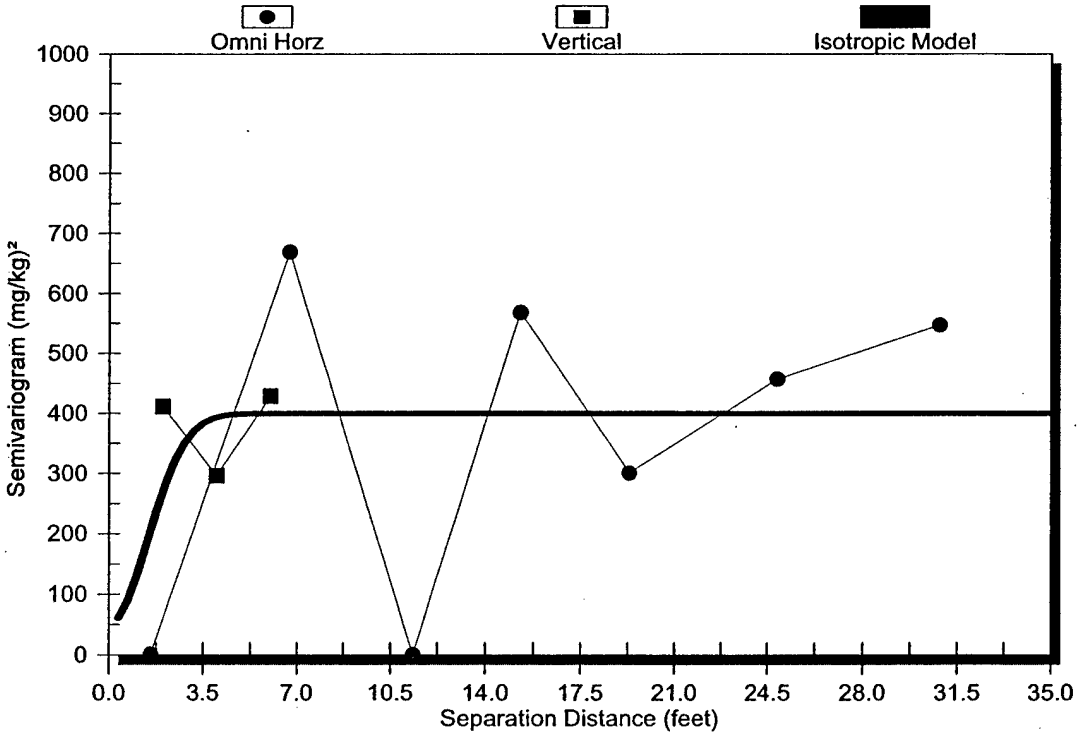


Figure A.1-11. Post-Remediation TCE Semivariograms for ISCO Plot and USU

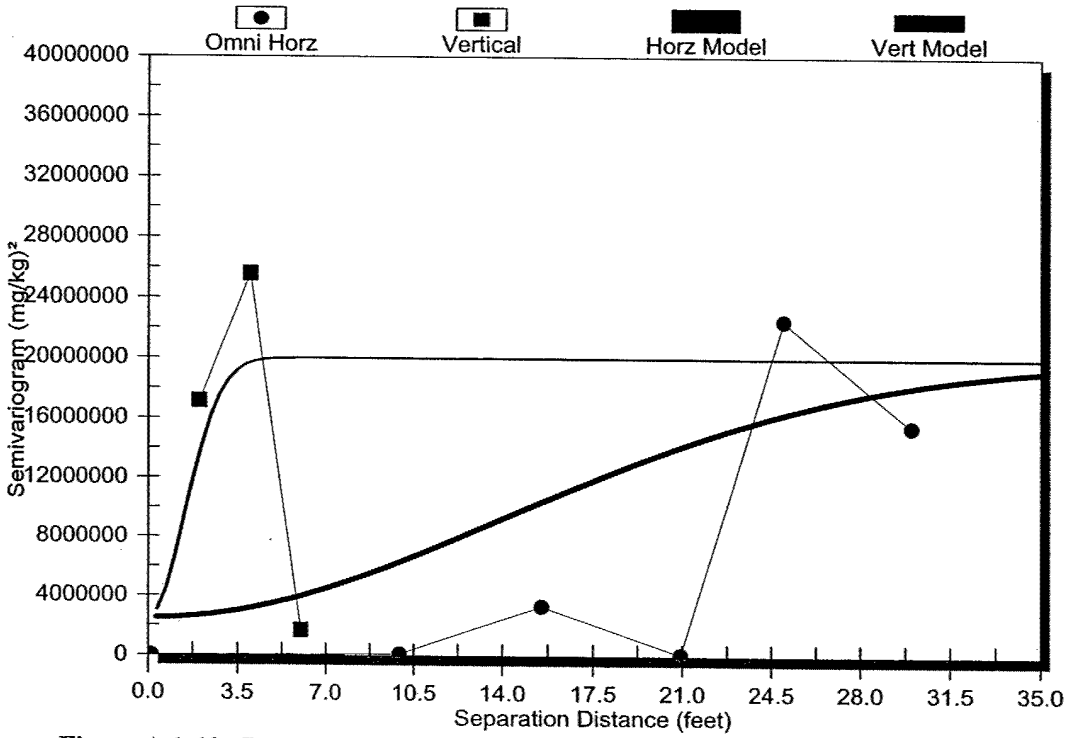


Figure A.1-12. Pre-Remediation TCE Semivariograms for ISCO Plot and MFGU

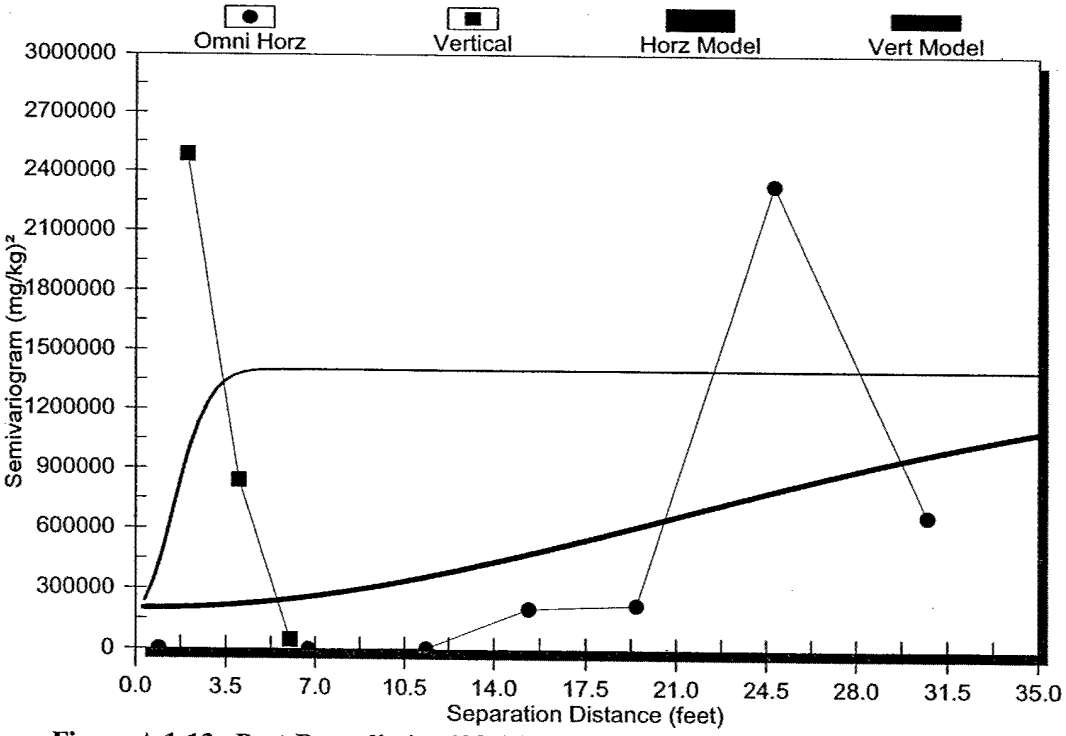


Figure A.1-13. Post-Remediation TCE Semivariograms for ISCO Plot and MFGU

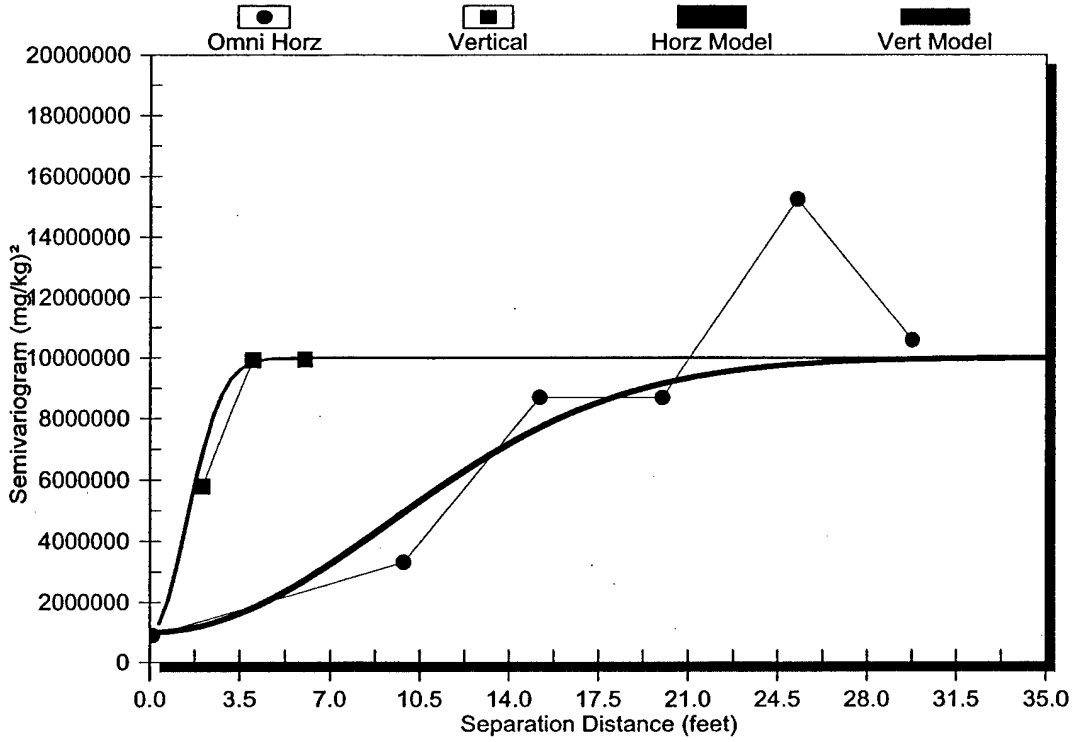


Figure A.1-14. Pre-Remediation TCE Semivariograms for ISCO Plot and LSU

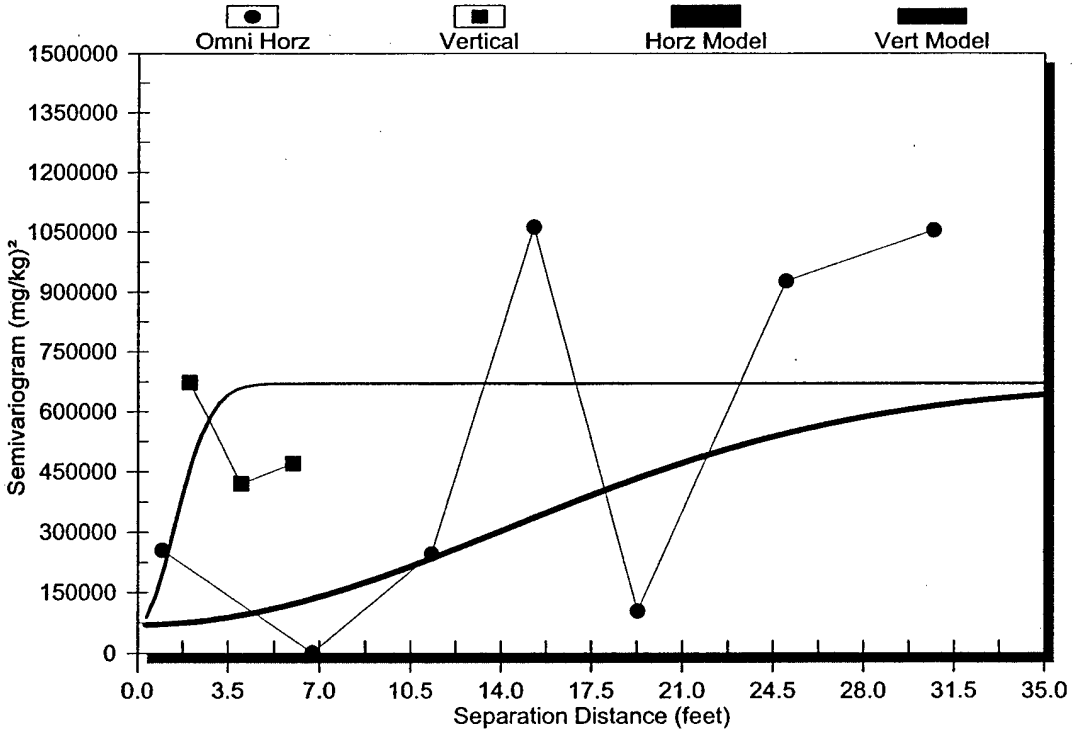


Figure A.1-15. Post-Remediation TCE Semivariograms for ISCO Plot and LSU

A.2 Sample Collection and Extraction Methods

This section describes the modification made to the EPA standard methods to address the lithologic heterogeneities and extreme variability of the contaminant distribution expected in the DNAPL source region at Launch Complex 34. Horizontal variability was addressed by collecting a statistically determined number (12) of soil cores in the ISCO Plot. The vertical variability at each soil coring location was addressed with this modified sampling and extraction procedure, which involved extraction of much larger quantities of soil in each extracted sample, as well as allowed collection and extraction of around 300 samples in the field per event. This extraction allowed the extraction and analysis of the entire vertical column of soil at a given coring location.

A.2.1 Soil Sample Collection (Modified ASTM D4547-91) (1997b)

The soil samples collected before and after the demonstration were sampled using a stainless steel sleeve driven into the subsurface by a cone penetrometer test (CPT) rig. After the sleeve had been driven the required distance, it was brought to the surface and the soil sample was examined and characterized for lithology. One quarter of the sample was sliced from the core and placed into a pre-weighed 500-mL polyethylene container. At locations where a field duplicate sample was collected, a second one-quarter sample was split from the core and placed into another pre-weighed 500-mL polyethylene container. The remaining portion of the core was placed into a 55-gallon drum and disposed of as waste. The samples were labeled with the date, time, and sample identification code, and stored on ice at 4°C until they were brought inside to the on-site laboratory for the extraction procedure.

After receiving the samples from the drilling activities, personnel staffing the field laboratory performed the methanol extraction procedure as outlined in Section A.2.2 of this appendix. The amount of methanol used to perform the extraction technique was 250 mL. The extraction procedure was performed on all of the primary samples collected during drilling activities and on 5% of the field duplicate samples collected for quality assurance. Samples were stored at 4°C until extraction procedures were performed. After the extraction procedure was finished, the soil samples were dried in an oven at 105°C and the dry weight of each sample was determined. The samples were then disposed of as waste. The remaining three-quarter section of each core previously stored in a separate 500-mL polyethylene bottle were archived until the off-site laboratory had completed the analysis of the methanol extract. The samples were then disposed of in an appropriate manner.

A.2.2 Soil Extraction Procedure (Modified EPA SW846-Method 5035)

After the soil samples were collected from the drilling operations, samples were placed in pre-labeled and pre-weighed 500-mL polyethylene containers with methanol and then stored in a refrigerator at 4°C until the extraction procedure was performed. Extraction procedures were performed on all of the "A" samples from the outdoor and indoor soil sampling. Extraction procedures also were performed on 5% of the duplicate (or "B") samples to provide adequate quality assurance/quality control (QA/QC) on the extraction technique.

Extreme care was taken to minimize the disturbance of the soil sample so that loss of volatile components was minimal. Nitrile gloves were worn by field personnel whenever handling sample cores or pre-weighed sample containers. A modification of EPA SW846-Method 5035 was used to procure the cored samples in the field. Method 5035 lists different procedures for processing samples that are expected to contain low concentrations (0.5 to 200 µg/kg) or high concentrations

(>200 µg/kg) of volatile organic compounds (VOCs). Procedures for high levels of VOCs were used in the field because those procedures facilitated the processing of large-volume sample cores collected during soil sampling activities.

Two sample collection options and corresponding sample purging procedures are described in Method 5035; however, the procedure chosen for this study was based on collecting approximately 150 to 200 g of wet soil sample in a pre-weighed bottle that contains 250 mL of methanol. A modification of this method was used in the study, as described by the following procedure:

- The 150 to 200 g wet soil sample was collected and placed in a pre-weighed 500 mL polypropylene bottle. After capping, the bottle was reweighed to determine the wet weight of the soil. The container was then filled with 250 ml of reagent grade methanol. The bottle was weighed a third time to determine the weight of the methanol added. The bottle was marked with the location and the depth at which the sample was collected.

- After the containers were filled with methanol and the soil sample they were placed on an orbital shaker table and agitated for approximately 30 min.

- Containers were removed from the shaker table and reweighed to ensure that no methanol was lost during the agitation period. The containers were then placed upright and suspended soil matter was allowed to settle for approximately 15 min.

- The 500 mL containers were then placed in a floor-mounted centrifuge. The centrifuge speed was set at 3,000 rpm and the samples were centrifuged for 10 min.

- Methanol extract was then decanted into disposable 20-mL glass volatile organic analysis (VOA) vials using 10-mL disposable pipettes. The 20-mL glass VOA vials containing the extract then were capped, labeled, and stored in a refrigerator at 4°C until they were shipped on ice to the analytical laboratory.

- Methanol samples in VOA vials were placed in ice chests and maintained at approximately 4°C with ice. Samples were then shipped with properly completed chain-of-custody forms and custody seals to the subcontracted off-site laboratory.

- The dry weight of each of the soil samples was determined gravimetrically after decanting the remaining solvent and drying the soil in an oven at 105°C. Final concentrations of VOCs were calculated per the dry weight of soil.

Three potential concerns existed with the modified solvent extraction method. The first concern was that the United States Environmental Protection Agency (U.S. EPA) had not formally evaluated the use of methanol as a preservative for VOCs. However, methanol extraction often is used in site characterization studies, so the uncertainty in using this approach was reasonable. The second concern was that the extraction procedure itself would introduce a significant dilution factor that could raise the method quantitation limit beyond that of a direct purge-and-trap procedure. The third concern was that excess methanol used in the extractions would likely fail the ignitability characteristic, thereby making the unused sample volume a hazardous waste. During characterization activities, the used methanol extract was disposed of as hazardous waste into a 55-gallon drum. This methanol extraction method was tested during preliminary site characterization activities at this site (see Appendix G, Table G-1) and, after a few refinements,

was found to perform acceptably in terms of matrix spike recoveries. Spiked TCE recoveries in replicate samples ranged from 72 to 86%.

The analytical portion of Method 5035 describes a closed-system purge-and-trap process for use on solid media such as soils, sediments, and solid waste. The purge-and-trap system consists of a unit that automatically adds water, surrogates, and internals standards to a vial containing the sample. Then the process purges the VOCs using an inert gas stream while agitating the contents of the vial, and finally traps the released VOCs for subsequent desorption into a gas chromatograph (GC). STL Environmental Services performed the analysis of the solvent extraction samples. Soil samples were analyzed for organic constituents according to the parameters summarized in Table A.2-1. Laboratory instruments were calibrated for VOCs listed under U.S. EPA Method 601 and 602. Samples were analyzed as soon as was practical and within the designated holding time from collection (14 days). No samples were analyzed outside of the designated 14-day holding time.

Table A.2-1. Soil Sampling and Analytical Parameters

Analytes	Extraction Method	Analytical Method	Sample Holding Time	Matrix
VOCs[(a)]	SW846-5035	SW846-8260	14 days	Methanol

(a) EPA 601/602 list.

A.3 List of Standard Sample Collection and Analytical Methods

Table A.3-1. Sample Collection Procedures

Measurements	Task/Sample Collection Method	Equipment Used
Primary Measurements		
CVOCs	Soil sampling/ Mod.[a] ASTM D4547-98 (1997c)	Stainless steel sleeve 500-mL plastic bottle
CVOCs	Groundwater sampling/ Mod.[a] ASTM D4448-01 (1997a)	Peristaltic pump Teflon™ tubing
Secondary Measurements		
TOC	Soil sampling/ Mod.[a] ASTM D4547-91 (1997c)	Stainless steel sleeve
Field parameters[b] TOC BOD Inorganics–cations Inorganics–anions TDS Alkalinity	Groundwater sampling/ Mod.[a] ASTM D4448-01 (1997a)	Peristaltic pump Teflon™ tubing
Hydraulic conductivity	Hydraulic conductivity/ ASTM D4044-96 (1997d)	Winsitu® troll Laptop computer
Groundwater level	Water levels	Water level indicator
CVOCs	Vapor Sampling/Tedlar Bag, TO-14	Vacuum Pump

(a) Modifications to ASTM are detailed in Appendix B.
(b) Field parameters include pH, ORP, temperature, DO, and conductivity. A flowthrough well will be attached to the peristaltic pump when measuring field parameters.
ASTM = American Society for Testing and Materials.

Table A.3-2. Sample Handling and Analytical Procedures

Measurements	Matrix	Amount Collected	Analytical Method	Maximum Holding Time[a]	Sample Preservation[b]	Sample Container	Sample Type
Primary Measurements							
CVOCs	Soil	250 g	Mod. EPA 8260[c]	14 days	4°C	Plastic	Grab
CVOCs	Groundwater	40-mL × 3	EPA 8260[d]	14 days	4°C, pH < 2 HCl	Glass	Grab
Secondary Measurements							
CVOCs	Groundwater	40-mL × 3	EPA 8021/8260[d]	14 days	4°C, pH < 2 HCl	Glass	Grab
CVOCs	Vapor	1 L	TO-14	14 days	NA	Tedlar™ Bag	Grab
pH	Soil	50 g	Mod. EPA 9045c	7 days	None	Plastic	Grab
pH	Groundwater	50 mL	EPA 150.1	1 hour	None	Plastic	Grab
TOC	Soil	20 g	SW 9060	28 days	None	Plastic	Grab
TOC	Groundwater	125 mL	EPA 415.1	28 days	4°C, pH < 2 H_2SO_4	Plastic	Grab
BOD	Groundwater	1,000 mL	EPA 405.1	48 hours	4°C	Plastic	Grab
Hydraulic conductivity	Aquifer	NA	ASTM D4044-96 (1997d)	NA	NA	NA	NA
Inorganics–cations[e]	Groundwater	100 mL	SW 6010	28 days	4°C, pH<2, HNO3	Plastic	Grab
Inorganics–anions[e]	Groundwater	50 mL	EPA 300.0	28 days	4°C	Plastic	Grab
TDS	Groundwater	500 mL	EPA 160.1	7 days	4°C	Plastic	Grab
Alkalinity	Groundwater	200 mL	EPA 310.1	14 days	4°C	Plastic	Grab
Water levels	Aquifer	NA	Water level from the top of well casing	NA	NA	NA	NA

(a) Samples will be analyzed as soon as possible after collection. The times listed are the maximum holding times which samples will be held before analysis and still be considered valid. All data obtained beyond the maximum holding times will be flagged.

(b) Samples will be preserved immediately upon sample collection, if required.

(c) Samples will be extracted using methanol on site. For the detailed extraction procedure see Appendix B.

(d) The off-site laboratory will use EPA 8260.

(e) Cations include Ca, Mg, Fe, Mn, Na, and K. Anions include Cl, SO_4, and NO_3/ NO_2.

HCl = Hydrochloric acid.

NA = Not applicable.

Appendix B

Hydrogeologic Measurements

B.1 Performance Monitoring Slug Tests

Slug tests were performed on well clusters BAT-3, BAT-5, and BAT-6 within the in-situ ISCO plot for pre-demonstration, post-demonstration, and the extended monitoring activities. Pre-demonstration tests were completed in August 1999, post-demonstration tests were completed in August 2000, and extended monitoring tests were completed in February 2001. Bat-5 was included because BAT-3S was unavailable during pre-demonstration activities due to the installation of the oxidation system equipment. The tests consisted of placing a pressure transducer and 1.5-inch-diameter by 5-ft-long solid PVC slug within the well. After the water level reached an equilibrium, the slug was removed rapidly. Removal of the slug created approximately 2 ft of change in water level within the well. Water level recovery was then monitored for 5-10 minutes using a TROLL pressure transducer/data logger. The data was then downloaded to a notebook computer.

The recovery rates of the water levels were analyzed with the Bouwer (1989) and Bouwer and Rice (1976) methods for slug tests in unconfined aquifers. Graphs were made showing the changes in water level versus time and curve fitted on a semi-logarithmic graph. The slope of the fitted line then was used in conjunction with the well parameters to provide a value of the permeability of the materials surrounding the well. The results show a good agreement between the replicate tests.

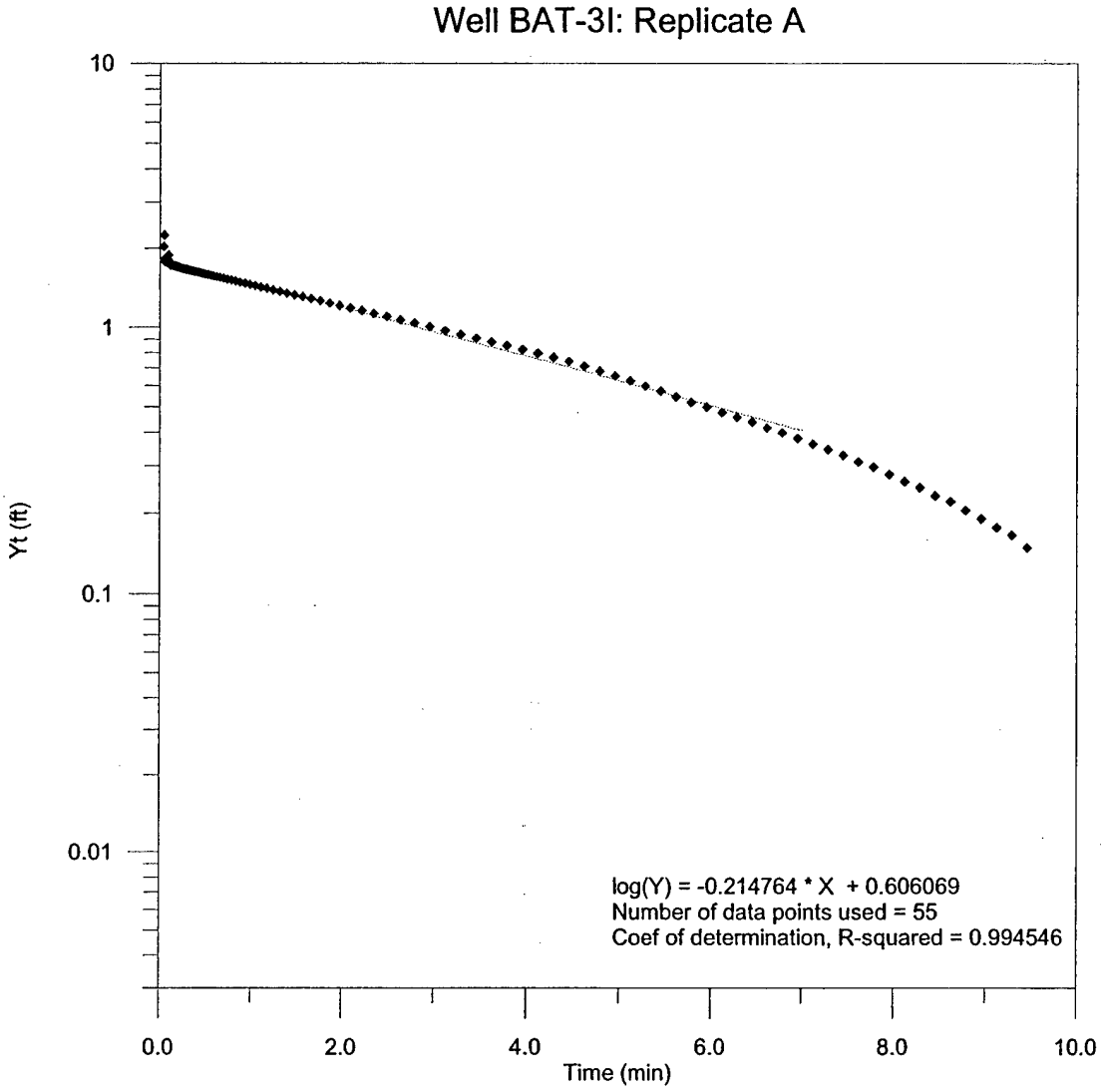
The tests are subject to minor variations. As such, a change of more than a magnitude of order would be required to indicate a change in the permeability of the sediments. Keeping this in mind, the tests showed a negligible change in permeability in most wells as shown on Table 1. The tests in wells BAT-3D and BAT6S may have increased substantially in permeability; although, the response to the slug was poor in these wells.

Table B-1. Slug Test Results in ISCO plot.

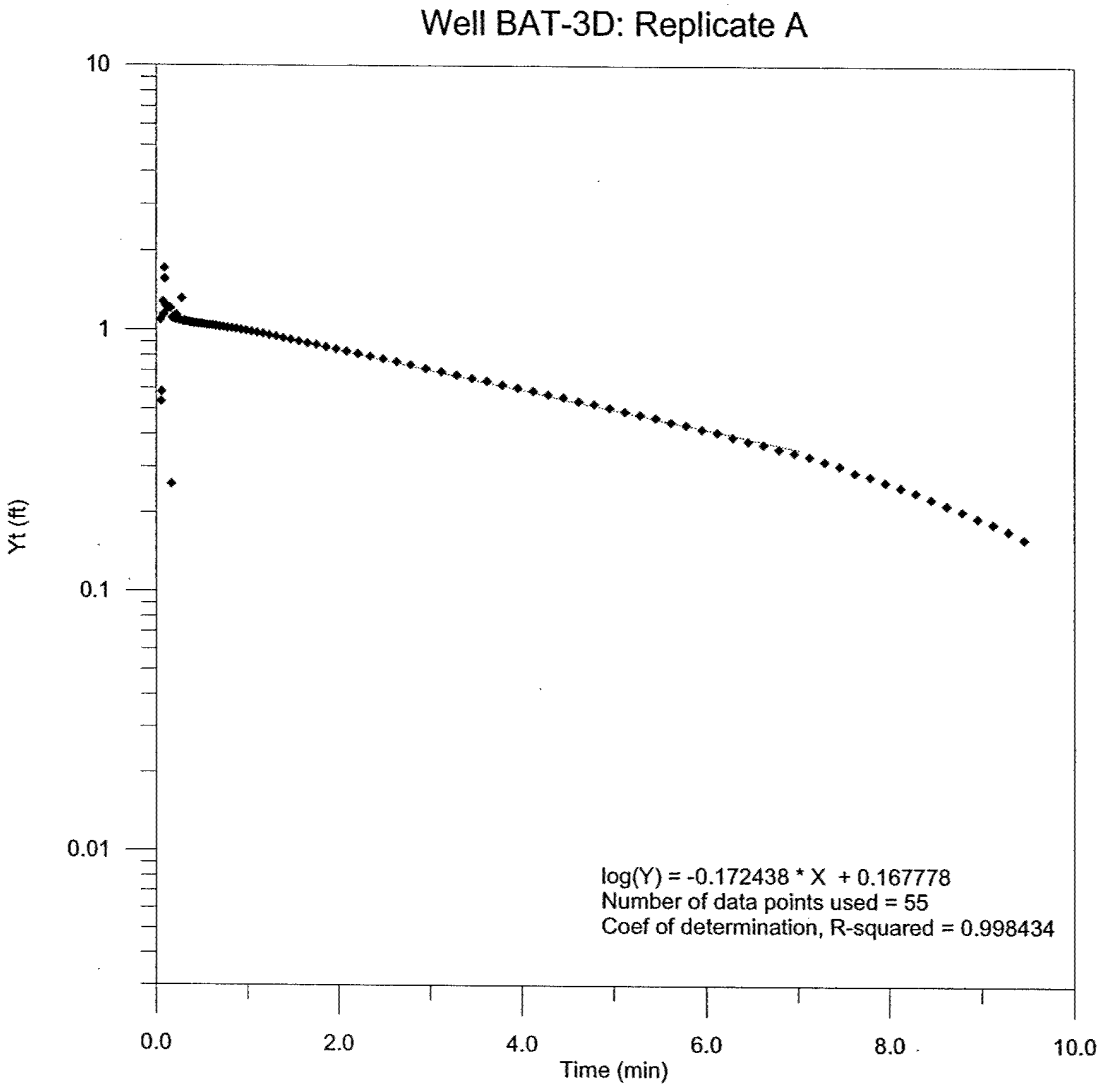
Well	Predemo	Postdemo	Ext. Mon.	Change	Response
BAT-3D	1.3	(26.4)	(65.8)	(increase?)	poor
BAT-3I	1.6	2.4	1.4	negligible	excellent
BAT-5I	6.4	1.5	6.2	negligible	fair
BAT-5S	4.0	5.0	1.5	negligible	good
BAT-6D	2.3	1.4	0.4	negligible	good
BAT-6I	1.4	3.7	1.2	negligible	fair
BAT-6S	5.1	(97.3)	(57.2)	(increase?)	poor

Bouwer, H., and R.C. Rice, 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, Water Resources Research, v.12, n.3, pp. 423-428.

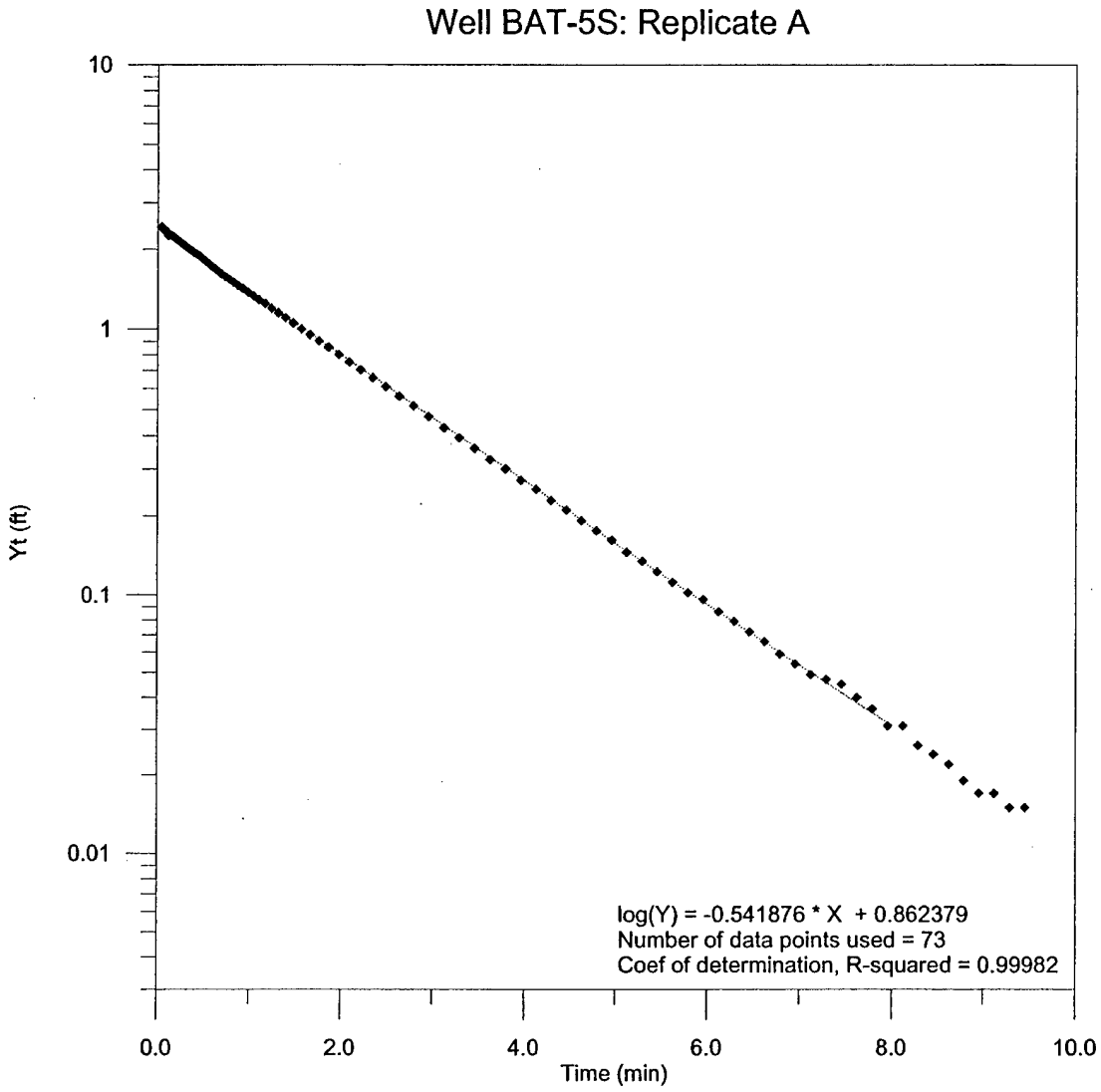
Bouwer, H., 1989, The Bouwer and Rice slug test- an update, Ground Water, v. 27, n.3., pp. 304-309.



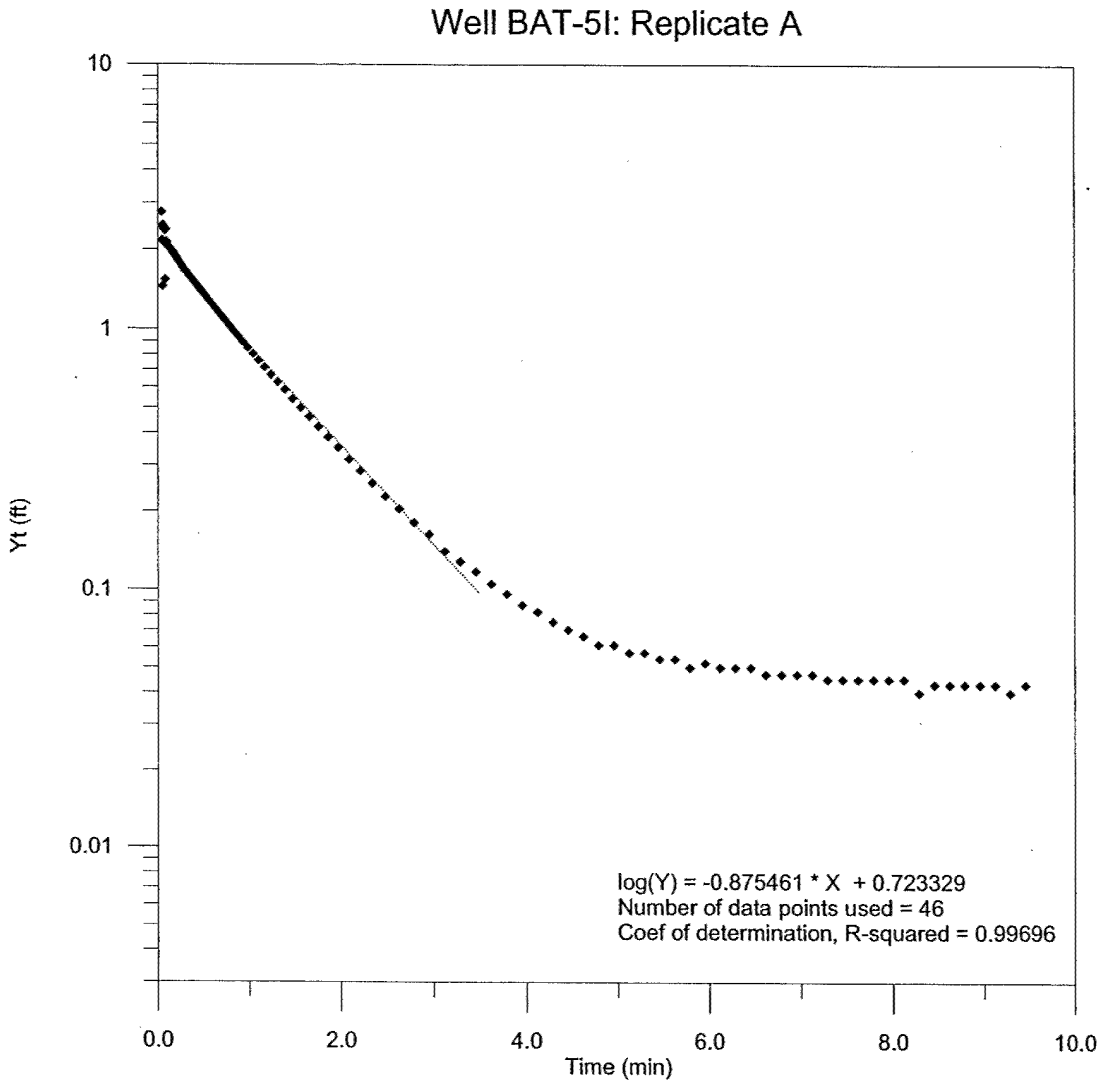
Pre-demonstration Slug Test Results: Well BAT-3I.



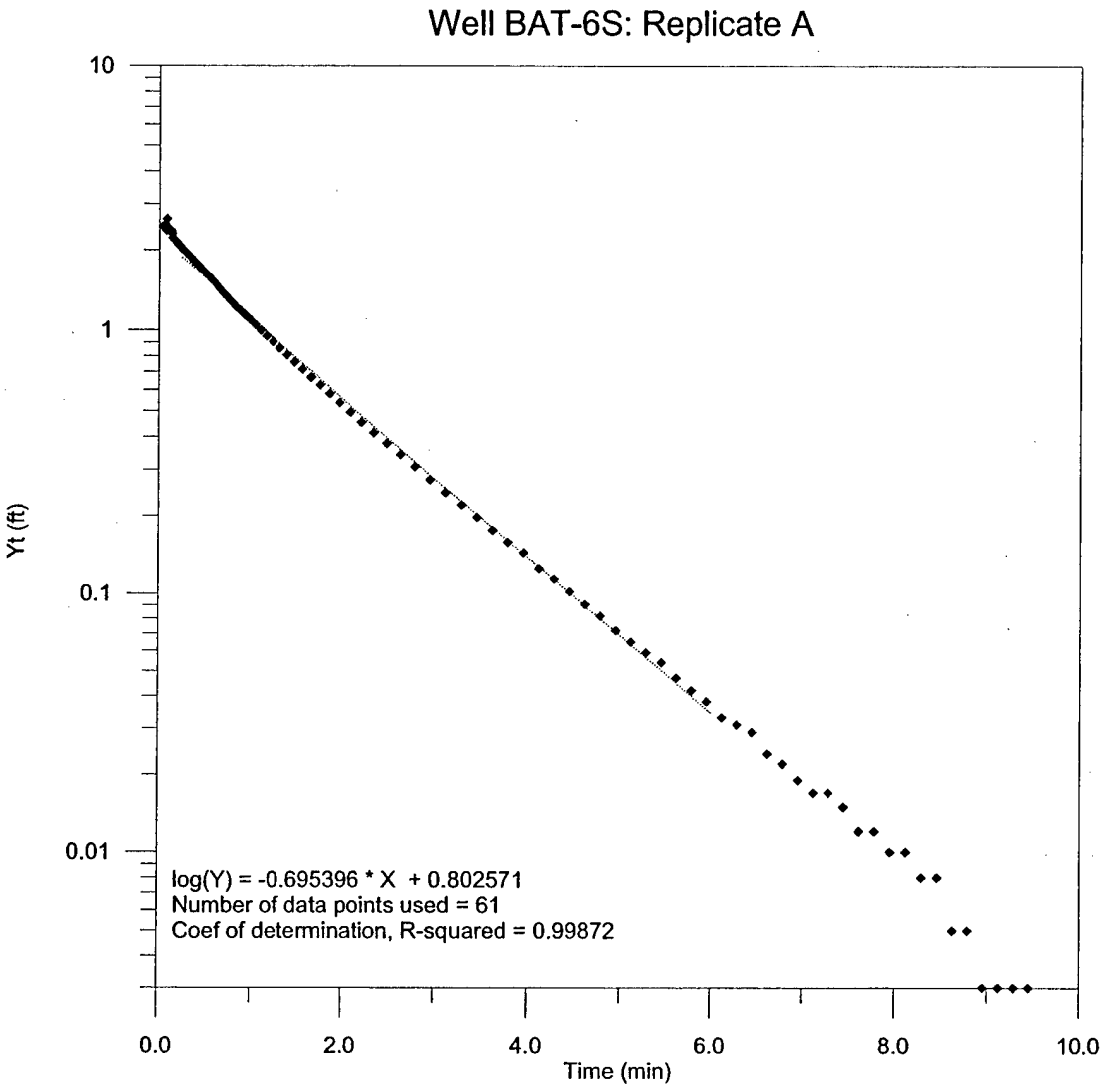
Pre-demonstration Slug Test Results: Well BAT-3D.



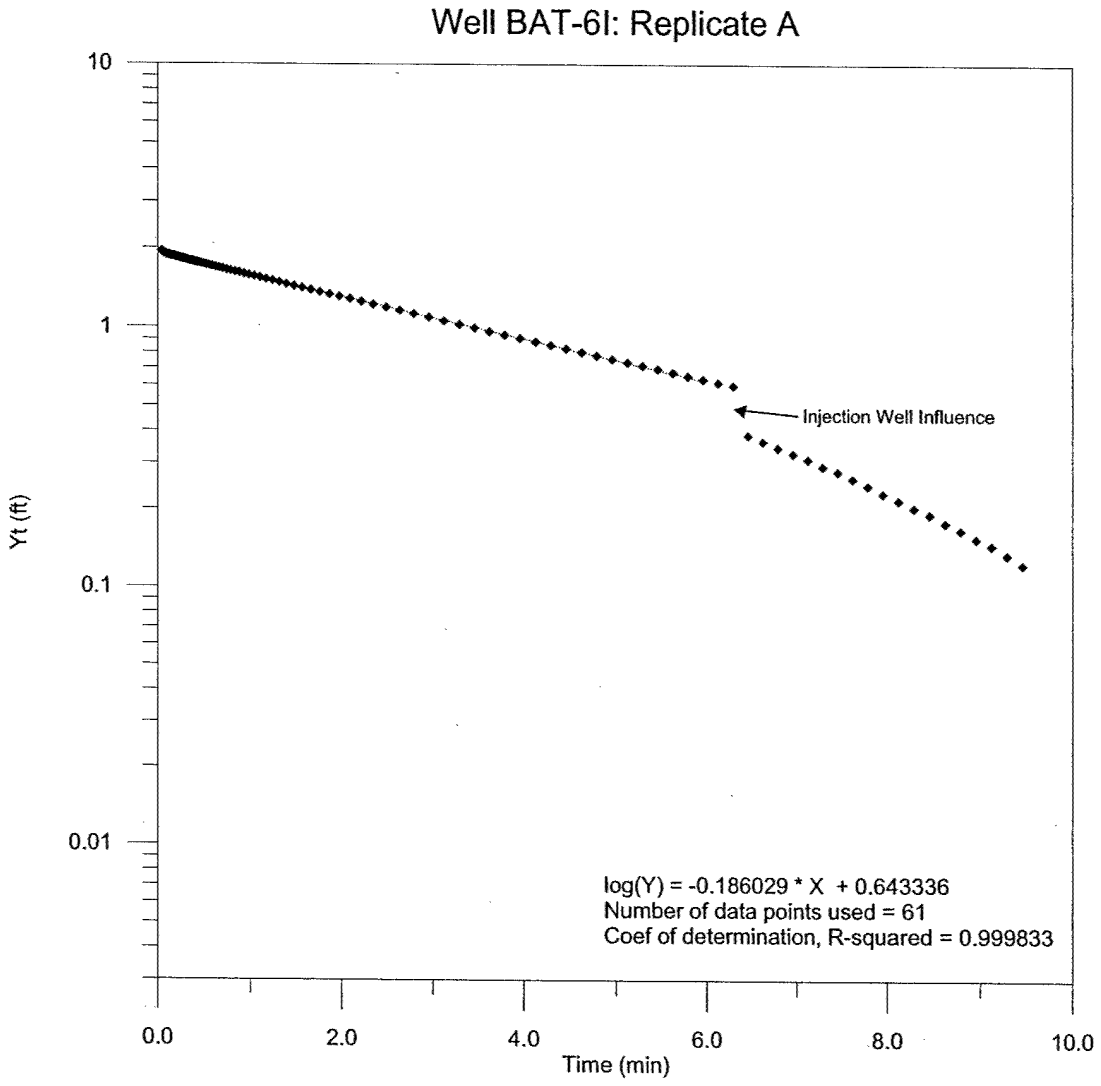
Pre-demonstration Slug Test Results: Well BAT-5S.



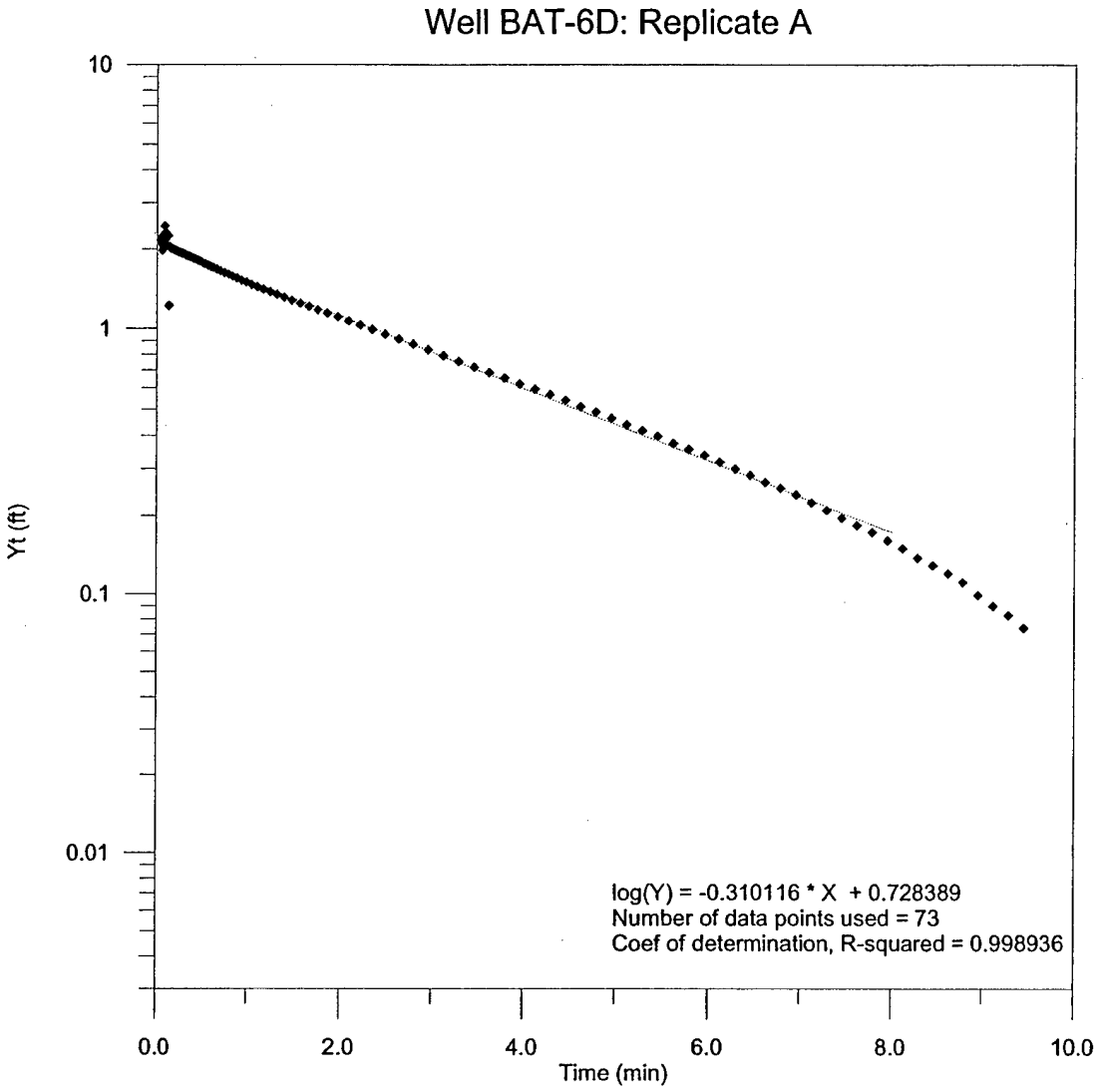
Pre-demonstration Slug Test Results: Well BAT-5I.



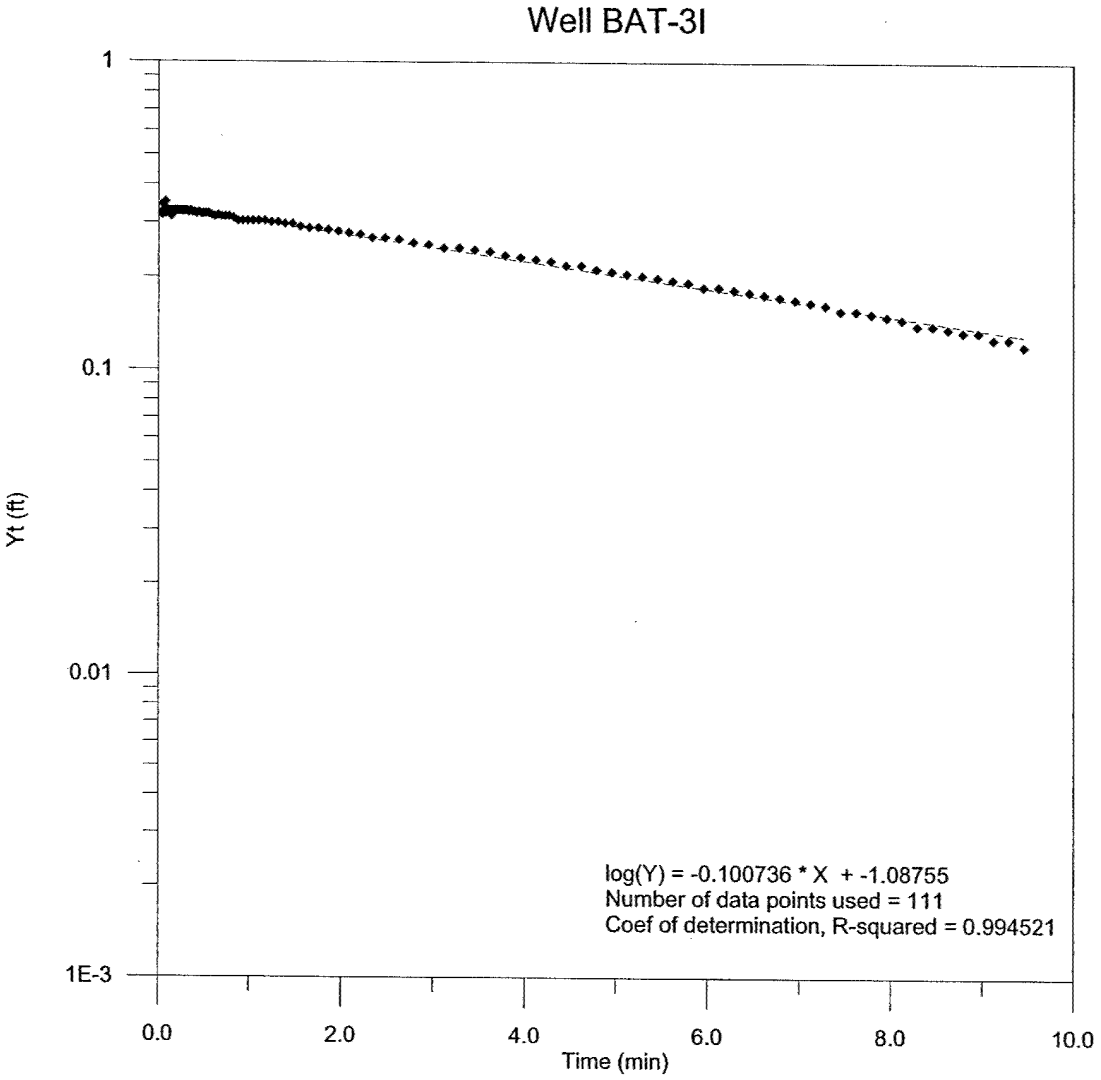
Pre-demonstration Slug Test Results: Well BAT-6S.



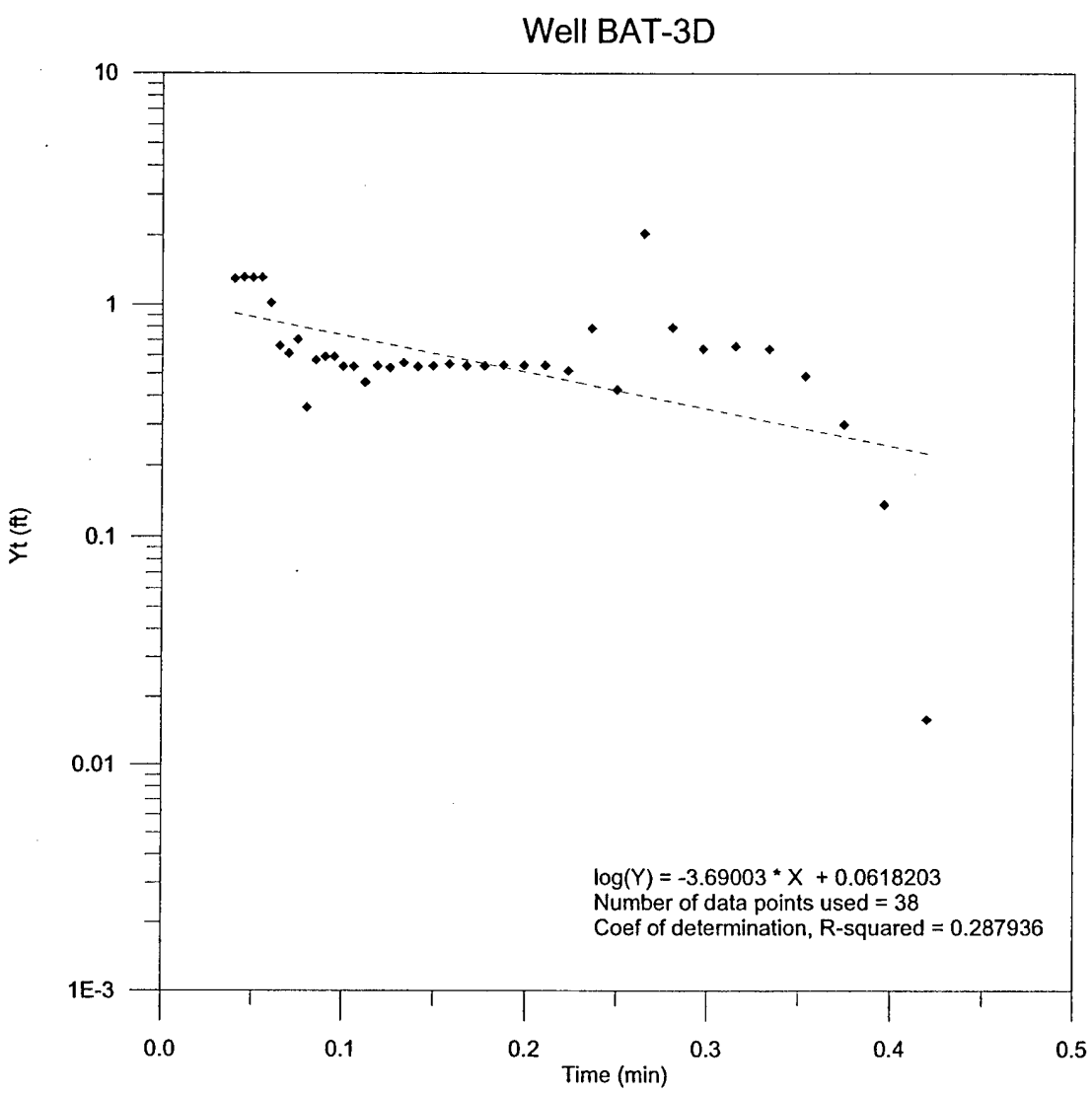
Pre-demonstration Slug Test Results: Well BAT-6I.



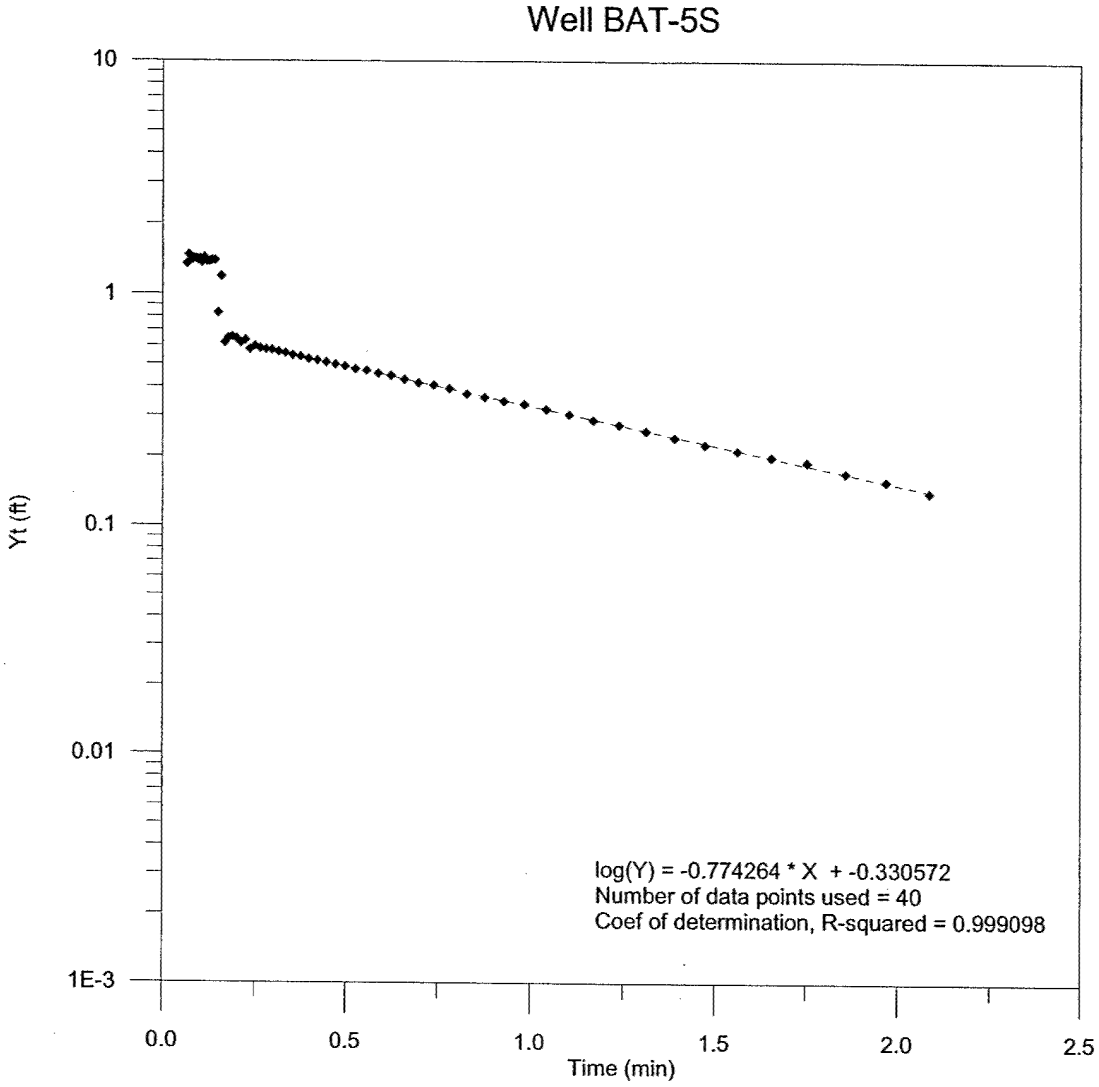
Pre-demonstration Slug Test Results: Well BAT-6D.



