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Demonstration of Resistive Heating Treatment of DNAPL Source Zone at Launch Complex 34 in Cape Canaveral Air Force Station, Florida

Final Innovative Technology Evaluation Report

by

Battelle
forColumbus, OH 43201

for

The Interagency DNAPL Consortium:

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Notice

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Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation’s land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA’s research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency’s center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory’s research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory’s strategic long-term research plan. It is published and made available by EPA’s Office of Research and Development (ORD) to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

Executive Summary

Dense, nonaqueous-phase liquid (DNAPL) contaminants are a challenge to characterize and remediate at many sites where such contaminants have entered the aquifer 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 is 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 (NASA) 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 and 45 ft below ground surface (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 contains the DNAPL source. The Lower Clay Unit appears to be pervasive throughout the demonstration area, although the effective thickness for the unit is only up to 3 ft. The hydraulic gradient in the surficial aquifer is relatively flat. The native aquifer contains relatively high levels of chloride and total dissolved solids (TDS).

The source zone was divided into three test plots, each 75 ft × 50 ft 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/July 2000 in the two outer plots, separated by about 80 ft. Steam injection will be tested in the middle plot, beginning June 2001. The IDC contracted MSE Technology Applications, Inc., to conduct the vendor selection and subcontracting for the three technologies, as well as to track the costs of the demonstration. Current Environmental Solutions (CES) was the vendor selected for implementing resistive heating at Launch Complex 34. Resistive heating was selected because it has the potential to heat the aquifer and remove DNAPL.

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 resistive heating technology. The objectives of the performance assessment were:

- Estimating change in TCE-DNAPL mass.
- Evaluating changes in aquifer quality.
- Evaluating the fate of the TCE-DNAPL removed from the resistive heating plot.
- Verifying resistive heating operating requirements and costs.

Estimating the TCE-DNAPL mass removal due to the resistive heating 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 (ESB). 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 pre-demonstration characterization of the resistive heating plot was conducted to initiate the performance assessment of the resistive heating technology. From September 1999 to July 2000, when the resistive heating field application was conducted, Battelle collected subsurface data to monitor the progress of the demonstration; the vendor collected additional aboveground data to aid in the operation of the technology. In August-December 2000, the post-demonstration assessment of the resistive heating plot was conducted after all parts of the aquifer had cooled to 90°C or less.

Change in TCE-DNAPL Mass

Detailed soil sampling was used as the main tool for determining changes in TCE-DNAPL mass in the test plot. 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 resistive heating plot. A systematic unaligned sampling scheme was used to conduct pre- and post-demonstration 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 resistive heating 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 a certified laboratory for analysis. In this manner, the entire soil column was analyzed from ground surface to aquitard, at each coring location. Pre-demonstration evaluation of this extraction method with Launch Complex 34 soil showed between 72 and 86% decrease in TCE mass in the test plot. Steps were taken during the post-demonstration soil sampling to cool the retrieved cores and to minimize volatilization losses from the hot soil.

The TCE concentrations (mg/kg of dry soil) obtained by this method were considered “total TCE.” The portion of the total TCE that exceeded a threshold concentration of 300 mg/kg was considered “DNAPL.” This threshold was determined as the maximum TCE concentration in the dissolved and adsorbed phases in the Launch Complex 34 soil; any TCE concentration exceeding this threshold would be DNAPL.

The results of the TCE-DNAPL mass estimation by soil sampling show the following:

- Contouring or linear interpolation of TCE concentrations between sampled points indicated that there was 11,313 kg of total TCE in the resistive heating plot before the demonstration; approximately 10,490 kg of this TCE mass was DNAPL. The total TCE mass in the plot decreased by approximately 90% and the DNAPL mass in the plot decreased by approximately 97% due to the resistive heating application. This predicted decrease in DNAPL mass exceeds the 90% DNAPL removal target proposed at the beginning of the demonstration.
- A statistical evaluation of the pre- and post-demonstration TCE concentrations confirmed these results. Kriging, a geostatistical tool that takes the spatial variability of the TCE distribution into account, indicated that between 7,498 and 15,677 kg of total TCE was present in the test plot before the demonstration. Kriging indicated that the total TCE mass in the test plot decreased between 80 and 93% following the technology application. These statistics are significant at the 80% confidence level specified before the demonstration.
- Kriging confirmed that the pre- and post-demonstration TCE mass estimates obtained by contouring were within the statistically acceptable range. The large number of soil samples that were collected did capture the spatial variability of the TCE distribution.
- The greatest change in TCE-DNAPL mass was observed in the Lower Sand Unit, followed by the Middle Fine-Grained Unit. The Upper Sand Unit showed the least removal. This shows that heating was most effective in the deeper portions of the aquifer. Limitations due to the new electrode design used at Launch Complex 34 and the loss of vadose zone encountered during high-rainfall events may have contributed to lower heating/steam stripping efficiency in the shallower regions of the aquifer. The temperature distribution in the test plot determined in May 2000, towards the end of the resistive heating field application, showed relatively good heating in all three aquifer units — Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit.
- Most of the DNAPL present in regions that would be considered difficult to access was removed from the test plot by resistive heating. Considerable DNAPL was removed from the region immediately above the aquitard (Lower Clay Unit) and from under the building.

- The change in TCE-DNAPL mass was relatively high under the building, indicating that these regions could be efficiently accessed by using angled electrodes outside the building. Any remediation of DNAPL from further under the building probably would require electrodes that are installed inside the building.

Changes in Aquifer Quality

Application of the resistive heating technology caused the following changes in the treated aquifer:

- Dissolved TCE levels declined in several monitoring wells in the resistive heating plot, although none of the wells showed post-demonstration concentrations of less than 5 µg/L, the federal drinking water standard, or 3 µg/L, the State of Florida ground-water target cleanup level. *Cis*-1,2-DCE levels remained above 70 µg/L and increased considerably in some wells. Vinyl chloride (1 µg/L State of Florida target) levels could not be accurately determined because higher TCE and *cis*-1,2-DCE levels elevated the detection limits of vinyl chloride. This indicates that, in the *short-term*, removal of DNAPL mass from the targeted aquifer caused ground-water TCE concentrations to decline. Dissolved-phase CVOCs were not as efficiently removed, especially from the upper portions of the aquifer, probably due to the lower heating/stripping efficiency in the shallower regions.
- The TCE degradation product *cis*-1,2-DCE appeared to be accumulating in the ground water in the test plot. *Cis*-1,2-DCE itself is subject to drinking water standards (70 µg/L) and its buildup in the plot could be a concern. Its accumulation in the plot may indicate that the degradation rate of *cis*-1,2-DCE is not as fast as the degradation rate of TCE, under the conditions prevalent in the aquifer.
- Ground-water pH and dissolved oxygen levels remained relatively constant, but chloride, sodium, potassium, sulfate, alkalinity (carbonate), and TDS levels rose sharply. TDS levels were above the secondary drinking water standard of 500 mg/L both before and after the demonstration, classifying the aquifer as brackish. Sources of these dissolved solids could include evaporative residue, saltwater intrusion, displacement of exchangeable sodium from aquifer minerals, migration from the ISCO plot, and/or CVOC degradation.
- Biological oxidation demand and total organic carbon (TOC) levels in the ground water generally increased. These increases could be due to dissolution of humic and fulvic matter in the aquifer under the heat treatment.
- The ground-water levels of iron, chromium, and nickel remained relatively constant. There does not appear to be any significant corrosion of the stainless steel monitoring wells of the kind experienced in the ISCO plot.
- Slug tests conducted in the resistive heating plot before and after the demonstration did not indicate any noticeable changes in the hydraulic conductivity of the aquifer.
- Although difficulties were encountered in operating the drill rig during post-demonstration coring, the geochemical composition of the soil does not appear to have changed much due to the heat treatment. Quartz and aragonite make up the majority of the minerals identified in soil samples from heat-affected and unaffected regions of the aquifer. Aragonite may be associated with the seashell fragments found in fair abundance in the aquifer. Calcite and margarite (mica) are less abundant in the aquifer.

Fate of TCE-DNAPL Mass in the Test Plot

The decrease in TCE-DNAPL mass in the plot could have resulted from one or more of the following pathways:

- Aboveground recovery. Vapor sampling conducted by the resistive heating vendor indicates that 1,947 kg of total TCE was recovered in the vapor extraction system. The initial estimate of total TCE mass in the subsurface was 11,313 kg.
- Degradation by biological or abiotic processes. There are indications that some TCE may have been degraded due to the heating in the resistive heating plot.
    - The sharp increase in *cis*-1,2-DCE levels in several monitoring wells inside the plot and perimeter indicate the possibility that some TCE may have degraded by reductive dechlorination. Microbial counts in soil and groundwater samples before and after the demonstration indicate that microbial populations survived the heat treatment in most parts of the plot. If TCE degradation to *cis*-1,2-DCE has been hastened, it is unclear as to the time frame over which *cis*-1,2-DCE itself may degrade. Accumulation of *cis*-1,2-DCE shows that the rate of degradation of TCE may be much faster than the rate of *cis*-1,2-DCE degradation.
    - The sharp increase in chloride, which would have been a strong indicator of dechlorination of CVOCs, proved to be inconclusive. Sodium, potassium, sulfate, alkalinity, and TDS increased sharply, concomitant with the increase in chloride — these are all seawater constituents. The possibility of the increase in chloride was caused by saltwater intrusion during the resistive heating application. Also, potential vaporization of the water may have resulted in the increased chloride concentrations.
    - Abiotic processes that may have degraded TCE include reductive dechlorination by the steel shot in the electrodes, hydrolysis, and/or oxidation. Any of these processes could have been promoted by the heating in the plot.
- Migration to surrounding regions. There are indications that some TCE, and perhaps DNAPL, may have migrated to regions surrounding the resistive heating plot.
    - Monitoring wells (IW-17S and IW-17I) outside the western perimeter of the plot showed a sustained increase in TCE concentrations during and after the demonstration. TCE was found in transient surface water that appeared along a ditch on the western side of the plot, following the two hurricane events. It is possible that when the water table rose to the ground surface, the vapor extraction piping in the plot was submerged. Hot water laden with TCE could have migrated westward along the topographic gradient. Another possible obstruction to the TCE vapors being extracted through the extraction pipes and plenum in the vadose zone and ground surface is the Middle Fine-Grained Unit. TCE vapors and steam migrating upwards could preferentially migrate horizontally in the sandy layer under the Middle Fine-Grained Unit rather than through the silty layer above. A limited number of exploratory soil cores collected in the regions surrounding the resistive heating plot after the demonstration did not show any signs of fresh DNAPL deposits.
    - DNAPL appeared in two of the wells (PA-2I and PA-2D) on the eastern side of the plot. It is not clear which of the two technologies, ISCO or resistive heating, caused DNAPL to migrate. ISCO in the neighboring test plot (80 ft away) created a strong hydraulic gradient that could potentially

  displace any mobile DNAPL in the aquifer. Resistive heating generates heat-induced convection gradients that could displace mobile DNAPL or mobilize residual DNAPL. On the other hand, the PA-2 well cluster was installed in a region that was showing dissolved TCE levels close to its solubility before the demonstration. It is possible that DNAPL would have eventually appeared in these wells regardless of the neighboring remediation activities.

  - Soil core samples from the vadose zone above the resistive heating-treated aquifer did not show any noticeable increase in TCE concentrations.
  - Surface emission tests conducted inside and around the plot on several occasions during and immediately following the resistive heating application showed noticeably elevated levels of TCE, compared to background levels. This indicated that the vapor capture system was not as efficient as would be desired and some CVOC vapors were migrating to the atmosphere. On some occasions, steam (and probably CVOC vapors) shot out of the monitoring wells for several seconds during sampling. This is another potential route for CVOC vapors.
  - After the resistive heating and ISCO demonstrations, three wells were installed into the confined aquifer – one in the parking lot to the north (PA-20), one in the ISCO plot (PA-21) and one in the resistive heating plot (PA-22). All three wells showed elevated levels of dissolved TCE, but the levels were especially high in PA-22. Ground water in PA-22 also had elevated temperature (44 to 49°C); it is not clear whether the elevation in temperature was caused by conduction or convection. The soil cores collected during the installation of these wells showed the presence of DNAPL in the Lower Clay Unit and confined aquifer below the ISCO plot and below the resistive heating plot, but not under the parking lot, which is outside the suspected DNAPL source zone. TCE concentrations were particularly high in soil and ground-water samples collected from under the resistive heating plot. Because these wells were installed only after the demonstration, it is unclear as to when the DNAPL migrated to the confined aquifer. The resistive heating treatment heated the base of the aquifer and probably the aquitard fairly well and the buoyancy of the water would probably create vertically upward gradients. It is possible that the DNAPL penetrated the aquitard gradually over time, long before the demonstration.
  - The power outage and ground-water recharge resulting from two hurricane events (Floyd, September 10, 1999; and Irene, October 17, 1999) during the operation may have caused some loss of TCE.

- Losses during sampling of hot soil cores. It is possible that some CVOC losses occurred during post-demonstration sampling of the hot (90°C or less) soil cores. This would cause an underestimation of the TCE-DNAPL mass remaining in the resistive heating plot after the demonstration. However, all precautions had been taken to minimize any such losses. By the time the post-demonstration soil sampling was done, the plot had cooled to 90°C or less, indicating that steam generation had subsided. Each time the soil sample barrel was retrieved from the ground, it was immediately capped at both ends and submerged in an ice bath until the core temperature cooled to ambient.

- The monitoring indicates that some TCE may have degraded through one or more of several heat-induced degradation (or accelerated biodegradation) mechanisms. It is also possible that some TCE may have migrated from the resistive heating plot through a variety of possible pathways. It also is possible

> that some of the migrating TCE was DNAPL. The resistive heating application at Launch Complex 34 generated the desired heating in most parts of the plot, even in difficult spots, such as immediately above the aquitard and under the building. Heating in the shallower regions of the plot was somewhat hampered by the deficiencies of the new electrode design and by the transient diminishing of the vadose zone. Vapor capture is the biggest challenge that the technology needs to engineer for in future applications.

In summary, the TCE in the plot probably was dissipated by the resistive heating treatment through a number of possible pathways, including aboveground vapor recovery and condensation, microbial degradation, and migration to the surrounding regions. The possible buildup and persistence of *cis*-1,2-DCE in the plot, as well as dechlorination to ethenes, due to heat-accelerated biodegradation needs to be studied. Ways of maximizing any such biodegradation and minimizing migration outside the plot need to be determined during future resistive heating applications.

At Launch Complex 34, a mechanism (such as a vertical pipe) for channeling upward-migrating CVOC vapors past the Middle Fine-Grained Unit probably would have improved capture. Better hydraulic and pneumatic control, as well as better heating, near the water table, vadose zone, and ground surface would have improved vapor capture. Better design could have increased observed recovery and decreased potentially undesirable losses outside the plot.

Verifying Operating Requirements

The resistive heating heat application began on August 18, 1999 and continued until July 12, 2000, with two major breaks in between. The SVE system was operated for two more months until September 19, 2000 so that continuing vapors from the still-hot aquifer could be recovered. Over the course of the demonstration, a total of 1,725,000 kW-hrs of energy was applied to the subsurface. The applied voltage ranged from 100 to 500 V, which resulted in an electrical current of 10 to 400 amps.

At this site, the vendor used a novel electrode design consisting of an electrical cable attached to a ground rod within a graphite backfill, instead of the traditional pipe electrode. However, this new design, coupled with excessive rainfall and a rising water table, resulted in insufficient heating of the upper part of the aquifer. Therefore, between February 24 and March 2, 2000, the vendor installed ground rods near each electrode to heat the 3- to 10-ft-bgs ground interval.

The first major interruption of the resistive heating operation occurred between September 30 and December 12, 1999. On September 10 a major hurricane (Hurricane Floyd) hit Cape Canaveral, followed by a second hurricane (Hurricane Irene) on October 17, 1999. The power supply was damaged and the water table rose significantly, from about 6 ft bgs before the demonstration to almost 1.5 ft bgs in monitoring well PA-2. In low-lying areas of the test plot, the ground water was probably near the ground surface. Elevated TCE levels discovered in ponded surface water in a ditch along the west side of the resistive heating plot indicate that some TCE migrated from the plot during this period. It is probable that infiltration of cooler rainwater from the storms caused the rising TCE vapors to condense near the ground surface. In addition, the rising water table submerged the SVE wells rendering them useless; it is probable that some TCE volatilized to the atmosphere during this time.

In October 1999, the vendor installed six horizontal wells in the northern half of the cell and seven shallow vertical wells in the southern half of the cell near the building. In addition, a surface cover (plenum) was placed over the plot to improve vapor capture. In October 1999, the vendor also installed a drainage diversion system consisting of a sandbag cutoff wall on the east side of the plot and a sump pump to divert the water through a PVC pipe to the drainage collection area in the west. Also, PVC risers on the six monitoring wells inside the plot were removed and replaced with stainless steel risers. Due to these modifications and the repairs resulting from the hurricanes, the resistive heating system was operated only for six weeks during the first heating cycle. The second heating cycle started on December 12, 1999 and continued for 13 weeks.

On March 24, 2000, operations were interrupted to replace the transformer, a major piece of equipment, whose lease had run out. A replacement transformer was obtained and installed in April, but the third heating cycle could begin only on May 11, 2000 due to an unusually heavy space shuttle launch schedule that necessitated work stoppages. The third heating cycle continued for eight weeks until July 12, 2000, when the IDC determined that VOC extraction rates had declined significantly. The SVE system remained operational until September 19, 2000, by which time subsurface temperatures had fallen below 95°C, indicating that steaming had stopped.

A major concern with the resistive heating technology was the high voltage (up to 500 V) required to be delivered to the subsurface. Despite all the difficulties involving hurricanes and flooding of the plot, the vendor successfully controlled the transport and distribution of the large amounts of electricity involved. At all times, the ground surface was successfully insulated from the electric current running through the aquifer. The ground surface above the resistive heating plot was available for other activities during the voltage applications. This successful management of the high voltage application is probably the most important safety achievement of the demonstration.

The voltage application was turned off whenever monitoring wells were sampled inside the test plot and all sampling events were conducted safely. Because the monitoring well screens were completely submerged under the water table, there was a tendency for steam pressure to build up in the monitoring wells. A pressure gauge and pressure release valve were installed on each monitoring well inside the plot and along the perimeter. System operators and sampling personnel wore Level D personal protective equipment at the site. No injuries were encountered during the demonstration.

Economics

The total cost of the resistive heating application was **$613,000**. The vendor incurred a total cost of approximately $569,000 for resistive heating treatment of the 75-ft x 50-ft x 45-ft test plot at Launch Complex 34. This total includes the design, equipment, mobilization/demobilization and operation costs. In addition, NASA incurred a cost of $44,000 for off-site waste disposal. Aboveground wastes requiring disposal included the condensate (shipped to the on-site wastewater treatment plant), spent carbon (shipped to the supplier for regeneration), and the permanganate-impregnated silica (shipped to a local landfill).

A comparison of the cost of resistive heating treatment of the DNAPL source the size of the resistive heating plot and an equivalent (2 gallon per minute [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 present value (PV) of building and operating a pump-and-treat system for 30 years was estimated as $1,406,000. Assuming that the resistive heating application was effective and displacement did not occur, the resistive heating application cost, therefore, is 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. Resistive heating treatment 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 over a pump-and-treat system at this site.

Site characterization costs were not included in the cost comparison because a good design of either a source treatment (e.g., resistive heating) or plume control (e.g., pump and treat) remedial action would 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, data analysis, and report.

Regulatory and Administrative Considerations

DNAPL source remediation, in general, and resistive heating, in particular, is a treatment option that results in risk reduction through removal of DNAPL from the subsurface. Contaminant volume reduction and, to some extent, toxicity reduction resulted from the TCE extraction and its possible degradation due to the resistive heating treatment. Better hydraulic and pneumatic control, as well as better heating, near the water table, vadose zone, and ground surface would improve vapor capture at future sites.

Although the eventual target for the Launch Complex 34 aquifer is to meet Florida state-mandated ground-water cleanup goals (3 µg/L of TCE, 70 µg/L of *cis*-1,2-DCE, and 1 µg/L of vinyl chloride), the Technical Advisory Group recommended a more feasible and economically viable goal of 90% removal of DNAPL mass. From the experience of the demonstration, it appears that, at least from the site owner's perspective, three types of cleanup goals may be envisioned for source remediation – a short-term goal, an intermediate-term goal, and a long-term goal. At Launch Complex 34, the **short-term goal** of the cleanup was to remove at least 90% of the DNAPL mass, and was the immediate goal given to the technology vendors. Although more than 90% reduction of the DNAPL mass was observed in the resistive heating plot, ground-water concentrations of TCE declined substantially, but not to 3 µg/L. On the other hand, *cis*-1,2-DCE levels increased, as some TCE probably degraded reductively. Although some rebound in TCE concentrations may be expected in the future, it is possible that in the intermediate term (say, a year after the source treatment), a weakened plume will result. Therefore, in the intermediate term, there is a possibility that the source treatment, in conjunction with natural attenuation (or other plume control measure, if necessary), would allow cleanup targets to be met at a downgradient compliance point (e.g., property boundary). With source treatment, meeting ground-water cleanup targets is likely to be an **intermediate-term** goal.

The **long-term goal** of source treatment would be faster dismantling of any interim plume control remedy (natural attenuation or other treatment) that may be implemented to meet ground-water cleanup targets at the compliance point. Faster dismantling of any interim remedy is likely to result from the fact that DNAPL mass removal would hasten the eventual depletion of the TCE source. A possible long-term benefit could also accrue from the fact that source treatment may result in a weakened plume that would require a much lower magnitude of long-term treatment (and cost).

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Acronyms and Abbreviations

ACL	alternative concentration limits
AFRL	Air Force Research Laboratory
ARARs	applicable or relevant and appropriate requirements
bgs	below ground surface
BOD	biological oxygen demand
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CES	Current Environmental Solutions
CVOC	chlorinated volatile organic compound
CWA	Clean Water Act
DCE	*cis*-1,2-dichloroethylene
DNAPL	dense, nonaqueous-phase liquid
DO	dissolved oxygen
DoD	Department of Defense
DOE	Department of Energy
EM50	Environmental Management 50 (Program)
ESB	Engineering Support Building
FDEP	(State of) Florida Department of Environmental Protection
FSU	Florida State University
GAC	granular activated carbon
gpm	gallon(s) per minute
HSWA	Hazardous and Solid Waste Amendments
IDC	Interagency DNAPL Consortium
ISCO	in situ chemical oxidation
ITRC	Interstate Technologies Regulatory Council
JCPDF	Joint Commission on Powder Diffraction Files
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.
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
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
OSWER	Office of Solid Waste and Emergency Response
PAH	polycyclic aromatic hydrocarbon
PCE	perchloroethylene
PID	photoionization detector
POTW	publicly owned treatment works
PV	present value
PVC	polyvinyl chloride
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RI/FS	Remedial Investigation/Feasibility Study
RIR	relative intensity ratio
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 Plans
SITE	Superfund Innovative Technology Evaluation (Program)
STL	STL Environmental Services, Inc.
SVE	soil vapor extraction
TCA	trichloroethane
TCE	trichloroethylene
TDS	total dissolved solids
TOC	total organic carbon
U.S. EPA	United States Environmental Protection Agency
VOA	volatile organic analysis
WSRC	Westinghouse Savannah River Company
XRD	x-ray diffraction

1. Introduction

This section is an introduction to the demonstration of the resistive heating technology for remediation of a dense, nonaqueous-phase liquid (DNAPL) source zone at Launch Complex 34, Cape Canaveral Air Force 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 performance of the resistive heating technology for remediation of DNAPL source zones. Resistive heating was demonstrated at Launch Complex 34, Cape Canaveral Air Force Station, FL, where the chlorinated volatile organic compound (CVOC) trichloroethylene (TCE) is present in the aquifer as a DNAPL source. Smaller amounts of dissolved *cis*-1,2-dichloroethylene (DCE) and vinyl chloride also are present in the ground water. The field application of the technology started in August 1999 and ended in July 2000. Pre- and post-demonstration performance assessment activities were conducted before, during, and after the field demonstration.

1.1.1 The Interagency DNAPL Consortium

The resistive heating 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:

- Department of Energy (DOE), Environmental Management 50 (EM50) Program
- U.S. Environmental Protection Agency (U.S. EPA), Superfund Innovative Technology Evaluation (SITE) Program
- 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, R.S. Kerr Environmental Research Center (RSKERC)
- Interstate Technologies Regulatory Council (ITRC).

Key representatives of the various agencies constituting the IDC have formed a Core Management Team, which guides the progress of the demonstration. An independent Technical Advisory Group has been formed to advise the Core Management Team on the technical aspects of the site characterization and selection, remediation technology selection and demonstration, and the performance assessment of the technologies. The Technical Advisory Group consists 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. Current Environmental Solutions (CES) was the selected vendor for implementing the resistive heating technology at Launch Complex 34. IT Corporation and Integrated Water Resources, Inc., were the vendors for the in situ chemical oxidation (ISCO) 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, QA, and data analysis (Battelle, 1999d). Once the demonstration started, Battelle prepared eight interim reports (Battelle 1999e, and f; Battelle 2000a, b, and c; Battelle 2001a, b, and c).

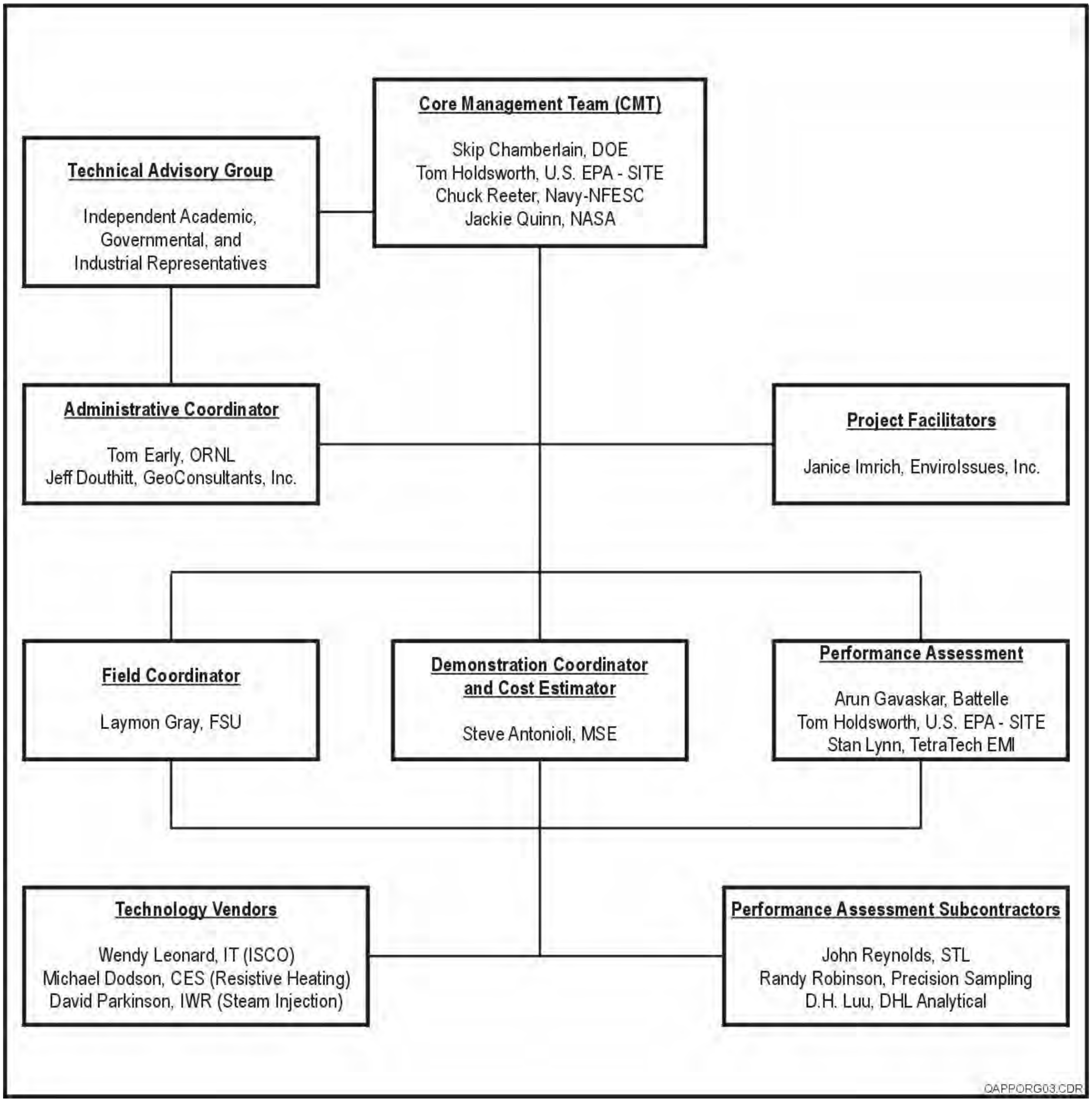

Figure 1-1. Project Organization for the IDC Demonstration at Launch Complex 34

1.1.3 The SITE Program

The performance assessment planning, field implementation, and data analysis and reporting for the resistive heating 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 (OSWER) 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 are also presented. This IDC report on the resistive heating 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 years (or decades). This free-phase solvent is called DNAPL.

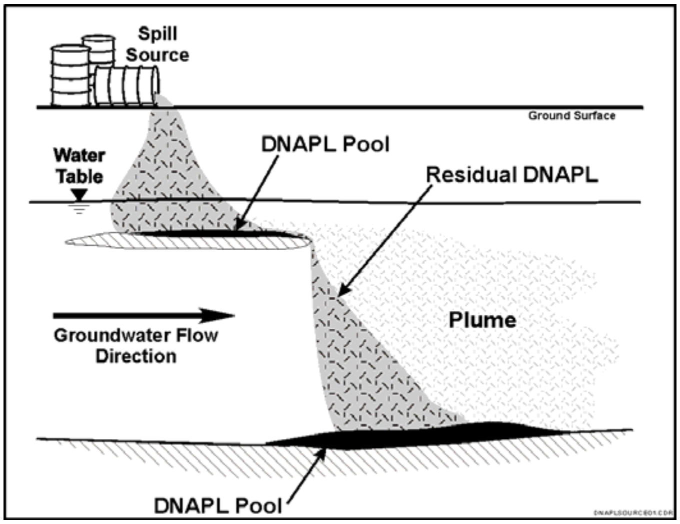

Figure 1-2. Formation of a DNAPL Source in an Aquifer

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

As long as there is DNAPL 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 to development and validation of techniques that have potential to affect 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 may not be economical for residual *DNAPL* source 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 ground-water flow. An innovative approach is required to address the DNAPL problem.

1.3 The Resistive Heating Technology

In the early 1990s, Pacific Northwest National Laboratory developed the resistive heating technology for heat treatment of vadose and saturated zone soils, as well as ground water. It splits conventional three-phase electricity into six electrical phases and delivers it to the subsurface through metal electrodes (see Figure 1-3). In the subsurface, the electrical energy resistively heats the soil and ground water to generate steam. A combination of direct volatilization and steam stripping drives contaminants to the vadose zone, where a vapor extraction system collects the steam and contaminant vapors and treats them in an aboveground treatment system. Typically, a condenser and activated carbon have been used as an aboveground treatment system for the extracted vapors. Thermal processes, such as steam injection and resistive heating, have also been reported as causing in situ degradation of organic contaminants by a variety of processes, such as hydrolysis, oxidation, and enhanced microbial action. Over the years, the resistive heating system has been developed to the point where the ground surface is insulated from the subsurface electrical energy and continued site access is possible to personnel during the application.