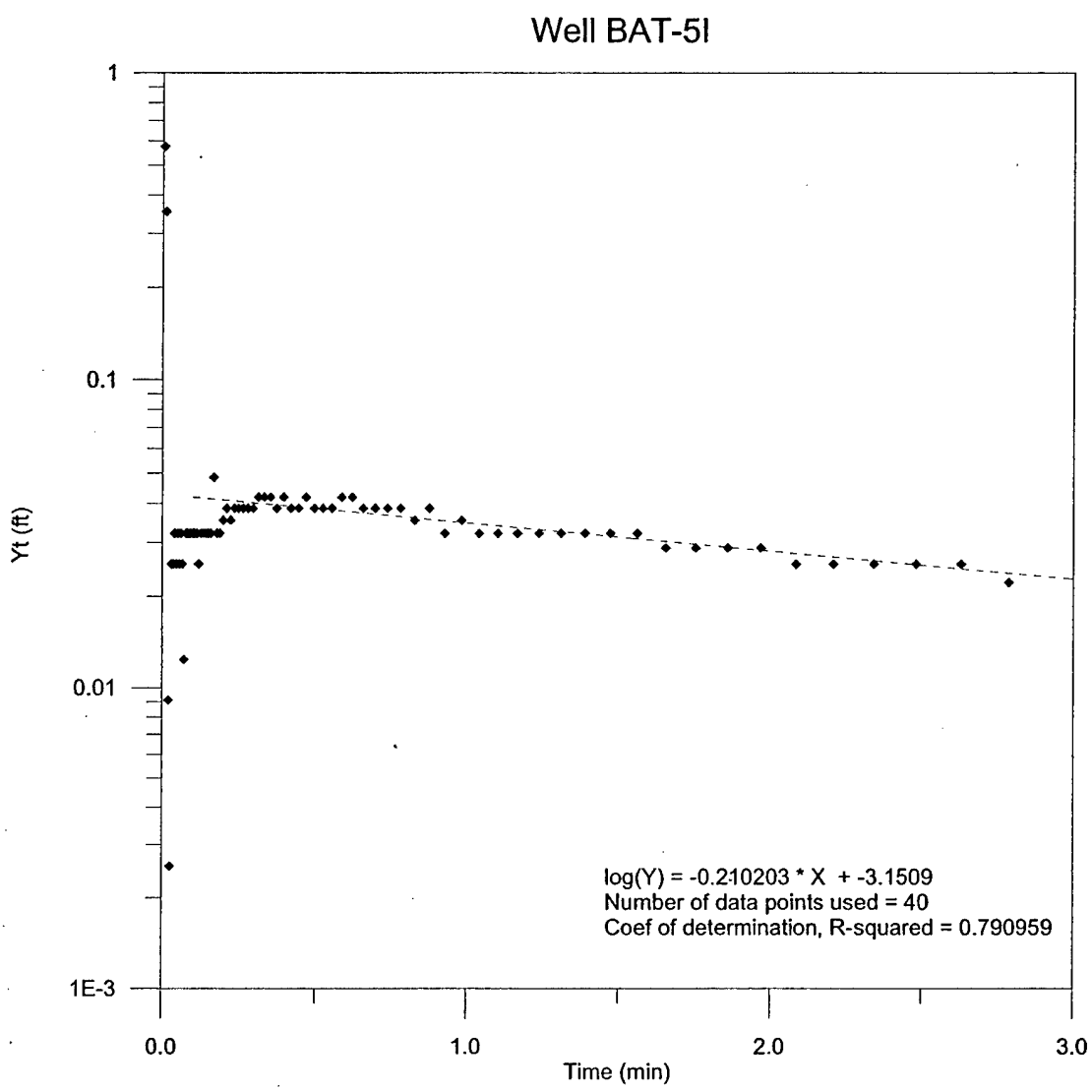
Post-demonstration Slug Test Results: Well BAT-3I.



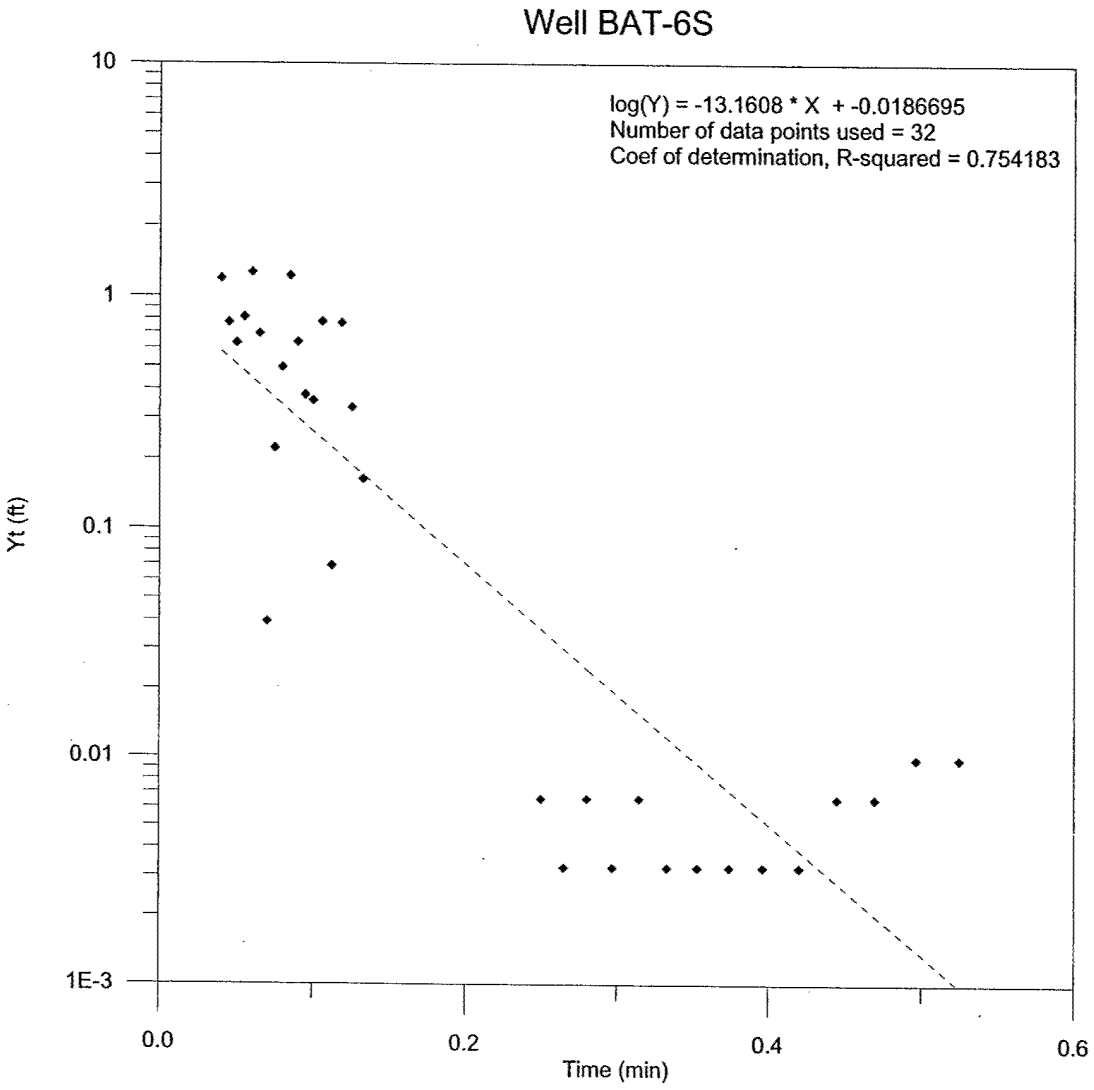
Post-demonstration Slug Test Results: Well BAT-3D.



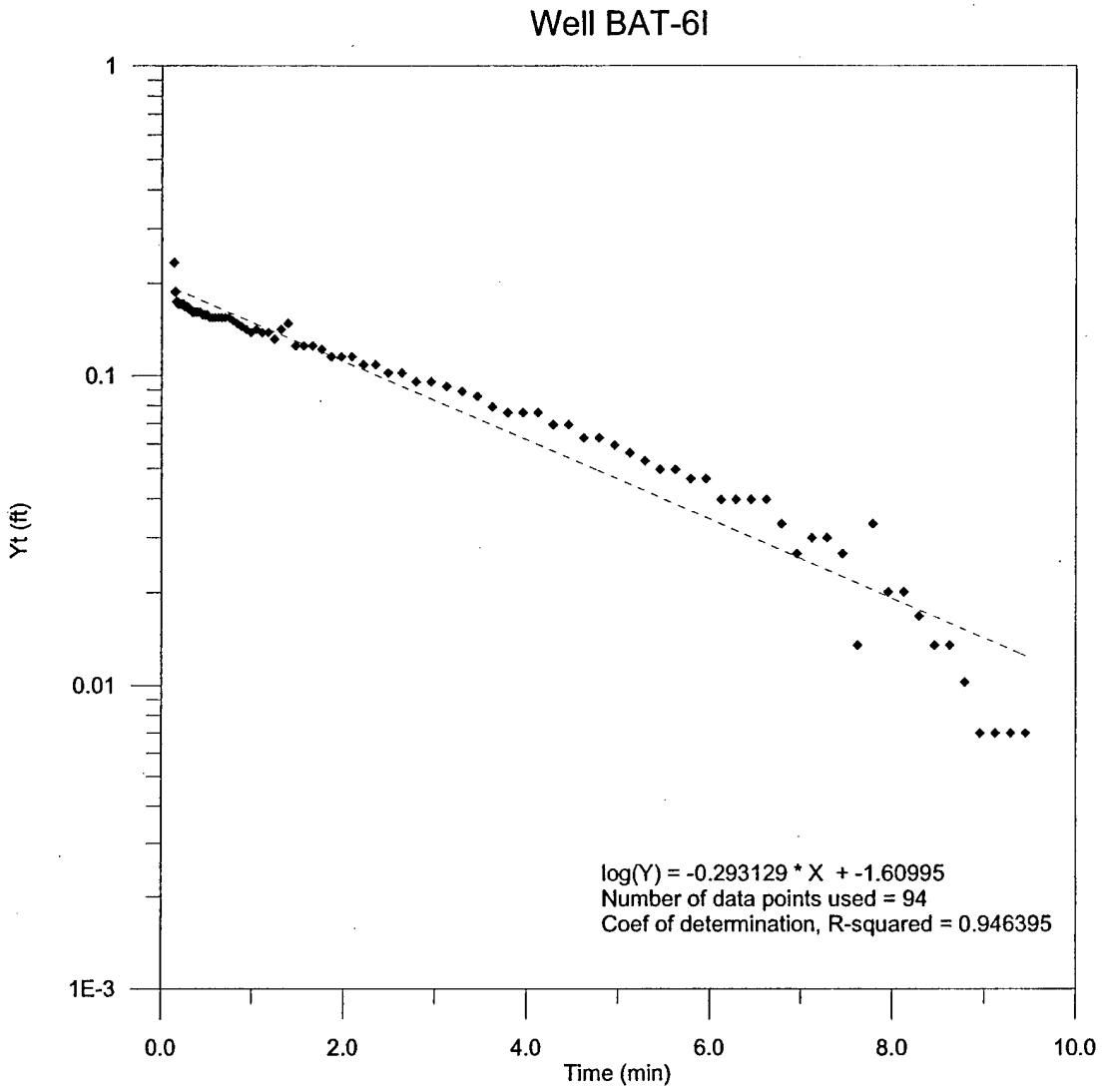
Post-demonstration Slug Test Results: Well BAT-5S.



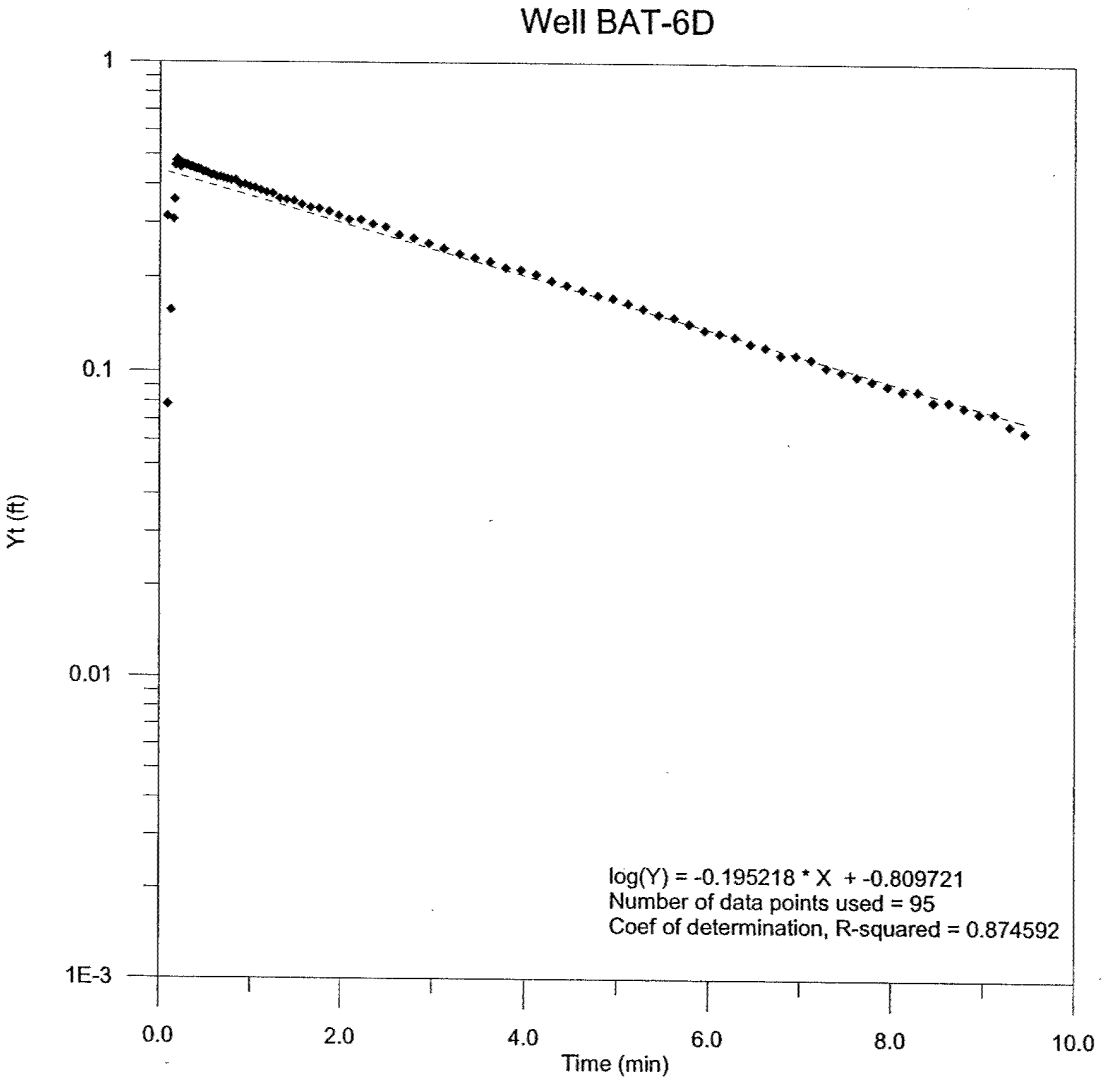
Post-demonstration Slug Test Results: Well BAT-5I.



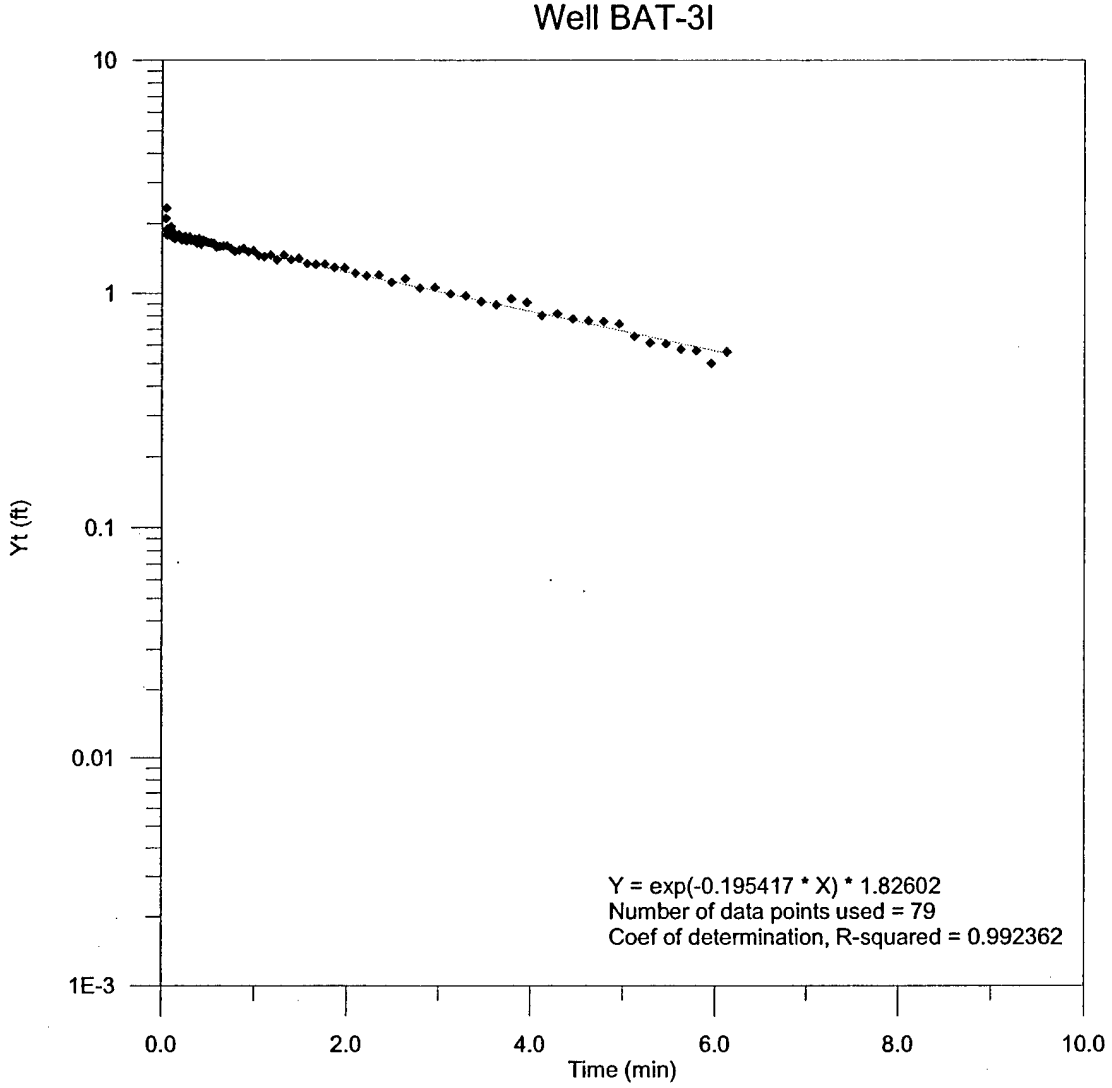
Post-demonstration Slug Test Results: Well BAT-6S.



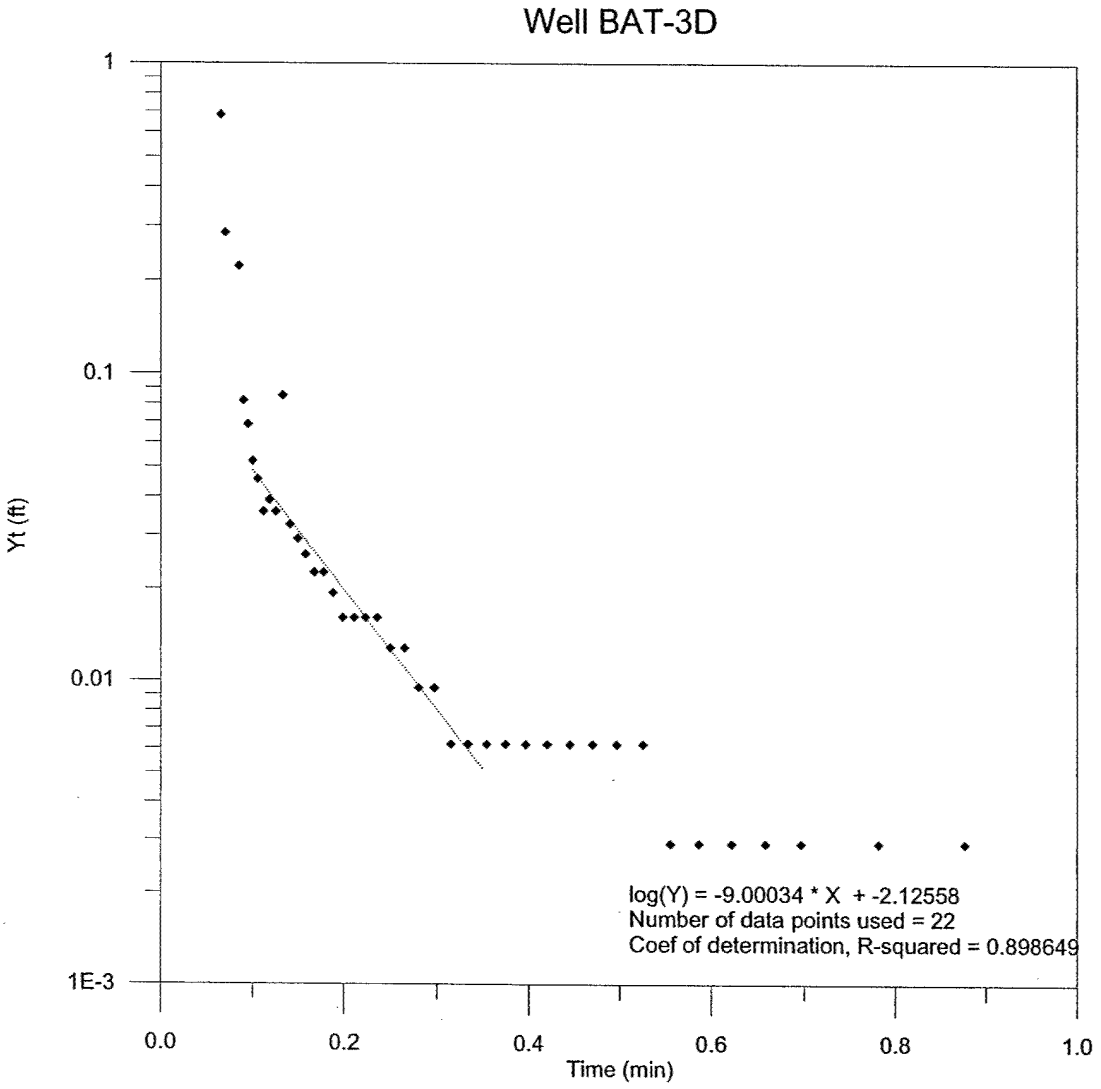
Post-demonstration Slug Test Results: Well BAT-6I.



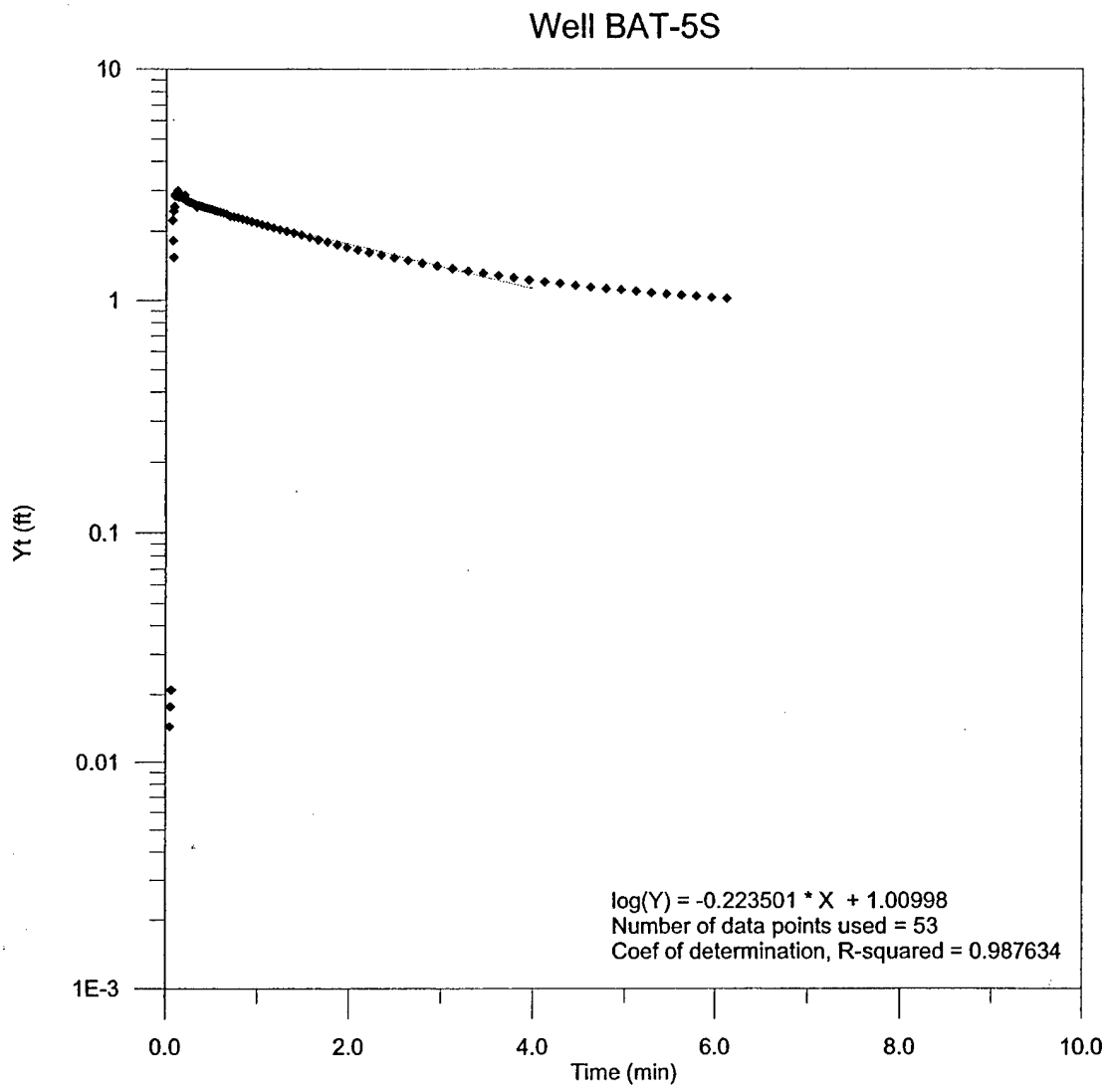
Post-demonstration Slug Test Results: Well BAT-6D.



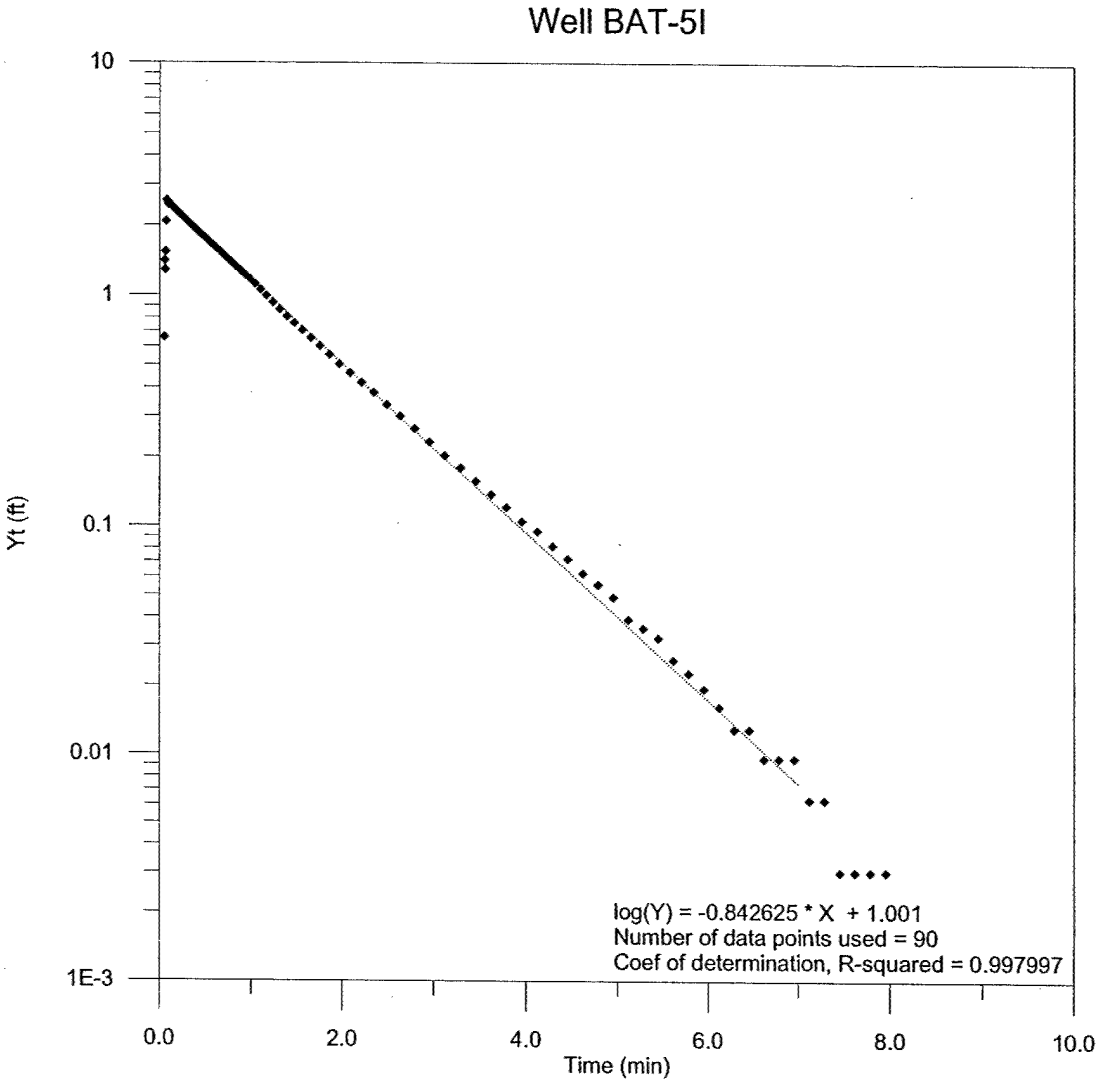
Extended Monitoring Slug Test Results: Well BAT-3I.



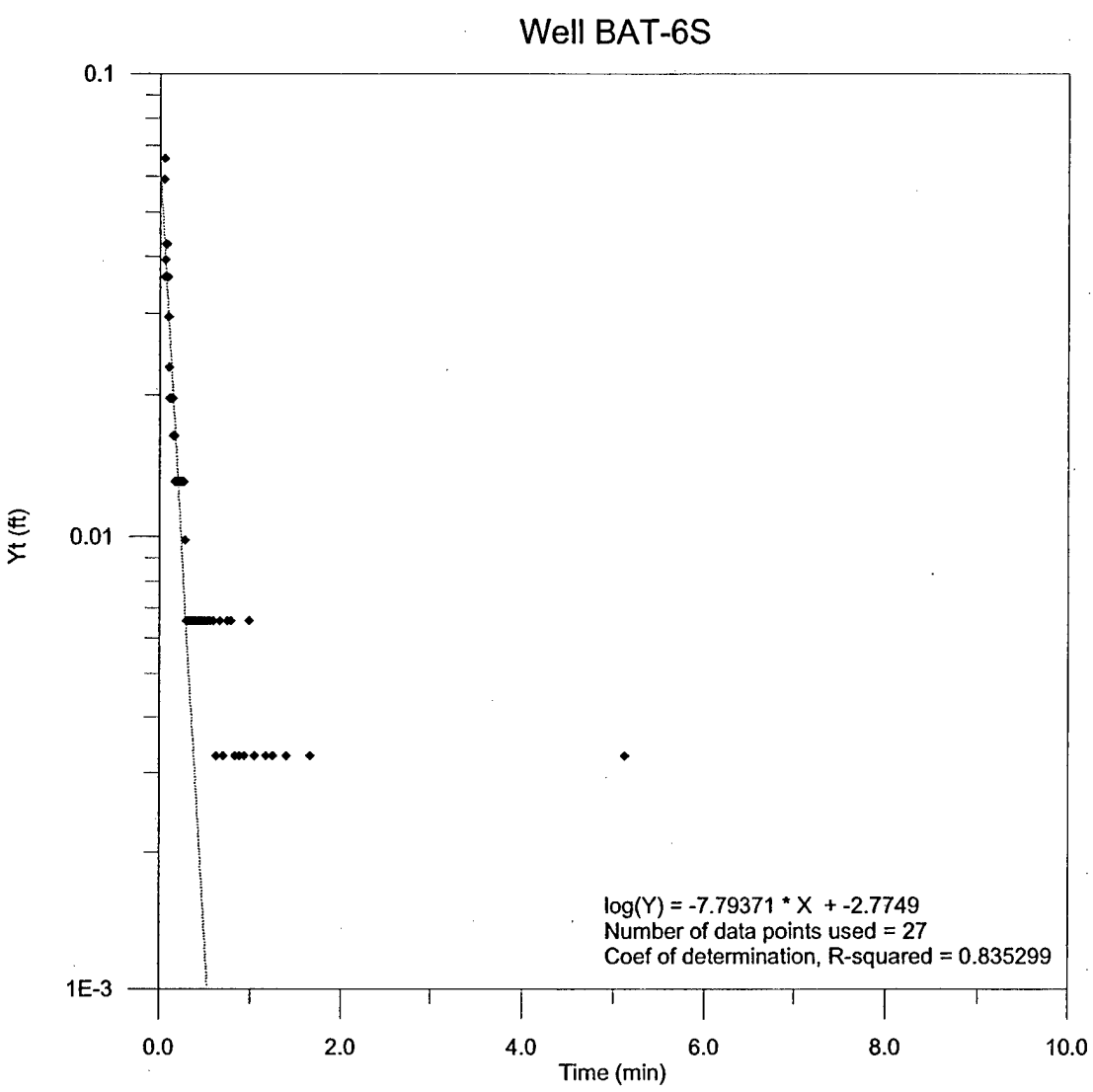
Extended Monitoring Slug Test Results: Well BAT-3D.



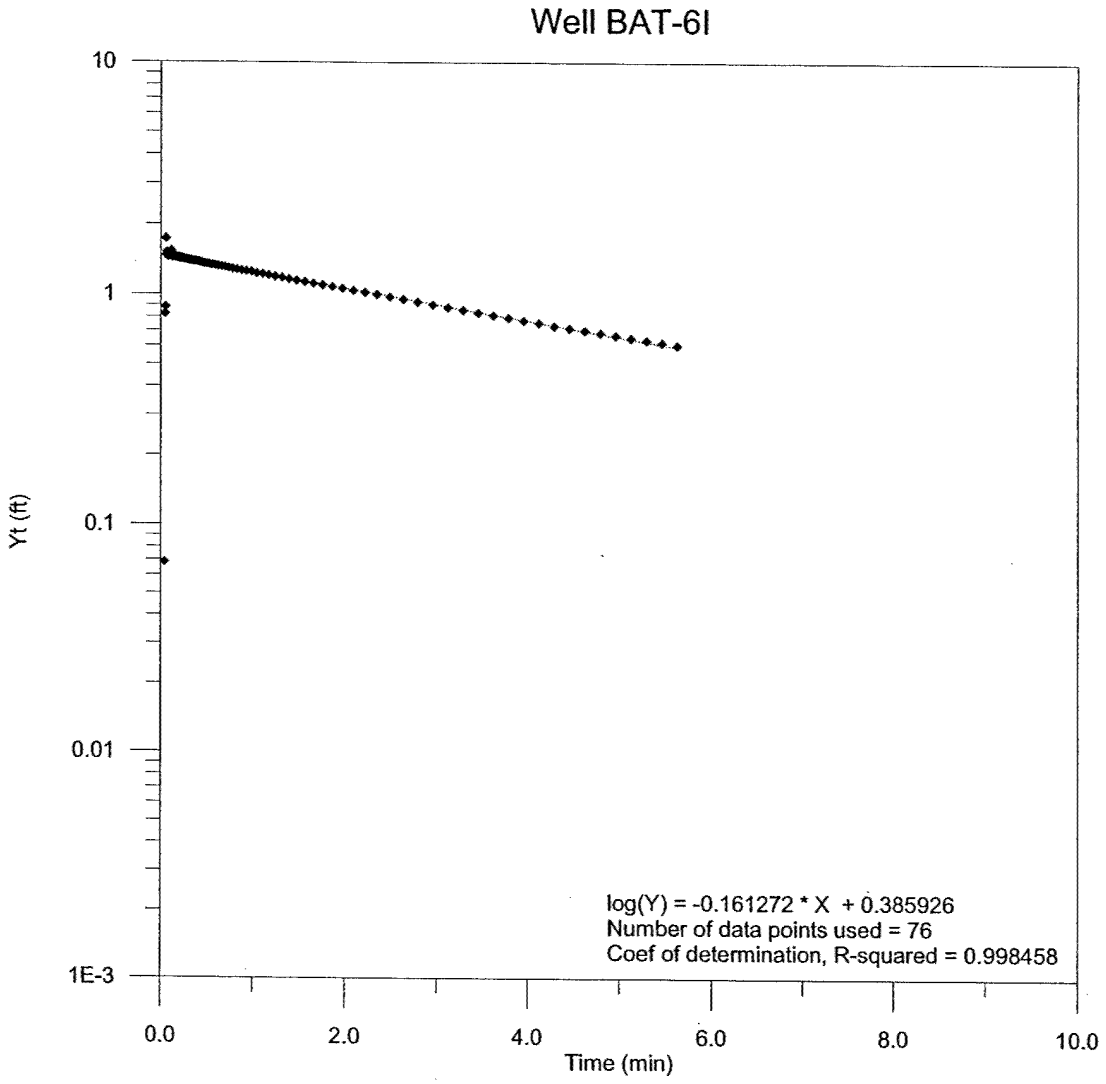
Extended Monitoring Slug Test Results: Well BAT-5S.



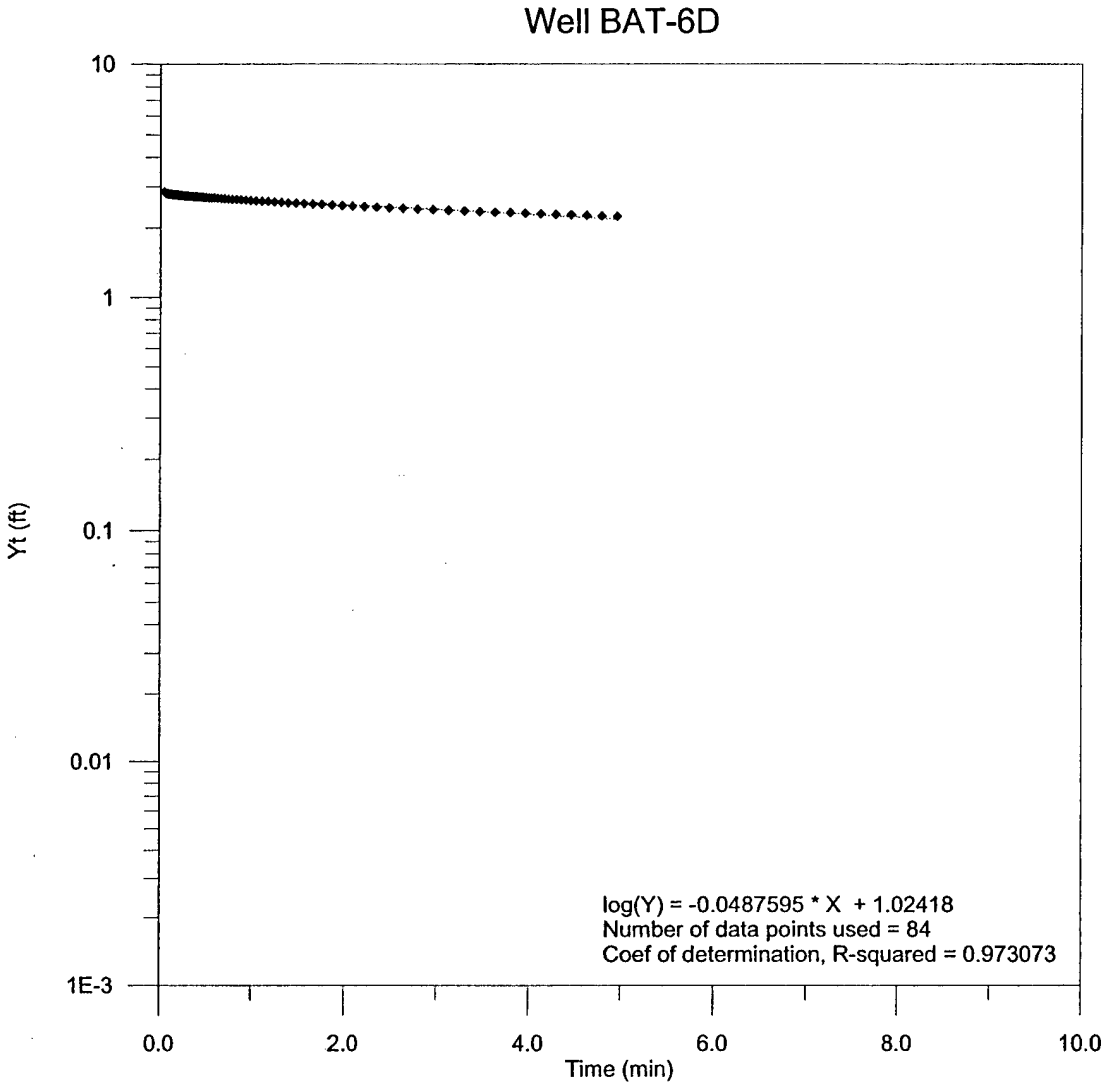
Extended Monitoring Slug Test Results: Well BAT-5I.



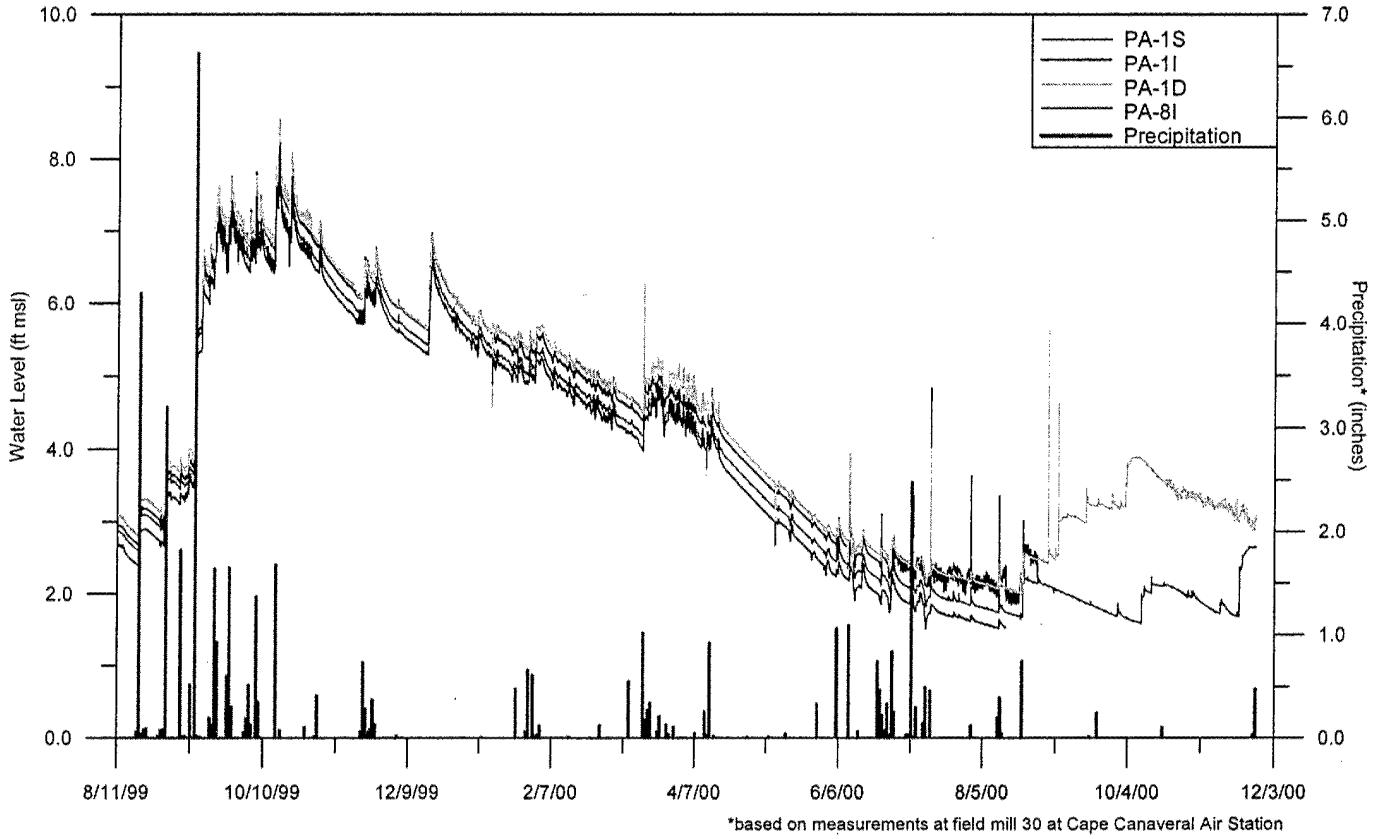
Extended Monitoring Slug Test Results: Well BAT-6S.



Extended Monitoring Slug Test Results: Well BAT-6I.



Extended Monitoring Slug Test Results: Well BAT-6D.


PA-1S
PA-1I
PA-1D
PA-8I
Precipitation
Water Level (ft msl)
Precipitation* (inches)
10.0
8.0
6.0
4.0
2.0
0.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
8/11/99
10/10/99
12/9/99
2/7/00
4/7/00
6/6/00
8/5/00
10/4/00
12/3/00
*based on measurements at field mill 30 at Cape Canaveral Air Station

Appendix C

CVOC Measurements

C.1 CVOC Measurements in Groundwater
C.2 TCE Analysis of Additional Soil Cores outside the ISCO Plot

Figure C-1. TCE Concentrations in Soil and Observed Soil Color Results at ISCO Plot (mg/kg) (Continued)

Top Depth	Bottom Depth	Pre-Demo SB14	Post-Demo SB214	Ext. Mon. SB314	Pre-Demo SB17	Post-Demo SB217	Post-Demo SB317	Pre-Demo SB20	Post-Demo SB220	Ext. Mon SB320	Pre-Demo SB23	Post-Demo SB223	Ext. Mon SB323	Ext. Mon. SB317B
0	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ND	[illegible]	[illegible]	ND	0.27
4	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ND	[illegible]	ND	ND	0.081 J
6	8	[illegible]	ND	0.17	ND	ND	0.8	[illegible]	ND	ND	[illegible]	[illegible]	ND	ND
8	10	[illegible]	ND	0.15	ND	ND	4.4	ND	0.5	2.22	ND	7.6	1.60	0.14 J
10	12	[illegible]	3.7	ND	ND	12.9	14.8	ND	ND	2.78	ND	39.9	2.54	0.46
12	14	[illegible]	ND	3.08	0.4	ND	1.0	ND	ND	3.50	[illegible]	44.8	1.11	6.13
14	16	0.4	ND	1.70	[illegible]	ND	ND	[illegible]	ND	0.23	ND	ND	3.14	87.34
16	18	[illegible]	ND	0.23	0.4	ND	ND	[illegible]	ND	20.56	[illegible]	6.2	2.92	93.78
18	20	28.5	ND	ND	14.1	ND	ND	[illegible]	ND	0.34	[illegible]	ND	0.31	73.74
20	22	114.3	ND	0.16 J	46.1	ND	ND	[illegible]	ND	1.78	[illegible]	88.0	1.10	13.82
22	24	236.0	ND	0.39	4412.4	0.6	ND	[illegible]	ND	ND	[illegible]	31.0	ND	1.74
24	26	225.8	ND	11.07	215.1	1.8	ND	[illegible]	ND	ND	[illegible]	[illegible]	ND	[illegible]
26	28	[illegible]	ND	0.07	[illegible]	17.6	[illegible]	[illegible]	ND	ND	[illegible]	[illegible]	0.29	[illegible]
28	30	[illegible]	NA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ND	0.39	[illegible]	[illegible]	0.22	[illegible]
30	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ND	0.55	[illegible]	[illegible]	7.63	[illegible]
32	34	[illegible]	288.3	[illegible]	[illegible]	1.1	[illegible]	[illegible]	ND	7.35	[illegible]	ND	3.20	[illegible]
34	36	[illegible]	1,201.7	6.74	[illegible]	0.5	29.4	[illegible]	ND	5.61	[illegible]	ND	657.33	63.77
36	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.7	[illegible]	ND	5.30	[illegible]	[illegible]	93.2	4.37
38	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ND	4.59	[illegible]	[illegible]	416.82	30.57
40	42	NA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ND	69.6	[illegible]	[illegible]	103.24	23.15
42	44	[illegible]	[illegible]	[illegible]	[illegible]	6.5	8.4	[illegible]	ND	7,533.6	[illegible]	[illegible]	[illegible]	756.88
44	46	[illegible]	[illegible]	NA	[illegible]	ND	857.6	[illegible]	[illegible]	NA	[illegible]	NA	[illegible]	NA

Figure C-1. TCE Concentrations in Soil and Observed Soil Color Results at ISCO Plot (mg/kg)

Top Depth	Bottom Depth	Pre-Demo SB13	Post-Demo SB213	Ext. Mon. SB313	Pre-Demo SB16	Post-Demo SB216	Ext. Mon SB316	Pre-Demo SB19	Post-Demo SB219	Ext. Mon SB319	Pre-Demo SB25	Post-Demo SB225	Ext. Mon SB325
0	2		ND										
2	4		ND							ND			
4	6			ND			0.08 J			ND			ND
6	8	0.4	ND			ND	0.23		2.4	ND			ND
8	10	0.5	ND	0.71		ND	1.11		57.3	0.23			1.23
10	12	0.6	ND	5.44	0.5	ND	0.29		42.7	0.88		24.4	1.64
12	14	0.4	ND	18.55	0.2	ND	0.25		23.4	1.22		1.5	2.18
14	16	3.8	ND	44.46	ND	ND	ND		26.0	5.69		ND	2.41
16	18	3.6	ND	0.47	2.6	ND	0.16 J		19.3	20.33		ND	0.55
18	20	21.9	ND	0.21	14.5	ND	ND		14.7	0.14 J		1.2	0.27
20	22	105.9	ND	ND	19.1	ND	1.16		1.4	0.20		ND	0.18 J
22	24	234.6	ND	0.15 J	176.6	ND	0.77			ND			0.36
24	26	304.2	ND	ND	272.4	1.8	0.18 J						
26	28	316.4	ND	ND			0.87						
28	30	NA	ND	0.22			10.97						
30	32	86.8	7.1	0.16			10.86			2.95			2.21
32	34	23.4	2.8	0.19 J			3.25		NA	8.27		ND	0.78
34	36	7.3	ND	ND		ND	0.98			2.65		ND	6.69
36	38	13.2	ND	0.31		ND	0.36		30.4	5.03		4.0	
38	40	19.9	2.2	0.43			ND		35.8	2.24		16.3	
40	42	6.8	5.7	0.71			37.21		37.1	40.69		4.0	0.37
42	44	41.0	ND	0.90			108.59		84.3	100.59		0.9	21.54
44	46	180.6	ND	NA		ND	NA			NA			NA

Figure C-1. TCE Concentrations in Soil and Observed Soil Color Results at ISCO Plot (mg/kg) (Continued)

Top Depth	Bottom Depth	Pre-Demo SB15	Post-Demo SB215	Ext. Mon. SB315	Pre-Demo SB18	Post-Demo SB218	Ext. Mon. SB318	Pre-Demo SB21	Post-Demo SB221	Ext. Mon SB321	Pre-Demo SB24	Post-Demo SB224	Ext. Mon SB324
0	2												
2	4									ND		ND	ND
4	6					ND	ND			ND		ND	ND
6	8					ND	ND		2.2	ND		ND	ND
8	10		1.0			ND	0.12 J		ND	1.29		ND	0.86
10	12		0.5	ND		ND	0.16		ND	0.86		ND	5.93
12	14		ND	ND		ND	8.87		ND	0.36		ND	8.30
14	16		ND	ND		ND	28.40		ND	1.24		ND	17.56
16	18		39.3	981.89		ND	5.23		ND	ND		ND	2.69
18	20		83.6	313.81		ND	3.32		ND	ND		ND	ND
20	22		6.2			ND	0.13 J		ND	ND		ND	ND
22	24					NA	ND		NA	ND		NA	ND
24	26					3.6	0.46		3.7	ND		ND	0.11 J
26	28					ND	ND		44.7	ND		198.4	51.08
28	30					ND	0.19 J		69.4	1.41		4,200.9	59.22
30	32					NA	ND		201.2	0.85		220.2	106.19
32	34					ND	0.30		3.5	0.03		297.3	61.06
34	36					NA	9.48		1,093.5	0.14		105.8	8.94
36	38					ND	2.38		409.5	0.91		278.2	14.80
38	40					ND	3.09		1,256.5	0.24		124.7	30.49
40	42					ND	5.25		65.3	0.25		583.1	52.74
42	44			NA		ND	8.92		4.3	0.36		NA	
44	46			NA		ND	NA	NA	NA	NA	NA	NA	

NA: Not available.
ND: Not detected.
Solid horizontal lines demarcate MFGU.

Table C-1. TCE Results of Groundwater Samples

Sampling Event[1]	TCE (µg/L)														
	Pre-Demo	Week 3-4		Week 5		Week 7-8		Jan 10-14, 2000		Apr 10-14, 2000[2]		ISCO Post-Demo		Extended Monitoring	
Well ID	Results	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.
ISCO Plot Wells															
BAT-1S	1,140,000	940,000	-18%	NA	NA	1,010,000	-11%	260,000	-77%	NA	NA	<5	>-99%	NA	NA
BAT-1I	1,060,000	NA	NA	NA	NA	360,000	-66%	830,000	-22%	NA	NA	360,000	-66%	NA	NA
BAT-1D	1,130,000	NA	NA	NA	NA	610,000	-46%	675,000	-40%	NA	NA	130,000	-88%	NA	NA
BAT-2S	1,110,000	14,100	-99%	NA	NA	457	>-99%	84,600	-92%	<5	>-99%	<5	>-99%	19 J	>-99%
BAT-2S-DUP	1,160,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BAT-2I	970,000	NA	NA	NA	NA	68,800	-93%	50,000	-95%	<5	>-99%	880	>-99%	937 D	>-99%
BAT-2I-DUP	NA	NA	NA	NA	NA	60,700	-94%	48,200	-95%	NA	NA	NA	NA	NA	NA
BAT-2D	1,160,000	NA	NA	NA	NA	835,000	-28%	675,000	-42%	NS[3]	NA	220,000	-81%	388,000 D	-67%
BAT-3S	1,100,000	229,000	-79%	NA	NA	262,000	-76%	79,400	-93%	NA	NA	630,000	-43%	NA	NA
BAT-3S-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	600,000	-45%	NA	NA
BAT-3I	990,000	NA	NA	NA	NA	1,060,000	7%	293,000	-70%	NA	NA	46,000D	-95%	NA	NA
BAT-3D	962,000	NA	NA	NA	NA	94,200	-90%	223,000	-77%	NA	NA	<5	>-99%	NA	NA
BAT-5S	298,000	47,800	-84%	NA	NA	1,240,000	316%	47,800	-94%	620,000	108%	410,000	38%	13,300 D	-96%
BAT-5I	868,000	NA	NA	NA	NA	985,000	13%	555	>-99%	<5	>-99%	<10	>-99%	356,000 D	-59%
BAT-5I-DUP	898,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BAT-5D	1,140,000	NA	NA	NA	NA	730,000	-36%	915,000	-20%	870,000	-24%	52,000	-95%	436,000 D	-62%
BAT-5D-DUP	NA	NA	NA	NA	NA	725,000	-36%	NA	NA	910,000	-20%	49,000	-96%	NA	NA
BAT-6S	1,090,000	122	>-99%	NA	NA	1,990	>-99%	432,000	-60%	NA	NA	23,000	-98%	NA	NA
BAT-6I	998,000	NA	NA	NA	NA	42,500	-96%	44,600	-96%	NA	NA	340	>-99%	NA	NA
BAT-6D	752,000	NA	NA	NA	NA	164,000	-78%	61,800	-92%	NA	NA	<5	>-99%	NA	NA
PA-4S	690,000	<2	>-99%	NA	NA	<2	>-99%	7,070	>-99%	NA	NA	<5	>-99%	NA	NA
PA-4S-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<5	>-99%	NA	NA
PA-4I	1,190,000	NA	NA	NA	NA	274	>-99%	42,500	-96%	NA	NA	<5	>-99%	NA	NA
PA-4D	1,160,000	NA	NA	NA	NA	1,050,000	-9%	1,120,000	-3%	NA	NA	<5	>-99%	NA	NA
MP-1A	778,000	6,490	-99%	NA	NA	630,000	-19%	5,420	>-99%	NA	NA	<5	>-99%	NA	NA
MP-1B	878,000	NA	NA	NA	NA	965,000	10%	775,000	-12%	NA	NA	NA	NA	NA	NA
MP-1C	812,000	NA	NA	NA	NA	590,000	-27%	540,000	-33%	NA	NA	120,000	-85%	NA	NA
MP-1D	608,000	NA	NA	NA	NA	603,000	-1%	484,000	-20%	NA	NA	120,000	-80%	NA	NA
MP-1E	628,000	NA	NA	NA	NA	965,000	54%	372,000	-41%	NA	NA	520,000D	-17%	NA	NA
ML-2	NA	92,500	NA	NA	NA	<2	>-99%	58.2	>-99%	NA	NA	<5	>-99%	NA	NA
ML-3	61,800	203,000	228%	NA	NA	Dry	NA	Dry	NA	NA	NA	Dry	NA	NA	NA
ML-4	982,000	1,010,000	3%	NA	NA	545,000	-45%	9,850	-99%	NA	NA	28,000	-97%	NA	NA
ML-5	750,000	NA	NA	NA	NA	595,000	-21%	240,000	-68%	NA	NA	270,000	-64%	NA	NA
ML-6	595,000	NA	NA	NA	NA	610,000	3%	273,000	-54%	NA	NA	340,000	-43%	NA	NA
ML-7	435,000	NA	NA	NA	NA	775,000	78%	350,000	-20%	NA	NA	160,000	-63%	NA	NA
MP-2A	428,000	5,050	>-99%	NA	NA	<2	>-99%	180	>-99%	NA	NA	<5	>-99%	NA	NA
MP-2A-2	NA	<2	>-99%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MP-2B	760,000	NA	NA	NA	NA	290	>-99%	Dry	NA	NA	NA	<5	NA	NA	NA
MP-2B-DUP	NA	NA	NA	NA	NA	265	>-99%	NA	NA	NA	NA	NA	NA	NA	NA

Table C-1. TCE Results of Groundwater Samples (Continued)

Sampling Event[1)]	TCE (µg/L)														
	Pre-Demo	Week 3-4		Week 5		Week 7-8		Jan 10-14, 2000		Apr 10-14, 2000[2)]		ISCO Post-Demo		Extended Monitoring	
Well ID	Results	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.
MP-2C	695,000	NA	NA	NA	NA	1.2J	>-99%	16.5	>-99%	NA	NA	<5	>-99%	NA	NA
MP-2D	635,000	NA	NA	NA	NA	1,300	>-99%	190,000	-70%	NA	NA	<5	>-99%	NA	NA
MP-2E	622,000	NA	NA	NA	NA	2,640	>-99%	29,700	-95%	NA	NA	2,300D	>-99%	NA	NA
MP-3A	515,000	36.3	>-99%	NA	NA	<2	>-99%	191,000	-63%	NA	NA	<5	>-99%	NA	NA
MP-3B	800,000	NA	NA	NA	NA	60,000	-93%	49,700	-94%	NA	NA	<5	>-99%	NA	NA
MP-3C	768,000	NA	NA	NA	NA	8.55	>-99%	247,000	-68%	NA	NA	<5	>-99%	NA	NA
MP-3D	528,000	NA	NA	NA	NA	127,000	-76%	432,000	-18%	NA	NA	<5	>-99%	NA	NA
MP-3E	558,000	NA	NA	NA	NA	420,000	-25%	341,000	-39%	NA	NA	<5	>-99%	NA	NA
MP-4A	745,000	<2	>99%	NA	NA	<2	>-99%	176	>-99%	NA	NA	<5	>-99%	NA	NA
MP-4C	810,000	NA	NA	NA	NA	2,980	>-99%	92,200	-89%	NA	NA	<5	>-99%	NA	NA
MP-4E	830,000	NA	NA	NA	NA	338,000	-59%	710,000	-14%	NA	NA	91,000	-89%	NA	NA
MP-4E-2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	26,000	-97%	NA	NA
ISCO Perimeter Plot Wells															
PA-3S	652,000	950,000	46%	NA	NA	580,000	-11%	85,800	-87%	<5	>-99%	<5	>-99%	NA	NA
PA-3S-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<5	>-99%	NA	NA
PA-3I	1,100,000	1,150,000	5%	NA	NA	600,000	-45%	39,300	-96%	5,500	>-99%	330J	>-99%	NA	NA
PA-3I-DUP	NA	1,160,000	5%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-3D	1,080,000	1,130,000	5%	NA	NA	585,000	-46%	650,000	-40%	<5	>-99%	<10	>-99%	NA	NA
PA-3D-DUP	NA	NA	NA	NA	NA	NA	NA	680,000	-37%	NA	NA	NA	NA	NA	NA
PA-5S	197	84,500	42,793%	NA	NA	9,600	4,773%	750,000	380,611%	170,000	86,194%	94,000	47,616%	NA	NA
PA-5I	17,200	71,000	313%	NA	NA	114,000	563%	670,000	3,795%	970,000	5,540%	920,000D	5,249%	NA	NA
PA-5D	183,000	170,000	-7%	NA	NA	258,000	41%	570,000	211%	91,000	-50%	66,000	-64%	NA	NA
PA-6S	290	993	242%	NA	NA	10,800	3,624%	68,400	23,486%	33,000	11,279%	24,000	8,176%	NA	NA
PA-6I	1,010,000	1,050,000	4%	NA	NA	1,280,000	27%	955,000	-5%	880,000	-13%	930,000D	-8%	NA	NA
PA-6D	988,000	406,000	-59%	NA	NA	665,000	-33%	860,000	-13%	800,000	-19%	610,000	-38%	NA	NA
PA-9S	790,000	1,100,000	39%	NA	NA	1,200,000	52%	1,060,000	34%	220,000	-72%	640,000	-19%	NA	NA
PA-9S-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	230,000	-71%	NA	NA	NA	NA
PA-9I	968,000	1,040,000	7%	NA	NA	900,000	-7%	790,000	-18%	530,000	-45%	530,000	-45%	NA	NA
PA-9D	288,000	295,000	2%	NA	NA	400,000	39%	580,000	101%	770,000	167%	790,000D	174%	NA	NA
PA-12S	482,000	870,000	80%	NA	NA	1,240,000	157%	1,100,000	128%	990,000	105%	760,000	58%	NA	NA
PA-12I	1,040,000	1,210,000	16%	NA	NA	1,320,000	27%	1,160,000	12%	1,300,000D	25%	1,100,000	6%	NA	NA
PA-12D	565,000	685,000	21%	NA	NA	945,000	67%	965,000	71%	840,000	49%	930,000	65%	NA	NA
Resistive Heating Plot Wells															
PA-13S	1,030,000	1,220,000	18%	476,000	-54%	NA	NA	NA	NA	180,000 *	-83%	NA	NA	714,000 D	-31%
PA-13S-DUP	1,100,000	1,240,000	13%	NA	NA	NA	NA	NA	NA	170,000 *	-85%	NA	NA	NA	NA
PA-13I	1,070,000	1,250,000	17%	268,000	-75%	NA	NA	NA	NA	1,300,000 D*	21%	NA	NA	NA	NA
PA-13D	892,000	1,160,000	30%	380,000	-57%	NA	NA	NA	NA	3,300 *	>-99%	NA	NA	626,000	-30%
PA-13D-DUP	730,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-14S	935,000	106,000	-89%	556	>-99%	NA	NA	NA	NA	9,400 *	>-99%	NA	NA	3,450 D	>-99%
PA-14I	960,000	75,500	-92%	NA	NA	NA	NA	NA	NA	46,000 *	-95%	NA	NA	NA	NA

Table C-1. TCE Results of Groundwater Samples (Continued)

Sampling Event[1)]	TCE (µg/L)														
	Pre-Demo	Week 3-4		Week 5		Week 7-8		Jan 10-14, 2000		Apr 10-14, 2000[2)]		ISCO Post-Demo		Extended Monitoring	
Well ID	Results	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.
PA-14D	868,000	482,000	-44%	NA	NA	NA	NA	NA	NA	68,000 *	-92%	NA	NA	562,000 D	-35%
Resistive Heating Perimeter Wells															
PA-2S	22,900	1,110	-95%	82.6	>-99%	NA	NA	17,400	-24%	6,400	-72%	19,000	-17%	NA	NA
PA-2I	1,140,000	720,000	-37%	425,000	-63%	NA	NA	1,100,000	-4%	1,800,000D	58%	980,000	-14%	NA	NA
PA-2I-DUP	NA	NA	NA	475,000	-58%	NA	NA	NA	NA	1,400,000D	23%	NA	NA	NA	NA
PA-2D	1,150,000	1,080,000	-6%	1,120,000	-3%	NA	NA	1,250,000	9%	1,300,000D	13%	990,000D	-14%	NA	NA
PA-7S	118,000	92,000	-22%	55,000	-53%	NA	NA	39,600	-66%	64,000	-46%	NA	NA	NA	NA
PA-7I	365,000	486,000	33%	438,000	20%	NA	NA	112,000	-69%	36,000	-90%	NA	NA	NA	NA
PA-7D	309	19,000	6,049%	23,100	7,376%	NA	NA	160,000	51,680%	33,000	10,580%	NA	NA	NA	NA
PA-10S	162,000	299,000	85%	182,000	12%	NA	NA	182,000	12%	760,000D	369%	NA	NA	NA	NA
PA-10I	1,100,000	860,000	-22%	458,000	-58%	NA	NA	280,000	-75%	740,000D	-33%	NA	NA	NA	NA
PA-10I-DUP	NA	NA	NA	451,000	-59%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-10D	1,120,000	180,000	-84%	825,000	-26%	NA	NA	1,060,000	-5%	1,000,000D	-11%	NA	NA	NA	NA
PA-10D-DUP	NA	NA	NA	NA	NA	NA	NA	1,120,000	0%	NA	NA	NA	NA	NA	NA
IW-17S	397	468,000	117,784%	494,000	124,333%	NA	NA	77,500	19,421%	Dry	NA	NA	NA	NA	NA
IW-17I	15,000	17,400	16%	31,000	107%	NA	NA	152,000	913%	680,000	4,433%	NA	NA	NA	NA
IW-17D	154,000	7,410	-95%	1,180	-99%	NA	NA	630J	>-99%	1,600J	>-99%	NA	NA	NA	NA
PA-15	NA	NA	NA	NA	NA	NA	NA	180,000	NA	270,000D	NA	NA	NA	NA	NA
Distant Wells															
PA-1S	984	2,550	159%	9,690	885%	19,400	1,872%	16,200	1,546%	3,700	276%	4,500	357%	NA	NA
PA-1I	2,920	4,420	51%	2,310	-21%	288	-90%	140J	-95%	510J	-83%	<2000	>-99%	NA	NA
PA-1I-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<2000	>-99%	NA	NA
PA-1D	172	845	391%	24.1	-86%	24.6	-86%	2.58	>-99%	0.67J	>-99%	2.80	-99%	NA	NA
PA-8S	5,730	15,300	167%	25,800	350%	115,000	1,907%	79,300	1,284%	740,000	12,814%	630,000	10,895%	NA	NA
PA-8S-DUP	NA	NA	NA	NA	NA	113,000	1,872%	84,400	1,373%	NA	NA	NA	NA	NA	NA
PA-8I	988,000	1,040,000	5%	1,390,000	41%	1,000,000	1%	805,000	-19%	190,000	-81%	330,000	-67%	NA	NA
PA-8D	478,000	625,000	31%	635,000	33%	900,000	88%	960,000	101%	1,300,000D	172%	1,800,000D	277%	NA	NA
PA-8D-DUP	NA	555,000	16%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-11S	865,000	800,000	-8%	790,000	-9%	810,000	-6%	1,090,000	26%	970,000	12%	<5	>-99%	NA	NA
PA-11I	1,060,000	1,280,000	21%	1,200,000	13%	1,190,000	12%	1,200,000	13%	1,200,000D	13%	1,200,000D	13%	NA	NA
PA-11D	1,010,000	1,240,000	23%	1,030,000	2%	1,250,000	24%	1,180,000	17%	1,300,000D	29%	1,400,000D	39%	NA	NA

Notes:

All units are in µg/L.

NA: Not available. NS: Not sampled.

<: The compound was analyzed but not detected at or above the specified reporting limit.

J: Result was estimated but below the reporting limit.

D: Result was quanitified after dilution.

1) Sampling Event Period:

Pre-demo: 8/3/99 to 8/9/99

Week 3-4: 9/24/99 to 9/30/99

Table C-1. TCE Results of Groundwater Samples (Continued)

Week 5: 10/6/99 to 10/8/99
Week 7-8: 10/19/99 to 10/28/99
Post-Demo: 5/8/00 to 5/14/00
Extended Monitoring: February 2001.
2) Some deeply colored samples which may have some sediments had higher reporting limits because only limited volume could be purged in the purge and trap GC instrument.
*: Resisitve Heating Plot wells sampled in Apr 2000 may not be representative because most of well screens were appeared to be submerged under sediments.
Red indicates that TCE concentration has increased compared to Pre-demo conditions.
Blue indicates that TCE concentration has decreased compared to Pre-demo conditions.
Purple bold face indicates that water sample was purple when collected.

Table C-2. Other CVOC Results of Groundwater Samples (Continued)

Well ID	Vinyl chloride (µg/L)							
	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring
PA-12S	<5,000	<10,000	NA	<100	<10,000	<50,000	<100,000	NA
PA-12I	<5,000	<10,000	NA	<100	<10,000	<50,000	<100,000	NA
PA-12D	<5,000	<10,000	NA	<1,000	<10,000	<50,000	<50,000	NA
Resistive Heating Plot Wells								
PA-13S	<5,000	<10,000	<5,000	NA	NA	<10,000	NA	<1,000
PA-13S-DUP	<5,000	<10,000	NA	NA	NA	<10,000	NA	NA
PA-13I	<5,000	<10,000	<5,000	NA	NA	<50,000	NA	NA
PA-13D	<5,000	<10,000	<5,000	NA	NA	21J	NA	<1,000
PA-13D	<83,000	NA	NA	NA	NA	NA	NA	NA
PA-14S	<5,000	170J	NA	NA	NA	<1,100	NA	22
PA-14I	<5,000	100J	NA	NA	NA	<10,000	NA	NA
PA-14I-DUP	<5,000	NA	NA	NA	NA	NA	NA	NA
PA-14D	<5,000	<10,000	NA	NA	NA	<8,300	NA	3,190
PA-14D-DUP	<5,000	NA	NA	NA	NA	NA	NA	NA
Resistive Heating Perimeter Wells								
PA-2S	<500	<20	<20	NA	<1,000	2,800J	4,100	NA
PA-2I	<5,000	<10,000	<5,000	NA	<10,000	<50,000	<50,000	NA
PA-2I-DUP	NA	NA	<5,000	NA	NA	<50,000	NA	NA
PA-2D	<5,000	<10,000	<5,000	NA	<10,000	<50,000	<50,000	NA
PA-7S	<5,000	<10,000	<5,000	NA	<400	1,200J	NA	NA
PA-7I	<5,000	<10,000	<5,000	NA	<1,000	<3,300	NA	NA
PA-7D	3.3	764	<10,000	NA	<10,000	6,400J	NA	NA
PA-10S	<5,000	<10,000	<2,000	NA	<10,000	2,500J	NA	NA
PA-10I	<5,000	<10,000	<10,000	NA	<10,000	<40,000	NA	NA
PA-10I-DUP	NA	NA	<10,000	NA	NA	NA	NA	NA
PA-10D	<5,000	<10,000	<10,000	NA	<10,000	<50,000	NA	NA
PA-10D-DUP	NA	NA	NA	NA	<10,000	NA	NA	NA
IW-17S	<20	292	<200	NA	<1,000	Dry	NA	NA
IW-17I	<5,000	<1,000	<5,000	NA	<1,000	<40,000	NA	NA
IW-17D	<5,000	428	<200	NA	<1,000	3,800J	NA	NA
PA-15	NA	NA	NA	NA	<10,000	590J	NA	NA
Distant Wells								

Table C-2. Other CVOC Results of Groundwater Samples (Continued)

Well ID	Vinyl chloride (µg/L)							
	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring
ISCO Plot Wells								
BAT-1S	<5,000	<10,000	NA	9,200J	<10,000	NA	<10	NA
BAT-1I	<5,000	NA	NA	<10,000	<10,000	NA	<33,000	NA
BAT-1D	<5,000	NA	NA	<10,000	<10,000	NA	<14,000	NA
BAT-2S	<5,000	1.4J	NA	<20	<2,000	<10	<10	<20
BAT-2S-DUP	<5,000	NA	NA	NA	NA	NA	NA	NA
BAT-2I	<5,000	NA	NA	20.7	<2,000	<10	<150	<1
BAT-2I-DUP	NA	NA	NA	20J	<2,000	NA	NA	NA
BAT-2D	<5,000	NA	NA	<10,000	9.79	NA	<20,000	<1,000
BAT-3S	<5,000	<10,000	NA	<10,000	<2,000	NA	<33,000	NA
BAT-3S-DUP	NA	NA	NA	NA	NA	NA	<33,000	NA
BAT-3I	<5,000	NA	NA	<10,000	<2,000	NA	<1,200	NA
BAT-3D	<5,000	NA	NA	<2,000	<2,000	NA	<10	NA
BAT-5S	<5,000	<500	NA	<10,000	<100	<10	<33,000	<20
BAT-5I	<5,000	NA	NA	5,100J	<2,000	<33,000	<20	<1,000
BAT-5I-DUP	<5,000	NA	NA	NA	NA	NA	NA	NA
BAT-5D	<5,000	NA	NA	<10,000	<10,000	<50,000	<3,300	<1,000
BAT-5D-DUP	NA	NA	NA	<10,000	NA	<50,000	<3,300	NA
BAT-6S	<5,000	<2	NA	<20	<2,000	NA	<2,000	NA
BAT-6I	<5,000	NA	NA	<10,000	<2,000	NA	<40	NA
BAT-6D	<5,000	NA	NA	<10,000	<2,000	NA	<10	NA
PA-4S	<5,000	<2	NA	<2	<2,000	NA	<10	NA
PA-4S-DUP	NA	NA	NA	NA	NA	NA	<10	NA
PA-4I	<5,000	NA	NA	<2	<2,000	NA	<10	NA
PA-4D	<5,000	NA	NA	<20,000	<10,000	NA	<10	NA
MP-1A	<5,000	<2	NA	<10,000	<200	NA	<10	NA
MP-1B	<5,000	NA	NA	<10,000	<2,000	NA	NA	NA
MP-1C	<5,000	NA	NA	<10,000	<10,000	NA	<17,000	NA
MP-1D	<5,000	NA	NA	<20,000	<10,000	NA	<12,000	NA
MP-1E	<5,000	NA	NA	<10,000	<10,000	NA	<10,000	NA
ML-2	NA	<1,000	NA	<2	<2	NA	<10	NA
ML-3	<5,000	<10,000	NA	Dry	Dry	NA	Dry	NA
ML-4	<5,000	<10,000	NA	<10,000	<200	NA	<5,000	NA

Table C-2. Other CVOC Results of Groundwater Samples (Continued)

Well ID	*cis*-1,2-DCE (µg/L)								*trans*-1,2-DCE (µg/L)							
	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring
PA-1S	1,190	945	5,030	12,800	20,000	29,000	[redacted]	NA	38.4	50J	220	484	714	1,400J	1,100J	NA
PA-1I	32,800	22,100	10,800	8,400	43,900	53,000	[redacted]	NA	1,540	1,220	530J	431	1,670	1,500J	1,400J	NA
PA-1I-DUP	NA	NA	NA	NA	NA	NA	47,000	NA	NA	NA	NA	NA	NA	NA	1,400J	NA
PA-1D	299	1,100	689	589	1.4J	6.2J	[redacted]	NA	22.9	64J	32.4	21.9	1.2J	0.46J	0.46J	NA
PA-8S	10,000	9,930	12,000	18,200	<2,000	23,000	[redacted]	NA	140J	220	220	352	<2,000	<20,000	<17,000	NA
PA-8S-DUP	NA	NA	NA	18,000	<2,000	NA	NA	NA	NA	NA	NA	368	<2,000	NA	NA	NA
PA-8I	36,800	51,000	64,000	104,000	128,000	220,000	[redacted]	NA	<5,000	<10,000	<1,000	<10,000	<10,000	<17,000	<10,000	NA
PA-8D	36,500	38,600	31,100	20,800	6,600J	11,000J	[redacted]	NA	<5,000	<10,000	<2,000	<10,000	<10,000	<20,000	<25,000	NA
PA-8D-DUP	NA	32,600	NA	NA	NA	NA	NA	NA	NA	<10,000	NA	NA	NA	NA	NA	NA
PA-11S	4,900J	8,000J	5,400J	5,600J	<10,000	<25,000	[redacted]	NA	<5,000	<10,000	<10,000	<10,000	<10,000	<25,000	<5	NA
PA-11I	4,900J	6,900J	5,200J	5,400J	<10,000	5,700J	<25,000	NA	<5,000	<10,000	<10,000	<10,000	<10,000	<25,000	<25,000	NA
PA-11D	6,180	<10,000	6,700J	<10,000	<10,000	<17,000	<25,000	NA	<5,000	<10,000	<10,000	<10,000	<10,000	<17,000	<25,000	NA

Table C-2. Other CVOC Results of Groundwater Samples (Continued)

Well ID	*cis*-1,2-DCE (µg/L)								*trans*-1,2-DCE (µg/L)							
	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring
PA-12S	9,380	23,800	NA	4,760	<10,000	<25,000	<50,000	NA	<5,000	<10,000	NA	72J	<10,000	<25,000	<50,000	NA
PA-12I	5,070	6,300J	NA	4,160	<10,000	<25,000	<50,000	NA	<5,000	<10,000	NA	<100	<10,000	<25,000	<50,000	NA
PA-12D	102,000	61,000	NA	45,000	9,800J	<25,000	<25000	NA	<5,000	<10,000	NA	<1,000	<10,000	<25,000	<25,000	NA
Resistive Heating Plot Wells																
PA-13S	4,400	17,400	350,000	NA	NA	[redacted]	NA	[redacted]	<5,000	<10,000	3,000J	NA	NA	<5,000	NA	<1,000
PA-13S-DUP	4,900	16,000	NA	NA	NA	[redacted]	NA	NA	<5,000	<10,000	NA	NA	NA	<5,000	NA	NA
PA-13I	4,900	<10,000	3,900J	NA	NA	[redacted]	NA	NA	<5,000	<10,000	<5,000	NA	NA	6,200J	NA	16
PA-13D	2,200	5,900J	3,000J	NA	NA	[redacted]	NA	[redacted]	<5,000	<10,000	<5,000	NA	NA	26J	NA	<1,000
PA-13D-DUP	<62,000	NA	NA	NA	NA	NA	NA	NA	<42,000	NA	NA	NA	NA	NA	NA	NA
PA-14S	5,880	2,090	19J	NA	NA	[redacted]	NA	[redacted]	<5,000	<200	<20	NA	NA	<560	NA	<1,000
PA-14I	26,000	349	NA	NA	NA	[redacted]	NA	NA	<5,000	<200	NA	NA	NA	<5,000	NA	1,150
PA-14I-DUP	25,500	NA	NA	NA	NA	NA	NA	NA	<5,000	NA	NA	NA	NA	NA	NA	NA
PA-14D	21,900	11,600	NA	NA	NA	[redacted]	NA	[redacted]	<5,000	<10,000	NA	NA	NA	<4,200	NA	33
PA-14D-DUP	23,200	NA	NA	NA	NA	NA	NA	NA	<5,000	NA	NA	NA	NA	NA	NA	NA
Resistive Heating Perimeter Wells																
PA-2S	3,020	3,520	2,170	NA	32,800	28,000	[redacted]	NA	<500	<20	<20	NA	<1,000	<2,500	<620	NA
PA-2I	5,480	33,600	2,900J	NA	<10,000	7,200J	[redacted]	NA	<5,000	<10,000	<5,000	NA	<10,000	<25,000	<25,000	NA
PA-2I-DUP	NA	NA	3,600J	NA	NA	12,000J	NA	NA	NA	NA	<5,000	NA	NA	<25,000	NA	NA
PA-2D	2,700	7,400J	3,600J	NA	8,500J	<25,000	<25,000	NA	<5,000	<10,000	<5,000	NA	<10,000	<25,000	<25,000	NA
PA-7S	22,100	19,200	7,430	NA	8,900	[redacted]	NA	NA	<5,000	<10,000	<5,000	NA	<400	<3,300	NA	NA
PA-7I	160,000	109,000	73,200	NA	21,400	[redacted]	NA	NA	<5,000	<10,000	<5,000	NA	<1,000	290J	NA	NA
PA-7D	21	38,000	41,800	NA	54,500	[redacted]	NA	NA	2.78	633	<10,000	NA	<10,000	<5,000	NA	NA
PA-10S	8,880	5,300J	1,900J	NA	81,000	[redacted]	NA	NA	<5,000	<10,000	<2,000	NA	<10,000	<20,000	NA	NA
PA-10I	4,700J	6,900J	4,900J	NA	<10,000	[redacted]	NA	NA	<5,000	<10,000	<10,000	NA	<10,000	<20,000	NA	NA
PA-10I-DUP	NA	NA	<10,000	NA	NA	NA	NA	NA	NA	NA	<10,000	NA	NA	NA	NA	NA
PA-10D	2,400J	<10,000	<10,000	NA	9,800J	[redacted]	NA	NA	<5,000	<10,000	<10,000	NA	<10,000	<25,000	NA	NA
PA-10D-DUP	NA	NA	NA	NA	12,300	NA	NA	NA	NA	NA	NA	NA	<10,000	NA	NA	NA
IW-17S	593	15,700	4,640	NA	4,180	Dry	NA	NA	<20	225	140J	NA	<1,000	Dry	NA	NA
IW-17I	123,000	7,150	7,950	NA	14,600	[redacted]	NA	NA	<5,000	<1,000	<5,000	NA	<1,000	<20,000	NA	NA
IW-17D	39,200	18,100	18,600	NA	70,000	[redacted]	NA	NA	<5,000	150J	251	NA	2,060	1,800J	NA	NA
PA-15	NA	NA	NA	NA	39,300	39,000	NA	NA	NA	NA	NA	NA	<10,000	<5,600	NA	NA
Distant Wells																

Table C-2. Other CVOC Results of Groundwater Samples (Continued)

Well ID	*cis*-1,2-DCE (µg/L)								*trans*-1,2-DCE (µg/L)							
	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring
ML-5	4,600J	NA	NA	<10,000	<10,000	NA	[redacted]	NA	<5,000	NA	NA	<10,000	<10,000	NA	<10,000	NA
ML-6	3,100J	NA	NA	<10,000	<10,000	NA	<25,000	NA	<5,000	NA	NA	<10,000	<10,000	NA	<25,000	NA
ML-7	3,000J	NA	NA	<10,000	<10,000	NA	[redacted]	NA	<5,000	NA	NA	<10,000	<10,000	NA	<10,000	NA
MP-2A	7,100	55J	NA	<2	<2	NA	[redacted]	NA	<5,000	<100	NA	<2	<2	NA	<5	NA
MP-2B	3,100J	NA	NA	14J	NA	NA	[redacted]	NA	<5,000	NA	NA	<20	NA	NA	<5	NA
MP-2C	<5,000	NA	NA	2.39	<2	NA	[redacted]	NA	<5,000	NA	NA	<2	<2	NA	<5	NA
MP-2D	<5,000	NA	NA	<40	95.5	NA	[redacted]	NA	<5,000	NA	NA	<40	<50	NA	<5	NA
MP-2E	<5,000	NA	NA	<40	<1,000	NA	[redacted]	NA	<5,000	NA	NA	<40	<1,000	NA	<20	NA
MP-3A	3,600J	1.7J	NA	<2	<2,000	NA	[redacted]	NA	<5,000	<2	NA	<2	<2,000	NA	<5	NA
MP-3B	5,780	NA	NA	84	<2,000	NA	[redacted]	NA	<5,000	NA	NA	<20	<2,000	NA	<5	NA
MP-3C	2,000J	NA	NA	4.87	<2,000	NA	[redacted]	NA	<5,000	NA	NA	<2	<2,000	NA	<5	NA
MP-3D	<5,000	NA	NA	<2,000	<10,000	NA	<5	NA	<5,000	NA	NA	<2,000	<10,000	NA	<5	NA
MP-3E	<5,000	NA	NA	<10,000	<2,000	NA	<5	NA	<5,000	NA	NA	<10,000	<2,000	NA	<5	NA
MP-4A	3,900J	6.34	NA	<2	<2	NA	[redacted]	NA	<5,000	<2	NA	<2	<2	NA	<5	NA
MP-4C	<5,000	NA	NA	<20	<2,000	NA	<5	NA	<5,000	NA	NA	<20	<2,000	NA	<5	NA
MP-4E	3,200J	NA	NA	<10,000	<10,000	NA	[redacted]	NA	<5,000	NA	NA	<10,000	<10,000	NA	<1,200	NA
MP-4E-2	NA	NA	NA	NA	NA	NA	<5,000	NA	NA	NA	NA	NA	NA	NA	<5,000	NA
ISCO Perimeter Wells																
PA-3S	5,250	9,100J	NA	<10,000	<2,000	<5	[redacted]	NA	<5,000	<10,000	NA	<10,000	<2,000	<5	<5	NA
PA-3S-DUP	NA	NA	NA	NA	NA	NA	<5	NA	NA	NA	NA	NA	NA	NA	<5	NA
PA-3I	8,750	12,300	NA	<10,000	<2,000	2,100	[redacted]	NA	<5,000	<10,000	NA	<10,000	<2,000	<150	<500	NA
PA-3I-DUP	NA	12,200	NA	NA	NA	NA	NA	NA	NA	<10,000	NA	NA	NA	NA	NA	NA
PA-3D	<5,000	11,500	NA	<10,000	<10,000	<5	<10	NA	<5,000	<10,000	NA	<10,000	<10,000	<5	<10	NA
PA-3D-DUP	NA	NA	NA	NA	<10,000	NA	NA	NA	NA	NA	NA	NA	<10,000	NA	NA	NA
PA-5S	2,020	9,800J	NA	6,750	8,330	15,000J	[redacted]	NA	22.6	<10,000	NA	118	<2,000	<33,000	<20,000	NA
PA-5I	33,500	38,200	NA	54,900	11,300	30,000	[redacted]	NA	<5,000	<10,000	NA	<2,000	<2,000	<10,000	<4,200	NA
PA-5D	68,200	65,500	NA	59,900	13,000	17,000	[redacted]	NA	<5,000	<10,000	NA	<2,000	<2,000	<4,500	<3,100	NA
PA-6S	774	2,830	NA	14,600	<2,000	1,200J	[redacted]	NA	14.7	47.2	NA	299	<2,000	<2,000	<1,000	NA
PA-6I	102,000	12,400	NA	24,600	5,570	<33,000	[redacted]	NA	<5,000	<10,000	NA	<10,000	<2,000	<33,000	<25,000	NA
PA-6D	8,920	90,000	NA	50,500	14,000	<33,000	[redacted]	NA	<5,000	<10,000	NA	<10,000	<2,000	<33,000	<17,000	NA
PA-9S	24,300	7,800J	NA	5,750	37,900	<25,000	[redacted]	NA	<5,000	<10,000	NA	<5,000	<2,000	<25,000	<17,000	NA
PA-9I	5,420	41,200	NA	64,200	75,000	200,000	[redacted]	NA	<5,000	<10,000	NA	<5,000	<10,000	<25,000	<17,000	NA
PA-9D	40,200	39,700	NA	38,000	20,400	14,000J	[redacted]	NA	<5,000	<10,000	NA	<5,000	<10,000	<25,000	<17,000	NA

Table C-2. Other CVOC Results of Groundwater Samples

Well ID	*cis*-1,2-DCE (µg/L)								*trans*-1,2-DCE (µg/L)							
	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring
ISCO Plot Wells																
BAT-1S	5,020	4,000J	NA	<10,000	<10,000	NA	[redacted]5	NA	<5,000	<10,000	NA	<10,000	<10,000	NA	<5	NA
BAT-1I	5,520	NA	NA	<10,000	<10,000	NA	<17,000	NA	<5,000	NA	NA	<10,000	<10,000	NA	<17,000	NA
BAT-1D	<5,000	NA	NA	<10,000	<10,000	NA	<7,100	NA	<5,000	NA	NA	<10,000	<10,000	NA	<7,100	NA
BAT-2S	4,900J	42.8	NA	<20	<2,000	<5	[redacted]<5	[redacted]<20	<5,000	<2	NA	<20	<2,000	<5	<5	<20
BAT-2S-DUP	4,800J	NA	NA	NA	NA	NA	NA	NA	<5,000	NA	NA	NA	NA	NA	NA	NA
BAT-2I	4,700J	NA	NA	152	<2,000	<5	[redacted]<77	[redacted]<77	<5,000	NA	NA	<20	<2,000	<5	<77	<1
BAT-2I-DUP	NA	NA	NA	150	<2,000	NA	NA	NA	NA	NA	NA	<20	<2,000	NA	NA	NA
BAT-2D	NA	NA	NA	<10,000	360	NA	<10,000	7,770	<5,000	NA	NA	<10,000	6	NA	<10,000	<1000
BAT-3S	4,900J	<10,000	NA	<10,000	8,330	NA	[redacted]3,500J	NA	<5,000	<10,000	NA	<10,000	<2,000	NA	<17,000	NA
BAT-3S-DUP	NA	NA	NA	NA	NA	NA	5,000J	NA	NA	NA	NA	NA	NA	NA	<17,000	NA
BAT-3I	7,020	NA	NA	<10,000	14,000	NA	[redacted]	NA	<5,000	NA	NA	<10,000	<2,000	NA	<620	NA
BAT-3D	9,180	NA	NA	<2,000	<2,000	NA	[redacted]<5	NA	<5,000	NA	NA	<2,000	<2,000	NA	<5	NA
BAT-5S	12,500	<500	NA	<10,000	<100	<5	<17,000	[redacted]5,300 D	<5,000	<500	NA	<10,000	<100	<5	<17,000	<20
BAT-5I	5,220	NA	NA	<10,000	<2,000	<17,000	[redacted]<10	[redacted]540J	<5,000	NA	NA	<10,000	<2,000	<17,000	<10	<1,000
BAT-5I-DUP	4,100J	NA	NA	NA	NA	NA	NA	NA	<5,000	NA	NA	NA	NA	NA	NA	NA
BAT-5D	NA	NA	NA	<10,000	<10,000	<25,000	<1,700	1,090	<5,000	NA	NA	<10,000	<10,000	<25,000	<1,700	<1,000
BAT-5D-DUP	NA	NA	NA	<10,000	NA	<25,000	<1,700	NA	NA	NA	NA	<10,000	NA	<25,000	<1,700	NA
BAT-6S	3,900J	2.11	NA	<20	1,400J	NA	[redacted]<1,000	NA	<5,000	<2	NA	<20	<2,000	NA	<1,000	NA
BAT-6I	21,300	NA	NA	<10,000	11,300	NA	[redacted]15J	NA	<5,000	NA	NA	<10,000	<2,000	NA	<20	NA
BAT-6D	44,500	NA	NA	20,200	6,830	NA	[redacted]<5	NA	<5,000	NA	NA	<10,000	<2,000	NA	<5	NA
PA-4S	5,750	3.46	NA	<2	<2,000	NA	[redacted]<5	NA	<5,000	<2	NA	<2	<2,000	NA	<5	NA
PA-4S-DUP	NA	NA	NA	NA	NA	NA	<5	NA	NA	NA	NA	NA	NA	NA	<5	NA
PA-4I	4,200J	NA	NA	7.54	<2,000	NA	[redacted]5	NA	<5,000	NA	NA	<2	<2,000	NA	<5	NA
PA-4D	NA	NA	NA	<20,000	<10,000	NA	<5	NA	<5,000	NA	NA	<20,000	<10,000	NA	<5	NA
MP-1A	7,180	1.5J	NA	<10,000	<200	NA	[redacted]<5	NA	<5,000	<2	NA	<10,000	<200	NA	<5	NA
MP-1B	5,000J	NA	NA	<10,000	1,000J	NA	NA	NA	<5,000	NA	NA	<10,000	<2,000	NA	NA	NA
MP-1C	3,200J	NA	NA	<10,000	<10,000	NA	<8,300	NA	<5,000	NA	NA	<10,000	<10,000	NA	<8,300	NA
MP-1D	2,400J	NA	NA	<20,000	<10,000	NA	[redacted]	NA	<5,000	NA	NA	<20,000	<10,000	NA	<6,200	NA
MP-1E	2,200J	NA	NA	<10,000	<10,000	NA	<5,000	NA	<5,000	NA	NA	<10,000	<10,000	NA	<5,000	NA
ML-2	NA	380J	NA	<2	<2	NA	<5	NA	NA	<1,000	NA	<2	<2	NA	<5	NA
ML-3	12,800	<10,000	NA	Dry	Dry	NA	Dry	NA	<5,000	<10,000	NA	Dry	Dry	NA	Dry	NA
ML-4	4,200J	4,800J	NA	<10,000	494	NA	[redacted]	NA	<5,000	<10,000	NA	<10,000	<200	NA	<2,500	NA

Table C-1. TCE Results of Groundwater Samples (Continued)

Week 5: 10/6/99 to 10/8/99
Week 7-8: 10/19/99 to 10/28/99
Post-Demo: 5/8/00 to 5/14/00
Extended Monitoring: February 2001.
2) Some deeply colored samples which may have some sediments had higher reporting limits because only limited volume could be purged in the purge and trap GC instrument.
*: Resisitve Heating Plot wells sampled in Apr 2000 may not be representative because most of well screens were appeared to be submerged under sediments.
Red indicates that TCE concentration has increased compared to Pre-demo conditions.
Blue indicates that TCE concentration has decreased compared to Pre-demo conditions.
Purple bold face indicates that water sample was purple when collected.

Table C-2. Other CVOC Results of Groundwater Samples (Continued)

Well ID	Vinyl chloride (µg/L)							
	Pre-Demo	Week 3-4	Week 5	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Extended Monitoring
PA-1S	<20	<100	30.3	152	<200	2,400J	2,300J	NA
PA-1I	1,910	1,700	1,260	1,250	6,260	7,200	6,500	NA
PA-1I-DUP	NA	NA	NA	NA	NA	NA	6,300	NA
PA-1D	171	338	332	195	12.1	5.1	4.5	NA
PA-8S	<200	<200	<20	<200	<2,000	<40,000	<33,000	NA
PA-8S-DUP	NA	NA	NA	<200	<2,000	NA	NA	NA
PA-8I	<5,000	<10,000	<1,000	<10,000	<10,000	<33,000	<20,000	NA
PA-8D	<5,000	<10,000	<2,000	<10,000	<10,000	<40,000	<50,000	NA
PA-8D-DUP	NA	<10,000	NA	NA	NA	NA	NA	NA
PA-11S	<5,000	<10,000	<10,000	<10,000	<10,000	<50,000	<10	NA
PA-11I	<5,000	<10,000	<10,000	<10,000	<10,000	<50,000	<50,000	NA
PA-11D	<5,000	<10,000	<10,000	<10,000	<10,000	<33,000	<50,000	NA

Notes:

NA: Not available.

<: The compound was analyzed but not detected at or above the specified reporting limit.

J: Result was estimated but below the reporting limit.

D: Result was quanitified after dilution.

Yellow indicates that a measurable concentration was obtained for this sample.

Red indicates that concentration in this well increased compared to pre-treatment levels.

Blue indicates that concentration in this well decreased comnpared to pre-treatment levels.

Pre-demo: 8/3/99 to 8/9/99

Week 3-4: 9/24/99 to 9/30/99

Week 5: 10/6/99 to 10/8/99

Week 7-8: 10/19/99 to 10/28/99

Post-Demo: 5/8/00 to 5/14/00

Extended Monitoring: February 2001.

Table C-3. Pre-Demo Results of Soil Samples

Analytical Sample ID	Sample ID	Sample Depth (ft)		MeOH (g)	Wet Soil Weight (g)	Dry Soil Weight (g)	TCE				*cis*-1,2-DCE				*trans*-1,2-DCE	Vinyl Chloride
		Top Depth	Bottom Depth				Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Result in Wet Soil (µg/kg)
SB-13-439	SB-13-2	0	2	195	142	129	330	J	430	0.4		<	430	ND	ND	ND
SB-13-440	SB-13-4	2	4	190	201	187	200	J	250	0.2		<	250	ND	ND	ND
SB-13-441	SB-13-6	4	6	189	215	194	160	J	280	0.2		<	280	ND	ND	ND
SB-13-442	SB-13-8	6	8	189	141	123	300	J	420	0.4		<	420	ND	ND	ND
SB-13-443	SB-13-10	8	10	195	198	170	410		310	0.5		<	310	ND	ND	ND
SB-13-444	SB-13-12	10	12	199	224	173	280		250	0.5		<	250	ND	ND	ND
SB-13-445	SB-13-14	12	14	191	241	202	300		250	0.4		<	250	ND	ND	ND
SB-13-446	SB-13-16	14	16	189	221	179	550		250	0.8		<	250	ND	ND	ND
SB-13-447	SB-13-18	16	18	189	192	160	4,600		310	6.5	400		310	0.6	ND	ND
SB-13-448	SB-13-20	18	20	191	167	134	15,000		720	21.9	880		720	1.3	ND	ND
SB-13-449	SB-13-22	20	22	189	228	179	66,000		2,500	105.9		<	2,500	ND	ND	ND
SB-13-450	SB-13-24	22	24	190	231	177	140,000		6,200	234.6		<	6,200	ND	ND	ND
SB-13-451	SB-13-26	24	26	192	248	178	160,000		6,200	304.2		<	6,200	ND	ND	ND
SB-13-452	SB-13-28	26	28	191	243	198	210,000		10,000	318.4	5,300	J	10,000	8.0	ND	ND
SB-13-452	SB-13-28	26	28	191	243	198	190,000		10,000	288.1		<	10,000	ND	ND	ND
SB-13-453	SB-13-32	30	32	190	300	235	39,000		2,500	66.8	33,000		2,500	56.5	ND	ND
SB-13-453	SB-13-32	30	32	190	300	235	33,000		2,500	56.5	28,000		2,500	48.0	ND	ND
SB-13-454	SB-13-32B	30	32	197	302	238	39,000		4,200	65.6	32,000		4,200	53.8	ND	ND
SB-13-454	SB-13-32B	30	32	197	302	238	36,000		1,800	60.5	29,000		1,800	48.8	ND	ND
SB-13-455	SB-13-34	32	34	190	193	151	18,000	E	250	28.1	38,000	E	250	59.3	ND	ND
SB-13-455	SB-13-34	32	34	190	193	151	15,000	D	1,200	23.4	30,000	D	1,200	46.8	ND	ND
SB-13-456	SB-13-36	34	36	191	245	197	4,700		2,100	7.3	30,000		2,100	46.7	ND	ND
SB-13-457	SB-13-38	36	38	196	198	144	7,500		2,600	13.2	41,000		2,600	71.9	ND	ND
SB-13-458	SB-13-40	38	40	195	195	154	13,000		630	19.9	19,000		630	29.1	ND	ND
SB-13-459	SB-13-42	40	42	186	215	163	4,000		250	6.8	7,400		250	12.5	ND	ND
SB-13-460	SB-13-44	42	44	192	275	203	22,000		1,000	41.0	11,000		1,000	20.5	ND	ND
SB-13-461	SB-13-46	44	46	191	209	160	110,000		2,500	180.5	4,000		2,500	6.6	ND	ND
SB-13-462	SB-13-BLANK	MeOH Blank Sample		NA	0	0	140	J,1	250	0.2		<	250	ND	ND	ND
SB-14-535	SB-14-2	0	2	190	148	138	140	J	440	0.2		<	440	ND	ND	ND
SB-14-536	SB-14-4	2	4	191	241	231	310		260	0.3		<	260	ND	ND	ND
SB-14-537	SB-14-6	4	6	191	180	174	150	J	350	0.2		<	350	ND	ND	ND
SB-14-538	SB-14-8	6	8	191	140	126	220	J	480	0.3		<	480	ND	ND	ND
SB-14-539	SB-14-10	8	10	191	201	171	210	J	290	0.3		<	290	ND	ND	ND
SB-14-540	SB-14-12	10	12	191	185	151	380	J	400	0.5		<	400	ND	ND	ND
SB-14-541	SB-14-16	14	16	191	204	158	220	J	320	0.4	180	J	320	0.3	ND	ND
SB-14-542	SB-14-18	16	18	190	153	124	2,700		480	3.8	470	J	480	0.7	ND	ND
SB-14-543	SB-14-20	18	20	190	222	175	18,000		630	28.5	670		630	1.1	ND	ND
SB-14-544	SB-14-22	20	22	189	233	183	71,000		3,200	114.3		<	3,200	ND	ND	ND
SB-14-545	SB-14-24	22	24	191	202	158	150,000		4,600	236.0		<	4,600	ND	ND	ND
SB-14-546	SB-14-26	24	26	192	221	172	140,000		4,600	225.8		<	4,600	ND	ND	ND
SB-14-547	SB-14-28	26	28	191	221	174	2,400,000		64,000	3,798.4		<	64,000	ND	ND	ND
SB-14-548	SB-14-30	28	30	191	186	133	250,000		9,100	446.6		<	9,100	ND	ND	ND
SB-14-549	SB-14-32	30	32	189	221	157	1,200,000		35,000	2,261.2		<	35,000	ND	ND	ND
SB-14-550	SB-14-34	32	34	191	198	154	19,000,000		460,000	30,056.1		<	460,000	ND	ND	ND
SB-14-551	SB-14-36	34	36	190	203	155	5,400,000		220,000	8,858.9		<	220,000	ND	ND	ND
SB-14-552	SB-14-38	36	38	190	186	146	9,800,000		270,000	15,113.3		<	270,000	ND	ND	ND

Table C-3. Pre-Demo Results of Soil Samples (Continued)

Analytical Sample ID	Sample ID	Sample Depth (ft)		MeOH (g)	Wet Soil Weight (g)	Dry Soil Weight (g)	TCE				*cis* -1,2-DCE				*trans* -1,2-DCE	Vinyl Chloride
		Top Depth	Bottom Depth				Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Result in Wet Soil (µg/kg)
SB-14-553	SB-14-40	38	40	191	122	84	490,000		14,000	853.3		<	14,000	ND	ND	ND
SB-14-554	SB-14-40B	38	40	190	156	112	440,000		11,000	754.8		<	11,000	ND	ND	ND
SB-14-555	SB-14-14	12	14	191	199	160	1,100		310	1.6		<	310	ND	ND	ND
SB-14-556	SB-14-44	42	44	191	258	184	650,000		18,000	1,264.5		<	18,000	ND	ND	ND
SB-14-557	SB-14-46	44	46	189	219	164	1,100,000		48,000	1,896.4		<	48,000	ND	ND	ND
SB-14-558	SB-14-BLANK	MeOH Blank Sample		184	0	0		<	250	ND		<	250	ND	ND	ND
SB-15-569	SB-15-2	0	2	191	174	167		<	360	ND		<	360	ND	ND	ND
SB-15-570	SB-15-4	2	4	190	107	102	180	J	590	0.2		<	590	ND	ND	ND
SB-15-571	SB-15-6	4	6	192	82	80	430	J	760	0.4		<	760	ND	ND	ND
SB-15-572	SB-15-8	6	8	190	125	120	410	J	500	0.4		<	500	ND	ND	ND
SB-15-573	SB-15-10	8	10	191	154	131	580	R	460	0.8		<	460	ND	ND	ND
SB-15-574	SB-15-12	10	12	190	210	174	1,100	R	300	1.6		<	300	ND	ND	ND
SB-15-575	SB-15-14	12	14	193	214	177	3,300	R	300	4.8		<	300	ND	ND	ND
SB-15-576	SB-15-16	14	16	191	208	170	340	R	310	0.5		<	310	ND	ND	ND
SB-15-577	SB-15-18	16	18	191	251	206	1,400	R	300	2.1	280	J	300	0.4	ND	ND
SB-15-578	SB-15-20	18	20	190	188	151	860	R	400	1.3		<	400	ND	ND	ND
SB-15-579	SB-15-22	20	22	190	170	140	20,000		1,400	28.1		<	1,400	ND	ND	ND
SB-15-580	SB-15-24	22	24	191	210	163	150,000		6,400	240.8		<	6,400	ND	ND	ND
SB-15-581	SB-15-24B	22	24	190	240	189	140,000		6,400	225.5		<	6,400	ND	ND	ND
SB-15-582	SB-15-26	24	26	191	203	167	2,100,000		100,000	3,033.8		<	100,000	ND	ND	ND
SB-15-583	SB-15-28	26	28	193	231	176	7,900,000		220,000	13,323.6		<	220,000	ND	ND	ND
SB-15-584	SB-15-30	28	30	192	175	136	11,000,000		890,000	17,029.5		<	890,000	ND	ND	ND
SB-15-585	SB-15-32	30	32	193	190	141	290,000		14,000	490.0		<	14,000	ND	ND	ND
SB-15-586	SB-15-34	32	34	193	293	216	350,000		23,000	664.2		<	23,000	ND	ND	ND
SB-15-587	SB-15-38	36	38	193	259	195	10,000,000		660,000	17,686.5		<	660,000	ND	ND	ND
SB-15-588	SB-15-40	38	40	190	286	226	6,800,000		210,000	11,322.8		<	210,000	ND	ND	ND
SB-15-589	SB-15-42	40	42	192	216	173	1,800,000		62,000	2,750.7		<	62,000	ND	ND	ND
SB-15-590	SB-15-44	42	44	193	235	168	2,300,000		58,000	4,334.1		<	58,000	ND	ND	ND
SB-15-591	SB-15-46	44	46	192	253	194	3,900,000		81,000	6,649.0		<	81,000	ND	ND	ND
SB-15-592	SB-15-BLANK	MeOH Blank Sample		192	0	0	780	1	250	1.2		<	250	ND	ND	ND
SB-16-390	SB-16-2	0	2	190	150	138		<	400	ND		<	400	ND	ND	ND
SB-16-391	SB-16-4	2	4	192	175	161		<	350	ND		<	350	ND	ND	ND
SB-16-392	SB-16-6	4	6	190	217	206		<	250	ND		<	250	ND	ND	ND
SB-16-393	SB-16-8	6	8	193	56	44	200	J	1,100	0.3		<	1,100	ND	ND	ND
SB-16-394	SB-16-10	8	10	192	124	100	130	J	490	0.2		<	490	ND	ND	ND
SB-16-395	SB-16-12	10	12	191	185	157	220	J	330	0.3		<	330	ND	ND	ND
SB-16-396	SB-16-12B	10	12	191	166	140	210	J	360	0.3		<	360	ND	ND	ND
SB-16-397	SB-16-14	12	14	190	224	177	130	J	250	0.2		<	250	ND	ND	ND
SB-16-397	SB-16-14	12	14	190	224	177	140	J	250	0.2		<	250	ND	ND	ND
SB-16-398	SB-16-16	14	16	188	162	135		<	370	ND		<	370	ND	ND	ND
SB-16-399	SB-16-18	16	18	192	162	131	1,800		370	2.6	390		370	0.6	ND	ND
SB-16-400	SB-16-20	18	20	192	207	160	9,000		500	14.5	860		500	1.4	ND	ND
SB-16-401	SB-16-22	20	22	191	119	102	15,000		1,000	19.1	250	J	1,000	0.3	ND	ND
SB-16-401	SB-16-22	20	22	191	119	102	16,000		510	20.3		<	510	ND	ND	ND
SB-16-402	SB-16-26	24	26	193	210	163	170,000		8,300	272.4		<	8,300	ND	ND	ND

Table C-3. Pre-Demo Results of Soil Samples (Continued)

Analytical Sample ID	Sample ID	Sample Depth (ft)		MeOH (g)	Wet Soil Weight (g)	Dry Soil Weight (g)	TCE				*cis*-1,2-DCE				*trans*-1,2-DCE	Vinyl Chloride
		Top Depth	Bottom Depth				Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Result in Wet Soil (µg/kg)
SB-16-403	SB-16-28	26	28	188	227	166	170,000		5,000	307.9		<	5,000	ND	ND	ND
SB-16-404	SB-16-30	28	30	189	227	166	220,000		6,200	397.9		<	6,200	ND	ND	ND
SB-16-405	SB-16-32	30	32	189	197	149	200,000		5,000	331.6		<	5,000	ND	ND	ND
SB-16-406	SB-16-34	32	34	190	167	129	130,000		3,600	202.0	1,600	J	3,600	2.5	ND	ND
SB-16-407	SB-16-36	34	36	191	196	150	140,000		5,000	227.0	4,500	J	5,000	7.3	ND	ND
SB-16-408	SB-16-38	36	38	189	240	147	120,000		5,000	292.3	29,000		5,000	70.6	ND	ND
SB-16-409	SB-16-40	38	40	194	145	109	54,000		1,400	85.2	29,000		1,400	45.7	ND	ND
SB-16-410	SB-16-42	40	42	192	208	161	140,000		6,200	225.1	3,700	J	6,200	6.0	ND	ND
SB-16-411	SB-16-44	42	44	192	189	145	170,000	E	3,200	272.4		<	3,200	ND	ND	ND
SB-16-411	SB-16-44	42	44	192	189	145	180,000	D	6,400	288.4		<	3,200	ND	ND	ND
SB-16-412	SB-16-46	44	46	195	203	170	35,000		2,500	48.9	1,600	J	2,500	2.2	ND	ND
SB-16-413	SB-16-24	22	24	189	197	152	110,000		6,200	176.5		<	6,200	ND	ND	ND
SB-16-414	SB-16-BLANK	MeOH Blank Sample		NA	0	0		<	250	ND		<	250	ND	ND	ND
SB-17-365	SB-17-2	0	2	187	101	94	120	J	580	0.1		<	580	ND	ND	ND
SB-17-366	SB-17-4	2	4	188	153	143		<	390	ND		<	390	ND	ND	ND
SB-17-367	SB-17-6	4	6	186	180	167	350		330	0.4		<	330	ND	ND	ND
SB-17-368	SB-17-8	6	8	186	127	107		<	460	ND		<	460	ND	ND	ND
SB-17-369	SB-17-10	8	10	193	176	148		<	350	ND		<	350	ND	ND	ND
SB-17-370	SB-17-12	10	12	189	139	115		<	430	ND		<	430	ND	ND	ND
SB-17-371	SB-17-14	12	14	188	220	183	250		250	0.4		<	250	ND	ND	ND
SB-17-372	SB-17-16	14	16	193	190	149	760		320	1.2		<	320	ND	ND	ND
SB-17-373	SB-17-18	16	18	188	164	145	330	J	360	0.4		<	360	ND	ND	ND
SB-17-374	SB-17-20	18	20	189	192	150	9,000		500	14.1		<	500	ND	ND	ND
SB-17-375	SB-17-22	20	22	188	182	140	29,000		1,300	46.1	730	J	1,300	1.2	ND	ND
SB-17-376	SB-17-24	22	24	188	221	185	3,100,000		170,000	4,412.4		<	170,000	ND	ND	ND
SB-17-377	SB-17-26	24	26	192	195	154	140,000		5,000	215.1		<	5,000	ND	ND	ND
SB-17-378	SB-17-28	26	28	190	137	106	140,000		5,500	210.5		<	5,500	ND	ND	ND
SB-17-379	SB-17-30	28	30	191	208	151	190,000		6,200	339.8		<	6,200	ND	ND	ND
SB-17-380	SB-17-32	30	32	192	171	124	210,000		7,100	360.5		<	7,100	ND	ND	ND
SB-17-381	SB-17-34	32	34	192	119	97	140,000		5,100	191.4		<	5,100	ND	ND	ND
SB-17-382	SB-17-34B	32	34	192	125	98	140,000		4,900	203.7		<	4,900	ND	ND	ND
SB-17-383	SB-17-36	34	36	193	238	184	130,000		5,000	215.2		<	5,000	ND	ND	ND
SB-17-384	SB-17-38	36	38	188	145	112	170,000		5,900	258.7		<	5,900	ND	ND	ND
SB-17-385	SB-17-40	38	40	190	191	141	110,000		4,500	188.2	2,400	J	4,500	4.1	ND	ND
SB-17-386	SB-17-42	40	42	186	218	173	100,000		3,600	156.5		<	3,600	ND	ND	ND
SB-17-387	SB-17-44	42	44	193	202	157	87,000		2,500	138.0	1,400	J	2,500	2.2	ND	ND
SB-17-388	SB-17-46	44	46	185	168	126	150,000		5,800	245.4		<	5,800	ND	ND	ND
SB-17-389	SB-17-BLANK	MeOH Blank Sample		NA	0	0	130	J, 1	250	0.2		<	250	ND	ND	ND
SB-18-293	SB-18-2		2	192	131	125	340	J	460	0.4		<	460	ND	ND	ND
SB-18-294	SB-18-4	2	4	189	178	168	190	J	340	0.2	230	J	340	0.3	ND	ND
SB-18-295	SB-18-6	4	6	188	187	175	270	J	320	0.3	220	J	320	0.3	ND	ND
SB-18-296	SB-18-8	6	8	190	71	63	5,700	R	850	6.7		<	850	ND	ND	ND
SB-18-297	SB-18-10	8	10	188	147	121	210	J	400	0.3		<	400	ND	ND	ND
SB-18-298	SB-18-12	10	12	194	186	154	360	R	330	0.5		<	330	ND	ND	ND
SB-18-299	SB-18-14	12	14	191	182	146	290	J	330	0.4		<	330	ND	ND	ND

Table C-3. Pre-Demo Results of Soil Samples (Continued)

Analytical Sample ID	Sample ID	Sample Depth (ft)		MeOH (g)	Wet Soil Weight (g)	Dry Soil Weight (g)	TCE				*cis*-1,2-DCE				*trans*-1,2-DCE	Vinyl Chloride
		Top Depth	Bottom Depth				Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Result in Wet Soil (µg/kg)
SB-18-300	SB-18-16	14	16	189	145	113	140	J	410	0.2	160	J	410	0.2	ND	ND
SB-18-301	SB-18-18	16	18	189	183	149	4,100	R	250	5.9	460		250	0.7	ND	ND
SB-18-302	SB-18-20	18	20	190	176	142	24,000	R	1,400	35.1	560	J	1,400	0.8	ND	ND
SB-18-303	SB-18-22	20	22	189	107	80	72,000	R	4,000	110.1		<	4,000	ND	ND	ND
SB-18-304	SB-18-22B	20	22	190	105	87	45,000	R	2,900	59.5		<	2,900	ND	ND	ND
SB-18-305	SB-18-24	22	24	185	213	178	2,600,000		72,000	3,699.8		<	72,000	ND	ND	ND
SB-18-306	SB-18-26	24	26	186	198	151	4,200,000		100,000	6,898.9		<	100,000	ND	ND	ND
SB-18-307	SB-18-28	26	28	187	174	136	700,000	E	6,800	1,077.6		<	6,800	ND	ND	ND
SB-18-307	SB-18-28	26	28	187	174	136	920,000	D	34,000	1,416.2		<	6,800	ND	ND	ND
SB-18-308	SB-18-30	28	30	191	171	128	270,000		10,000	441.9		<	10,000	ND	ND	ND
SB-18-309	SB-18-32	30	32	191	155	115	360,000		19,000	586.8		<	19,000	ND	ND	ND
SB-18-310	SB-18-34	32	34	190	123	96	220,000		9,800	321.9		<	9,800	ND	ND	ND
SB-18-311	SB-18-36	34	36	189	206	168	1,200,000		29,000	1,767.3		<	29,000	ND	ND	ND
SB-18-312	SB-18-38	36	38	190	175	129	1,900,000		57,000	3,201.6		<	57,000	ND	ND	ND
SB-18-313	SB-18-40	38	40	189	149	99	4,400,000		130,000	8,374.1		<	130,000	ND	ND	ND
SB-18-314	SB-18-42	40	42	190	143	110	510,000		17,000	778.2		<	17,000	ND	ND	ND
SB-18-315	SB-18-44	42	44	190	142	106	210,000		11,000	334.6		<	11,000	ND	ND	ND
SB-18-316	SB-18-46	44	46	187	254	199	5,400,000		170,000	8,919.7		<	170,000	ND	ND	ND
SB-18-317	SB-18-BLANK	MeOH Blank Sample		NA	0	0	5,100	1	250	8.0		<	250	ND	ND	ND
SB-19-268	SB-19-2	0	2	189	138.1	135	410	J	430	0.4		<	430	ND	ND	ND
SB-19-269	SB-19-4	2	4	190	106.8	99	470	J	560	0.5	160	J	560	0.2	ND	ND
SB-19-270	SB-19-6	4	6	190	93.7	88	630	J	640	0.7	190	J	640	0.2	ND	ND
SB-19-271	SB-19-8	6	8	190	112.6	93	2,200		530	2.9		<	530	ND	ND	ND
SB-19-272	SB-19-10	8	10	191	141.2	119	5,600		430	7.4		<	430	ND	ND	ND
SB-19-273	SB-19-12	10	12	189	223.3	187	420		250	0.6		<	250	ND	ND	ND
SB-19-274	SB-19-14	12	14	190	174	145	6,300		340	8.7		<	340	ND	ND	ND
SB-19-275	SB-19-16	14	16	190	180.8	147	300	J	330	0.4		<	330	ND	ND	ND
SB-19-276	SB-19-18	16	18	190	167.3	135	730		360	1.1	220	J	360	0.3	ND	ND
SB-19-277	SB-19-20	18	20	191	208.7	170	1,700		250	2.5	430		250	0.6	ND	ND
SB-19-278	SB-19-22	20	22	190	210.9	176	8,200		250	11.6	1,000		250	1.4	ND	ND
SB-19-279	SB-19-24	22	24	190	205.5	158	71,000		2,500	115.4		<	2,500	ND	ND	ND
SB-19-280	SB-19-26	24	26	190	192.2	94	68,000		1,800	210.9		<	1,800	ND	ND	ND
SB-19-281	SB-19-28	26	28	192	160.6	109	150,000		5,400	280.4		<	5,400	ND	ND	ND
SB-19-282	SB-19-30	28	30	191	228.8	163	98,000		3,600	185.0		<	3,600	ND	ND	ND
SB-19-283	SB-19-30B	28	30	188	261.2	200	100,000		3,800	173.1		<	3,800	ND	ND	ND
SB-19-284	SB-19-32	30	32	191	157.2	123	83,000		2,700	125.1		<	2,700	ND	ND	ND
SB-19-285	SB-19-34	32	34	190	140.4	114	63,000		3,600	88.4		<	3,600	ND	ND	ND
SB-19-286	SB-19-36	34	36	189	196.5	153	83,000		3,100	131.1		<	3,100	ND	ND	ND
SB-19-287	SB-19-38	36	38	189	144.2	113	79,000		4,100	117.5		<	4,100	ND	ND	ND
SB-19-288	SB-19-40	38	40	191	244	167	97,000		4,200	198.9	3,500	J	4,200	7.2	ND	ND
SB-19-289	SB-19-42	40	42	190	151	120	49,000		2,300	71.7	2,500		2,300	3.7	ND	ND
SB-19-290	SB-19-44	42	44	192	160	123	75,000		3,800	116.4		<	3,800	ND	ND	ND
SB-19-291	SB-19-46	44	46	190	213.8	166	95,000		3,600	153.1		<	3,600	ND	ND	ND
SB-19-292	SB-19-BLANK	MeOH Blank Sample		NA	0	0	130	J,1	250	0.2		<	250	ND	ND	ND
SB-20-318	SB-20-2	0	2	189	106.8	99	4,200		560	4.7		<	560	ND	ND	ND

Table C-3. Pre-Demo Results of Soil Samples (Continued)