1.4 The Demonstration Site

Launch Complex 34, the site selected for this demonstration, is located at Cape Canaveral Air Force Station, FL (see Figure 1-4). Launch Complex 34 was used as a launch site for Saturn rockets from 1960 to 1968. Historical 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 depicting the Engineering Support Building and vicinity, where the demonstration was conducted. The DNAPL source zone was large enough that the IDC and the Technical Advisory Group could assign three separate test plots

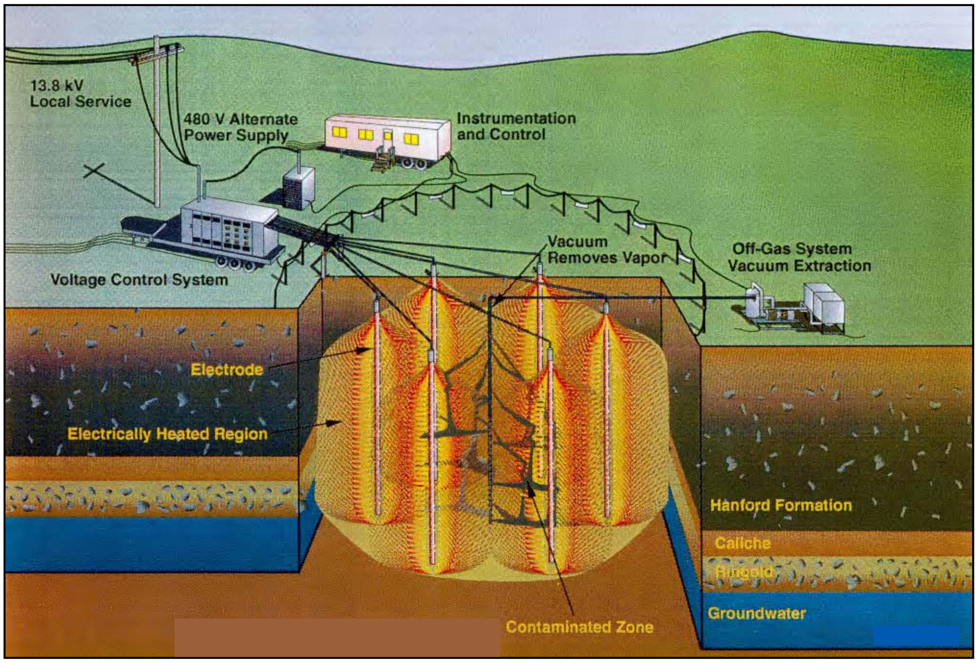

Figure 1-3. Illustration of the Resistive Heating Technology for Subsurface Treatment

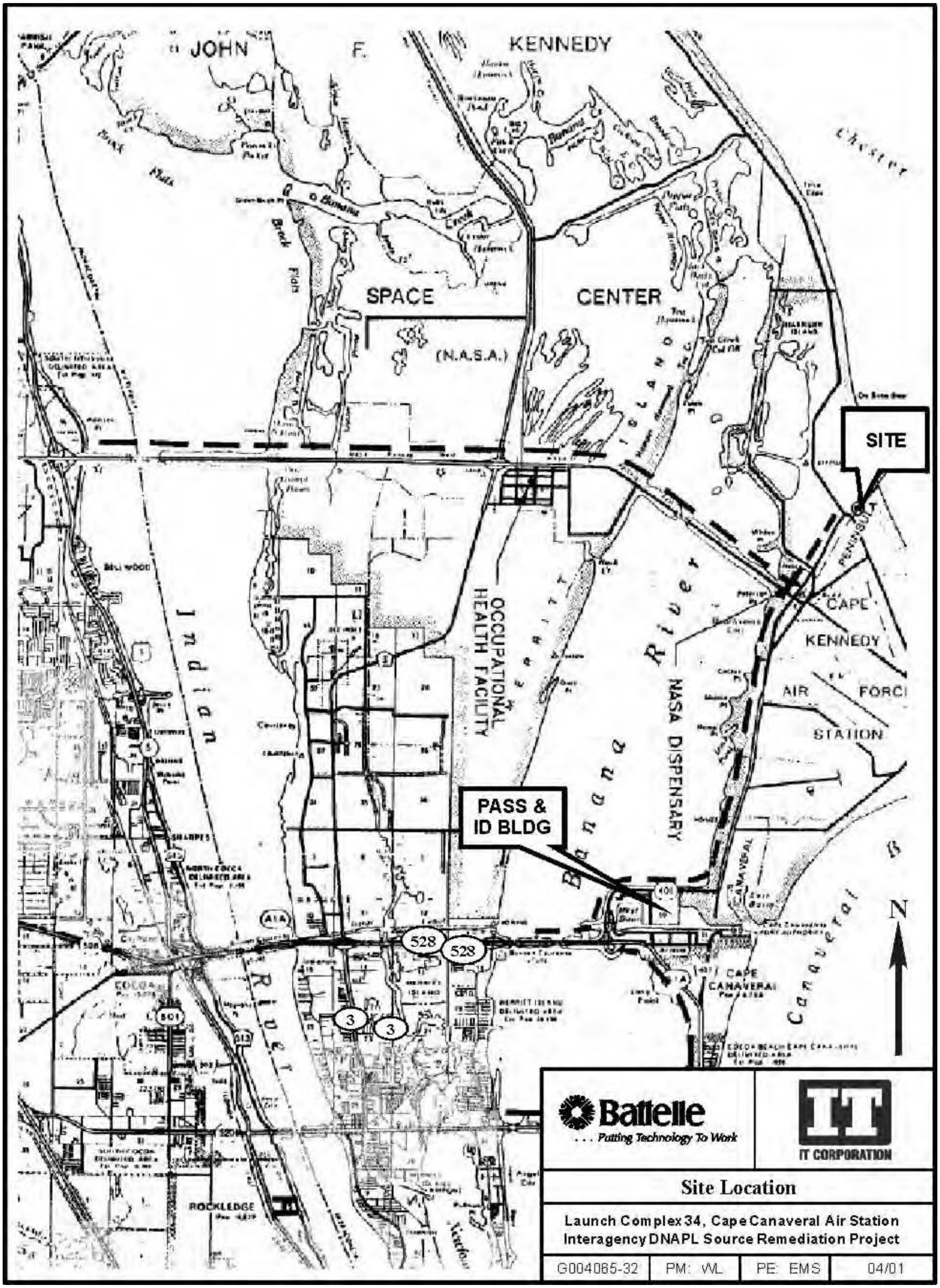

Figure 1-4. Demonstration Site Location

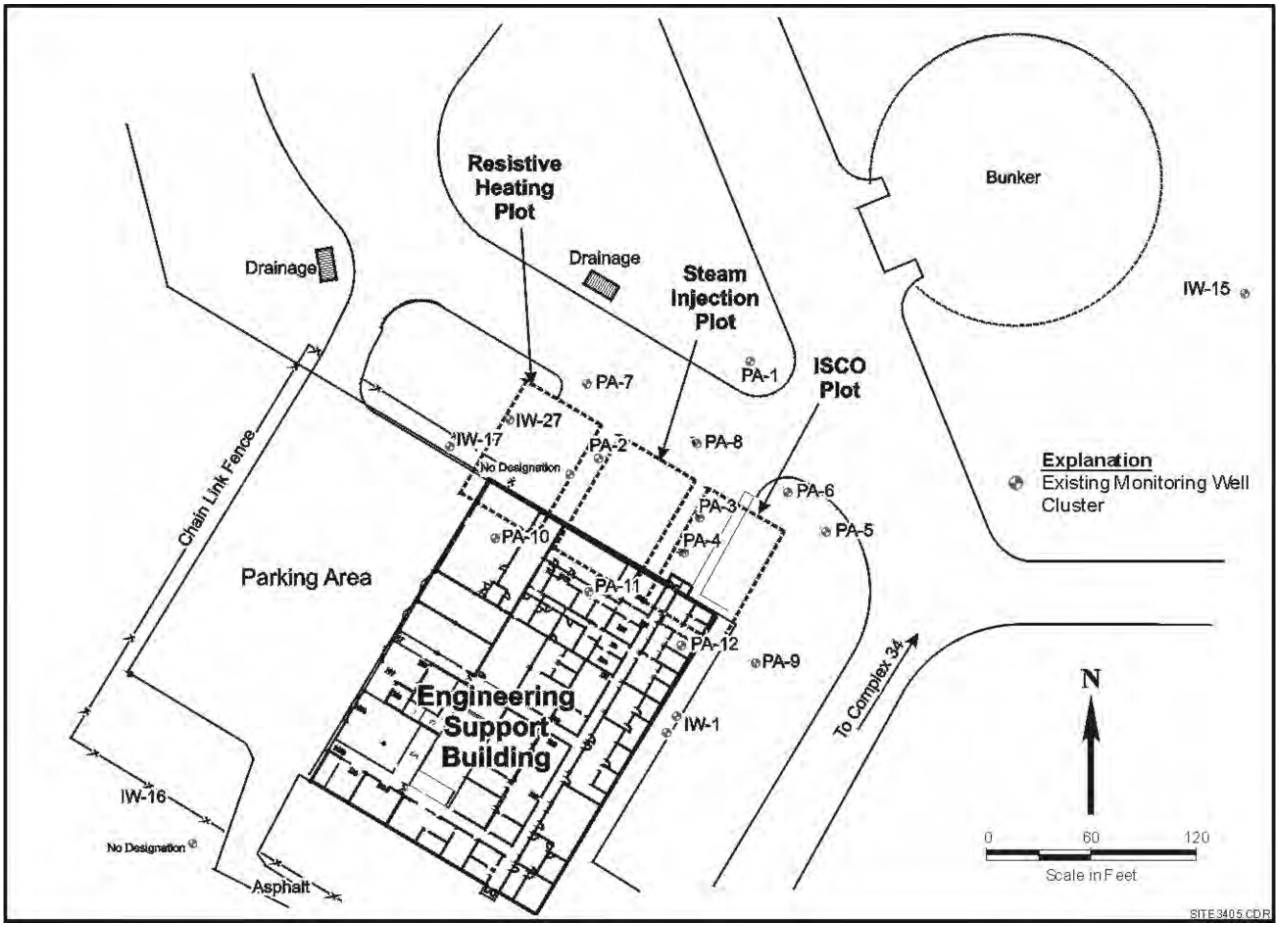

Figure 1-5. Location Map of Launch Complex 34 Site at Cape Canaveral Air Force Station

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 resistive heating plot is the westernmost (to the right in Figure 1-6) 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 so as to encompass the portion of the DNAPL source under the building.

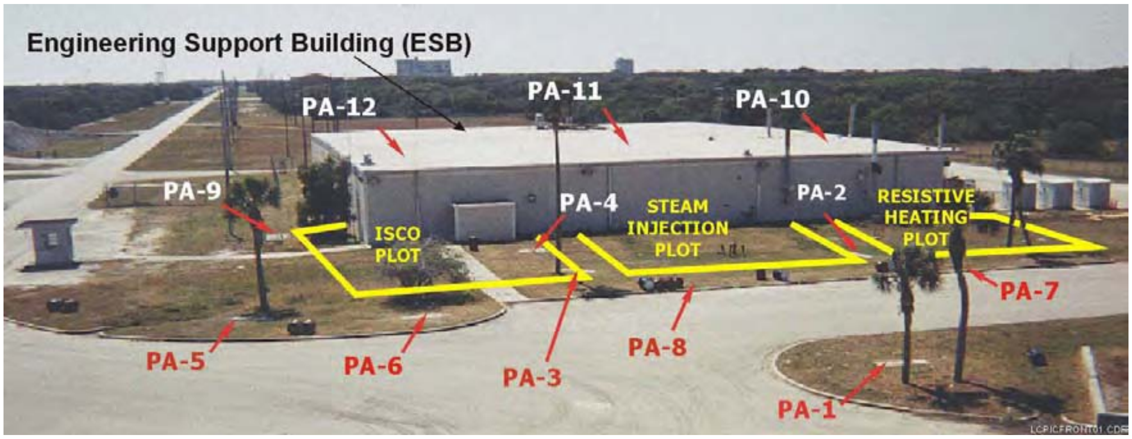

Figure 1-6. Looking Southward towards Launch Complex 34, the Engineering Support Building, and the Three Test Plots

1.5 Technology Evaluation Report Structure

This resistive heating 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:

- 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 of the Technology (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).

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 pre-demonstration 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 resistive heating 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 in some areas, especially under the resistive heating plot (3 ft thick in most areas, but only 1.5 ft thick 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, 2001b).

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	Semiconfined
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

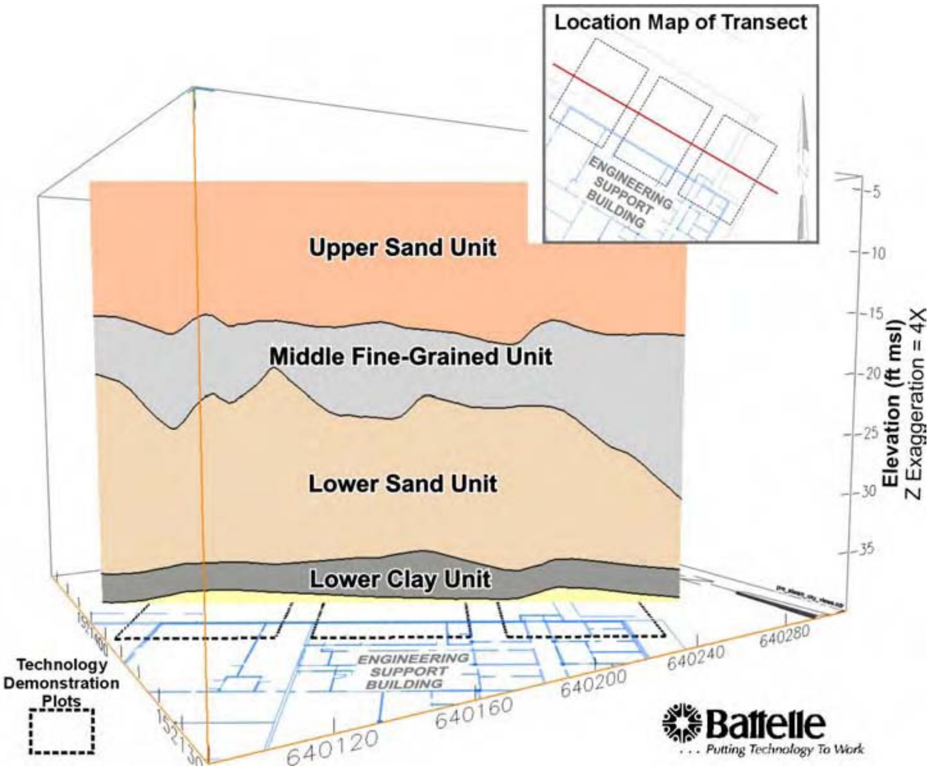

Figure 2-1. NW-SE Geologic Cross Section through the Three Test Plots

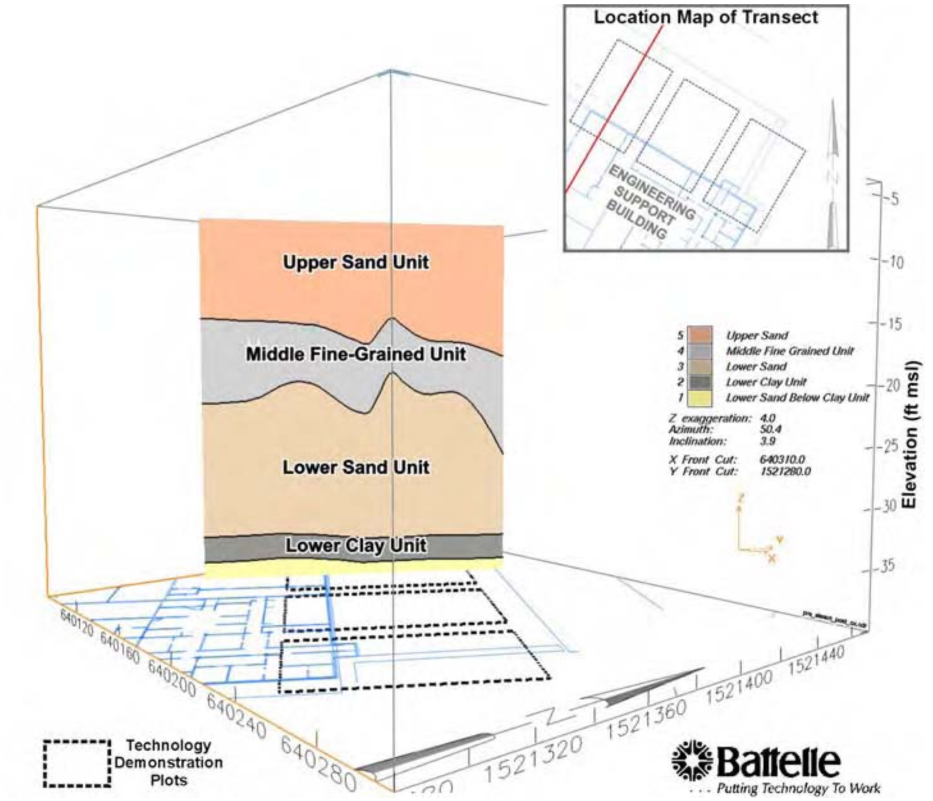

Figure 2-2. SW-NE Geologic Cross Section through Resistive Heating Plot

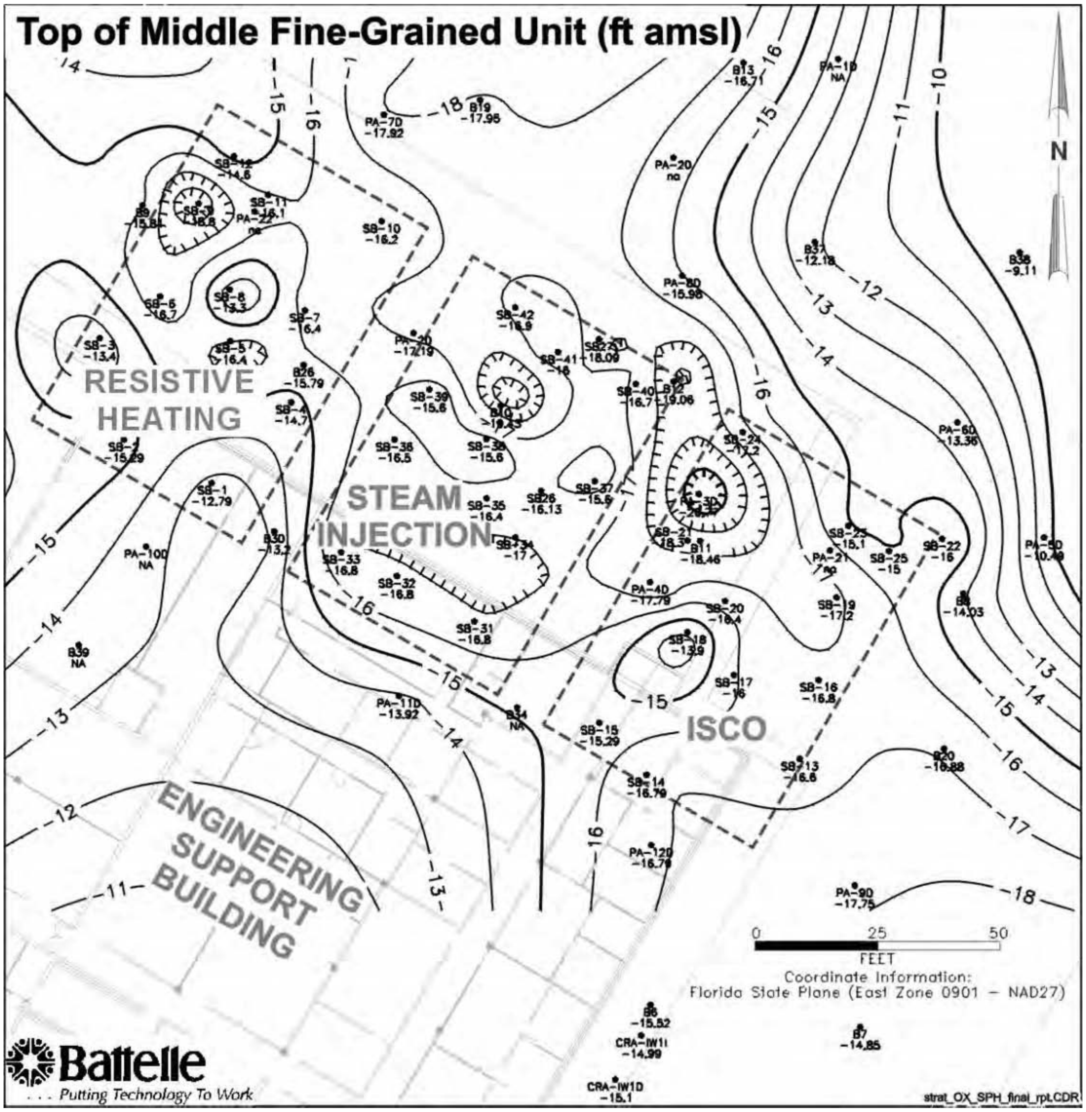

Figure 2-3. Topography of Top of Middle Fine-Grained Unit

The semi-confined aquifer underlies the Lower Clay Unit. During the investigation, the aquifer was found to consist of gray fine to medium-sized sand, clay, and shell fragments to the aquifer below the Lower Clay Unit (Battelle 2001b). 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.

Pre-demonstration 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

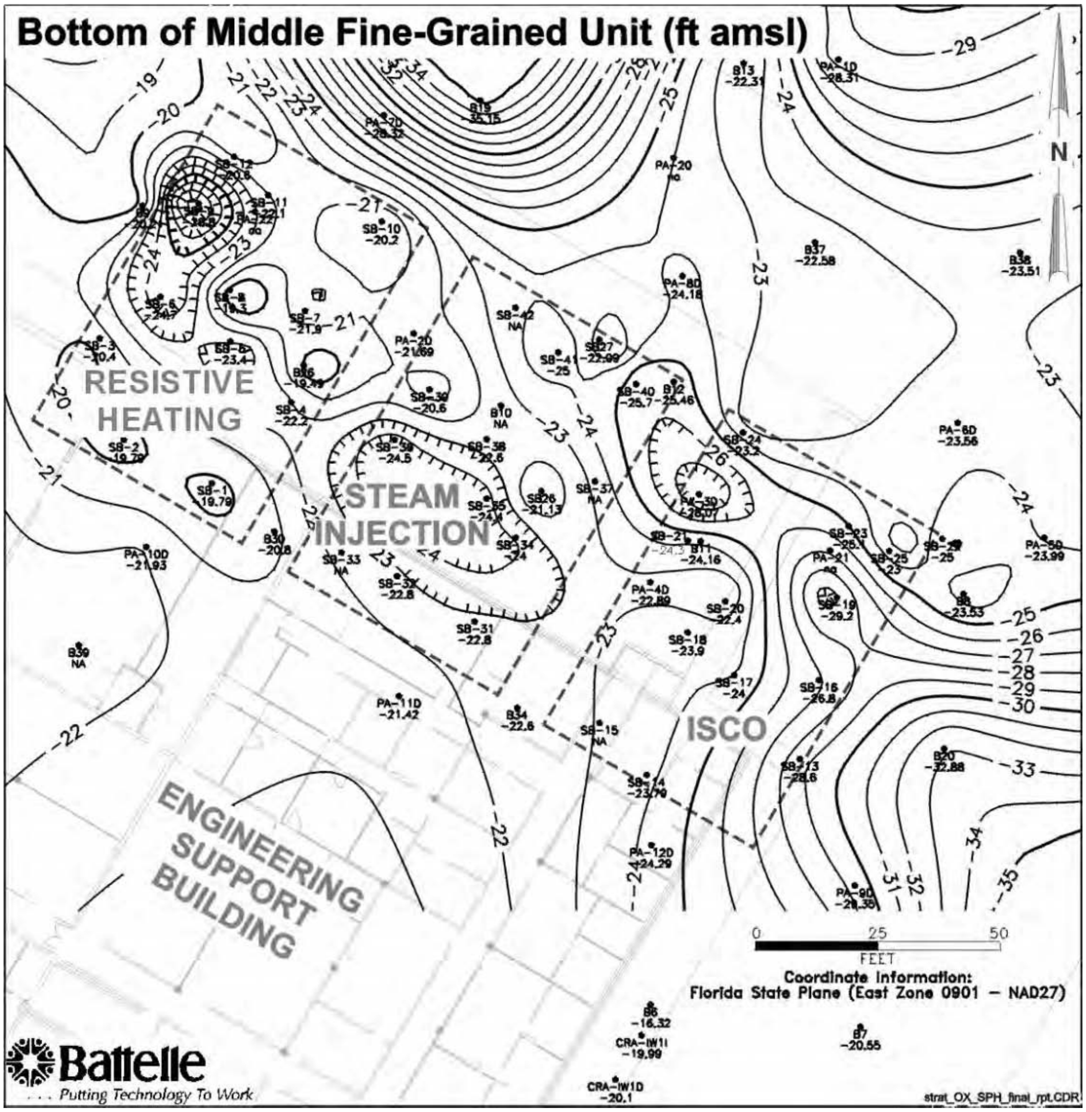

Figure 2-4. Topography of Bottom of Middle Fine-Grained Unit

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, pre-demonstration 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). Ground-water 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 intermediate well screens include portions of the Upper Sand Unit. The hydraulic conductivity of the

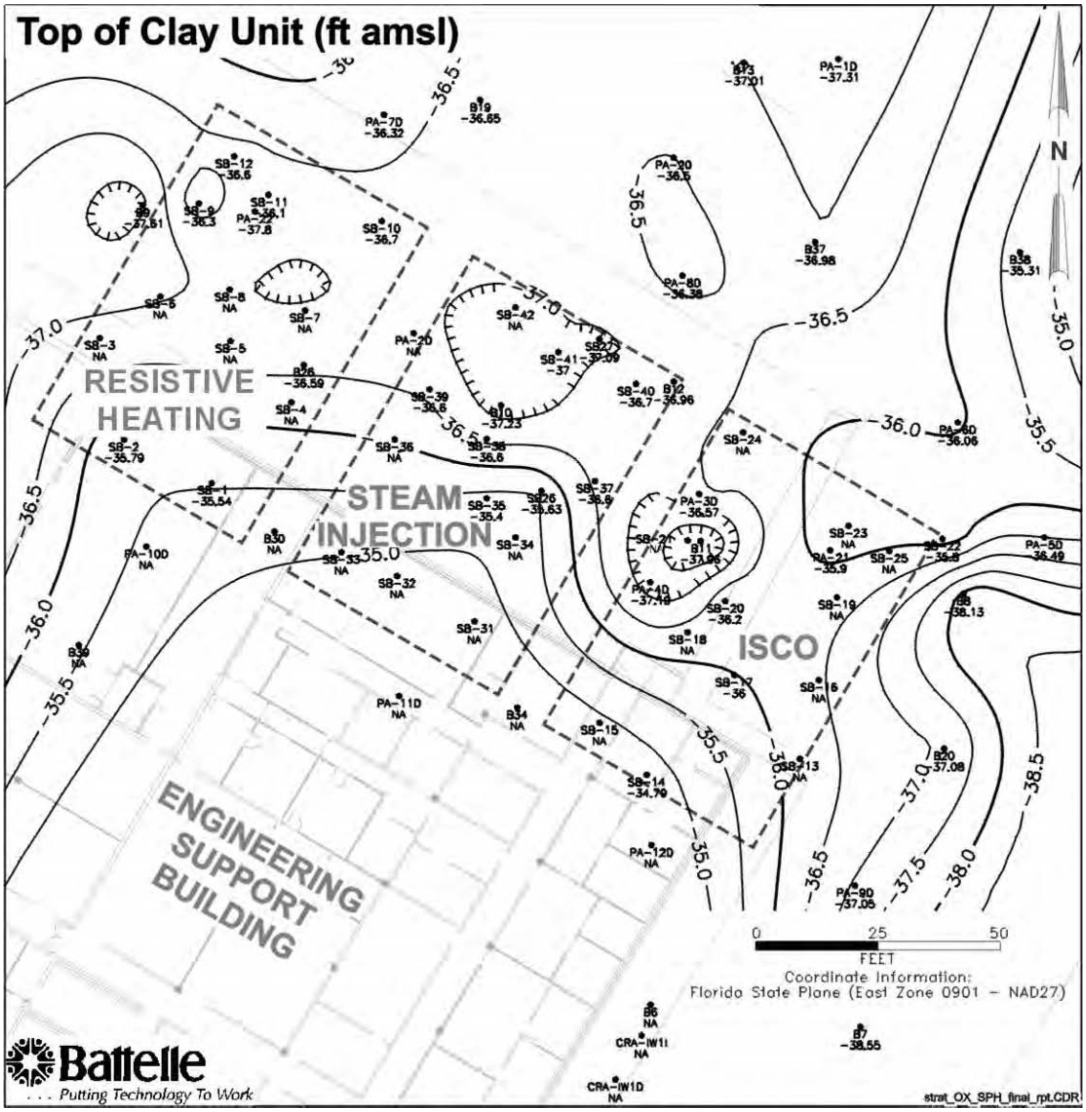

Figure 2-5. Topography of Top of Lower Clay Unit

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). Ground-water 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-level 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 are well above the semi-confining unit, indicating that the aquifer is semi-confined. The gradient in the semi-confined 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 confined aquifer 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.

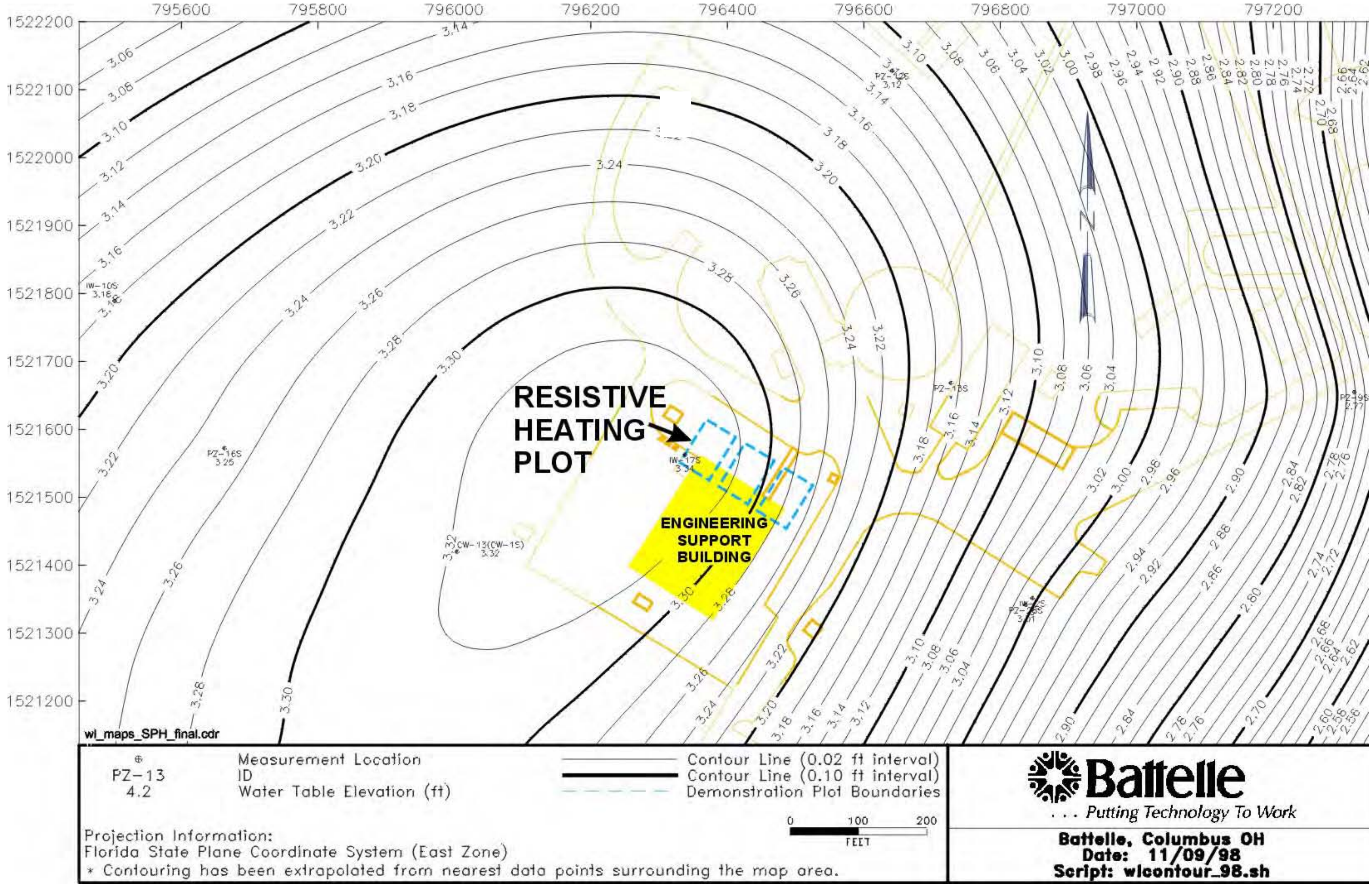

Figure 2-6. Water Table Elevation Map for Surficial Aquifer from June 1998

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

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

2.3 TCE-DNAPL Contamination in the Resistive Heating Plot and Vicinity

Figures 2-10 to 2-12 show representative pre-demonstration distributions of dissolved TCE, the primary contaminant at Launch Complex 34, in the shallow,

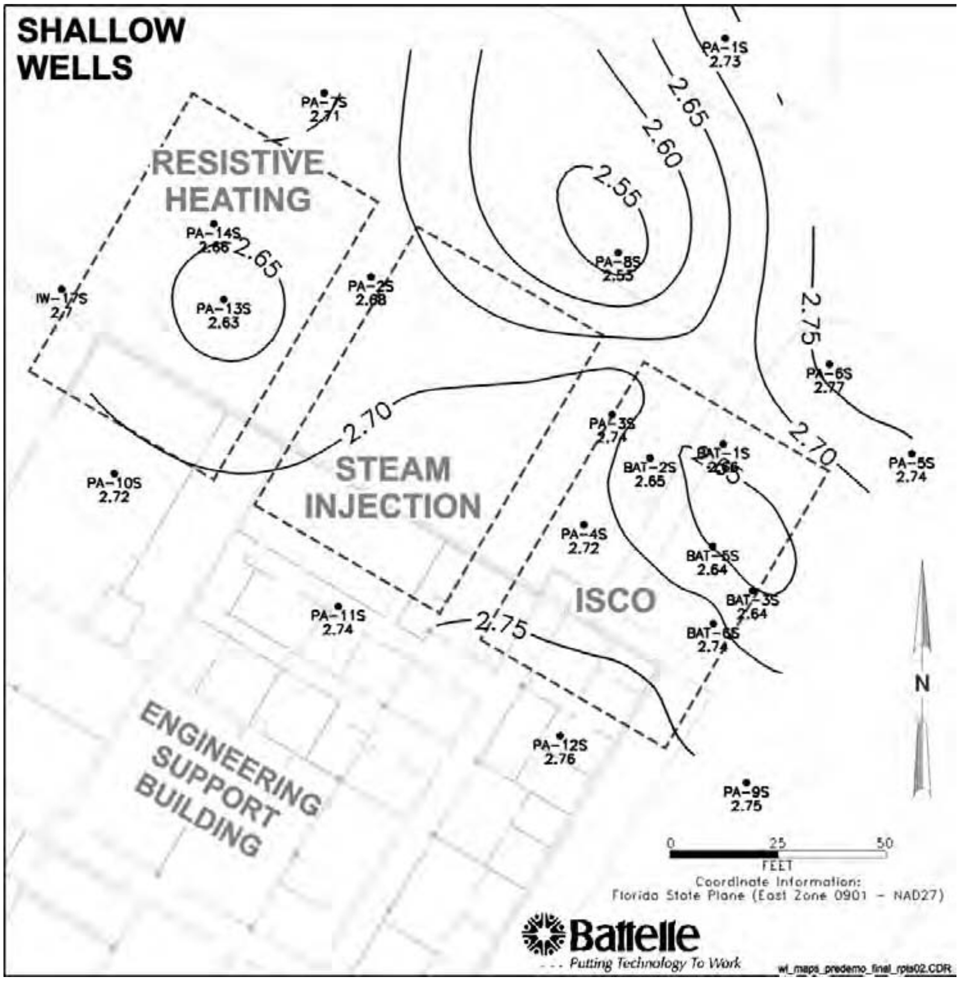

Figure 2-7. Pre-Demonstration Water Levels (as Elevations msl) in Shallow Wells at Launch Complex 34 (September 1999)

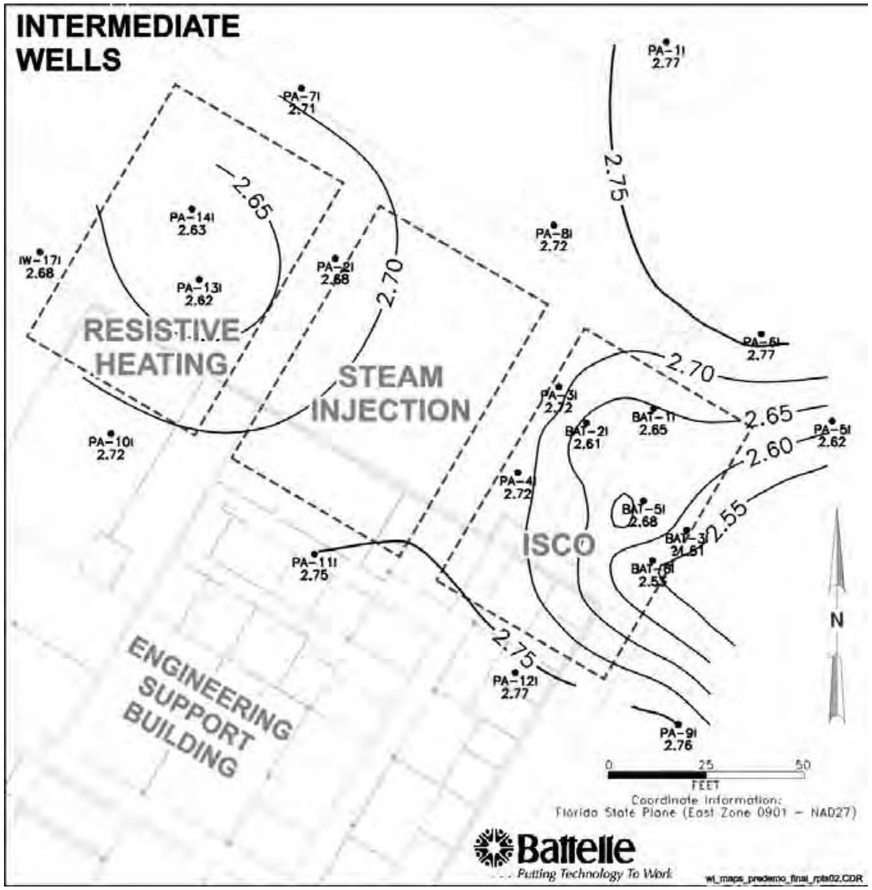

Figure 2-8. Pre-Demonstration Water Levels (as Elevations msl) in Intermediate Wells at Launch Complex 34 (September 1999)