Analytical Sample ID	Sample ID	Sample Depth (ft)		MeOH (g)	Wet Soil Weight (g)	Dry Soil Weight (g)	TCE				*cis* -1,2-DCE				*trans* -1,2-DCE	Vinyl Chloride
		Top Depth	Bottom Depth				Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Result in Wet Soil (µg/kg)
SB-20-319	SB-20-4	2	4	193	83	77	880	R	730	1.0		<	730	ND	ND	ND
SB-20-320	SB-20-6	4	6	186	142.2	131	6,800		410	7.8		<	410	ND	ND	ND
SB-20-321	SB-20-8	6	8	189	104	87	120	J	570	0.2		<	570	ND	ND	ND
SB-20-322	SB-20-10	8	10	192	94	81		<	640	ND		<	640	ND	ND	ND
SB-20-323	SB-20-12	10	12	192	173	147		<	350	ND		<	350	ND	ND	ND
SB-20-324	SB-20-14	12	14	190	164	137		<	370	ND		<	370	ND	ND	ND
SB-20-325	SB-20-16	14	16	193	156	128	190	J	390	0.3		<	390	ND	ND	ND
SB-20-326	SB-20-18	16	18	194	145	120	1,300	R	420	1.8	520		420	0.7	ND	ND
SB-20-327	SB-20-20	18	20	189	94	74	8,100		640	11.4	170	J	640	0.2	ND	ND
SB-20-328	SB-20-22	20	22	190	150	121	53,000		2,000	75.7	730	J	2,000	1.0	ND	ND
SB-20-329	SB-20-24	22	24	190	231	180	99,000		3,600	161.2		<	3,600	ND	ND	ND
SB-20-330	SB-20-26	24	26	189	253	199	110,000		5,000	179.8		<	5,000	ND	ND	ND
SB-20-331	SB-20-26B	24	26	191	179	140	120,000		4,800	184.8		<	4,800	ND	ND	ND
SB-20-332	SB-20-28	26	28	191	243	140	200,000		8,300	534.3		<	8,300	ND	ND	ND
SB-20-332	SB-20-28	26	28	191	243	140	170,000		6,200	454.2		<	6,200	ND	ND	ND
SB-20-333	SB-20-30	28	30	187	114	82	160,000		5,200	260.5		<	5,200	ND	ND	ND
SB-20-334	SB-20-32	30	32	187	139	103	130,000		4,200	209.2		<	4,200	ND	ND	ND
SB-20-335	SB-20-34	32	34	186	147	120	140,000		5,700	196.4		<	5,700	ND	ND	ND
SB-20-335	SB-20-34	32	34	186	147	120	120,000		5,000	168.3		<	5,000	ND	ND	ND
SB-20-336	SB-20-36	34	36	191	194	152	110,000		3,600	171.3		<	3,600	ND	ND	ND
SB-20-337	SB-20-38	36	38	186	174	135	120,000		3,400	187.1		<	3,400	ND	ND	ND
SB-20-338	SB-20-40	38	40	190	233	179	92,000		4,200	153.8		<	4,200	ND	ND	ND
SB-20-339	SB-20-44	42	44	189	219	169	150,000		5,000	245.8		<	5,000	ND	ND	ND
SB-20-340	SB-20-46	44	46	189	122	167	15,000,000		490,000	8,349.0		<	490,000	ND	ND	ND
SB-20-341	SB-20-BLANK	MeOH Blank Sample		NA	0	0	600	1	250	0.9		<	250	ND	ND	ND
SB-21-245	SB-21-2	0	2	192	86	80	310	J	710	0.3	440	J	710	0.5	ND	ND
SB-21-246	SB-21-4	2	4	187	58	52	600	J	1,000	0.7	610	J	1,000	0.7	ND	ND
SB-21-247	SB-21-6	4	6	191	75	64	200	J	800	0.2	200	J	800	0.2	ND	ND
SB-21-248	SB-21-8	6	8	189	129	95.2		<	460	ND	180	J	460	0.3	ND	ND
SB-21-249	SB-21-10	8	10	190	123	109	220	J	490	0.3		<	490	ND	ND	ND
SB-21-250	SB-21-12	10	12	193	146	116	290	J	420	0.4	360	J	420	0.5	ND	ND
SB-21-251	SB-21-14	12	14	190	101	85	580	J	590	0.7	260	J	590	0.3	ND	ND
SB-21-252	SB-21-16	14	16	191	154	131	350	J	390	0.5	230	J	390	0.3	ND	ND
SB-21-253	SB-21-18	16	18	189	136	120	900		440	1.1	300	J	440	0.4	ND	ND
SB-21-254	SB-21-20	18	20	193	157.3	125	2,300		390	3.4	170	J	390	0.2	ND	ND
SB-21-255	SB-21-22	20	22	190	159.1	129	36,000		1,900	51.4		<	1,900	ND	ND	ND
SB-21-256	SB-21-24	22	24	188	170.4	134	48,000		2,500	72.9		<	2,500	ND	ND	ND
SB-21-257	SB-21-26	24	26	189	146.1	115	44,000		2,000	65.1		<	2,000	ND	ND	ND
SB-21-258	SB-21-28	26	28	190	192.8	141	130,000		2,500	226.2		<	2,500	ND	ND	ND
SB-21-259	SB-21-32	30	32	189	160	122	120,000		6,200	189.0		<	6,200	ND	ND	ND
SB-21-260	SB-21-34	32	34	187	222.2	182	66,000		2,500	97.9		<	2,500	ND	ND	ND
SB-21-261	SB-21-36	34	36	192	260.8	205	7,100,000	E	120,000	11,657.7		<	120,000	ND	ND	ND
SB-21-261	SB-21-36	34	36	192	260.8	205	4,800,000	D	250,000	7,881.2		<	250,000	ND	ND	ND
SB-21-262	SB-21-38	36	38	194	184.3	148	5,000,000		170,000	7,391.4		<	170,000	ND	ND	ND
SB-21-263	SB-21-40	38	40	193	264.3	NA	4,700,000	1	500,000	7,397.8		<	500,000	ND	ND	ND
SB-21-264	SB-21-42	40	42	188	120.6	95	4,100,000		98,000	5,913.6		<	98,000	ND	ND	ND

Table C-3. Pre-Demo Results of Soil Samples (Continued)

Analytical Sample ID	Sample ID	Sample Depth (ft)		MeOH	Wet Soil	Dry Soil	TCE				*cis* -1,2-DCE				*trans* -1,2-DCE	Vinyl Chloride
		Top Depth	Bottom Depth	(g)	Weight (g)	Weight (g)	Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Result in Wet Soil (µg/kg)
SB-21-265	SB-21-42B	40	42	190	178.7	140	5,800,000		220,000	8,911.2		<	220,000	ND	ND	ND
SB-21-266	SB-21-44	42	44	192	210.7	154	5,900,000		170,000	10,456.1		<	170,000	ND	ND	ND
SB-21-267	SB-21-BLANK	MeOH Blank Sample		NA	0	0		<	250	ND		<	250	ND	ND	ND
SB-22-011	SB-22-2	0	2	191	168.2	161.2	2,700		250	2.9		<	250	ND	ND	ND
SB-22-012	SB-22-4	2	4	193	284.2	275.3		<	250	ND		<	250	ND	ND	ND
SB-22-013	SB-22-6	4	6	191	252.2	229.8	1,600		250	2.0		<	250	ND	ND	ND
SB-22-014	SB-22-8	6	8	192	162.2	142.2		<	250	ND		<	250	ND	ND	ND
SB-22-015	SB-22-10	8	10	193	130.2	100.4		<	250	ND		<	250	ND	ND	ND
SB-22-016	SB-22-12	10	12	191	184.2	151.6		<	250	ND		<	250	ND	ND	ND
SB-22-017	SB-22-14	12	14	190	184.2	151.6		<	250	ND		<	250	ND	ND	ND
SB-22-018	SB-22-16	14	16	193	224.2	186.9	1,800		250	2.6		<	250	ND	ND	ND
SB-22-019	SB-22-16B	14	16	192	292.2	236.9	1,300		250	2.1		<	250	ND	ND	ND
SB-22-020	SB-22-18	16	18	191	184.2	155	420		250	0.6		<	250	ND	ND	ND
SB-22-021	SB-22-20	18	20	193	176.2	138.9	4,400		500	6.7		<	250	ND	ND	ND
SB-22-022	SB-22-22	20	22	192	162.2	131.9	8,800		1,000	12.5		<	250	ND	ND	ND
SB-22-023	SB-22-24	22	24	189	144.2	120.2	37,000		2,000	50.0		<	250	ND	ND	ND
SB-22-024	SB-22-26	24	26	193	186.2	155.5	40,000		5,000	55.5		<	250	ND	ND	ND
SB-22-025	SB-22-28	26	28	190	186.6	143.1	97,000		12,000	155.4		<	250	ND	ND	ND
SB-22-026	SB-22-30	28	30	190	233.5	177.1	84,000		12,000	143.6		<	250	ND	ND	ND
SB-22-027	SB-22-32	30	32	192	239.1	197.2	39,000		5,000	57.6		<	250	ND	ND	ND
SB-22-028	SB-22-34	32	34	188	193.2	168.5	39,000		2,500	50.6		<	250	ND	ND	ND
SB-22-029	SB-22-36	34	36	191	254.2	193.6	49,000	E	3,100	84.8	11,000		3,100	19.0	ND	ND
SB-22-029	SB-22-36	34	36	191	254.2	193.6	52,000	D	5,000	89.9		<	250	ND	ND	ND
SB-22-030	SB-22-38	36	38	191	266.2	203	95,000		12,000	165.8		<	250	ND	ND	ND
SB-22-031	SB-22-40	38	40	188	252.2	202	85,000	E	5,000	134.5		<	250	ND	ND	ND
SB-22-031	SB-22-40	38	40	188	252.2	202	73,000	D	10,000	115.5		<	250	ND	ND	ND
SB-22-032	SB-22-42	40	42	190	154.2	130	69,000	E	2,500	92.3		<	250	ND	ND	ND
SB-22-032	SB-22-42	40	42	190	154.2	130	78,000	D	5,000	104.3		<	250	ND	ND	ND
SB-22-033	SB-22-44	42	44	190	279.2	227	37,000	E	2,500	58.0	2,900		2,500	4.5	ND	ND
SB-22-033	SB-22-44	42	44	190	279.2	227	36,000	D	5,000	56.4		<	250	ND	ND	ND
SB-22-035	SB-22-46	44	46	188	211.2	161	13,000		1,000	21.6	2,100		1,000	3.5	ND	ND
SB-22-055	SB-22-BLANK	MeOH Blank Sample		NA	0	0		<	250	ND		<	250	ND	ND	ND
SB-23-001	SB-23-2	0	2	191	256.2	243.7		<	250	ND		<	250	ND	ND	ND
SB-23-002	SB-23-4	2	4	191	270.2	263	1,700		250	1.8		<	250	ND	ND	ND
SB-23-003	SB-23-6	4	6	191	250.2	233	1,600		250	1.9		<	250	ND	ND	ND
SB-23-056	SB-23-8	6	8	193	136	114.8		<	450	ND		<	450	ND	ND	ND
SB-23-057	SB-23-10	8	10	191	126	101		<	480	ND		<	480	ND	ND	ND
SB-23-058	SB-23-12	10	12	193	196	161.8		<	250	ND		<	250	ND	ND	ND
SB-23-059	SB-23-14	12	14	192	156	125.8	210	J	390	0.3		<	390	ND	ND	ND
SB-23-060	SB-23-16	14	16	190	163	136.8		<	370	ND		<	370	ND	ND	ND
SB-23-061	SB-23-18	16	18	192	123	100	540		490	0.7	190	J	490	0.3	ND	ND
SB-23-062	SB-23-20	18	20	192	214	179.2	940		250	1.3	560		250	0.8	ND	ND
SB-23-063	SB-23-22	20	22	190	199	160.2	40,000		1,200	59.8	1,200		1,200	1.8	ND	ND
SB-23-064	SB-23-24	22	24	186	162	123.9	100,000		3,600	157.5		<	3,600	ND	ND	ND
SB-23-065	SB-23-26	24	26	193	147	111	110,000		4,100	172.8		<	4,100	ND	ND	ND

Table C-3. Pre-Demo Results of Soil Samples (Continued)

Analytical Sample ID	Sample ID	Sample Depth (ft)		MeOH	Wet Soil	Dry Soil	TCE				*cis*-1,2-DCE				*trans*-1,2-DCE	Vinyl Chloride
		Top Depth	Bottom Depth	(g)	Weight (g)	Weight (g)	Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Result in Wet Soil (µg/kg)
SB-23-066	SB-23-28	26	28	193	143	102	160,000		5,700	272.0		<	5,700	ND	ND	ND
SB-23-067	SB-23-30	28	30	193	215	153.9	180,000		5,000	331.1		<	5,000	ND	ND	ND
SB-23-068	SB-23-32	30	32	192	177	123.9	170,000		6,800	310.0		<	6,800	ND	ND	ND
SB-23-069	SB-23-34	32	34	192	185	146.6	97,000		3,300	146.9		<	3,300	ND	ND	ND
SB-23-070	SB-23-34B	32	34	193	124	97.9	87,000		3,300	125.1		<	3,300	ND	ND	ND
SB-23-071	SB-23-36	34	36	188	167	132	68,000		2,000	102.0		<	2,000	ND	ND	ND
SB-23-072	SB-23-38	36	38	192	142	NA	170,000	1	5,700	267.6		<	5,700	ND	ND	ND
SB-23-073	SB-23-40	38	40	193	131	92	130,000		6,200	222.5		<	6,200	ND	ND	ND
SB-23-074	SB-23-42	40	42	188	174	132.4	90,000		3,400	144.5		<	3,400	ND	ND	ND
SB-23-075	SB-23-45	43	45	192	189	NA	84,000	E,1	320	132.2		<	320	ND	ND	ND
SB-23-075	SB-23-45	43	45	192	189	NA	95,000	D,1	6,400	149.5		<	320	ND	ND	ND
SB-23-076	SB-23-BLANK	MeOH Blank Sample		NA	0	0	750	1	250	1.8		<	250	ND	ND	ND
SB-24-149	SB-24-2	0	2	192	120	112	440		250	0.5		<	250	ND	ND	ND
SB-24-150	SB-24-4	2	4	191	120	113	250		250	0.3		<	250	ND	ND	ND
SB-24-151	SB-24-6	4	6	191	195	175		<	250	ND		<	250	ND	ND	ND
SB-24-152	SB-24-8	6	8	189	59	47		<	250	ND		<	250	ND	ND	ND
SB-24-153	SB-24-10	8	10	190	143	115	6,000		500	8.6		<	500	ND	ND	ND
SB-24-154	SB-24-12	10	12	190	97	80	5,600		250	7.4		<	250	ND	ND	ND
SB-24-155	SB-24-14	12	14	190	187	142	2,600		250	4.2		<	250	ND	ND	ND
SB-24-156	SB-24-16	14	16	193	123	100	3,900		250	5.4		<	250	ND	ND	ND
SB-24-157	SB-24-18	16	18	191	135	110	3,700		250	5.1	260		250	0.4	ND	ND
SB-24-158	SB-24-20	18	20	191	113	86	6,700		500	10.0		<	500	ND	ND	ND
SB-24-159	SB-24-22	20	22	190	205	161	22,000		2,500	34.5		<	2,500	ND	ND	ND
SB-24-160	SB-24-24	22	24	192	137	103	37,000		2,500	57.9		<	2,500	ND	ND	ND
SB-24-161	SB-24-26	24	26	191	250	204	39,000		5,000	59.3		<	5,000	ND	ND	ND
SB-24-162	SB-24-28	26	28	190	159	120	120,000		10,000	191.6		<	10,000	ND	ND	ND
SB-24-163	SB-24-30	28	30	190	216	163	81,000		10,000	137.3		<	10,000	ND	ND	ND
SB-24-164	SB-24-32	30	32	191	171	136	57,000		5,000	84.8		<	5,000	ND	ND	ND
SB-24-165	SB-24-34	32	34	190	132	106	44,000		5,000	62.3		<	5,000	ND	ND	ND
SB-24-166	SB-24-36	34	36	190	194	138	85,000		10,000	154.7		<	10,000	ND	ND	ND
SB-24-167	SB-24-38	36	38	191	114	84	280,000		12,000	439.7		<	12,000	ND	ND	ND
SB-24-168	SB-24-40	38	40	190	261	184	51,000		10,000	101.7		<	10,000	ND	ND	ND
SB-24-169	SB-24-42	40	42	191	166	129	28,000		2,000	43.0	10,000		2,000	15.4	ND	ND
SB-24-170	SB-24-42B	40	42	189	146	115	24,000		2,000	35.5	8,500		2,000	12.6	ND	ND
SB-24-171	SB-24-44	42	44	191	151	115	73,000		5,000	113.9		<	5,000	ND	ND	ND
SB-24-172	SB-24-46	44	46	190	165	126	88,000		10,000	138.9		<	10,000	ND	ND	ND
SB-24-173	SB-24-BLANK	MeOH Blank Sample		NA	0	0		<	250	ND		<	250	ND	ND	ND
SB-25-463	SB-25-2	0	2	189	179	157	250	J	330	0.3		<	330	ND	ND	ND
SB-25-464	SB-25-4	2	4	190	147	131	140	J	410	0.2		<	410	ND	ND	ND
SB-25-465	SB-25-6	4	6	192	187	165	220	J	320	0.3		<	320	ND	ND	ND
SB-25-466	SB-25-8	6	8	193	216	176	240	J	250	0.4		<	250	ND	ND	ND
SB-25-467	SB-25-12	10	12	191	193	163	470		310	0.6		<	310	ND	ND	ND
SB-25-468	SB-25-14	12	14	192	192	154	350		320	0.5		<	320	ND	ND	ND
SB-25-469	SB-25-16	14	16	191	168	141	400		360	0.5		<	360	ND	ND	ND
SB-25-470	SB-25-18	16	18	189	172	133	1,000		350	1.6	690		350	1.1	ND	ND

Table C-3. Pre-Demo Results of Soil Samples (Continued)

Analytical Sample ID	Sample ID	Sample Depth (ft)		MeOH (g)	Wet Soil Weight (g)	Dry Soil Weight (g)	TCE				*cis*-1,2-DCE				*trans*-1,2-DCE	Vinyl Chloride
		Top Depth	Bottom Depth				Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Qual	Reporting Limit	Result in Dry Soil (mg/kg)	Result in Wet Soil (µg/kg)	Result in Wet Soil (µg/kg)
SB-25-471	SB-25-18B	16	18	189	173	127	1,400		340	2.4	790		340	1.3	ND	ND
SB-25-472	SB-25-20	18	20	189	148	112	4,900		400	7.7	1,200		400	1.9	ND	ND
SB-25-473	SB-25-22	20	22	192	205	156	9,000		500	14.8	1,600		500	2.6	ND	ND
SB-25-474	SB-25-24	22	24	188	161	127	130,000		6,100	194.6		<	6,100	ND	ND	ND
SB-25-475	SB-25-26	24	26	192	289	220	140,000		8,300	250.0		<	8,300	ND	ND	ND
SB-25-476	SB-25-28	26	28	192	157	112	250,000		7,700	432.6	4,200	J	7,700	7.3	ND	ND
SB-25-477	SB-25-30	28	30	190	231	169	220,000		8,300	398.8		<	8,300	ND	ND	ND
SB-25-478	SB-25-32	30	32	193	185	154	14,000		660	19.5	3,300		660	4.6	ND	ND
SB-25-479	SB-25-34	32	34	190	198	154	160,000		5,000	253.4		<	5,000	ND	ND	ND
SB-25-480	SB-25-36	34	36	192	201	165	66,000		2,100	95.5	1,100	J	2,100	1.6	ND	ND
SB-25-481	SB-25-38	36	38	191	259	183	120,000		5,000	237.4	4,500	J	5,000	8.9	ND	ND
SB-25-482	SB-25-40	38	40	192	204	149	47,000		1,800	82.8	21,000		1,800	37.0	ND	ND
SB-25-483	SB-25-42	40	42	191	224	162	60,000		2,500	109.9	27,000		2,500	49.5	ND	ND
SB-25-484	SB-25-44	42	44	190	232	179	100,000		4,200	165.8	10,000		4,200	16.6	ND	ND
SB-25-485	SB-25-46	44	46	192	241	166	130,000		6,200	262.5		<	6,200	ND	ND	ND
SB-25-486	SB-25-BLANK	MeOH Blank Sample		NA	0	0		<	250	ND		<	250	ND	ND	ND

Notes:

NA: Not available.

ND: Not detected.

<: Result was not detected at or above the stated reporting limit.

1. Dry soil concentration is calculated as 1.57 times of wet soil concentration to account for average moisture content.

D: Result was obtained from the analysis of a dilution.

E: Estimated result. Result concentration exceeds the calibration range.

J: Result was estimated but below the reporting limit.

R: Corresponding rinsate blank contained more than 10 % of this sample result.

Table C-4. Post-Demo VOC Results of Soil Samples

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
DC-1-1	DC-1-2	0	2	5/24/2000	193	124	121	<250	ND	<250	ND	<250	ND	<500	ND
DC-1-2	DC-1-4	2	4	5/24/2000	196	153	146	330	0.6	<250	ND	<250	ND	<500	ND
DC-1-3	DC-1-6	4	6	5/24/2000	193	123	112	330	0.8	<250	ND	<250	ND	<500	ND
DC-2-4	DC-2-2	0	2	5/24/2000	193	123	118	1,500	3.2	<250	ND	<250	ND	<500	ND
DC-2-5	DC-2-4	2	4	5/24/2000	192	135	134	1,500	2.7	<250	ND	<250	ND	<500	ND
DC-2-6	DC-2-6	4	6	5/24/2000	165	105	99	3,100	6.7	260.0	0.6	<250	ND	<500	ND
DC-3-7	DC-3-2	0	2	5/24/2000	193	148	99	530	1.6	420.0	1.2	<250	ND	<500	ND
DC-3-8	DC-3-4	2	4	5/24/2000	193	186	108	650	1.9	<250	ND	<250	ND	<500	ND
DC-3-9	DC-3-6	4	6	5/24/2000	193	108	107	700	1.6	<250	ND	<250	ND	<500	ND
SB-213-213	SB213-2	0	2	5/24/2000	202	153	151	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-214	SB213-4	2	4	5/24/2000	196	145	141	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-215	SB213-6	4	6	5/24/2000	196	141	134	1,200	2.3	<250	ND	<250	ND	<500	ND
SB-213-216	SB213-8	6	8	5/24/2000	200	179	168	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-217	SB213-10	8	10	5/24/2000	196	148	119	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-239	SB213-12	10	12	5/24/2000	195	187	159	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-240	SB213-14	12	14	5/24/2000	196	184	152	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-241	SB213-16	14	16	5/24/2000	198	237	185	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-242	SB213-18	16	18	5/24/2000	198	288	227	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-243	SB213-20	18	20	5/24/2000	193	217	167	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-244	SB213-22	20	22	5/24/2000	199	240	192	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-245	SB213-24	22	24	5/24/2000	201	297	228	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-246	SB213-26	24	26	5/24/2000	199	257	200	<830	ND	15,000	23.2	<830	ND	<1,700	ND
SB-213-247	SB213-28	26	28	5/24/2000	202	242	180	<330	ND	5,900	10.4	<330	ND	<660	ND
SB-213-248	SB213-30	28	30	5/24/2000	199	254	185	<250	ND	2,700	4.7	<250	ND	<500	ND
SB-213-249	SB213-30B	28	30	5/24/2000	196	340	189	<250	ND	3,900	8.2	<250	ND	<500	ND
SB-213-250	SB213-32	30	32	5/24/2000	195	267	99	1,700	7.1	1,700	7.1	<250	ND	<500	ND
SB-213-251	SB213-34	32	34	5/24/2000	195	232	186	1,800	2.8	2,000	3.1	<250	ND	<500	ND
SB-213-252	SB213-36	34	36	5/24/2000	199	270	209	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-253	SB213-38	36	38	5/24/2000	199	253	197	<250	ND	1,400	2.2	<250	ND	<500	ND
SB-213-254	SB213-40	38	40	5/24/2000	203	212	154	1,100	2.2	1,800	3.7	<250	ND	<500	ND
SB-213-255	SB213-42	40	42	5/24/2000	197	219	178	3,500	5.7	1,700	2.8	<250	ND	<500	ND
SB-213-256	SB213-44	42	44	5/24/2000	199	272	194	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-257	SB213-46	44	46	5/24/2000	201	203	157	<250	ND	<250	ND	<250	ND	<500	ND
SB-213-258	SB213-46 *S*	44	46	5/24/2000	191	271	111	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-306	SB214-2	0	2	5/31/2000	192	225	211	<250	ND	<250	ND	<250	ND	<500	ND

Table C-4. Post-Demo VOC Results of Soil Samples (Continued)

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
SB-214-307	SB214-4	2	4	5/31/2000	195	190	185	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-308	SB214-6	4	6	5/31/2000	192	257	253	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-309	SB214-8	6	8	5/31/2000	195	101	104	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-310	SB214-10	8	10	5/31/2000	200	118	103	<250	ND	790	2.1	<250	ND	<500	ND
SB-214-311	SB214-12	10	12	5/31/2000	197	218	189	2,500	3.7	<250	ND	<250	ND	<500	ND
SB-214-312	SB214-14	12	14	5/31/2000	203	188	160	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-313	SB214-16	14	16	5/31/2000	192	185	158	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-314	SB214-18	16	18	5/31/2000	192	200	173	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-315	SB214-20	18	20	5/31/2000	192	232	199	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-316	SB214-22	20	22	5/31/2000	194	292	231	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-317	SB214-24	22	24	5/31/2000	198	277	133	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-318	SB214-26	24	26	5/31/2000	189	230	183	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-319	SB214-28	26	28	5/31/2000	190	265	215	<250	ND	<250	ND	<250	ND	<500	ND
SB-214-320	SB214-32	30	32	5/31/2000	193	295	217	21,000	31.2	<1,000	ND	<1,000	ND	<2,000	ND
SB-214-321	SB214-34	32	34	5/31/2000	193	273	218	210,000 D	288.3	<2,500	ND	<2,500	ND	<5,000	ND
SB-214-322	SB214-36	34	36	5/31/2000	185	246	189	780,000	1,201.7	<25,000	ND	<25,000	ND	<50,000	ND
SB-214-323	SB214-38	36	38	5/31/2000	196	280	238	80,000	97.5	<1,700	ND	<1,700	ND	<3,300	ND
SB-214-324	SB214-40	38	40	5/31/2000	194	260	180	460,000	832.0	<12,000	ND	<12,000	ND	<25,000	ND
SB-214-325	SB214-42	40	42	5/31/2000	194	322	250	260,000	330.3	<8,300	ND	<8,300	ND	<17,000	ND
SB-214-326	SB214-44	42	44	5/31/2000	193	303	239	12,000	15.5	<250	ND	<250	ND	<500	ND
SB-214-327	SB214-46	44	46	5/31/2000	191	317	257	180,000	211.4	<3,600	ND	<3,600	ND	<7,200	ND
SB-215-328	SB215-2	0	2	6/1/2000	189	214	208	330	0.4	<250	ND	<250	ND	<500	ND
SB-215-329	SB215-4	2	4	6/1/2000	196	249	240	350	0.4	<250	ND	<250	ND	<500	ND
SB-215-330	SB215-6	4	6	6/1/2000	194	240	146	250	0.6	<250	ND	<250	ND	<500	ND
SB-215-331	SB215-8	6	8	6/1/2000	200	158	153	<250	ND	<250	ND	<250	ND	<500	ND
SB-215-332	SB215-10	8	10	6/1/2000	197	177	169	670	1.0	<250	ND	<250	ND	<500	ND
SB-215-333	SB215-12	10	12	6/1/2000	192	244	207	340	0.5	700.0	0.9	<250	ND	<500	ND
SB-215-334	SB215-14	12	14	6/1/2000	192	233	198	<250	ND	<250	ND	<250	ND	<500	ND
SB-215-335	SB215-16	14	16	6/1/2000	196	295	257	<250	ND	<250	ND	<250	ND	<500	ND
SB-215-336	SB215-18	16	18	6/1/2000	192	324	267	35,000	39.3	<1,200	ND	<1,200	ND	<2,500	ND
SB-215-337	SB215-20	18	20	6/1/2000	195	194	167	51,000	83.6	<1,800	ND	<1,800	ND	<3,600	ND
SB-215-338	SB215-22	20	22	6/1/2000	196	307	240	4,700	6.2	<250	ND	<250	ND	<500	ND
SB-215-339	SB215-24	22	24	6/1/2000	200	321	264	210,000	246.7	<10,000	ND	<10,000	ND	<20,000	ND
SB-215-340	SB215-26	24	26	6/1/2000	190	212	173	1,400,000	2,261.9	<50,000	ND	<50,000	ND	<100,000	ND
SB-215-341	SB215-28	26	28	6/1/2000	191	216	171	5,800,000 D	9,726.8	<83,000	ND	<83,000	ND	<170,000	ND

Table C-4. Post-Demo VOC Results of Soil Samples (Continued)

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
SB-215-342	SB215-30	28	30	6/1/2000	196	198	151	200,000	390.9	<8,300	ND	<8,300	ND	<17,000	ND
SB-215-343	SB215-32	30	32	6/1/2000	194	267	196	2,100,000	3,391.8	<50,000	ND	<50,000	ND	<100,000	ND
SB-215-344	SB215-34	32	34	6/1/2000	193	380	298	3,400,000	3,722.9	<83,000	ND	<83,000	ND	<170,000	ND
SB-215-349	SB215-34B	32	34	6/1/2000	193	367	276	3,200,000 D	3,887.6	<50,000	ND	<50,000	ND	<100,000	ND
SB-215-345	SB215-36	34	36	6/1/2000	198	270	220	2,400,000	3,279.6	<83,000	ND	<83,000	ND	<170,000	ND
SB-215-346	SB215-38	36	38	6/1/2000	193	262	217	3,100,000	4,132.9	<62,000	ND	<62,000	ND	<120,000	ND
SB-215-347	SB215-40	38	40	6/1/2000	200	269	186	4,600,000 D	8,313.7	<83,000	ND	<83,000	ND	<170,000	ND
SB-215-348	SB215-42	40	42	6/1/2000	195	245	191	530,000	834.8	<25,000	ND	<25,000	ND	<50,000	ND
SB-216-130	SB216-2	0	2	5/22/2000	195	130	75	<250	ND	<250	ND	<250	ND	<500	ND
SB-216-131	SB216-4	2	4	5/22/2000	202	138	93	<250	ND	<250	ND	<250	ND	<500	ND
SB-216-132	SB216-6	4	6	5/22/2000	199	134	112	<250	ND	<250	ND	<250	ND	<500	ND
SB-216-218	SB216-8	6	8	5/24/2000	200	254	211	<250	ND	2,100	2.9	<250	ND	<500	ND
SB-216-219	SB216-10	8	10	5/24/2000	192	147	125	<250	ND	460	1.0	<250	ND	<500	ND
SB-216-220	SB216-12	10	12	5/24/2000	193	182	153	<250	ND	<250	ND	<250	ND	<500	ND
SB-216-221	SB216-14	12	14	5/24/2000	197	194	157	<250	ND	<250	ND	<250	ND	<500	ND
SB-216-222	SB216-16	14	16	5/24/2000	202	234	178	<250	ND	<250	ND	<250	ND	<500	ND
SB-216-223	SB216-18	16	18	5/24/2000	198	254	193	<250	ND	<250	ND	<250	ND	<500	ND
SB-216-224	SB216-20	18	20	5/24/2000	192	223	175	<250	ND	<250	ND	<250	ND	<500	ND
SB-216-225	SB216-22	20	22	5/24/2000	196	183	146	<250	ND	<250	ND	<250	ND	<500	ND
SB-216-227	SB216-24	22	24	5/24/2000	199	290	216	<250	ND	<250	ND	<250	ND	<500	ND
SB-216-228	SB216-26	24	26	5/24/2000	203	241	112	530	1.8	<250	ND	<250	ND	<500	ND
SB-216-229	SB216-28	26	28	5/24/2000	199	150	115	4,000	10.0	<250	ND	<250	ND	<500	ND
SB-216-226	SB216-28B	26	28	5/24/2000	195	250	107	6,500	23.7	<250	ND	<250	ND	<500	ND
SB-216-230	SB216-30	28	30	5/24/2000	198	338	273	1,200	1.4	<250	ND	<250	ND	<500	ND
SB-216-231	SB216-32	30	32	5/24/2000	195	259	191	3,000	4.9	<250	ND	<250	ND	<500	ND
SB-216-232	SB216-34	32	34	5/24/2000	198	267	209	390	0.6	<250	ND	<250	ND	<500	ND
SB-216-233	SB216-36	34	36	5/24/2000	203	171	135	<250	ND	960	2.1	<250	ND	<500	ND
SB-216-234	SB216-38	36	38	5/24/2000	197	265	210	<830	ND	17,000	24.6	<830	ND	<1,700	ND
SB-216-235	SB216-40	38	40	5/24/2000	198	339	253	3,100	4.1	6,700	8.9	<330	ND	<660	ND
SB-216-236	SB216-42	40	42	5/24/2000	199	314	247	2,800	3.6	1,300	1.7	<250	ND	<500	ND
SB-216-237	SB216-44	42	44	5/24/2000	192	282	230	1,300	1.7	<250	ND	<250	ND	<500	ND
SB-216-238	SB216-46	44	46	5/24/2000	204	273	209	<250	ND	<250	ND	<250	ND	<500	ND
SB-217-127	SB217-2	0	2	5/22/2000	194	123	94	<250	ND	<250	ND	<250	ND	<500	ND
SB-217-128	SB217-4	2	4	5/22/2000	189	133	71	<250	ND	<250	ND	<250	ND	<500	ND
SB-217-129	SB217-6	4	6	5/22/2000	191	130	50	<250	ND	<250	ND	<250	ND	<500	ND

Table C-4. Post-Demo VOC Results of Soil Samples (Continued)

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
SB-217-170	SB217-8	6	8	5/23/2000	197	185	154	<250	ND	3,300	6.0	<250	ND	<500	ND
SB-217-171	SB217-10	8	10	5/23/2000	194	208	169	<250	ND	1,600	2.7	<250	ND	<500	ND
SB-217-172	SB217-12	10	12	5/23/2000	200	200	161	7,100	12.9	<250	ND	<250	ND	<500	ND
SB-217-173	SB217-14	12	14	5/23/2000	194	192	149	<250	ND	<250	ND	<250	ND	<500	ND
SB-217-174	SB217-16	14	16	5/23/2000	199	196	152	<250	ND	<250	ND	<250	ND	<500	ND
SB-217-175	SB217-18	16	18	5/23/2000	201	202	166	<250	ND	<250	ND	<250	ND	<500	ND
SB-217-176	SB217-20	18	20	5/23/2000	195	184	143	<250	ND	<250	ND	<250	ND	<500	ND
SB-217-177	SB217-22	20	22	5/23/2000	192	257	196	<250	ND	<250	ND	<250	ND	<500	ND
SB-217-178	SB217-24	22	24	5/23/2000	193	272	197	350	0.6	<250	ND	<250	ND	<500	ND
SB-217-179	SB217-26	24	26	5/23/2000	195	213	164	1,000	1.8	<250	ND	<250	ND	<500	ND
SB-217-180	SB217-28	26	28	5/23/2000	199	194	143	8,300	17.6	<330	ND	<330	ND	<660	ND
SB-217-181	SB217-30	28	30	5/23/2000	207	194	140	16,000	36.1	<830	ND	<830	ND	<1,700	ND
SB-217-182	SB217-30B	28	30	5/23/2000	199	310	171	34,000	77.7	<1,700	ND	<1,700	ND	<3,300	ND
SB-217-183	SB217-32	30	32	5/23/2000	199	310	159	2,700	6.8	<250	ND	<250	ND	<500	ND
SB-217-184	SB217-34	32	34	5/23/2000	194	208	160	610	1.1	<250	ND	<250	ND	<500	ND
SB-217-185	SB217-36	34	36	5/23/2000	196	240	184	310	0.5	<250	ND	<250	ND	<500	ND
SB-217-186	SB217-38	36	38	5/23/2000	199	196	128	8,300	20.7	<500	ND	<500	ND	<1,000	ND
SB-217-187	SB217-40	38	40	5/23/2000	194	230	176	79,000 D	134.5	1,300	2.2	<250	ND	<500	ND
SB-217-188	SB217-42	40	42	5/23/2000	196	209	157	17,000	32.5	1,300	2.5	<500	ND	<1,000	ND
SB-217-189	SB217-42 *S*	40	42	5/23/2000	201	205	177	15,000	23.9	1,300	2.1	<830	ND	<1,700	ND
SB-217-190	SB217-44	42	44	5/23/2000	196	317	228	4,400	6.5	<250	ND	<250	ND	<500	ND
SB-217-191	SB217-46	44	46	5/23/2000	197	237	169	<250	ND	<250	ND	<250	ND	<500	ND
SB-317-167	SB317-2	0	2	5/22/2000	196	151	80	<250	ND	<250	ND	<250	ND	<500	ND
SB-317-166	SB317-4	2	4	5/22/2000	196	99	102	<250	ND	<250	ND	<250	ND	<500	ND
SB-317-168	SB317-6	4	6	5/22/2000	194	126	76	<250	ND	<250	ND	<250	ND	<500	ND
SB-317-192	SB317-8	6	8	5/23/2000	197	150	122	330	0.8	1,900.0	4.3	<250	ND	<500	ND
SB-317-193	SB317-10	8	10	5/23/2000	195	235	192	2,900	4.4	840.0	1.3	<250	ND	<500	ND
SB-317-194	SB317-12	10	12	5/23/2000	198	179	142	7,300	14.8	<500	ND	<500	ND	<1,000	ND
SB-317-195	SB317-14	12	14	5/23/2000	200	101	82	310	1.0	<250	ND	<250	ND	<500	ND
SB-317-196	SB317-16	14	16	5/23/2000	189	198	157	<250	ND	<250	ND	<250	ND	<500	ND
SB-317-197	SB317-18	16	18	5/23/2000	196	168	132	<250	ND	<250	ND	<250	ND	<500	ND
SB-317-198	SB317-20	18	20	5/23/2000	192	247	190	<250	ND	<250	ND	<250	ND	<500	ND
SB-317-199	SB317-22	20	22	5/23/2000	196	240	191	<250	ND	<250	ND	<250	ND	<500	ND
SB-317-200	SB317-24	22	24	5/23/2000	198	223	167	<250	ND	<250	ND	<250	ND	<500	ND
SB-317-201	SB317-26	24	26	5/23/2000	193	214	167	<250	ND	<250	ND	<250	ND	<500	ND

Table C-4. Post-Demo VOC Results of Soil Samples (Continued)

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
SB-317-202	SB317-28	26	28	5/23/2000	200	265	202	2,800	4.4	<250	ND	<250	ND	<500	ND
SB-317-203	SB317-30	28	30	5/23/2000	194	173	129	20,000	44.9	<1,000	ND	<1,000	ND	<2,000	ND
SB-317-204	SB317-32	30	32	5/23/2000	203	236	184	1,100	1.8	<250	ND	<250	ND	<500	ND
SB-317-205	SB317-34	32	34	5/23/2000	194	295	230	6,300	8.5	<420	ND	<420	ND	<840	ND
SB-317-206	SB317-36	34	36	5/23/2000	195	297	220	20,000	29.4	<1,200	ND	<1,200	ND	<2,500	ND
SB-317-207	SB317-36B	34	36	5/23/2000	193	343	167	23,000	57.9	<1,800	ND	<1,800	ND	<3,600	ND
SB-317-208	SB317-38	36	38	5/23/2000	195	297	149	15,000	39.7	<1,200	ND	<1,200	ND	<2,500	ND
SB-317-209	SB317-40	38	40	5/23/2000	192	249	178	110,000	194.1	<8,300	ND	<8,300	ND	<17,000	ND
SB-317-210	SB317-42	40	42	5/23/2000	198	128	95	4,000	11.9	480.0	1.4	<250	ND	<500	ND
SB-317-211	SB317-44	42	44	5/23/2000	201	156	121	3,500	8.4	<250	ND	<250	ND	<500	ND
SB-317-212	SB317-46	44	46	5/23/2000	197	242	192	550,000	857.6	<50,000	ND	<50,000	ND	<100,000	ND
SB-218-118	SB218-2	0	2	5/18/2000	203	127	69	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-120	SB218-4	2	4	5/18/2000	193	160	103	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-119	SB218-6	4	6	5/18/2000	197	136	74	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-148	SB218-8	6	8	5/22/2000	200	136	127	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-150	SB218-10	8	10	5/22/2000	198	191	162	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-149	SB218-12	10	12	5/22/2000	198	164	137	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-151	SB218-14	12	14	5/22/2000	193	149	123	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-152	SB218-16	14	16	5/22/2000	193	187	153	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-153	SB218-18	16	18	5/22/2000	195	165	140	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-154	SB218-20	18	20	5/22/2000	199	208	164	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-155	SB218-20B	18	20	5/22/2000	195	165	97	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-156	SB218-22	20	22	5/22/2000	193	180	142	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-157	SB218-24	22	24	5/22/2000	197	183	146	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-158	SB218-26	24	26	5/22/2000	193	211	162	2,000	3.6	<250	ND	<250	ND	<500	ND
SB-218-159	SB218-28	26	28	5/22/2000	190	201	158	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-160	SB218-30	28	30	5/22/2000	192	195	154	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-161	SB218-34	32	34	5/22/2000	193	175	109	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-162	SB218-38	36	38	5/22/2000	200	225	187	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-163	SB218-40	38	40	5/22/2000	196	168	107	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-164	SB218-42	40	42	5/22/2000	195	168	124	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-165	SB218-44	42	44	5/22/2000	204	198	156	<250	ND	<250	ND	<250	ND	<500	ND
SB-218-169	SB218-46	44	46	5/22/2000	196	151	78	<250	ND	<250	ND	<250	ND	<500	ND
SB-219-11	SB219-2	0	2	5/18/2000	194	100	96	<250	ND	<250	ND	<250	ND	<500	ND
SB-219-12	SB219-4	2	4	5/18/2000	195	153	151	<250	ND	<250	ND	<250	ND	<500	ND

Table C-4. Post-Demo VOC Results of Soil Samples (Continued)

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
SB-219-13	SB219-6	4	6	5/18/2000	189	159	152	<250	ND	<250	ND	<250	ND	<500	ND
SB-219-73	SB219-8	6	8	5/19/2000	188	206	165	1,400	2.4	1,000	1.7	<250	ND	<500	ND
SB-219-74	SB219-10	8	10	5/19/2000	200	232	184	35,000	57.3	<2,100	ND	<2,100	ND	<4,200	ND
SB-219-75	SB219-12	10	12	5/19/2000	193	193	153	23,000	42.7	<750	ND	<750	ND	<1,500	ND
SB-219-76	SB219-14	12	14	5/19/2000	192	190	147	12,000	23.4	<500	ND	<500	ND	<1,000	ND
SB-219-77	SB219-16	14	16	5/19/2000	195	204	169	15,000	25.0	510	0.9	<500	ND	<1,000	ND
SB-219-78	SB219-18	16	18	5/19/2000	193	264	214	14,000	19.3	620	0.9	<500	ND	<1,000	ND
SB-219-79	SB219-20	18	20	5/19/2000	192	251	199	9,900	14.7	850	1.3	<330	ND	<660	ND
SB-219-80	SB219-22	20	22	5/19/2000	202	250	207	1,000	1.4	1,300	1.9	<250	ND	<500	ND
SB-219-81	SB219-24	22	24	5/19/2000	191	187	137	460	1.0	500	1.1	<250	ND	<500	ND
SB-219-82	SB219-28	26	28	5/19/2000	200	254	186	4,800	8.3	940	1.6	<250	ND	<500	ND
SB-219-83	SB219-30	28	30	5/19/2000	201	170	86	11,000	43.3	470	1.8	<250	ND	<500	ND
SB-219-84	SB219-32	30	32	5/19/2000	190	224	172	7,600	12.9	380	0.6	<250	ND	<500	ND
SB-219-85	SB219-36	34	36	5/19/2000	198	214	172	7,700	13.1	260	0.4	<250	ND	<500	ND
SB-219-86	SB219-36B	34	36	5/19/2000	196	165	64	6,700	36.5	<250	ND	<250	ND	<500	ND
SB-219-87	SB219-38	36	38	5/20/2000	195	178	113	11,000	30.4	270	0.7	<250	ND	<500	ND
SB-219-88	SB219-40	38	40	5/20/2000	192	195	141	17,000	35.8	800	1.7	<500	ND	<1,000	ND
SB-219-89	SB219-42	40	42	5/20/2000	194	177	143	19,000	37.1	<500	ND	<500	ND	<1,000	ND
SB-219-90	SB219-44	42	44	5/20/2000	199	219	159	43,000	84.3	<1,200	ND	<1,200	ND	<2,500	ND
SB-219-91	SB219-46	44	46	5/20/2000	193	219	134	250,000	614.4	<6,200	ND	<6,200	ND	<12,000	ND
SB-220-14	SB220-2	0	2	5/18/2000	194	163	163	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-15	SB220-4	2	4	5/18/2000	189	170	163	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-16	SB220-6	4	6	5/18/2000	193	189	179	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-92	SB220-8	6	8	5/20/2000	200	262	129	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-93	SB220-10	8	10	5/20/2000	194	242	195	350	0.5	<250	ND	<250	ND	<500	ND
SB-220-94	SB220-12	10	12	5/20/2000	192	267	219	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-95	SB220-14	12	14	5/20/2000	198	203	172	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-96	SB220-16	14	16	5/20/2000	205	211	180	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-97	SB220-18	16	18	5/20/2000	190	217	153	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-98	SB220-20	18	20	5/20/2000	192	223	175	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-99	SB220-22	20	22	5/20/2000	194	211	167	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-100	SB220-24	22	24	5/20/2000	193	203	161	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-101	SB220-26	24	26	5/20/2000	195	246	186	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-102	SB220-28	26	28	5/20/2000	193	240	183	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-104	SB220-30	28	30	5/20/2000	190	186	134	<250	ND	<250	ND	<250	ND	<500	ND

Table C-4. Post-Demo VOC Results of Soil Samples (Continued)

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
SB-220-103	SB220-32	30	32	5/20/2000	194	241	191	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-105	SB220-34	32	34	5/20/2000	194	232	187	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-106	SB220-34B	32	34	5/20/2000	194	242	93	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-107	SB220-36	34	36	5/20/2000	193	212	168	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-108	SB220-38	36	38	5/20/2000	193	212	183	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-109	SB220-40	38	40	5/20/2000	201	242	142	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-110	SB220-42	40	42	5/20/2000	193	225	187	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-111	SB220-44	42	44	5/20/2000	193	289	230	<250	ND	<250	ND	<250	ND	<500	ND
SB-220-112	SB220-46	44	46	5/20/2000	196	245	176	6,000	10.8	<250	ND	<250	ND	<500	ND
SB-221-17	SB221-2	0	2	5/18/2000	190	171	166	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-18	SB221-4	2	4	5/18/2000	194	259	253	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-19	SB221-6	4	6	5/18/2000	195	213	209	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-113	SB221-8	6	8	5/21/2000	196	153	133	1,100	2.2	<250	ND	<250	ND	<500	ND
SB-221-114	SB221-10	8	10	5/21/2000	194	160	129	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-115	SB221-12	10	12	5/21/2000	192	198	156	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-116	SB221-14	12	14	5/21/2000	189	269	209	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-117	SB221-16	14	16	5/21/2000	249	179	151	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-133	SB221-18	16	18	5/22/2000	193	270	210	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-134	SB221-20	18	20	5/22/2000	193	297	244	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-135	SB221-22	20	22	5/22/2000	191	261	203	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-136	SB221-24	22	24	5/22/2000	195	231	182	<250	ND	<250	ND	<250	ND	<500	ND
SB-221-137	SB221-26	24	26	5/22/2000	191	180	139	1,800	3.7	<250	ND	<250	ND	<500	ND
SB-221-138	SB221-28	26	28	5/22/2000	201	232	170	24,000	44.7	<1,200	ND	<1,200	ND	<2,500	ND
SB-221-139	SB221-30	28	30	5/22/2000	201	186	139	32,000	69.4	<2,100	ND	<2,100	ND	<4,200	ND
SB-221-140	SB221-32	30	32	5/22/2000	193	214	147	95,000	201.2	<5,000	ND	<5,000	ND	<10,000	ND
SB-221-141	SB221-34	32	34	5/22/2000	195	173	137	1,700	3.5	<250	ND	<250	ND	<500	ND
SB-221-142	SB221-36	34	36	5/22/2000	199	247	186	650,000	1,093.5	<42,000	ND	<42,000	ND	<84,000	ND
SB-221-143	SB221-38	36	38	5/22/2000	192	128	36	44,000	409.5	<2,500	ND	<2,500	ND	<5,000	ND
SB-221-144	SB221-40	38	40	5/22/2000	194	193	154	680,000	1,256.5	<42,000	ND	<42,000	ND	<84,000	ND
SB-221-145	SB221-42	40	42	5/22/2000	194	159	102	22,000	65.3	<1,200	ND	<1,200	ND	<2,500	ND
SB-221-146	SB221-42B	40	42	5/22/2000	194	138	96	19,000	56.9	<1,000	ND	<1,000	ND	<2,000	ND
SB-221-147	SB221-45	43	45	5/22/2000	195	172	147	2,300	4.3	<250	ND	<250	ND	<500	ND
SB-223-121	SB223-2	0	2	5/19/2000	192	136	76	<250	ND	<250	ND	<250	ND	<500	ND
SB-223-126	SB223-4	2	4	5/19/2000	194	134	102	<250	ND	<250	ND	<250	ND	<500	ND
SB-223-122	SB223-6	4	6	5/19/2000	195	167	88	<250	ND	<250	ND	<250	ND	<500	ND

Table C-4. Post-Demo VOC Results of Soil Samples (Continued)

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
SB-223-53	SB223-8	6	8	5/19/2000	198	153	122	2,300	5.3	260	0.6	<250	ND	<500	ND
SB-223-54	SB223-10	8	10	5/19/2000	192	86	71	2,100	7.6	<250	ND	<250	ND	<500	ND
SB-223-55	SB223-12	10	12	5/19/2000	196	187	150	21,000	39.9	<500	ND	<500	ND	<1,000	ND
SB-223-56	SB223-14	12	14	5/19/2000	194	156	124	20,000	44.8	<500	ND	<500	ND	<1,000	ND
SB-223-57	SB223-16	14	16	5/19/2000	194	216	184	<250	ND	<250	ND	<250	ND	<500	ND
SB-223-58	SB223-18	16	18	5/19/2000	191	194	145	3,100	6.2	<250	ND	<250	ND	<500	ND
SB-223-59	SB223-20	18	20	5/19/2000	192	217	173	<250	ND	<250	ND	<250	ND	<500	ND
SB-223-60	SB223-22	20	22	5/19/2000	191	201	152	46,000	88.0	<2,500	ND	<2,500	ND	<5,000	ND
SB-223-61	SB223-24	22	24	5/19/2000	194	189	148	16,000	31.0	<750	ND	<750	ND	<1,500	ND
SB-223-62	SB223-26	24	26	5/19/2000	198	192	143	1,900	4.0	<250	ND	<250	ND	<500	ND
SB-223-63	SB223-28	26	28	5/19/2000	193	216	151	3,500	7.2	350	0.7	<250	ND	<500	ND
SB-223-64	SB223-30	28	30	5/19/2000	192	261	187	6,900	11.7	890	1.5	<330	ND	<660	ND
SB-223-65	SB223-32	30	32	5/19/2000	196	215	161	1,700	3.2	<250	ND	<250	ND	<500	ND
SB-223-66	SB223-34	32	34	5/19/2000	198	239	193	<250	ND	<250	ND	<250	ND	<500	ND
SB-223-67	SB223-34B	32	34	5/19/2000	194	185	110	4,100	11.9	330	1.0	<250	ND	<500	ND
SB-223-68	SB223-36	34	36	5/19/2000	195	183	139	<250	ND	<250	ND	<250	ND	<500	ND
SB-223-69	SB223-38	36	38	5/19/2000	195	248	177	40,000	71.8	<2,100	ND	<2,100	ND	<4,200	ND
SB-223-70	SB223-40	38	40	5/19/2000	196	240	174	12,000	21.7	1,400	2.5	<500	ND	<1,000	ND
SB-223-71	SB223-42	40	42	5/19/2000	193	203	152	2,900	5.6	410	0.8	<250	ND	<500	ND
SB-223-72	SB223-45	42	45	5/19/2000	194	204	151	47,000	92.9	<2,500	ND	<2,500	ND	<5,000	ND
SB-224-20	SB224-2	0	2	5/18/2000	194	130	130	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-21	SB224-4	2	4	5/18/2000	193	117	115	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-22	SB224-6	4	6	5/18/2000	193	209	204	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-32	SB224-8	6	8	5/18/2000	193	127	103	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-33	SB224-10	8	10	5/18/2000	197	198	163	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-34	SB224-12	10	12	5/18/2000	189	198	161	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-36	SB224-14	12	14	5/18/2000	195	255	183	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-37	SB224-16	14	16	5/18/2000	193	256	211	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-38	SB224-18	16	18	5/18/2000	195	217	166	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-39	SB224-20	18	20	5/18/2000	193	217	165	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-40	SB224-22	20	22	5/18/2000	193	181	119	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-41	SB224-24	22	24	5/18/2000	194	233	169	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-42	SB224-26	24	26	5/18/2000	193	202	150	<250	ND	<250	ND	<250	ND	<500	ND
SB-224-43	SB224-28	26	28	5/18/2000	194	248	186	120,000	198.4	<3,600	ND	<3,600	ND	<7,200	ND
SB-224-44	SB224-30	28	30	5/18/2000	194	297	217	2,800,000	4,200.9	<62,000	ND	<62,000	ND	<120,000	ND

Table C-4. Post-Demo VOC Results of Soil Samples (Continued)

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
SB-224-45	SB224-32	30	32	5/18/2000	197	242	191	140,000	220.2	<5,000	ND	<5,000	ND	<10,000	ND
SB-224-46	SB224-34	32	34	5/18/2000	194	294	217	200,000	297.3	<8,300	ND	<8,300	ND	<17,000	ND
SB-224-47	SB224-36	34	36	5/19/2000	196	174	126	45,000	105.8	<1,200	ND	<1,200	ND	<2,500	ND
SB-224-48	SB224-38	36	38	5/19/2000	190	127	86	85,000	278.2	<2,500	ND	<2,500	ND	<5,000	ND
SB-224-50	SB224-38B	36	38	5/19/2000	382	186	141	720,000	2,698.9	<25,000	ND	<25,000	ND	<50,000	ND
SB-224-51	SB224-40	38	40	5/19/2000	193	143	114	52,000	124.7	<1,200	ND	<1,200	ND	<2,500	ND
SB-224-52	SB224-42	40	42	5/19/2000	190	187	142	290,000	583.1	<10,000	ND	<10,000	ND	<20,000	ND
SB-224-49	SB224-45	42	45	5/19/2000	189	214	169	110,000	185.0	<2,500	ND	<2,500	ND	<5,000	ND
SB-225-123	SB225-2	0	2	5/18/2000	193	132	92	<250	ND	<250	ND	<250	ND	<500	ND
SB-225-124	SB225-4	2	4	5/18/2000	194	139	82	<250	ND	<250	ND	<250	ND	<500	ND
SB-225-125	SB225-6	4	6	5/18/2000	194	134	90	<250	ND	<250	ND	<250	ND	<500	ND
SB-225-1	SB225-8	6	8	5/18/2000	193	235	196	<250	ND	750	1.1	<250	ND	<500	ND
SB-225-2	SB225-12	10	12	5/18/2000	192	188	157	14,000	24.4	<500	ND	<500	ND	<1,000	ND
SB-225-3	SB225-14	12	14	5/18/2000	195	163	135	760	1.5	<250	ND	<250	ND	<500	ND
SB-225-4	SB225-16	14	16	5/18/2000	197	191	164	<250	ND	<250	ND	<250	ND	<500	ND
SB-225-5	SB225-18	16	18	5/18/2000	197	299	258	<250	ND	<250	ND	<250	ND	<500	ND
SB-225-6	SB225-20	18	20	5/18/2000	194	244	202	840	1.2	370.0	0.5	<250	ND	<500	ND
SB-225-7	SB225-22	20	22	5/18/2000	185	201	163	<250	ND	<250	ND	<250	ND	<500	ND
SB-225-8	SB225-24	22	24	5/18/2000	187	266	211	1,700	2.4	1,400	1.9	<250	ND	<500	ND
SB-225-9	SB225-26	24	26	5/18/2000	190	270	208	4,600	6.7	1,200	1.7	<250	ND	<500	ND
SB-225-10	SB225-28	26	28	5/18/2000	193	299	214	9,900	15.2	2,000	3.1	<500	ND	<1,000	ND
SB-225-23	SB225-30	28	30	5/18/2000	192	192	136	5,900	13.0	910	2.0	<250	ND	<500	ND
SB-225-24	SB225-32	30	32	5/18/2000	191	225	170	320	0.6	<250	ND	<250	ND	<500	ND
SB-225-25	SB225-34	32	34	5/18/2000	194	255	194	<250	ND	<250	ND	<250	ND	<500	ND
SB-225-26	SB225-36	34	36	5/18/2000	191	284	207	<250	ND	<250	ND	<250	ND	<500	ND
SB-225-27	SB225-38	36	38	5/18/2000	191	210	135	1,700	4.0	<250	ND	<250	ND	<500	ND
SB-225-28	SB225-40	38	40	5/18/2000	196	218	169	9,300	16.3	2,700	4.7	<250	ND	<500	ND
SB-225-29	SB225-40B	38	40	5/18/2000	193	179	86	4,700	18.4	1,500	5.9	<250	ND	<500	ND
SB-225-30	SB225-42	40	42	5/18/2000	197	187	136	1,800	4.0	700	1.5	<250	ND	<500	ND
SB-225-31	SB225-44	42	44	5/18/2000	192	177	133	430	0.9	<250	ND	<250	ND	<500	ND
SB-225-35	SB225-46	44	46	5/18/2000	197	205	152	110,000	218.8	<3,600	ND	<3,600	ND	<7,200	ND
SB-26-259	SB26-2	0	2	5/24/2000	193	127	124	<250	ND	<250	ND	<250	ND	<500	ND
SB-26-260	SB26-4	2	4	5/24/2000	193	181	179	<250	ND	<250	ND	<250	ND	<500	ND
SB-26-261	SB26-6	4	6	5/24/2000	193	164	157	<250	ND	<250	ND	<250	ND	<500	ND
SB-26-262	SB26-8	6	8	5/25/2000	193	127	73	<250	ND	<250	ND	<250	ND	<500	ND

Table C-4. Post-Demo VOC Results of Soil Samples (Continued)

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
SB-26-263	SB26-10	8	10	5/25/2000	193	194	110	<250	ND	<250	ND	<250	ND	<500	ND
SB-26-264	SB26-12	10	12	5/25/2000	193	219	181	<250	ND	<250	ND	<250	ND	<500	ND
SB-26-265	SB26-14	12	14	5/25/2000	193	197	168	5,200	8.5	<250	ND	<250	ND	<500	ND
SB-26-266	SB26-16	14	16	5/25/2000	193	241	199	19,000	27.3	<830	ND	<830	ND	<1,700	ND
SB-26-267	SB26-18	16	18	5/25/2000	196	222	174	<250	ND	<250	ND	<250	ND	<500	ND
SB-26-268	SB26-20	18	20	5/25/2000	199	249	203	40,000	58.7	<1,000	ND	<1,000	ND	<2,000	ND
SB-26-269	SB26-22	20	22	5/25/2000	194	185	147	90,000	173.6	<3,100	ND	<3,100	ND	<6,200	ND
SB-26-270	SB26-24	22	24	5/25/2000	193	241	184	180,000 D	294.8	<3,600	ND	<3,600	ND	<7,200	ND
SB-26-276	SB26-26	24	26	5/25/2000	193	244	191	520,000	809.4	<25,000	ND	<25,000	ND	<50,000	ND
SB-26-277	SB26-28	26	28	5/25/2000	194	285	210	290,000	442.7	<12,000	ND	<12,000	ND	<25,000	ND
SB-26-278	SB26-30	28	30	5/25/2000	194	246	140	270,000	678.0	<12,000	ND	<12,000	ND	<25,000	ND
SB-26-279	SB26-32	30	32	5/25/2000	192	199	160	160,000	282.0	<5,000	ND	<5,000	ND	<10,000	ND
SB-26-280	SB26-34	32	34	5/25/2000	193	165	129	120,000	260.7	<5,000	ND	<5,000	ND	<10,000	ND
SB-26-281	SB26-34B	32	34	5/25/2000	195	235	103	160,000	588.5	<8,300	ND	<8,300	ND	<17,000	ND
SB-26-282	SB26-36	34	36	5/25/2000	195	235	132	160,000	424.0	<5,000	ND	<5,000	ND	<10,000	ND
SB-26-283	SB26-38	36	38	5/25/2000	192	217	157	190,000	366.7	<8,300	ND	<8,300	ND	<17,000	ND
SB-26-284	SB26-40	38	40	5/25/2000	194	370	271	320,000	406.9	<12,000	ND	<12,000	ND	<25,000	ND
SB-26-285	SB26-42	40	42	5/25/2000	195	411	294	5,000,000	6,187.7	<100,000	ND	<100,000	ND	<200,000	ND
SB-26-286	SB26-44	42	44	5/25/2000	200	247	199	2,900,000 D	4,388.8	<62,000	ND	<62,000	ND	<120,000	ND
SB-26-287	SB26-46	44	46	5/25/2000	197	199	150	2,000,000	3,978.2	<62,000	ND	<62,000	ND	<120,000	ND
SB-27-271	SB27-2	0	2	5/25/2000	195	110	113	<250	ND	<250	ND	<250	ND	<500	ND
SB-27-272	SB27-4	2	4	5/25/2000	195	158	158	<250	ND	<250	ND	<250	ND	<500	ND
SB-27-273	SB27-6	4	6	5/25/2000	196	101	96	<250	ND	<250	ND	<250	ND	<500	ND
SB-27-274	SB27-8	6	8	5/25/2000	192	227	182	<250	ND	<250	ND	<250	ND	<500	ND
SB-27-275	SB27-10	8	10	5/25/2000	202	278	224	<250	ND	<250	ND	<250	ND	<500	ND
SB-27-288	SB27-12	10	12	5/25/2000	196	179	143	6,400	12.7	500	1.0	<330	ND	<660	ND
SB-27-289	SB27-14	12	14	5/25/2000	199	208	170	420	0.7	<250	ND	<250	ND	<500	ND
SB-27-290	SB27-14B	12	14	5/25/2000	199	282	99	3,000	13.2	<250	ND	<250	ND	<500	ND
SB-27-291	SB27-16	14	16	5/25/2000	200	208	118	860	2.5	<250	ND	<250	ND	<500	ND
SB-27-292	SB27-18	16	18	5/25/2000	202	187	163	3,000	5.1	<250	ND	<250	ND	<500	ND
SB-27-293	SB27-20	18	20	5/25/2000	195	257	207	54,000	77.4	<2,500	ND	<2,500	ND	<5,000	ND
SB-27-294	SB27-22	20	22	5/25/2000	197	223	175	110,000	186.9	<5,000	ND	<5,000	ND	<10,000	ND
SB-27-295	SB27-24	22	24	5/25/2000	197	206	160	130,000	240.0	6,700	12.4	<5,000	ND	<10,000	ND
SB-27-296	SB27-24 *S*	22	24	5/25/2000	193	238	128	140,000	387.5	8,500	23.5	<5,000	ND	<10,000	ND
SB-27-297	SB27-26	24	26	5/25/2000	192	263	136	160,000	435.3	<6,200	ND	<6,200	ND	<12,000	ND

Table C-4. Post-Demo VOC Results of Soil Samples (Continued)

Preliminary Draft		Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Analytical Sample ID	Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)	Result in MeOH (µg/L)	Result in Dry Soil (mg/kg)
SB-27-298	SB27-28	26	28	5/25/2000	194	226	171	210,000 D	369.1	3,500	6.2	<250	ND	<500	ND
SB-27-299	SB27-32	30	32	5/25/2000	204	323	247	120,000	162.4	29,000	39.2	<3,100	ND	<6,200	ND
SB-27-300	SB27-34	32	34	5/25/2000	193	216	115	29,000	87.1	34,000	102.1	<2,500	ND	<5,000	ND
SB-27-301	SB27-36	34	36	5/25/2000	193	329	173	48,000	111.1	64,000	148.1	<2,500	ND	<5,000	ND
SB-27-302	SB27-38	36	38	5/25/2000	189	317	145	48,000	136.1	34,000	96.4	<2,500	ND	<5,000	ND
SB-27-303	SB27-40	38	40	5/25/2000	193	321	151	130,000 D	356.7	16,000	43.9	<1,200	ND	<2,500	ND
SB-27-304	SB27-42	40	42	5/25/2000	194	384	154	220,000	679.4	<8,300	ND	<8,300	ND	<17,000	ND
SB-27-305	SB27-45	43	45	5/26/2000	190	246	160	820,000	1,673.3	<30,000	ND	<30,000	ND	<60,000	ND
SB-28-350	SB-28-2	0	2	6/2/2000	195	234	82	1,500	7.3	<250	ND	<250	ND	<500	ND
SB-28-351	SB-28-4	2	4	6/2/2000	191	233	73	4,600	25.3	<250	ND	<250	ND	<500	ND
SB-28-352	SB-28-6	4	6	6/2/2000	192	131	87	7,100	23.4	<250	ND	<250	ND	<500	ND
SB-28-353	SB-28-8	6	8	6/2/2000	191	205	110	<250	ND	<250	ND	<250	ND	<500	ND
SB-28-354	SB-28-10	8	10	6/2/2000	194	192	124	<250	ND	<250	ND	<250	ND	<500	ND
SB-28-355	SB-28-12	10	12	6/2/2000	197	226	116	2,900	9.0	800	2.5	<250	ND	<500	ND
SB-28-356	SB-28-14	12	14	6/2/2000	197	169	79	6,600	28.4	1,600	6.9	<250	ND	<500	ND
SB-28-357	SB-28-14B	12	14	6/2/2000	194	193	69	4,700	25.2	1,700	9.1	<250	ND	<500	ND

Notes:

NA: Not available.

ND: Not detected.

<: Result was not detected at or above the stated reporting limit.

D: Result was obtained from the analysis of a dilution.

DC: Ditch Core.

S: Spiked sample

Table C-5. Extended Monitoring VOC Results of Soil Samples (mg/Kg)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)
SB-313-2	0	2	2/20/2001	189	97	96	85 J	0.11 J	<100	ND	<100	ND	<100	ND
SB-313-4	2	4	2/20/2001	198	111	109	1,020	1.33	245	0.32	<100	ND	<100	ND
SB-313-6	4	6	2/20/2001	194	153	150	<100	ND	<100	ND	<100	ND	<100	ND
SB-313-8	6	8	2/20/2001	204	92	91	58 J	0.07 J	48 J	0.06 J	<100	ND	<100	ND
SB-313-10	8	10	2/24/2001	193	72	64	457	0.71	152	0.24	<100	ND	<100	ND
SB-313-12	10	12	2/24/2001	194	158	138	3,410	5.44	1,130	1.80	<100	ND	<100	ND
SB-313-14	12	14	2/24/2001	195	109	94	11,400	18.55	839	1.37	<100	ND	<100	ND
SB-313-16	14	16	2/24/2001	194	294	241	25,200	44.46	5,120	9.03	45 J	0.08 J	<100	ND
SB-313-18	16	18	2/24/2001	193	189	158	272	0.47	280	0.48	<100	ND	<100	ND
SB-313-20	18	20	2/24/2001	193	91	77	128	0.21	46 J	0.08 J	<100	ND	<100	ND
SB-313-22	20	22	2/24/2001	193	194	160	<100	ND	<100	ND	<100	ND	<100	ND
SB-313-24	22	24	2/24/2001	193	165	135	86 J	0.15 J	<100	ND	<100	ND	<100	ND
SB-313-26	24	26	2/24/2001	188	175	134	<100	ND	<100	ND	<100	ND	<100	ND
SB-313-28	26	28	2/24/2001	193	100	76	<100	ND	27 J	0.05 J	<100	ND	<100	ND
SB-313-30	28	30	2/24/2001	193	216	165	111	0.22	385	0.76	<100	ND	<100	ND
SB-313-32	30	32	2/24/2001	200	223	194	101	0.16	56 J	0.09 J	<100	ND	<100	ND
SB-313-34	32	34	2/24/2001	192	173	127	90 J	0.19 J	51 J	0.11 J	<100	ND	<100	ND
SB-313-34B	32	34	2/24/2001	197	146	110	95 J	0.19 J	41 J	0.08 J	<100	ND	<100	ND
SB-313-36	34	36	2/24/2001	193	125	101	<100	ND	40 J	0.07 J	<100	ND	<100	ND
SB-313-38	36	38	2/24/2001	195	175	120	135	0.31	726	1.67	28 J	0.06 J	<100	ND
SB-313-40	38	40	2/24/2001	191	142	105	210	0.43	581	1.20	34 J	0.07 J	<100	ND
SB-313-43	40	43	2/24/2001	190	82	64	375	0.71	115	0.22	<100	ND	<100	ND
SB-313-45	43	45	2/24/2001	192	156	143	614	0.90	61 J	0.09 J	<100	ND	<100	ND
SB-313-MB1	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-313-MB13	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-313-MB14	Lab Blank			NA	NA	NA	55	0.10 J	<100	ND	<100	ND	<100	ND
SB-314-2	0	2	2/23/2001	191	91	89	86 J	0.11 J	<100	ND	<100	ND	<100	ND
SB-314-4	2	4	2/23/2001	195	109	109	66 J	0.08 J	<100	ND	<100	ND	<100	ND
SB-314-6	4	6	2/23/2001	194	88	88	<100	ND	<100	ND	<100	ND	<100	ND
SB-314-8	6	8	2/23/2001	195	112	112	135	0.17	<100	ND	<100	ND	<100	ND
SB-314-10	8	10	2/23/2001	193	71	69	109	0.15	<100	ND	<100	ND	<100	ND
SB-314-10B	8	10	2/23/2001	193	62	62	190	0.24	<100	ND	<100	ND	<100	ND
SB-314-12	10	12	2/23/2001	193	143	126	<100	ND	53 J	0.08 J	<100	ND	<100	ND
SB-314-14	12	14	2/23/2001	193	113	99	1,940	3.08	606	0.96	<100	ND	<100	ND
SB-314-16	14	16	2/23/2001	194	124	103	985	1.70	101	0.17	<100	ND	<100	ND
SB-314-18	16	18	2/23/2001	194	78	67	140	0.23	<100	ND	<100	ND	<100	ND

Table C-5. Extended Monitoring VOC Results of Soil Samples (mg/Kg) (Continued)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)
SB-314-20	18	20	2/23/2001	195	132	105	<100	ND	<100	ND	<100	ND	<100	ND
SB-314-22	20	22	2/23/2001	192	96	80	92 J	0.16 J	<100	ND	<100	ND	<100	ND
SB-314-24	22	24	2/23/2001	193	130	107	225	0.39	<100	ND	<100	ND	<100	ND
SB-314-26	24	26	2/23/2001	194	120	96	6,370	11.67	<100	ND	<100	ND	<100	ND
SB-314-28	26	28	2/23/2001	194	128	99	346	0.67	<100	ND	<100	ND	<100	ND
SB-314-30	28	30	2/23/2001	193	193	110	19,000	56.53	<100	ND	<100	ND	<100	ND
SB-314-32	30	32	2/23/2001	193	135	93	19,100	43.72 D	<100	ND	<100	ND	<100	ND
SB-314-34	32	34	2/23/2001	193	109	75	9,050	20.75	<100	ND	<100	ND	<100	ND
SB-314-36	34	36	2/23/2001	194	82	58	3,060	6.74	<100	ND	<100	ND	<100	ND
SB-314-38	36	38	2/23/2001	195	116	98	750,000	1,261.50 D	<1,000	ND	<1,000	ND	<1,000	ND
SB-314-40	38	40	2/23/2001	193	60	53	29,600	46.33 D	<100	ND	<100	ND	<100	ND
SB-314-43	40	43	2/23/2001	193	123	97	44,100	82.61 D	<100	ND	<100	ND	<100	ND
SB-314-45	43	45	2/23/2001	194	69	59	3,000	4.95	<100	ND	<100	ND	<100	ND
SB-314-MB9	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-315-2	0	2	2/22/2001	187	55	55	<100	ND	<100	ND	<100	ND	<100	ND
SB-315-4	2	4	2/22/2001	195	107	107	<100	ND	<100	ND	<100	ND	<100	ND
SB-315-6	4	6	2/22/2001	194	100	98	590	0.77	<100	ND	<100	ND	<100	ND
SB-315-8	6	8	2/22/2001	193	86	86	116	0.15	<100	ND	<100	ND	<100	ND
SB-315-10	8	10	2/22/2001	193	70	68	<100	ND	<100	ND	<100	ND	<100	ND
SB-315-12	10	12	2/22/2001	193	100	94	<100	ND	<100	ND	<100	ND	<100	ND
SB-315-14	12	14	2/22/2001	194	98	84	<100	ND	101	0.17	<100	ND	<100	ND
SB-315-16	14	16	2/22/2001	196	138	112	<100	ND	<100	ND	<100	ND	<100	ND
SB-315-18	16	18	2/22/2001	193	100	87	612,000	981.89 D	<100	ND	<100	ND	<100	ND
SB-315-20	18	20	2/22/2001	192	111	92	181,000	313.81 D	<100	ND	<100	ND	<100	ND
SB-315-22	20	22	2/22/2001	195	59	52	28,500	44.77 D	<100	ND	<100	ND	<100	ND
SB-315-24	22	24	2/22/2001	193	118	102	2,810,000	4,555.70	<2,000	ND	<2,000	ND	<2,000	ND
SB-315-26	24	26	2/22/2001	191	112	93	104,000	179.79	<100	ND	<100	ND	<100	ND
SB-315-28	26	28	2/22/2001	194	148	117	77,800	145.19 D	62 J	0.12 J	<100	ND	<100	ND
SB-315-30	28	30	2/23/2001	193	50	40	505,000	925.30 D	<400	ND	<400	ND	<400	ND
SB-315-32	30	32	2/23/2001	193	73	56	1,220,000	2,383.47 D	<1,000	ND	<1,000	ND	<1,000	ND
SB-315-34	32	34	2/23/2001	195	111	66	1,280,000	3,597.70 D	<1,000	ND	<1,000	ND	<1,000	ND
SB-315-36	34	36	2/23/2001	193	122	86	565,000	1,251.08 D	<1,000	ND	<1,000	ND	<1,000	ND
SB-315-38	36	38	2/23/2001	193	60	49	788,000	1,398.29 D	<1,000	ND	<1,000	ND	<1,000	ND
SB-315-40	38	40	2/23/2001	193	52	43	277,000	482.00 D	<1,000	ND	<1,000	ND	<1,000	ND
SB-315-40B	38	40	2/23/2001	194	46	41	162,000	249.83 D	<100	ND	<100	ND	<100	ND
SB-315-42	40	42	2/23/2001	194	65	55	435,000	729.84 D	<100	ND	<100	ND	<100	ND

Table C-5. Extended Monitoring VOC Results of Soil Samples (mg/Kg) (Continued)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)
SB-315-MB7	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-316-2	0	2	2/20/2001	192	147	142	<100	ND	<100	ND	<100	ND	<100	ND
SB-316-4	2	4	2/20/2001	195	122	118	<100	ND	<100	ND	<100	ND	<100	ND
SB-316-6	4	6	2/20/2001	192	140	136	61 J	0.08 J	<100	ND	<100	ND	<100	ND
SB-316-8	6	8	2/20/2001	195	76	73	170	0.23	<100	ND	<100	ND	<100	ND
SB-316-10	8	10	2/24/2001	193	156	132	660	1.11	118	0.20	<100	ND	<100	ND
SB-316-12	10	12	2/24/2001	193	186	156	173	0.29	<100	ND	<100	ND	<100	ND
SB-316-14	12	14	2/24/2001	193	185	156	151	0.25	<100	ND	<100	ND	<100	ND
SB-316-16	14	16	2/24/2001	192	101	87	<100	ND	<100	ND	<100	ND	<100	ND
SB-316-18	16	18	2/24/2001	191	155	127	88 J	0.16 J	<100	ND	<100	ND	<100	ND
SB-316-20	18	20	2/24/2001	194	172	138	<100	ND	<100	ND	<100	ND	<100	ND
SB-316-22	20	22	2/24/2001	191	102	74	548	1.16	<100	ND	<100	ND	<100	ND
SB-316-24	22	24	2/24/2001	193	93	76	434	0.77	22 J	0.04 J	<100	ND	<100	ND
SB-316-24B	22	24	2/24/2001	191	88	66	346	0.70	<100	ND	<100	ND	<100	ND
SB-316-26	24	26	2/24/2001	195	114	90	96 J	0.18 J	<100	ND	<100	ND	<100	ND
SB-316-26B	Check COC			NA	NA	NA	85 J	0.15 J	<100	ND	<100	ND	<100	ND
SB-316-28	26	28	2/24/2001	193	117	93	472	0.87	117	0.22	<100	ND	<100	ND
SB-316-30	28	30	2/24/2001	193	79	61	5,670	10.97	461	0.89	<100	ND	<100	ND
SB-316-32	30	32	2/24/2001	195	124	99	5,910	10.86	1,200	2.21	<100	ND	<100	ND
SB-316-34	32	34	2/24/2001	193	91	74	1,820	3.25	549	0.98	<100	ND	<100	ND
SB-316-36	34	36	2/24/2001	194	90	74	556	0.98	1,070	1.88	<100	ND	<100	ND
SB-316-38	36	38	2/24/2001	194	107	74	158	0.36	2,950	6.71	48 J	0.11 J	<100	ND
SB-316-40	38	40	2/24/2001	193	110	88	<100	ND	1,970	3.61	12 J	0.02 J	<100	ND
SB-316-43	40	43	2/24/2001	193	167	134	20,400	37.21	<100	ND	<100	ND	<100	ND
SB-316-45	43	45	2/24/2001	194	194	76	22,700	108.59 D	<100	ND	<100	ND	<100	ND
SB-317-2	0	2	2/20/2001	197	126	122	2,220	2.98	<100	ND	<100	ND	<100	ND
SB-317-4	2	4	2/20/2001	192	97	94	202	0.27	213	0.29	<100	ND	<100	ND
SB-317-6	4	6	2/20/2001	193	108	99	55 J	0.08 J	<100	ND	<100	ND	<100	ND
SB-317-8	6	8	2/20/2001	190	67	66	<100	ND	<100	ND	<100	ND	<100	ND
SB-317-10	8	10	2/23/2001	192	97	82	84 J	0.14 J	<100	ND	<100	ND	<100	ND
SB-317-12	10	12	2/23/2001	195	79	65	265	0.46	<100	ND	<100	ND	<100	ND
SB-317-14	12	14	2/23/2001	195	102	82	3,370	6.13	<100	ND	<100	ND	<100	ND
SB-317-16	14	16	2/23/2001	194	137	112	49,300	87.34 D	22 J	0.04 J	<100	ND	<100	ND
SB-317-18	16	18	2/23/2001	193	81	69	56,500	93.78 D	<100	ND	<100	ND	<100	ND
SB-317-20	18	20	2/23/2001	193	68	57	43,300	73.74 D	<100	ND	<100	ND	<100	ND
SB-317-22	20	22	2/23/2001	194	79	66	8,070	13.82	<100	ND	<100	ND	<100	ND

Table C-5. Extended Monitoring VOC Results of Soil Samples (mg/Kg) (Continued)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)
SB-317-24	22	24	2/23/2001	193	110	82	854	1.74	<100	ND	<100	ND	<100	ND
SB-317-26	24	26	2/23/2001	194	93	74	426	0.79	<100	ND	<100	ND	<100	ND
SB-317-26B	24	26	2/23/2001	193	63	49	448	0.86	51 J	0.10 J	<100	ND	<100	ND
SB-317-28	26	28	2/23/2001	193	120	91	6,600	13.12	550	1.09	<100	ND	<100	ND
SB-317-30	28	30	2/23/2001	193	137	106	68,900	132.87 D	51 J	0.10 J	<100	ND	<100	ND
SB-317-32	30	32	2/23/2001	194	134	106	55,100	102.73 D	75 J	0.14 J	<100	ND	<100	ND
SB-317-34	32	34	2/23/2001	193	103	91	17,900	28.01 D	488	0.76	<100	ND	<100	ND
SB-317-36	34	36	2/23/2001	194	68	55	35,400	63.77 D	<100	ND	<100	ND	<100	ND
SB-317-38	36	38	2/23/2001	193	126	83	1,790	4.37	<100	ND	<100	ND	<100	ND
SB-317-40	38	40	2/23/2001	194	204	148	14,400	30.57	75 J	0.16 J	<100	ND	<100	ND
SB-317-43	40	43	2/23/2001	194	173	136	12,300	23.15	<100	ND	<100	ND	<100	ND
SB-317-45	43	45	2/23/2001	193	195	155	409,000	756.88	142	0.26	<100	ND	<100	ND
SB-317-MB8	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-318-2	0	2	2/20/2001	192	134	134	<100	ND	<100	ND	<100	ND	<100	ND
SB-318-4	2	4	2/20/2001	192	206	201	<100	ND	<100	ND	<100	ND	<100	ND
SB-318-6	4	6	2/20/2001	192	182	179	<100	ND	<100	ND	<100	ND	<100	ND
SB-318-8	6	8	2/20/2001	192	109	107	<100	ND	<100	ND	<100	ND	<100	ND
SB-318-10	8	10	2/23/2001	194	108	95	73 J	0.12 J	<100	ND	<100	ND	<100	ND
SB-318-12	10	12	2/23/2001	193	53	51	118	0.16	<100	ND	<100	ND	<100	ND
SB-318-14	12	14	2/23/2001	193	84	72	5,400	8.87	23 J	0.04 J	<100	ND	<100	ND
SB-318-16	14	16	2/23/2001	192	100	87	17,700	28.40	30 J	0.05 J	<100	ND	<100	ND
SB-318-18	16	18	2/23/2001	193	117	98	3,070	5.23	<100	ND	<100	ND	<100	ND
SB-318-20	18	20	2/23/2001	194	148	122	1,900	3.32	<100	ND	<100	ND	<100	ND
SB-318-22	20	22	2/23/2001	193	88	74	77 J	0.13 J	<100	ND	<100	ND	<100	ND
SB-318-24	22	24	2/23/2001	193	105	88	<100	ND	<100	ND	<100	ND	<100	ND
SB-318-26	24	26	2/23/2001	193	165	134	57 J	0.10 J	<100	ND	<100	ND	<100	ND
SB-318-26B	24	26	2/23/2001	194	173	128	221	0.46	<100	ND	<100	ND	<100	ND
SB-318-28	26	28	2/23/2001	194	125	99	<100	ND	<100	ND	<100	ND	<100	ND
SB-318-30	28	30	2/23/2001	193	123	95	97 J	0.19 J	<100	ND	<100	ND	<100	ND
SB-318-32	30	32	2/23/2001	194	67	55	<100	ND	<100	ND	<100	ND	<100	ND
SB-318-34	32	34	2/23/2001	193	149	121	167	0.30	<100	ND	<100	ND	<100	ND
SB-318-36	34	36	2/23/2001	192	138	111	5,220	9.48	<100	ND	<100	ND	<100	ND
SB-318-38	36	38	2/23/2001	194	90	66	1,140	2.38	<100	ND	<100	ND	<100	ND
SB-318-40	38	40	2/23/2001	195	131	102	1,620	3.09	<100	ND	<100	ND	<100	ND
SB-318-43	40	43	2/23/2001	194	139	114	2,980	5.25	<100	ND	<100	ND	<100	ND
SB-318-45	43	45	2/23/2001	193	149	122	5,050	8.92	<100	ND	<100	ND	<100	ND

Table C-5. Extended Monitoring VOC Results of Soil Samples (mg/Kg) (Continued)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)
SB-318-MB10	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-318-MB11	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-318-MB12	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-319-2	0	2	2/20/2001	193	142	136	<100	ND	<100	ND	<100	ND	<100	ND
SB-319-4	2	4	2/20/2001	193	127	126	<100	ND	<100	ND	<100	ND	<100	ND
SB-319-6	4	6	2/20/2001	192	104	99	<100	ND	<100	ND	<100	ND	<100	ND
SB-319-8	6	8	2/20/2001	192	78	75	<100	ND	<100	ND	<100	ND	<100	ND
SB-319-10	8	10	2/22/2001	193	96	80	133	0.23	<100	ND	<100	ND	<100	ND
SB-319-10B	8	10	2/22/2001	193	112	96	120	0.20	<100	ND	<100	ND	<100	ND
SB-319-12	10	12	2/22/2001	193	119	100	518	0.88	<100	ND	<100	ND	<100	ND
SB-319-14	12	14	2/22/2001	193	119	101	729	1.22	<100	ND	<100	ND	<100	ND
SB-319-16	14	16	2/22/2001	194	149	123	3,260	5.69	<100	ND	<100	ND	<100	ND
SB-319-18	16	18	2/22/2001	192	131	109	11,800	20.33	21 J	0.04 J	<100	ND	<100	ND
SB-319-20	18	20	2/22/2001	193	105	92	87 J	0.14 J	<100	ND	<100	ND	<100	ND
SB-319-22	20	22	2/22/2001	194	150	122	112	0.20	<100	ND	<100	ND	<100	ND
SB-319-24	22	24	2/22/2001	192	124	101	<100	ND	<100	ND	<100	ND	<100	ND
SB-319-30	28	30	2/22/2001	193	140	111	3,120	5.80	5,200	9.66	55 J	0.10 J	<100	ND
SB-319-32	30	32	2/22/2001	193	133	111	1,720	2.95	1,940	3.33	51 J	0.09 J	<100	ND
SB-319-34	32	34	2/22/2001	193	158	124	4,380	8.27	112	0.21	<100	ND	<100	ND
SB-319-36	34	36	2/22/2001	192	138	105	1,340	2.65	46 J	0.09 J	<100	ND	<100	ND
SB-319-38	36	38	2/22/2001	193	94	72	2,570	5.03	4,040	7.91	71 J	0.14 J	<100	ND
SB-319-40	38	40	2/22/2001	192	155	119	1,150	2.24	10,200	19.90	96 J	0.19 J	<100	ND
SB-319-43	40	43	2/22/2001	192	126	99	21,600	40.69 D	<100	ND	<100	ND	<100	ND
SB-319-45	43	45	2/22/2001	192	90	72	54,900	100.59 D	121	0.22	<100	ND	<100	ND
SB-319-MB6	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-320-2	0	2	2/20/2001	193	139	139	<100	ND	<100	ND	<100	ND	<100	ND
SB-320-4	2	4	2/20/2001	193	107	107	<100	ND	<100	ND	<100	ND	<100	ND
SB-320-6	4	6	2/20/2001	192	139	134	<100	ND	<100	ND	<100	ND	<100	ND
SB-320-8	6	8	2/20/2001	192	67	67	<100	ND	<100	ND	<100	ND	<100	ND
SB-320-10	8	10	2/22/2001	194	173	147	1,330	2.22	15 J	0.02 J	<100	ND	<100	ND
SB-320-12	10	12	2/22/2001	194	102	89	1,740	2.78	103	0.16	<100	ND	<100	ND
SB-320-14	12	14	2/22/2001	192	139	124	2,270	3.50	<100	ND	<100	ND	<100	ND
SB-320-16	14	16	2/22/2001	193	160	135	139	0.23	<100	ND	<100	ND	<100	ND
SB-320-18	16	18	2/22/2001	194	137	115	12,100	20.56	<100	ND	<100	ND	<100	ND
SB-320-20	18	20	2/22/2001	194	160	132	194	0.34	<100	ND	<100	ND	<100	ND
SB-320-22	20	22	2/22/2001	193	134	110	1,010	1.78	<100	ND	<100	ND	<100	ND

Table C-5. Extended Monitoring VOC Results of Soil Samples (mg/Kg) (Continued)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)
SB-320-24	22	24	2/22/2001	193	112	91	<100	ND	<100	ND	<100	ND	<100	ND
SB-320-26	24	26	2/22/2001	195	131	102	<100	ND	<100	ND	<100	ND	<100	ND
SB-320-28	26	28	2/22/2001	193	117	92	<100	ND	<100	ND	<100	ND	<100	ND
SB-320-30	28	30	2/22/2001	196	112	90	213	0.39	<100	ND	<100	ND	<100	ND
SB-320-32	30	32	2/22/2001	195	125	100	299	0.55	<100	ND	<100	ND	<100	ND
SB-320-34	32	34	2/22/2001	194	135	109	4,070	7.35	104	0.19	<100	ND	<100	ND
SB-320-36	34	36	2/22/2001	196	94	75	3,050	5.61	110	0.20	<100	ND	<100	ND
SB-320-38	36	38	2/22/2001	195	95	69	2,500	5.30	56 J	0.12 J	<100	ND	<100	ND
SB-320-40	38	40	2/22/2001	194	100	75	2,270	4.59	119	0.24	<100	ND	<100	ND
SB-320-43	40	43	2/22/2001	191	102	83	39,000	69.60 D	<100	ND	<100	ND	<100	ND
SB-320-43B	40	43	2/22/2001	192	88	72	36,800	65.11	<100	ND	<100	ND	<100	ND
SB-320-45	43	45	2/22/2001	NA	193	77	1,610,000	7,533.62 D	175	0.82	<100	ND	<100	ND
SB-310-MB5	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-321-2	0	2	2/20/2001	193	80	80	<100	ND	<100	ND	<100	ND	<100	ND
SB-321-4	2	4	2/20/2001	191	117	117	<100	ND	<100	ND	<100	ND	<100	ND
SB-321-6	4	6	2/20/2001	194	157	152	<100	ND	<100	ND	<100	ND	<100	ND
SB-321-8	6	8	2/20/2001	193	109	102	<100	ND	<100	ND	<100	ND	<100	ND
SB-321-10	8	10	2/21/2001	194	86	74	791	1.29	<100	ND	<100	ND	<100	ND
SB-321-12	10	12	2/21/2001	191	118	99	562	0.96	152	0.26	<100	ND	<100	ND
SB-321-14	12	14	2/21/2001	191	47	42	233	0.36	<100	ND	<100	ND	<100	ND
SB-321-14B	12	14	2/21/2001	196	64	57	213	0.33	<100	ND	<100	ND	<100	ND
SB-321-16	14	16	2/21/2001	194	83	73	789	1.24	<100	ND	<100	ND	<100	ND
SB-321-18	16	18	2/21/2001	192	167	138	<100	ND	<100	ND	<100	ND	<100	ND
SB-321-20	18	20	2/21/2001	193	105	88	<100	ND	<100	ND	<100	ND	<100	ND
SB-321-22	20	22	2/21/2001	193	143	118	<100	ND	<100	ND	<100	ND	<100	ND
SB-321-24	22	24	2/21/2001	189	140	114	<100	ND	<100	ND	<100	ND	<100	ND
SB-321-26	24	26	2/21/2001	194	139	107	<100	ND	<100	ND	<100	ND	<100	ND
SB-321-28	26	28	2/21/2001	190	182	142	<100	ND	<100	ND	<100	ND	<100	ND
SB-321-30	28	30	2/21/2001	193	166	135	789	1.41	<100	ND	<100	ND	<100	ND
SB-321-32	30	32	2/21/2001	183	210	163	443	0.85	<100	ND	<100	ND	<100	ND
SB-321-34	32	34	2/21/2001	193	157	125	17	0.03	<100	ND	<100	ND	<100	ND
SB-321-36	34	36	2/21/2001	193	151	116	74	0.14	<100	ND	<100	ND	<100	ND
SB-321-38	36	38	2/21/2001	194	156	118	458	0.91	869	1.73	<100	ND	<100	ND
SB-321-40	38	40	2/21/2001	192	191	148	126	0.24	172	0.33	<100	ND	<100	ND
SB-321-43	40	43	2/21/2001	193	137	106	132	0.25 D	23 J	0.04 J	<100	ND	<100	ND
SB-321-45	43	45	2/21/2001	194	173	133	187	0.36 D	145	0.28	<100	ND	<100	ND

Table C-5. Extended Monitoring VOC Results of Soil Samples (mg/Kg) (Continued)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)
SB-321-MB2	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-321-MB4	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND
SB-323-2	0	2	2/20/2001	190	95	93	<100	ND	<100	ND	<100	ND	<100	ND
SB-323-4	2	4	2/20/2001	191	100	100	<100	ND	<100	ND	<100	ND	<100	ND
SB-323-6	4	6	2/20/2001	191	120	118	<100	ND	<100	ND	<100	ND	<100	ND
SB-323-8	6	8	2/20/2001	192	111	100	<100	ND	<100	ND	<100	ND	<100	ND
SB-323-10	8	10	2/20/2001	183	146	125	970	1.60	<100	ND	<100	ND	<100	ND
SB-323-12	10	12	2/20/2001	195	166	138	1,470	2.54	1,000	1.73	<100	ND	<100	ND
SB-323-14	12	14	2/20/2001	176	135	116	681	1.11	1,670	2.73	<100	ND	<100	ND
SB-323-14B	12	14	2/20/2001	192	97	84	434	0.70	1,210	1.96	<100	ND	<100	ND
SB-323-16	14	16	2/20/2001	191	179	150	1,840	3.14	1,130	1.93	<100	ND	<100	ND
SB-323-18	16	18	2/20/2001	193	182	149	1,650	2.92	715	1.26	<100	ND	<100	ND
SB-323-20	18	20	2/20/2001	193	216	184	185	0.31	40 J	0.07 J	<100	ND	<100	ND
SB-323-22	20	22	2/20/2001	193	154	129	648	1.10	<100	ND	<100	ND	<100	ND
SB-323-24	22	24	2/20/2001	194	147	120	<100	ND	<100	ND	<100	ND	<100	ND
SB-323-26	24	26	2/20/2001	191	164	136	<100	ND	<100	ND	<100	ND	<100	ND
SB-323-28	26	28	2/20/2001	191	176	131	140	0.29	<100	ND	<100	ND	<100	ND
SB-323-30	28	30	2/20/2001	191	132	105	117	0.22	<100	ND	<100	ND	<100	ND
SB-323-32	30	32	2/20/2001	194	206	149	3,580	7.63	<100	ND	<100	ND	<100	ND
SB-323-34	32	34	2/20/2001	192	116	95	1,810	3.20	<100	ND	<100	ND	<100	ND
SB-323-36	34	36	2/20/2001	194	143	102	302,000	657.33 D	923	2.01	11 J	0.02	<100	ND
SB-323-38	36	38	2/20/2001	195	212	155	44,400	93.20 D	180	0.38	<100	ND	<100	ND
SB-323-40	38	40	2/20/2001	188	205	139	178,000	416.82 D	248	0.58	<100	ND	<100	ND
SB-323-42	40	42	2/20/2001	193	194	144	50,300	103.24 D	<100	ND	<100	ND	<100	ND
SB-323-42B	40	42	2/20/2001	NA	194	144	36,800	75.53 D	<100	ND	<100	ND	<100	ND
SB-323-44	42	44	2/20/2001	185	145	116	542,000	993.09 D	<1,000	ND	<1,000	ND	<1,000	ND
SB-323-46	44	46	2/20/2001	189	186	135	12,400,000	26,310.32 D	4,640	9.85	<2,000	ND	<2,000	ND
SB-324-2	0	2	2/20/2001	194	78	77	<100	ND	<100	ND	<100	ND	<100	ND
SB-324-4	2	4	2/20/2001	184	91	91	<100	ND	<100	ND	<100	ND	<100	ND
SB-324-6	4	6	2/20/2001	191	167	162	<100	ND	<100	ND	<100	ND	<100	ND
SB-324-8	6	8	2/20/2001	192	122	104	<100	ND	176	0.29	<100	ND	<100	ND
SB-324-10	8	10	2/20/2001	191	152	128	509	0.86	355	0.60	<100	ND	<100	ND
SB-324-12	10	12	2/20/2001	191	147	123	3,470	5.93	76 J	0.13 J	<100	ND	<100	ND
SB-324-14	12	14	2/20/2001	191	68	61	5,440	8.30	<100	ND	<100	ND	<100	ND
SB-324-16	14	16	2/20/2001	193	111	93	10,300	17.56	<100	ND	<100	ND	<100	ND
SB-324-18	16	18	2/20/2001	192	119	94	1,440	2.69	<100	ND	<100	ND	<100	ND

Table C-5. Extended Monitoring VOC Results of Soil Samples (mg/Kg) (Continued)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)
SB-324-20	18	20	2/20/2001	191	135	108	<100	ND	<100	ND	<100	ND	<100	ND
SB-324-22	20	22	2/20/2001	192	96	79	<100	ND	<100	ND	<100	ND	<100	ND
SB-324-24	22	24	2/20/2001	193	150	120	<100	ND	<100	ND	<100	ND	<100	ND
SB-324-26	24	26	2/20/2001	191	147	115	56 J	0.11 J	<100	ND	<100	ND	<100	ND
SB-324-28	26	28	2/20/2001	192	156	118	25,600	51.08 D	<100	ND	<100	ND	<100	ND
SB-324-30	28	30	2/20/2001	195	120	98	24,600	43.65 D	23 J	0.04 J	<100	ND	<100	ND
SB-324-30B	28	30	2/20/2001	190	156	124	32,000	59.22 D	33 J	0.06 J	<100	ND	<100	ND
SB-324-32	30	32	2/20/2001	187	196	156	57,500	106.19 D	<100	ND	<100	ND	<100	ND
SB-324-34	32	34	2/20/2001	188	203	162	33,200	61.06 D	28 J	0.05 J	<100	ND	<100	ND
SB-324-36	34	36	2/20/2001	189	106	100	6,380	8.94	62 J	0.09 J	<100	ND	<100	ND
SB-324-38	36	38	2/20/2001	188	135	83	5,510	14.80	68 J	0.18 J	<100	ND	<100	ND
SB-324-40	38	40	2/20/2001	183	194	141	14,400	30.49 D	226	0.48	<100	ND	<100	ND
SB-324-42	40	42	2/20/2001	185	148	109	25,400	52.74 D	102	0.21	<100	ND	<100	ND
SB-324-44	42	44	2/20/2001	182	185	130	1,090,000	2,424.64 D	272	0.61	<100	ND	<100	ND
SB-324-46	44	46	2/20/2001	191	226	161	18,300,000	39,904.91 D	3,060	6.67	16 J	0.03 J	16 J	0.03 J
SB-325-2	0	2	2/20/2001	186	89	85	<100	ND	<100	ND	<100	ND	<100	ND
SB-325-4	2	4	2/20/2001	194	145	144	<100	ND	<100	ND	<100	ND	<100	ND
SB-325-6	4	6	2/20/2001	193	121	117	<100	ND	<100	ND	<100	ND	<100	ND
SB-325-8	6	8	2/20/2001	190	73	72	<100	ND	<100	ND	<100	ND	<100	ND
SB-325-10	8	10	2/21/2001	194	84	73	763	1.23	209	0.34	<100	ND	<100	ND
SB-325-12	10	12	2/21/2001	194	132	112	979	1.64	1,430	2.39	20 J	0.03 J	<100	ND
SB-325-14	12	14	2/21/2001	194	74	63	1,310	2.18	486	0.81	<100	ND	<100	ND
SB-325-16	14	16	2/21/2001	195	104	90	1,490	2.41	23 J	0.04 J	<100	ND	<100	ND
SB-325-18	16	18	2/21/2001	195	134	105	293	0.55	<100	ND	<100	ND	<100	ND
SB-325-20	18	20	2/21/2001	195	117	98	158	0.27	<100	ND	<100	ND	<100	ND
SB-325-22	20	22	2/21/2001	195	159	125	97 J	0.18 J	<100	ND	<100	ND	<100	ND
SB-325-24	22	24	2/21/2001	194	134	105	188	0.36	<100	ND	<100	ND	<100	ND
SB-325-26	24	26	2/21/2001	190	91	71	2,940	5.60	510	0.97	<100	ND	<100	ND
SB-325-28	26	28	2/21/2001	189	166	124	6,280	12.77	3,800	7.73	<100	ND	<100	ND
SB-325-30	28	30	2/21/2001	195	212	167	8,880	16.66	2,240	4.20	<100	ND	<100	ND
SB-325-32	30	32	2/21/2001	195	166	140	1,310	2.21	33 J	0.06 J	<100	ND	<100	ND
SB-325-34	32	34	2/21/2001	193	180	140	406	0.78	<100	ND	<100	ND	<100	ND
SB-325-36	34	36	2/21/2001	193	136	101	3,260	6.69	517	1.06	<100	ND	<100	ND
SB-325-36B	34	36	2/21/2001	194	103	79	83 J	0.16 J	15,000	29.31	29 J	0.06 J	296	0.58
SB-325-38	36	38	2/21/2001	194	147	111	1,150	2.30	10,500	21.01	24 J	0.05 J	262	0.52
SB-325-40	38	40	2/21/2001	190	123	93	133	0.27	6,440	12.86	<100	ND	266	0.53

Table C-5. Extended Monitoring VOC Results of Soil Samples (mg/Kg) (Continued)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)	Results in MeOH (ug/L)	Results in Dry Soil (mg/kg)
SB-325-43	40	43	2/21/2001	196	137	107	192	0.37	<100	ND	<100	ND	<100	ND
SB-325-45	43	45	2/21/2001	194	176	134	10,900	21.54	556	1.10	<100	ND	<100	ND
SB-325-MB3	Lab Blank			NA	NA	NA	<170	ND	<100	ND	<100	ND	<100	ND

NA: Not available.
ND: Not detected.
D: Diluted.
J: Estimated value.

Table C-6. VOC Results of Soil Samples from Semi-confined Aquifer (mg/Kg)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (µg/L)	Results in Dry Soil (mg/kg)	Results in MeOH (µg/L)	Results in Dry Soil (mg/kg)	Results in MeOH (µg/L)	Results in Dry Soil (mg/kg)	Results in MeOH (µg/L)	Results in Dry Soil (mg/kg)
SB-50-43	41	43	4/2/2001	190	313	257	98,700	173.67	2,150	3.78	<100	ND	<100	ND
SB-50-45	43	45	4/2/2001	193	292	217	35,200	72.12	7,060	14.47	17 J	0.03 J	<100	ND
SB-50-46	45	46	4/2/2001	188	168	135	10,500	19.11	2,490	4.53	<100	ND	<100	ND
SB-50-48	46	48	4/2/2001	190	289	209	18,400	39.25	5,300	11.31	<100	ND	<100	ND
SB-50-50	48	50	4/4/2001	188	235	190	2,530	4.56	1,400	2.52	<100	ND	<100	ND
SB-50-52	50	52	4/4/2001	189	283	240	738	1.23	480	0.80	<100	ND	<100	ND
SB-50-52B	50	52	4/4/2001	191	293	249	1,000	1.67	612	1.02	<100	ND	<100	ND
SB-50-54	52	54	4/4/2001	189	325	257	156	0.29	33 J	0.06 J	<100	ND	<100	ND
SB-50-56	54	56	4/4/2001	192	289	217	358	0.72	<100	ND	<100	ND	<100	ND
SB-50-58	56	58	4/4/2001	191	384	308	1,110	2.03	<100	ND	<100	ND	<100	ND
SB-50-60	58	60	4/4/2001	192	187	156	55 J	0.09 J	<100	ND	<100	ND	<100	ND
SB-50-MB1	Lab Blanks			NA	NA	NA	86 J	0.16 J	<100	ND	<100	ND	<100	ND
SB-51-41	39	41	4/3/2001	192	301	254	39,000	65.72	66 J	0.11 J	<100	ND	<100	ND
SB-51-44	41	44	4/3/2001	193	323	244	3,290,000	6,578.12	<4,000	ND	<4,000	ND	<4,000	ND
SB-51-44B	41	44	4/3/2001	192	297	252	231,000	385.87	290 J	0.48 J	<400	ND	<400	ND
SB-51-45	44	45	4/3/2001	192	222	162	1,820,000	3,831.13	1,500 J	3.16 J	<4,000	ND	<4,000	ND
SB-51-46	45	46	4/3/2001	192	282	204	328,000	699.35	2,870	6.12	<400	ND	<400	ND
SB-51-48	46	48	4/5/2001	192	241	188	1,500,000	2,856.89	9,160	17.45	<4,000	ND	<4,000	ND
SB-51-48B	46	48	4/5/2001	193	238	184	1,850,000	3,571.97	14,800	28.58	<2,000	ND	<2,000	ND
SB-51-50	48	50	4/5/2001	190	222	182	25,800	45.51	3,140	5.54	<100	ND	<100	ND
SB-51-52	50	52	4/5/2001	192	372	279	24,100	48.71	4,190	8.47	<100	ND	<100	ND
SB-51-54	52	54	4/5/2001	193	258	218	1,840	3.09	866	1.46	<100	ND	<100	ND
SB-51-56	54	56	4/5/2001	192	257	196	207	0.41	246	0.48	<100	ND	<100	ND
SB-51-58	56	58	4/5/2001	192	253	201	266	0.49	34 J	0.06 J	<100	ND	<100	ND
SB-51-60	58	60	4/5/2001	192	266	216	65 J	0.12 J	<100	ND	<100	ND	<100	ND
SB-51-MB2	Lab Blanks		4/4/2001	NA	NA	NA	62 J	0.12 J	<100	ND	<100	ND	<100	ND
SB-52-42	40	42	4/4/2001	190	276	235	11,900	19.77	1,810	3.01	<100	ND	<100	ND
SB-52-44	42	44	4/4/2001	189	334	284	12,600	20.98	1,760	2.93	<100	ND	<100	ND
SB-52-45	44	45	4/4/2001	190	251	203	20,800	37.47	2,490	4.49	<100	ND	<100	ND
SB-52-46	45	46	4/4/2001	191	205	158	71,300	138.31	4,520	8.77	57 J	0.11 J	<100	ND
SB-52-47	46	47	4/4/2001	191	210	163	243,000	466.36	2,900	5.57	<400	ND	<400	ND
SB-52-47B	46	47	4/4/2001	192	168	140	106,000	182.21	1,200	2.06	<100	ND	<100	ND
SB-52-47.5	47	47.5	4/5/2001	193	240	179	162,000	330.15	5,740	11.70	110 J	0.22 J	<200	ND
SB-52-48	47.5	48	4/5/2001	193	228	185	173,000	310.10	1,550	2.78	<200	ND	<200	ND
SB-52-49	48	49	4/5/2001	194	191	160	77,500	132.12	1,190	2.03	<100	ND	<100	ND
SB-52-49B	48	49	4/5/2001	193	269	220	90,800	160.76	2,020	3.58	41 J	0.07 J	<100	ND

Table C-6. VOC Results of Soil Samples from Semi-confined Aquifer (mg/Kg) (Continued)

	Sample Depth (ft)				Wet Soil	Dry Soil	TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl chloride	
Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Weight (g)	Weight (g)	Results in MeOH (µg/L)	Results in Dry Soil (mg/kg)	Results in MeOH (µg/L)	Results in Dry Soil (mg/kg)	Results in MeOH (µg/L)	Results in Dry Soil (mg/kg)	Results in MeOH (µg/L)	Results in Dry Soil (mg/kg)
SB-52-50	49	50	4/5/2001	192	211	173	208,000	366.81	1,560	2.75	<200	ND	<200	ND
SB-52-51	50	51	4/5/2001	192	314	258	269,000	472.80	2,060	3.62	<200	ND	<200	ND
SB-52-54	51	54	4/5/2001	192	265	204	364,000	707.38	1,840	3.58	<400	ND	<400	ND
SB-52-56	54	56	4/5/2001	192	321	250	4,450,000	8,496.46	5,340	10.20	130	0.25	<100	ND
SB-52-56B	54	56	4/5/2001	192	335	262	5,640,000	10,699.87	5,660	10.74	121	0.23	<100	ND
SB-52-58	56	58	4/5/2001	190	346	244	18,300,000	40,498.10	43,600	96.49	<20,000	ND	<20,000	ND
SB-52-60	58	60	4/5/2001	193	242	204	72,000	121.53	760	1.28	<100	ND	<100	ND
SB-52-MB3	Lab Blanks		4/5/2001	NA	NA	NA	64 J	0.12 J	<100	ND	<100	ND	<100	ND

NA: Not available.
ND: Not detected.
D: Diluted.
J: Estimated value.

Table C-7. VOC Results of Semi-Confined Aquifer Wells

Well ID	TCE						
	Feb 2001	Apr 2001	May 2002	Jun 2001	Aug 2001	Nov 2001	Feb 2002
Confined Aquifer Wells							
PA-20	67.1	447	111	350	19	15	181
PA-20-DUP	58.4	NA	NA	NA	NA	NA	NA
PA-21	7,840	15,700	6,400	5,030	790	1,640	416
PA-22	736,000	980,000	877,000	801,000	1,000,000	1,110,000	1,240,000
PA-22-DUP	NA	NA	939,000	NA	1,000,000	NA	NA

Well ID	*cis*-1,2-DCE						
	Feb 2001	Apr 2001	May 2002	Jun 2001	Aug 2001	Nov 2001	Feb 2002
Confined Aquifer Wells							
PA-20	21.7	199	37.4	145	10	52	66
PA-20-DUP	18.5	NA	NA	NA	NA	NA	NA
PA-21	1,190	5,790	1,490	1,080	330	5,140	315
PA-22	8,130	8,860	11,000	11,900	12,000 J	14,900	13,300
PA-22-DUP	NA	NA	10,700	NA	12,000 J	NA	NA

	trans-1,2-DCE						
PA-20	<0.1	1.45	0.24J	0.38	<1.0	0.48J	0.3J
PA-20-DUP	<0.1	NA	NA	NA	NA	NA	NA
PA-21	<1	51.7	6 J	5	<33	<10	2
PA-22	<100	<1,000	<1,120	<100	<17,000	<100	<1,000
PA-22-DUP	NA	NA	<1,090	NA	<17,000	NA	NA

	Vinyl Chloride						
PA-20	<0.1	0.36J	<1.08	<0.1	<2.0	<0.10	<1.0
PA-20-DUP	<0.1	NA	NA	NA	NA	NA	NA
PA-21	<1	4.22	<22.2	<1	<67	1,050	<1.0
PA-22	<100	<1,000	<1,120	<100	<33,000	<100	260J
PA-22-DUP	NA	NA	<1,090	NA	<33,000	NA	NA

NA: Not analyzed.

J: Estimated value, below reporting limit

Appendix D

Inorganic and Other Aquifer Parameters

Table D-1. Groundwater Field Parameters

Well ID	pH							ORP (mV)						
	Pre-Demo	Week 3-4	Week 7-8	Jan. 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan. 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-1S	7.29	NA	NA	NA	NA	NA	NA	-116.7	NA	NA	NA	NA	NA	NA
BAT-1I	7.60	NA	NA	NA	NA	NA	NA	-142.4	NA	NA	NA	NA	NA	NA
BAT-1D	7.53	NA	NA	NA	NA	NA	NA	-138.3	NA	NA	NA	NA	NA	NA
BAT-2S	7.33	8.07	7.95	7.65	NM	NM	NA	-115.3	579.5	471.8	70.4	NM	NM	469.3
BAT-2I	7.50	NA	7.08	8.40	NM	NM	6.76	-149.1	NA	396.1	71.1	NM	384.2	-102.9
BAT-2D	7.47	NA	6.57	6.63	NM	NM	5.46	-143.6	NA	211.8	129.9	NM	NM	166.4
BAT-3S	7.38	NA	NA	NA	NA	NA	NA	-138.2	NA	NA	NA	NA	NA	NA
BAT-3I	7.60	NA	NA	NA	NA	6.56	NA	-153.1	NA	NA	NA	NA	-96.7	NA
BAT-3D	7.52	NA	NA	NA	NA	NA	NA	-150.1	NA	NA	NA	NA	NA	NA
BAT-5S	7.01	6.92	6.97	8.34	7.21	7.16	7.49	-148.7	172.8	334.9	91.3	-93.5	-2.0	-40.0
BAT-5I	7.50	NA	7.64	8.42	NM	NM	7.68	-164.5	NA	250.5	145.2	NM	NM	-28.6
BAT-5D	7.50	NA	7.18	7.65	6.87	6.41	6.98	-130.9	NA	108.4	172.1	39.0	-83.6	-170.5
BAT-6S	7.36	NA	NA	NA	NA	NA	NA	-137.3	NA	NA	NA	NA	NA	NA
BAT-6I	7.60	NA	NA	NA	NA	NA	NA	-160.6	NA	NA	NA	NA	NA	NA
BAT-6D	7.52	NA	NA	NA	NA	NA	NA	-146.3	NA	NA	NA	NA	NA	NA
PA-4S	7.10	NA	NA	NA	NA	NA	NA	-25.2	NA	NA	NA	NA	NA	NA
PA-4I	7.26	NA	NA	NA	NA	NA	NA	-37.6	NA	NA	NA	NA	NA	NA
PA-4D	7.41	NA	NA	NA	NA	NA	NA	-22.2	NA	NA	NA	NA	NA	NA
ISCO Perimeter Wells														
PA-3S	7.08	7.02	6.87	8.25	NM	NM	NA	-34.9	-87.9	149.5	100.2	NM	NM	NA
PA-3I	7.57	7.62	7.11	7.72	7.09	6.09	NA	-27.7	-51.0	41.4	153.0	-331.9	-95.0	NA
PA-3D	7.19	7.47	7.03	9.57	NM	NM	NA	-90.3	-53.7	-36.9	156.9	NM	NM	NA
PA-5S	7.18	7.20	7.13	7.28	6.86	NM	NA	-47.9	-30.5	-5.2	-115.9	-78.2	NM	NA
PA-5I	7.10	7.26	7.08	7.42	7.11	6.88	NA	-79.7	-123.6	-100.8	-98.9	-85.0	-82.1	NA
PA-5D	7.47	7.66	7.45	7.73	7.53	7.39	NA	-62.7	-86.9	-71.8	-113.9	-223.2	-153.3	NA
PA-6S	7.17	7.26	7.14	7.90	7.84	7.91	NA	-75.2	-155.8	-137.1	136.0	-149.8	-52.8	NA
PA-6I	7.45	7.50	7.44	7.87	7.53	7.38	NA	-26.0	-77.4	-76.8	55.6	-150.2	-30.1	NA
PA-6D	7.41	7.52	7.46	7.61	7.49	7.46	NA	-73.0	-128.4	-57.9	61.7	-174.5	-143.5	NA
PA-9S	7.47	7.51	7.39	7.82	8.64	7.29	NA	-32.3	-93.4	-14.0	-100.7	9.1	-89.6	NA
PA-9I	7.43	7.65	7.49	7.88	7.39	7.42	NA	-31.4	-120.9	-98.4	-157.8	-94.0	-70.6	NA
PA-9D	7.42	7.65	7.53	7.89	7.33	7.37	NA	-73.4	-83.5	-50.4	-121.0	-215.9	-107.5	NA
PA-12S	7.03	7.18	7.04	6.44	7.02	6.82	NA	-135.4	-128.2	-133.2	-123.0	-124.3	-97.9	NA
PA-12I	7.42	7.54	7.41	7.89	7.27	7.30	NA	-138.8	-126.2	-126.2	-174.4	-140.3	-109.5	NA

Table D-1. Groundwater Field Parameters (Continued)

Well ID	pH							ORP (mV)						
	Pre-Demo	Week 3-4	Week 7-8	Jan. 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan. 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.
PA-12D	7.49	7.50	7.33	7.76	6.91	6.87	NA	-151.0	-120.7	-125.9	-187.1	-169.4	-136.1	NA
Resistive Heating Plot Wells														
PA-13S	6.87	6.29	NA	NA	7.04	NA	NA	-107.9	-83.7	NA	NA	-286.1	NA	NA
PA-13I	7.38	7.81	NA	NA	8.41	NA	NA	-73.9	-146.8	NA	NA	-82.5	NA	NA
PA-13D	7.24	7.98	NA	NA	8.50	NA	NA	-105.8	-71.4	NA	NA	-111.6	NA	NA
PA-14S	7.13	9.15	NA	NA	6.72	NA	NA	-129.6	-196.3	NA	NA	-208.0	NA	NA
PA-14I	7.51	8.89	NA	NA	6.62	NA	NA	-118.3	-151.9	NA	NA	-260.1	NA	NA
PA-14D	7.45	7.57	NA	NA	NA	NA	NA	-141.7	-58.5	NA	NA	-231.0	NA	NA
Resistive Heating Perimeter Wells														
PA-2S	6.94	7.37	NA	7.50	6.90	6.62	NA	-58.3	-138.5	NA	-97.6	-277.7	-153.1	NA
PA-2I	7.30	6.50	NA	7.50	6.77	6.75	NA	-31.9	-68.9	NA	-127.0	-102.6	-134.7	NA
PA-2D	7.27	6.99	NA	7.46	4.10?	7.00	NA	-89.8	-163.6	NA	-132.0	-75.7	-112.6	NA
PA-7S	6.86	6.59	NA	7.14	6.60	NA	NA	-82.5	-111.2	NA	-121.6	-157.0	NA	NA
PA-7I	7.31	7.26	NA	7.51	6.85	NA	NA	-33.9	-80.3	NA	-120.4	-89.4	NA	NA
PA-7D	7.49	7.00	NA	7.14	7.81	NA	NA	-56.1	-144.0	NA	-127.9	-58.3	NA	NA
PA-10S	6.78	6.72	NA	6.98	6.63	NA	NA	-119.5	-99.2	NA	-142.8	-121.9	NA	NA
PA-10I	6.86	6.72	NA	6.81	6.63	NA	NA	-129.7	-99.8	NA	-132.4	-125.2	NA	NA
PA-10D	7.37	6.48	NA	6.87	7.04	NA	NA	-131.1	46.2	NA	-125.4	-89.4	NA	NA
IW-17S	6.79	5.93	NA	7.85	Dry	NA	NA	-12.4	-29.5	NA	-122.3	Dry	NA	NA
IW-17I	7.41	6.92	NA	6.83	6.20	NA	NA	-12.3	-96.6	NA	-132.5	-76.9	NA	NA
IW-17D	7.39	NA	NA	8.43	7.56	NA	NA	-115.8	-242.3	NA	-144.5	-85.7	NA	NA
PA-15	NA	NA	NA	6.86	6.37	NA	NA	NA	NA	NA	-154.1	-190.4	NA	NA
Distant Wells														
PA-1S	7.58	7.79	7.65	8.15	7.54	7.29	NA	-57.4	1.6	148.2	43.4	-55.0	-117.1	NA
PA-1I	7.72	8.39	NM	8.27	7.64	7.60	NA	-13.3	-19.5	54.8	-94.6	3.1	-65.3	NA
PA-1D	7.57	7.88	7.90	7.97	7.52	7.50	NA	-112.2	-13.4	-762.4	-124.8	-66.8	-90.1	NA
PA-8S	6.93	7.08	7.22	6.87	6.66	6.54	NA	-96.2	-61.8	-115.9	209.6	-33.4	-58.4	NA
PA-8I	7.27	7.41	7.52	7.43	7.21	7.16	NA	-6.6	4.3	-31.8	109.5	-99.2	-114.8	NA
PA-8D	7.45	7.66	7.73	7.85	6.86	6.78	NA	-19.0	9.0	-50.7	87.0	-123.8	-52.8	NA
PA-11S	7.02	6.95	6.75	7.45	6.37	NM	NA	-124.8	-77.8	-76.0	-152.1	-71.3	NM	NA
PA-11I	7.11	7.25	7.07	7.24	7.01	6.22	NA	-136.4	-93.9	-133.5	-127.2	-86.0	-75.9	NA
PA-11D	7.55	7.69	7.41	7.71	7.45	7.46	NA	-136.3	-73.2	-96.7	-156.4	-143.9	-133.3	NA

Table D-1. Groundwater Field Parameters (Continued)

Well ID	DO (mg/L)							Temperature (°C)						
	Pre-Demo	Week 3-4	Week 7-8	Jan. 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan. 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-1S	2.73	NA	NA	NA	NA	NA	NA	26.84	NA	NA	NA	NA	NA	NA
BAT-1I	0.61	NA	NA	NA	NA	NA	NA	26.51	NA	NA	NA	NA	NA	NA
BAT-1D	NA	NA	NA	NA	NA	NA	NA	26.77	NA	NA	NA	NA	NA	NA
BAT-2S	0.38	NM	1.91	NM	NM	NM	NA	26.85	29.33	28.75	23.48	NM	NM	28.58
BAT-2I	0.87	NA	0.67	NM	NM	3.06	0.72	27.88	NA	29.51	23.93	NM	28.29	28.09
BAT-2D	0.87	NA	NA	NM	NM	NM	0.92	26.82	NA	27.92	25.84	NM	NM	28.14
BAT-3S	0.91	NA	NA	NA	NA	NA	NA	26.44	NA	NA	NA	NA	NA	NA
BAT-3I	0.70	NA	NA	NA	NA	0.28	NA	26.56	NA	NA	NA	NA	26.69	NA
BAT-3D	0.76	NA	NA	NA	NA	NA	NA	26.29	NA	NA	NA	NA	NA	NA
BAT-5S	0.43	0.71	1.73	NM	0.53	0.33	1.38	28.51	29.43	28.08	26.28	24.52	27.04	26.10
BAT-5I	0.52	NA	2.03	NM	NM	NM	NA	27.40	NA	27.93	23.00	NM	NM	26.54
BAT-5D	0.64	NA	0.69	NM	0.87	0.74	0.06	27.62	NA	26.52	24.03	25.66	28.72	26.56
BAT-6S	0.50	NA	NA	NA	NA	NA	NA	26.72	NA	NA	NA	NA	NA	NA
BAT-6I	0.50	NA	NA	NA	NA	NA	NA	27.30	NA	NA	NA	NA	NA	NA
BAT-6D	0.41	NA	NA	NA	NA	NA	NA	26.49	NA	NA	NA	NA	NA	NA
PA-4S	0.49	NA	NA	NA	NA	NA	NA	26.30	NA	NA	NA	NA	NA	NA
PA-4I	0.59	NA	NA	NA	NA	NA	NA	26.64	NA	NA	NA	NA	NA	NA
PA-4D	0.30	NA	NA	NA	NA	NA	NA	26.09	NA	NA	NA	NA	NA	NA
ISCO Perimeter Wells														
PA-3S	0.51	0.71	1.73	1.50	NM	NM	NA	26.07	28.11	28.94	23.46	NM	NM	NA
PA-3I	0.63	0.64	2.49	1.07	0.54	0.26	NA	26.44	27.93	28.62	23.44	26.12	28.42	NA
PA-3D	1.07	0.77	3.52	0.16	NM	NM	NA	26.81	27.80	29.29	24.24	NM	NM	NA
PA-5S	0.11	0.35	0.64	NA	0.37	NM	NA	28.25	27.34	27.28	25.84	24.28	NM	NA
PA-5I	1.85	0.43	0.72	NA	0.35	0.83	NA	28.87	27.22	27.10	26.01	24.91	25.23	NA
PA-5D	0.46	0.45	1.57	NA	0.57	0.82	NA	27.02	26.86	26.89	25.76	25.70	25.89	NA
PA-6S	0.87	0.40	0.70	0.22	0.22	0.73	NA	28.22	27.49	27.24	25.08	23.01	25.05	NA
PA-6I	0.66	0.45	0.76	0.16	0.25	1.09	NA	28.45	27.27	26.60	25.62	23.95	25.58	NA
PA-6D	0.70	0.54	1.57	NA	0.34	0.65	NA	27.81	26.59	26.42	25.47	24.54	26.45	NA
PA-9S	0.47	0.39	2.15	1.15	2.20	0.38	NA	26.79	27.36	26.12	25.63	25.68	26.25	NA
PA-9I	1.01	0.73	2.65	2.19	0.32	0.31	NA	26.52	28.20	26.15	25.71	26.15	26.10	NA
PA-9D	1.03	0.77	2.06	2.88	0.31	0.43	NA	26.25	27.04	25.87	25.43	25.88	26.01	NA
PA-12S	0.65	0.70	1.47	NA	0.28	0.50	NA	25.67	26.26	26.48	27.13	25.35	26.34	NA
PA-12I	0.59	0.76	1.96	NA	0.34	0.46	NA	26.01	26.65	26.41	26.49	25.46	26.09	NA

Table D-1. Groundwater Field Parameters (Continued)

Well ID	DO (mg/L)							Temperature (°C)						
	Pre-Demo	Week 3-4	Week 7-8	Jan. 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan. 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.
PA-12D	0.43	0.90	2.13	NA	0.41	0.57	NA	25.99	25.97	26.19	25.79	25.31	26.23	NA
Resistive Heating Plot Wells														
PA-13S	0.28	0.86	NA	NA	0.22	NA	NA	26.12	43.74	NA	NA	43.71	NA	NA
PA-13I	0.27	0.91	NA	NA	0.07	NA	NA	27.36	30.93	NA	NA	31.12	NA	NA
PA-13D	0.62	2.21	NA	NA	0.02	NA	NA	27.26	44.51	NA	NA	40.86	NA	NA
PA-14S	0.31	0.10	NA	NA	0.34	NA	NA	26.94	30.29	NA	NA	53.97	NA	NA
PA-14I	0.40	0.77	NA	NA	0.15	NA	NA	27.70	39.99	NA	NA	38.29	NA	NA
PA-14D	0.10	1.13	NA	NA	0.24	NA	NA	27.29	43.32	NA	NA	37.70	NA	NA
Resistive Heating Perimeter Wells														
PA-2S	0.84	0.42	NA	NA	0.46	0.34	NA	27.00	27.45	NA	21.57	42.07	34.61	NA
PA-2I	0.48	0.79	NA	NA	0.39	0.45	NA	27.03	27.43	NA	24.66	26.68	32.22	NA
PA-2D	0.80	0.29	NA	NA	0.36	0.68	NA	26.36	27.80	NA	23.15	30.91	33.29	NA
PA-7S	0.52	0.41	NA	NA	1.02	NA	NA	28.84	28.60	NA	29.42	49.21	NA	NA
PA-7I	0.43	0.58	NA	NA	1.46	NA	NA	28.53	28.74	NA	26.77	36.14	NA	NA
PA-7D	0.43	0.73	NA	NA	NA	NA	NA	28.08	28.33	NA	28.29	39.63	NA	NA
PA-10S	0.54	0.96	NA	NA	1.24	NA	NA	23.67	36.77	NA	29.95	45.76	NA	NA
PA-10I	0.54	0.76	NA	NA	0.85	NA	NA	23.71	30.73	NA	32.16	32.95	NA	NA
PA-10D	0.89	0.46	NA	NA	1.47	NA	NA	23.76	29.88	NA	32.10	33.60	NA	NA
IW-17S	0.46	2.46	NA	NA	Dry	NA	NA	28.39	40.76	NA	44.32	Dry	NA	NA
IW-17I	0.47	0.79	NA	NA	0.73	NA	NA	27.01	29.37	NA	37.25	39.02	NA	NA
IW-17D	0.34	0.81	NA	NA	0.34	NA	NA	26.85	28.05	NA	30.45	40.30	NA	NA
PA-15	NA	NA	NA	NA	0.27	NA	NA	NA	NA	NA	36.75	32.57	NA	NA
Distant Wells														
PA-1S	0.43	0.58	1.11	0.18	0.42	0.37	NA	26.96	27.25	27.62	26.03	24.46	24.96	NA
PA-1I	0.49	0.41	0.33	1.23	0.64	0.41	NA	27.60	30.42	27.49	26.10	25.27	25.73	NA
PA-1D	0.23	0.51	0.39	1.43	0.48	0.48	NA	27.09	27.43	27.38	25.94	25.64	26.39	NA
PA-8S	0.69	0.40	0.30	NA	0.47	0.38	NA	28.91	28.74	27.97	25.55	24.96	26.32	NA
PA-8I	0.68	0.87	0.51	NA	0.48	0.36	NA	28.65	28.51	27.58	25.28	25.60	26.40	NA
PA-8D	0.73	0.56	0.84	NA	0.55	0.68	NA	27.67	27.78	27.43	25.15	25.76	26.13	NA
PA-11S	0.47	0.54	0.67	NA	0.50	NM	NA	24.82	25.58	26.15	25.45	24.83	NM	NA
PA-11I	0.21	0.66	1.20	NA	0.52	0.56	NA	25.29	25.87	26.01	25.14	24.75	25.80	NA
PA-11D	0.54	1.09	2.38	NA	0.60	0.66	NA	24.64	25.43	25.51	24.83	24.53	25.12	NA