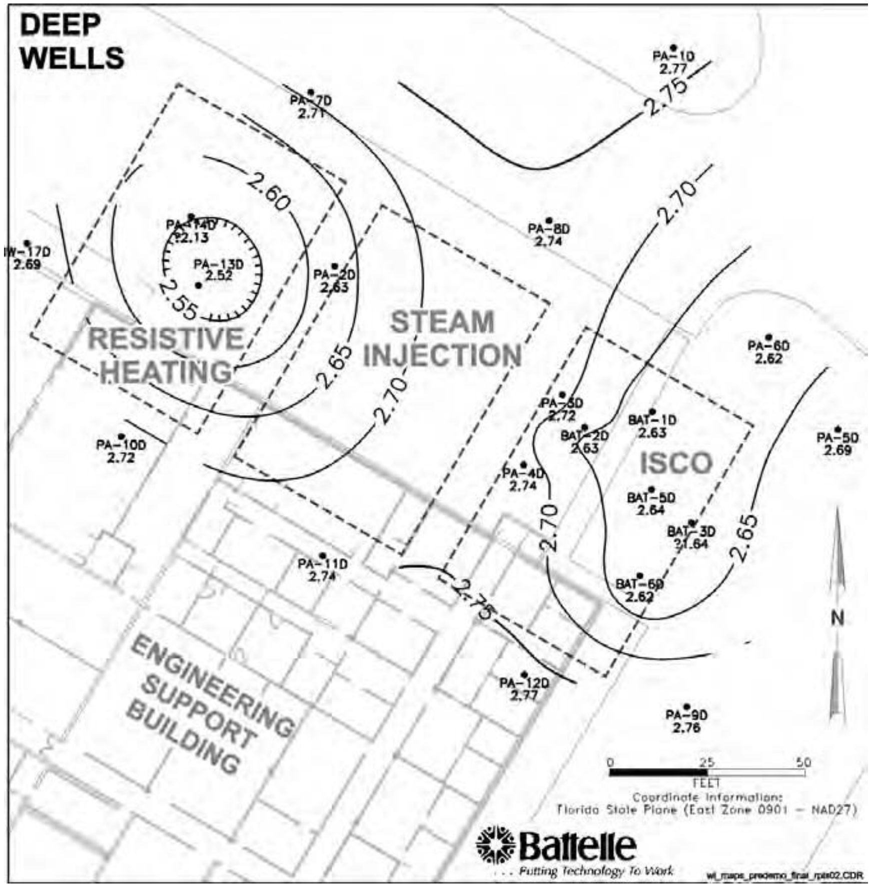

Figure 2-9. Pre-Demonstration Water Levels (as Elevations msl) in Deep Wells at Launch Complex 34 (September 1999)

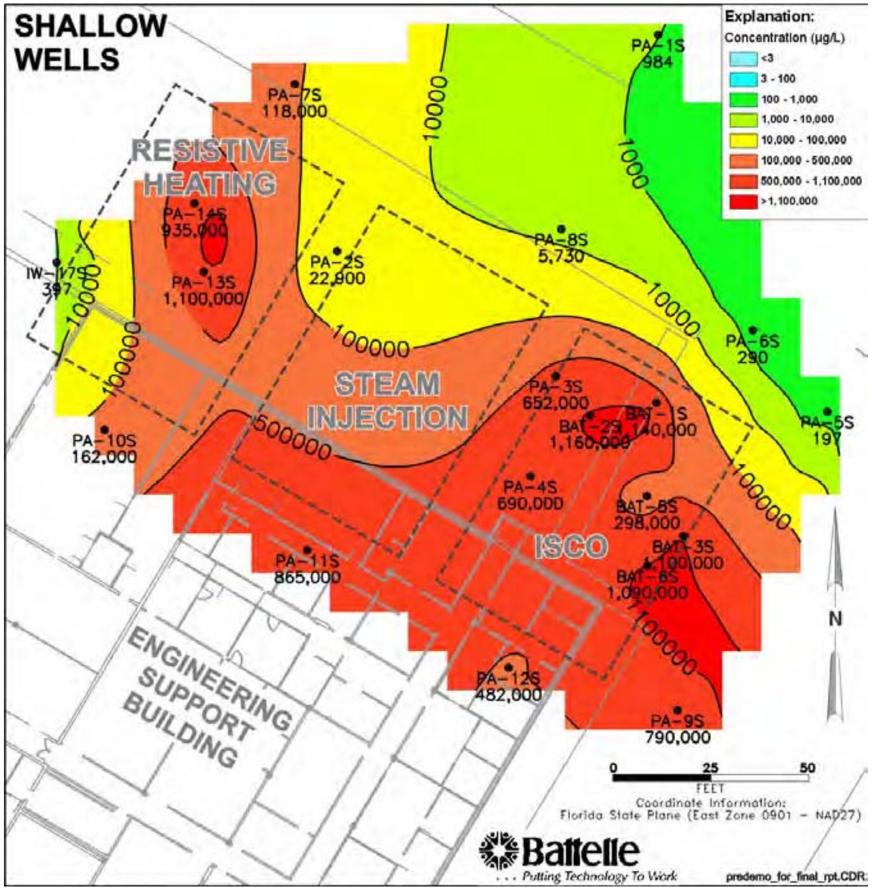

Figure 2-10. Pre-Demonstration Dissolved TCE Concentrations (µg/L) in Shallow Wells at Launch Complex 34 (September 1999)

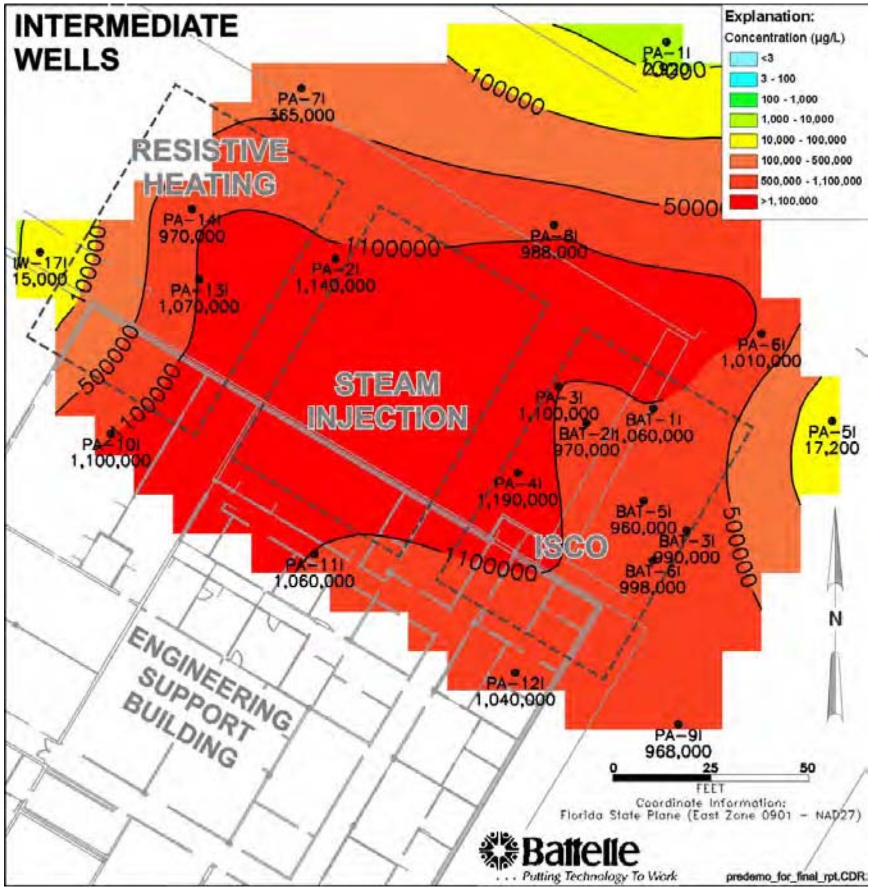

Figure 2-11. Pre-Demonstration Dissolved TCE Concentrations (µg/L) in Intermediate Wells at Launch Complex 34 (September 1999)

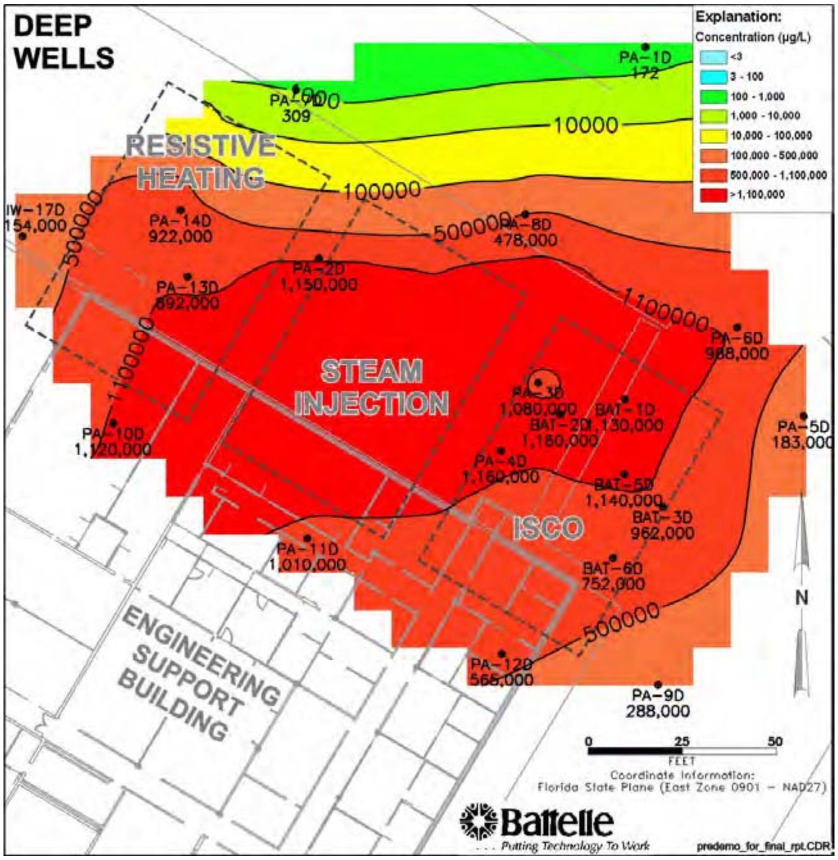

Figure 2-12. Pre-Demonstration Dissolved TCE Concentrations (µg/L) in Deep Wells at Launch Complex 34 (September 1999)

intermediate, and deep wells (Battelle, 1999c). No free-phase solvent was visible in any of the wells during the pre-demonstration sampling; however, ground-water analysis in many wells showed 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. Ground-water 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 pre-demonstration horizontal distributions of TCE in soil from the Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit (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.

The pre-demonstration soil sampling indicated that approximately 11,313 kg of total TCE was present in the resistive heating plot before the demonstration (Battelle, 1999c). Approximately 10,490 kg of this TCE may occur as DNAPL, based on a threshold TCE concentration of about 300 mg/kg in the soil. This threshold has been 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)].

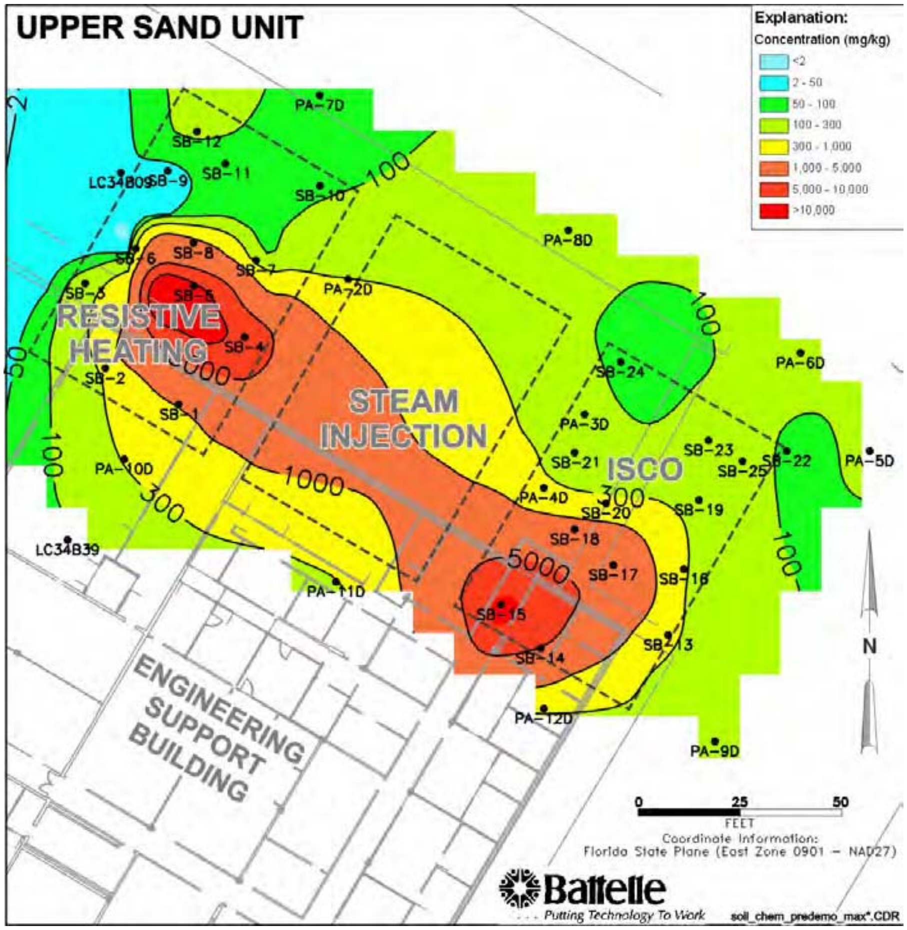

Figure 2-13. Pre-Demonstration TCE Concentrations (mg/kg) in the Upper Sand Unit [–15±2.5 ft msl] Soil at Launch Complex 34 (September 1999)

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 threshold 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 the least to greatest presence of DNAPL, respectively. 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 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 5.1.2 contains a more detailed description of the TCE-DNAPL mass estimation procedures for the resistive heating 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 pre-demonstration ground-water analysis. Pre-demonstration ground-water 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 6.9 to 7.5. Dissolved oxygen (DO) levels were measured with a flowthrough cell, and were mostly less than 1 mg/L in the deep wells, indicating that the aquifer was anaerobic, especially at greater depths. Oxidation-reduction potential (ORP) from all the sampled wells ranged from –142 to –74 millivolts (mV). Total organic carbon (TOC) concentrations ranged from 6 to 40 mg/L in water samples and from 0.9 to 1.7% in soil samples; much of this TOC is probably TCE-DNAPL, as the samples were collected from the DNAPL source region. Biological oxygen demand (BOD) ranged from <3 to 20 mg/L in ground water.

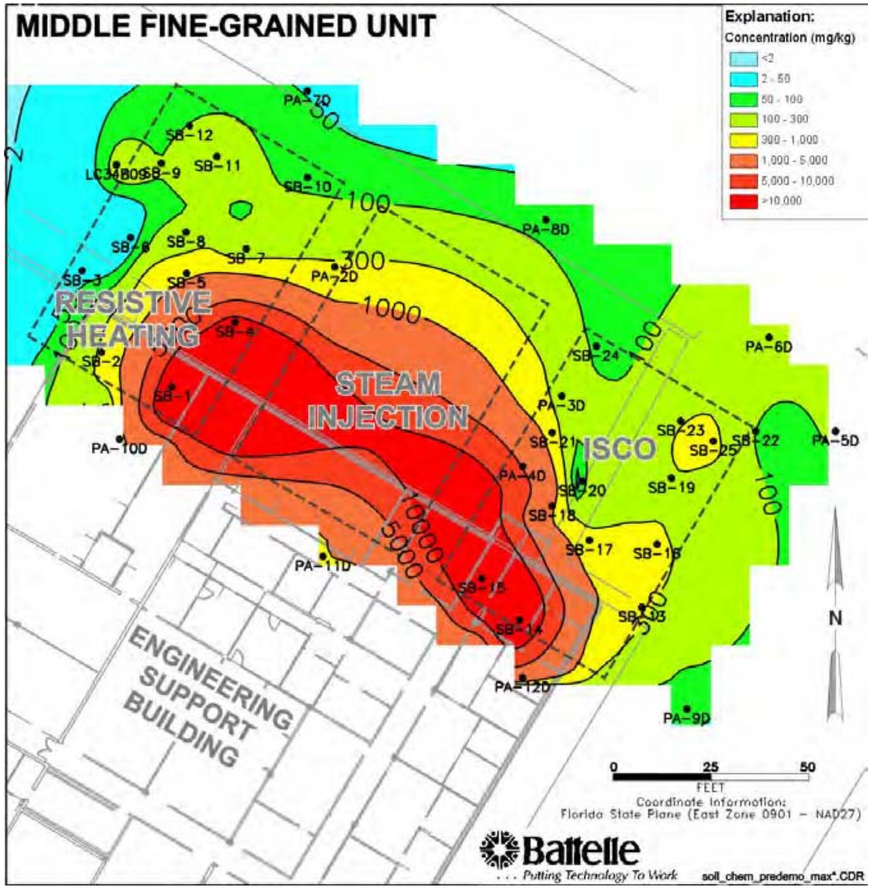

Figure 2-14. Pre-Demonstration TCE Concentrations (mg/kg) in the Middle Fine-Grained Unit [-20±2.5 ft msl] Soil at Launch Complex 34 (September 1999)

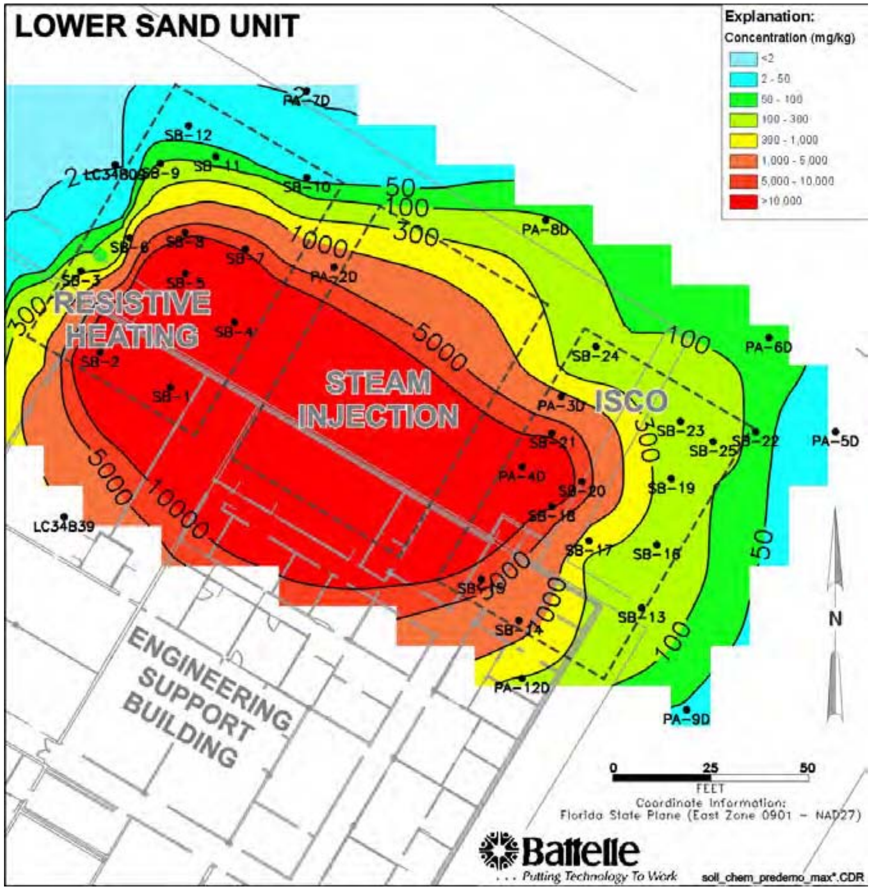

Figure 2-15. Pre-Demonstration TCE Concentrations (mg/kg) in the Lower Sand Unit [–35 ±2.5 ft msl] Soil at Launch Complex 34 (September 1999)

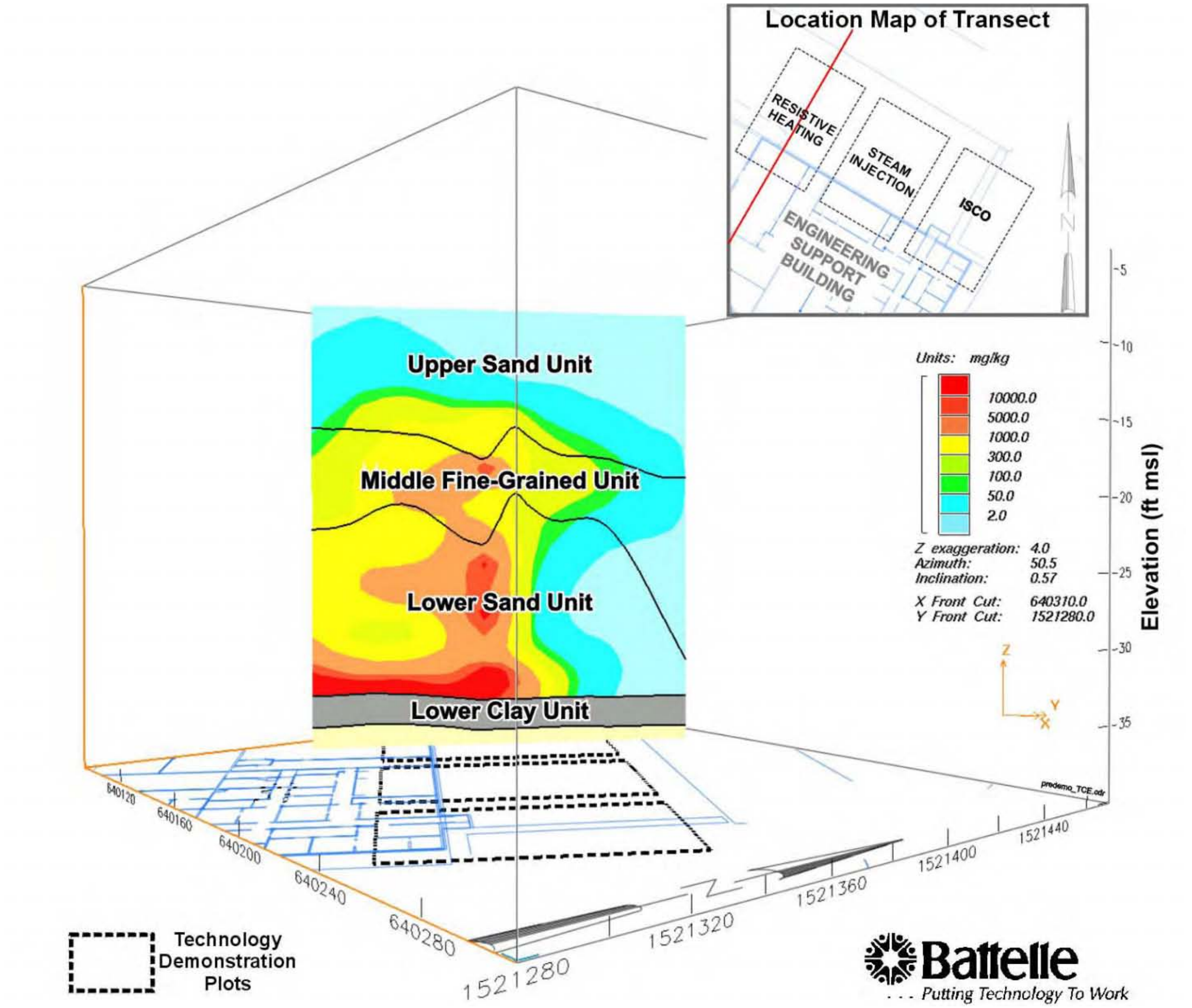

Figure 2-16. Vertical Cross Section through Resistive Heating Plot Showing TCE Concentrations (mg/kg) in the Subsurface

Inorganic ground-water parameters were tested in August 1999 in select wells to determine the pre-demonstration quality of the ground water in the target area (Battelle, 1999c). Inorganic parameters in the ground water 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 548 to 1,980 mg/L. Chloride concentrations ranged from 11 to 774 mg/L and increased sharply with depth, indicating some saltwater intrusion in the deeper layers. These high levels of native chloride made a chloride mass balance (a possible indicator of TCE degradation) difficult during the performance assessment. Sodium, another major seawater constituent, ranged from 17 to 369 mg/L and also increased sharply with depth.
- Alkalinity levels ranged from 337 to 479 mg/L and showed little trend with depth or distance.
- Iron concentrations ranged from <0.05 to 11 mg/L in the ground water, and manganese concentrations ranged from <0.015 to 1.1 mg/L with little vertical or lateral trend.

- Calcium concentrations ranged from 60 to 143 mg/L and magnesium concentrations ranged from 23 to 113 mg/L. Both parameters appeared to increase slightly with depth.
- Sulfate concentrations were between 39 and 104 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 pre-demonstration and post-demonstration aquifer in the resistive heating plot under a Work Plan prepared by Battelle and Lawrence Berkeley National Laboratory (Battelle, 2000d). The approach and preliminary results of this study are presented in Appendix E.

3. Technology Operation

This section describes how the resistive heating technology was implemented at Launch Complex 34.

3.1 Resistive Heating Concept

As described in Figure 1-3 and Section 1.3, the resistive heating technology uses a strong voltage (of the order of 500 kW or more) to generate resistive heating of subsurface soils. Volatile and semivolatile contaminants are removed from the subsurface by a combination of direct volatilization and steam stripping. A surface plenum and/or vadose zone piping are used to extract the vaporized contaminants and steam to the ground surface, where they are condensed and treated. Part of the vadose zone is heated by the rising steam and this prevents recondensation of the contaminant vapors.

The aboveground system typically consists of a water-cooled condenser and activated carbon. The off-gas from the carbon is discharged to the atmosphere. The condensate may be treated on site or disposed off site. The condensate and spent carbon typically are the wastestreams generated by resistive heating treatment. Recent reports have also claimed that organic contaminants degrade in situ due to heat-accelerated abiotic and/or biotic processes. Abiotic processes may include hydrolysis and/or oxidation.

3.2 Application of Resistive Heating at Launch Complex 34

In the IDC demonstration, resistive heating was used for heating a DNAPL source zone consisting primarily of TCE. Lesser amounts of dissolved *cis*-1,2-DCE were also present in the aquifer at Launch Complex 34, the site of the demonstration. 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 resistive heating technology is shown in Figure 3-1 and is referred to as the resistive heating 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 was conducted after completing the resistive heating and ISCO demonstrations.

In their draft-final report (CES, 2001) on the IDC demonstration, the vendor has provided a detailed description of their resistive heating equipment, application methodology, and process measurements. A summary description of the resistive heating process implemented by the vendor at Launch Complex 34 follows in this section. Table 3-1 includes a chronology of events constituting the resistive heating demonstration. The field application of the technology was conducted over a period of 11 months from August 1999 to July 2000. The vendor experienced some periods of downtime. An unexpected interruption occurred from September 30 to December 12 after two hurricanes damaged the power supply. Also, changing the power supply caused an additional interruption in early 2000.

3.2.1 Resistive Heating Equipment and Setup at Launch Complex 34

Figure 3-2 is a photo of the resistive heating system installed at Launch Complex 34. As shown in the equipment layout in Figure 3-3, the resistive heating system at Launch Complex 34 used 13 electrodes. Three of the electrodes that were near the Engineering Support Building were installed at an angle of 18 degrees to provide heat to the 15 ft of test plot that lies under the building. To protect the thin aquitard, the electrodes were completed slightly above the Lower Clay Unit. Each electrode consisted of two conductive intervals—one from 23 to 30 ft bgs (in the Upper Sand Unit) and the other from 38 to 45 ft bgs (in the Lower Sand Unit). The lower heating interval was configured to provide a “hot floor” for the treated aquifer and to mitigate the potential for downward migration of DNAPL. The upper conductive interval was configured to provide heat to the Upper Sand Unit and the Middle Fine-Grained Unit.

Twelve soil vapor extraction (SVE) wells were installed with 2-ft screens to depths of 4 to 6 ft bgs to recover the

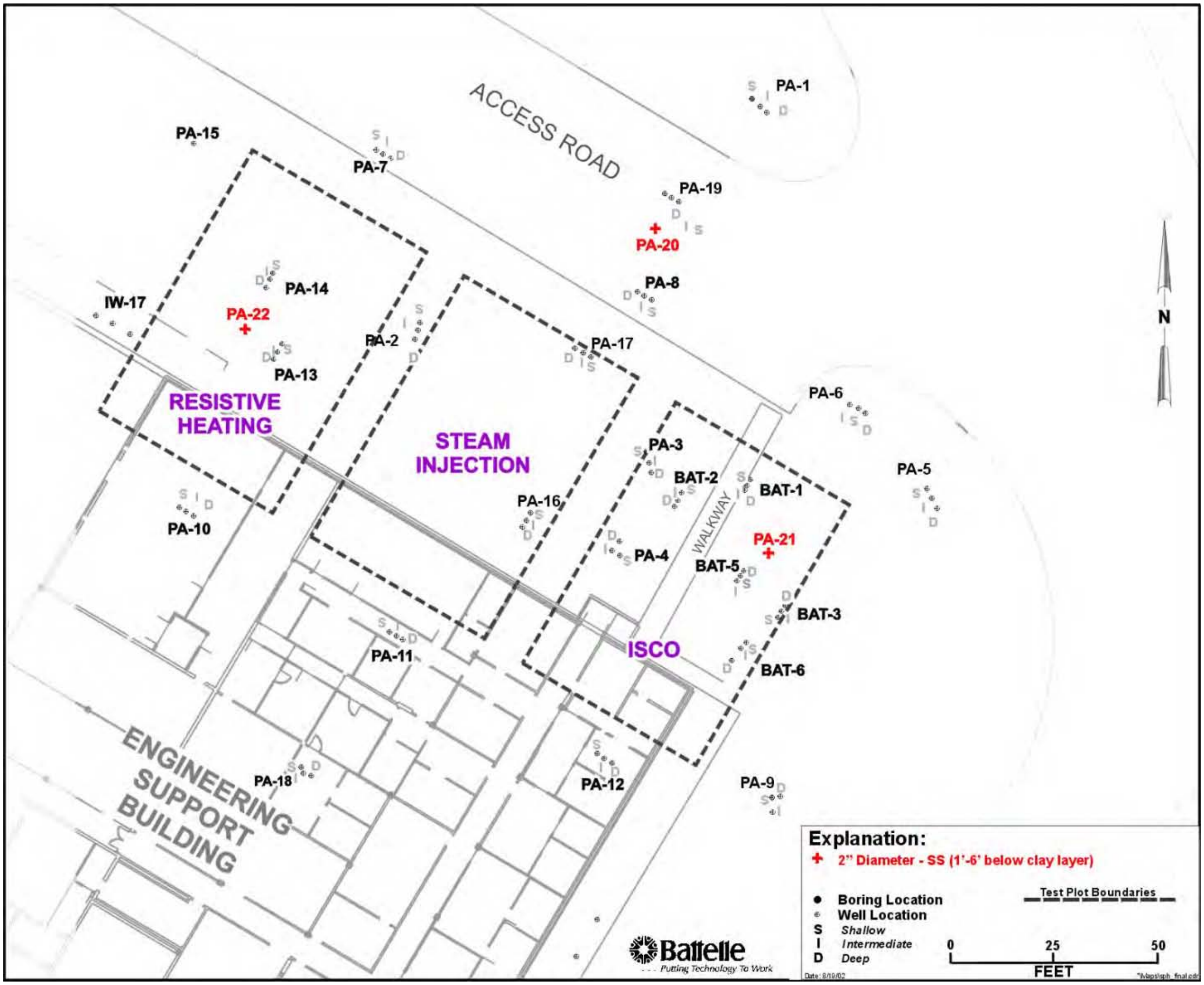

Figure 3-1. Resistive Heating Plot and Monitoring Well Layout for Performance Assessment

vapors. The extracted vapor and steam were passed through an air-water knockout drum, a heat exchanger, a condensate collection drum, and a centrifugal blower. The off-gas from the blower was treated by a 20,000-lb vessel of granular activated carbon (GAC). Additional treatment of the off-gas to remove vinyl chloride was accomplished by a 1,000-lb vapor-phase GAC vessel, followed by an 800-lb silica polish bed impregnated with potassium permanganate. The steam condensate was pumped through a 1,000-lb liquid-phase GAC vessel to a cooling tower, where it was evaporated to provide cooling for the heat exchange process. Excess condensate was transferred to a 6,500-gal storage tank.

At the end of the demonstration, the stored condensate was analyzed and transported to the on-site wastewater treatment facility. The GAC was analyzed and shipped to an off-site facility for regeneration. The permanganate-impregnated silica was disposed of in a landfill.

3.2.2 Resistive Heating Field Operation

The vendor prepared and submitted a draft-final report (CES, 2001) describing the details of the resistive heating system setup and operation at Launch Complex 34. This section summarizes the resistive heating operation described in this report and observed during the demonstration. As shown in Table 3-1, the resistive heating heat application began on August 18, 1999 and continued until July 12, 2000, with two major breaks in between. The SVE system was operated for two more

Table 3-1. Timeline for Resistive Heating Technology Demonstration

Start Date	End Date	Number of Days	Events/Heat Application Stage	Energy Applied during this Time Period (kW-hrs)	Temperature (°C) at Top/Bottom of Aquifer at the start of time period	Temperature (°C) at Top/Bottom of Aquifer at the end of time period	Comments
	6/18/98		Solicitation received from IDC	—	—	—	
			Design/modeling/ treatability tests	—	—	—	
	7/1/99		IDC approval to proceed	—	—	—	
7/29/99 6/3/99	8/17/99		Mobilization to site and setup	—	—	—	
4/1/00	6/25/00	90	Test Plan/Quality Assurance Project Plan (QAPP)	—	—	—	
6/21/00	7/17/00	27	Pre-demonstration characterization of resistive heating plot	—	—	—	
8/18/00	9/30/00	43	First heat application	216,915	30/24	47/92	
9/30/99	12/12/99	77	Break	—	—	—	Hurricane damaged step-down transformer in power supply/TCE concentration in ditch adjacent to treatment cell
12/12/99	3/24/00	98	Second heat application	821,100	39/75	100/124	2/28-3/2. Upgrade electrodes to enhance power input.
3/24/00	5/11/00	48	Break	—	—	—	Heating near septic tank/ power supply replacement/ delay resulting from rocket launches
5/11/00	7/12/00	62	Third heat application	687,800	60/82	100/124	
7/12/00	9/19/00	79	Heating off, vapor recovery system on	—	—	—	To evacuate any TCE vapors generated while the aquifer is at elevated temperature
8/1/00	12/31/00	120	Post-demonstration characterization	—	—	—	

Figure 3-2. Resistive Heating System in Operation at Launch Complex 34

months until September 19, 2000 so that continuing vapors from the still hot aquifer could be recovered. Over the course of the demonstration, a total of 1,725,000 kW-hrs of energy was applied to the subsurface. The applied voltage ranged from 100 to 500 V, which resulted in an electrical current of 10 to 400 amps.

At this site, the vendor used a novel electrode design consisting of an electrical cable attached to a ground rod within a graphite backfill, instead of the traditional pipe electrode. However, this new design, coupled with excessive rainfall and a rising water table, resulted in insufficient heating in the shallow portion of the Upper Sand Unit. Therefore, between February 24 and March 2, 2000, the vendor installed ground rods near each electrode to heat the 3- to 10-ft-bgs ground interval.

The first major interruption of the resistive heating operation occurred between September 30 and December 12, 1999. On September 10 a major hurricane (Hurricane Floyd) hit Cape Canaveral, followed by a second hurricane (Hurricane Irene) on October 17, 1999. The power supply was damaged and the water table rose significantly, from about 6 ft bgs before the demonstration to almost 1.5 ft bgs in monitoring well PA-2. In low-lying areas of the test plot, the ground water was probably near the ground surface. Elevated TCE levels discovered in ponded surface water in a ditch along the west side of the resistive heating plot indicate that some TCE migrated from the plot during this period. It is probable that infiltration of cooler rainwater from the storms caused the rising TCE vapors to condense near the ground surface. Typically, the buoyancy of the hot water generated in the plot leads to a convection cycle, in which hot water builds up near the water table and migrates sideways out of the plot. This loss of water is made up by cooler water entering from the bottom of the test plot, near the aquitard. During the hurricanes and the consequent high rainfall events, the hot ground water laden with TCE near the water table possibly migrated westward from the plot along the surface topographic gradient. In addition, the rising water table submerged the SVE wells, rendering them useless; it is possible that some TCE volatilized to the atmosphere during this time.

In October 1999, the vendor modified the design during the demonstration and installed six horizontal wells in the northern half of the cell and seven shallow vertical wells in the southern half of the cell near the building. In addition, a surface cover (plenum) was placed over the plot to improve vapor capture. In November 1999 the plenum was expanded and two additional horizontal wells were installed. The plenum was expanded again in March 2000 on the west side of the plot, after surface emission tests and dried vegetation indicated that hot vapors were probably reaching the ground surface there. In October 1999, the vendor also installed a drainage diversion system consisting of a sandbag cutoff wall on the east side of the plot and a sump pump to divert the water through a PVC pipe to the drainage collection area in the west. Also, PVC risers on the six monitoring wells inside the plot were beginning to melt down because of the heat conducted by the stainless steel wells below. These risers were removed and replaced with stainless steel risers. During the repair, surrounding aquifer materials got into well casings of performance monitoring wells (PA-13 and PA-14). The monitoring wells had to be cleaned out later by surge-and-purge to pump out the sediments inside the well casings. Due to these modifications and the repairs resulting from the hurricanes, the resistive heating system was operated only for six weeks during the first heating cycle. The second heating cycle started on December 12, 1999, and continued for 13 weeks.

On March 24, 2000, operations were interrupted to replace the transformer, a major piece of equipment, on which the lease had run out. A replacement transformer was obtained and installed in April, but the third heating cycle could begin only on May 11, 2000 due to an unusually heavy space shuttle launch schedule that necessitated work stoppages. The third heating cycle continued for eight weeks until July 12, 2000, when the IDC determined that VOC extraction rates had declined significantly. The SVE system remained operational until September 19, 2000, by which time subsurface temperatures had fallen below 95°C, indicating that steaming had stopped.

During the demonstration, the vendor monitored VOC levels and flowrate of the extracted vapor stream. The

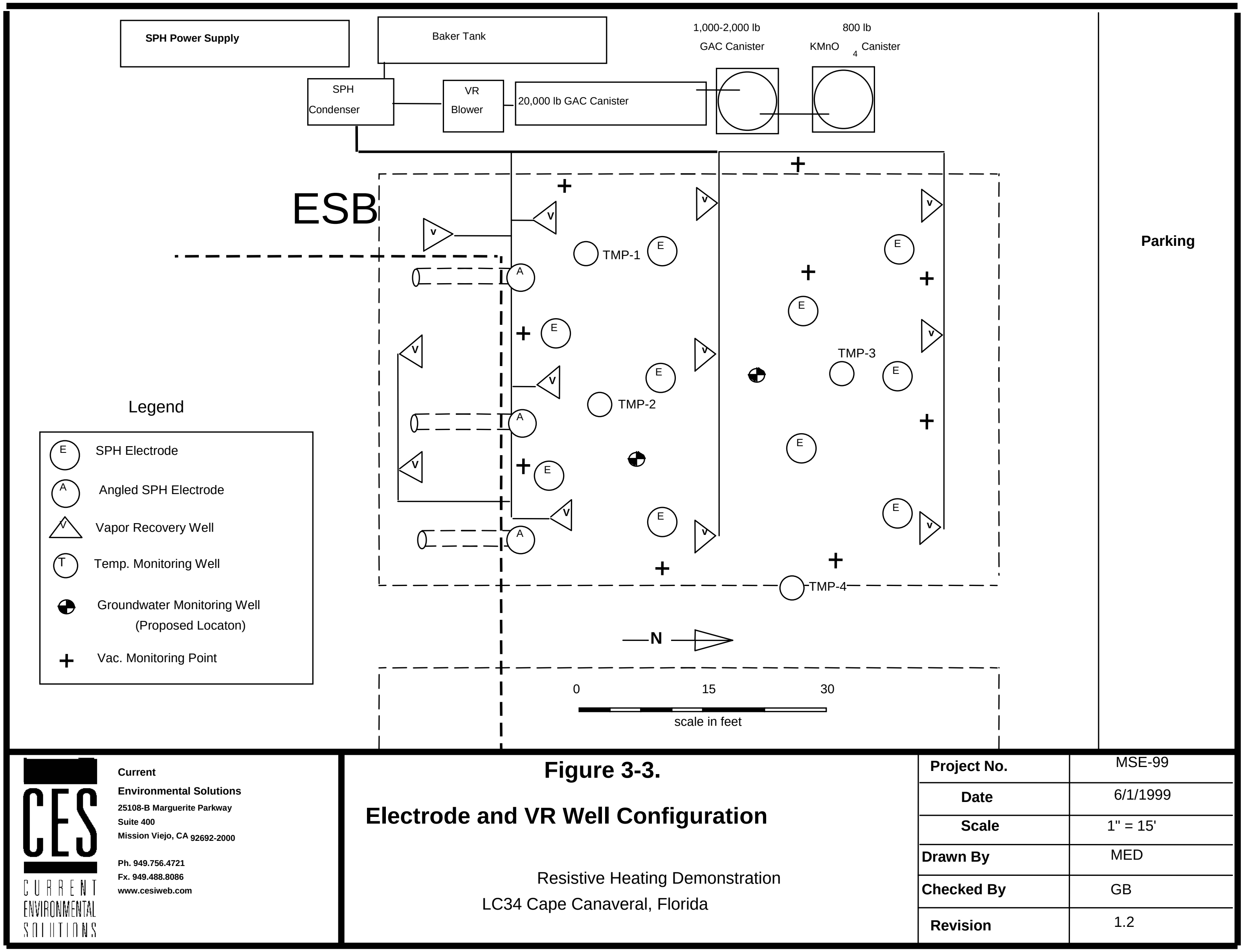

Figure 3-3. Resistive Heating System Layout at Launch Complex 34

vendor also monitored temperatures in the plot through the four thermocouple bundles (TMP-1 through TMP-4, shown in Figure 3-3). This monitoring was separate from the performance assessment conducted by Battelle and was done primarily to make operational decisions.

3.2.3 Health and Safety Issues

A major initial concern with the resistive heating technology was the high voltage (up to 500 V) required to be delivered to the subsurface. Despite all the difficulties involving hurricanes and flooding of the plot, the vendor successfully controlled the transport and distribution of the large amounts of electricity involved. At all times, the ground surface was insulated from the electric current running through the aquifer. The ground surface above the resistive heating plot was available for other activities during the voltage applications. This successful management of the high voltage application is probably the most important safety achievement of the demonstration.

The voltage application was turned off whenever monitoring wells were sampled inside the test plot and all sampling events were conducted safely. Because the monitoring well screens were completely submerged under the water table, there was steam pressure buildup in the monitoring wells. It was agreed that the initial procedure was to open the well caps slowly to release any pressure. Sampling personnel wore heat-resistant gloves and face shields when opening the wells.

However, on one occasion, a jet of steam rose from the wellhead and continued for several seconds. Subsequently, a pressure gauge and pressure release valve were installed on each monitoring well inside the plot and along the perimeter. This seemed to help; but there were times when, despite releasing the pressure in the wells until the pressure gauge showed zero, steam still came rushing out in a jet above the well during sampling. There were no injuries, as sampling personnel were alert to the sounds of steam welling up in the well; however, monitoring the inside of the hot treated plot continued to be a necessary, but difficult task.

System operators and sampling personnel wore Level D personal protective equipment at the site. Heavy equipment movement during mobilization and demobilization and handling of hot fluids were hazards that were recognized in the Health and Safety Plan prepared at the beginning of the demonstration. No injuries were encountered 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 resistive heating 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 change in TCE-DNAPL mass
- Evaluating changes in aquifer quality due to the treatment
- Evaluating the fate of TCE-DNAPL removed from the resistive heating plot
- Verifying resistive heating 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 methodology used to achieve them.

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

4.1 Estimating the Change in TCE-DNAPL Mass in the Plot

The primary objective of the performance assessment was to estimate the change in mass 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. Soil sampling in the resistive heating plot before and after the demonstration was the method used for estimating TCE-DNAPL mass changes.

At the outset of the demonstration, the Technical Advisory Group proposed 90% DNAPL mass removal as a target for the three remediation 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 change in TCE-DNAPL mass at this site. Previous soil coring, sampling, and analysis at Launch Complex 34 (Battelle, 1999b; Eddy-Dilek et al., 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 resistive heating 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.

The primary focus of the performance assessment was on TCE, *cis*-1,2-DCE and vinyl chloride in the soil samples. However, high TCE 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 resistive heating plot is described in Appendix A.1. Based on the horizontal and vertical

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

Objective	Measurements	Sampling Locations[(a)]
Estimating TCE-DNAPL mass removal	CVOCs in soil; before and after treatment	12 spatial locations, every 2-ft depth interval
Evaluating changes in aquifer quality	CVOCs in ground water; before, during, and after treatment	Primary well clusters PA-13 and PA-14
	Field parameters in ground water; before, during, and after treatment	Primary well clusters PA-13 and PA-14; perimeter wells[(b)] for verifying spread
	Inorganic parameters in ground water (cations, anions, including alkalinity); before and after treatment	Primary well clusters PA-13 and PA-14; 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	Primary well clusters PA-13 and PA-14
	Hydraulic conductivity; before and after treatment	Primary well clusters PA-13 and PA-14
Evaluating fate of TCE-DNAPL	Chloride in ground water	Primarily well clusters PA-13 and PA-14 in the plot; perimeter wells[(b)]
	Inorganics in ground water	Primary well clusters PA-13 and PA-14
	Hydraulic gradients	All wells
	CVOCs in soil surrounding the plot; before and after treatment	Fourteen locations outside the resistive heating plot (See Figure 4-3)
	CVOCs and inorganics in soil and ground water in the confined aquifer	Wells PA-20, PA-21, and PA-22
	Surface emissions; primarily during oxidant injection	Three locations inside plot or around the plenum; 3 background locations
Verify 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 resistive heating plot are shown in Figure 3-1. Soil coring locations are shown in Figures 4-2 (pre-demonstration) and 4-3 (post-demonstration).

(b) Perimeter wells are PA-2, PA-10, IW-17, PA-15, and PA-7. 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.

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-1 to SB-12 in Figure 4-2) as described in the QAPP (Battelle, 1999d). The resulting 12 cores provided good spatial coverage of the 75-ft × 50-ft resistive heating plot and included two cores inside the Engineering Support Building. For each soil core, the entire soil column from ground surface to aquitard was sampled and analyzed in 2-ft sections. Another set of 12 cores was similarly collected after the demonstration. The soil boring locations are shown as SB-201 to SB-212 in Figure 4-3. Each sampling event, therefore, consisted of nearly 300 soil samples (12 cores, 23 2-ft intervals per core, plus duplicates). The line of dashes in Figures 4-2 and 4-3 represents the pre-demonstration DNAPL source boundary. This boundary includes all the soil coring locations where at least one of the pre-demonstration soil samples (depth intervals) showed TCE levels above 300 mg/kg.

An additional 12 soil cores were collected outside the plot, towards the end of the resistive heating application, before the post-demonstration monitoring. The objective of these cores was to determine if there had been significant migration of TCE and DNAPL outside the resistive heating plot. These coring locations are also shown in Figure 4-3.

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 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

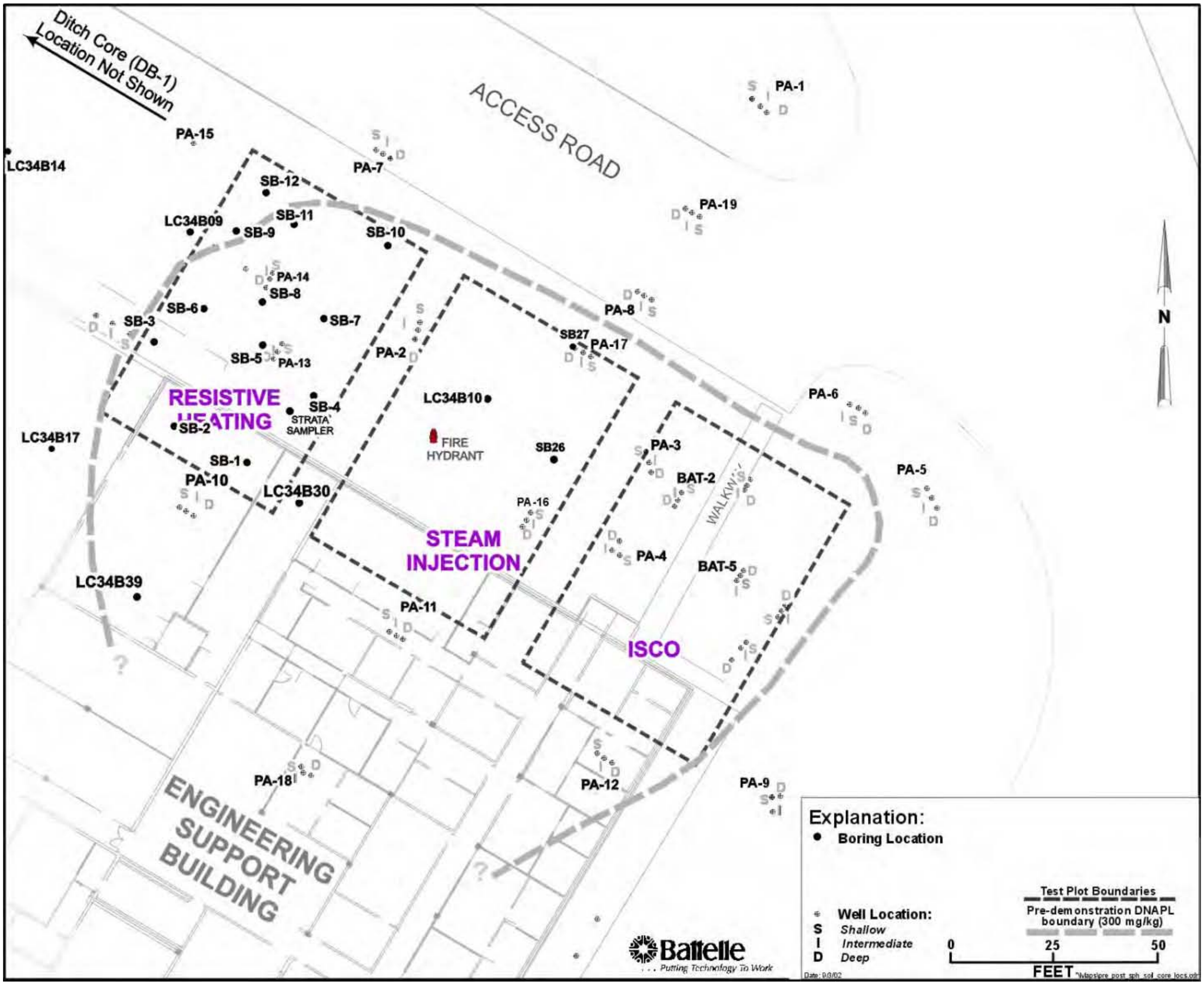

Figure 4-2. Pre-Demonstration Soil Coring Locations (SB-1 to SB-12) in Resistive Heating Plot (June 1999)

was greater than the horizontal variability, and this sampling and extraction method allowed continuous vertical coverage of the soil column.

One challenge during post-demonstration soil coring in the resistive heating plot was handling hot cores. The following steps were taken to minimize CVOC losses due to volatilization:

- Post-demonstration coring was delayed until all parts of the plot were below 90°C and steaming had stopped.
- As soon as the soil core barrel was withdrawn, both ends were capped and the barrel was dipped in an ice bath until the core had cooled to ambient temperature. The core barrel was kept in the ice bath long enough to cool the cores without breaking the seals at the capped ends (due to contraction of the barrel metals).

The efficiency of TCE recovery by this soil core processing method (modified EPA Method 5035; see Appendix A.2) was evaluated through a series of surrogate spike 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. The surrogate was spiked into separate soil cores both before and after

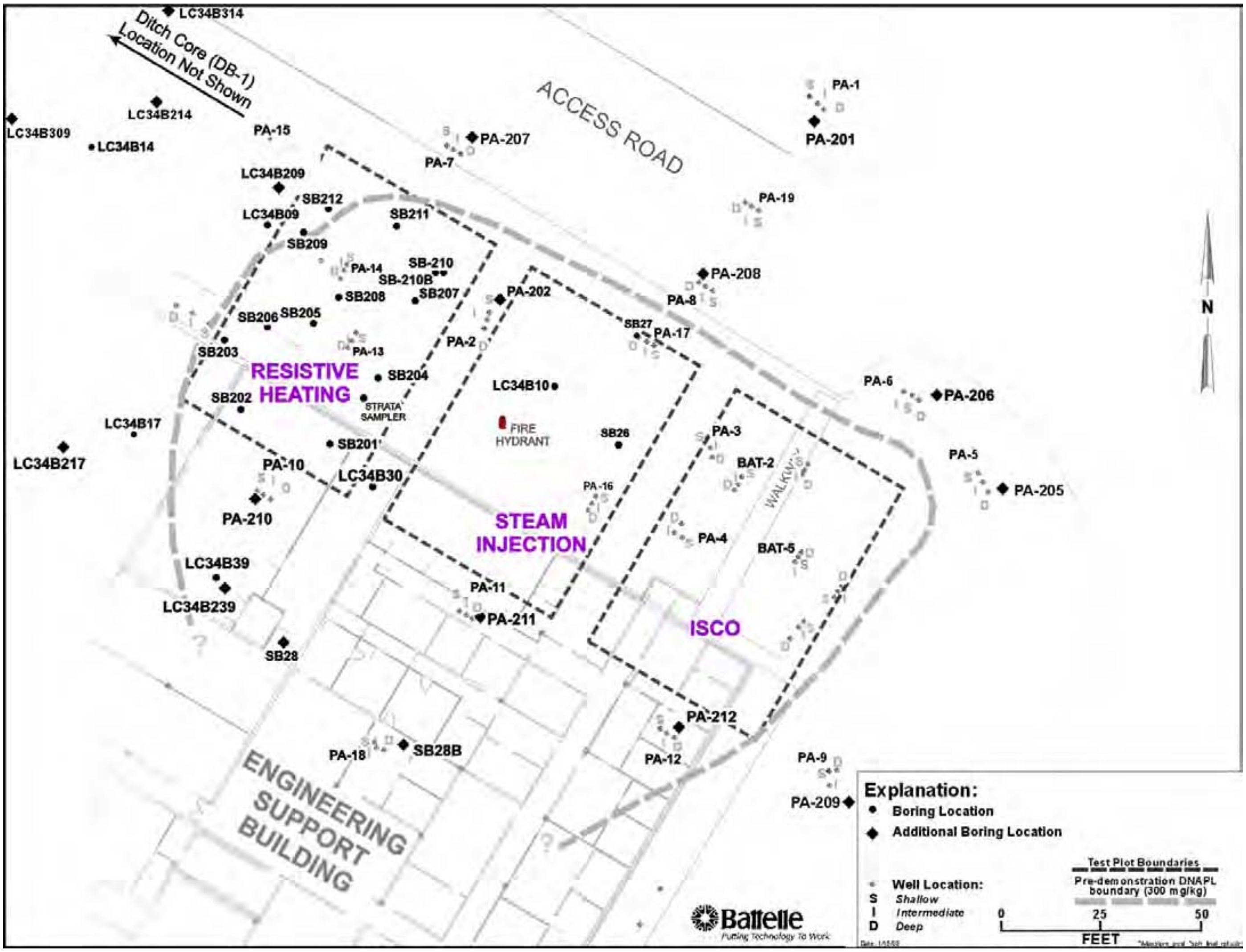

Figure 4-3. Post-Demonstration Soil Coring Locations (SB-201 to SB-212) in Resisitve Heating Plot (December 2000); Additional Soil Coring Locations Around Resistive Heating Plot (August-December 2000)

cooling to determine both the level of any volatilization losses from the core and the efficiency of extraction of the surrogate from the soil. 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 (see Section 6 on Quality Assurance).

Two data evaluation methods were used for estimating TCE-DNAPL mass removal in the resistive heating plot: linear interpolation (or contouring), and kriging. The spatial variability or spread of the TCE distribution in a DNAPL source zone typically is high, because 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 resistive heating 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).

4.1.1 Linear Interpolation

Linear interpolation (or contouring) is the most 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

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

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. Nearly 300 soil samples were collected from the 12 coring locations in the plot during each event (pre-demonstration and post-demonstration), which was the highest number practical for this project. Appendix A.1 describes how the number and distribution of these sampling points were determined to obtain good coverage of the plot. The contouring software EarthVision™ takes the same methodology that is used for plotting 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 isoconcentration shells. The TCE concentration in 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 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.

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

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 desirable at the beginning of the demonstration (Battelle, 1999d).

4.1.3 Interpreting the Results of the Two Mass Estimation Methods

The two 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 linear interpolation 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 because it takes into account the spatial correlations in the TCE distribution and the uncertainties (errors) 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 linear interpolation was able to overcome the spatial variability to a considerable extent and provide mass estimates that are close to 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. Resistive heating may affect both the contaminant and the native aquifer characteristics. Pre- and post-demonstration measurements conducted to evaluate the short-term impacts of the technology application on the aquifer included:

- CVOC measurements in the ground water inside the resistive heating plot
- Field parameter measurements in the ground water
- Inorganic measurements (common cations and anions) in the ground water
- Geochemical composition of the aquifer
- TDS, TOC, and 5-day BOD in the ground water
- 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 in the Test Plot

Another secondary objective was to evaluate the fate of the TCE in the plot due to the resistive heating application. Possible pathways (or processes) for the TCE removed from the plot include degradation (destruction of TCE) and migration from the resistive heating plot (to the surrounding regions). These pathways were evaluated by the following measurements:

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

- Chloride (mineralization of CVOCs leads to formation of chloride) and other inorganic constituents in ground water
- Hydraulic gradients (gradients indicative of ground-water movement)
- Potassium ion in the resistive heating plot and surrounding wells (potassium ion from potassium permanganate addition in the ISCO plot acts as a conservative tracer for tracking movement of injected solution)
- Surface emission tests were conducted as described in Appendix F to evaluate the potential for CVOC losses to the vadose zone and atmosphere (see the testing setup, Figure 4-7, and the map, Figure 5-29)
- CVOC concentrations in soil outside the resistive heating plot (vadose and saturated zones)

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

- CVOC concentrations in the Lower Clay Unit and semi-confined aquifer below the resistive heating plot.

4.3.1 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, FL. 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 semi-confined aquifer and to assess the effect of the DNAPL remediation demonstration on the semi-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 thin aquitard (Lower Clay Unit). However, by early 2001, nonintrusive geophysical tests indicated the possibility of DNAPL in the semi-confined aquifer. It was not clear whether any DNAPL in the semi-confined aquifer would be related to the demonstration activities or not. However, the IDC and Battelle decided that there were enough questions about the status of the confined aquifer that it would be worthwhile to characterize the deeper aquifer. Suitable precautions would be taken to mitigate any risk of downward migration of contamination during the well installation.

WSRC sent an observer to monitor the field installation of the wells. The observer verified that the wells were

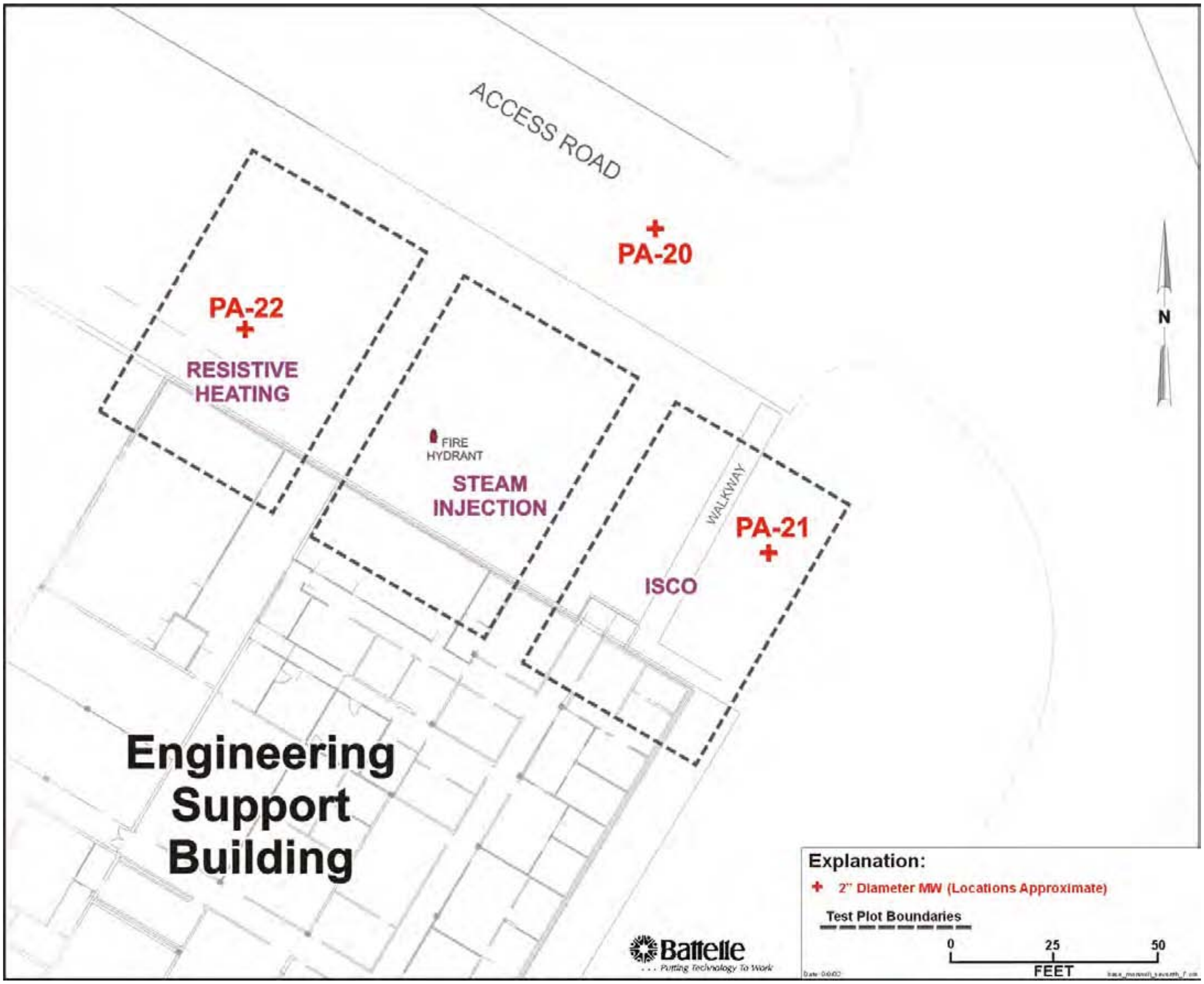

Figure 4-8. Location of Semi-Confined Aquifer Wells at Launch Complex 34

installed properly and that no drag-down of contaminants was created during their installation.

4.3.1.1 Geologic Background at Launch Complex 34

At the Launch Complex 34 area, there are several aquifers, reflecting a barrier island complex overlying coastal sediments (Figure 4-9). The surficial aquifer is comprised of layers of silty sand and shells, and includes the Upper Sand Unit, the Middle Fine-Grained Unit, and the Lower Sand Unit. 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 confined aquifer (Caloosahatchee Marl equivalent) resides under the Lower Clay Unit and is composed of silty to clayey sand and shells. As shown in Figure 4-9, Launch Complex 34 is situated just above the semi-confined aquifer in the Hawthorne Formation, which is 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 (Schmalzer and Hinkle, 1990).

4.3.1.2 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 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 semi-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 well installation method is as follows.

To verify the depth of the Lower Clay 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 Lower Clay Unit or aquitard. Upon retrieval of a 2-ft split-spoon sample, the borehole was then deepened to the bottom of the previously spooned interval. Once the previously spooned interval was drilled, the drilling rods and bit were pulled 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

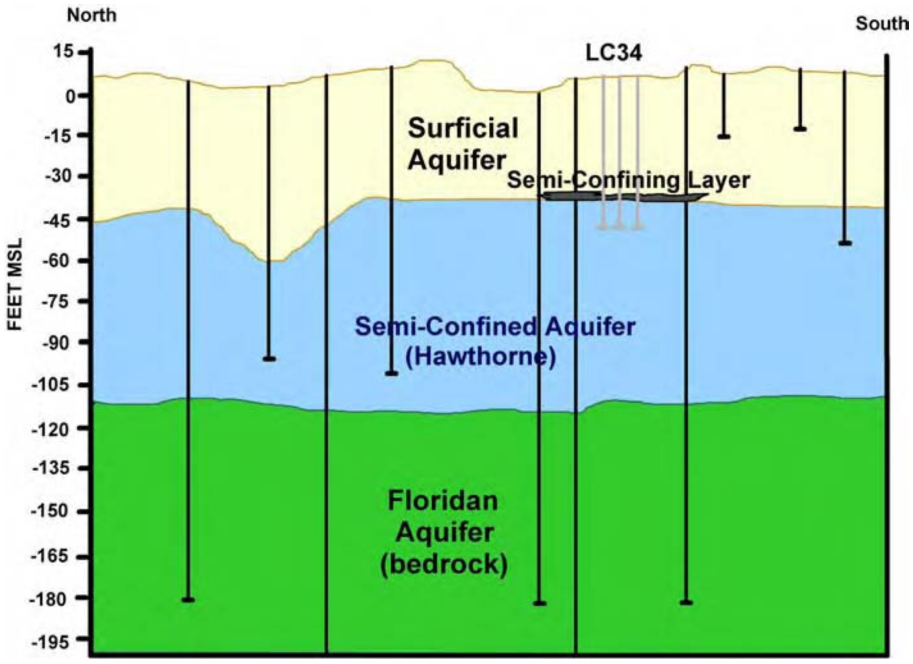

Figure 4-9. Regional Hydrogeologic Cross Section through the Kennedy Space Center Area (after Schmalzer and Hinkle, 1990)

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 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.
Pleistocene (1.8-0.1 MYA)					
Pliocene (1.8-5 MYA)	Upper Miocene and Pliocene Deposits (Calooshatchee 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 ground water 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.

Project #: G004065-31	Site: LC34, Cape Canaveral	Well #: PA-20/21/22
Drilling Contractor: EDS (SBC)	Rig Type and Drilling Method: Rotary	Date: 4/5/01
Reviewed By: S. Yoon	Driller: R. Hutchinson	Hydrologist: C. J. Perry

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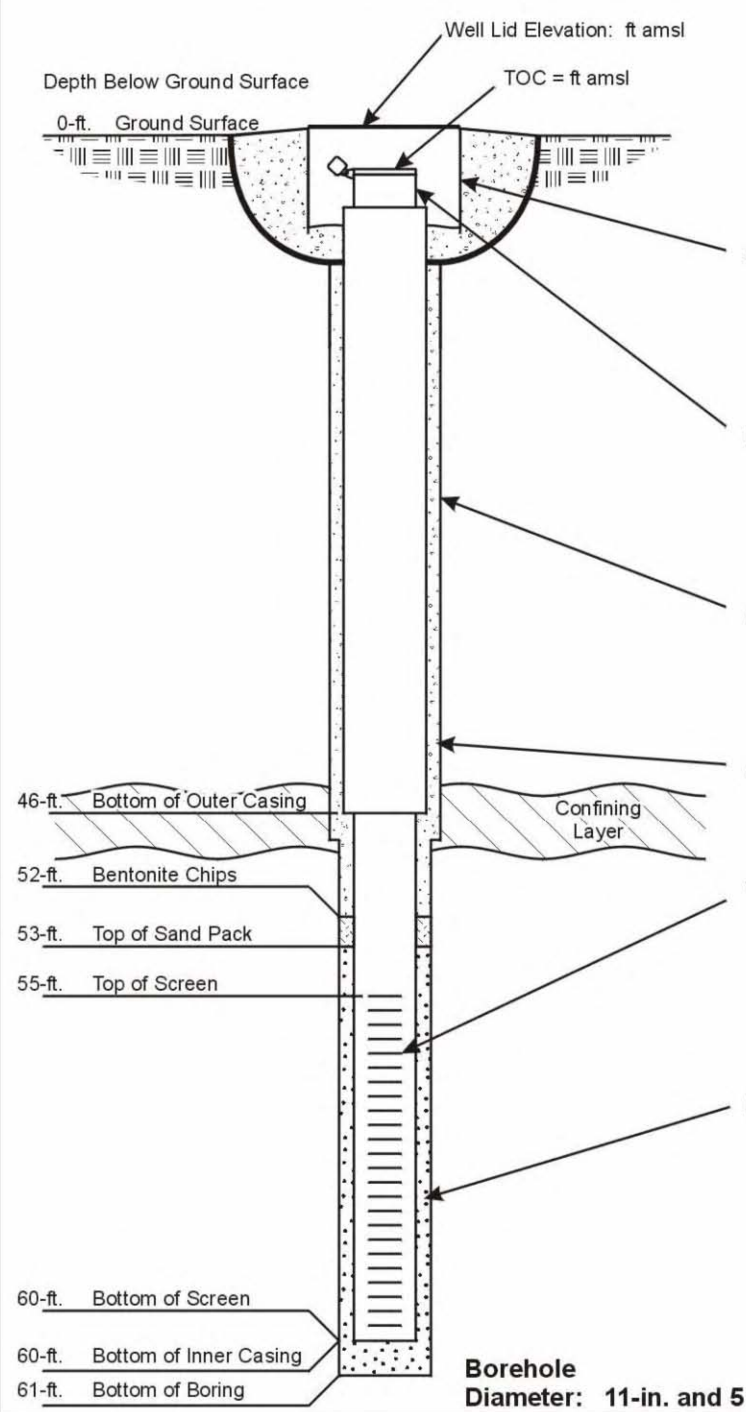

Surface Completion:

Size 7" 2'x2' Concrete Pad

Type Water Tight Well Cover

Well Cap Locking Well Cap

Inside Well Casing:

Type 304 SS SCH10

Diameter 2-in.

Amount 60-ft.-long section

Outer Well Casing:

Type 304 SS SCH10

Diameter 6-in.

Amount 46-ft.-long section

Grout:

Type Type G + 30% Silica Sand

Well Screen:

Type 304 SS SCH10

Amount 5-in.

Diameter 2-in.

Slot Size 0.010

Filter Pack:

Type #20/30 Sand

NOT TO SCALE

Borehole Diameter: 11-in. and 5 7/8-in.

WELGRM20.CDR

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

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

logged during each split-spoon advance. The blow counts were useful in identifying the soil types that are penetrated during spooning. They were also 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.

Once the top portion (approximately the first 1.5 ft) of the Lower Clay 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 polyvinyl chloride (PVC) slipcap was placed on the bottom of the casing to keep it free of drilling mud and soil. Use of slipcaps 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 split cap was drilled through with a 5⅞-inch roller bit. Then split-spoon sampling progressed through the remainder of the Lower Clay Unit and into the semi-confined aquifer. Split-spoon samples were collected totaling 4 ft of lifts before the hole was reamed with the 5⅞ 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) was then tremied in around 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 ground water 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 ground water 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 was then 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. Ground-water sampling was performed following well development. Standard water quality parameters were measured during sampling, and ground-water samples were collected after these parameters became stable.

4.4 Verifying Resistive Heating 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 resistive heating application (CES, 2001). 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 resistive heating 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 Change in TCE-DNAPL Mass in the Plot

Section 4.1 describes the methodology used to estimate the masses of total TCE and DNAPL removed from the plot due to the resistive heating application 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 post-demonstration concentrations of TCE at 12 soil coring locations (nearly 300 soil samples) inside the resistive heating plot were tabulated and graphed to *qualitatively* identify changes in TCE-DNAPL mass distribution and efficiency of the resistive heating application in different parts of the plot (Section 5.1.1). In addition, TCE-DNAPL mass removal was *quantified* by two methods:

- Linear Interpolation (Section 5.1.2)
- Kriging (Section 5.1.3)

These quanititative techniques for estimating TCE-DNAPL mass removal due to the resistive heating application are described in Section 4.1; the results are described in Sections 5.1.2 through 5.1.4.

5.1.1 Qualitative Evaluation of Changes in TCE-DNAPL Distribution

Figure 5-1 charts the pre- and post-demonstration concentrations of TCE in the soil samples from the 12 coring locations in the resistive heating plot as shown in Figures 4-2 (pre-demonstration) and 4-3 (post-demonstration). This chart allows a simple numerical comparison of the pre- and post-demonstration TCE concentrations at paired locations. Colors in the chart indicate the represented soil color observed in each soil sample of 2-ft intervals during the soil sample collection. Gray and tan are natural colors observed above and below the ground-water table from Launch Complex 34 soil samples. The chart in Figure 5-1 shows that at several locations in the plot, TCE concentrations were considerably lower in all three units. The thicker horizontal lines in the chart indicate the depths at which the Middle Fine-Grained Unit was encountered at each location. As seen in Figure 5-1, the highest pre-demonstration contamination detected was under the Engineering Support Building in the deepest samples from soil cores SB-1 (37,537 mg/kg) and SB-2 (41,044 mg/kg).