Table D-1. Groundwater Field Parameters (Continued)

Well ID	Eh (mV)							Conductivity (mS/cm)						
	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-1S	80.3	NA	NA	NA	NA	NA	NA	0.790	NA	NA	NA	NA	NA	NA
BAT-1I	54.6	NA	NA	NA	NA	NA	NA	1.383	NA	NA	NA	NA	NA	NA
BAT-1D	58.7	NA	NA	NA	NA	NA	NA	2.519	NA	NA	NA	NA	NA	NA
BAT-2S	81.7	776.5	668.8	367.4	NA	NA	666.3	0.760	6.049	16.260	4.836	NM	NM	13.96
BAT-2I	47.9	NA	593.1	368.1	NA	681.2	94.10	1.343	NA	14.340	5.012	NM	9.47	10.69
BAT-2D	53.4	NA	408.8	426.9	NA	NA	363.4	2.552	NA	3.852	12.170	NM	NM	20.97
BAT-3S	58.8	NA	NA	NA	NA	NA	NA	0.673	NA	NA	NA	NA	NA	NA
BAT-3I	43.9	NA	NA	NA	NA	200.3	NA	1.360	NA	NA	NA	NA	10.03	NA
BAT-3D	46.9	NA	NA	NA	NA	NA	NA	2.626	NA	NA	NA	NA	NA	NA
BAT-5S	48.3	369.8	531.9	388.3	203.5	295.0	157.00	0.520	1.759	2.869	1.034	6.60	6.65	10.77
BAT-5I	32.5	NA	447.5	442.2	NA	NA	168.4	0.679	NA	3.145	1.117	NM	NM	9.27
BAT-5D	66.1	NA	305.4	469.1	336.0	213.4	26.50	2.584	NA	3.609	3.720	11.86	14.62	13.26
BAT-6S	59.7	NA	NA	NA	NA	NA	NA	0.910	NA	NA	NA	NA	NA	NA
BAT-6I	36.4	NA	NA	NA	NA	NA	NA	1.356	NA	NA	NA	NA	NA	NA
BAT-6D	50.7	NA	NA	NA	NA	NA	NA	2.684	NA	NA	NA	NA	NA	NA
PA-4S	171.8	NA	NA	NA	NA	NA	NA	0.620	NA	NA	NA	NA	NA	NA
PA-4I	159.4	NA	NA	NA	NA	NA	NA	0.756	NA	NA	NA	NA	NA	NA
PA-4D	174.8	NA	NA	NA	NA	NA	NA	2.664	NA	NA	NA	NA	NA	NA
ISCO Perimeter Wells														
PA-3S	162.1	109.1	346.5	397.2	NA	NA	NA	0.655	1.264	5.043	1.823	NM	NM	NA
PA-3I	169.3	146.0	238.4	450.0	-34.9	202.0	NA	1.097	1.047	6.186	2.219	10.57	8.64	NA
PA-3D	106.7	143.3	160.1	453.9	NA	NA	NA	2.827	2.493	12.570	3.709	NM	NM	NA
PA-5S	149.1	166.5	191.8	181.1	218.8	NA	NA	0.512	0.448	1.079	1.883	144.60	NM	NA
PA-5I	117.3	73.4	96.2	198.1	212.0	214.9	NA	0.668	0.611	1.334	1.787	59.80	2.81	NA
PA-5D	134.3	110.1	125.2	183.1	73.8	143.7	NA	2.492	2.364	5.308	5.543	56.52	2.42	NA
PA-6S	121.8	41.2	59.9	433.0	147.2	244.2	NA	0.545	0.489	1.225	4.167	42.46	1.74	NA
PA-6I	171.0	119.6	120.2	352.6	146.8	266.9	NA	0.874	0.836	2.078	2.616	75.62	3.27	NA
PA-6D	124.0	68.6	139.1	358.7	122.5	153.5	NA	2.626	2.544	5.318	5.746	97.40	3.64	NA
PA-9S	164.7	103.6	183.0	196.3	306.1	207.4	NA	1.444	0.927	2.275	2.754	27.23	4.13	NA
PA-9I	165.6	76.1	98.6	139.2	203.0	226.4	NA	1.051	1.444	3.532	4.129	96.81	4.21	NA
PA-9D	123.6	113.5	146.6	176.0	81.1	189.5	NA	2.521	2.341	5.096	5.654	107.10	4.07	NA
PA-12S	61.6	68.8	63.8	174.0	172.7	199.1	NA	0.711	0.644	1.520	10.590	162.40	7.94	NA
PA-12I	58.2	70.8	70.8	122.6	156.7	187.5	NA	0.957	0.964	2.390	3.415	110.50	5.13	NA

Table D-1. Groundwater Field Parameters (Continued)

Well ID	Eh (mV)							Conductivity (mS/cm)						
	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.
PA-12D	46.0	76.3	71.1	109.9	127.6	160.9	NA	2.663	2.587	5.725	6.247	140.00	6.20	NA
Resistive Heating Plot Wells														
PA-13S	89.1	113.3	NA	NA	10.9	NA	NA	0.884	1.013	NA	NA	125.90	NA	NA
PA-13I	123.1	50.2	NA	NA	214.5	NA	NA	0.926	0.991	NA	NA	146.40	NA	NA
PA-13D	91.2	125.6	NA	NA	185.4	NA	NA	3.384	2.663	NA	NA	377.80	NA	NA
PA-14S	67.4	0.7	NA	NA	89.0	NA	NA	0.776	1.187	NA	NA	251.60	NA	NA
PA-14I	78.7	45.1	NA	NA	36.9	NA	NA	1.171	4.457	NA	NA	272.50	NA	NA
PA-14D	55.3	138.5	NA	NA	66.0	NA	NA	2.836	2.771	NA	NA	224.40	NA	NA
Resistive Heating Perimeter Wells														
PA-2S	138.7	58.5	NA	199.4	19.3	143.9	NA	0.669	0.579	NA	2.762	84.69	3.33	NA
PA-2I	165.1	128.1	NA	170.0	194.4	162.3	NA	0.900	1.439	NA	1.723	93.10	3.09	NA
PA-2D	107.2	33.4	NA	165.0	221.3	184.4	NA	3.108	0.663	NA	4.294	146.60	5.48	NA
PA-7S	114.5	85.8	NA	175.4	140.0	NA	NA	0.854	0.932	NA	1.678	48.07	NA	NA
PA-7I	163.1	116.7	NA	176.6	207.6	NA	NA	1.704	1.335	NA	1.887	60.81	NA	NA
PA-7D	140.9	53.0	NA	169.1	238.7	NA	NA	2.562	1.840	NA	3.060	39.63	NA	NA
PA-10S	77.5	97.8	NA	154.2	175.1	NA	NA	0.804	0.817	NA	3.245	66.59	NA	NA
PA-10I	67.3	97.2	NA	164.6	171.8	NA	NA	0.953	0.893	NA	1.980	48.10	NA	NA
PA-10D	65.9	243.2	NA	171.6	207.6	NA	NA	3.125	1.414	NA	6.474	121.90	NA	NA
IW-17S	184.6	167.5	NA	174.7	NA	NA	NA	0.783	1.333	NA	2.475	Dry	NA	NA
IW-17I	184.7	100.4	NA	164.5	220.1	NA	NA	2.202	0.835	NA	2.160	111.90	NA	NA
IW-17D	81.2	-45.3	NA	152.5	211.3	NA	NA	2.607	2.197	NA	5.720	116.30	NA	NA
PA-15	NA	NA	NA	142.9	106.6	NA	NA	NA	NA	NA	4.041	76.05	NA	NA
Distant Wells														
PA-1S	139.6	198.6	345.2	340.4	242.0	NA	NA	0.355	0.389	1.221	1.375	1.26	1.39	NA
PA-1I	183.7	177.5	251.8	202.4	300.1	231.7	NA	0.676	0.450	0.860	1.861	1.93	1.73	NA
PA-1D	84.8	183.6	-565.4	172.2	230.2	206.9	NA	2.225	1.347	4.449	5.392	4.76	4.79	NA
PA-8S	100.8	135.2	81.1	506.6	263.6	238.6	NA	0.746	0.666	1.373	5.615	4.92	5.11	NA
PA-8I	190.4	201.3	165.2	406.5	197.8	182.2	NA	1.043	1.029	2.688	3.572	3.92	3.81	NA
PA-8D	178	206.0	146.3	384.0	173.2	244.2	NA	2.600	2.328	5.216	5.752	7.53	7.22	NA
PA-11S	72.2	119.2	121.0	144.9	225.7	NA	NA	0.829	0.737	1.534	1.517	187.20	NM	NA
PA-11I	60.6	103.1	63.5	169.8	211.0	221.1	NA	0.878	0.750	1.773	1.848	67.76	11.92	NA
PA-11D	60.7	123.8	100.3	140.6	153.1	163.7	NA	2.881	2.474	5.635	6.103	121.60	5.52	NA

Table D-1. Groundwater Field Parameters (Continued)

NA: Not available.
NM: Not measureable.
Pre-demo: 8/3/99 to 8/9/99
Week 3-4: 9/24/99 to 9/30/99
Week 7-8: 10/19/99 to 10/28/99
Post-Demo: 5/8/00 to 5/14/00
Ext. mon.: February 2001.

Table D-2. Iron and Manganese Results of Groundwater Samples

Compound	Iron (mg/L)							Manganese (mg/L)						
SMCL	0.3 mg/L							0.05 mg/L						
Well ID	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-2S	0.26	<0.05	<1.2	<0.050	<0.05	<0.1	<0.1	0.016						
BAT-2I		NA	<0.05	<0.050	<0.05	<0.1		0.018	NA					
BAT-2I-DUP	NA	NA	<0.05	<0.050	NA	NA	NA	NA	NA			NA	NA	NA
BAT-2D	0.12	NA	0.11	0.16	NS[1]	<0.05		0.015	NA			NS[1]		
BAT-5S		0.74		<0.050	0.15	<0.05					<0.015			
BAT-5I	<0.05	NA		<0.050	<0.05	<0.1	<0.1	<0.015	NA					
BAT-5D		NA		0.14	<0.05			0.025	NA					
BAT-5D-DUP	NA	NA		NA	<0.05		NA	NA	NA		NA			NA
ISCO Perimeter Wells														
PA-3S			<0.05	<0.050	<0.05	<0.1	NA		0.047					NA
PA-3S-DUP	NA	NA	NA	NA	NA	<0.1	NA	NA	NA	NA	NA	NA		NA
PA-3I	0.1				0.24		NA	0.018	0.022					NA
PA-3I-DUP	NA	0.23	NA	NA	NA	NA	NA	NA	0.015	NA	NA	NA	NA	NA
PA-3D	0.2	0.18		<0.050	<0.05	<0.25	NA							NA
PA-3D-DUP	NA	NA	NA	<0.050	NA	NA	NA	NA	NA	NA		NA	NA	NA
PA-5S						0.18	NA	0.026	0.022	0.03	0.047			NA
PA-5I							NA		0.043	0.04	0.028			NA
PA-5D	<0.05	0.18	<0.05	0.09	<0.05	<0.05	NA	0.024	0.023	<0.015	0.017	0.016	0.032	NA
PA-6S				0.5	<0.05	0.05	NA	0.027	0.030	0.036	0.019	<0.015	<0.015	NA
PA-6I	<0.05		0.18	0.14	<0.05	<0.05	NA	0.022	0.019	<0.015	0.015	<0.015	0.024	NA
PA-6D	0.13	0.27	0.13	0.13	<0.05		NA		0.024	0.015	0.015	<0.015		NA
PA-9S	<0.05				<0.05		NA	0.026	0.031	0.025	0.023	0.023		NA
PA-9S-DUP	NA	NA	NA	NA	<0.05	NA	NA	NA	NA	NA	NA	0.022	NA	NA
PA-9I	0.092			0.29	<0.05	<0.05	NA	0.031	0.027	0.027	0.024	0.015		NA
PA-9D	0.24	0.097	0.051	<0.050	<0.05	<0.05	NA	0.034	0.022	0.015	0.016	<0.015	0.015	NA
PA-12S							NA			0.044		0.12		NA
PA-12I							NA	0.047	0.027	0.02	<0.015			NA
PA-12D							NA		0.048	0.03				NA
Resistive Heating Plot Wells														
PA-13S		NA	NA	NA	0.24	NA	NA		NA	NA	NA	0.038	NA	NA
PA-13I		NA	NA	NA		NA	NA	0.023	NA	NA	NA		NA	NA
PA-13D	<0.05	NA	NA	NA		NA	NA	<0.015	NA	NA	NA	<0.015	NA	NA
PA-14S		NA	NA	NA		NA	NA	0.022	NA	NA	NA	0.015	NA	NA
PA-14I		NA	NA	NA		NA	NA		NA	NA	NA		NA	NA
PA-14D		NA	NA	NA		NA	NA	0.02	NA	NA	NA	0.028	NA	NA
Resistive Heating Plot Perimeter Wells														
PA-2S			NA				NA			NA	0.06			NA
PA-2I	0.28		NA				NA	0.03		NA			0.048	NA
PA-2I-DUP	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA		NA	NA
PA-2D			NA				NA			NA	0.033		0.036	NA
PA-7S			NA			NA	NA	0.037		NA			NA	NA
PA-7I	<0.05	<0.05	NA	0.26		NA	NA	0.03	0.026	NA	0.02		NA	NA
PA-7D	<0.05		NA		0.24	NA	NA	0.028	0.039	NA	0.03		NA	NA

Table D-2. Iron and Manganese Results of Groundwater Samples (Continued)

Compound	Iron (mg/L)							Manganese (mg/L)						
SMCL	0.3 mg/L							0.05 mg/L						
Well ID	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.
PA-7D-Dup	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		NA	NA
PA-10S			NA			NA	NA		0.039	NA	0.044	0.047	NA	NA
PA-10I			NA			NA	NA			NA	0.12		NA	NA
PA-10I-Dup	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-10D			NA			NA	NA	0.029		NA	0.044	0.021	NA	NA
PA-10D-DUP	NA	NA	NA		NA	NA	NA	NA	NA	NA	0.044	NA	NA	NA
IW-17S	0.16		NA	0.099	NS[2]	NA	NA	0.035		NA	<0.015	NS[2]	NA	NA
IW-17I	<0.05		NA			NA	NA			NA			NA	NA
IW-17D	0.24	NA	NA	<0.050	<0.05	NA	NA		NA	NA	<0.015	0.024	NA	NA
PA-15	NA	NA	NA	<0.050		NA	NA	NA	NA	NA	<0.015		NA	NA
Distant Wells														
PA-1S	0.12	<0.05	<0.05		0.2		NA	<0.015	<0.015	<0.015	0.039	0.015	0.019	NA
PA-1I	<0.05	<0.05	<0.05	0.082	<0.05	<0.05	NA	<0.015	<0.015	<0.015	<0.015	0.018	0.017	NA
PA-1I-DUP	NA	NA	NA	NA	NA	<0.05	NA	NA	NA	NA	NA	NA	0.019	NA
PA-1D	0.11	0.12	0.16	0.15	<0.05	<0.05	NA	0.037	0.040	0.037	0.026	0.021	0.021	NA
PA-1D-Dup	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-8S				0.16			NA							NA
PA-8S-DUP	NA	NA			NA	NA	NA	NA	NA			NA	NA	NA
PA-8I	0.23	0.14	<0.05				NA	0.028	0.027	0.028				NA
PA-8D	<0.05	<0.05	<0.05				NA	0.029	0.022	<0.015	0.045			NA
PA-8D-DUP	NA	<0.05	NA	NA	NA	NA	NA	NA	0.026	NA	NA	NA	NA	NA
PA-11S						<0.1	NA		0.061		0.046			NA
PA-11I							NA	0.028	0.034	0.043	0.028			NA
PA-11D							NA	0.026	0.019	0.023	0.019	0.022	0.019	NA

NA: Not available.

NS: Not sampled.

<: The compound was analyzed but not detected at or above the specified reporting limit.

SMCL: Secondary Maximum Contaminant Level.

s that the concentration exceeds or equals to the SMCL.

1. Sample was not collected due to excess amount of $KMnO_4$ in the flush mount.
2. Sample was not collected because the well was dry.

Pre-demo: 8/3/99 to 8/9/99
Week 3-4: 9/24/99 to 9/30/99
Week 5: 10/6/99 to 10/8/99
Week 7-8: 10/19/99 to 10/28/99
Post-Demo: 5/8/00 to 5/14/00

Table D-3. Chloride and Total Dissolved Solids Results of Groundwater Samples

SMCL	Chloride (mg/L) 250 mg/L							TDS (mg/L) 500 mg/L						
Well ID	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-2S	52.5	<1,000	<1,000		228 J	237 J	126	499						
BAT-2I	181	NA		105		238	186		NA					
BAT-2I-DUP	NA	NA		125	NA	NA	NA	NA	NA			NA	NA	NA
BAT-2D		NA	109		NS				NA			NS		
BAT-5S	37.5	101	141	77.8	234 J	236		387			361			
BAT-5S-DUP	NA	NA	NA	NA	NA	NA		402	NA	NA	NA	NA	NA	
BAT-5I	57	NA		77					NA		329			
BAT-5I-DUP	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA
BAT-5D		NA							NA					
BAT-5D-DUP	NA	NA		NA			NA	NA	NA		NA			NA
ISCO Perimeter Wells														
PA-3S	30.2	119		88.4	146 J		NA	398			475			NA
PA-3S-DUP	NA	NA	NA	NA	NA	153 J	NA	NA	NA	NA	NA	NA		NA
PA-3I	114	121		86.4	110	156	NA							NA
PA-3I-DUP	NA	121	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA
PA-3D				123			NA							NA
PA-3D-DUP	NA	NA	NA		NA	NA	NA	NA	NA	NA		NA	NA	NA
Distant Wells														
PA-1S	9.8	13.9	23	33.9	51.6	60.3	NA	205	293	319	326	413	470	NA
PA-1I	66.2	44.3	32.5	92.6	122	105	NA	424	313	277	442			NA
PA-1I-DUP	NA	NA	NA	NA	NA	111	NA	NA	NA	NA	NA	NA		NA
PA-1D							NA							NA
PA-1D-Dup	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-8S	24.2	23.8	26.3				NA	445	458	415				NA
PA-8S-DUP	NA	NA	26.9		NA	NA	NA	NA	NA	405		NA	NA	NA
PA-8I	119	130	182				NA							NA
PA-8D							NA							NA
PA-8D-DUP	NA	723	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA
PA-11S	36.7	28.3	28.9	34.1			NA							NA
PA-11I	49	44.2	46.7	48.5	248		NA							NA
PA-11D							NA							NA
PA-11D-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1,760	NA

NA: Not available.
NS: Not sampled.
SMCL: Secondary Maximum Contaminant Level
J: Estimated but below the detection limit.
Shading denotes that the concentration exceeds the SMCL Level.
Pre-demo: 8/3/99 to 8/9/99
Week 3-4: 9/24/99 to 9/30/99
Week 5: 10/6/99 to 10/8/99
Week 7-8: 10/19/99 to 10/28/99
Post-Demo: 5/8/00 to 5/14/00
Ext. Mon.: February 2001.

Table D-4. Potassium Results of Groundwater Samples

Units (mg/L)	$KMnO_4$	Mn	MnO_4	$KMnO_4$	Mn	MnO_4	$KMnO_4$	Mn	MnO_4	$KMnO_4$	Mn	MnO_4	$KMnO_4$	Mn	MnO_4
Well ID	**4/12 - 4/16/00**			**4/26 - 4/27/00**			**5/11 - 5/12/00**			**8/22 - 8/23/00**			**11/29 - 11/30/00**		
ISCO Plot Wells															
BAT-1S	NA	NA	NA	7	3	6	>6,000	>2,000	>6,000	NA	NA	NA	NA	NA	NA
BAT-1I	NA	NA	NA	8	3	6	27	10	20	NA	NA	NA	NA	NA	NA
BAT-1D	NA	NA	NA	265	92	200	117	41	88	NA	NA	NA	NA	NA	NA
BAT-2S	>6,000	>2,000	>6,000	1,150	400	870	1,100	380	830	1,500	490	1,020	2,020	690	1,510
BAT-2I	NA	NA	NA	1,260	440	950	250	90	190	340	120	220	8.8	3.8	6.7
BAT-2D	NA	NA	NA	5	2	4	10	4	8	8	2	6	19.3	8.2	14.6
BAT-3S	NA	NA	NA	448	156	337	159	55	120	NA	NA	NA	NA	NA	NA
BAT-3I	NA	NA	NA	4	1	3	19	7	14	NA	NA	NA	NA	NA	NA
BAT-3D	NA	NA	NA	5,050	1,760	3,800	2,490	870	1,880	NA	NA	NA	NA	NA	NA
BAT-5S	3	1	2	9.0	3.0	7.0	1.3	0.5	1.0	0.8	0.3	0.6	6.5	2.8	5.5
BAT-5I	>6,000	>2,000	>6,000	3,660	1,270	2,750	>6,000	>2,000	>6,000	>6,000	>2,000	>6,000	>6,000	>2,000	>6,000
BAT-5D	3	1	2	30	10	22	3	1	2	1.9	0.8	1.5	2.1	1.0	1.7
BAT-6S	NA	NA	NA	280	100	210	200	70	150	NA	NA	NA	NA	NA	NA
BAT-6I	NA	NA	NA	470	160	350	77	27	58	NA	NA	NA	NA	NA	NA
BAT-6D	NA	NA	NA	195	65	145	650	230	490	NA	NA	NA	NA	NA	NA
PA-4S	NA	NA	NA	2780	970	2090	1,420	490	1,070	NA	NA	NA	NA	NA	NA
PA-4I	NA	NA	NA	670	230	510	1,940	670	1,460	NA	NA	NA	NA	NA	NA
PA-4D	NA	NA	NA	>6,000	>2,000	>6,000	5,490	1,910	4,130	NA	NA	NA	NA	NA	NA
ISCO Perimeter Wells															
PA-3S	>6,000	>2,000	>6,000	>6,000	>2,000	>6,000	>6,000	>2,000	>6,000	>6,000	>2,000	>6,000	NA	NA	NA
PA-3I	>60	>20	>60	9.0	3.0	7.0	90	31	68	75	22	54	NA	NA	NA
PA-3D	>6,000	>2,000	>6,000	>6,000	>2,000	>6,000	6,450	2,240	4,860	>6,000	>2,000	>6,000	NA	NA	NA
PA-5S	35.4	12.3	26.7	42.6	14.8	32.1	5	2	4	NA	NA	NA	NA	NA	NA
PA-5I	0.4	0.1	0.3	1.0	0.4	0.8	20.0	7.0	15.0	NA	NA	NA	NA	NA	NA
PA-5D	0.1	0	0.1	1.4	0.5	1.1	1.0	1.0	1.0	NA	NA	NA	NA	NA	NA
PA-6S	0.2	0.1	0.1	0.6	0.2	0.5	0.5	0.2	0.4	NA	NA	NA	NA	NA	NA
PA-6I	0.1	0	0.1	0.2	0.1	0.2	0.3	0.1	0.2	NA	NA	NA	NA	NA	NA
PA-6D	0.1	0	0.1	1.3	0.4	0.9	1.6	0.6	1.2	NA	NA	NA	NA	NA	NA
PA-9S	0.2	0.1	0.1	0.6	0.2	0.4	0.3	0.1	0.3	NA	NA	NA	NA	NA	NA
PA-9I	0.1	0	0.1	1.8	0.6	1.3	0.7	0.2	0.5	NA	NA	NA	NA	NA	NA
PA-9D	0.2	0.1	0.2	1.2	0.4	0.9	1.5	0.5	1.1	NA	NA	NA	NA	NA	NA

Table D-4. Potassium Results of Groundwater Samples (Continued)

Units (mg/L)	$KMnO_4$	Mn	MnO_4	$KMnO_4$	Mn	MnO_4	$KMnO_4$	Mn	MnO_4	$KMnO_4$	Mn	MnO_4	$KMnO_4$	Mn	MnO_4
Well ID	**4/12 - 4/16/00**			**4/26 - 4/27/00**			**5/11 - 5/12/00**			**8/22 - 8/23/00**			**11/29 - 11/30/00**		
PA-12S	1.1	0.4	0.9	1.3	0.4	1.0	2.0	0.7	1.5	NA	NA	NA	NA	NA	NA
PA-12I	0.7	0.2	0.5	1.3	0.4	1.0	0.5	0.2	0.4	NA	NA	NA	NA	NA	NA
PA-12D	3.8	1.3	2.9	>60	>20	>60	44.0	15.0	33.0	NA	NA	NA	NA	NA	NA
Resistive Heating Perimeter Wells															
PA-2S	NA	NA	NA	NA	NA	NA	0.5	0.2	0.4	0.3	0.1	0.1	NA	NA	NA
PA-2I	NA	NA	NA	NA	NA	NA	1.2	0.4	0.9	0.3	0.1	0.2	NA	NA	NA
PA-2I-DUP	NA	NA	NA	NA	NA	NA	8.9	3.1	6.7	0.4	0.2	0.2	NA	NA	NA
Distant Wells															
PA-1S	NA	NA	NA	NA	NA	NA	0.4	0.2	0.3	0.4	0.2	0.3	NA	NA	NA
PA-1I	NA	NA	NA	NA	NA	NA	0.5	0.2	0.4	0.5	0.2	0.4	NA	NA	NA
PA-1D	NA	NA	NA	NA	NA	NA	1.2	0.4	0.9	1.2	0.4	0.9	NA	NA	NA
PA-8S	NA	NA	NA	NA	NA	NA	6.8	2.4	5.1	NA	NA	NA	NA	NA	NA
PA-8I	NA	NA	NA	NA	NA	NA	1.9	0.7	1.5	NA	NA	NA	NA	NA	NA
PA-8D	NA	NA	NA	NA	NA	NA	1.3	0.5	1	NA	NA	NA	NA	NA	NA
PA-11S	NA	NA	NA	NA	NA	NA	**1,280**	**450**	**970**	NA	NA	NA	NA	NA	NA
PA-11I	NA	NA	NA	NA	NA	NA	17	6	12	NA	NA	NA	NA	NA	NA
PA-11D	NA	NA	NA	NA	NA	NA	2	1	1	NA	NA	NA	NA	NA	NA
PA-16S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.8	0.4	0.6
PA-16I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.4	0.2	0.3
PA-16D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.7	0.3	0.5
PA-17S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.5	0.2	0.4
PA-17I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.3	0.1	0.1
PA-17D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.4	0.2	0.2

NA: Not available.

Purple bold face indicates that water sample was purple when collected.

Table D-5. Trace Metal Results of Groundwater Samples

Compound	Aluminum (mg/L)							Antimony (mg/L)						
MCL	0.2 (Florida Secondary Standard)							0.006						
Well ID	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-2S	<0.2	<0.2	<5	<0.2	<0.2	<0.4	<0.1	<0.006	<0.006	<0.15	<0.006	<0.006	<0.012	<0.0012
BAT-2I	<0.2	NA	<0.2	<0.2	<0.2	<0.4	<0.1	<0.006	NA	<0.006	<0.006	<0.006	<0.012	<0.0012
BAT-2I-DUP	NA	NA	<0.2	<0.2	NA	<0.2	NA	NA	NA	<0.006	<0.006	NA	<0.006	NA
BAT-2D	<0.2	NA	<0.2	<0.2	NS	<0.2	<0.1	<0.006	NA	<0.006	<0.006	NS	<0.006	<0.0012
BAT-5S	<0.2		<0.2	<0.2	<0.2	<0.4	<0.1	<0.006	<0.006	<0.006	<0.006	<0.006	<0.012	<0.0012
BAT-5I	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.1	<0.006	NA	<0.006	<0.006	<0.006	<0.006	<0.0012
BAT-5D	<0.2	NA	<0.2	<0.2	<0.2	<0.2	<0.1	<0.006	NA	<0.006	<0.006	<0.006	<0.006	<0.0012
BAT-5D-DUP	NA	NA	<0.2	NA	<0.2	NA	NA	NA	NA	<0.006	NA	<0.006	NA	NA
ISCO Perimeter Wells														
PA-3S	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.012	NA
PA-3S-DUP	NA	NA	NA	NA	NA	<0.4	NA	NA	NA	NA	NA	NA	<0.012	NA
PA-3I	<0.2	0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-3I-DUP	NA	<0.2	NA	NA	NA	NA	NA	NA	<0.006	NA	NA	NA	NA	NA
PA-3D	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.03	NA
PA-3D-DUP	NA	NA	NA	<0.2	NA	NA	NA	NA	NA	NA	<0.006	NA	NA	NA
PA-5S	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-5I	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-5D	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-6S	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-6I	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-6D	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-9S	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-9S-DUP	NA	NA	NA	NA	<0.2	NA	NA	NA	NA	NA	NA	<0.006	NA	NA
PA-9I	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-9D	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-12S	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-12I	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
PA-12D	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	NA	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	NA
Distant Wells														
PA-11S	NA	NA	NA	NA	NA	<0.4	NA	NA	NA	NA	NA	NA	<0.012	NA
PA-11I	NA	NA	NA	NA	NA	<0.2	NA	NA	NA	NA	NA	NA	<0.006	NA
PA-11D	NA	NA	NA	NA	NA	<0.2	NA	NA	NA	NA	NA	NA	<0.006	NA

Table D-5. Trace Metal Results of Groundwater Samples

Compound	Arsenic (mg/L)							Barium (mg/L)						
MCL	0.05							2						
Well ID	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-2S	<0.005	<0.005	<0.12	0.0068	<0.005	<0.01	<0.01	<0.1	<0.1	<2.5	<0.1	<0.1	<0.2	<0.01
BAT-2I	<0.005	NA	0.0084	0.0058	<0.005	<0.01	<0.01	<0.1	NA	<0.1	<0.1	<0.1	<0.2	<0.01
BAT-2I-DUP	NA	NA	0.0075	0.0062	NA	<0.005	NA	NA	NA	<0.1	<0.1	NA	<0.1	NA
BAT-2D	<0.005	NA	<0.005	<0.005	NS	0.021	<0.01	<0.1	NA	<0.1	<0.1	NS	<0.1	<0.01
BAT-5S	[redacted]	0.014	0.0061	0.0063	<0.005	<0.01	0.0171	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.01
BAT-5I	<0.005	NA	<0.005	0.0058	0.013	0.0078	<0.01	<0.1	NA	<0.1	<0.1	<0.1	<0.1	<0.01
BAT-5D	<0.005	NA	<0.005	<0.005	0.0055	0.0056	<0.01	<0.1	NA	<0.1	<0.1	<0.1	<0.1	<0.01
BAT-5D-DUP	NA	NA	<0.005	NA	<0.005	NA	NA	NA	NA	<0.1	NA	<0.1	NA	NA
ISCO Perimeter Wells														
PA-3S	0.0058	0.0074	<0.005	<0.005	<0.005	<0.01	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	NA
PA-3S-DUP	NA	NA	NA	NA	NA	<0.01	NA	NA	NA	NA	NA	NA	<0.2	NA
PA-3I	<0.005	<0.005	0.0072	0.0062	0.018	0.018	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-3I-DUP	NA	<0.005	NA	NA	NA	NA	NA	NA	<0.1	NA	NA	NA	NA	NA
PA-3D	<0.005	<0.005	0.028	0.0055	<0.005	<0.025	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	NA
PA-3D-DUP	NA	NA	NA	<0.005	NA	NA	NA	NA	NA	NA	<0.1	NA	NA	NA
PA-5S	0.0053	<0.005	0.0078	0.016	0.0055	<0.005	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-5I	0.0092	0.0052	0.0085	0.0087	<0.005	0.0078	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-5D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-6S	0.0066	<0.005	0.0054	0.0079	<0.005	<0.005	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-6I	<0.005	<0.005	<0.005	0.0068	<0.005	<0.005	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-6D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-9S	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-9S-DUP	NA	NA	NA	NA	<0.005	NA	NA	NA	NA	NA	NA	<0.1	NA	NA
PA-9I	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-9D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-12S	0.0072	0.0074	0.011	0.018	0.01	0.017	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-12I	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
PA-12D	<0.005	<0.005	<0.005	<0.005	<0.005	0.0069	NA	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	NA
Distant Wells														
PA-11S	NA	NA	NA	NA	NA	<0.01	NA	NA	NA	NA	NA	NA	<0.2	NA
PA-11I	NA	NA	NA	NA	NA	0.019	NA	NA	NA	NA	NA	NA	<0.1	NA
PA-11D	NA	NA	NA	NA	NA	0.0059	NA	NA	NA	NA	NA	NA	<0.1	NA

Table D-5. Trace Metal Results of Groundwater Samples

Compound	Beryllium (mg/L)							Chromium (mg/L)						
MCL	0.004							0.1						
Well ID	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-2S	<0.005	<0.005	<0.12	<0.005	<0.005	<0.01	<0.0008	<0.01			0.032			
BAT-2I	<0.005	NA	<0.005	<0.005	<0.005	<0.01	<0.0008	<0.01	NA		0.027			0.0698
BAT-2I-DUP	NA	NA	<0.005	<0.005	NA	<0.005	NA	NA	NA		0.026	NA		NA
BAT-2D	<0.005	NA	<0.005	<0.005	NS	<0.005	<0.0008	<0.01	NA			NS	<0.005	
BAT-5S	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.0008	<0.005	<0.005	0.011	<0.005			0.0485
BAT-5I	<0.005	NA	<0.005	<0.005	<0.005	<0.005	<0.0008	<0.005	NA	0.019	<0.005	<0.005	0.012	<0.01
BAT-5D	<0.1	NA	<0.005	<0.005	<0.005	<0.005	<0.0008	<0.01	NA	<0.005	<0.005	<0.005	0.013	<0.01
BAT-5D-DUP	NA	NA	<0.005	NA	<0.005	NA	NA	NA	NA	<0.005	NA	<0.005	NA	NA
ISCO Perimeter Wells														
PA-3S	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	NA	<0.01	<0.005		0.09			NA
PA-3S-DUP	NA	NA	NA	NA	NA	<0.01	NA	NA	NA	NA	NA	NA		NA
PA-3I	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.01	0.041	<0.005	0.011	0.026	0.055	NA
PA-3I-DUP	NA	<0.005	NA	NA	NA	NA	NA	NA	0.01	NA	NA	NA	NA	NA
PA-3D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	NA	0.013	0.0067	0.033	<0.005			NA
PA-3D-DUP	NA	NA	NA	<0.005	NA	NA	NA	NA	NA	NA	<0.005	NA	NA	NA
PA-5S	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.01	0.0054	<0.005	<0.005	0.0058		NA
PA-5I	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
PA-5D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
PA-6S	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
PA-6I	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.01	0.0093	<0.005	<0.005	<0.005	<0.005	NA
PA-6D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.01	<0.005	<0.005	<0.005	<0.005	<0.005	NA
PA-9S	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.005	<0.005	0.0063	<0.005	<0.005	<0.005	NA
PA-9S-DUP	NA	NA	NA	NA	<0.005	NA	NA	NA	NA	NA	NA	<0.005	NA	NA
PA-9I	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA
PA-9D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA
PA-12S	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.01	<0.005	0.0057	<0.01	0.012	0.022	NA
PA-12I	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.01	<0.005	<0.005	<0.005	0.01	<0.005	NA
PA-12D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	NA	<0.01	<0.005	<0.005	<0.005	0.043		NA
Distant Wells														
PA-11S	NA	NA	NA	NA	NA	<0.01	NA	NA	NA	NA	NA	NA		NA
PA-11I	NA	NA	NA	NA	NA	<0.005	NA	NA	NA	NA	NA	NA	<0.01	NA
PA-11D	NA	NA	NA	NA	NA	<0.005	NA	NA	NA	NA	NA	NA	<0.005	NA

Table D-5. Trace Metal Results of Groundwater Samples

Compound	Copper (mg/L)							Lead (mg/L)						
MCL	1 (Florida Secondary Standard)							TT						
Well ID	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-2S	<0.025	<0.025	<0.62	<0.025	0.05	<0.05	<0.01	<0.003	<0.15	<0.075	<0.003	<0.09	<0.06	<0.003
BAT-2I	<0.025	NA	<0.025	<0.025	<0.025	<0.05	<0.01	<0.003	NA	<0.003	<0.003	<0.09	<0.015	<0.003
BAT-2I-DUP	NA	NA	<0.025	<0.025	NA	<0.025	NA	NA	NA	<0.003	<0.003	NA	0.0046	NA
BAT-2D	<0.025	NA	<0.025	<0.025	NS	<0.025	0.0504	<0.003	NA	<0.003	<0.003	NS	<0.003	<0.003
BAT-5S	<0.025	<0.025	<0.025	<0.025	<0.025	<0.05	<0.01	<0.003	<0.003	<0.003	<0.003	<0.09	<0.09	<0.003
BAT-5I	<0.025	NA	<0.025	<0.025	<0.025	<0.025	<0.01	<0.003	NA	<0.003	<0.003	<0.003	<0.003	<0.003
BAT-5D	<0.025	NA	<0.025	<0.025	<0.025	<0.025	<0.01	<0.003	NA	<0.003	<0.003	<0.003	0.0034	<0.003
BAT-5D-DUP	NA	NA	<0.025	NA	<0.025	NA	NA	NA	NA	<0.003	NA	<0.003	NA	NA
ISCO Perimeter Wells														
PA-3S	<0.025	<0.025	<0.025	<0.025	<0.025	<0.05	NA	<0.003	<0.003	<0.006	<0.003	<0.06	<0.09	NA
PA-3S-DUP	NA	NA	NA	NA	NA	<0.05	NA	NA	NA	NA	NA	NA	<0.09	NA
PA-3I	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
PA-3I-DUP	NA	<0.025	NA	NA	NA	NA	NA	NA	<0.003	NA	NA	NA	NA	NA
PA-3D	<0.025	<0.025	<0.025	<0.025	<0.025	<0.05	NA	<0.003	<0.003	<0.003	<0.003	<0.09	<0.09	NA
PA-3D-DUP	NA	NA	NA	<0.025	NA	NA	NA	NA	NA	NA	<0.003	NA	NA	NA
PA-5S	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	0.003	<0.003	<0.009	NA
PA-5I	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
PA-5D	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
PA-6S	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
PA-6I	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
PA-6D	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
PA-9S	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
PA-9S-DUP	NA	NA	NA	NA	<0.025	NA	NA	NA	NA	NA	NA	<0.003	NA	NA
PA-9I	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
PA-9D	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
PA-12S	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	0.011	<0.003	<0.003	NA
PA-12I	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
PA-12D	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	NA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	NA
Distant Wells														
PA-11S	NA	NA	NA	NA	NA	<0.05	NA	NA	NA	NA	NA	NA	<0.06	NA
PA-11I	NA	NA	NA	NA	NA	<0.025	NA	NA	NA	NA	NA	NA	0.012	NA
PA-11D	NA	NA	NA	NA	NA	<0.025	NA	NA	NA	NA	NA	NA	<0.003	NA

Table D-5. Trace Metal Results of Groundwater Samples

Compound	Nickel (mg/L)							Silver (mg/L)						
MCL	0.1							1 (Florida Secondary Standard)						
Well ID	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-2S	<0.04	0.047	<1		<0.04	<0.08	<0.01	<0.01	0.035	<0.25	<0.01	0.044	<0.02	<0.002
BAT-2I	<0.04	NA			<0.04			<0.01	NA	<0.01	<0.01	0.039	<0.02	<0.002
BAT-2I-DUP	NA	NA			NA		NA	NA	NA	<0.01	<0.01	NA	<0.01	NA
BAT-2D	<0.04	NA			NS			<0.01	NA	<0.01	<0.01	NS	<0.01	<0.002
BAT-5S	<0.04	<0.04		0.045	<0.04		0.0208	<0.01	<0.01	<0.01	<0.01	0.042	0.038	<0.002
BAT-5I	<0.04	NA	0.072					<0.01	NA	<0.01	<0.01	<0.01	<0.01	<0.002
BAT-5D	0.066	NA						<0.01	NA	<0.01	<0.01	<0.01	<0.01	<0.002
BAT-5D-DUP	NA	NA				NA	NA	NA	NA	<0.01	NA	<0.01	NA	NA
ISCO Perimeter Wells														
PA-3S	<0.04	<0.04	<0.04		<0.04	<0.08	NA	<0.01	<0.01	<0.01	<0.01	0.035	0.036	NA
PA-3S-DUP	NA	NA	NA	NA	NA	<0.08	NA	NA	NA	NA	NA	NA	0.033	NA
PA-3I	<0.04	<0.04			<0.04	<0.04	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-3I-DUP	NA	<0.04	NA	NA	NA	NA	NA	NA	<0.01	NA	NA	NA	NA	NA
PA-3D					0.078	<0.08	NA	<0.01	<0.01	<0.01	<0.01	0.032	0.03	NA
PA-3D-DUP	NA	NA	NA		NA	NA	NA	NA	NA	NA	<0.01	NA	NA	NA
PA-5S	<0.04	<0.04	<0.04	<0.04			NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-5I	<0.04	<0.04	<0.04	<0.04			NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-5D	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-6S	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-6I	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-6D	0.083	<0.04	<0.04	<0.04	<0.04		NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-9S	<0.04	<0.04	<0.04	<0.04	<0.04	0.073	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-9S-DUP	NA	NA	NA	NA	<0.04	NA	NA	NA	NA	NA	NA	<0.01	NA	NA
PA-9I	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-9D	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-12S	0.044	<0.04	<0.04	<0.04			NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-12I	<0.04	<0.04	<0.04	<0.04			NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
PA-12D	<0.04	<0.04	<0.04	<0.04			NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA
Distant Wells														
PA-11S	NA	NA	NA	NA	NA	<0.08	NA	NA	NA	NA	NA	NA	0.028	NA
PA-11I	NA	NA	NA	NA	NA	<0.04	NA	NA	NA	NA	NA	NA	<0.01	NA
PA-11D	NA	NA	NA	NA	NA	<0.04	NA	NA	NA	NA	NA	NA	<0.01	NA

Table D-5. Trace Metal Results of Groundwater Samples

Compound	Thallium (mg/L)							Zinc (mg/L)						
MCL	0.002							5 (Florida Secondary Standard)						
Well ID	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	Post-Demo	Ext. Mon.
ISCO Plot Wells														
BAT-2S	<0.01	<0.5	<0.25		<0.3	<0.2	<0.001	<0.02	<0.02	<0.5	<0.02	0.081	<0.04	<0.01
BAT-2I	<0.01	NA	<0.01		<0.3	<0.05	<0.001	<0.02	NA	<0.02	<0.02	<0.02	<0.04	<0.01
BAT-2I-DUP	NA	NA	<0.01		NA		NA	NA	NA	<0.02	<0.02	NA	<0.02	NA
BAT-2D	<0.01	NA	<0.01		NS	<0.01	<0.001	<0.02	NA	<0.02	<0.02	NS	<0.02	<0.01
BAT-5S	<0.01	<0.01	<0.01		<0.3	<0.3	<0.001	<0.02	<0.02	<0.02	<0.02	<0.02	<0.04	<0.01
BAT-5I	<0.01	NA	<0.01		<0.01		<0.001	<0.02	NA	<0.02	<0.02	<0.02	<0.02	<0.01
BAT-5D	<0.01	NA	<0.01		<0.01	<0.01	<0.001	<0.02	NA	<0.02	<0.02	<0.02	<0.02	<0.01
BAT-5D-DUP	NA	NA	<0.01	NA	<0.01	NA	NA	NA	NA	<0.02	NA	<0.02	NA	NA
ISCO Perimeter Wells														
PA-3S	<0.01	<0.01	<0.02		<0.2	<0.3	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.04	NA
PA-3S-DUP	NA	NA	NA	NA	NA	<0.3	NA	NA	NA	NA	NA	NA	<0.04	NA
PA-3I	<0.01	<0.01	<0.01		<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-3I-DUP	NA	<0.01	NA	NA	NA	NA	NA	NA	<0.02	NA	NA	NA	NA	NA
PA-3D	<0.01	<0.01	<0.01		<0.3	<0.3	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.04	NA
PA-3D-DUP	NA	NA	NA		NA	NA	NA	NA	NA	NA	<0.02	NA	NA	NA
PA-5S	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-5I	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-5D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-6S	<0.01	<0.01	<0.01	0.016	<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-6I	<0.01	<0.01	<0.01	0.014	<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-6D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-9S	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-9S-DUP	NA	NA	NA	NA	<0.01	NA	NA	NA	NA	NA	NA	<0.02	NA	NA
PA-9I	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-9D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-12S	<0.01	<0.01	<0.01		<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.04	<0.02	<0.02	NA
PA-12I	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
PA-12D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA
Distiant Wells														
PA-11S	NA	NA	NA	NA	NA	<0.2	NA	NA	NA	NA	NA	NA	0.056	NA
PA-11I	NA	NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	<0.04	NA
PA-11D	NA	NA	NA	NA	NA	<0.01	NA	NA	NA	NA	NA	NA	0.025	NA

Notes:

All units are in mg/L.

MCL: Maximum contaminant limit.

NA: Not available.

Shading denotes that the concentration exceeds the MCL level listed.

<: The compound was analyzed but not detected at or above the specified reporting limit.

Pre-demo: 8/3/99 to 8/9/99

Week 3-4: 9/24/99 to 9/30/99

Week 5: 10/6/99 to 10/8/99

Week 7-8: 10/19/99 to 10/28/99

Post-Demo: 5/8/00 to 5/14/00

Ext. Mon.: February 2001.

Table D-6. Other Parameter Results of Groundwater Samples

	Ca (mg/L)			Mg (mg/L)			Na (mg/L)			Alkalinity (mg/L)		
Well ID	Pre-Demo	Post-Demo	Ext. Mon.	Pre-Demo	Post-Demo	Ext. Mon.	Pre-Demo	Post-Demo	Ext. Mon.	Pre-Demo	Post-Demo	Ext. Mon.
ISCO Plot Wells Wells												
BAT-2S	70.3	3.5	1.09	53.3	2.1	0.321	28.2	68.2	64.0	316	1,500	1,700
BAT-2I	41.2	3.8	63.0	58.5	3.0	31.7	164.0	74.2	58	323	1,280	1,060
BAT-2D	87.5	349.0	1,760	84.4	52.5	82.8	305.0	90.8	64	208	1,300	359
BAT-5S	NA	70.1	6.87	NA	111.0	22.5	NA	125.0	65	269	1,060	2,010
BAT-5S-DUP	NA	NA	7.78	NA	NA	23.3	NA	NA	75	NA	NA	1,980
BAT-5I	NA	48.5	32.6	NA	19.4	45.1	NA	73.0	187	291	1,280	1,860
BAT-5D	84.0	210.0	86.0	81.5	203.0	201	311.0	125.0	115	204	2,140	1,610
BAT-5D-DUP	NA	214.0	NA	NA	203.0	NA	NA	124.0	NA	NA	2,070	NA

	NO_3-NO_2 (mg/L)			SO_4 (mg/L)			BOD (mg/L)			TOC (mg/L)		
Well ID	Pre-Demo	OX Post-Demo	Ext. Mon.	Pre-Demo	OX Post-Demo	Ext. Mon.	Pre-Demo	OX Post-Demo	Ext. Mon.	Pre-Demo	OX Post-Demo	Ext. Mon.
ISCO Plot Wells Wells												
BAT-2S	<0.1	NA[1]	16.6	46.0	<1,000	1,330	<3.0	<3.0	<2	6.1	422.0	95
BAT-2I	<0.1	NA[1]	8.17	138	NA	1,810	16	<3.0	8.6	15.5	86.2	23.9
BAT-2D	<0.1	1	<2.5	103	379	517	13	16	15	10.2	9.7	31.5
BAT-5S	<0.1	<0.1	<2.5	28.7	483.0	790	<3.0	112	8.1	4.2	157.0	50.5
BAT-5S-DUP	NA	NA	<2.5	NA	NA	778	NA	NA	18	NA	NA	51.5
BAT-5I	<0.1	NA[1]	<2.5	49.7	1,380.0	618	<3.0	<3.0	>74	5.8	2,110	109
BAT-5D	<0.1	1	<2.5	67.9	535.0	781	13	108	>74	10.5	131.0	233
BAT-5D-DUP	NA	1	NA	NA	529	NA	NA	98	NA	NA	129	NA

NA: Not available.

BOD: Biological oxygen demand.

TOC: Total organic carbon.

1. NO_3-NO_2 as nitrogen for BAT-2S/I and BAT-5I could not be analyzed due to abundant $KMnO_4$. Also, BOD showed no depletion because of the oxidized nature of the matrix.

Pre-Demo: 8/3/99 to 8/9/99

Post-Demo: 5/8/00 to 5/14/00

Ext. Mon: February 2001.

Table D-7. Surface Emission Test Results

Sample ID	Sample Date	TCE ppb (v/v)	Sample ID	Sample Date	TCE ppb (v/v)
ISCO Plot			*Resistive Heating Plot*		
OX-SE-1	9/30/1999	1.6	SPH-SE-1	10/8/1999	2.1
OX-SE-2	9/30/1999	2.4	SPH-SE-2	10/8/1999	3.6
OX-SE-3	10/1/1999	3.4	SPH-SE-3	10/8/1999	2
OX-SE-4	10/25/1999	0.68	SPH-SE-4	10/22/1999	13,000
OX-SE-5	10/25/1999	1.1	SPH-SE-5	10/22/1999	12,000
OX-SE-6	10/25/1999	1.4	SPH-SE-6	10/22/1999	13,000
OX-SE-7	1/17/2000	11	SPH-SE-7	1/18/2000	23
OX-SE-8	1/17/2000	7.6	SPH-SE-8	1/18/2000	78
OX-SE-9	1/17/2000	5.8	SPH-SE-9	1/18/2000	35
OX-SE-10	4/11/2000	2.6	SPH-SE-10	4/11/2000	0.93
OX-SE-11	4/11/2000	0.69	SPH-SE-11	4/11/2000	0.67
OX-SE-12	4/11/2000	1.7	SPH-SE-12	4/11/2000	<0.37
			SPH-SE-13	4/11/2000	1,300
Background			*Ambient Air at Shoulder Level*		
DW-SE-1	10/1/1999	< 0.42	SPH-SE-14	5/9/2000	<0.39[a]
DW-SE-2	10/8/1999	< 0.44	SPH-SE-15	5/9/2000	<0.39[a]
DW-SE-3	10/25/1999	0.44	SPH-SE-C27	9/1/2000	<0.88
DW-SE-4	10/22/1999	6,000[b]	DW-C1	4/11/2000	2.1[c]
DW-SE-5	1/17/2000	< 0.38	DW-C2	5/9/2000	<0.39
DW-SE-6	4/11/2000	0.43	DW-C3	5/9/2000	<0.39
DW-SE-7	4/11/2000	0.86			
DW-SE-8	4/11/2000	0.79			

ppb (v/v): parts per billion by volume.

a. SPH-SE-14/15 samples were collected at an ambient elevation east and west edge of the Resistive Heating plot without using an air collection box.

[b] Background sample (10/22/99) was collected immediately after SPH-SE-6 sample (the last sample for this event), which had an unexpectedly high concentration of 13,000 ppbv. This may indicate condensation of TCE in the emissions collection box at levels that could not be removed by the standard decontamination procedure of purging the box with air for two hours. In subsequent events (1/17/2000 background), special additional decontamination steps were taken to minimize carryover.

[c] This sample was collected by holding a Summa canister at shoulder level collecting an ambient air sample to evaluate local background air.

Appendix E

Microbiological Assessment

E.1 Microbiological Evaluation Work Plan

Biological Sampling & Analysis Work Plan

The Effect of Source Remediation Methods on the Presence and Activity of Indigenous Subsurface Bacteria at Launch Complex 34, Cape Canaveral Air Station, Florida

Prepared by
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June 28, 1999

(Modified by T. C. Hazen, LBNL; G. Sewell, EPA;
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1.0 Purpose and Objectives

Overall purpose is to evaluate effects of three DNAPL source remediation treatments on the indigenous bacterial population. The three treatments in three different plots at LC34 are resistive heating, in-situ chemical oxidation (ISCO), and steam injection (SI). The objectives of the biological sampling and analysis are:

1. To determine the immediate effect that each remediation technology has on the microbial community structure and specifically on TCE biodegraders.
2. To establish how quickly the microbial communities at the site recover and if any of the effects could be long-term.
3. To determine at what point that biodegradation could be used to complete remediation of the plume.
4. To establish if any of the technologies could cause and short-term effect on significant biogeochemical processes and the distribution and abundance of potential pathogens in the environment.

2.0 Background

Launch Pad 34 at Cape Canaveral Air Station has dense non-aqueous phase (DNAPL) concentrations of TCE over a wide aerial extent in relatively sandy soils with a shallow groundwater table (Resource Conservation and Recovery Act Facility Investigation Work Plan for Launch Complex 34, Cape Canaveral Air Station, Brevard County, Florida, 1996, Kennedy Space Center Report KSC-JJ-4277.). These conditions have made it an ideal site for side-by-side comparison of various DNAPL remediation technologies currently being conducted by the DNAPL Remediation Multi-agency Consortium. Initial sampling at the site revealed that there are also high concentrations of vinyl chloride and dichloroethylene indicating natural attenuation via biodegradation of the TCE plume has been occurring. Since these compounds are daughter products of the anaerobic reductive dechlorination of TCE by microbes (see discussion below) it is probable that these conditions could be greatly effected by the source remediation processes being tested. Since most of these processes will introduce air into the subsurface and are potentially toxic to many microbes they could have a variety of effects on the biological activity and biodegradation rates of contaminants in the source area and the surrounding plume. The effects could range from long-term disruption of the microbial community structure and biological activity at the site,

to a significant stimulation of biodegradation of TCE. Whatever the effect, it needs to be monitored carefully since the long-term remediation of this or any similar site will be significantly effected not only by the technologies ability to remove the DNAPL source but also by the rate of biodegradation both natural and stimulated that can occur in the aquifer after the source is removed. The rate and extent of biodegradation will effect how low the technology must lower the source concentration before natural or stimulated bioremediation can complete the remediation to the ppb levels normally used as cleanup goals. It could also have a major effect on the life-cycle costs of remediation of these sites.

Secondarily, unlikely as this is, it is also important to verify that these source remediation technologies do not cause any gross changes biogeochemistry, and distribution and abundance of potential pathogens. The pathogens are a possibility at this site since there was long-term sewage discharge at the edge of test plots. Studies at other sites have suggested that stimulation of pathogens especially by thermal increases could be a possibility and thus should be considered in the overall risk scenario for these remediation technologies.

Reductive Dechlorination of Chlorinated Solvents

Microbial degradation of chlorinated solvents has been shown to occur under both anaerobic and aerobic conditions. Highly chlorinated solvents are in a relatively oxidized state and are hence more readily degraded under anaerobic conditions than under aerobic conditions (Vogel et al., 1987). In subsurface environments where oxygen is not always available, reductive dechlorination is one of most important naturally occurring biotransformation reactions for chlorinated solvents. Microbial reductive dechlorination is a redox reaction that requires the presence of a suitable electron donor to provide electrons for dechlorination of chlorinated organic (Freedman and Gossett, 1989).

Highly chlorinated solvents, such as tetrachloroethylene (PCE) and trichloroethylene (TCE), are commonly detected in the subsurface. Under anaerobic conditions, PCE is reductively dechlorinated to TCE, which in turn may be dechlorinated to 1,2-dichloroethylene (cis-1,2-DCE, or trans-1,2-DCE), followed sequentially by vinyl chloride (VC) and finally ethylene (Freedman and Gossett, 1989) or ethane (Debruin et al. 1992). Further reductive dechlorination of DCE and VC to CO_2 and complete dechlorination of PCE to CO_2 are possible under anaerobic conditions (Bradley and Chapelle, 1996; Bradley and Chapelle, 1997; Bradley et al., 1998; Cabirol et al., 1998). However, complete dechlorination of PCE is often not achieved due to slow dechlorination process of its reduced intermediates, cis-1,2-DCE and VC, resulting the accumulation of these unfavorable intermediates in anaerobic environments. The accumulation of cis-1,2-DCE and VC is of great concern because they are known carcinogens. Such incomplete dechlorination is commonly observed in fields where reductive dechlorination of PCE and TCE is taking place (McCarty, 1996).

Reductive dechlorination reactions can be carried out by anaerobic microorganisms via either energy yielding or cometabolic processes. The energy-yielding process involves the use of chlorinated solvents as terminal electron acceptors (sometimes referred to as dehalorespiration). Anaerobic cultures that are capable of using PCE or TCE as terminal electron acceptors include the obligate anaerobes *Dehalospirillum multivorans* (Scholz-Muramatsu et al., 1995), *Dehalococcoides ethenogenes* (Maymo-Gattel et al., 1997), *Desulfitobacterium sp.* strain PCE1 (Gerritse et al ., 1996), *Desulfitobacterium sp.* strain PCE-S (Miller et al., 1997; Miller et al., 1998), *Desulfomonile tiedjei* (Fathepure et al., 1987; DeWeerd et al., 1990), *Dehalobacter restrictus* (Holliger and Schumacher, 1994; Holliger et al., 1998), strain TT4B (Krumholz et al., 1996), and the facultative organism strain MS-1 (Sharma and McCarty, 1996). With the exception of *Dehalococcoides ethenogenes* which dechlorinates PCE to ethene, and *Desulfitobacterium sp.* strain PCE1 which dechlorinates PCE to TCE, the end product of PCE dechlorination for all described pure cultures is cis-1,2, DCE. The end products of reductive dechlorination reactions vary depending on the physiological groups of bacteria involved. In acetogens, methanogens, and some other anaerobic bacteria, reductive dechlorination is believed to be mediated by metallocoenzymes like the cobalt containing vitamin B12 and related corrinoids, and by the nickel containing cofactor F430. These metallocoenzymes are present as components of enzymes that catalyze normal physiological pathways in several anaerobic bacteria, and fortuitously are able to reductively

dechlorinate several chlorinated compounds. Acetogenic and methanogenic bacteria contain high levels of these metallocoenzymes, the concentrations of which can be strongly dependent on growth substrates (Deikert et al., 1981; Krzycki and Zeikus, 1980).

The presence of a suitable electron donor, such as hydrogen or reduced organic compounds including hydrocarbons, natural organic matter, glucose, sucrose, propionate, benzoate, lactate, butyrate, ethanol, methanol, and acetate have been reported serve as electron donors for reductive dechlorination (Bouwer and McCarty, 1983; Carr and Hughes, 1998; DiStefano et al., 1992; Fennell and Gossett, 1997; Freedman and Gossett, 1989; Gibson and Sewell, 1992; Holliger et al., 1993; Lee et al., 1997; Tandoi et al., 1994). However, since the microbial populations differ from site to site and their responses to substrates vary greatly, the addition of certain types of electron donors may or may not effectively enhance reductive dechlorination processes. Both laboratory studies and field observations suggest that the addition of electron donors for the enhancement of dechlorination can induce complex scenarios that are a function of the subsurface conditions (Carr and Hughes, 1998; Fennell and Gossett, 1997) and the indigenous microbial population (Gibson and Sewell, 1992). Although it is known that hydrogen serves as the specific electron donor for reductive dechlorination (Holliger et al., 1993; Holliger and Schumacher, 1994; Maymo-Gatell et al., 1995), different concentrations of hydrogen stimulate different groups of anaerobic microbial populations which may or may not be responsible for dechlorination, and may out compete the halorespirers, making the direct addition of hydrogen problematic. In fact, recent research has indicated that dechlorinating bacteria possess lower half-velocity coefficients for H_2 utilization than methanogens, suggesting that dechlorinating bacteria should out compete methanogens at low H_2 concentrations (Ballapragada et al., 1997; Smatlak et al., 1996). In short-term microcosm studies, the addition of slow-release H_2 donors butyrate and propionate was found to support complete dechlorination as well as to enrich PCE-degrading bacteria (Fennell and Gossett, 1997). In contrast, the addition of fast-release H_2 donors ethanol, lactate, and acetate did not result in complete dechlorination. However, both ethanol and lactate did support sustained dechlorination during long-term tests. In some cases, the addition of acetate and methanol to laboratory microcosms with PCE contaminated soil did not enhance dechlorination (Gibson and Sewell, 1992). Complex substrates such as molasses and yeast extract have been shown to result in higher dechlorination levels than simple substrates (Lee et al, 1997; Odem et al., 1995; Rasmussen et al., 1994). Apparently, the fate of amended electron donors and the dynamic changes of microbial populations responsible for reductive dechlorination within soils are still not well understood.

Aerobic Degradation of Chlorinated Solvents

Under aerobic conditions, microbial degradation of chlorinated solvents to non-toxic products can occur by metabolic or cometabolic transformation reactions. DCE and VC have both been shown to be aerobically degraded in energy-yielding reactions. Recently, several aerobic strains that are capable of using VC as primary carbon and energy source have been isolated. These aerobic microorganisms include Mycobacterium sp.(Hartmans and De Bont, 1992), *Rhodococcus sp.*(Malachowsky et al., 1994), *Actinomycetales sp.*(Phelps et al., 1991), and *Nitrosomonas sp.* (Vanelli et al., 1990). It is suggested that these VC-utilizers may not play significant roles in contaminated site remediation due to their long doubling time.

While there have been no reports of aerobic cultures that can oxidize TCE for growth, methanotrophs are one group of bacteria that can cometabolically oxidize chlorinated solvents such as TCE, DCE, and VC to carbon dioxide and chloride ions. These organisms utilize methane as their primary carbon and energy source and produce methane monooxygenase, a key enzyme that is involved in the oxidation of methane. The same enzyme can also cometabolically oxidize chlorinated solvents. Typically, the chloroethenes are initially oxidized to chloroethene epoxides, which in turn decompose into various readily degradable chlorinated and non-chlorinated acids, alcohols or aldehydes, and carbon monoxide (Oldenhuis et al., 1989; Strandberg et al., 1989; Tsien et al., 1989; Little et al., 1988; Alvarez-Cohen and McCarty, 1991; Neuman and Wackett, 1991; Fox et al., 1990; Chang and Alvarez-Cohen, 1996). Anaerobic reductive dechlorination has also been shown to occur under bulk aerobic conditions

dominated by aerobic co-metabolic biodegradation both in the field and in soil columns (Enzien et al., 1994)

3.0 Scope

Launch Complex 34 at Cape Canaveral Air Station in Florida is the test site for the remediation technology evaluation study. Separate testing plots will be established for each of the following three remediation technologies:

1. Resistive Heating by Six-Phase Heating™
2. In-Situ Oxidation (ISCO)
3. Steam Injection (SI)

Soil core samples and groundwater samples at different depths (subsurface layers) from each plot will be collected and analyzed by microbiology and molecular biology methods before and after remediation treatment in order to determine the effect of the treatments on the indigenous microbial population.

4.0 Analytical Approach and Justification

Several different microbiology and molecular analysis will be conducted to evaluate the effect of the remediation technologies used on the microbial community. The following analyses will be conducted:

- Total Heterotrophic Counts
- Viability Analysis
- Coliform and *Legionella* Analysis
- PLFA Analysis
- DNA Analysis

At this time, there are no fool-proof, broadly applicable methods for functionally characterizing microbial communities. The combination of assays we propose will provide a broadly based characterization of the microbial community by utilizing a crude phylogenetic characterization (PLFA), DNA-based characterization of community components, and microscopic counts of viable (aerobic and anaerobic) bacteria and total bacteria. We anticipate that this array of methods that we will help avoid some of the common pitfalls of environmental microbiology studies generally (Madsen, 1998).

Heterotrophic Counts Analysis. The concentration of culturable bacteria in a subset of samples collected from each plot at each event will be done using very low carbon availability media such as 0.1% PTYG or dilute soil-extract media amended with citrate and formate. This has been found to give the best overall recovery of subsurface bacteria (Balkwill, 1989). These viable counts can be done using either MPN or plating techniques for both soil and water. These analyses can be done both under aerobic or anaerobic conditions (Gas-Pak) to provide an estimate of changes in culturable bacteria. This analysis should be used more as a check to verify changes in viable biomass changes, community shifts from anaerobic to aerobic, and direct effects that these remediation technologies may have on the culturability of indigenous

bacteria. These data will help determine if these more conventional microbiological analyses can be used to monitor the effects of the remediation technologies in future applications.

Viability Analysis. In addition, the proportion of live and dead bacteria in these samples will be determined using a fluorescence-based assay (Molecular Probes, LIVE/DEAD® *Bac*Light™ Viability Kit). Since these technologies, especially the thermal ones, may kill bacteria it is important to determine the proportion of the total bacteria observed are dead and how this proportion is changed by the remediation technology being tested. Note: dead bacteria will still be visible by direct count, and thus you could have a total count of 10 billion cells/ml and yet no biological activity because they are all dead.

Coliform and Legionella Analysis. Water samples, collected near the sewage outfall and a few, will be analyzed for total coliforms. One-two liter samples will be collected specifically for this analysis. Samples will be shipped to BMI on ice for inventory and sample management. Coliforms are the primary indicator of human fecal contamination and thus the potential for presence of human pathogens. Since the site has a long-term sewage outfall at the edge of the test beds and since this environment is generally warm and contains high levels of nutrients it is possible that human pathogens may have survived and may be stimulated by the remediation technologies being tested. The coliform analyses of groundwater samples will verify it pathogens could be present. If initial screening indicates no coliforms than this sampling can be dropped; however, if coliforms are present it may be necessary to expand this analysis to determine the extent of their influence and the effect of that the remediation technology is having on them. *Legionella pneumophila* is a frank human pathogen that causes legionnaires disease (an often fatal pneumonia) that is found widely in the environment. It can become a problem in areas that are thermally altered, eg. nuclear reactor cooling reservoirs, pools, cooling towers, air conditioners, etc. A preliminary study done at SRS during a demonstration of radio frequency heating suggested that thermal alteration of the vadose zone could increase the density of legionella in the sediment. Since there is a sewage outfall nearby, since two of the remediation technologies are thermal, and since the remediation technologies are extracting VOC from the subsurface it would be prudent to test the subsurface for changes in *Legionella pneumophila.* This can be done by using commercially available DNA probes for *Legionella pneumophila* and testing both the soil and groundwater samples being analyzed for nucleic acid probes. This adds very little expense and can be done as part of that analyses, see below.

PLFA/FAME Analysis. Phospholipid ester-linked fatty acids (PLFA) and Fatty Acid Methyl Ester (FAME) analysis can measure viable biomass, characterize the types of organisms, and determine the physiological status of the microbial community. Aliquots of each sample (100 g soil and 1-2 L water) will be shipped to frozen to EPA for analysis. The PLFA method is based on extraction and GC/MS analysis of "signature" lipid biomarkers from the cell membranes and walls of microorganisms. A profile of the fatty acids and other lipids is used to determine the characteristics of the microbial community. Water will be filtered with organic free filters in the field and shipped to EPA frozen. The filter can be used to extract both nucleic acids for probe analyses and lipids for PLFA/FAME analyses. Depending on the biomass in the water 1-10 liters will need to be filtered for each sample.

DNA Analysis. DNA probe analysis allow examination of sediment and water samples directly for community structure, and functional components by determining the frequency and abundance to certain enzyme systems critical to biogeochemistry and biodegradation potential of that environment. Sediment samples will be collected aseptically in sleeves and shipped frozen to EPA. These sediment samples will than be extracted and the DNA analyzed for presence of certain probes for specific genetically elements. Water samples will be filtered in the field to remove the microbiota and shipped frozen to EPA for subsequent extraction and probing. The Universal probe 1390 and Bacterial domain probe 338 will help quantify the DNA extracted from the samples. This information will be useful to determine the portion of DNA that is of bacterial origin and the amount of DNA to be used in the analysis of specific bacterial groups. Transformation of chlorinated ethenes by aerobic methylotrophic bacteria that use the methane

monooxygenase enzyme has been reported (Little et al., 1988). Methanotrophs can be separated into coherent phylogenetic clusters that share common physiological characteristics (Murrell, 1998) making the use of 16S rRNA probe technology useful for studying their ecology. Therefore, this study will use 16S rRNA-targeted probes, Ser-987 and RuMP-998, to detect Type II and Type I methanotrophs, respectively. Together, these probes will be used to monitor shifts in methanotroph population numbers that may result from the application of the chemical oxidation technology. Reductive dechlorination of chlorinated ethenes has also been reported under anaerobic conditions. Therefore, we propose the use of archaea domain (Arch-915) and sulfate-reducing specific probes (Dsv-689) to assess microbial communities involved in reductive dechlorination. The characterization of enzymes capable of reductive dehalogenation such as the dehalogenase of *Dehalospirillum multivorans* (Neumann et al., 1995) or the PCE reductive-dehalogenase of *Dehalococcoides ethenogenes* (Maymo-Gatell et al., 1999) provides promise for future gene probe design. As these gene probes become available, they will be utilized for this study. The detection of *Legionella* has been improved using a combined approach of PCR primers and oligonucleotide probe that target the 16S rRNA gene has been reported (Miyamoto et al., 1997; Maiwald et al., 1998). These PCR primers and probes will be used in this study to assess the effects of steam injection on members of this species. The following table provides the list of 16S rRNA-targeted probes that we propose to use in this study.

Target	Probe/Primer Name	Target site[a]	Probe/Primer Sequence 5'--3'	Reference
Universal	S-*-Univ-1390-a-A-18	1407-1390	GACGGGCGGTGTGTACAA	Zheng et al., 1996
Bacteria domain	S-D-Bact-0338-a-A-18	338-355	GCTGCCTCCCGTAGGAGT	Amann et al., 1990a
Archeae domain	S-D-Arch-0915-a-A-20	915-934	GTGCTCCCCCGCCAATTCCT	Amann et al., 1990b
Desulfovibrio spp.	S-F-Dsv-0687-a-A-16	687-702	TACGGATTTCACTCCT	Devereux et al., 1992
Type II Methanotrophs	S-*-M.Ser-0987-a-A-22	987-1008	CCATACCGGACATGTCAAAAGC	Brusseau et al., 1994
Type I Methanotrophs	S-*-M.RuMP-0998-a-A-20	988-1007	GATTCTCTGGATGTCAAGGG	Brusseau et al., 1994
Legionella spp.	*Legionella* CP2 Probe	649-630	CAACCAGTATTATCTGACCG	Jonas et al., 1995
Legionella spp.	Primer LEG 225	225-244	AAGATTAGCCTGCGTCCGAT	Miyamoto et al., 1997
Legionella spp.	Primer LEG 858	880-859	GTCAACTTATCGCGTTTGCT	Miyamoto et al., 1997

[a] *Escherichia coli* numbering

In addition to hybridization of 16S rRNA gene probes hybridization to DNA extracted by a direct method, we will also utilize the denaturing gradient gel electrophoresis (DGGE) described in Muyzer et al., 1996. The DGGE method has been used to detect overall shifts in reductively dechlorinating microbial communities (Flynn et al., 2000). If significant shifts are observed, the DNA bands will be sequenced to analyzed the genetic diversity of the communities.

5.0 Sample Collection, Transport, and Storage

In each test plot, soil samples of approximately 500-g each (250 g frozen for DNA/PLFA analysis; 250 g ambient for microbial counts) will be collected using sterile brass core cylinders. Each clinder holds approximately 250 g of soil. Sterilization of soil sample containers will involve detergent wash, water wash, heating (100 C), and alcohol wash. Polyethylene caps will not be heated, just sterilized with alcohol. Sterilization of drilling equipment will involve steam cleaning between samples.

Five borings per test plot will be used to collect aquifer samples at four depths (capillary fringe, upper sand unit [USU], middle fine grained unit [MFGU], and lower sand unit [LSU]). In addition, groundwater samples will be collected from two well clusters at three depths per plot (USU, MFGU, and LSU). Control samples from an unaffected control area will be collected under the same sampling regime. Soil controls will be collected from five locations, four depths each for consistency with treatment plot samples. Similarly, groundwater controls will be collected from 2 well clusters, at 3 depths each, if available.

Samples will be collected at four events for each technology/plot within two phases:

Phase 1 (June '99 – Sep '00)
T<0 month (pretreatment for SPH and OX)
T= 0 months (post treatment; SPH and OX)
T<0 month (pretreatment; SI)

Phase 2 (Sep '00 – Sep '01)
T= 6 months (post-treatment; SPH, OX, and SI)
T= 12 months (post-treatment; SPH)

Tables 1 and 2 show the number of soil and groundwater samples involved. Table 3 shows the sampling requirements for this evaluation. Immediately after soil samples are retrieved from the borings, the collection cylinders will be tightly capped and sealed to minimize changes in environmental conditions, primarily oxygen content, of the samples. This will subsequently minimize adverse effects to the microbial population during sample transport. Samples for DNA/PLFA analysis will be frozen under nitrogen and shipped via express mail. Samples for microbial counts will be shipped at ambient temperature to an off-site lab designated by the IDC. Microbiology analysis will be conducted within 24 hours of sample collection. Approximately 5-10 g aliquots from each sample will be stored at <-60°C for molecular analysis. The study will be conducted over the course of 1.5 years in which two of the three remediation treatment methods will be demonstrated simultaneously.

Soil and groundwater sample from the region near the historical sewage outfall will be collected and analyzed as shown in Table 3.

As shown in Table 3, groundwater samples will include unfiltered groundwater (for microbial counts) and filters (for DNA/PLFA analysis) from filtration of 1 to 4 L of groundwater. Anodisc™ filters will be used and filtration apparatus will be autoclaved for 20 minutes between samples.

Table 1. Overall Soil Sample Collection Requirement

Plot (Remediation Treatment)	"Event" or Time Points (<0, 0, 6, 12 mo.)	Depths (5, 15, 30, 45 ft.)	Sampling Locations per Plot	Total # Soil Samples Collected Per Plot	Total # of Soil Samples Collected
Resistive Heating[a]	3	4	5	80	344
ISCO[b]	3	4	5	80	
Steam Injection	4	4	5	80	
Control	4	4	5	80	
Baseline (T<0 for SPH and OX)	1	4	3[c]	12	
Sewage Outfall	1	4	3	12	

a Fresh samples to be collected as baseline or T<0; shown in last row
b Fresh samples to be collected as baseline or T<0; shown in last row
c From undisturbed DNAPL area inside ESB

Table 2. Overall Groundwater Sample Collection Requirement

Plot (Remediation Treatment)	"Event" or Time Points (<0, 0, 6, 12 mo.	Depths (5, 30, 45 ft.)	Sampling Well Clusters per Plot	Total # of groundwater Samples Collected Per Plot	Total # of Groundwater Samples Collected
Resistive Heating[a]	3	3	2	18	87
ISCO[b]	3	3	2	18	
Steam Injection	4	3	2	24	
None (control)	3	3	2	18	
Sewage Outfall	3	3	1	9	

Table 3. Summary of Soil and Groundwater Sampling Requirements

		Native Microbes Analysis				Pathogens Analysis		
Medium	Plot	PLFA/DNA[1]	*Microbial*[2]	Locations	Sample	*Coliform/ Legionella*	*Locations*	Sample
Soil[3]	Resisitive Heating	Freeze, store	*Ambient, 24 hrs*	5 cores per plot, 4 depths	2x250 g	*NA*		
	ISCO	Freeze, store	*Ambient, 24 hrs*		2x250 g	*NA*		
	Steam Injection	Freeze, store	*Ambient, 24 hrs*		2x250 g	*NA*		
	Control	Freeze, store	*Ambient, 24 hrs*		2x250 g	*NA*		
	Baseline	*Freeze, store*	*Ambient, 24 hrs*	*Inside ESB, 3 cores 4 depths*	*2x250 g*	*NA*		
	Sewage Outfall	*NA*				*3 cores near sewage outfall at 4 depths each*		*2x250 g*
Ground -water[4]	*Resistive Heating*	*Filters from 1-4 L filtering, Freeze*	*500 mL unfiltered in Whirl-Pak, ambient*	*PA-13S/D and PA-14S/D*		*NA*		
	ISCO	*Filters from 1-4 L filtering, Freeze*	*500 mL unfiltered in Whirl-Pak, ambient*	*BAT-2S/I/D and BAT-5S/I/D*		*NA*		
	Steam Injection	*Filters from 1-4 L filtering, Freeze*	*500 mL unfiltered in Whirl-Pak, ambient*	*PA-16S/I/D and PA-17S/I/D*		*NA*		
	Control	*Filters from 1-4 L filtering, Freeze*	*500 mL unfiltered in Whirl-Pak, ambient*	*IW-1I/D and PA-1S/I/D*		*NA*		
	Sewage Outfall	*NA*	*NA*	*NA*		*1 L unfiltered in Whirl-Pak*	*IW-17I/D and PA-15*	

Shaded and italicized text indicates new sampling and analysis scope that needs to be funded. Bold and italics indicates that the sampling is funded but the analysis is not funded.

NA: Not applicable

[1] DNA/PLFA: DNA/PLFA Analysis. Sleeves are frozen in Nitrogen before shipping.

[2] Microbial: Total Heterotrophic Counts/Viability Analysis. Sleeves are shipped at ambient temperature for analysis within 24 hrs.

[3] Soil samples will be collected in 6"-long 1.5"-dia brass sleeves, then capped. Brass sleeves need to be autoclaved and wiped with ethanol just before use. Caps need to be wiped with ethanol prior to use.

[4] 3 to 4 liters of groundwater will be filtered and filters will be shipped for analysis. Filters for DNA analysis will be frozen under N_2 before shipping. Groundwater for microbial analysis will be shipped at ambient temperature for analysis within 24 hrs. Between samples; filtration apparatus needs to be autoclaved for 20 minutes.

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E.2 Microbiological Evaluation Sampling Procedures

Work Plan for Biological Soil and Groundwater Sampling and Procedure

Battelle
January 4, 2001

Soil Sampling

Soil samples are collected at four discrete depths in the subsurface with a 2-inch diameter sample barrel containing sample sleeves. Once the sample is retrieved, the sleeves are removed from the sample barrel, capped at both ends, and preserved accordingly. The sleeves are then transported to off-site analytical laboratories for analyses. Field personnel should change their gloves after each sample to prevent cross-contamination. The details of the sampling are provided below:

Samplers: The Mostap™ is 20-inch long with a 1.5-inch diameter and the Macro-core™ sampler is about 33-inch long with a 2-inch diameter. Sleeves (brass or stainless steel) are placed in a sample sampler (Macro-core™ or Mostap™). Brass sleeves with 1.5-inch diameter and 6-inch long are used for a Cone-Penetrometer (CPT) rig from U.S. EPA. Stainless steel sleeves with 2-inch diameter and 6-inch long are used with a rig from a contracted drilling company rig.

For Mostap™, three of these brass sleeves and one spacer will be placed in the sampler. For the Macro- Core™ sampler, five 6-inch long stainless sleeves and one spacer are required. All sleeves and spacers need to be sterilized and the procedure is as follows.

Procedures: sampling preparation procedures are as follows:

1. Preparation for sterilization:

   - Dip sleeves in an isopropyl alcohol bath to clean surface inside and outside
   - Air-dry the sleeves at ambient temperature until they are dried
   - Wrap up the sleeves with aluminum foil
   - Place the aluminum foil-wrapped sleeves in an autoclavable bag and keep the bag in a heat-resistant plastic container
   - Place the container in an autoclave for 30 minutes at about 140 °C
   - Once the autoclaving is completed, let the sleeves sit until the materials are cool, and then pack and ship to the field site.

2. In the field, drive the sample barrel down to four different depths: approximately 8 (capillary fringe), 15 (USU below water table), 23 (MFGU), and 45 (LSU) ft below ground surface (bgs). Once the sample barrel is withdrawn, the sleeves are extruded from the sample barrel. Each sleeve immediately capped with plastic end caps that have been previously wiped with isopropyl alcohol. After capping, clear labeling of the sleeve is required including sample site, sample ID, actual depth of the sample, collection date and time, percentage of recovery in each sleeve, and markings for top and bottom of the sample sleeves.

Sample Preservation: one of the sleeves is kept at ambient temperature. At least, two of the sleeves need to be frozen in liquid nitrogen immediately then stored in a freezer at temperature below freezing point.

Off-site Laboratories: The sample sleeve at ambient temperature is to be shipped off to Florida State University for analyses of ***live/dead stain test*** and ***aerobic and anaerobic heterotrophic counting***. The frozen samples are shipped off to EPA Ada Laboratory, an off-site laboratory for ***DNA*** and ***Phospholipids Fatty Acid Analyses (PLFA)***.

3. Decontamination Procedure: after the samples are extruded, the sample barrel used to collect the soil samples needs to be disassembled and cleaned in Alconox® detergent mixed water. The sample barrel is then rinsed with tap water, followed by de-ionized (DI) water. The sample barrel is air-dried and rinsed with isopropyl alcohol before the next sampling.

Groundwater Sampling

Groundwater sampling involves collection of groundwater from performance monitoring wells using a peristaltic pump and Teflon® tubing. During the groundwater sampling, unfiltered water samples will be collected. Large volume of groundwater will be filtered through in-line filtration unit and the filter will be retrieved and this filter will be preserved necessarily.

1. Preparation for Sterlization
   - Dip in-line filter holders in an alcohol bath and air-dry
   - Wrap each filter unit up in aluminum foil
   - Place them in an autoclavable bag and keep the bag in a heat resistant container
   - Autoclave the container with filters for 30 minutes at 140°C
   - Once the autoclaving is completed, let the sleeves sit until the materials are cool, and then pack and ship to the field site.

2. Materials and Equipments: Non-carbon Anodisc® 0.2 μm pore size supported filters, filtration equipment, a low-flow pump, Teflon tubing and Viton® tubing and a vacuum (or pressure) pump.

The dimensions of the Anodisc® filters are 0.2 micron pore size and 47-mm diameter. The filters are pre-sterilized by the manufacturer. Each filter is carefully placed inside a filter holder case. A forcep is used to place a filter in either an in-line polycarbon filter holder or in an off-line filter holder. The filter is very brittle and should be handled delicately.

3. Filter samples by using an in-line filter holder: An Anodisc® filter is wetted with D.I. water and placed on the influent end of the filter holder. A rubber o-ring is gently placed on the filter holder. The filter holder is connected to the effluent end of the peristaltic pump with Teflon® tubing and approximately one liter of groundwater is filtered through it. The filter is retrieved from the filter holder carefully with forceps and placed in a Whirl-Pak®. The filter, along with the bag, is deep frozen under liquid nitrogen and stored in a freezer until shipping.

4. Filter Samples by using an filtration unit: To use this filtration device, a vacuum or pressure pump is required to pull or push the water through. Influent water from a low-flow peristaltic pump goes into a funnel-shaped water container. The filter will be retrieved after water

filtration and the filtrated water can be disposed. The filter is frozen immediately in liquid nitrogen and stored then kept in a freezer.

5. Unfiltered Groundwater Samples: unfiltered groundwater samples are collected into each 500-mLWhirl-Pak® bag. This water sample is kept at ambient temperature.

6. Labeling includes sample ID, same date and time, and site ID on the Whirl-Pak® after the sample is placed with a permanent marker.

7. Sterilization of the filter holders may be done as follows:

- Clean forceps and filter holder in warm detergent mixed water, then rinse with isopropyl alcohol and air-dry at room temperature.
- The cleaned forceps and filter holders are wrapped in aluminum foil and taped with a piece of autoclave tape that indicates when the autoclaving is completed.
- These items are then placed in an autoclavable bag and the bag is placed in an autoclave for about 30 minutes at 140 °C. After taking them out of the autoclave, the items sit until cool.

8. Off-site laboratories: The unfiltered water samples are shipped off to Florida State University for ***aerobic and anaerobic heterotrophic count tests and viability analysis*** at ambient temperature within 24 hours. The filter samples are shipped off in dry-ice condition to EPA Ada Lab for ***DNA, PLFA, and Legionella analyses***.

Sample Locations

Soil Sampling

Five biological sampling locations will be located in each of three plots in January 2001. One duplicate samples will be collected from one of the five boring locations in each plot (Figure 1). At each location, soil samples will be collected at four depths (Capillary fringe, USU, MFGU and LSU). Soil sampling procedures are described in previous sections. Summary of the biological soil sampling is shown in Table 1.

Table 1. Biological Soil Sampling in January-February 2001

Plot	Event	Number of Coring	Total Number of Samples
Steam Injection	Pre-Demo (T<0)	5	20 + 1 (Dup)
ISCO	6 Months After (T=6)	5	20 + 1 (Dup)
Control	-	5	20
SPH*	Post-Demo (T=0)	5	20 + 1 (Dup)

* In February along with chemical coring in ISCO plot.

Groundwater Sampling

Biological groundwater samples will be collected from wells within the Steam Injection plot, the ISCO plot, and the resistive heating plot in January 2001 in conjunction with the biological soil

sampling. Groundwater sampling will be completed as described previously. One QA groundwater sample will be completed at a random well location. Table 2 summarizes the performance monitoring wells (Figure 1) to be sampled.

Table 2. Biological Groundwater Sampling in January-February 2001

Plot	Event	Well ID	Total Number of Samples
Steam Injection	Pre-Demo (T<0)	PA-16S/I/D PA-17S/I/D	6
ISCO	6 Months After (T=6)	BAT-2S/I/D BAT-5S/I/D	6
Resistive Heating	Post-Demo (T=0)	PA-13S/D PA-14S/D	4
Control	-	PA-18S/I/D	3
QA	-	random	1

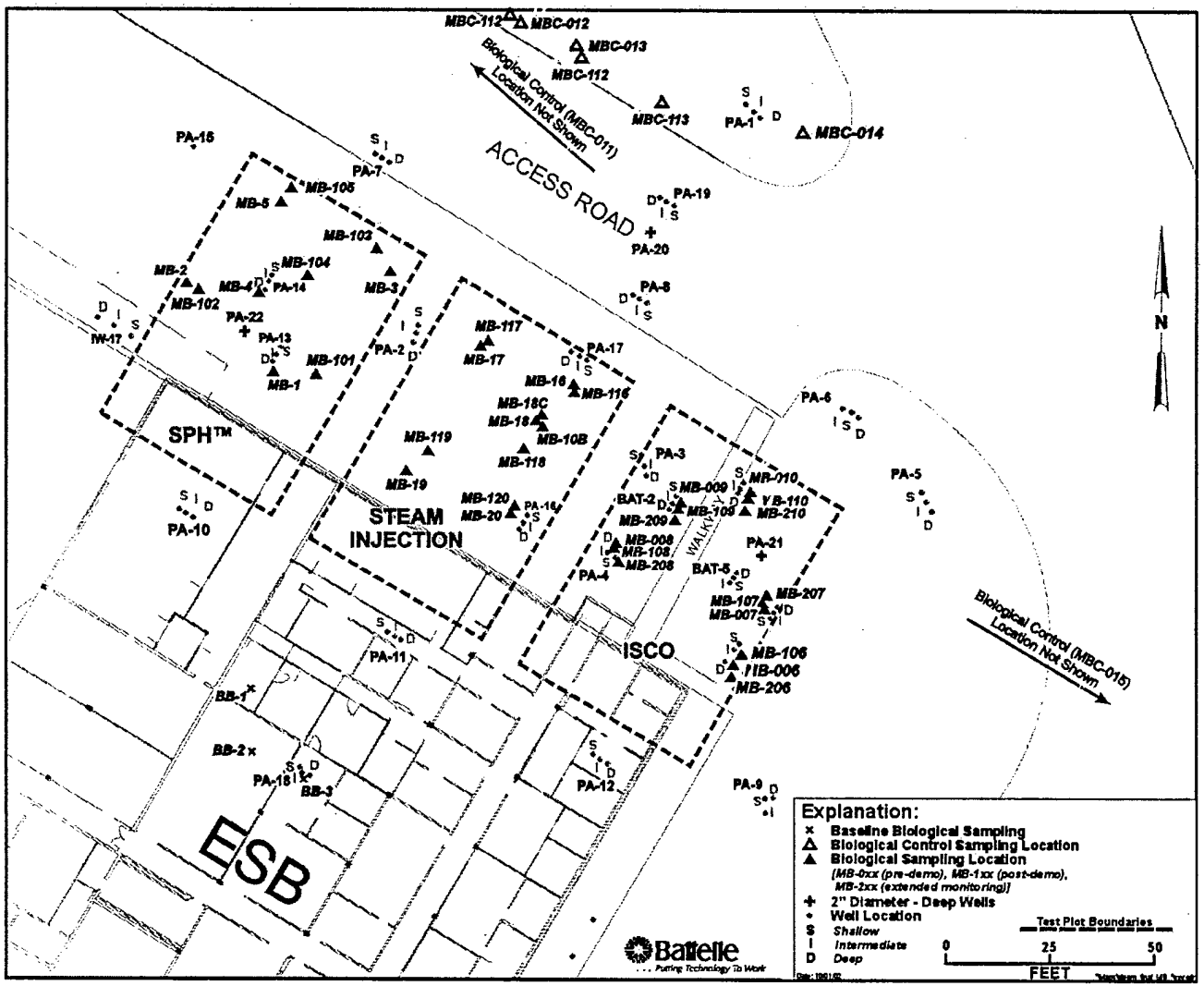


Figure 2. Map of Biological Sampling Location at LC34

E.3 Microbiological Evaluation Results

Some results of the microbiological evaluation described in Appendix E.1 are contained in Tables E-1 and E-2. Only the soil and groundwater samples collected for microbial counts analysis have been analyzed. The samples collected for DNA probes analysis were frozen under nitrogen and shipped to the U.S. EPA's R.S. Kerr Environmental Research Center and are awaiting analysis.

Table E-1 describes the microbial counts analysis of soil samples that represent predemonstration (baseline or T<0) and postdemonstration (Treated, T=0) conditions in the ISCO plot. The results of an extended monitoring event (Treated, T=6) conducted 6 months after the end of oxidation treatment in the plot are also listed. The control samples (control, untreated) are samples collected from an unaffected (TCE contaminated, but not in the oxidation zone) portion of the Launch Complex 34 aquifer; these control samples were collected at the same time as the postdemonstration (T=0) sampling event. Table E-2 lists similar results for groundwater samples.

Because of the large variability in the data, only a few general trends were identified. As seen in Table E-1, both aerobic and anaerobic plate counts in the soil were lower in the treated soil (T=0) compared to the untreated (baseline) soil or control samples. In some regions, microbial populations appear to have been eliminated completely. This indicates that oxidation diminishes the microbial populations in the short term. The differences in surviving population numbers in different parts of the plot are probably indicative of the differential distribution of the oxidant. However, six months later, the microbial populations reappeared strongly in both aerobic and anaerobic conditions.

As seen in Table E-2, the groundwater analysis shows similar trends. Aerobic and anaerobic counts in the groundwater were diminished by the oxidation treatment, but rebounded within six months.

This indicates that the chemical oxidation application reduces microbial populations in the short-term, but the populations rebound within a six-month period. Rebound in microbial populations is important because of the reliance on natural attenuation to address any residual contamination in the aquifer, following chemical oxidation treatment.

Table E-1. Results of Microbial Counts of Soil Samples

Sample ID	Top Depth ft bgs	Bottom Depth ft bgs	Aerobic Heterotrophic Counts CFU/g* or MPN/g	Anaerobic Heterotrophic Counts Cells/g or MPN/g	BacLight Counts/ Live dead stain %live/%dead
Soil Core Samples					
Baseline Samples (August 2000)					
BB1-A	7	9	15,849	7,943	59/41
BB1-A	15.5	17	<316.23	158	25/75
BB2-A	7	9	19,953	31,623	70/30
BB3-A	9	11	12,589	3,162	39/61
BB3-A	15	17	<316.23	<1.78	28/72
BB-1-7.0	6.5	7.0	79,432.8	1,584,893.2	40/60
BB-1-14.0	13.5	14.0	<316.2	631.0	32/68
BB-1-24.0	23.5	24.0	199.5	1,584.9	28/72
BB-1-44.0	43.5	44.0	<316.2	316.2	82/18
BB-2'-7.0	6.5	7.0	19,952.6	19,952.6	43/57
BB-2-7.0	6.5	7.0	31,622.8	10,000.0	27/73
BB-2-16.5	16.0	16.5	2,511.9	3,162.3	15/85
BB-2-23.0	22.5	23.0	1,584,893.2	1,258,925.4	24/76
BB-2-24.0	23.5	24.0	<316.2	No Growth	10/90
BB-2-44.0	43.5	44.0	<316.2	251.2	92/08
BB-3-7.0	6.5	7.0	199,526.2	158,489.3	99/01
BB-3-14.0	13.5	14.0	6,309.6	50,118.7	84/16
BB-3-24.0	23.5	24.0	631.0	501.2	100/0
BB-3-44.0	43.5	44.0	25,118.9	63,095.7	56/44
Control Samples, Untreated (June 2000 except MBC014 in January 2001)					
MBC011-A-1	6	7.5	1,584,893	1,584,893	77/23
MBC011-A-2	15	16.5	501,187	794,328	79/26
MBC011-A-3	30	31.5	15,849	7,943	75/25
MBC011-A-4	40	41.5	316,228	63,096	26/74
MBC012-A-1	6	7.5	25,119	50,119	43/57
MBC012-A-3	30	31.5	125,893	6,310	48/52
MBC012-A-4	40	41.5	1,585	794	59/41
MBC013-A-1	6	7.5	125,893	19,953	50/50
MBC013-A-2	15	16.5	1,259	2,512	61/39
MBC013-A-3	30	31.5	501	794	44/56
MBC013-A-4	40	41.5	7,943	5,012	18/82
MBC014	7	7.5	63,095.73	79,432.82	47/53
MBC014	16	16.5	100,000.00	316,227.77	43/57
MBC014	31	31.5	39,810.72	79,432.82	55/45
MBC014	41	41.5	7,943.28	25,118.86	50/50
MBC015-A-1	6	7.5	3,981	5,012	53/47
MBC015-A-3	35	36.5	316	251	41/59
ISCO Plot, Treated T=1 month (June 2000)					
MB06-A-1	6	7.5	6,309,573	1,584,893	40/60
MB06-A-2	15	16.5	7,943	6,310	60/40
MB06-A-3	30	31.5	7,943	31,623	43/57

Table E-1. Results of Microbial Counts of Soil Samples (Continued)

Sample ID	Top Depth ft bgs	Bottom Depth ft bgs	Aerobic Heterotrophic Counts CFU/g* or MPN/g	Anaerobic Heterotrophic Counts Cells/g or MPN/g	BacLight Counts/ Live dead stain %live/%dead
MB06-A-4	40	41.5	199,526	501,187	33/67
MB07-A-1	6	7.5	7,943,282	>1,584,893.19	66/34
MB07-A-3	17	18.5	<316.23	<1.78	10/90
MB07-A-4	30	31.5	1,584,893	1,584,893	37/63
MB07-A-5	40	41.5	7,943,282	>1,584,893.19	24/76
MB08-A-1	6	7.5	100,000,000	1,584,893	61/39
MB08-A-2	26	16.5	<316.23	<1.78	51/49
MB08-A-3	30	31.5	<316.23	<1.78	42/58
MB08-A-4	40	41.5	7,943	1,259	56/44
MB09-A-2	15	16.5	<316.23	<1.78	49/51
MB09-A-3	30	31.5	398,107	1,584,893	34/66
MB09-A-4	40	41.5	199,526	501,187	80/20
MB10-A-1	6	7.5	3,162,278	1,584,893	46/54
MB10-A-3	30	31.5	1,259	5,012	45/55
MB10-A-4	40	41.5	199,526	1,584,893	55/45
ISCO Plot, Treated T=9 months (January 2001)					
MB-106A	10	10.5	3,162,277.66	12,589,254.12	75/25
MB-106B	16	16.5	1,995,262.31	5,011,872.34	100/0
MB-106C	31	31.5	1,258,925.41	3,162,277.66	97/03
MB-106D	41	41.5	316,227.77	1,000,000.00	100/0
MB-107A	7	7.5	6,309,573.44	7,943,282.35	80/20
MB-107B	17.5	18	7,943,282.35	19,952,623.15	39/61
MB-107C	31	31.5	630,957.34	316,227.77	92/08
MB-107D	41	41.5	794,328.23	3,981,071.71	76/24
MB-108A	6	6.5	63,095.73	316,227.77	74/26
MB-108B	15	15.5	501,187.23	1,584,893.19	96/04
MB-108C	30	30.5	398,107.17	1,584,893.19	100/0
MB-108D	40	40.5	19,952.62	50,118.72	100/0
MB-109A	8	8.5	63,095,734.45	>31,622,776.60	86/14
MB-109B	16	16.5	398,107.17	501,187.23	91/09
MB-109C	31	31.5	125,892.54	251,188.64	84/16
MB-109D	33	33.5	630,957.34	1,584,893.19	88/12
MB-109E	41	41.5	25,118.86	501,187.23	96/04
MB-110A	10	10.5	19,952.62	251,188.64	79/21
MB-110B	16	16.5	7,943.28	199,526.23	74/26
MB-110C	30	30.5	15,848.93	7,943.28	82/18
MB-110D	41	41.5	158,489.32	125,892.54	84/16
ISCO Plot, Treated T=13 months (May 2001)					
MB-206	7	7.5	100,000	316,228	86/14
MB-206	15	15.5	1,584,893	1,584,893	100/0
MB-206	30	30.5	316,228	501,187	89/11
MB-206	40	40.5	63,096	501,187	76/24
MB-207	6	6.5	3,981,072	12,589,254	96/04

Table E-1. Results of Microbial Counts of Soil Samples (Continued)

Sample ID	Top Depth ft bgs	Bottom Depth ft bgs	Aerobic Heterotrophic Counts CFU/g* or MPN/g	Anaerobic Heterotrophic Counts Cells/g or MPN/g	BacLight Counts/ Live dead stain %live/%dead
MB-207	15	15.5	39,811	251,189	98/02
MB-207	30	30.5	1,000,000	1,995,262	88/12
MB-207	40	40.5	50,119	100,000	100/0
MB-207	43	43.5	19,953	1,584,893	100/0
MB-208	6	6.5	3,162,278	7,943,282	29/71
MB-208	17	17.5	794,328	1,000,000	91/09
MB-208	30	30.5	63,096	251,189	97/03
MB-208	40	40.5	125,893	31,623	98/02
MB-209	9	9.5	15,849	10,000	97/03
MB-209	15	15.5	3,162,278	3,981,072	95/05
MB-209	30	30.5	251,189	1,584,893	93/07
MB-209	40	40.5	630,957	316,228	89/11
MB-210	6	6.5	1,995,262	6,309,573	100/0
MB-210	8	8.5	630,957	1,995,262	98/02
MB-210	15	15.5	199,526	1,000,000	100/0
MB-210	30	30.5	3,162	2,512	95/05
MB-210	40.5	41	19,953	25,119	88/12

bgs: Below ground surface.

*CFU: Colony-forming units (roughly, number of culturable cells).

Table E-2. Results of Microbial Counts Groundwater Samples

Sample ID	Aerobic Plate Counts CFU/mL*	Anaerobic Viable Counts Cells/mL	BacLight Counts %live/%dead
Groundwater Samples			
Control Samples, Untreated, Distant Wells (June 2000)			
IW-1I	79,433	>1,584,893.19	31/69
IW-1D	5,012	15,849	35/65
PA-1S	15,849	158,489	50/50
PA-1I	501,187	>1,584,893.19	31/69
PA-1D	39,811	1,584,893	31/69
ISCO Plot Wells, Treated, T= 1 month (January 2001)			
BAT-2S	<31.62	25	50/50
BAT-2I	39,811	100,000	13/87
BAT-2D	630,957	1,584,893	60/40
BAT-5S	12,589	1,584,893	25/75
BAT-5I	32	25	75/25
BAT-5D	39,811	31,623	24/76
ISCO Plot Wells, Treated, T=9 months (January 2001)			
BAT-2S	<31.7	<1.78	48/52
BAT-2I	125,893	1,584,893.19	51/49
BAT-2D	6,310	50,118.72	35/65
BAT-5S	125,893	1,995,262.31	25/75
BAT-5I	158,489	3,981,071.71	36/64
BAT-5D	2,512	12,589.25	43/57
ISCO Plot Wells, Treated, T=13 months (April 2001)			
BAT-2S	<31.7	<1.78	83/17
BAT-2I	125,893	79,433	44/56
BAT-2D	63,096	158,489	44/56
BAT-2D-Dup	19,953	25,119	45/55
BAT-5S	39,811	25,119	81/19
BAT-5I	12,589	50,119	90/10
BAT-5D	251	126	96/04

*CFU: Colony-forming units (roughly, number of culturable cells).

Appendix F

Surface Emissions Testing

F.1 Surface Emission Test Methodology
F.2 Surface Emission Test Results

F.1 Surface Emissions Testing Methods and Procedures

One of the concerns about the technology as a means of soil and groundwater remediation was the possibility of transferring chlorinated volatile organic compounds (CVOCs) to the atmosphere through the ground surface or injection and monitoring wells. Emissions testing was performed to obtain a qualitative picture of VOC losses to the atmosphere from a mass balance perspective. Trying to quantify these discharges to the atmosphere went well beyond the resources of this study. The sampling and analytical methodologies for the emissions tests are presented in the following subsections.

F.1.1 Dynamic Surface Emissions Sampling Methodology

A dynamic surface emissions sampling method was used at the LC34 site. This method involves enclosing an area of soil under an inert box designed to allow the purging of the enclosure with high-purity air (Dupont, 1987). The box was purged with high-purity air for two hours to remove any ambient air from the region above the soil and to allow equilibrium to be established between the VOCs emitted from the soil and the organic-free air. The airstream was then sampled by drawing a known volume of the VOC/pure air mixture through a 1-L Summa canister. The Summa canister captured any organics associated with surface emissions from the test plot. The Summa canisters were then shipped to the off-site laboratory with a completed chain-of—custody form. The Summa canisters were then connected to an air sampler that was attached to a GC, which is where the concentrations of organics were quantified. These measured concentrations were used to calculate emission rates for the VOCs from the soil to the atmosphere.

A schematic diagram of the surface emissions sampling system is shown as Figure F-1. The system consists of a stainless steel box that covers a surface area of approximately 0.5 m^2. The box was fitted with inlet and outlet ports for the entry and exit of high-purity air, which is supplied via a gas cylinder. Inside the box was a manifold that delivered the air supply uniformly across the soil surface. The same type of manifold was also fitted to the exit port of the box. The configuration was designed to deliver an even flow of air across the entire soil surface under the box so that a representative sample was generated. To collect the sample, the air exiting the box was pulled by vacuum into the Summa canister.

In all testing cases, a totally inert system was employed. Teflon™ tubing and stainless steel fittings were used to ensure that there was no contribution to or removal of organics from the air stream. The Summa canister was located on the backside of the emissions box so that it would not be in a position to reverse the flow of air inside the box.

F.1.2 Sampling Schedule

Three surface emissions sampling locations were selected around the resistive heating plot during the technology demonstration. The emissions box was placed strategically between two soil vapor extraction wells. The locations of the emissions sampling were chosen because this area had the highest probability of surface emissions during operations. The proposed testing occurred in the third, sixth, and ninth week of operations; these weeks were chosen because by then any vapor generated by the injection technology would be formed.

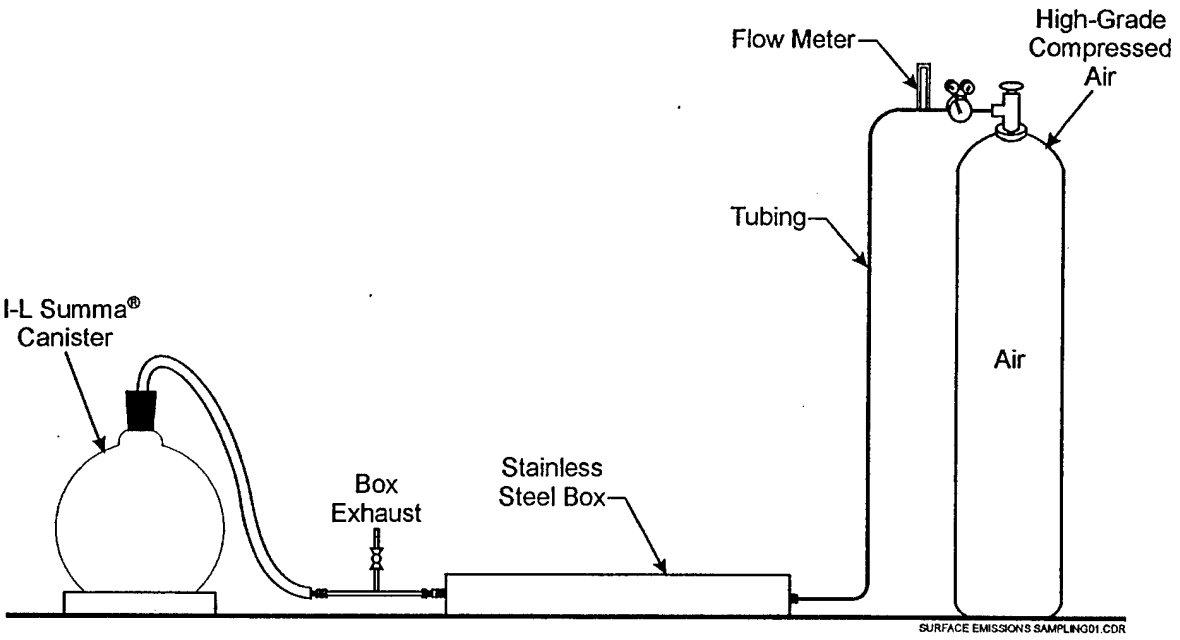


Figure F-1. Schematic Diagram of the Surface Emissions Sampling System

F.1.3 Analytical Calculations

The complete analytical results from the surface emissions sampling at LC34 are presented in this final report. The data is represented temporally, reflecting the three sampling events at the site. Flux values in μg of compound emitted into the atmosphere per unit of time were calculated. The results from the analysis of the Summa canisters and ambient air samples are presented in the final report. The ambient air samples were collected as reference concentrations of the emission levels to the existing air quality. GC calibration data is presented to verify the precision and accuracy of the sampling/analytical method.

To calculate actual emission rates of organic compounds from the soil surface into the atmosphere, the following equation for dynamic enclosure techniques was used (McVeety, 1991):

$$F = CV_r/S \qquad \text{(F-1)}$$

where: F = flux in mass-area/time ($\mu g\ m^2/min$)
C = the concentration of gas in units of mass/volume ($\mu g/m^3$)
V_r = volumetric flowrate of sweep gas (m^3/min)
S = soil surface covered by the enclosure (m^2).

Table F-1. Surface Emission Test Results

Sample ID	Sample Date	TCE ppb (v/v)	Sample ID	Sample Date	TCE ppb (v/v)
Oxidation Plot			***SPH Plot***		
OX-SE-1	9/30/99	1.6	SPH-SE-1	10/8/99	2.1
OX-SE-2	9/30/99	2.4	SPH-SE-2	10/8/99	3.6
OX-SE-3	10/1/99	3.4	SPH-SE-3	10/8/99	2
OX-SE-4	10/25/99	0.68	SPH-SE-4	10/22/99	13,000
OX-SE-5	10/25/99	1.1	SPH-SE-5	10/22/99	12,000
OX-SE-6	10/25/99	1.4	SPH-SE-6	10/22/99	13,000
OX-SE-7	1/17/00	11	SPH-SE-7	1/18/00	23
OX-SE-8	1/17/00	7.6	SPH-SE-8	1/18/00	78
OX-SE-9	1/17/00	5.8	SPH-SE-9	1/18/00	35
OX-SE-10	4/11/00	2.6	SPH-SE-10	4/11/00	0.93
OX-SE-11	4/11/00	0.69	SPH-SE-11	4/11/00	0.67
OX-SE-12	4/11/00	1.7	SPH-SE-12	4/11/00	<0.37
OX-SE-21	8/29/00	16	SPH-SE-13	4/11/00	1,300
OX-SE-22	8/29/00	130	NA	NA	NA
OX-SE-23	8/30/00	180	NA	NA	NA
Background			***Ambient Air at Shoulder Level***		
DW-SE-1	10/1/99	< 0.42	SPH-SE-14	5/9/00	<0.39[a]
DW-SE-2	10/8/99	< 0.44	SPH-SE-15	5/9/00	<0.39[a]
DW-SE-3	10/25/99	0.44	SPH-SE-C27	9/1/00	<0.88
DW-SE-4	10/22/99	6,000[b]	DW-C1	4/11/00	2.1[c]
DW-SE-5	1/17/00	< 0.38	DW-C2	5/9/00	<0.39
DW-SE-6	4/11/00	0.43	DW-C3	5/9/00	<0.39
DW-SE-7	4/11/00	0.86	NA	NA	NA
DW-SE-8	4/11/00	0.79	NA	NA	NA

ppb (v/v): parts per billion by volume.

a. SPH-SE-14/15 samples were collected at an ambient elevation east and west edge of the SPH plot w/o using an air collection box.

b. Background sample (10/22/99) was taken immediately after SPH-SE-6 sample (the last sample for this event), which had an unexpectedly high concentration of 13,000 ppbv. This may indicate condensation of TCE in the emissions collection box at levels that could not be removed by the standard decontamination procedure of purging the box with air for two hours. In subsequent events (1/17/2000 background), special additional decontamination steps were taken to minimize carryover.

c. This sample was collected by holding a Summa canister at shoulder level collecting an ambient air sample to evaluate local background air.

Appendix G

Quality Assurance/Quality Control Information

Appendix G.1 Investigating VOC Losses During Postdemonstration Soil Core Recovery and Soil Sampling

Field procedures for collecting soil cores and soil samples from the steam injection plot were modified in an effort to minimize VOC losses that can occur when sampling soil at elevated temperatures (Battelle, 2001). The primary modifications included: (1) additional personnel safety equipment, such as thermal-insulated gloves for core handling; (2) the addition of a cooling period to bring the soil cores to approximately 20°C before collecting samples; and (3) capping the core ends while the cores were cooling. Concerns were raised about the possibility that increased handling times during soil coring, soil cooling, and sample collection may result in an increase in VOC losses. An experiment was conducted using soil samples spiked with a surrogate compound to investigate the effectiveness of the field procedures developed for LC34 in minimizing VOC losses.

Materials and Methods

Soil cores were collected in a 2-inch diameter, 4-foot long acetate sleeve that was placed tightly inside a 2-inch diameter stainless steel core barrel. The acetate sleeve was immediately capped on both ends with a protective polymer covering. The sleeve was placed in an ice bath to cool the heated core to below ambient groundwater temperatures (approximately 20°C). The temperature of the soil core was monitored during the cooling process with a meat thermometer that was pushed into one end cap (see Figure G-1). Approximately 30 minutes was required to cool each 4-foot long, 2-inch diameter soil core from 50-95°C to below 20°C (see Figure G-2). Upon reaching ambient temperature, the core sleeve was then uncapped and cut open along its length to collect the soil sample for contaminant analysis (see Figure G-3).



FIGURE G-1. A soil core capped and cooling in an ice bath. The thermometer is visible in the end cap.

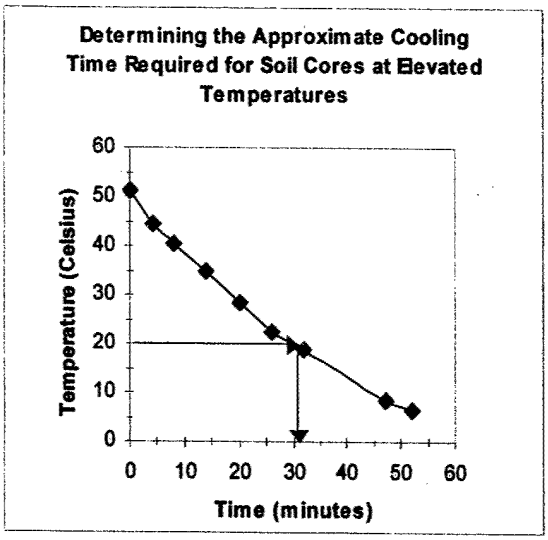


FIGURE G-2. Determining the length of time required to cool a soil core.

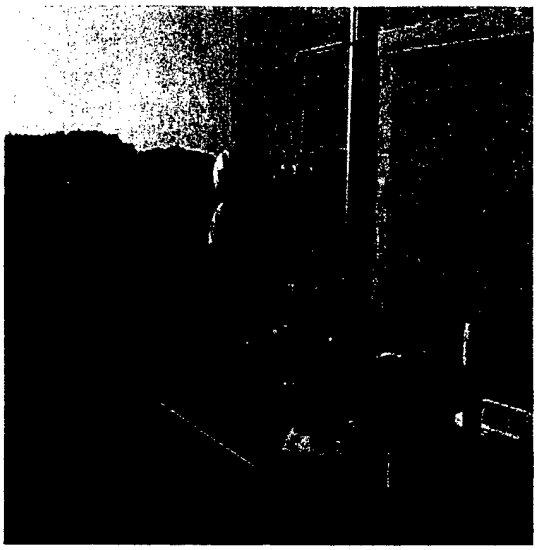


FIGURE G-3. A soil sample being collected from along the length of the core into a bottle 7containing methanol.

Soil samples were collected in relatively large quantities (approximately 200 g) along the entire length of the core rather than sampling small aliquots of the soil within the core, as required by the conventional method (EPA SW5035). This modification is advantageous because the resultant data provide an understanding of the continuous VOC distribution with depth. VOC losses during sampling were further minimized by placing the recovered soil samples directly into bottles containing methanol (approximately 250 mL) and extracting them on site. The extracted methanol was centrifuged and sent to an off-site laboratory for VOC analysis. The soil sampling and extraction strategy is described in more detail in Gavaskar et al. (2000).

To evaluate the efficiency of the sampling method in recovering VOCs, hot soil cores were extracted from 14 through 24 feet below ground surface and spiked with a surrogate compound, 1,1,1-trichloroethane (1,1,1-TCA). The surrogate was added to the intact soil core by using a 6" needle to inject 25 μL of surrogate into each end of the core for a total of 50 μL of 1,1,1-TCA. In order to evaluate the effect of the cooling period on VOC loss, three soil cores were spiked with TCA prior to cooling in the ice bath and three cores were spiked with TCA after cooling in the ice bath. In the pre-cooling test, the surrogate was injected as described above and the core barrels were subsequently capped and placed in the ice bath for the 30 minutes of cooling time required to bring the soil core to below 20°C. A thermometer was inserted through the cap to monitor the temperature of the soil core.

In the post-cooling test, the soil cores were injected with TCA after the soil core had been cooled in the ice bath to below 20°C. After cooling, the caps on the core barrel were removed and the surrogate compound was injected in the same manner, 25 μL per each end of the core barrel using a 6" syringe. The core was recapped and allowed to equilibrate for a few minutes before it was opened and samples were collected. Only for the purpose of the surrogate recovery tests, the entire contents of the sampling sleeve were collected and extracted on site with methanol. The soil:methanol ratio was kept approximately the same as during the regular soil sample collection and extraction. Several (four) aliquots of soil and several (four) bottles of methanol were required to extract the entire contents of the sample sleeve.

Two different capping methods were used during this experiment to evaluate the effectiveness of each cap type. Two of the soil cores were capped using flexible polymer sheets attached to the sleeve with rubber bands. The remaining four soil cores were capped with tight-fitting rigid polymer end caps. One reason that the polymer sheets were preferred over the rigid caps was that the flexible sheets were better positioned to handle any contraction of the sleeve during cooling.

Results

The results from the surrogate spiking experiment are shown in Table G-1. Soil cores 1, 3, and 5 received the surrogate spike prior to cooling in the ice bath. Soil cores 2, 4, and 6 received the surrogate spike after cooling in the ice bath. The results show that between 84 and 113% of the surrogate spike was recovered from the soil cores. Recovery comparison is not expected to be influenced significantly by soil type because all samples were collected from a fine grained to medium fine-grained sand unit. The results also indicate that the timing of the surrogate spike (i.e., pre- or post-cooling) appeared to have only a slight effect on the amount of surrogate recovered. Slightly less surrogate was recovered from the soil cores spiked prior to cooling. This implies that any losses of TCA in the soil samples spiked prior to cooling are minimal and acceptable, within the limitations of the field sampling protocol. The field sampling protocol was designed to process up to 300 soil samples that were collected over a 3-week period, during each monitoring event.

Table G-1. Recovery in Soil Cores Spiked with 1,1,1-TCA Surrogate

Soil Cores Spiked Prior to Cooling	Capping Method	1,1,1-TCA Recovery (%)	Soil Cores Spiked After Cooling	Capping Method	1,1,1-TCA Recovery (%)
Core 1	Flexible polymer sheet with rubber bands	96.3	Core 2	Flexible polymer sheet with rubber bands	98.7
Core 3	Rigid End Cap	101.0	Core 4	Rigid End Cap	112.6
Core 5	Rigid End Cap	84.3	Core 6	Rigid End Cap	109.6

The capping method (flexible versus rigid cap) did not show any clear differences in the surrogate recoveries. The flexible sheets are easier to use and appear to be sufficient to ensure good target compound recovery.

This experiment demonstrates that the soil core handling procedures developed for use at LC34 were successful in minimizing volatility losses associated with the extreme temperatures of the soil cores. It also shows that collecting and extracting larger aliquots of soil in the field is a good way of characterizing DNAPL source zones.

References

Battelle, 2001. *Quality Assurance Project Plan for Performance Evaluation of In-Situ Thermal Remediation System for DNAPL Removal at Launch Complex 34, Cape Canaveral, Florida.* Prepared by Battelle for Naval Facilities Engineering Service Center, June.

Gavaskar, A., S. Rosansky, S. Naber, N. Gupta, B. Sass, J. Sminchak, P. DeVane, and T. Holdsworth. 2000. "DNAPL Delineation with Soil and Groundwater Sampling." Proceedings of the Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 22-25. Battelle Press. 2(2): 49-58.

Table G-2. 1,1,1-TCA Surrogate Spike Recovery Values for Soil Samples Collected During the Steam Postdemonstration Sampling

Steam Treatment Plot: Extraction Efficiency Test **QA/QC Target Level Recovery % = 70 – 130 %** **QA/QC Target Level RPD < 30.0 %**					**Total Number of Samples Collected = 312** **Total Number of Spiked Soil Samples Analyzed = 13** **Total Number of Spiked Methanol Blanks Analyzed = 13**				
Steam Demonstration: 1,1,1-TCA Spiked Samples									
Sample ID	**Sample Date**	**1,1,1-TCA Recovery (µg)**	**1,1,1-TCA Recovery (%)**	**RPD (%)**	**Sample ID**	**Sample Date**	**1,1,1-TCA Recovery (µg)**	**1,1,1-TCA Recovery (%)**	**RPD (%)**
SB-231-2(SS)	1/30/02	1,575	118	4.4	SB-238-2(SS)	2/14/02	1,254	94	4.6
SB-231-MB(SS)[a]		1,509	113		SB-238-MB(SS)		1,315	98	
SB-232-2(SS)	1/29/02	1,337	100	4.0	SB-239-2(SS)	2/06/02	1,300	97	14.3
SB-232-MB(SS)		1,286	96		SB-239-MB(SS)		1,518	113	
SB-233-2(SS)	1/28/02	1,308	98	13.1	SB-240-2(SS)	2/04/02	1,073	80	3.5
SB-233-MB(SS)		1,504	112		SB-240-MB(SS)		1,112	83	
SB-234-2(SS)	2/13/02	1,220	91	5.8	SB-241-2(SS)	2/01/02	780	58	38.1
SB-234-MB(SS)		1,153	86		SB-241-MB(SS)		1,261	94	
SB-235-2(SS)	2/14/02	1,244	93	5.2	SB-242-2(SS)	1/30/02	1,082	81	8.5
SB-235-MB(SS)		1,182	88		SB-242-MB(SS)		1,182	88	
SB-236-2(SS)	2/12/02	1,324	99	1.8	SB-339-2(SS)	2/08/02	1,382	103	17.9
SB-236-MB(SS)		1,300	97		SB-339-MB(SS)		1,173	88	
SB-237-2(SS)	2/7/02	1,148	86	4.1	Range of Recovery in Soil Samples: 58-118% Average: 92%				
SB-237-MB(SS)		1,103	82						

(a) Samples listed as –MB are methanol blanks spiked with 1,1,1-TCA for the purpose of comparing to the amount of 1,1,1-TCA recovered from the soil samples.

Table G-3. Results of the Extraction Procedure Performed on PA-4 Soil Samples

Extraction Procedure Conditions	Combined
Total Weight of Wet Soil (g) = 2,124.2	1,587.8 g dry soil from PA-4 boring
Concentration (mg TCE/g soil) = 3.3	529.3 g deionized water
Moisture Content of Soil (%) = 24.9	5 mL TCE

Laboratory Extraction Sample ID	TCE Concentration in MeOH (mg/L)	TCE Mass in MeOH (mg)	TCE Concentration in Spiked Soil (mg/kg)	Theoretical TCE Mass Expected in MeOH (mg)	Percentage Recovery of Spiked TCE (%)
1st Extraction procedure on same set of samples					
SEP-1-1	1800.0	547.1	3252.5	744.11	73.53
SEP-1-2	1650.0	501.8	3164.9	701.26	71.55
SEP-1-3	1950.0	592.2	3782.3	692.62	85.51
SEP-1-4	1840.0	558.1	3340.2	739.13	75.51
SEP-1-5	1860.0	564.0	3533.9	705.91	79.89
SEP-1-6 (Control)	78.3	19.4	-	25.00	77.65
				Average % Recovery =	77.20
2nd Extraction procedure on same set of samples					
SEP-2-1	568.0	172.7	861.1	887.28	19.47
SEP-2-2	315.0	95.5	500.5	843.77	11.31
SEP-2-3	170.0	51.3	268.2	846.42	6.06
SEP-2-4	329.0	99.8	498.4	885.29	11.27
SEP-2-5	312.0	94.8	476.3	880.31	10.77
SEP-2-6 (Control)	82.6	20.4	-	25.00	81.79
				Average % Recovery =	11.78
3rd Extraction procedure on same set of samples					
SEP-3-1	55.8	17.0	84.6	885.96	1.91
SEP-3-2	59.0	17.9	94.2	841.77	2.13
SEP-3-3	56.8	17.2	90.1	846.42	2.04
SEP-3-4	63.0	19.1	95.2	888.61	2.15
SEP-3-5	52.2	15.8	80.0	875.99	1.81
SEP-3-6 (Control)	84.3	20.9	-	25.00	83.55
				Average % Recovery =	2.01

Table G-4. Results and Precision of the Field Duplicate Samples Collected During the Pre- and Post-Demonstration Soil Sampling

Oxidation Treatment Plot Field Duplicate Soil Samples QA/QC Target Level < 30.0 %				Total Number of Soil Samples Collected = 665 Total Number of Field Duplicate Samples Analyzed = 26			
Pre-Demonstration				Post-Demonstration			
Sample ID	Sample Date	Result (mg/kg)	RPD (%)	Sample ID	Sample Date	Result (mg/kg)	RPD (%)
SB-22-16	06/22/1999	2.58	22.03	SB-225-40	05/18/2000	16.35	11.99
SB-22-16B		2.07		SB-225-40B		18.43	
SB-23-34	06/23/1999	146.89	16.03	SB-219-36	05/19/2000	13.10	94.45[a]
SB-23-34B		125.10		SB-219-36B		36.55	
SB-24-42	06/25/1999	43.01	19.22	SB-223-34	05/19/2000	ND	169.11[a]
SB-24-42B		35.47		SB-223-34B		11.95	
SB-21-42	06/28/1999	5,913.59	40.44[b]	SB-224-38	05/19/2000	278.20	40.24[a]
SB-21-42B		8,911.22		SB-224-38B		185.00	
SB-19-30	06/28/1999	184.95	6.61	SB-220-34	05/20/2000	ND	0.00
SB-19-30B		173.11		SB-220-34B		ND	
SB-18-22	06/29/1999	110.06	59.70[a]	SB-218-20	05/22/2000	ND	0.00
SB-18-22B		59.46		SB-218-20B		ND	
SB-20-26	06/29/1999	179.81	2.72	SB-221-42	05/22/2000	65.26	13.66
SB-20-26B		184.76		SB-221-42B		56.91	
SB-17-34	06/30/1999	191.43	6.20	SB-217-30	05/23/2000	36.12	73.09[a]
SB-17-34B		203.68		SB-217-30B		77.72	
SB-16-12	06/30/1999	0.30	4.94	SB-317-36	05/23/2000	29.44	65.15[a]
SB-16-12B		0.28		SB-317-36B		57.89	
SB-13-32	07/01/1999	56.54	14.78	SB-213-30	05/24/2000	ND	0.00
SB-13-32B		65.56		SB-213-30B		ND	
SB-25-18	07/01/1999	1.56	41.27[a]	SB-216-28	05/24/2000	9.98	81.42[a]
SB-25-18B		2.37		SB-216-28B		23.68	
SB-14-40	07/15/1999	853.25	12.25	SB-215-34	06/01/2000	3,722.93	4.33
SB-14-40B		754.78		SB-215-34B		3,887.58	
SB-15-24	07/16/1999	240.81	6.57	SB-28-14	06/02/2000	28.35	11.88
SB-15-24B		225.50		SB-28-14B		25.17	

(a) Samples had high RPD values due to the effect of low (or below detect) concentrations of TCE drastically affected the RPD calculation.
(b) Samples had high RPD values probably due to high levels of DNAPL distributed heterogeneously through the soil core sample.