Figures 5-2 to 5-4 show representative pre- and post-demonstration distributions of TCE in soil from the Upper Sand Unit, Middle Fine-Grained Unit, and Lower Sand Unit in the resistive heating plot and surrounding aquifer. A graphical representation of the TCE data illustrates the areal and vertical extent of the initial contaminant distribution and the subsequent changes in TCE concentrations. The colors yellow to red indicate DNAPL (TCE >300 mg/kg). In general, the portions of the aquifer under or near the building (SB-201, SB-202, and SB-204) and along the eastern half of the plot (SB-207 and SB-208) had the highest pre-demonstration contamination generally occurring right on top of the Lower Clay Unit. The post-demonstration coring showed that the resistive heating process had caused a considerable decline in TCE concentrations in several parts of the resistive heating plot, especially in the Lower Sand Unit, which showed the sharpest declines in TCE-DNAPL concentrations. Access to the portion of the test plot under the building by the application of the resistive heating technology also appeared to be good, given that angled electrodes were inserted into this region from outside the building. Some portion of cores SB-201, SB-202, and SB-203, collected under and near the building, contained considerable post-demonstration concentrations of both total TCE and DNAPL. Figure 5-5 depicts three-dimensional (3-D) DNAPL distributions identified (based on the 300 mg/kg threshold or greater) during the pre- and post-demonstration sampling in the resistive heating plot. Most of the remaining DNAPL in the plot appears to be in and near the Middle Fine-Grained Unit.

Top Depth	Bottom Depth	Pre-Demo SB1	Post-Demo SB201	Pre-Demo SB2	Post-Demo SB202	Pre-Demo SB3	Post-Demo SB203	Pre-Demo SB4	Post-Demo SB204
0	2	8	0.8	NA	ND	9.2	1	ND	1
2	4	5	1.8	NA	ND	0.9	ND	4.6	3
4	6	0.3	2.9	1.7	2.9	0.1 J	1	5.1	ND
6	8	3	1.4	0.7	6.7	0.3 J	3	48.7	5
8	10	11	18	0.4 J	40.2	0.3 J	90	0.2 J	6
10	12	9	13	0.7	29.2	0.3 J	114	4.6	32
12	14	12	ND	ND	9.4	0.3 J	61	NA	NA
14	16	NA	ND	1.1	1.9	0.6	126	8.3	NA
16	18	4	NA	0.7	53	1.3	97	6.5	19
18	20	122	ND	2.5	111	1.0	71	6.0	2
20	22	315	28	2	4,295	8.9	NA	54.1	83
22	24	1,935	60	50	1,248	NA	NA	60	105
24	26	820	3,927	108	102	183	258	9,051	240
26	28	526	401	292	353	109	247	185	195
28	30	941	467	458	5,561	35	1,217	167	403
30	32	19,091	385	295	390	5	287	12,669	197
32	34	349	211	174	465	17	56	112	263
34	36	624	254	176	102	35.5 D	77	100	178
36	38	1,025	265	440	429	1.4 J	308	288	425
38	40	5,874	318	558	474	27	302	848	139
40	42	5,677	186	5	250	115	186	160	388
42	44	368	146	249	335	204	34	167	364
44	46	33,100	364	251	8	220	41	30,223	NA
46	48	37,537	270	41,044	NA	NA	NA	NA	NA

Figure 5-1. Distribution of TCE Concentrations (mg/kg) During Pre- and Post-Demonstration in the Resistive Heating Plot Soil (page 1 of 3)

Top Depth	Bottom Depth	Pre-Demo SB5	Post-Demo SB205	Pre-Demo SB6	Post-Demo SB206	Post-Demo SB7	Post-Demo SB207	Pre-Demo SB8	Post-Demo SB208
0	2	**ND**	**6**	**ND**	**6**	**0.6**	**ND**	**0.3 J**	**2**
2	4	**ND**	**1**	**ND**	**ND**	**0.1**	**0**	**0.2 J**	**1**
4	6	**ND**	**12**	**ND**	**6**	**ND**	**6**	**ND**	**5**
6	8	**ND**	**5**	**ND**	**3**	**ND**	**61**	**1.1**	**72**
8	10	**ND**	**10**	**ND**	**55**	**1.0**	**ND**	**0.5 J**	**ND**
10	12	**0.3 J**	**10**	**ND**	**69**	**0.0**	**ND**	**0.8**	**ND**
12	14	**ND**	**17**	**ND**	**71**	**ND**	**ND**	**1.2 J**	**24**
14	16	**ND**	**122**	**ND**	**76**	**0.2**	**1**	**342**	**6**
16	18	**ND**	**197**	**1.9**	**164**	**0.0**	**1**	**0.5 J**	**27**
18	20	**5.2**	**89**	**ND**	**119**	**10**	**ND**	**1.7**	**NA**
20	22	**27.7**	**61**	**3.9**	**224**	**31**	**58**	**217**	**33**
22	24	**1,835**	**NA**	**18.6**	**135**	**NA**	**85**	**329**	**12**
24	26	**260**	**177**	**10.8**	**213**	**143**	**516**	**330**	**29**
26	28	**5,880**	**177**	**69.1**	**235**	**330**	**367**	**184**	**31**
28	30	**542**	**102**	**54.6**	**105**	**140**	**186**	**182**	**34**
30	32	**902**	**150**	**17.0**	**86**	**125**	**196**	**157**	**NA**
32	34	**5,345**	**140**	**17.5**	**63**	**91**	**389**	**294**	**52**
34	36	**23,362**	**64**	**11.4**	**35**	**139**	**403**	**113**	**63**
36	38	**8,062**	**146**	**20.5**	**99**	**260**	**159**	**141**	**2**
38	40	**28,168**	**236**	**11.2**	**89**	**113**	**82**	**NA**	**11**
40	42	**6,534**	**97**	**18.8**	**149**	**217**	**511**	**209**	**4**
42	44	**37,104**	**129**	**5.8**	**126**	**8,802**	**273**	**6,711**	**52**
44	46	**NA**	**NA**	**313.1**	**NA**	**NA**	**NA**	**NA**	**160**

Figure 5-1. Distribution of TCE Concentrations (mg/kg) During Pre- and Post-Demonstration in the Resistive Heating Plot Soil (page 2 of 3)

Top Depth	***Bottom Depth***	***Pre-Demo SB9***	***Post-Demo SB209***	***Pre-Demo SB10***	***Post-Demo SB210***	***Post-Demo SB210B***	***Pre-Demo SB11***	***Post-Demo SB211***	***Pre-Demo SB12***	***Post-Demo SB212***
0	2	**ND**	**ND**	**ND**	**ND**	**3**	**4.1**	**6**	**ND**	**ND**
2	4	**0.9**	**ND**	**ND**	**ND**	**2**	**2.8**	**2**	**ND**	**3**
4	6	**ND**	**4**	**ND**	**3**	**23**	**2.1**	**3**	**ND**	**10**
6	8	**ND**	**5**	**3.9**	**26**	**20**	**2.7**	**49**	**NA**	**12**
8	10	**6.5**	**1**	**2.8**	**NA**	**NA**	**0.7**	**1**	**ND**	**16**
10	12	**0.5**	**1**	**ND**	**NA**	**NA**	**1.1**	**NA**	**2.4**	**ND**
12	14	**ND**	**5**	**1.9**	**ND**	**ND**	**ND**	**ND**	**0.4 J**	**1**
14	16	**0.8**	**4**	**ND**	**6**	**ND**	**1.2**	**NA**	**ND**	**1**
16	18	**0.4**	**13**	**ND**	**NA**	**1**	**1.6**	**2**	**NA**	**ND**
18	20	**5**	**3**	**0.7**	**10**	**6**	**ND**	**3**	**ND**	**5**
20	22	**14**	**28**	**30.9**	**90**	**16**	**9.2**	**14**	**15.3**	**4**
22	24	**29**	**34**	**92.4**	**46**	**49**	**NA**	**8**	**40.1**	**6**
24	26	**26**	**64**	**106**	**265**	**569**	**94**	**4**	**112.1**	**20**
26	28	**84**	**36**	**98**	**117**	**310**	**167**	**13**	**256.9**	**10**
28	30	**30**	**28**	**40.3**	**170**	**77**	**49**	**319**	**29.6**	**7**
30	32	**2.5**	**11**	**4.8**	**287**	**27**	**43.7**	**102**	**2.2**	**3**
32	34	**ND**	**NA**	**ND**	**209**	**344**	**21.4**	**79**	**0.4**	**23**
34	36	**1.4**	**5**	**ND**	**428**	**315**	**2.0**	**71**	**0.2 J**	**1**
36	38	**ND**	**74**	**ND**	**264**	**124**	**0.0**	**14**	**0.7**	**3**
38	40	**3.4**	**54**	**13.9**	**242**	**219**	**0.4**	**9**	**0.5 J**	**ND**
40	42	**51**	**77**	**12.6**	**257**	**236**	**36.0**	**2**	**16.1**	**1**
42	44	**67**	**52**	**25.4**	**101**	**297**	**46.0**	**ND**	**36.5**	**2**
44	46	**NA**	**NA**	**11.8**	**59**	**NA**	**NA**	**NA**	**1.5**	**8**

NA: Not available due to no recovery or no sample collection at the sample depth.
ND: Not detected.
Color in the chart represents the soil sample color observed during the soil sample collection.
Solid horizontal lines demarcate the Middle Fine-Grained Unit.

Figure 5-1. Distribution of TCE Concentrations (mg/kg) During Pre- and Post-Demonstration in the Resistive Heating Plot Soil (page 3 of 3)

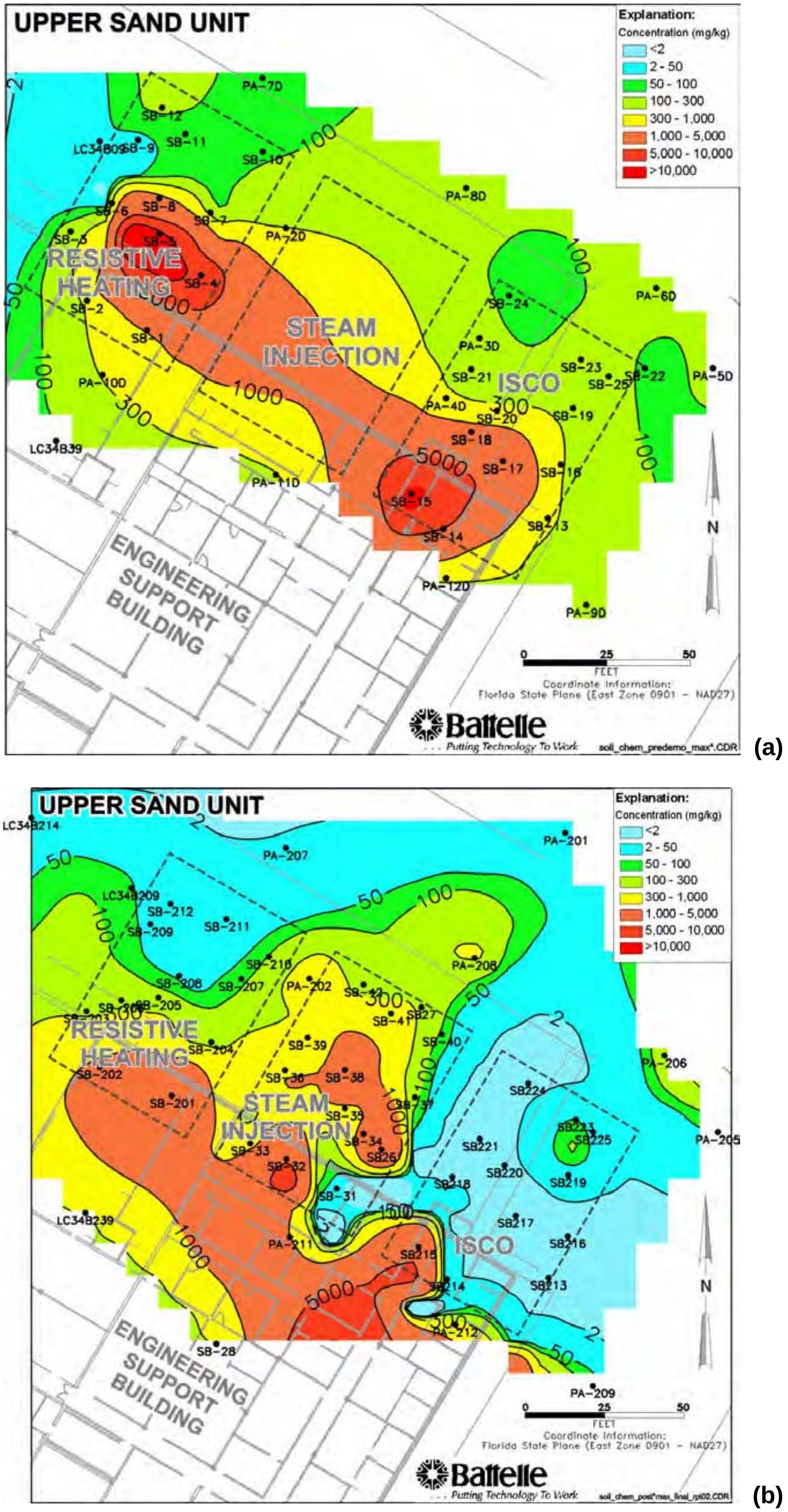

Figure 5-2. Representative (a) Pre-Demonstration (June 1999) and (b) Post-Demonstration (December 2000) Horizontal Cross Sections of TCE (mg/kg) in the Upper Sand Unit Soil

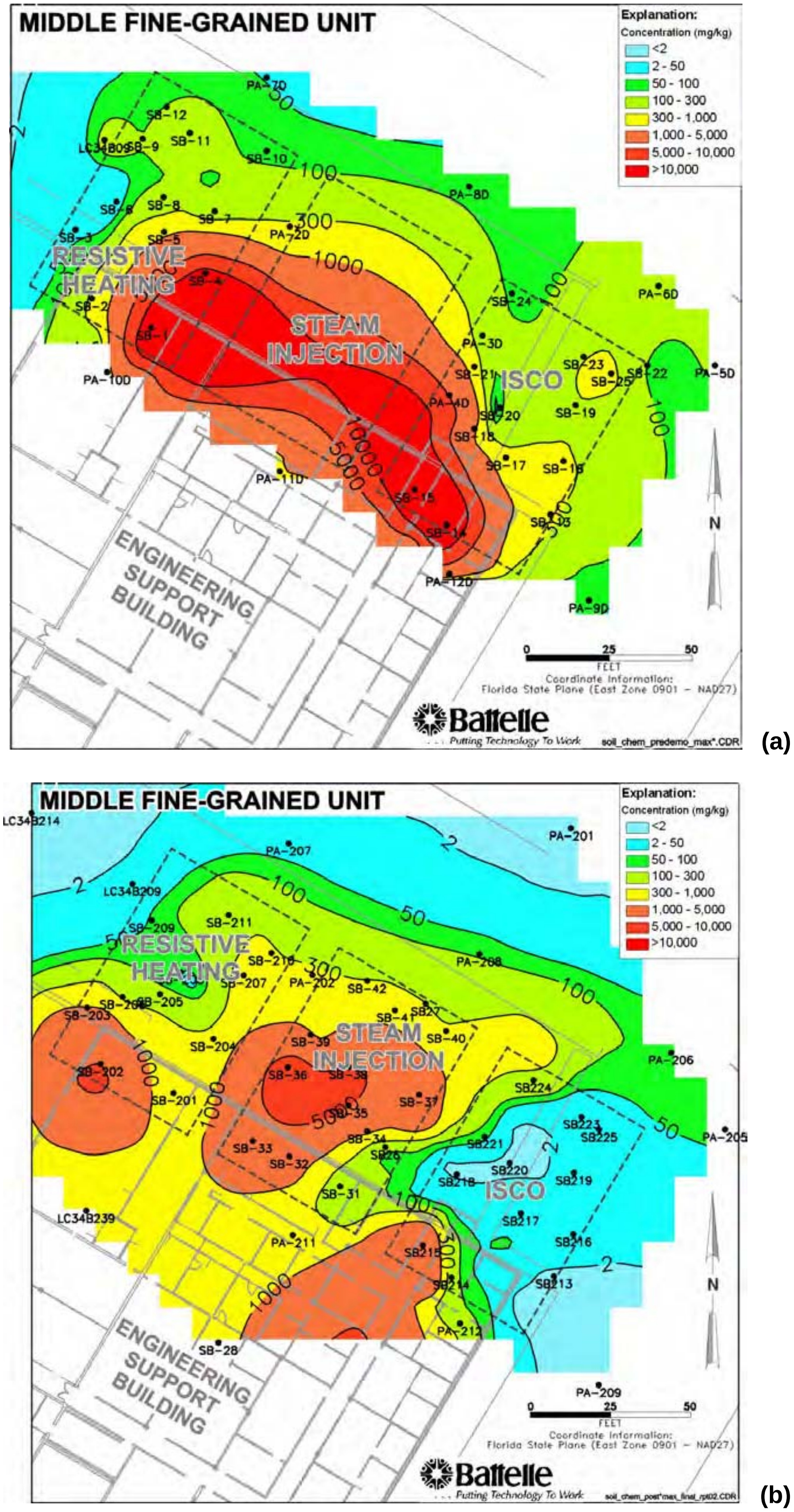

Figure 5-3. Representative (a) Pre-Demonstration (June 1999) and (b) Post-Demonstration (December 2000) Horizontal Cross Sections of TCE (mg/kg) in the Middle Fine-Grained Unit

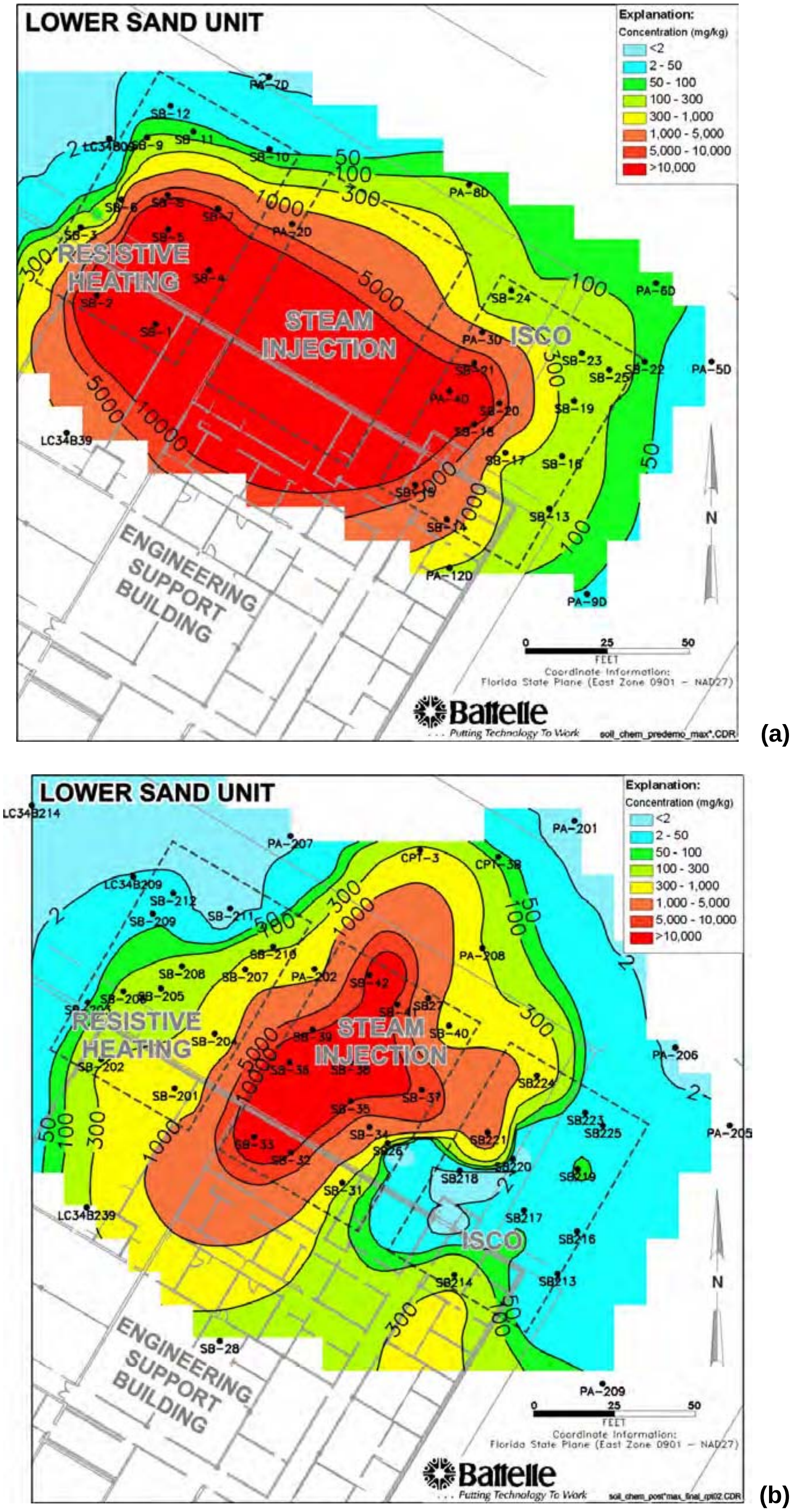

Figure 5-4. Representative (a) Pre-Demonstration (June 1999) and (b) Post-Demonstration (December 2000) Horizontal Cross Sections of TCE (mg/kg) in the Lower Sand Unit

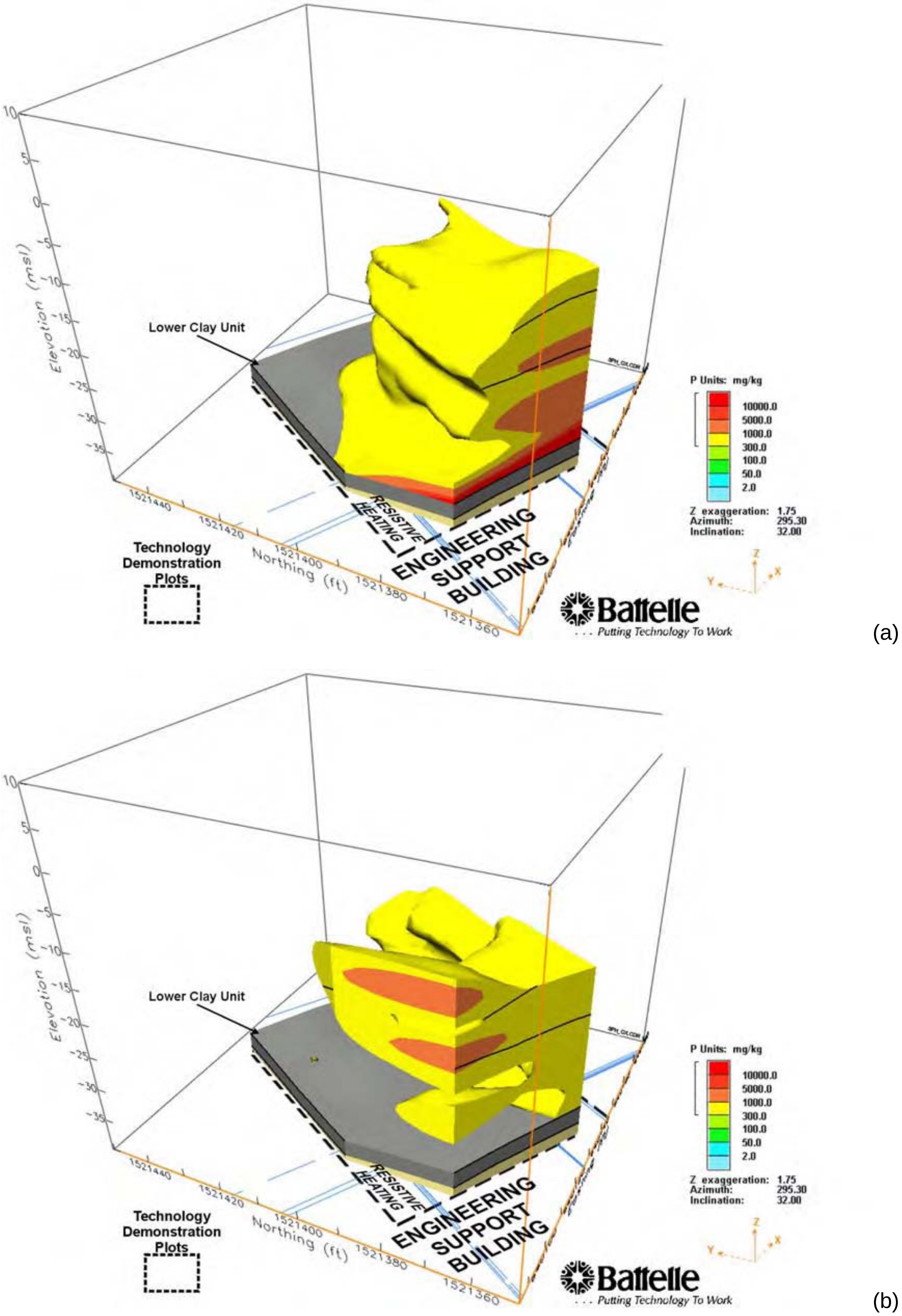

Figure 5-5. Three-Dimensional Distribution of DNAPL in the Resistive Heating Plot Based on (a) Pre-Demonstration (June 1999) and (b) Post-Demonstration (December 2000) Soil Sampling Events

This indicates that some TCE-DNAPL may have accumulated in or immediately above the Middle Fine-Grained Unit on its way up to the vadose zone and the vapor extraction system.

Figures 5-6 to 5-8 show the post-demonstration distribution of temperature of the aquifer in the shallow, intermediate, and deep wells in the Launch Complex 34 aquifer, as measured by existing thermocouples installed in the plot and by a downhole thermocouple in May 2000, toward the end of the resistive heating application and after electrode modifications had been made to improve heating efficiency (see Section 3.2.2). The temperature levels in the monitoring wells are a measure of the aquifer, although the absolute temperatures in the aquifer are probably slightly higher than in the wells. These figures show that all three layers — shallow, intermediate, and deep — eventually were heated well and probably achieved the desired boiling temperatures during the demonstration. These temperature measurements (in the monitoring wells) correspond well with the temperature measurements conducted by the vendor using thermocouples embedded in the test plot soil (CES, 2001).

In summary, a qualitative examination of the TCE-DNAPL and temperature data indicate that the resistive heating treatment generally achieved the desired level of heating in most parts of the plot, even in the relatively low-permeability Middle Fine-Grained Unit. The resistive heating treatment also was able to access and heat those portions of the test plot (e.g., right above the aquitard and under the building) that would be considered difficult to remediate. Heating in the Upper Sand Unit was not very efficient at the beginning of the demonstration, but modifications made by the vendor to the electrodes subsequently improved heating.

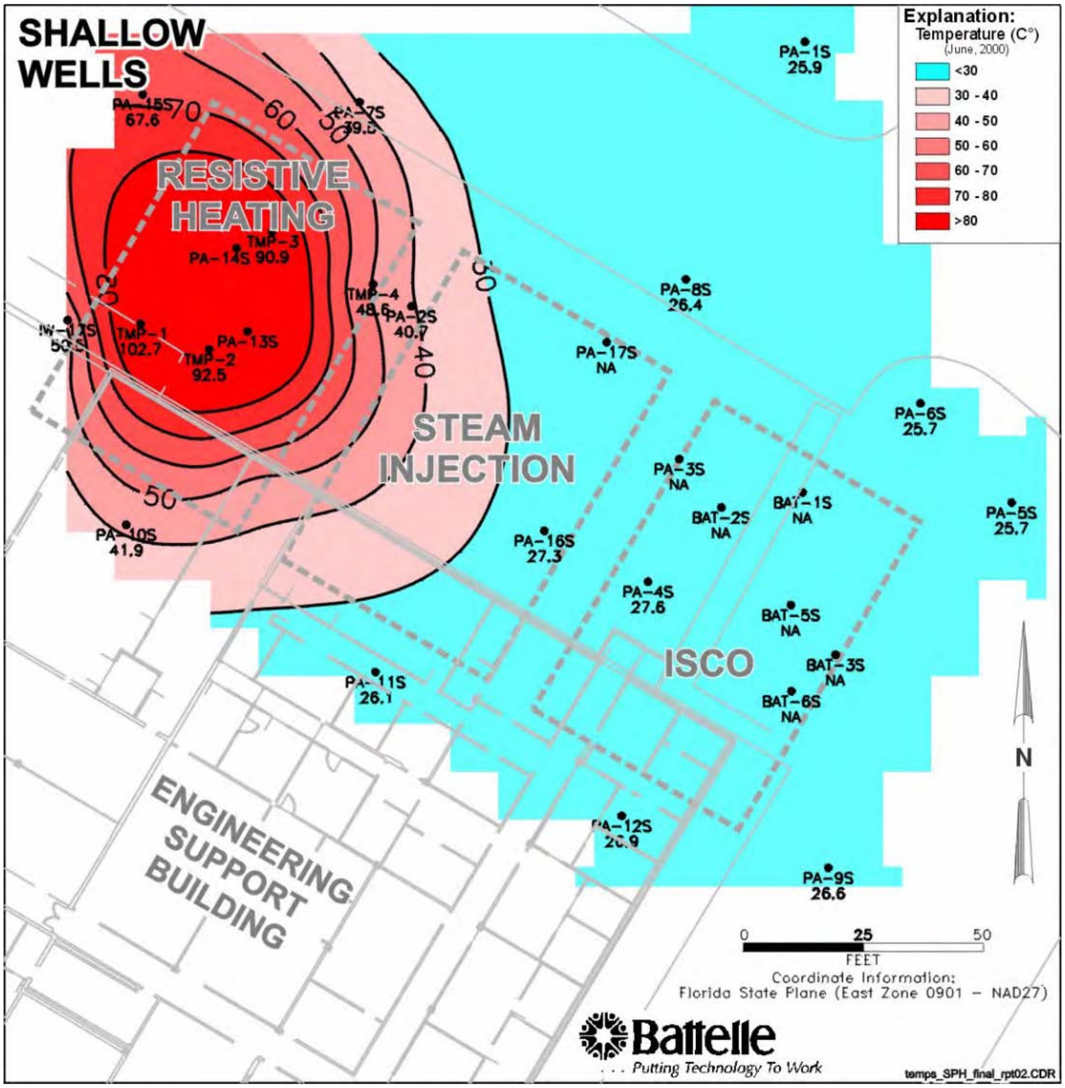

Figure 5-6. Distribution of Temperature in Shallow Wells near the Engineering Support Building at Launch Complex 34 (May 2000)

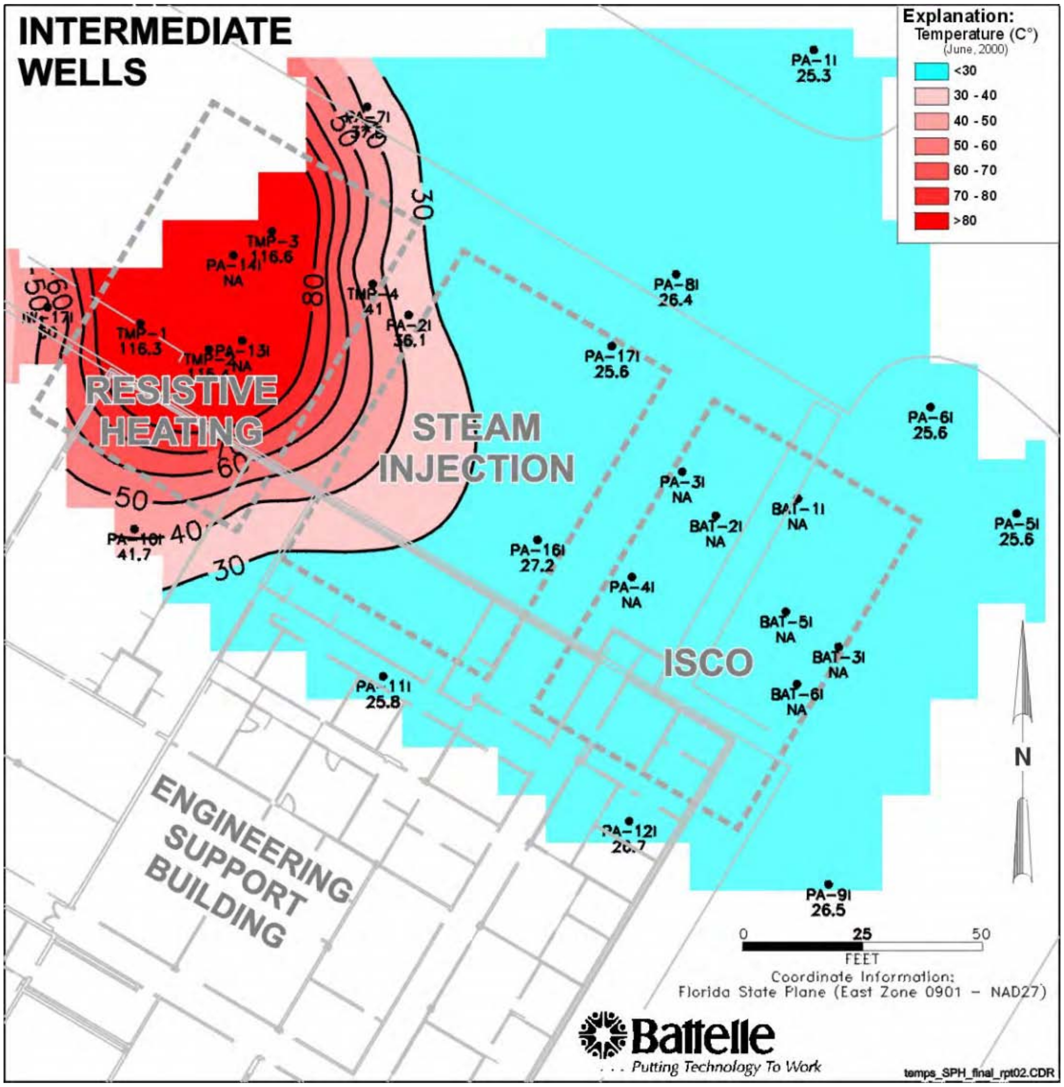

Figure 5-7. Distribution of Temperature in Intermediate Wells near the Engineering Support Building at Launch Complex 34 (May 2000)

5.1.2 TCE-DNAPL Mass Estimation by Linear Interpolation

Section 4.1.1 describes the use of contouring to estimate pre- and post-demonstration TCE-DNAPL masses and calculate TCE-DNAPL mass changes within the plot. In this method, EarthVision™, a three-dimensional contouring software, is used to group the TCE concentration distribution in the resistive heating 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 post-demonstration TCE distributions in the resistive heating plot. The pre-demonstration TCE-DNAPL mass in the entire plot then can be compared with the post-demonstration mass in the entire plot to estimate the change in TCE-DNAPL mass in the plot. The results of this evaluation are described in this section.

Table 5-1 presents the estimated masses of total TCE and DNAPL in the resistive heating plot and the three individual stratigraphic units. Under pre-demonstration conditions, soil sampling indicated the presence of 11,313 kg of total TCE (dissolved and free phase), approximately 10,490 kg of which was DNAPL based on the 300 mg/kg of DNAPL criterion. Following the demonstration, soil sampling indicated that 1,101 kg of total TCE remained in the plot; approximately 338 kg of this remnant TCE was DNAPL. Therefore, the overall mass removal indicated by contouring was 90% of total TCE and 97% of DNAPL.

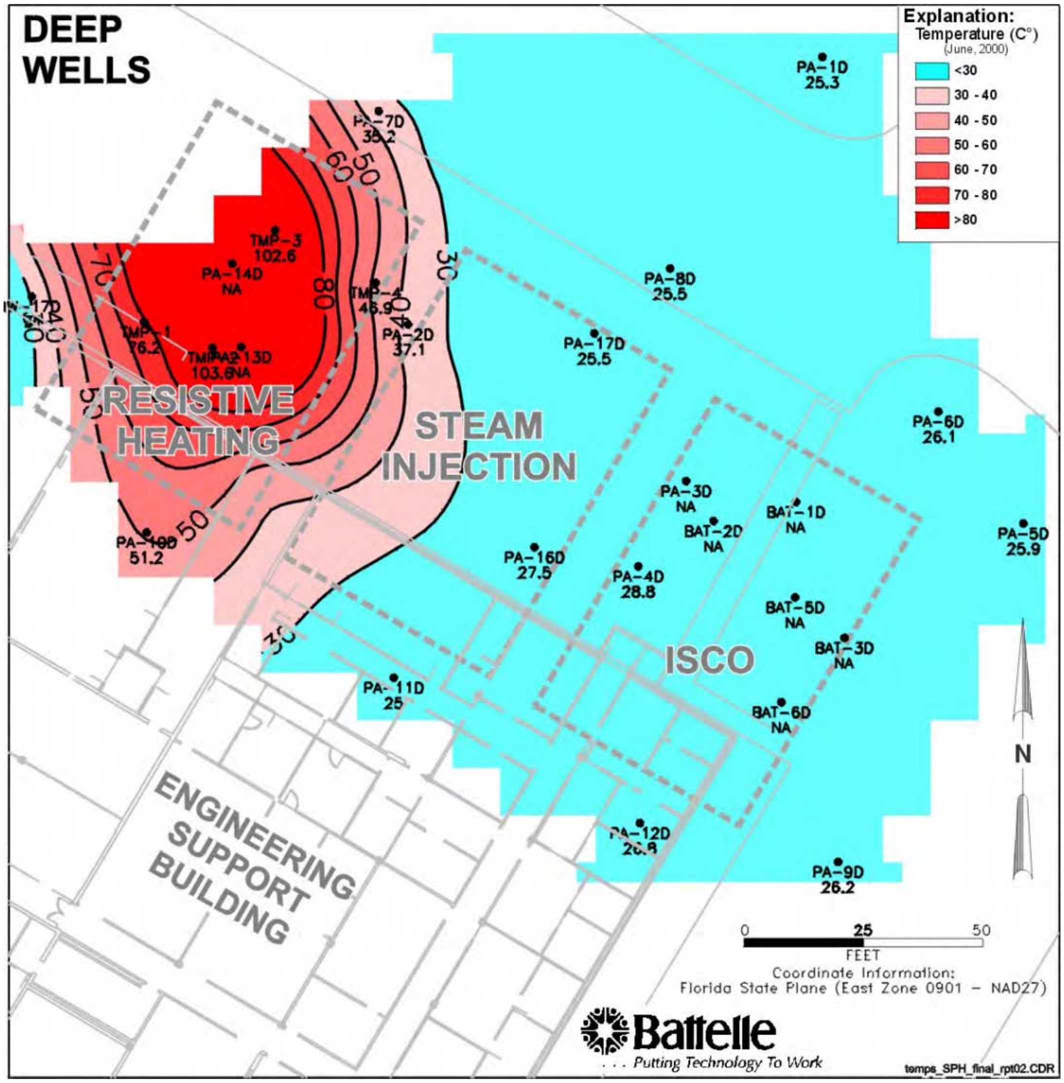

Figure 5-8. Distribution of Temperature in Deep Wells near the Engineering Support Building at Launch Complex 34 (May 2000)

Table 5-1 indicates that the highest mass removal (94% of total TCE and 98% of DNAPL) was achieved in the Lower Sand Unit, followed by the Middle Fine-Grained Unit. The removal efficiency appears to be substantially lower in the Upper Sand Unit, where heating was not as efficient (see Section 3.2.2) as in the deeper units. Because more than 90% of the pre-demonstration DNAPL mass resided in the Lower Sand Unit, the greater efficiency of removal in this unit was the driving factor behind the high removal percentage in the entire plot.

Table 5-1. Estimated Total TCE and DNAPL Mass Removal by Linear Interpolation of the TCE Distribution in Soil

	Pre-Demonstration		Post-Demonstration		Change in Mass (%)	
Stratigraphic Unit	Total TCE Mass (kg)	DNAPL Mass (kg)	Total TCE Mass (kg)	DNAPL Mass (kg)	Total TCE	DNAPL
Upper Sand Unit	183	70	141	35	–23	–50
Middle Fine-Grained Unit	611	447	304	124	–50	–72
Lower Sand Unit	10,519	9,973	656	179	–94	–98
Total (Entire Plot)	**11,313**	**10,490**	**1,101**	**338**	**–90**	**–97**

5.1.3 TCE Mass Estimation by Kriging

Section 4.1.2 describes the use of kriging to estimate the pre- and post-demonstration 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 is a good way of obtaining a global estimate (for one of the three stratigraphic units or the entire plot) for the parameters of interest (such as pre- and post-demonstration 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 resistive heating plot. Table 5-2 summarizes the total TCE mass estimates obtained from kriging. This table contains an average and range for each global estimate (Upper Sand Unit, Middle Fine-Grained Unit, Lower Sand Unit, and the entire plot total). 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 few data points (especially for the post-demonstration DNAPL mass estimates), kriging was conducted on total TCE values only.

The pre- and post-demonstration total TCE mass ranges estimated from kriging match the total TCE obtained from contouring relatively well, probably because the high sampling density (almost 300 soil samples in the plot per event) allows contouring to capture much of the variability of the TCE distribution in the plot. Kriging shows that the estimated decrease in TCE mass in the plot due to the resistive heating application is between 80 and 93% (89% on average). The decrease in TCE mass was highest in the Lower Sand Unit, followed by the Middle Fine-Grained Unit. The positive mass change numbers for the Upper Sand Unit indicate that the TCE mass in this unit may have increased. The Upper Sand Unit was not as efficiently heated as the other two units (see Section 3.2.2) and this may have caused upward-migrating TCE vapors to condense near the water table. An interesting observation from Table 5-2 is that the estimated ranges for the pre- and post-demonstration TCE masses do not overlap at all, either for the entire plot or for the Lower Sand or Middle Fine-Grained units; this indicates that the mass removal by the resistive heating application is significant at the 80% confidence level. The estimated decrease in TCE mass in the plot due to the resistive heating application is at least 80%.

The mass removal estimates obtained in the resistive heating plot by the two methods (linear interpolation and kriging) are consistent. Confidence intervals were not calculated for DNAPL removal from the individual units because an even smaller subset of samples (only those samples with TCE greater than 300 mg/kg) would be involved.

5.1.4 Summary of Changes in the TCE-DNAPL Mass in the Plot

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

- In the horizontal plane, the highest pre-demonstration DNAPL contamination was under the Engineering Support Building and in the eastern half of the resistive heating plot.
- In the vertical plane, the highest pre-demonstration DNAPL contamination was immediately above the Lower Clay Unit.
- Linear interpolation of the pre- and post-demonstration TCE-DNAPL soil concentrations shows that the estimated pre-demonstration DNAPL mass in the resistive heating plot decreased by approximately 97% due to the heat application. Based on these estimates, the goal for 90% DNAPL mass removal was achieved.

Table 5-2. Estimated Total TCE Mass Removal by Kriging the TCE Distribution in Soil

	Pre-Demonstration Total TCE Mass[a]			Post-Demonstration Total TCE Mass			Change in Mass		
Stratigraphic Unit	**Average (kg)**	**Lower Bound (kg)**	**Upper Bound (kg)**	**Average (kg)**	**Lower Bound (kg)**	**Upper Bound (kg)**	**Average (%)**	**Lower Bound (%)**	**Upper Bound (%)**
Upper Sand Unit	168	90	247	310	176	443	84	393	–29
Middle Fine-Grained Unit	2,087	929	3,245	536	328	745	–74	–23	–90
Lower Sand Unit	9,332	5,411	13,253	437	391	483	–95	–91	–97
Total (Entire Plot)	**11,588**	**7,498**	**15,677**	**1,283**	**1,031**	**1,545**	**–89**	**–80**	**–93**

(a) Average and 80% confidence intervals (bounds).

- A statistical evaluation (kriging) of the pre- and post-demonstration TCE concentrations in soil shows that the estimated pre-demonstration total TCE mass in the resistive heating plot decreased between 80 and 93% due to the heat application. Total TCE includes both dissolved-phase TCE and DNAPL. The kriging results are generally consistent with the contouring results and indicate a high probability (80% confidence level) that the mass removal estimates are accurate.
- The estimated decrease in TCE-DNAPL mass in the plot was highest in the Lower Sand Unit, which contained the highest pre-demonstration TCE-DNAPL mass. Mass removal was especially good in difficult spots, such as immediately above the aquitard and under the Engineering Support Building.
- It is possible that some TCE-DNAPL accumulated in the Upper Sand Unit, immediately above the Middle Fine-Grained Unit, during the upward migration of the volatilized TCE. This possibility is discussed further in Section 5.3.2.

5.2 Changes in Aquifer Characteristics

This section describes the short-term changes in aquifer characteristics created by the resistive heating application at Launch Complex 34, as measured by monitoring conducted before, during, and immediately 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 the pre- and post-demonstration levels of various ground-water parameters that are indicative of aquifer quality and the impact of the resistive heating treatment. Other important organic and inorganic aquifer parameters are discussed in the text. A separate microbiological evaluation of the aquifer is described in Appendix E.

5.2.1 Changes in CVOC Levels in Ground Water

Considerable DNAPL mass removed was expected to reduce CVOC levels in ground water, at least in the short term. Although influx from surrounding contamination is possible, it was not expected to contribute significantly to the post-demonstration sampling in the short term because of the relatively flat natural hydraulic gradient at the site. Therefore, CVOC levels were measured in the resistive heating plot wells before, during, and after the demonstration to evaluate short-term changes in CVOC levels in the ground water.

Appendix C tabulates the levels of TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and vinyl chloride in the ground water in the resistive heating plot wells. Figures 5-9 to 5-11 show dissolved TCE concentrations in the shallow, intermediate, and deep wells in the resistive heating 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., PA-13S, PA-13I, PA-14S and PA-14D) declined considerably, indicating that the treatment improved ground-water quality within the plot in the short term, whereas TCE concentrations in some of the monitoring wells (PA-7D and IW-17S) on the perimeter of the plot increased sharply.

The concentration of *cis*-1,2-DCE increased considerably in several wells (e.g., PA-13S, PA-13D, and PA-14S) within the plot. Although one well (PA-14D) showed a decline in *cis*-1,2-DCE levels, in general, there appears to have been some accumulation of *cis*-1,2-DCE in the plot. An increase in *cis*-1,2-DCE would indicate that some reductive dechlorination of TCE was taking place (biotically or abiotically). Recent research (Truex, 2003) has indicated heat-accelerated biodegradation of TCE to ethenes (acetylene, ethane, and ethene) at elevated temperatures. However, these byproducts were not evaluated for this demonstration of the resistive heating technology at Launch Complex 34. The possibility of TCE degradation is discussed further in Sections 5.3.1 and 5.3.2, but needs to be further evaluated. 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

The geochemical composition of both ground water and soil were examined to evaluate the effects of resistive heating application.

5.2.2.1 Changes in Ground-Water Chemistry

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

Table 5-3. Pre- and Post-Demonstration Levels of Ground-Water Parameters Indicative of Aquifer Quality

Ground-Water Parameter (applicable ground-water standard, if any) (mg/L)	Aquifer Depth	Pre-Demonstration (mg/L)[(a)]	Post-Demonstration[(b)] (mg/L)[(a)]
TCE (0.003)	Shallow	935 to 1,100	647 to 820
	Intermediate	960 to 1,070	60 to 174
	Deep	730 tot 892	3 to 920
cis-1,2-DCE (0.070)	Shallow	4 to 6	14 to 95
	Intermediate	5 to 26	9 to 80
	Deep	2 to 23	3 to 52
Vinyl chloride (0.001)	Shallow	<5	0.022 to <50
	Intermediate	<5	<0.010 to 1.7
	Deep	<5 to <83	0.032 to <50
pH	Shallow	6.9 to 7.1	6.3 to 7.6
	Intermediate	7.4 to 7.5	7.1 to 7.4
	Deep	7.2 to 7.5	6.5 to 6.8
ORP	Shallow	–130 to –108	–107 to –44
	Intermediate	–118 to –74	–89 to –68
	Deep	–142 to –106	–250 to –97
DO	Shallow	0.28 to 0.31	0.60 to 0.63
	Intermediate	0.27 to 0.40	0.99 to 1.11
	Deep	0.10 to 0.62	0.71 to 0.81
Calcium	Shallow	97 to 143	7 to 233
	Intermediate	60 to 70	14 to 153
	Deep	93 to 113	819 to 1,060
Magnesium	Shallow	23 to 37	<1 to 54
	Intermediate	54 to 74	1.2 to 77
	Deep	90 to 113	30 to 51
Alkalinity	Shallow	337 to 479	588 to 898
	Intermediate	351 to 465	243 to 434
	Deep	343 to 410	231 to 421
Chloride (250)	Shallow	37 to 38	141 to 383
	Intermediate	66 to 123	156 to 233
	Deep	11 to 774	3,520 to 4,800
Manganese (0.050)	Shallow	0.022 to 0.963	<0.015 to 0.079
	Intermediate	0.023 to 1.1	<0.015 to 0.11
	Deep	<0.015 to 0.02	0.021 to 0.16
Iron (0.3)	Shallow	0.78 to 3	<0.25 to 0.52
	Intermediate	0.33 to 11	<0.05 to 0.45
	Deep	<0.05 to 0.31	<0.25
Sodium	Shallow	17 to 24	113 to 467
	Intermediate	33 to 120	97 to 258
	Deep	325 to 369	1,530 to 3,130
TDS (500)	Shallow	548 to 587	1,330 to 1,750
	Intermediate	712 to 724	870 to 925
	Deep	1,030 to 1,980	7,220 to 10,600
BOD	Shallow	<3 to 20	32 to 42
	Intermediate	<3 to 9	3 to 4
	Deep	6 to 13	288 to 360
TOC	Shallow	6 to 6	35 to 45
	Intermediate	7 to 23	9 to 15
	Deep	9 to 40	270 to 300

(a) All reported quantities are in mg/L, except for pH (unitless), conductivity (mS/cm), and ORP (mV).

(b) Post-demonstration monitoring was conducted twice (December 2000 and June 2001) because some of the PA wells (PA-13 and PA-14) were plugged during the demonstration while their casings were being repaired. The cleaning process was performed after the initial post-demonstration monitoring in December 2000. Therefore, the results from the monitoring in June 2001 were incorporated in this table and the interpretation.

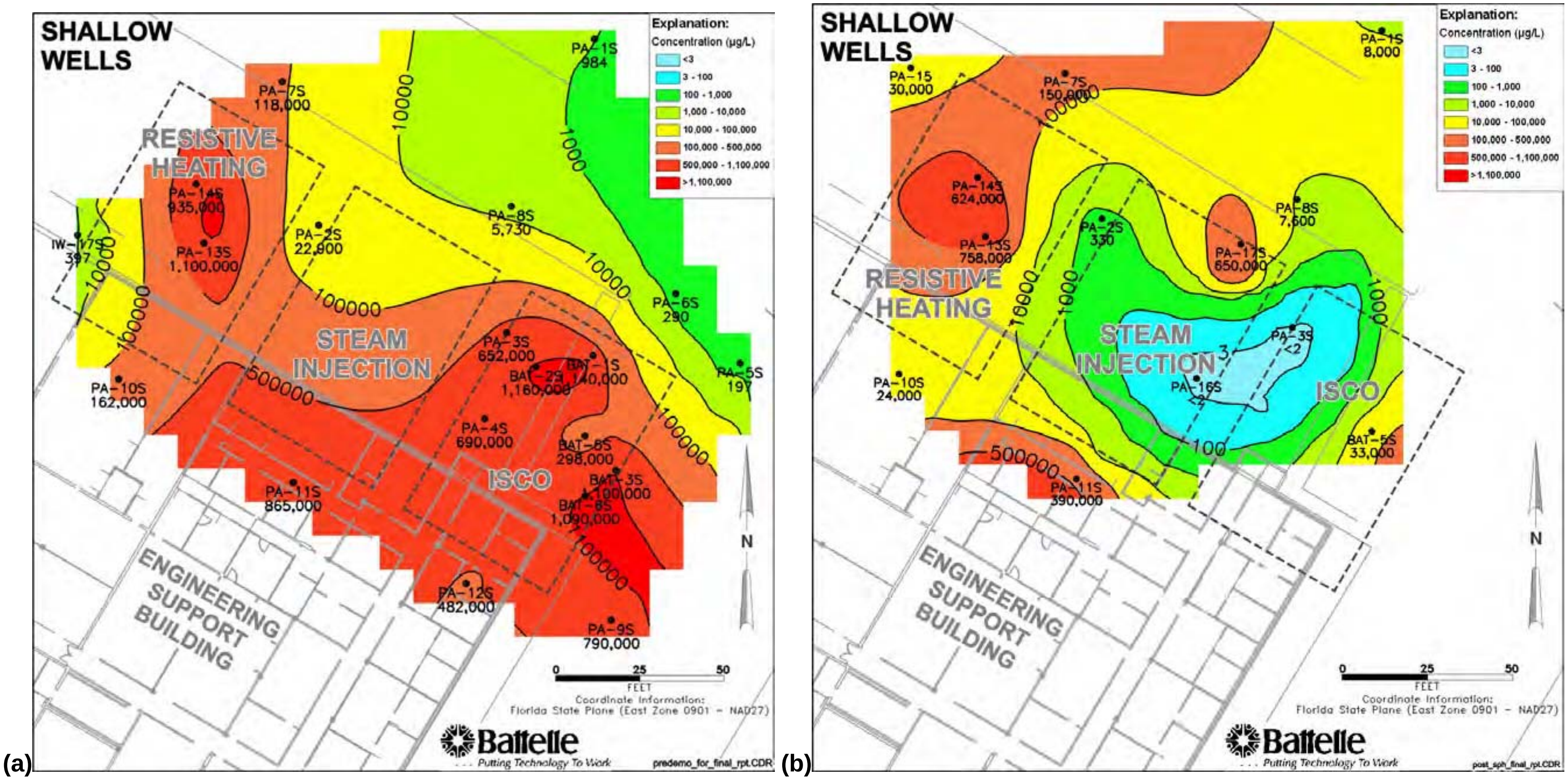

Figure 5-9. Dissolved TCE Concentrations (µg/L) during (a) Pre-Demonstration (August 1999) and (b) Post-Demonstration (December 2000) Sampling of Shallow Wells

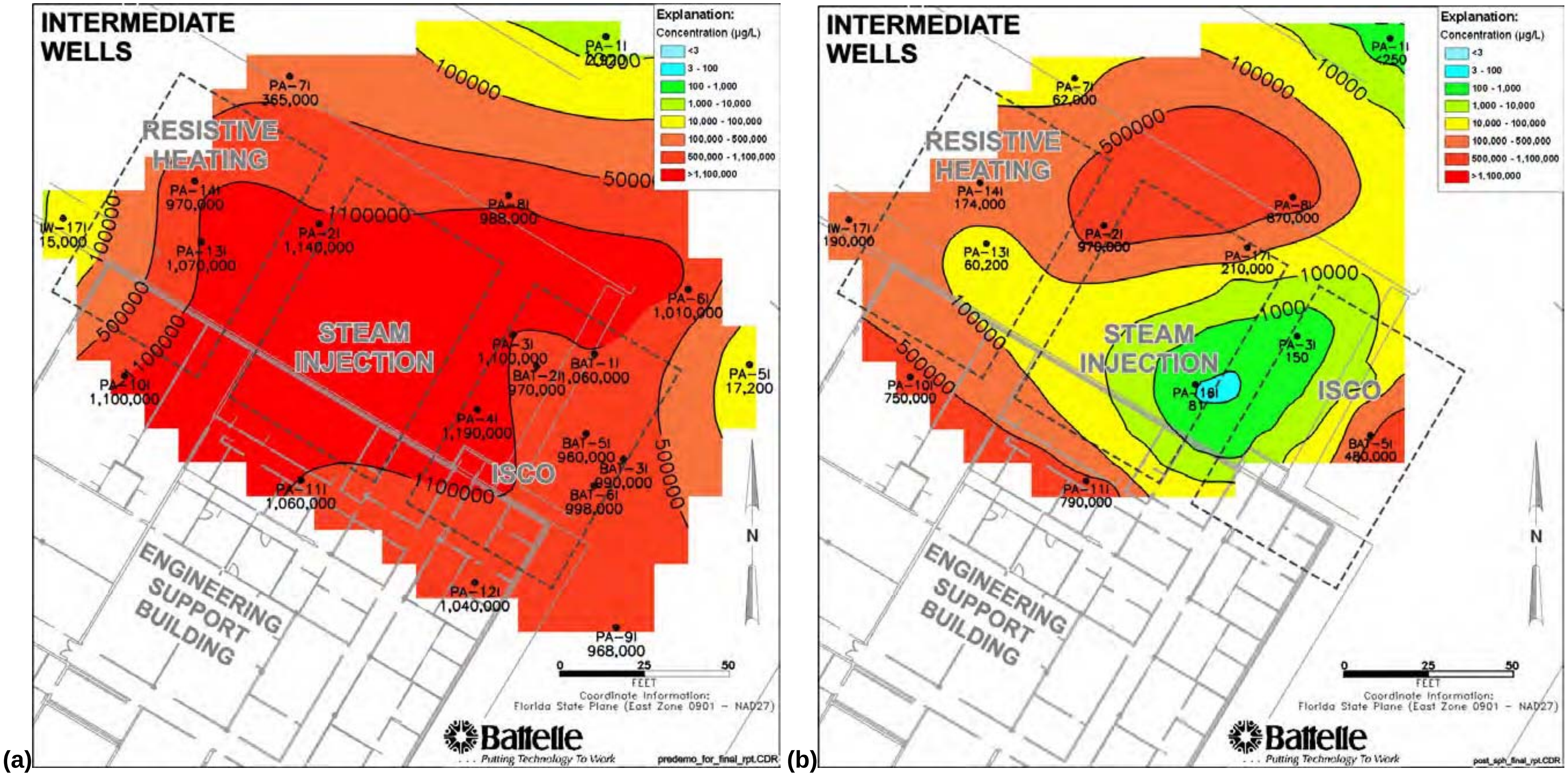

Figure 5-10. Dissolved TCE Concentrations (µg/L) during (a) Pre-Demonstration (August 1999) and (b) Post-Demonstration (December 2000) Sampling of Intermediate Wells

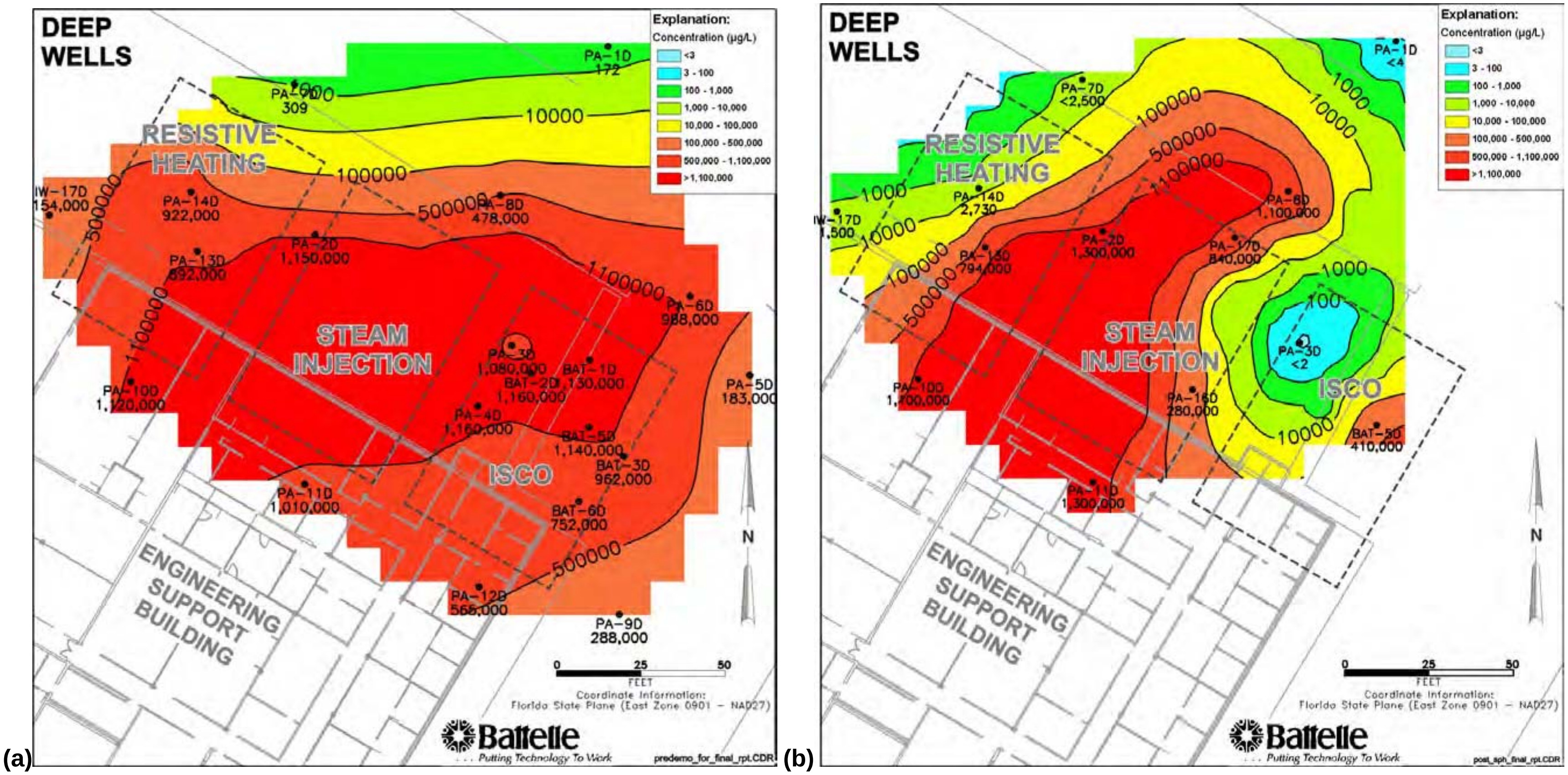

Figure 5-11. Dissolved TCE Concentrations (µg/L) during (a) Pre-Demonstration (August 1999) and (b) Post-Demonstration (December 2000) Sampling of Deep Wells

- Ground-water *pH* ranged from 6.9 to 7.5 before the demonstration to 6.3 to 7.6 after the demonstration, and relatively changed.
- *ORP* remained relatively unchanged, from −142 to −74 mV before the demonstration to −250 to −44 mV after the demonstration.
- *DO* ranged from 0.10 to 0.62 mg/L before the demonstration to 0.60 to 1.11 mg/L after the demonstration. Due to the limitations of measuring DO with a flowthrough cell, ground water with DO levels below 0.5 or even 1.0 is considered anaerobic. Except for the shallower regions, the aquifer was mostly anaerobic throughout the demonstration.
- *Specific Conductivity* increased from 0.776 to 3.384 mS/cm before the demonstration to 4.03 to 29.05 mS/cm after the demonstration. The increase is likely attributed to a buildup of dissolved ions due to the resistive heating treatment and also sea water intrusion.

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

- *Calcium* levels increased sharply, from 60 to 143 mg/L before the demonstration to 7 to 1,060 mg/L after the demonstration. Magnesium levels remained relatively unchanged from before to after the demonstration. Ground-water *alkalinity* increased from 337 to 479 mg/L before the demonstration to 231 to 898 mg/L after the demonstration. The increases in calcium and alkalinity (carbonate) may be due to contributions from additional saltwater intrusion or from the effect of heat on the seashell material (aragonite [see Section 5.2.2.2]) in the soil matrix.
- *Chloride* levels may have been relatively high in the aquifer due to possible historical saltwater intrusion, especially in the deeper units. Despite relatively high native chloride levels in the aquifer, chloride concentrations increased sharply in the three stratigraphic units. In the shallow wells, chloride increased from 37 to 38 mg/L before the demonstration to 141 to 383 mg/L after the demonstration. In the intermediate wells, chloride increased from 66 to 123 mg/L before the demonstration to 156 to 233 mg/L after the demonstration. In the deep wells, chloride levels increased from 11 to 774 mg/L before the demonstration to 3,520 to 4,800 mg/L after the demonstration. These increased chloride levels normally would be a primary indicator of CVOC destruction. However, in this case, there are other possible sources of chloride (see Section 5.3.1). The secondary drinking water limit for chloride is 250 mg/L.
- *Manganese* levels in the plot decreased slightly from <0.015 to 1.1 mg/L before the demonstration to <0.015 to 0.16 mg/L 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 relatively unchanged levels of manganese (0.03 to 0.11 mg/L). 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).
- *Iron* levels in the resistive heating plot remained relatively unchanged or decreased slightly, from <0.05 to 11 mg/L in the native ground water and <0.05 to 0.52 mg/L in the post-demonstration water; the secondary drinking water limit for iron is 0.3 mg/L, which was exceeded both before and after the demonstration. There was a possibility that chloride might corrode the stainless steel monitoring wells and dissolve some iron. This does not appear to have happened. In fact, it is possible that some dissolved iron precipitated out in the shallower regions of the aquifer.
- *Sodium* levels increased sharply, from 17 to 369 mg/L before the demonstration to 97 to 3,130 mg/L after the demonstration. Because sodium was not a concern as part of the resistive heating treatment, it was not measured during the demonstration.
- *Alkalinity* levels increased from 337 to 479 mg/L before the demonstration to 231 to 898 mg/L after the demonstration.
- Overall *sulfate* levels remained relatively constant, from 39 to 104 mg/L before the demonstration to 30 to 169 mg/L after the demonstration. However, sulfate levels did increase in the deep wells.
- *TDS* levels increased considerably in all three units. In the shallow wells, TDS levels rose from 548 to 587 mg/L before the demonstration to 1,330 to 1,750 mg/L after the demonstration; in the intermediate wells, TDS rose from 712 to 724 mg/L before to 870 to 925 mg/L after the demonstration; in the deep wells, TDS rose from 1,030 to 1,980 mg/L before to 7,220 to 10,600 mg/L after the demonstration. The secondary drinking water limit for TDS is 500 mg/L, which was exceeded both before and after the demonstration.
- *TOC and BOD* data were difficult to interpret. TOC in ground water increased from 6 to 40 mg/L before the demonstration to 9 to 300 mg/L after the

demonstration. BOD increased sharply in PA-13D and PA-14D, from <3 to 20 mg/L before the demonstration to 3 to 360 mg/L after the demonstration. The increase in ground-water TOC and BOD may indicate greater dissolution of native organic species (humic and fulvic materials) from the soil due to heating. TOC levels measured in soil increased sharply, ranging from <0.2 to 0.29 mg/kg before the demonstration to <100 to 986 mg/kg after the demonstration (see Table D-6 in Appendix D). The increase in soil TOC levels is difficult to explain; perhaps organic matter from surrounding regions deposited in the plot due to the heat-related convection.

Inorganic parameters were measured in the resistive heating plot wells, but they also were measured in the perimeter wells surrounding the plot and selected distant wells to see how far the influence of the applied technologies would progress. Further discussion about these inorganic parameters is presented in Section 5.3.1. The effect of the resistive heating treatment on the aquifer microbiology was evaluated in a separate study, as described in Appendix E.

5.2.2.2 Changes in Soil Geochemistry

In addition to the ground-water monitoring of geochemical parameters, post-demonstration soil samples were collected in the resistive heating plot and a control location in an unaffected area outside the plot (see Appendix D, Tables D-7 and D-8). These samples were initiated after unexpected drilling difficulties were encountered during post-demonstration soil coring by two different direct-push rigs at depths of approximately 16 to 18 ft bgs; neither rig could advance beyond this depth. Preliminary soil samples collected just above the obstruction depth were analyzed and appeared to indicate an increase in calcite deposits. An attempt was made later to penetrate the obstruction and collect additional soil samples for mineralogical analysis in order to evaluate any mineralogical changes that may have occurred due to the resistive heating application.

In May 2001, soil samples were successfully collected at multiple depths using a direct-push and vibratory hammer coring method. A visual inspection of the samples showed that they consisted of unconsolidated sand and contained whole shells and fragments of shell material (shell hash). Under low-power microscope the grains appeared coarse and ranged from light to dark in color, indicating the presence of several mineral types. No cementation of particles was observed.

Soil sample information is listed in Table 5-4. Cores labeled CCB1 were collected outside the resistive heating plot, and are thus expected to represent background

Table 5-4. Results of XRD Analysis (Weight Percent Abundances of Identified Minerals)

Core	Location	Depth (ft)	Quartz (%)	Calcite (%)	Aragonite (%)	Margarite (%)	Residue Error (%)
			Control				
CCB1	Outside the plot	16-18	85.0	5.3	7.6	2.1	69.0
CCB1		20-22	89.2	2.5	7.1	1.2	53.6
CCB1		22-24	95.7	0.5	3.5	0.2	68.4
CCB1		28-30	77.5	3.4	9.1	10.0	66.6
CCB1		32-34	54.1	5.5	37.8	2.6	65.2
CCB1		38-40	45.5	9.8	43.2	1.5	66.4
			Resistive Heating Plot				
CCB2	Inside the plot	16-18	86.8	2.0	9.9	1.3	70.5
CCB2		18-20	71.4	5.0	21.0	2.6	84.1
CCB2		22-24	88.8	1.7	7.1	2.5	67.6
CCB2[(a)]		28-30	NA	NA	NA	NA	NA
CCB2		30-33	70.8	6.5	20.6	2.2	56.4
CCB2		34-36	48.1	10.0	37.0	4.9	74.3
CCB3	Inside the plot	18-20	66.7	4.3	23.7	5.3	90.4
CCB3		20-22	66.0	2.3	5.9	25.9	72.6
CCB3		22-26	83.1	3.9	10.7	2.3	52.0
CCB3		26-30	67.8	6.0	24.3	1.9	57.8
CCB3		30-32	44.4	10.8	43.3	1.5	66.1
CCB3		38-40	46.6	11.4	38.0	4.0	89.2
CCB4	Inside the plot	16-18	52.6	11.5	33.8	2.1	84.7
CCB4		20-22	87.7	1.3	9.9	1.0	46.2
CCB4		24-26	64.8	5.2	27.3	2.7	77.3
CCB4		26-30	88.2	3.2	7.0	1.6	41.5
CCB4		34-36	69.5	3.4	23.3	3.8	94.0
CCB4		36-38	47.0	16.4	33.3	3.3	50.5

(a) In sample CCB2 (28-30 ft), a large unidentified peak occurred at 36.55° 2θ.

levels of minerals. Cores labeled CCB2, -3, and -4 were collected inside the SPH plot. The samples (24) were analyzed by x-ray diffraction (XRD) to determine relative abundances of minerals and other crystalline matter. XRD is a semiquantitative technique in which solid samples are analyzed nondestructively and without requiring preprocessing. Samples were scanned from 5° to 90° 2θ using a Rigaku powder diffractometer. Identification of compounds was facilitated by commercial software (Jade Software International) for matching observed peaks with known patterns from the Joint Commission on Powder Diffraction Files (JCPDF) database. Intensity measurements were converted to relative mass using relative Results of the XRD analysis are given in Table 5-4. Note that the composition of sample CCB2 (28-30 ft) was not determined due to the presence of a large unidentified peak, which would have rendered such a calculation uncertain.