Table G-5. Results of the Rinsate Blank Samples Collected During the Post-Demonstration Soil Sampling

Total Number of Samples Collected = 357 Total Number of Field Samples Analyzed = 7			
Post-Demonstration Rinsate Blank Samples			
Sample ID	**Sample Date**	**Result (ug/L)**	**Comments**
RB-24-1	05/18/2000	<5.0	Met QA/QC Target Criteria
RB-23-2	05/19/2000	<5.0	Met QA/QC Target Criteria
RB-220-3	05/20/2000	<5.0	Met QA/QC Target Criteria
RB-216-4	05/22/2000	<5.0	Met QA/QC Target Criteria
RB-317-5	05/23/2000	<5.0	Met QA/QC Target Criteria
RB-213-6	05/25/2000	<5.0	Met QA/QC Target Criteria
RB-26-7	05/25/2000	<5.0	Met QA/QC Target Criteria

(a) Pre-demonstration equipment blanks were not collected.

Table G-6. Results of the Methanol Blank Samples Collected During the Pre- and Post-Demonstration Soil Sampling

Oxidation Methanol Blank Soil Extraction QA/QC Samples QA/QC Target Level < 1.0 mg/kg				Total Number of Soil Samples Collected = 665 Total Number of Field Samples Analyzed = 26			
Pre-Demonstration Methanol Blank Samples				Post-Demonstration Methanol Blank Samples			
Sample ID	Sample Date	Result (mg/kg)	Comments	Sample ID	Sample Date	Result (mg/kg)	Comments
SB-22-Blank	06/23/1999	<0.250	Met QA/QC Target Criteria	SB-225-Blank	05/18/2000	<0.250	Met QA/QC Target Criteria
SB-23-Blank	06/23/1999	1.800[a]	See footnote.	SB-223-Blank	05/19/2000	<0.250	Met QA/QC Target Criteria
SB-24-Blank	06/25/1999	<0.250	Met QA/QC Target Criteria	SB-219-Blank	05/19/2000	<0.250	Met QA/QC Target Criteria
SB-21-Blank	06/28/1999	<0.250	Met QA/QC Target Criteria	SB-224-Blank	05/20/2000	<0.250	Met QA/QC Target Criteria
SB-19-Blank	06/28/1999	0.205	Met QA/QC Target Criteria	SB-220-Blank	05/20/2000	<0.250	Met QA/QC Target Criteria
SB-18-Blank	06/29/1999	8.027[b]	See footnote.	SB-221-Blank	05/21/2000	<0.250	Met QA/QC Target Criteria
SB-20-Blank	06/29/1999	0.944	Met QA/QC Target Criteria	SB-218-Blank	05/22/2000	<0.250	Met QA/QC Target Criteria
SB-17-Blank	06/30/1999	0.205	Met QA/QC Target Criteria	SB-217-Blank	05/23/2000	<0.250	Met QA/QC Target Criteria
SB-16-Blank	06/30/1999	<0.250	Met QA/QC Target Criteria	SB-317-Blank	05/23/2000	<0.250	Met QA/QC Target Criteria
SB-13-Blank	07/01/1999	0.220	Met QA/QC Target Criteria	SB-216-Blank	05/24/2000	<0.250	Met QA/QC Target Criteria
SB-25-Blank	07/01/1999	<0.250	Met QA/QC Target Criteria	SB-213-Blank	05/24/2000	<0.250	Met QA/QC Target Criteria
SB-14-Blank	07/15/1999	<0.250	Met QA/QC Target Criteria	SB-214-Blank	05/31/2000	<0.250	Met QA/QC Target Criteria
SB-15-Blank	07/16/1999	1.228[c]	See footnote.	SB-215-Blank	06/01/2000	<0.250	Met QA/QC Target Criteria

(a) Methanol Blank sample concentrations were below 10% of the TCE results for the samples in these batches. This batch included the following set of samples: SB-23-055 through SB-23-075

(b) Methanol Blank sample concentrations were below 10% of the TCE results for the samples in these batches. This batch included the following set of samples: SB-18-293 through SB-18-317

(c) Methanol Blank sample concentrations were below 10% of the TCE results for the samples in these batches. This batch included the following set of samples: SB-15-569 through SB-15-592

Table G-7. Results and Precision of the Field Duplicate Samples Collected During the Pre- and Post-Demonstration Groundwater Sampling

Oxidation Treatment Plot Field Duplicate Groundwater Samples QA/QC Target Level < 30.0 %				Total Number of Groundwater Samples Collected = 107 (Pre-) 80 (Post-) Total Number of Field Duplicate Samples Analyzed = 9			
Pre-Demonstration				Post-Demonstration			
Sample ID	Sample Date	Result (ug/L)	RPD (%)	Sample ID	Sample Date	Result (ug/L)	RPD (%)
BAT-2S	08/05/1999	1,112,500	4.61	PA-4S	05/15/2000	<5.0	0.00
BAT-2S DUP		1,165,000		PA-4S DUP		<5.0	
BAT-5I	08/05/1999	867,500	3.40	BAT-3S	05/15/2000	630,000	4.88
BAT-5I DUP		897,500		BAT-3S DUP		600,000	
BAT-2S	08/09/1999	1,100,000	0.00	BAT-5D	05/18/2000	52,000	5.94
BAT-2S DUP		1,100,000		BAT-5D DUP		49,000	
BAT-5I	08/09/1999	960,000	23.26	PA-3S	05/18/2000	<5.0	0.00
BAT-5I DUP		760,000		PA-3S DUP		<5.0	
				PA-1I	05/19/2000	<2,000	0.00
				PA-1I DUP		<2,000	

Table G-8. Results and Precision of the Field Duplicate Samples Collected During the Oxidation Demonstration Groundwater Sampling

Oxidation Treatment Plot Field Duplicate Groundwater Samples QA/QC Target Level < 30.0 %				Total Number of Groundwater Samples Collected = 154 Total Number of Field Duplicate Samples Analyzed = 10			
Demonstration							
Sample ID	Sample Date	Result (ug/L)	RPD (%)	Sample ID	Sample Date	Result (ug/L)	RPD (%)
PA-3I	09/28/1999	1,150,000	0.87	BAT-5D	11/16/1999	730,000	0.69
PA-3I DUP		1,160,000		BAT-5D DUP		725,000	
PA-8D	09/29/1999	625,000	11.86	BAT-2I	01/12/2000	50,000	3.67
PA-8D DUP		555,000		BAT-2I DUP		48,200	
PA-8S	10/20/1999	115,000	1.75	PA-3D	01/12/2000	650,000	4.51
PA-8S DUP		113,000		PA-3D DUP		680,000	
BAT-2I	10/25/1999	68,800	12.51	BAT-5D	04/12/2000	870,000	4.49
BAT-2I DUP		60,700		BAT-5D DUP		910,000	
MP-2B	10/26/1999	290	9.01	PA-9S	04/13/2000	220,000	4.44
MP-2B DUP		265		PA-9S DUP		230,000	

Table G-9. Rinsate Blank Results for Groundwater Samples Collected for the Oxidation Pre-and Post-Demonstration Groundwater Sampling

Oxidation Pre-Demonstration Groundwater QA/QC Samples QA/QC Target Level < 3.0 ug/L			Total Number of Samples Collected = 107 (Pre-) 80 (Post-) Total Number of Rinsate Blank Samples Analyzed = 11		
Pre-Demonstration Rinsate Blanks			Post-Demonstration Rinsate Blanks		
Analysis Date	TCE Concentration (ug/L)	Comments	Analysis Date	TCE Concentration (ug/L)	Comments
08/05/1999	3,236.0	Before switching to disposal tubing.	05/16/2000	0.25	Met QA/QC Target Criteria
08/05/1999	227.0	Before switching to disposal tubing.	05/17/2000	0.33	Met QA/QC Target Criteria
08/07/1999	58.3	Before switching to disposal tubing.	05/19/2000	1.1	Met QA/QC Target Criteria
08/10/1999	2,980.0	Before switching to disposal tubing.	05/20/2000	11.0[a)]	Sampling procedure for this set repeated.
08/12/1999	140.0	Before switching to disposal tubing.			
08/12/1999	31.3	Before switching to disposal tubing.			
08/12/1999	339.0	Before switching to disposal tubing.			

a) Samples in this set included PA-12D, PA-11S, I, D. PA-11S was collected prior to the field blank, PA-11I and PA-11D were collected after, but the field blank sample was less than 10% of the concentration results in these two samples.

Table G-10. Rinsate Blank Results for Groundwater Samples Collected for the Oxidation Demonstration Groundwater Sampling

Oxidation Demonstration Groundwater QA/QC Samples QA/QC Target Level < 3.0 ug/L			Total Number of Samples Collected = 154 Total Number of Rinsate Blank Samples Analyzed = 22		
Demonstration					
Analysis Date	TCE Concentration (ug/L)	Comments	Analysis Date	TCE Concentration (ug/L)	Comments
09/27/1999	174.0	Before switching to disposal tubing.	10/22/1999	<2.0	Met QA/QC Target Criteria
09/27/1999	170.0	Before switching to disposal tubing.	10/26/1999	<2.0	Met QA/QC Target Criteria
09/27/1999	233.0	Before switching to disposal tubing.	10/26/1999	<2.0	Met QA/QC Target Criteria
09/28/1999	79.5	Before switching to disposal tubing.	11/16/1999	<2.0	Met QA/QC Target Criteria
09/28/1999	2,740.0	Before switching to disposal tubing.	01/11/2000	<2.0	Met QA/QC Target Criteria
09/28/1999	2,430.0	Before switching to disposal tubing.	01/12/2000	<2.0	Met QA/QC Target Criteria
09/30/1999	46.3	Before switching to disposal tubing.	01/13/2000	<3.0	Met QA/QC Target Criteria
09/28/1999	43.8	Before switching to disposal tubing.	01/14/2000	<2.0	Met QA/QC Target Criteria
09/28/1999	29.2	Before switching to disposal tubing.	04/11/2000	<1.0	Met QA/QC Target Criteria
10/06/1999	<2.0	Met QA/QC Target Criteria	04/12/2000	<1.0	Met QA/QC Target Criteria
10/07/1999	<2.0	Met QA/QC Target Criteria	04/13/2000	<1.0	Met QA/QC Target Criteria

Table G-11. Results of the Trip Blank Samples Analyzed During the Oxidation Demonstration Soil and Groundwater Sampling

Total Number of Samples Collected = 665 (Soil) 496 (Groundwater) [a] Total Number of Field Samples Analyzed = 14							
Oxidation Demonstration Trip Blanks							
Sample ID	**Sample Date**	**Result (ug/L)**	**Comments**	**Sample ID**	**Sample Date**	**Result (ug/L)**	**Comments**
Trip Blank-1	08/03/1999	<1.0	Met QA/QC target criteria.	Trip Blank-9	05/22/2000	<5.0	Met QA/QC target criteria.
Trip Blank-2	01/05/2000	<1.0	Met QA/QC target criteria.	Trip Blank-10	05/23/2000	<5.0	Met QA/QC target criteria.
Trip Blank-3	04/13/2000	<1.0	Met QA/QC target criteria.	Trip Blank-11	05/24/2000	<5.0	Met QA/QC target criteria.
Trip Blank-4	04/13/2000	<1.0	Met QA/QC target criteria.	Trip Blank-12	05/25/2000	<5.0	Met QA/QC target criteria.
Trip Blank-5	04/13/2000	<1.0	Met QA/QC target criteria.	Trip Blank-13	05/26/2000	<5.0	Met QA/QC target criteria.
Trip Blank-6	05/09/2000	<1.0	Met QA/QC target criteria.	Trip Blank-14	06/01/2000	<5.0	Met QA/QC target criteria.
Trip Blank-7	05/11/2000	<2.0	Met QA/QC target criteria.	Trip Blank-15	06/01/2000	<5.0	Met QA/QC target criteria.
Trip Blank-8	05/19/2000	<5.0	Met QA/QC target criteria.	Trip Blank-16	06/02/2000	<5.0	Met QA/QC target criteria.

(a) Groundwater samples that were analyzed by the on site mobile laboratory were not delivered with a trip blank sample for analysis.

Table G-12. Spike Recovery and Precision Values for Matrix Spike Samples Analyzed During the Oxidation Pre-Demonstration Soil Sampling

Oxidation Treatment Plot MS/MSD Samples QA/QC Target Level Recovery % = 70 – 130 % QA/QC Target Level < 30.0 %			Total Number of Soil Samples Collected = 308 Total Number of MS/MSD Samples Analyzed = 12		
Pre-Demonstration					
Sample Date	**TCE Recovery (%)**	**RPD (%)**	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**
06/28/1999	113 115	1.5	07/07/1999	118 116	1.5
06/30/1999	123 123	0.03	07/09/1999	112 112	0.4
07/02/1999	91 92	0.26	07/09/1999	106 106	0.19
07/02/1999	118 114	3.6	07/13/1999	119 119	0.02
07/05/1999	100 82	14.0	07/16/1999	117 114	2.8
07/06/1999	104 110	5.2	07/22/1999	111 111	0.32

Table G-13. Spike Recovery and Precision Values for Matrix Spike Samples Analyzed During the Oxidation Post-Demonstration Soil Sampling

Oxidation Treatment Plot MS/MSD Samples QA/QC Target Level Recovery % = 70 – 130 % QA/QC Target Level < 30.0 %			Total Number of Soil Samples Collected = 357 Total Number of MS/MSD Samples Analyzed = 21		
Post-Demonstration					
Sample Date	**TCE Recovery (%)**	**RPD (%)**	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**
05/18/2000	96 97	0.27	05/24/2000	93 99	6.80
05/18/2000	96 98	1.80	05/24/2000	100 100	0.12
05/18/2000	102 91	11.00	05/25/2000	134[a] 106	5.40
05/19/2000	87 94	4.40	05/25/2000	101 94	3.00
05/20/2000	91 93	1.80	05/26/2000	100 88	3.80
05/20/2000	100 100	0.56	05/31/2000	104 104	0.23
05/22/2000	88 90	1.80	05/31/2000	144[a] 127	2.60
05/22/2000	107 105	1.80	05/31/2000	81 111	5.00
05/22/2000	107 108	0.33	06/01/2000	53[a] 73	6.10
05/23/2000	88 82	2.60	06/01/2000	179[a] 129	12.00
05/23/2000	77 76	0.18			

(a) Samples had high RPD values due to the effect of low (or below detect) concentrations of TCE drastically affected the RPD calculation.

Table G-14. Spike Recovery Values for Soil Laboratory Control Spike Samples Collected for the Oxidation Pre-Demonstration

Oxidation Treatment Plot LCS/LCSD Samples QA/QC Target Level Recovery % = 70 – 130 % QA/QC Target Level < 30.0 %			Total Number of Soil Samples Collected = 308 Total Number of LCS/LCSD Samples Analyzed = 22		
Pre-Demonstration					
Sample Date	**TCE Recovery (%)**	**RPD (%)**	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**
06/28/1999	110 105	4.6	07/06/1999	91 93	2.0
06/30/1999	121 124	2.4	07/06/1999	118 117	0.48
06/30/1999	109 108	0.46	07/07/1999	112 113	0.73
07/01/1999	122 120	1.9	07/08/1999	104 104	0.36
07/02/1999	94 95	1.6	07/09/1999	89 94	5.0
07/02/1999	92 93	0.91	07/09/1999	110 111	1.5
07/02/1999	107 110	2.5	07/12/1999	116 111	4.9
07/02/1999	118 114	3.6	07/13/1999	116 116	0.25
07/04/1999	92 96	3.9	07/14/1999	110 110	0.6
07/05/1999	110 109	0.88	07/21/1999	110 112	2.4
07/06/1999	117 118	0.76	07/24/1999	117 117	0.6

Table G-15. Spike Recovery Values for Soil Laboratory Control Spike Samples Collected for the Oxidation Post-Demonstration

Oxidation Treatment Plot LCS/LCSD Samples QA/QC Target Level Recovery % = 70 – 130 % QA/QC Target Level < 30.0 %			Total Number of Soil Samples Collected = 357 Total Number of LCS/LCSD Samples Analyzed = 30		
Post-Demonstration					
Sample Date	**TCE Recovery (%)**	**RPD (%)**	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**
05/25/2000	96 97	0.27	05/31/2000	76 118	18.0
05/25/2000	96 98	1.8	05/31/2000	88 82	2.6
05/25/2000	102 91	11.0	05/31/2000	77 76	0.18
05/26/2000	100 100	0.56	05/31/2000	123 132[a]	2.7
05/26/2000	87 94	4.4	05/31/2000	93 99	6.8
05/28/2000	88 90	1.8	06/01/2000	93 99	6.8
05/28/2000	106 101	4.9	06/02/2000	134[a] 106	5.4
05/28/2000	100 101	1.4	06/03/2000	100 100	0.12
05/29/2000	91 93	1.8	06/05/2000	100 88	3.8
05/29/2000	88 90	1.8	06/06/2000	104 104	0.23
05/29/2000	85 90	6.1	06/06/2000	101 94	3.0
05/30/2000	107 105	1.8	06/07/2000	81 111	5.0
05/30/2000	112 111	0.17	06/07/2000	144[a] 127	2.6
05/31/2000	107 108	0.33	06/09/2000	96 97	1.2

(a) Outside the targeted range, but at measurable levels, given the possible matrix interference from the potassium permanganate injection.

Table G-16. Method Blank Samples Analyzed During the Oxidation Pre-Demonstration Soil Sampling

Oxidation Pre-Demonstration Soil QA/QC Samples QA/QC Target Level < 1.0 mg/kg			Total Number of Samples Collected = 308 Total Number of Method Blank Samples Analyzed = 38		
Pre-Demonstration Method Blanks					
Analysis Date	**TCE Concentration (mg/kg)**	**Comments**	**Analysis Date**	**TCE Concentration (mg/kg)**	**Comments**
06/28/1999	<0.250	Met QA/QC Target Criteria	07/06/1999	<0.250	Met QA/QC Target Criteria
06/28/1999	<0.250	Met QA/QC Target Criteria	07/06/1999	<0.250	Met QA/QC Target Criteria
06/30/1999	<0.250	Met QA/QC Target Criteria	07/06/1999	<0.250	Met QA/QC Target Criteria
06/30/1999	<0.250	Met QA/QC Target Criteria	07/06/1999	<0.250	Met QA/QC Target Criteria
06/30/1999	<0.250	Met QA/QC Target Criteria	07/07/1999	<0.250	Met QA/QC Target Criteria
06/30/1999	<0.250	Met QA/QC Target Criteria	07/07/1999	<0.250	Met QA/QC Target Criteria
06/30/1999	<0.250	Met QA/QC Target Criteria	07/08/1999	<0.250	Met QA/QC Target Criteria
07/01/1999	<0.250	Met QA/QC Target Criteria	07/09/1999	<0.250	Met QA/QC Target Criteria
07/02/1999	<0.250	Met QA/QC Target Criteria	07/09/1999	<0.250	Met QA/QC Target Criteria
07/02/1999	<0.250	Met QA/QC Target Criteria	07/09/1999	<0.250	Met QA/QC Target Criteria
07/02/1999	<0.250	Met QA/QC Target Criteria	07/09/1999	<0.250	Met QA/QC Target Criteria
07/02/1999	<0.250	Met QA/QC Target Criteria	07/12/1999	<0.250	Met QA/QC Target Criteria
07/02/1999	<0.250	Met QA/QC Target Criteria	07/13/1999	<0.250	Met QA/QC Target Criteria
07/03/1999	<0.250	Met QA/QC Target Criteria	07/13/1999	<0.250	Met QA/QC Target Criteria
07/04/1999	<0.250	Met QA/QC Target Criteria	07/14/1999	<0.250	Met QA/QC Target Criteria
07/05/1999	<0.250	Met QA/QC Target Criteria	07/21/1999	<0.250	Met QA/QC Target Criteria
07/06/1999	<0.250	Met QA/QC Target Criteria	07/22/1999	<0.250	Met QA/QC Target Criteria
07/06/1999	<0.250	Met QA/QC Target Criteria	07/23/1999	<0.250	Met QA/QC Target Criteria
07/06/1999	<0.250	Met QA/QC Target Criteria	07/24/1999	<0.250	Met QA/QC Target Criteria
07/01/1999	<0.250	Met QA/QC Target Criteria	07/09/1999	<0.250	Met QA/QC Target Criteria
07/01/1999	<0.250	Met QA/QC Target Criteria	07/09/1999	<0.250	Met QA/QC Target Criteria
07/15/1999	<0.250	Met QA/QC Target Criteria	07/09/1999	<0.250	Met QA/QC Target Criteria
07/15/1999	<0.250	Met QA/QC Target Criteria	07/12/1999	<0.250	Met QA/QC Target Criteria

Table G-17. Method Blank Samples Analyzed During the Oxidation Post-Demonstration Soil Sampling

Oxidation Pre-Demonstration Soil QA/QC Samples QA/QC Target Level < 1.0 mg/kg			Total Number of Samples Collected = 357 Total Number of Method Blank Samples Analyzed = 36		
Post-Demonstration Method Blanks					
Analysis Date	**TCE Concentration (mg/kg)**	**Comments**	**Analysis Date**	**TCE Concentration (mg/kg)**	**Comments**
05/25/2000	<0.250	Met QA/QC Target Criteria	05/31/2000	<0.250	Met QA/QC Target Criteria
05/25/2000	<0.250	Met QA/QC Target Criteria	06/01/2000	<0.250	Met QA/QC Target Criteria
05/25/2000	<0.250	Met QA/QC Target Criteria	05/19/2000	<0.250	Met QA/QC Target Criteria
05/26/2000	<0.250	Met QA/QC Target Criteria	06/01/2000	<0.250	Met QA/QC Target Criteria
05/27/2000	<0.250	Met QA/QC Target Criteria	06/01/2000	<0.250	Met QA/QC Target Criteria
05/27/2000	<0.250	Met QA/QC Target Criteria	06/02/2000	<0.250	Met QA/QC Target Criteria
05/28/2000	<0.250	Met QA/QC Target Criteria	06/02/2000	<0.250	Met QA/QC Target Criteria
05/28/2000	<0.250	Met QA/QC Target Criteria	06/03/2000	<0.250	Met QA/QC Target Criteria
05/28/2000	<0.250	Met QA/QC Target Criteria	06/05/2000	<0.250	Met QA/QC Target Criteria
05/29/2000	<0.250	Met QA/QC Target Criteria	06/06/2000	<0.250	Met QA/QC Target Criteria
05/29/2000	<0.250	Met QA/QC Target Criteria	06/07/2000	<0.250	Met QA/QC Target Criteria
05/30/2000	<0.250	Met QA/QC Target Criteria	06/07/2000	<0.250	Met QA/QC Target Criteria
05/30/2000	<0.250	Met QA/QC Target Criteria	06/07/2000	<0.250	Met QA/QC Target Criteria
05/30/2000	<0.250	Met QA/QC Target Criteria	06/07/2000	<0.250	Met QA/QC Target Criteria
05/30/2000	<0.250	Met QA/QC Target Criteria	06/07/2000	<0.250	Met QA/QC Target Criteria
05/31/2000	<0.250	Met QA/QC Target Criteria	06/08/2000	<0.250	Met QA/QC Target Criteria
05/31/2000	<0.250	Met QA/QC Target Criteria	06/09/2000	<0.250	Met QA/QC Target Criteria
05/31/2000	<0.250	Met QA/QC Target Criteria	06/01/2000	<0.250	Met QA/QC Target Criteria

Table G-18. Spike Recovery and Precision Values for Matrix Spike Samples Analyzed During the Oxidation Demonstration Groundwater Sampling

Oxidation Treatment Plot Groundwater QA/QC QA/QC Target Level Recovery % = 70 – 130 % QA/QC Target Level RPD < 30.0 %							
Oxidation Demonstration Matrix Spike Samples							
Sample ID	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**	**Sample ID**	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**
BAT-2S MS	08/03/1999	104	0.11	MP-2C MS	10/26/1999	109	0.4
BAT-2S MSD		103		MP-2C MSD		109	
BAT-5I MS	08/03/1999	51[a]	5.6	ML-2 MS	01/14/2000	181[a]	6.63
BAT-5I MSD		27[a]		ML-2 MSD		202[a]	
PA-7D MS	08/07/1999	92.0	0.6	PA-3D DUP MS	01/15/2000	130	0.874
PA-7D MSD		96.0		PA-3D DUP MSD		126	
MP-3A MS	09/30/1999	89	4.3	PA-1D MS	01/16/2000	94	3.56
MP-3A MSD		82		PA-1D MSD		98	
ML-2 MS	10/25/1999	116	0.9	PA-8S MS	06/15/2000	78	12.0
ML-2 MSD		115		PA-8S MSD		88	

(a) TCE recovery was affected by interference from excess potassium permanganate in these groundwater samples.

Table G-19. Spike Recovery and Precision Values for Laboratory Control Spike Samples Analyzed During the Pre- and Post-Demonstration Groundwater Sampling

Oxidation Treatment Plot Groundwater QA/QC QA/QC Target Level Recovery % = 70 – 130 % QA/QC Target Level RPD < 30.0 %				Total Number of Samples Collected = 107 (Pre-) 80 (Post-) Total Number of Matrix Spike Samples Analyzed = 18			
Pre-Demonstration LCS/LCSD Samples				Post-Demonstration LCS/LCSD Samples			
Sample ID	Sample Date	TCE Recovery (%)	RPD (%)	Sample ID	Sample Date	TCE Recovery (%)	RPD (%)
LCS-990805	08/05/1999	115	5.9	DD6K8102-LCS	05/15/2000	91	2.6
LCSD-990805		122		DD6K8103-LCSD		93	
LCS-990806	08/06/1999	107	3.1	DD7JQ102-LCS	05/16/2000	93	3.6
LCSD-990806		111		DD7JQ103-LCSD		97	
LCS-990807	08/07/1999	113	0.4	DDC22102-LCS	05/18/2000	94	1.9
LCSD-990807		113		DDC22103-LCSD		93	
LCS-990809	08/09/1999	109	2.0	DDDEQ102-LCS	05/18/2000	96	1.2
LCSD-990809		106		DDDEQ103-LCSD		97	
LCS-990810	08/10/1999	111	2.5	DDF78102-LCS	05/19/2000	84	2.9
LCSD-990810		109		DDF78103-LCSD		87	
LCS-990811	08/11/1999	112	3.8	DDG8R102-LCS	05/20/2000	100	4.2
LCSD-990811		108		DDG8R103-LCSD		95	
LCS-990812	08/12/1999	106	0.6	DDH5F102-LCS	05/21/2000	97	4.9
LCSD-990812		105		DDH5F103-LCSD		92	
LCS-990813	08/13/1999	98	4.0	DDH76102-LCS	05/22/2000	90	1.1
LCSD-990813		102		DDH76103-LCSD		91	
				DF2FM102-LCS	06/20/2000	84	11.0
				DF2FM103-LCSD		94	
				DF4F5102-LCS	06/21/2000	89	0.88
				DF4F5103-LCSD		88	

Table G-20. Spike Recovery and Precision Values for Laboratory Control Spike Samples Analyzed During the Oxidation Demonstration Groundwater Sampling

Oxidation Treatment Plot Groundwater QA/QC QA/QC Target Level Recovery % = 70 – 130 % QA/QC Target Level RPD < 30.0 %				Total Number of Samples Collected = 309 Total Number of Matrix Spike Samples Analyzed = 15			
Demonstration LCS/LCSD Spike Samples							
Sample ID	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**	**Sample ID**	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**
LCS-990927	09/27/1999	95	12.1	LCS-991025	10/25/1999	113	0.9
LCSD-990927		107		LCSD-991025		112	
LCS-990928	09/28/1999	113	5.1	LCS-991026	10/26/1999	112	4.6
LCSD-990928		107		LCSD-991026		107	
LCS-990929	09/29/1999	107	4.2	LCS-991118	11/18/1999	109	17.6
LCSD-990929		111		LCSD-991118		91	
LCS-991018	10/18/1999	114	1.4	LCS-00113	01/13/2000	101	-
LCSD-991018		115		LCSD-00113		-	
LCS-991019	10/19/1999	119	6.2	LCS-00114	01/14/2000	106	-
LCSD-991019		112		LCSD-00114		-	
LCS-991020	10/20/1999	109	9.8	LCS-00115	01/15/2000	113	1.16
LCSD-991020		99		LCSD-00115		103	
LCS-991021	10/21/1999	111	5.3	LCS-00116	01/16/2000	104	1.94
LCSD-991021		117		LCSD-00116		102	
LCS-991022	10/22/1999	108	3.3				
LCSD-991022		112					

Table G-21. Method Blank Samples Analyzed During the Oxidation Pre-Demonstration Groundwater Sampling

Oxidation Pre- and Post-Demo Groundwater QA/QC Samples QA/QC Target Level < 3.0 ug/L			Total Number of Samples Collected = 107 (Pre-) 80 (Post-) Total Number of Method Blank Samples Analyzed = 18		
Pre-Demonstration Method Blanks			Post-Demonstration Method Blanks		
Analysis Date	TCE Concentration (ug/L)	Comments	Analysis Date	TCE Concentration (ug/L)	Comments
08/05/1999	<2.0	Met QA/QC Target Criteria	08/09/1999	<1.0	Met QA/QC Target Criteria
08/06/1999	<2.0	Met QA/QC Target Criteria	05/15/2000	<1.0	Met QA/QC Target Criteria
08/07/1999	<2.0	Met QA/QC Target Criteria	05/16/2000	<1.0	Met QA/QC Target Criteria
08/08/1999	<2.0	Met QA/QC Target Criteria	05/18/2000	<1.0	Met QA/QC Target Criteria
08/09/1999	<2.0	Met QA/QC Target Criteria	05/18/2000	<1.0	Met QA/QC Target Criteria
08/10/1999	<2.0	Met QA/QC Target Criteria	05/19/2000	<1.0	Met QA/QC Target Criteria
08/11/1999	<2.0	Met QA/QC Target Criteria	05/20/2000	<1.0	Met QA/QC Target Criteria
08/12/1999	<2.0	Met QA/QC Target Criteria	05/21/2000	<1.0	Met QA/QC Target Criteria
08/09/1999	<1.0	Met QA/QC Target Criteria	05/22/2000	<1.0	Met QA/QC Target Criteria

Table G-22. Method Blank Samples Analyzed During the Oxidation Demonstration Groundwater Sampling

Oxidation Demonstration Groundwater QA/QC Samples QA/QC Target Level < 3.0 ug/L			Total Number of Samples Collected = 309 Total Number of Method Blank Samples Analyzed = 21		
Demonstration					
Analysis Date	TCE Concentration (ug/L)	Comments	Analysis Date	TCE Concentration (ug/L)	Comments
09/27/1999	<2.0	Met QA/QC Target Criteria	11/16/1999	<2.0	Met QA/QC Target Criteria
09/28/1999	<2.0	Met QA/QC Target Criteria	01/13/2000	<2.0	Met QA/QC Target Criteria
09/29/1999	<2.0	Met QA/QC Target Criteria	01/14/2000	<2.0	Met QA/QC Target Criteria
09/30/1999	<2.0	Met QA/QC Target Criteria	01/15/2000	<2.0	Met QA/QC Target Criteria
10/06/1999	<2.0	Met QA/QC Target Criteria	01/16/2000	<2.0	Met QA/QC Target Criteria
10/07/1999	<2.0	Met QA/QC Target Criteria	01/17/2000	<2.0	Met QA/QC Target Criteria
10/20/1999	<2.0	Met QA/QC Target Criteria	04/11/2000	<1.0	Met QA/QC Target Criteria
10/21/1999	<2.0	Met QA/QC Target Criteria	04/13/2000	<1.0	Met QA/QC Target Criteria
10/22/1999	<2.0	Met QA/QC Target Criteria	04/18/2000	<1.0	Met QA/QC Target Criteria
10/25/1999	<2.0	Met QA/QC Target Criteria	04/21/2000	<1.0	Met QA/QC Target Criteria
10/26/1999	<2.0	Met QA/QC Target Criteria			

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DATE: 11/8/01 PAGE 1 OF 2
PO #: DHL WORK ORDER #: 0111041
PROJECT LOCATION OR NAME: CCAS
CLIENT PROJECT #: COLLECTOR: ED, JS

Authorize 5% surcharge for TRRP report? ☐ Yes ☐ No

S=SOIL W=WATER A=AIR P=PAINT SL=SLUDGE OT=OTHER

PRESERVATION: HCl, HNO_3, H_2SO_4 ☐ NaOH ☐, ICE, UNPRESERVED

ANALYSES: BTEX ☐ MTBE ☐ / TRPH 418.1 ☐ / GASOLINE MOD 8015 ☐ / TPH 1005 ☐ TPH 1006 ☐ / DIESEL - MOD 8015 ☐ / VOC 8260 ☒ SEE LIST / SVOC 8270 ☐ PAH 8270 ☐ / 8081 PESTICIDES ☐ 8151 HERBICIDES ☐ / 8082 PCBS ☐ / TCLP - METALS (RCRA) ☐ TCLP VOC ☐ / TCLP - PEST ☐ HERB ☐ Semi-VOC ☐ / TOTAL METALS (RCRA) ☐ OTHER LIST ☐ / LEAD - TOTAL ☐ D.W. 200.8 ☐ TCLP ☐ / RCI ☐ TOX ☐ FLASHPOINT ☐ / TDS ☐ TSS ☐ % MOISTURE ☐ / pH ☐ HEXAVALENT CHROMIUM ☐ / EXPLOSIVES ☐ PECHLORATE ☐ / CHLORIDE ☐ ANIONS ☐ ALKALINITY ☐

Field Sample I.D.	DHL Lab #	Date	Time	Matrix	Container Type	# of Containers	HCl	HNO_3	H_2SO_4 ☐ NaOH ☐	ICE	UNPRESERVED	VOC 8260	FIELD NOTES
BAT-3S	01A	11/7/01	09:20	W	40mL VOA	3	X					X	SEE LIST FOR
BAT-3I	02A		09:30	W		3	X					X	VOCs to be
BAT-3D	03A		10:00	W		3	X					X	analyzed.
PA-20	04A		11:00	W		3	X					X	
PA-21	05A		10:30	W		3	X					X	
PA-22	06A		14:00	W		3	X					X	
PA-14S	07A		15:00	W		3	X					X	
PA-14S DUP	08A		15:00	W		3	X					X	
PA-14I	09A		15:30	W		3	X					X	
PA-14D	10A		16:00	W		3	X					X	
PA-18S	11A		16:30	W		3	X					X	
PA-18I	12A		17:00	W		3	X					X	
PA-18D	13A	↓	17:30	W		3	X					X	
Trip Blank	14A	11/8/01	10:00	W	↓	2	X					X	
Rinsate-1	15A	11/7	830	W	↓	2	X					X	

RELINQUISHED BY: (Signature) Eric Drumheller — DATE/TIME 11/8/01 10:00 — RECEIVED BY: (Signature) Fed Ex

RELINQUISHED BY: (Signature) Fed Ex — DATE/TIME 11/9/01 9:00 AM — RECEIVED BY: (Signature)

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LABORATORY USE ONLY:
RECEIVING TEMP: 2.3, 1.6 °C Temp Blank
CUSTODY SEALS - ☐ BROKEN ☐ INTACT ☒ NOT USED
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Appendix H

Economic Analysis Information

Appendix H

Economic Analysis Information

This appendix details the cost assessment for the application of the pump and treat (P&T) system for containment of a DNAPL source at Launch Complex 34, for a source zone that is the same size as the ISCO plot. Because the groundwater flow in this area is generally to the northeast, the DNAPL source could be contained by installing one cluster (of 3 in each lithologic unit) or more extraction wells on the northeast side of the ISCO plot. The life cycle cost of a pump-and-treat system can be compared to the cost of DNAPL source removal using chemical oxidation, as described in Section 7 of the main report.

Experience at previous sites indicates that the most efficient long-term P&T system is one that is operated at the minimum rate necessary to contain a plume or source zone (Cherry et al., 1996). Table H-1 shows a preliminary size determination for the P&T system. The P&T system should be capable of capturing the groundwater flowing through a cross-section that is approximately 50 ft wide (width of ISCO plot) and 40 ft deep (thickness of surficial aquifer). Because capture with P&T systems is somewhat inefficient in that cleaner water from surrounding parts of the aquifer may also be drawn in, an additional safety factor of 100% was applied to ensure that any uncertainties in aquifer capture zone or DNAPL source characterization are accounted for. An extraction rate of 2 gallon per minute (gpm) is found to be sufficient to contain the source.

One advantage of low groundwater extraction rates is that the air effluent from stripping often does not have to be treated, as the rate of volatile organic compound (VOC) discharge to the ambient air is often within regulatory limits. The longer period of operation required (at a low withdrawal rate) is more than offset by higher efficiency (lower influx of clean water from outside the plume), lower initial capital investment (smaller treatment system), and lower annual operations and maintenance (O&M) requirements. Another advantage of a containment type P&T system is that, unlike source removal technologies, it does not require very extensive DNAPL zone characterization.

H.1.1 Capital Investment for the P&T System

The P&T system designed for this application consists of the components shown in Table H-2. Pneumatically driven pulse pumps, which are used in each well, are safer than electrical pumps in the presence of trichloroethylene (TCE) vapors in the wells. This type of pump can sustain low flowrates during continuous operation. Stainless steel and Teflon™ construction ensure compatibility with the high concentrations (up to 1,100 mg/L TCE) of dissolved solvent and any free-phase DNAPL that may be expected. Extraction wells are assumed to be 40 ft deep, 2 inches in diameter, and have stainless steel screens with polyvinyl chloride (PVC) risers.

The aboveground treatment system consists of a DNAPL separator and air stripper. Very little free-phase solvent is expected and the separator may be disconnected after the first year of operation, if desired. The air stripper used is a low-profile tray-type air stripper. As opposed to conventional packed towers, low-profile strippers have a smaller footprint, much smaller height, and can handle large air:water ratios (higher mass transfer rate of contaminants) without generating significant pressure losses. Because of their small size and easy installation, they are more often used in groundwater remediation. The capacity of the air stripper selected is much higher than 2 gpm, so that additional flow (or additional extraction wells) can be handled if required.

The high air:water ratio ensures that TCE (and other minor volatile components) are removed to the desired levels. The treated water effluent from the air stripper is discharged to the sewer. At the low groundwater extraction rate required, the resulting contaminant mass in the air effluent from the stripper is less than 2 lbs/day, and below a typical regulatory limit of 6 lbs/day. The air effluent can be discharged without further treatment.

The piping from the wells to the air stripper is run through a 1-ft-deep covered trench. The air stripper and other associated equipment are housed on a 20-ft-x-20-ft concrete pad, covered by a basic shelter. The base will provide a power drop (through a pole transformer) and a licensed electrician will be used for the power hookups. Meters and control valves are strategically placed to control water and air flow through the system.

The existing monitoring system at the site will have to be supplemented with seven long-screen (10-foot screen) monitoring wells. The objective of these wells is to ensure that the desired containment is being achieved.

H.1.2 Annual Cost of the P&T System

The annual costs of P&T are shown in Table H-3 and include annual operation and maintenance (O&M) and monitoring. Annual O&M costs include the labor, materials, energy, and waste disposal cost of operating the system and routine maintenance (including scheduled replacement of seals, gaskets, and O-rings). Routine monitoring of the stripper influent and effluent is done through ports on the feed and effluent lines on a monthly basis. Groundwater monitoring is conducted on a quarterly basis through seven monitoring wells. All water samples are analyzed for PCE and other chlorinated volatile organic compound (CVOC) by-products.

H.1.3 Periodic Maintenance Cost

In addition to the routine maintenance described above, periodic maintenance will be required, as shown in Table H-3, to replace worn-out equipment. Based on manufacturers' recommendations for the respective equipment, replacement is done once in 5 or 10 years. In general, all equipment involving moving parts is assumed will be replaced once every 5 years, whereas other equipment is changed every 10 years.

H.1.4 Present Value (PV) Cost of P&T

Because a P&T system is operated for the long term, a 30-year period of operation is assumed for estimating cost. Because capital investment, annual costs, and periodic maintenance costs occur at different points in time, a life cycle analysis or present value analysis is conducted to estimate the long-term cost of P&T in today's dollars. This life cycle analysis approach is recommended for long-term remediation applications by the guidance provided in the Federal Technologies Roundtable's *Guide to Documenting and Managing Cost and Performance Information for Remediation Projects* (United States Environmental Protection Agency [U.S. EPA], 1998). The PV cost can then be compared with the cost of faster (DNAPL source reduction) remedies.

$$PV_{\text{P\&T costs}} = \sum \frac{\text{Annual Cost in Year t}}{(1+r)^t} \qquad \text{Equation (H-1)}$$

$$PV_{P\&T\ costs} = \text{Capital Investment} + \frac{\text{Annual cost in Year 1}}{(1+r)^1} + \ldots + \frac{\text{Annual cost in Year n}}{(1+r)^n}$$

Equation (H-2)

Table 4 shows the PV calculation for P&T based on Equation 1. In Equation 1, each year's cost is divided by a discount factor that reflects the rate of return that is foregone by incurring the cost. As seen in Equation 2, at time t = 0, which is in the present, the cost incurred is the initial capital investment in equipment and labor to design, procure, and build the P&T system. Every year after that, a cost is incurred to operate and maintain the P&T system. A real rate of return (or discount rate), r, of 2.9% is used in the analysis as per recent U.S. EPA guidance on discount rates (U.S. EPA, 1999). The total PV cost of purchasing, installing, and operating a 1-gpm P&T source containment system for 30 years is estimated to be **$1,406,000** (rounded to the nearest thousand).

Long-term remediation costs are typically estimated for 30-year periods as mentioned above. Although the DNAPL source may persist for a much longer time, the contribution of costs incurred in later years to the PV cost of the P&T system is not very significant and the total 30-year cost is indicative of the total cost incurred for this application. This can be seen from the fact that in Years 28, 29, and 30, the differences in cumulative PV cost are not as significant as the difference in, say, Years 2, 3, and 4. The implication is that, due to the effect of discounting, costs that can be postponed to later years have a lower impact than costs that are incurred in the present.

As an illustration of a DNAPL source that may last much longer than the 30-year period of calculation, Figure H-1 shows a graphic representation of PV costs assuming that the same P&T system is operated for 100 years instead of 30 years. The PV cost curve flattens with each passing year. The total PV cost after 100 years is estimated at $2,195,000.

Table H-1. Pump & Treat (P&T) System Design Basis for Site 88 DNAPL Zone at Camp

Item	Value	Units	Item	Value	Units
Width of DNAPL zone, w	50	ft	Hyd. conductivity, K	40	ft/d
Depth of DNAPL zone, d	40	ft	Hyd. gradient, I	0.0007	ft/ft
Crossectional area of DNAPL zone, a	2000	sq ft	Porosity, n	0.3	
Capture zone required	187	cu ft/d	Gw velocity, v	0.093333	ft/d
Safety factor, 100%	2				
Required capture zone	373	cu ft/d	GPM =	1.9	gpm
Design pumping rate	2	gpm	Number of wells to achieve capture	1	
Pumping rate per well	2	gpm			
TCE conc. in water near DNAPL zone	100	mg/L	TCE allowed in discharge water	1	mg/L
Air stripper removal efficiency required	99.00%				
TCE in air effluent from stripper	2.4	lbs/day	TCE allowed in air effluent	6	lbs/day

Table H-2. Capital Investment for a P&T System at Launch Complex 34, Cape Canaveral

Item	# units		Unit Price	Cost	Basis
Design/Procurement					
Engineer	160	hrs	$85	$13,600	
Drafter	80	hrs	$40	$3,200	
Hydrologist	160	hrs	$85	$13,600	
Contingency	1	ea	$10,000	$10,000	10% of total capital
TOTAL				$30,400	
Pumping system					
Extraction wells	1	ea	$5,000	$5,000	2-inch, 40 ft deep, 30-foot SS screen; PVC; includes installation
Pulse pumps	1	ea	$595	$595	2.1 gpm max., 1.66"OD for 2-inch wells; handles solvent contact; pneumatic; with chec valves
Controllers	1	ea	$1,115	$1,115	Solar powered or 110 V; with pilot valve
Air compressor	1	ea	$645	$645	100 psi (125 psi max), 4.3 cfm continuous duty, oil-less; 1 hp
Miscellaneous fittings	1	ea	$5,000	$5,000	Estimate
Tubing	150	ft	$3	$509	1/2-inch OD, chemical resistant; well to surface manifold
TOTAL				$12,864	
Treatment System					
Piping	150	ft	$3	$509	chemical resistant
Trench	1	day	$320	$320	ground surface
DNAPL separarator tank	1	ea	$120	$120	125 gal; high grade steel with epoxy lining; conical bottom with discharge
Air stripper feed pump	1	ea	$460	$460	0.5 hp; up to 15 gpm
Piping	50	ft	$3	$170	0.5 inch, chemical resistant; feed pump to stripper
Water flow meter	1	ea	$160	$160	Low flow; with read out
Low-profile air stripper with control panel	1	ea	$9,400	$9,400	1-25 gpm, 4 tray; SS shell and trays
Pressure gauge	1	ea	50	$50	SS; 0-30 psi
Blower	1	ea	$1,650	$1,650	5 hp
Air flow meter	1	ea	$175	$175	Orifice type; 0-50 cfm
Catalytic Oxidizer	1	ea	$65,000	$65,000	
Stack	10	ft	$2	$20	2 inch, PVC, lead out of housing
Carbon	2	ea	$1,000	$2,000	
Stripper sump pump	1	ea	$130	$130	To sewer
Misc. fittings, switches	1	ea	$5,000	$5,000	Estimate (sample ports, valves, etc.)
TOTAL				$85,163	
Site Preparation					
Conctrete pad	400	sq ft	$3	$1,200	20 ft x 20 ft with berm; for air stripper and associated equipment
Berm	80	ft	$7	$539	
Power drop	1	ea	$5,838	$5,838	230 V, 50 Amps; pole transformer and licensed electrician
Monitoring wells	5	wells	$2,149	$10,745	Verify source containment; 2-inch PVC with SS screens
Sewer connection fee	1	ea	$2,150	$2,150	
Sewer pipe	300	ft	$10	$3,102	
Housing	1	ea	$2,280	$2,280	20 ft x 20 ft; shelter for air stripper and associated equipment
TOTAL				$25,854	
Installation/Start Up of Treatment System					
Engineer	60	hrs	$85	$5,100	Labor
Technician	200	hrs	$40	$8,000	Labor
TOTAL				$13,100	
TOTAL CAPITAL INVESTMENT				**$167,381**	

Table H-2. Capital Investment for a P&T System at Launch Complex 34, Cape Canaveral (continued)

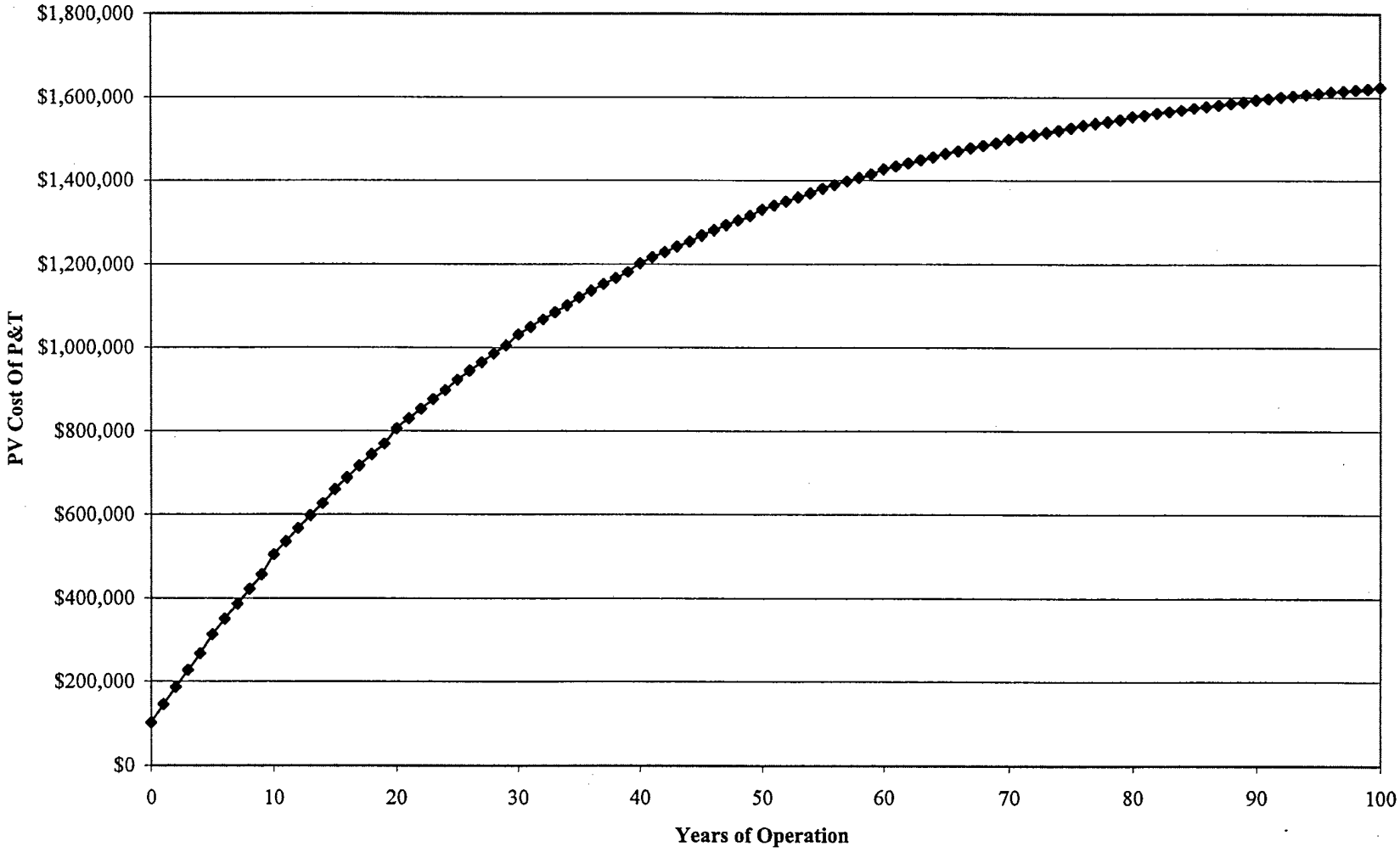
O&M Cost for P&T Sytem					
Annual Operation & Maintenance					
Engineer	80	hrs	$85	$6,800	Oversight
Technician	500	hrs	$40	$20,000	Routine operation; annual cleaning of air stripper trays, routine replacement of parts; any waste disposal
Replacement materials	1	ea	$2,000	$2,000	Seals, o-rings, tubing, etc.
Electricity	52,560	kW-hrs	$0.10	$5,256	8 hp (~6 kW) over 1 year of operation
Fuel (catlytic oxidizer	2,200	10M BTU	$6	$13,200	
Sewer disposal fee	525,600	gal/yr	$0.00152	$799	
Carbon disposal	2		$1,000	$2,000	
Waste disposal	1	drum	$80	$200	30 gal drum; DNAPL, if any; haul to incinerator
TOTAL				**$50,255**	
Annual Monitoring					
Air stripper influen	12	smpls	$120	$1,440	Verify air stripper loading; monthly
Air stripper effluent	14	smpls	$120	$1,680	Discharge quality confirmation; monthly; CVOC analysis; MS, MSD
Monitoring wells	34	smpls	$120	$4,080	5 wells; quarterly; MS, MSD
Sampling materials	1	ea	$500	$500	Miscellaneous
Technician	64	hrs	40	$2,560	Quarterly monitoring labor (from wells) only; weekly monitoring (from sample ports) included in O&M cost
Engineer	40	hrs	85	$3,400	Oversight; quarterly report
TOTAL				$7,200	
TOTAL ANNUAL COST				**$57,455**	
Periodic Maintenance, Every 5 years					
Pulse pumps	4	ea	$595	$2,380	As above
Air compressor	1	ea	$645	$645	As above
Air stripper feed pump	1	ea	$460	$460	As above
Blower	1	ea	$1,650	$1,650	As above
Catalyst replacement	1	ea	$5,000	$5,000	
Stripper sump pump	1	ea	$130	$130	As above
Miscellaneous materials	1	ea	$1,000	$1,000	Estimate
Technician	40	hrs	$40	$1,600	Labor
TOTAL				**$12,865**	
				$70,320	
Periodic Maintenance, Every 10 years					
Air stripper	1	ea	$9,400	$9,400	As above
catalytic oxidizer	1	ea	$16,000	$16,000	Major overhaul
Water flow meters	1	ea	160	$160	As above
Air flow meter	1	ea	175	$175	As above
Technician	40	hrs	$40	$1,600	Labor
Miscellaneous materials	1	ea	$1,000	$1,000	Estimate
TOTAL				**$28,335**	
TOTAL PERIODIC MAINTENANCE COSTS				**$98,655**	

Table H-3. Present Value of P&T System Costs for 30 years of operation

Year	P&T		
	Annual Cost *	PV of Annual Cost	Cumulative PV of Annual Cost
0	**$167,381**	$167,381	$167,381
1	$57,455	$55,836	$223,217
2	$57,455	$54,262	$277,479
3	$57,455	$52,733	$330,212
4	$57,455	$51,247	$381,459
5	**$70,320**	$60,954	$442,413
6	$57,455	$48,399	$490,811
7	$57,455	$47,035	$537,846
8	$57,455	$45,709	$583,556
9	$57,455	$44,421	$627,977
10	**$98,655**	$74,125	$702,102
11	$57,455	$41,953	$744,054
12	$57,455	$40,770	$784,825
13	$57,455	$39,621	$824,446
14	$57,455	$38,505	$862,951
15	**$70,320**	$45,798	$908,749
16	$57,455	$36,365	$945,114
17	$57,455	$35,340	$980,454
18	$57,455	$34,344	$1,014,798
19	$57,455	$33,376	$1,048,174
20	**$98,655**	$55,694	$1,103,868
21	$57,455	$31,521	$1,135,389
22	$57,455	$30,633	$1,166,022
23	$57,455	$29,770	$1,195,792
24	$57,455	$28,931	$1,224,723
25	**$70,320**	$34,411	$1,259,134
26	$57,455	$27,323	$1,286,457
27	$57,455	$26,553	$1,313,010
28	$57,455	$25,805	$1,338,814
29	$57,455	$25,077	$1,363,892
30	**$98,655**	$41,846	$1,405,738

* Annual cost in Year zero is equal to the capital investment.
Annual cost in other years is annual O&M cost plus annual monitoring cost
Annual costs in Years 10, 20, and 30 include annual
O&M, annual monitoring, and periodic maintenance

Figure H-1. P&T System Costs - 100 years



Appendix I

Technical Information for $KMnO_4$ Used for the ISCO Demonstration

CAIROX®

Potassium Permanganate

CAS Registry No. 7722-64-7

Free-Flowing Grade

Free-Flowing Grade is recommended where potassium permanganate is subjected to high humidity conditions and where the material is to be dry fed through a chemical feeder or stored in a bin or hopper.

Free-Flowing Grade

Assay

Guaranteed 97% $KMnO_4$

Particle Size

20% maximum retained on #425 U.S. Standard Sieve (formerly #40)

7% maximum through #75 U.S. Standard Sieve (formerly #200)

Standards and Specifications

CAIROX® Potassium Permanganate is certified by the National Sanitation Foundation (NSF) to ANSI/NSF Standard 60: Drinking Water Treatment Chemicals - Health Effects.

Technical Grade meets:

- AWWA Standard B603
- Military Specifications MIL-P-11970-C dated 14 October 1983
- Water Chemical Codex RMIC values

Chemical/Physical Data

Formula	$KMnO_4$
Formula Weight	158.0 g/mol
Form	Granular Crystalline
Specific Gravity	
Solid	2.703 g/cm^3
3% Solution	1.020 g/mL by weight, 20°C / 4°C
Bulk Density	Approximately 100 lb/ft^3

Decomposition may start at 150 °C / 302 °F

Solubility in Distilled Water

Temperature		Solubility	
°C	°F	g/L	oz/gal
0	32	27.8	3.7
20	68	65.0	8.6
40	104	125.2	16.7
60	140	230.0	30.7
70	158	286.4	38.3
75	167	323.5	43.2

For more information, refer to the *Solubility Fact Sheet.*

Shipping Containers

25 kg pail[1] (55.125 lb) net, with handle, made of HDPE, weighs 3.1 lb. It is tapered to allow nested storage of empty drums, stands approximately 15½ inches high and has a maximum diameter of 12 inches.

150 kg drum[1] (330.750 lb) net, made of 22-gauge steel, weighs 22.4 lbs. It stands approximately 29½ inches high and is approximately 19¾ inches in diameter.

1500 kg Cycle-Bin™[2] (3307 lb) net.

Bulk, up to 48,000 lbs.

Special Packages will be considered on request.

(1) Meets UN performance oriented packaging requirements.
(2) The Cycle-Bin™ meets DOT 56 Specifications.

Description

Crystals or granules are dark purple with a metallic sheen, sometimes with a dark bronze-like appearance. Free-Flowing Grade is gray due to an additive. Potassium permanganate has a sweetish, astringent taste and is odorless.

Handling, Storage, and Incompatibility

Protect containers against physical damage. When handling potassium permanganate, respirators should be worn to avoid irritation of or damage to mucous membranes. Eye protection should also be worn when handling potassium permanganate as a solid or in solution.

Potassium permanganate is stable and will keep indefinitely if stored in a cool, dry area in closed containers. Concrete floors are preferred to wooden decks. To clean up spills and leaks, follow the steps recommended in the MSDS. Be sure to use goggles, rubber gloves, and respirator when cleaning up a spill or leak.

Avoid contact with acids, peroxides, and all combustible organic or readily oxidizable materials including inorganic oxidizable materials and metal powders. With hydrochloric acid, chlorine gas is liberated. Potassium permanganate is not combustible, but will support combustion. It may decompose if exposed to intense heat. Fires may be controlled and extinguished by using large quantities of water. Refer to the *MSDS* for more information.

Corrosive Properties

Potassium permanganate is compatible with many metals and synthetic materials. Natural rubbers and fibers are often incompatible. Solution pH and temperature are also important factors. The material must be compatible with either the acid or alkali also being used.

In neutral and alkaline solutions, potassium permanganate is not corrosive to iron, mild steel, or stainless steel; however, chloride corrosion of metals may be accelerated when an oxidant such as permanganate is present in solution. Plastics such as polypropylene, polyvinyl chloride Type I (PVC I), epoxy resins, fiberglass reinforced plastic (FRP), Penton, Lucite, Viton A, and Hypalon are suitable. Teflon FEP and TFE, and Tefzel ETFE are best. *Refer to Material Compatibility Chart.*

Aluminum, zinc, copper, lead, and alloys containing these metals may be (slightly) affected by potassium permanganate solutions. Actual studies should be made under the conditions in which permanganate will be used.

Shipping

Potassium permanganate is classified by the Hazardous Materials Transportation Board (HMTB) as an oxidizer. It is shipped under Interstate Commerce Comission's (ICC) Tariff 19.

Proper Shipping Name:	Potassium Permanganate (RQ-100/45.4)
Hazard Class:	Oxidizer
Identification Number:	UN 1490
Label Requirements:	Oxidizer
Packaging Requirements:	49 CFR Parts 100 to 199, Sections: 173.152, 173.153, 173.194

Shipping Limitations:

Minimum quantities:

Rail car: See Tariff for destination
Truck: No minimum

Postal regulations:

Information applicable to packaging of oxidizers for shipment by the U.S. Postal Service to domestic and foreign destinations is readily available from the local postmaster.

United Parcel Service accepts 25 lbs as largest unit quantity properly packaged; consult United Parcel Service.

Regulations concerning shipping and packing should be consulted regularly due to frequent changes.

Repacking

When potassium permanganate is repacked, the packing, markings, labels, and shipping conditions must meet applicable Federal regulations. See Code of Federal Regulations-49, Transportation (parts 100-199) and Federal Hazardous Materials Substances Act, 15 U.S.C. 1261.

Applications

Listed below are some of the many applications of potassium permanganate. Permanganate is a powerful oxidizing agent. The optimum condition under which it is to be used can be easily established through technical service evaluations or laboratory testing.

Oxidation and Synthesis - Organic chemicals and intermediates manufacture. Oxidizes impurities in organic and inorganic chemicals.

Water Treatment - Oxidizes iron, manganese, and hydrogen sulfide; controls taste and odor; and is an alternate pre-oxidant for Disinfection By-Product (THMs and HAAs) control.

Municipal Wastewater Treatment - Destroys hydrogen sulfide in wastewater and sludge. Improves sludge dewatering.

Industrial Wastewater Treatment - Oxidizes hydrogen sulfide, phenols, iron, manganese, and many other organic and inorganic contaminants; resultant manganese dioxide aids in removing heavy metals.

Metal Surface Treatment - Conditions mill scale and smut to facilitate subsequent removal by acid pickling in wrought metals manufacturing and jet engine cleaning.

Equipment Cleaning - Assists in cleaning organic and inorganic residues from refining and cooling towers and other processing equipment. Decontaminates hydrogen sulfides, pyrophoric iron sulfides, phenols, and others.

Purification of Gases - Removes trace impurities of sulfur, arsine, phosphine, silane, borane, and sulfides from carbon dioxide and other industrial gases.

Mining and Metallurgical - Aids in separation of molybdenum from copper; removes impurities from zinc and cadmium; oxidizes flotation compounds. Removes iron and manganese from acid mine drainage.

Hazardous Waste Treatment or Remediation - Treats phenols, chlorinated solvents (TCE, PCE), tetraethyl lead, chelated metals, cyanides, and sulfides.

Slag Quenching - Controls hydrogen sulfide and acetylene emissions during quenching of hot slag.

Food Processing - Controls sulfides, soluble animal oil, grease, organic acids, ketones, nitrogen compounds, mercaptans, and BOD.

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