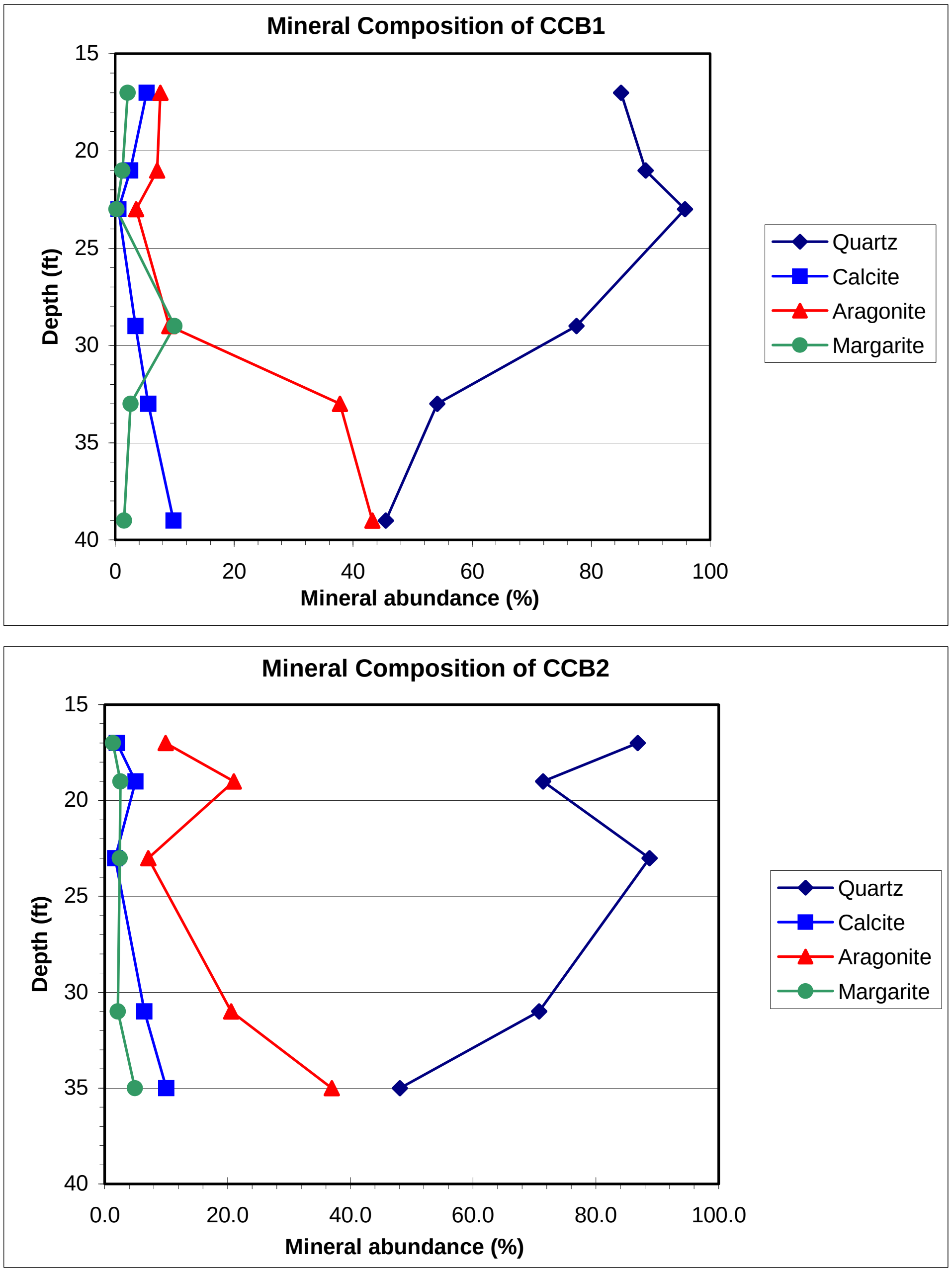

Figure 5-12. Mineral Abundance in Control (CCB1) and Resistive Heating Plot (CCB2) Soil Samples

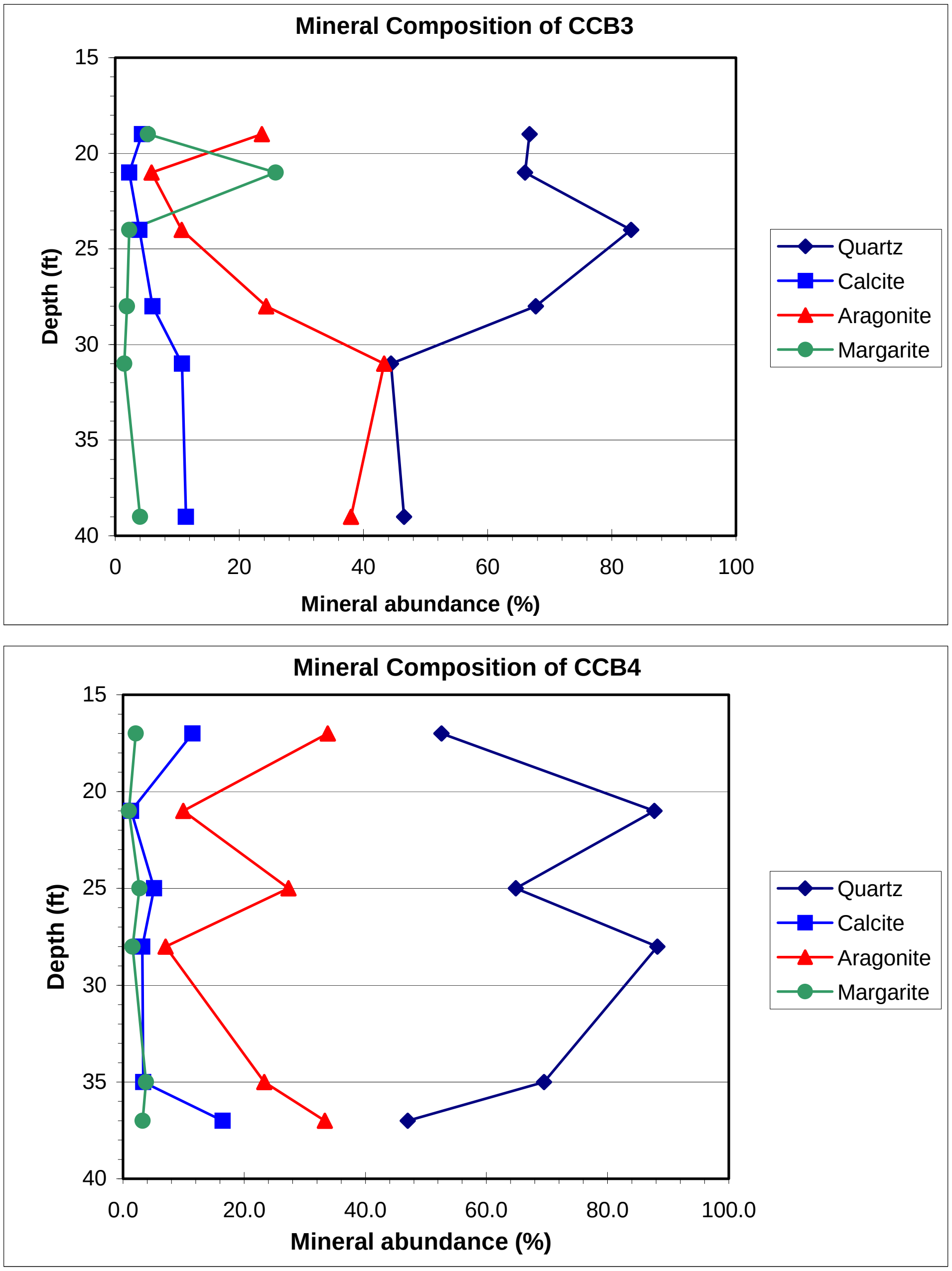

Figure 5-13. Mineral Abundance in Resistive Heating Plot Soil Samples CCB3 and CCB4

Graphs based on the data in Table 5-4 help illustrate the distribution of minerals in the subsurface in Figures 5-12 and 5-13. These data show that quartz and aragonite make up the majority of minerals identified in the core samples. The maximum amount of aragonite seems to occur at 30 to 40 ft bgs. Aragonite may be associated with shell material; if this is the case, then the increase in aragonite at 30 to 40 ft could coincide with a native sediment layer that is high in shell material. Calcite and margarite (mica) are less abundant. There appears to be a tendency for calcite to increase slightly with depth, which also corresponds to the ground-water monitoring of calcium.

In summary, the mineralogical composition of the post-demonstration resistive heating plot soil does not appear to be noticeably different from that of the soil in the unaffected region (control). It is possible that the drilling problem was a transient phenomenon or that it was caused by a change in the texture of the soil rather than by its composition.

5.2.3 Changes in the Hydraulic Properties of the Aquifer

Table 5-5 shows the results of pre- and post-demonstration slug tests conducted in the resistive heating plot wells. The hydraulic conductivity of the aquifer remained relatively unchanged during the resistive heating application.

Table 5-5. Pre- and Post-Demonstration Hydraulic Conductivity in the Resistive Heating Plot Aquifer

	Hydraulic Conductivity (ft/day)	
Well	Pre-Demonstration	Post-Demonstration
PA-13S	14.1	17.4
PA-13I	2.4	1.2
PA-13D	1.1	5.4
PA-14S	10.3	23.6
PA-14I	4.1	11.4
PA-14D	1.9	7.3

5.2.4 Changes in the Microbiology of the Resistive Heating Plot

Microbiological analysis of soil and ground-water samples was conducted to evaluate the effect of resistive heating treatment on the microbial community (see Appendix E.3 for details). Samples were collected before and twice (eight months and eighteen months) after the resistive heating demonstration. During pre- and post-demonstration monitoring events, soil samples were collected from five locations in the plot and five locations in a control (unaffected) area. Eighteen (18) months after the demonstration was complete, only three sets of samples were collected at similar depths in the plot. The results are presented in Appendix E.3.

Table 5-6 summarizes the soil analysis results. The geometric mean typically is the mean of the five samples collected in each stratigraphic unit in the plot. The eight months of time that elapsed since the end of resistive heating application and collection of the microbial samples may have given time for microbial populations to reestablish. Only in the Middle Fine-Grained Unit does it seem that the resistive heating application caused a reduction in microbial populations that persisted until the sampling. If microbial populations were reduced immediately after the demonstration, they seem to have re-established in the following eight months. In the capillary fringe and in the Upper Sand Unit, microbial populations appeared to have increased by an order of magnitude. The persistence of these microorganisms despite the autoclave-like conditions in the resistive heating plot may have positive implications for biodegradation of any TCE residuals following the resistive heating treatment.

5.2.5 Summary of Changes in Aquifer Quality

Application of the resistive heating technology caused the following changes in the treated aquifer:

- Dissolved TCE levels declined in several monitoring wells in the resistive heating plot, although none of the wells showed post-demonstration concentrations of less than 5 µg/L, the federal drinking water standard, or 3 µg/L, the State of Florida ground-water target cleanup level. *Cis*-1,2-DCE levels remained above 70 µg/L and increased considerably in some wells. Vinyl chloride (1 µg/L State of Florida target) levels could not be accurately determined because higher TCE and *cis*-1,2-DCE levels elevated the detection limits of vinyl chloride. This indicates that, in the *short term*, removal of DNAPL mass from the targeted aquifer caused ground-water TCE concentrations to decline. Dissolved-phase

Table 5-6. Geometric Mean of Microbial Counts in the Resistive Heating Plot (Full Range of Replicate Sample Analyses Given in Parentheses)

Resistive Heating Plot	**Pre-Demonstration Aerobic Plate Counts (CFU/g)**	**Post-Demonstration Aerobic Plate Counts (8 months after) (CFU/g)**	**Pre-Demonstration Anaerobic Viable Counts (Cells/g)**	**Post-Demonstration Anaerobic Viable Counts (8 months after) (Cells/g)**
Capillary Fringe	32,680 (12,589 to199,526)	3,285,993 (63,096 to 63,095,734)	32,680 (3,162 to 1,584,893)	2,818,383 (79,433 to 15,848,932)
Upper Sand Unit	575 (<316 to 6,310)	5,410 (100 to 1,258,925)	1,050 (158 to 50,119)	11,961 (126 to 15,848,932)
Middle Fine-Grained Unit	2,370 (200 to 1,584,893)	<316.2[(a)]	10,000 (501 to 1,258,925)	251.2[(a)]
Lower Sand Unit	856 (<316 to 25,119)	758 (158 to 25,119)	1,711 (251 to 63,096)	2,188 (251 to 50,119)

(a) Only one sample was collected in this stratigraphic unit.

CVOCs were not as efficiently removed, especially from the upper portions of the aquifer, probably due to the lower heating/stripping efficiency in the shallower regions.

- Compared to short-term post-demonstration levels, dissolved TCE levels in the plot in the *intermediate term* could either increase (due to rebound from any remaining DNAPL) or decrease (due to continued degradation of CVOCs by any abiotic or biological mechanisms). Because resistive heating treatment has depleted the DNAPL source, any intermediate term rebound in TCE concentrations is not likely to restore dissolved TCE levels to pre-demonstration levels. A weakened plume may be generated and the resulting CVOC levels may be more amenable to natural attenuation. The downgradient point at which ground water meets federal or state cleanup targets is likely to move closer to the DNAPL source, resulting in a concomitant risk reduction.
- In the *long term*, DNAPL mass removal is expected to lead to eventual and earlier depletion of the plume and earlier dismantling of any interim remedy to control plume movement.
- The TCE degradation product *cis*-1,2-DCE, which also is subject to drinking water standards (70 µg/L), appeared to be accumulating in the ground water in the test plot, and its buildup could be a concern. Its accumulation may indicate that the degradation rate of *cis*-1,2-DCE is not as fast as the degradation rate of TCE, under the conditions prevalent in the aquifer.
- Ground-water pH and dissolved oxygen levels remained relatively constant, but chloride, sodium, potassium, sulfate, alkalinity (carbonate), and TDS levels rose sharply. TDS levels were above the secondary drinking water standard of 500 mg/L both before and after the demonstration, classifying the aquifer as brackish. Sources of these dissolved solids could include evaporative residue, saltwater intrusion, displacement of exchangeable sodium from aquifer minerals, and/or CVOC degradation.
- Biological oxidation demand and TOC levels in the ground water generally increased. These increases could be due to dissolution of humic and fulvic matter in the aquifer under the heat treatment.
- The ground-water levels of iron, chromium, and nickel remained relatively constant. There does not appear to be any significant corrosion of the stainless steel monitoring wells of the kind experienced in the ISCO plot.
- Slug tests conducted in the resistive heating plot before and after the demonstration did not indicate any noticeable changes in the hydraulic conductivity of the aquifer.
- Although difficulties were encountered in operating the drill rig during post-demonstration coring, the geochemical composition of the soil does not appear to have changed much due to the heat treatment. Quartz and aragonite make up the majority of the minerals identified in soil samples from heat-affected and unaffected regions of the aquifer. Aragonite may be associated with the seashell fragments found in fair abundance in the aquifer. Calcite and margarite (mica) are less abundant in the aquifer.

5.3 Fate of the TCE-DNAPL Mass in the Plot

This part of the assessment was the most difficult because the DNAPL could have taken one or more of the following pathways when subjected to the resistive heating treatment:

- TCE recovery in the resistive heating vapor recovery system
- TCE-DNAPL degradation through biological or abiotic mechanisms
- DNAPL migration to surrounding regions
- Potential TCE losses during post-demonstration sampling of hot soil cores.

Vapor sampling conducted by the resistive heating vendor indicates that 1,947 kg of total TCE was recovered in the vapor extraction system. The initial estimate of total TCE mass in the subsurface was 11,313 kg. Other pathways that the TCE in the plot may have taken are discussed in this section.

The chloride mass estimates, which are potential TCE degradation indicators, are considered somewhat coarse approximations for the following reasons:

- *Relatively low sampling density* compared to the sampling density for TCE, which was the main focus of the performance assessment
- *Possible migration of chloride in directions where there are no monitoring wells* (e.g., east and southeast side of ISCO plot and west and southwest side of resistive heating plot). The samples labeled CHL-# and collected with a Geoprobe® by FSU and NASA do help to cover some of these data gaps.
- *Timing of post-demonstration samples*. Because the ISCO and resistive heating demonstrations

ended at different times, the post-demonstration sampling for the two plots and perimeter wells was spread over several months. In the absence of an artificial gradient (such as that created in the ISCO plot during injection in April 2000), the ground water is relatively stagnant; therefore, any changes in chloride levels during the somewhat wide sampling period are likely to be due to diffusion and therefore relatively low.

Despite these limitations, a chloride evaluation does provide some insights into the occurrences in the two test plots.

5.3.1 TCE-DNAPL Degradation through Biological or Abiotic Mechanisms

As reported in Appendix D, ground-water samples collected from the Launch Complex 34 wells and GeoProbe® monitoring points were analyzed for chloride (see Figure 5-14 for sampling locations). The chloride analysis was evaluated because an increase in chloride levels is a potential indicator of CVOC degradation, either by abiotic or biologically mediated pathways. Table 5-7 shows the changes in concentrations of chloride and other ground-water constituents in the resistive heating plot. Figures 5-15 to 5-17 show the distribution of excess chloride concentrations in the ground water at Launch Complex 34—excess chloride plotted in these figures is the difference in chloride concentrations between post-demonstration and pre-demonstration (baseline) levels. The excess chloride represents chloride accumulating in the aquifer at Launch Complex 34 due to the implementation of the resistive heating and/or ISCO technologies. Chloride levels rose in both resistive heating and ISCO plots by 7 to 10 times the pre-demonstration concentration in the resistive heating plot wells.

As shown in Table 5-8, the chloride concentrations were converted to chloride masses in different target regions of the aquifer. The mass estimates in Table 5-8 were done using four target boundaries:

- Each individual test plot only
- Each test plot and its perimeter (extending up to the nearest perimeter well outside the plot). This was done on the assumption that the chloride generated inside the plot spreads at least to the immediate perimeter area around the plot.
- Each test plot and its perimeter, as well as the areas covered by the GeoProbe® samples (labeled "CHL" samples) collected by FSU, following the resistive heating and ISCO demonstrations. The GeoProbe® samples provide additional resolution to the perimeter areas.
- All three plots ("entire site") and their perimeter (with and without the CHL sample data).

The interpolation used to calculate the masses in Table 5-8 is linear and the contouring software (EarthVision™) used for estimating TCE mass was also used to estimate chloride mass. The volumetric package in this application software calculates the volume of isoconcentration shells that are contoured in three dimensions using the spatial chloride data. A chloride mass is calculated in each isoconcentration shell covering the region of interest (e.g., test plot only, or test plot and perimeter, etc.). For both plots, the total increase in chloride mass is much larger when the chloride levels in the perimeter wells are taken into account. This shows that the chloride formed in the plot spreads to surrounding regions.

At Launch Complex 34, there are a variety of factors that make it important that the chloride data not be viewed in isolation. Rather, due to the particular site characteristics of Launch Complex 34, the changes in chloride need to be viewed from the perspective of site location, aquifer geochemistry, the type of treatments applied in the test plots, and any crossover effects due to the simultaneous implementation of the resistive heating and ISCO technologies. TDS levels rose in several monitoring wells following the demonstration at Launch Complex 34, and only a part of this increase is attributable to chloride. Therefore, it also is important to identify potential sources for the increased levels of dissolved constituents other than chloride.

The elevated chloride concentrations (and masses) in the resistive heating plot can be attributed to one or more of the following causes:

- Evaporation of ground water from the resistive heating plot
- Redistribution of ground water due to convection, advection and displacement
- Dechlorination of TCE, *cis*-1,2-DCE, and/or vinyl chloride due to microbial interaction
- Saltwater intrusion into the resistive heating plot
- Migration from the ISCO plot
- Dechlorination of TCE, *cis*-1,2-DCE, and/or vinyl chloride by abiotic mechanisms.

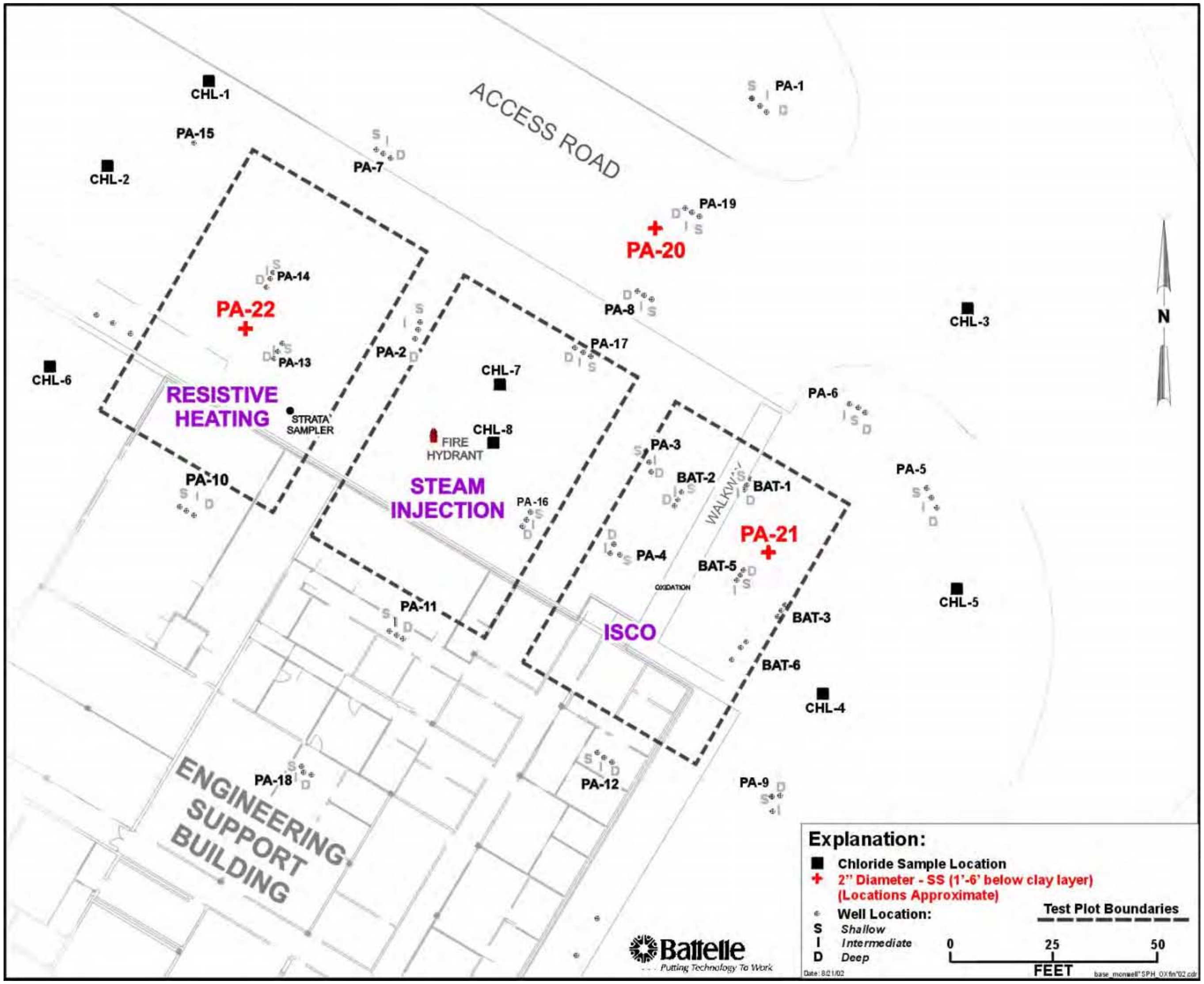

Figure 5-14. Monitoring Wells and GeoProbe® Monitoring Points (CHL-#) for Chloride Analysis (Sampled January to May 2001)

Table 5-7. Pre- and Post-Demonstration Inorganic and TOC/BOD Measurements in Resistive Heating Plot Wells

	Calcium			Magnesium			Sodium			Potassium		
Well ID	Pre-Demo	Post-Demo	July 2001	Pre-Demo	Post-Demo	July 2001	Pre-Demo	Post-Demo	July 2001	Pre-Demo	Post-Demo	July 2001
PA-13S	<1	**233**	**97.4**	23.4	54.4	40	23.9	**161**	**113**	< 5	**126**	**174**
PA-13I	70.1	NA	153	54	NA	76.5	33.1	NA	96.7	13	NA	49
PA-13D	113	**819**	**647**	113	51.4	75	369	**2,070**	**1,530**	20	**136**	86
PA-14S	97.4	6.6	55.3	37.4	<1	10.6	17.4	**467**	**138**	NA	9.8	43
PA-14I	60.3	NA	13.6	73.7	NA	1.2	120	NA	258	NA	NA	14
PA-14D	93.1	**1,060**	**662**	90.3	30	30.2	325	**3,130**	**2,490**	NA	143	94

	Chloride			NO_3-NO_2			Sulfate			Alkalinity as $CaCO_3$		
Well ID	Pre- Demo	Post-Demo	July 2001	Pre- Demo	Post-Demo	July 2001	Pre-Demo	Post-Demo	July 2001	Pre-Demo	Post-Demo	July 2001
PA-13S	38	**383**	277	<0.1	<0.1	<0.1	74	169	123	479	588	424
PA-13I	66	NA	233	<0.1	NA	<0.1	64.8	NA	150	351	NA	243
PA-13D	NA	**4800**	**3610**	<0.1	<0.1	0.21	78.3	166	139	410	231	268
PA-14S	37	141	101	<0.1	<0.1	<0.1	39	37.1	18.6	337	898	388
PA-14I	123	NA	156	<0.1	NA	<0.1	104	NA	30	465	NA	434
PA-14D	774	**3520**	**4790**	<0.1	<0.1	<0.1	68.3	117	163	343	421	394

	TDS (mg/L)			BOD (mg/L)			TOC (mg/L)		
Well ID	Pre- Demo	Post-Demo	July 2001	Pre-Demo	Post-Demo	July 2001	Pre-Demo	Post-Demo	July 2001
PA-13S	583	**1,750**	**1,190**	20	32.4	25.8	5.6	**44.8**	**39.6**
PA-13I	NA	NA	925	<3	NA	3.3	7.1	NA	14.9
PA-13D	NA	**10,600**	**8,360**	13.2	**360**	**360**	39.6	**300**	**273**
PA-14S	548	**1,330**	772	<3	**42**	**22.2**	5.7	34.7	18.7
PA-14I	724	NA	870	8.9	NA	3.7	23.4	NA	8.9
PA-14D	1,980	**7,220**	**10,700**	6	**288**	**560**	9	**270**	**326**

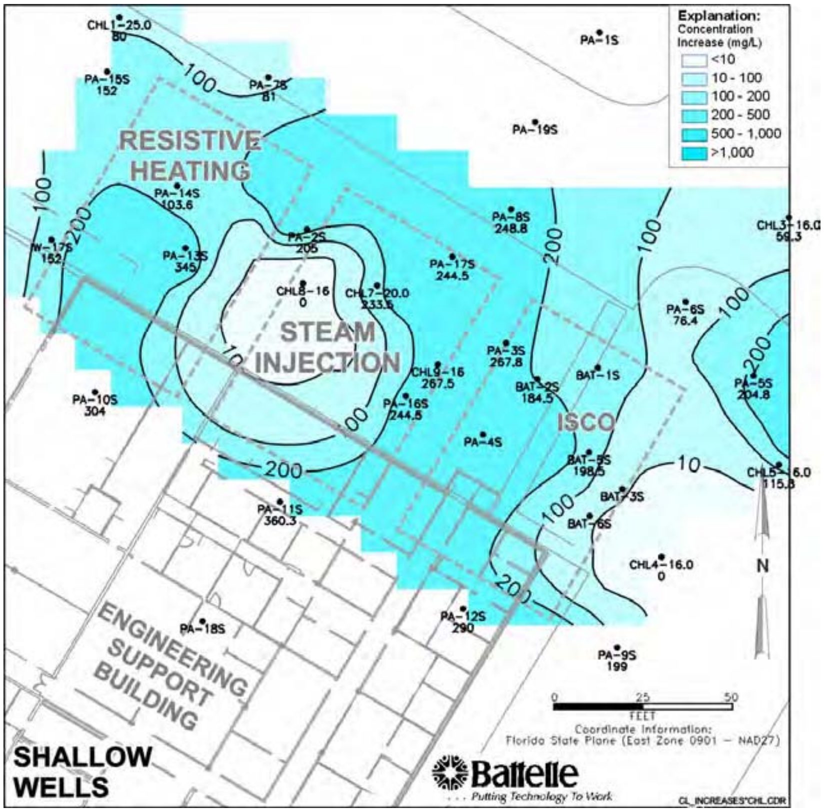

Figure 5-15. Increase in Chloride Levels in Shallow Wells (Sampled January to May 2001)

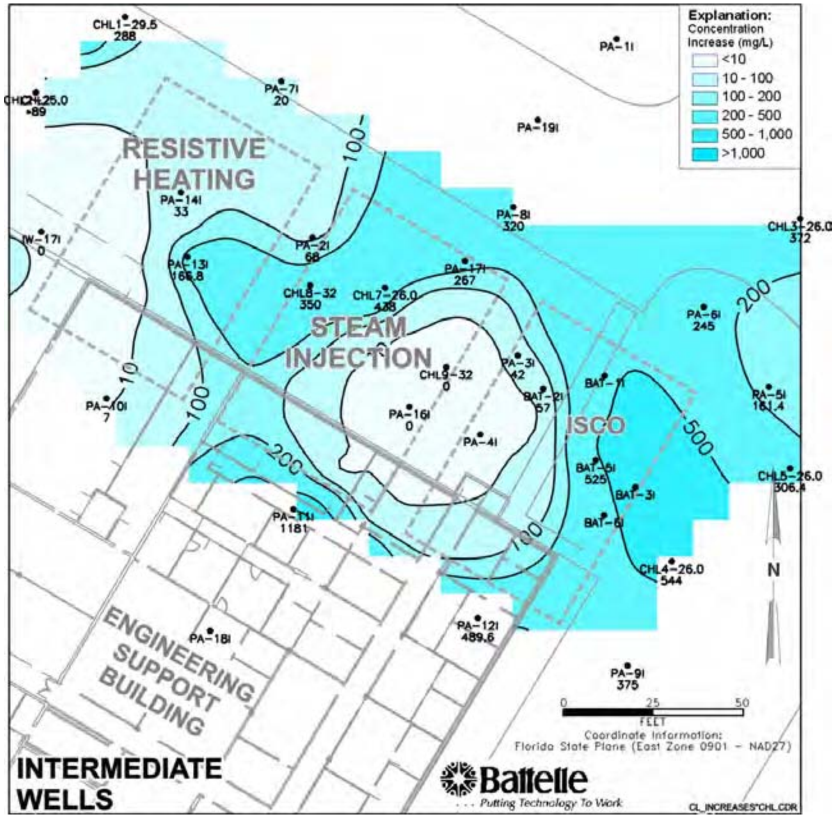

Figure 5-16. Increase in Chloride Levels in Intermediate Wells (Sampled January to May 2001)

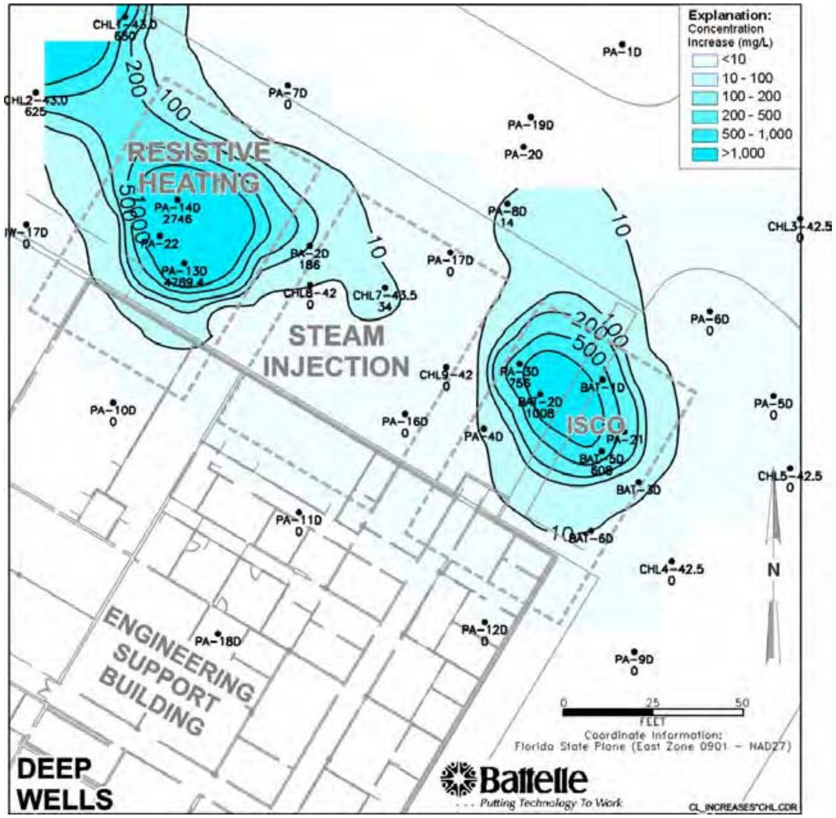

Figure 5-17. Increase in Chloride Levels in Deep Wells (Sampled January to May 2001)

Table 5-8. Chloride Mass Estimate for Various Regions of the Launch Complex 34 Aquifer

Boundaries for Estimate	Pre-Demonstration Chloride Mass (kg)	Post-Demonstration Chloride Mass (kg)	Increase in Chloride Mass (kg)	% Increase in Mass (%)
ISCO Plot Only	828	1,822	994	120%
Resistive Heating Plot Only	524	2,160	1,636	**312%**
ISCO Plot and Perimeter	2,438	4,934	2,495	102%
Resistive Heating Plot and Perimeter	1,606	4,241	2,635	**164%**
ISCO Plot and Perimeter/CHL Data	3,219	5,524	2,304	72%
Resistive Heating Plot and Perimeter/CHL Data	1,722	4,491	2,770	**161%**
Entire Site	4,264	9,188	4,923	115%
Entire Site with CHL Data	4,900	9,118	4,219	86%

Boldface in the table denotes the significant increase of chloride mass after the application of the resistive heating treatment.

5.3.1.1 Evaporation as a Potential Source of Chloride

The thermal treatment in the resistive heating plot causes some ground water to evaporate, leaving behind dissolved solids (including chloride) as residue. Table 5-9 provides a calculation of the amount of chloride that may have been deposited in the resistive heating plot by the water evaporating due to the heating. The 371,074 L of condensate collected above ground would have left behind 153 kg of chloride, if only the measurements in the wells inside the plot are taken into account (that is, the concentrations in PA-13 and PA-14 are assumed to extend to the boundaries of the plot). If the measurements in the perimeter wells are taken into account, 468 kg of chloride would have been left behind by the condensate. The chloride deposited by evaporation accounts for only 9 to 18% of the total increase in chloride in the resistive heating plot.

5.3.1.2 Microbial Degradation as a Source of Chloride

It is possible that some TCE was reductively dechlorinated due to microbial interactions. The biological sampling (see Section 5.2.4) indicated that microbes did survive after the heat treatment. Considerably elevated levels of *cis*-1,2-DCE, a degradation byproduct, are also apparent in some monitoring wells in and around the resistive heating plot (see the *cis*-1,2-DCE analysis summary in Table 5-10), although in one of the wells (PA-14D), *cis*-1,2-DCE levels dropped sharply following the demonstration. If microbial degradation is a viable mechanism, one concern would be the buildup of *cis*-1,2-DCE, which is subject to applicable ground-water cleanup standards (typically 70 µg/L). Degradation of TCE by reductive dechlorination may be a much faster process as compared to degradation of *cis*-1,2-DCE under the anaerobic conditions of the aquifer. Persistence of *cis*-1,2-DCE

Table 5-9. Contribution of Chloride from Evaporation in the Resistive Heating Plot and Vicinity

Calculated Parameter	Chloride Mass Estimation Using Resistive Heating Plot Well Data Only[(a)]	Chloride Mass Estimation Using Resistive Heating Plot and Perimeter Well Data
Pre-Demonstration Chloride Mass	524 kg	1,606 kg
Volume of Water Condensate Recovered	371,074 L (98,038 gal)	371,074 L (98,038 gal)
Volume of Pore Water in Plot (based on a porosity of 0.3)	1,274,265 L	1,274,265 L
Estimated Chloride Mass Left Behind by Condensate	153 kg	468 kg
Estimated Total Increase in Chloride Mass in the Plot (from Table 5-1)	1,636 kg	2,635 kg
Amount of Total Increase in Chloride Mass Accounted for by Evaporative Residue	9%	18%

(a) Based on chloride concentrations in monitoring well clusters PA-13 and PA-14.

Table 5-10. *cis*-1,2-DCE Levels in Resistive Heating Plot and Perimeter Wells

Well ID	Pre-Demo	Post-Demo	June 2001
Resistive Heating Plot Wells			
PA-13S	4,400	21,000 J	14,000
PA-13I	4,900	NA	9,370
PA-13D	2,200	18,000 J	52,000
PA-14S	5,880	95,000	73,800
PA-14I	26,000	NA	80,000
PA-14D	21,900	1,100	2,660
Resistive Heating Plot Perimeter Wells			
PA-2S	3,020	6,000	NA
PA-2I	5,480	11,000 J	NA
PA-2D	2,700	<33,000	NA
PA-7S	22,100	130,000	NA
PA-7I	160,000	170,000	NA
PA-7D	21	30,000	NA
PA-10S	8,880	19,000	NA
PA-10I	4,700J	12,000 J	NA
PA-10D	2,400J	23,000 J	NA
IW-17S	593	Dry	NA
IW-17I	123,000	30,000	NA
IW-17D	39,200	16,000 D	NA
PA-15	NA	170,000	NA

and probably vinyl chloride (which was not detected in many ground-water samples due to the masking effect of TCE and *cis*-1,2-DCE) in the aquifer is a concern. The limiting conditions obstructing *cis*-1,2-DCE degradation may need to be determined and addressed to control *cis*-1,2-DCE and vinyl chloride plume strengthening.

5.3.1.3 Saltwater Intrusion as a Source of Chloride

It is *possible* that saltwater intrusion into the resistive heating plot led to the sharp increases in sodium and chloride. No other source is apparent that would contribute to such high levels of both sodium and chloride, which are the two main constituents of seawater (see Table 5-11). Sodium increased by up to 9 times in the resistive heating plot wells, an increase similar in proportion to the increase in chloride. Both sodium and chloride are especially high in the deeper regions of the aquifer. Heating of the plot and the resulting convection could cause the highly saline water at the bottom of the aquifer to rise into the bulk of the aquifer. This water would then be replaced with additional saline water from the bottom of the surrounding aquifer regions. The elevated temperatures in the resistive heating plot could have caused an increase in the solubility of sodium and chloride and contributed to the retention of chloride in the plot. Because of normally stagnant ground-water conditions in the plot, the sodium and chloride could be retained in the plot during the subsequent cooling of the ground water. The noticeable increases in sulfate, potassium, and calcium levels in the plot also are indicative of saltwater intrusion, although, unlike sodium, they could have come from other sources— the calcium from the seashell material in the aquifer, and/or the calcium, potassium, and sulfate from migration from the ISCO plot.

Table 5-11. Seawater Composition

Element	Concentration (mg/L)
Chloride	18,980
Sodium	10,561
Magnesium	1,272
Sulfur	884
Calcium	400
Potassium	380

It is possible that some *exchangeable* sodium was released from clay minerals when the Middle Fine-Grained Unit or Lower Clay Unit (aquitard) was heated. Alternatively, some influx of potassium ion from the ISCO plot (see Section 5.3.2.1) could have caused displacement of sodium ions. But the relatively low proportion of the clay (approximately 1.5 ft thick) versus the sandy/silty aquifer (40 ft thick) makes it unlikely that so much sodium was contributed to the aquifer by the clay.

5.3.1.4 Migration from the ISCO Plot as a Source of Chloride

It is possible that some chloride migrated from the ISCO plot, just as the potassium did. Increased levels of these constituents in the wells between the oxidation and resistive heating plots are indicative of this pathway. As seen in Tables 5-12 and 5-13 and in Figures 5-15 to 5-17, many of the monitoring wells in the migration path, such as PA-16, PA-17, PA-8, and PA-11 in the steam plot and vicinity, showed increased levels of chloride and TDS, especially in the shallow and intermediate levels. The increase in potassium can be similarly tracked from the ISCO plot to the resistive heating plot, as reported in the Fourth Interim Report (Battelle, 2000b). Similar migration trends can be seen for calcium, alkalinity, TOC, and BOD, which increased in the steam injection plot wells as well. Part of the increase in potassium levels in the resistive heating plot could have been due to saltwater intrusion rather than crossover from the ISCO plot.

5.3.1.5 Abiotic Degradation as a Source of Chloride

It is possible that some TCE was degraded abiotically by reductive dechlorination caused by exposure of the ground water and TCE to the carbon steel shot used in the electrodes. The steel shot are relatively fine and not too different in size and composition from the granular cast iron used in permeable barriers for ground-water treatment. Other possible abiotic mechanisms are heat-induced hydrolysis or oxidation.

Table 5-12. Chloride and TDS Measurements in Monitoring Wells Surrounding the Resistive Heating Plot

	Chloride (mg/L)			TDS (mg/L)	
Well ID	Pre-Demo	ISCO Post-Demo	Resistive Heating Post-Demo	Pre-Demo	Post-Demo
Resistive Heating Perimeter Wells					
PA-2S	34(a)	247	243	520(a)	915
PA-2I	55(a)	234	191	580(a)	1,050
PA-2D	760(a)	695	960	1,700(a)	2,720
PA-7S	NA	NA	119	NA	657
PA-7I	NA	NA	143	NA	752
PA-7D	NA	NA	531	NA	1,260
PA-7D-DUP	NA	NA	522	NA	1,270
PA-10S	NA	NA	342	NA	1,040
PA-10I	NA	NA	130	NA	789
PA-10I-DUP	NA	NA	128	NA	777
PA-10D	NA	NA	701	NA	1,580
IW-17S	NA	NA	NA	NA	NA
IW-17I	NA	NA	73.7	NA	663
IW-17D	NA	NA	640	NA	1,350
PA-15	NA	NA	190	NA	975
Resistive Heating Vicinity Wells					
PA-16S	NA	NA	<1,000	NA	2,470
PA-16I	NA	NA	42.8	NA	814
PA-16D	NA	NA	415	NA	4,510
PA-17S	NA	NA	297	NA	1,740
PA-17I	NA	NA	448	NA	1,360
PA-17D	NA	NA	305	NA	1,200
PA-17D-Dup	NA	NA	318	NA	1,340
PA-8S	24.2	273	101	445	1,600
PA-8S-DUP	NA	NA	NA	NA	NA
PA-8I	119	439	504	706	2,200
PA-8D	774	788	640	1,410	1,910
PA-8D-DUP	NA	NA	NA	NA	NA
PA-11S	36.7	397	357	531	2,900
PA-11I	49	1,230	635	549	3,790
PA-11D	819	756	737	1,540	1,670
PA-11D-DUP	NA	NA	NA	NA	NA

(a) Pre-demonstration levels of chloride in PA-2 are based on concentrations in neighboring wells. PA-2 itself was not one of the wells sampled for chloride during the pre-demonstration event.

Table 5-13. Inorganic and TOC Measurements (mg/L) in Ground Water from the Steam Injection Plot after Resistive Heating Demonstration(a)

Well ID	Sodium	Potassium	Calcium	Magnesium	Sulfate	Alkalinity	TOC
PA-16S	45	1,560	28	<2	<1,000	661	1,680
PA-16I	42	511	31	4	104	380	31
PA-16D	72	1,600	111	179	681	2,500	134
PA-17S	189	330	108	74	293	1,430	74
PA-17I	213	33	93	101	120	422	2
PA-17D	147	103	91	100	202	479	20

(a) These wells were installed only after the resistive heating and ISCO treatment demonstrations were completed. The parameter levels before the resistive heating and ISCO treatments began (see Table 5-3) can be compared to the values in the surrounding wells.

5.3.2 Potential for DNAPL Migration from the Resistive Heating Plot

The seven measurements conducted to evaluate the potential for DNAPL migration to the surrounding aquifer include:

- Hydraulic gradient in the aquifer
- Temperature measurements in the resistive heating plot and vicinity
- 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
- TCE concentrations in the confined aquifer.

5.3.2.1 Potential for DNAPL Migration to the Surrounding Aquifer

Hydraulic gradients (water-level measurements). As mentioned in Section 5.2, pre-demonstration *hydraulic gradients* in the Launch Complex 34 aquifer are relatively flat in all three stratigraphic units. There was no noticeable change in hydraulic gradient in the resistive heating plot and vicinity *during* the demonstration, although the monitoring wells inside the resistive heating plot were not available for monitoring at all times. On the other hand, water-level measurements collected in April 2000 (see Figures 5-18 to 5-20) in the surrounding wells showed a sharp hydraulic gradient emanating radially from the ISCO plot, especially in the Lower Sand Unit. These measurements were taken while the third and final oxidant injection was under way in the Lower Sand Unit of the ISCO plot. During the April 2000 event, the gradient was not as strong in the shallow and intermediate wells, indicating that the Middle Fine-Grained Unit acts as a conspicuous hydraulic barrier. Residual DNAPL cannot migrate due to hydraulic gradient alone, no matter how strong. However, if there was *mobile* DNAPL present in the aquifer, strong injection pressures could have caused DNAPL movement from the ISCO or steam injection plot. Also, the heating in the resistive heating plot could have caused some of the residual DNAPL in the plot to become more mobile (heating reduces surface tension of the DNAPL causing it to move more easily) and migrate under the influence of these externally generated hydraulic gradients. In general, the strong hydraulic gradients originating from the ISCO plot makes evaluation of DNAPL migration in the resistive heating plot difficult.

Temperature measurements conducted with a downhole thermocouple in May 2000 are shown in Figures 5-6 to 5-8 for the shallow, intermediate, and deep wells in the resistive heating plot and vicinity. As expected, the largest increase in temperature was in the middle of the resistive heating plot (where the electrodes were installed). Temperature increased noticeably in all five perimeter well clusters (PA-10, IW-17, PA-15, PA-7, and PA-2) but remained at baseline (pre-demonstration) levels in the more distant wells. Post-demonstration soil cores collected around the resistive heating plot and inside the building also were warm, indicating that heat generated in the resistive heating plot had spread to the surrounding regions through conduction and/or convection. The temperature data indicate that DNAPL in the resistive heating plot and vicinity had the potential to be mobilized by hydraulic gradients. At ambient temperatures, residual DNAPL cannot be mobilized, but heating reduces surface tension of the DNAPL making it more amenable to movement in the aquifer. This could be one explanation for the DNAPL that appeared in PA-2I and PA-2D wells, after the resistive heating demonstration had commenced. Thermally induced convection could assist such movement. Alternatively, heat-vaporized TCE migrating upward in the Lower Sand Unit could have encountered the Middle Fine-Grained Unit and migrated sideways to the surrounding aquifer. It is difficult to interpret the true effect of a mix of thermal and hydraulic gradients in the resistive heating plot resulting from the demonstration.

Migration of ground water and dissolved ground-water constituents from the ISCO plot are exemplified by the movement of **potassium ion** in the aquifer, as shown in Figures 5-21 to 5-23. Potassium, originating from the injected oxidant, acts as a conservative tracer for tracking ground-water movement. Figures 5-21 to 5-23 show the excess potassium (above pre-demonstration levels) in the ground water at Launch Complex 34. Because more monitoring wells are present on the western side of the ISCO plot, movement seems to be occurring to the west; however, similar ground-water transport probably occurred in all directions from the plot. This migration of ground water 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. In summary, both technologies, the resistive heating and ISCO treatments, created conditions conducive to DNAPL migration.

TCE and other CVOCs are among the dissolved species that migrated from the resistive heating plot as indicated by the TCE measurements in perimeter and distant wells (see Appendix C). Figures 5-24 to 5-26 show the TCE trends observed in the **perimeter wells**. TCE levels in the perimeter wells IW-17S and IW-17I (on the west side of the resistive heating plot) rose sharply when the

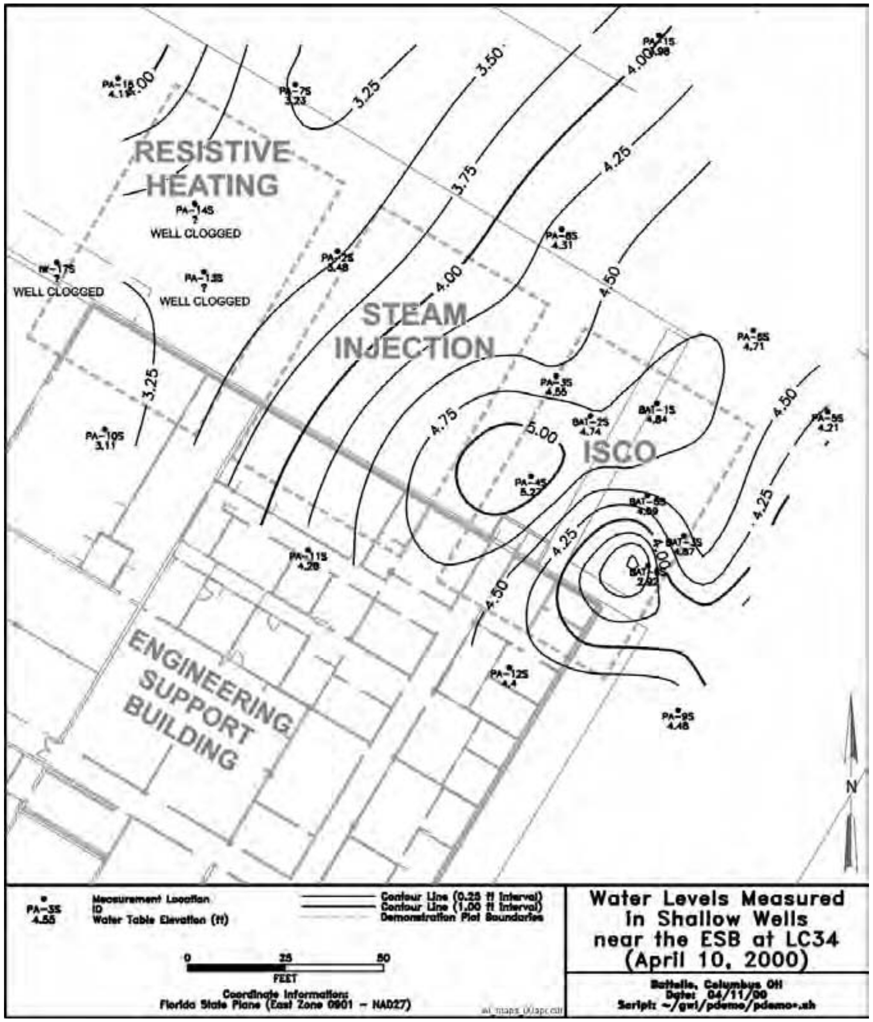

Figure 5-18. Water Levels Measured in Shallow Wells near the Engineering Support Building at Launch Complex 34 (April 10, 2000)

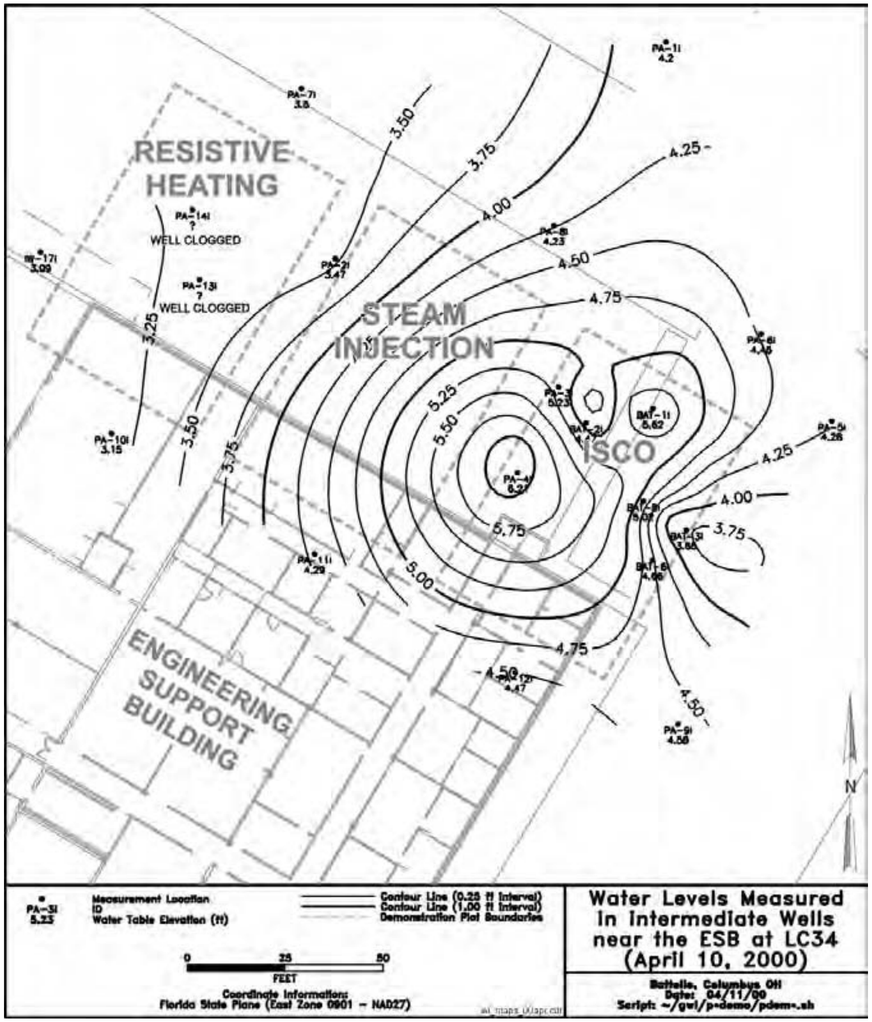

Figure 5-19. Water Levels Measured in Intermediate Wells near the Engineering Support Building at Launch Complex 34 (April 10, 2000)

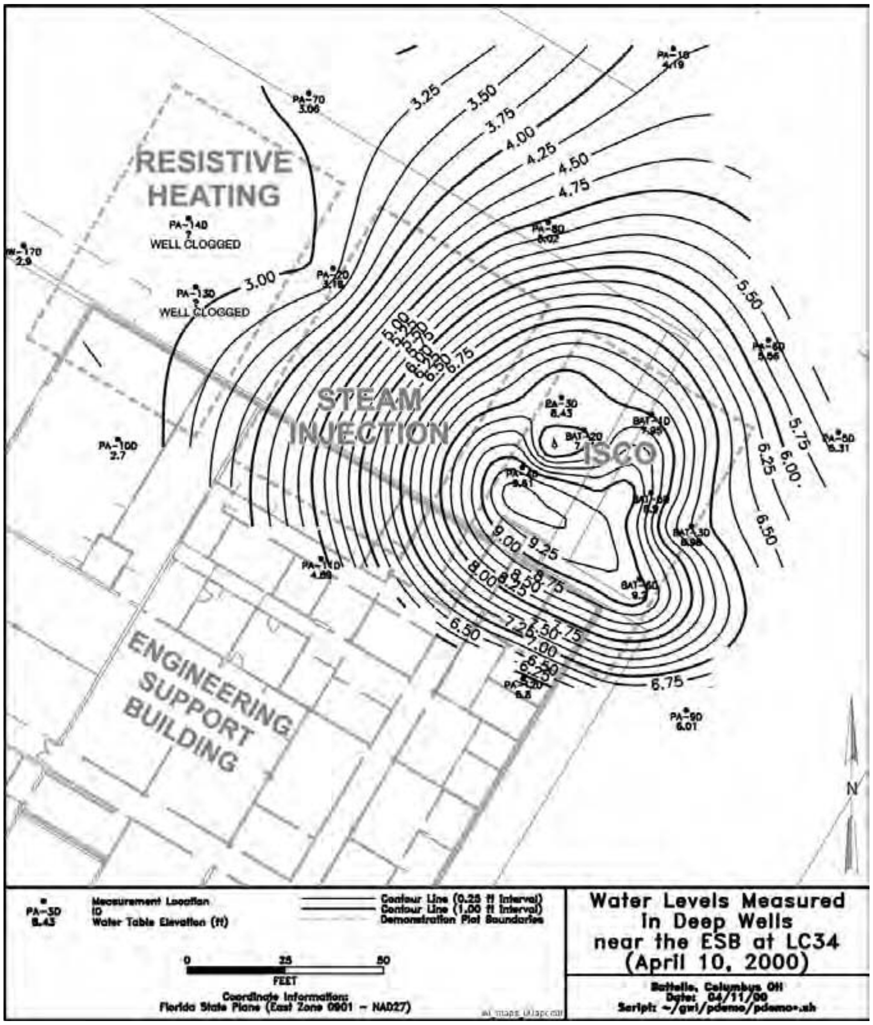

Figure 5-20. Water Levels Measured in Deep Wells near the Engineering Support Building at Launch Complex 34 (April 10, 2000)

resistive heating treatment started and the increase 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.

Figure 5-27 shows the **TCE** trends observed in **distant well** clusters PA-8 and PA-1. PA-8 is closer to the resistive heating plot to the northeast of the plot. PA-1 is further away towards the north-northeast side. The PA-8 cluster showed a significant increase in TCE concentrations in the shallow and deep wells. After the ISCO and resistive heating treatments started, DNAPL was observed for the first time in a distant well, PA-11D, as well as perimeter wells PA-2I, and PA-2D, all of which are on the east side of the resistive heating plot, near remaining DNAPL after the treatment shown in Figure 5-5, and 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 moved under the influence of the sharp hydraulic gradient induced by the oxidant injection pressures alone. Residual DNAPL, by nature, would not be expected to move.

When the ground-water data indicated that DNAPL movement had occurred, additional post-demonstration **soil cores** were collected from areas **surrounding the resistive heating plot** (see Figure 4-3 in Section 4). The additional soil coring locations surrounding the resistive

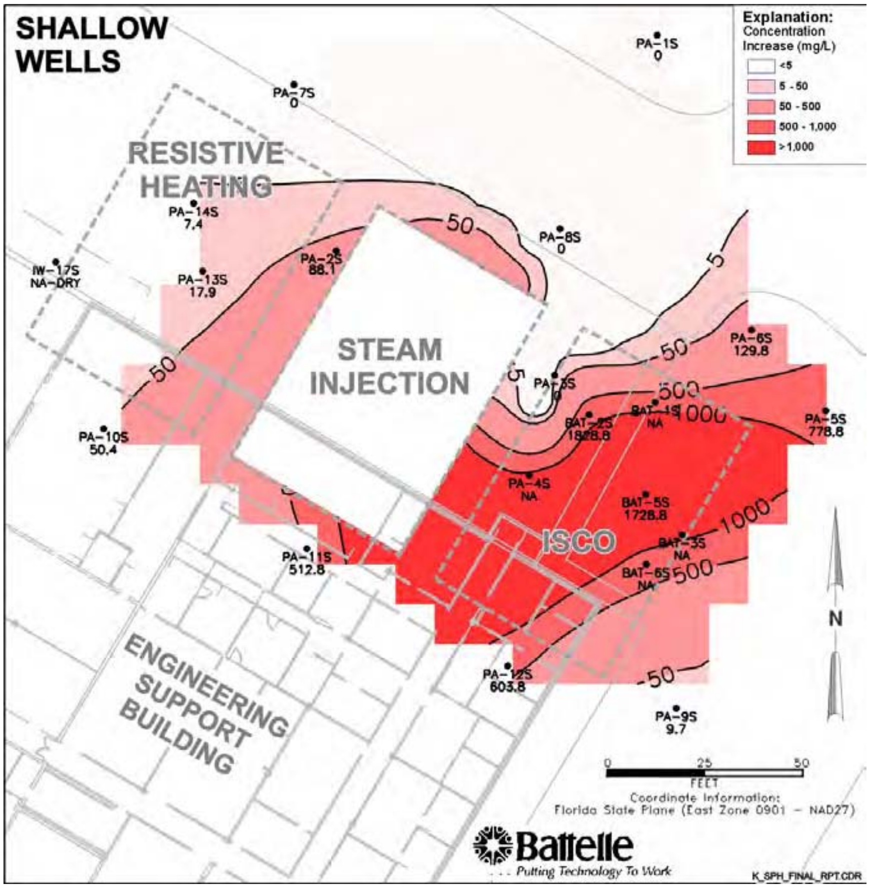

Figure 5-21. Distribution of Potassium (K) Produced by ISCO Technology in Shallow Wells near the Engineering Support Building at Launch Complex 34 (April 2000)

heating plot were selected because these were the only locations in the immediate vicinity of the resistive heating plot where pre-demonstration soil core data were available for comparison. As shown in Figure 5-28, in none of these perimeter soil samples was there a noticeable increase in TCE or DNAPL concentration 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. None of these soil cores showed any noticeable increase in DNAPL levels (TCE greater than 300 mg/kg), although the DNAPL already present under the Engineering Support Building and on the east side of the plot would tend to mask the appearance of fresh DNAPL and make it difficult to identify DNAPL migration in these directions.

To evaluate the possibility of TCE-DNAPL migration to the **vadose zone**, all pre- and post-demonstration **soil cores** in the resistive heating plot included soil samples collected at 2-ft intervals in the vadose zone. As seen in Figure 5-25, there was no noticeable deposition of TCE in the vadose zone soil due to the resistive heating 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 5-14, there was a noticeable increase in TCE concentrations between surface emission samples collected in the resistive heating plot (or around the plenum) and at background locations at various times during the demonstration (see Figure 5-29 for the samples locations). This indicates that there was some loss of TCE to the ambient air around the plot during the heat treatment and that the vapor extraction system was not as efficient at controlling vapor losses as would be desirable. The relatively shallow vadose zone could be one of the factors driving the difficulty in vapor capture. In addition, the vadose zone completely disappeared during hurricane events in September 1999, as the water table rose to ground surface (the resistive heating plot is at a topographic low point at Launch Complex 34).

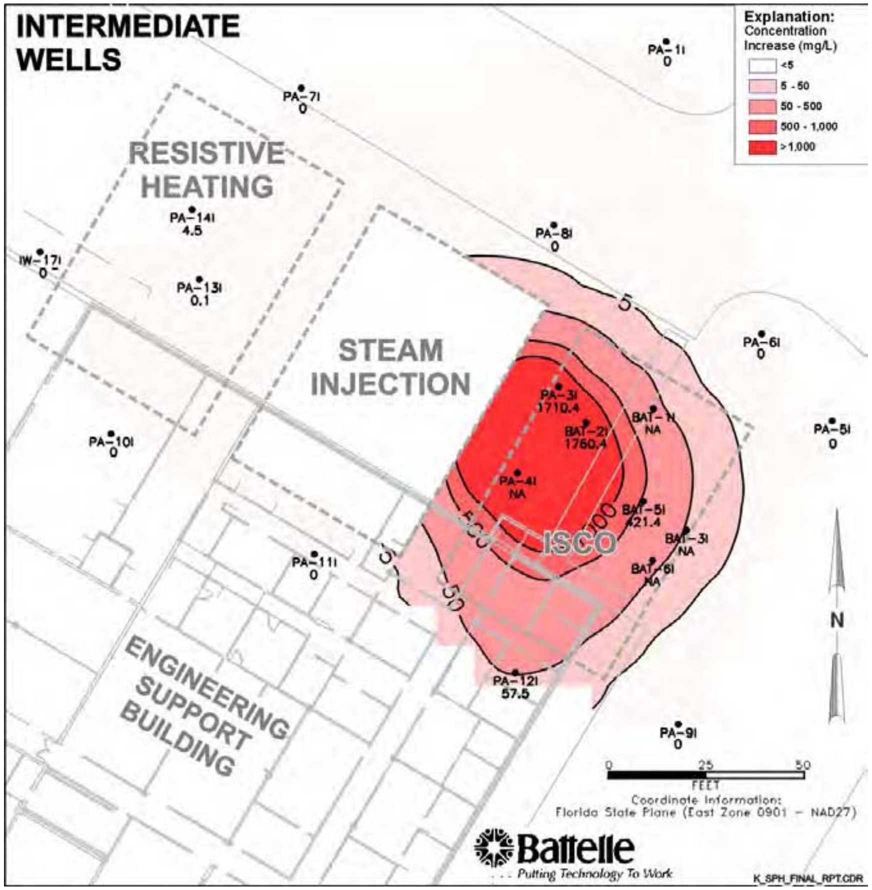

Figure 5-22. Distribution of Potassium (K) Produced by ISCO Technology in Intermediate Wells near the Engineering Support Building at Launch Complex 34 (April 2000)

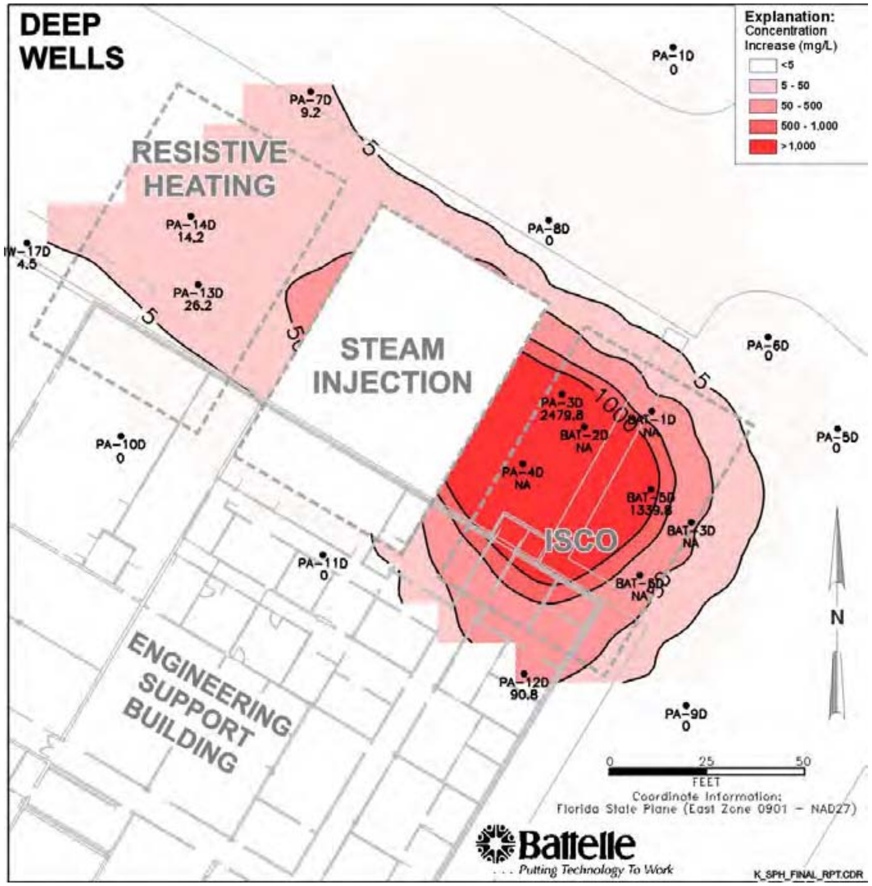

Figure 5-23. Distribution of Potassium (K) Produced by ISCO Technology in Deep Wells near the Engineering Support Building at Launch Complex 34 (April 2000)

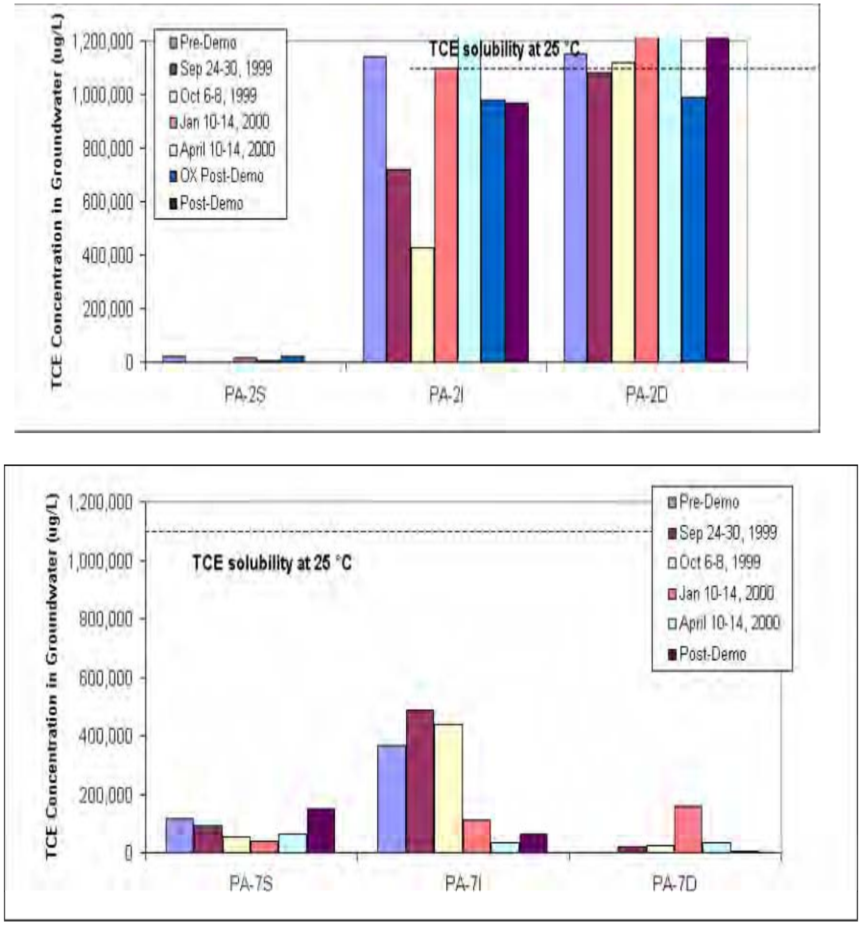

Figure 5-24. Dissolved TCE Levels (µg/L) in Perimeter Wells on the Eastern (PA-2) and Northern (PA-7) Side of the Resistive Heating Plot

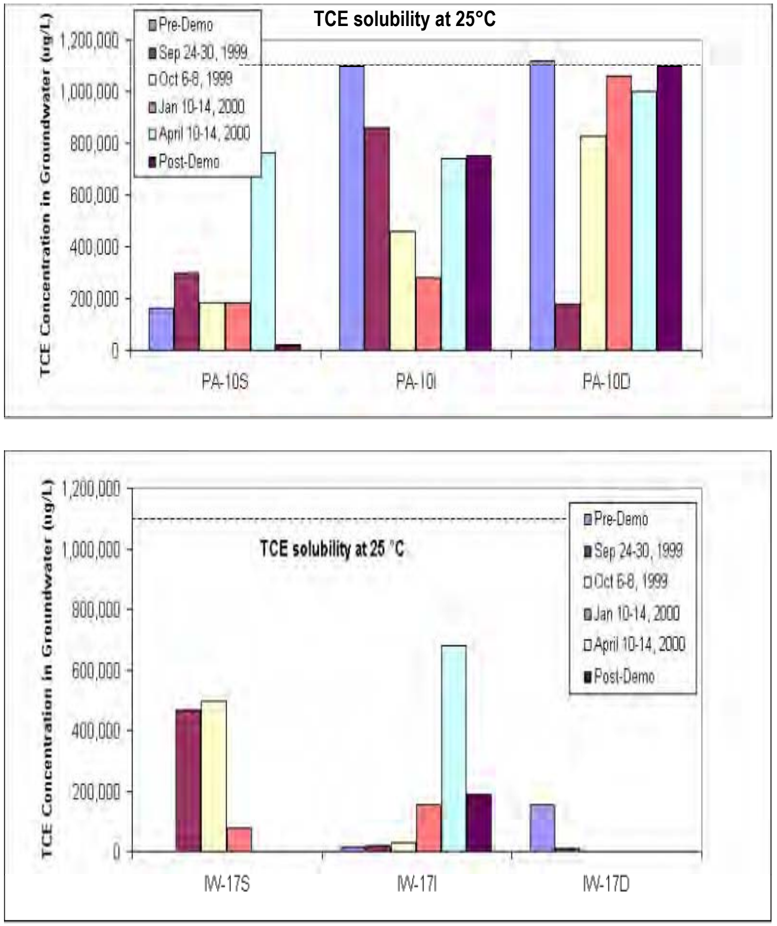

Figure 5-25. Dissolved TCE Levels (µg/L) in Perimeter Wells on the Southern and Western Sides of the Resistive Heating Plot

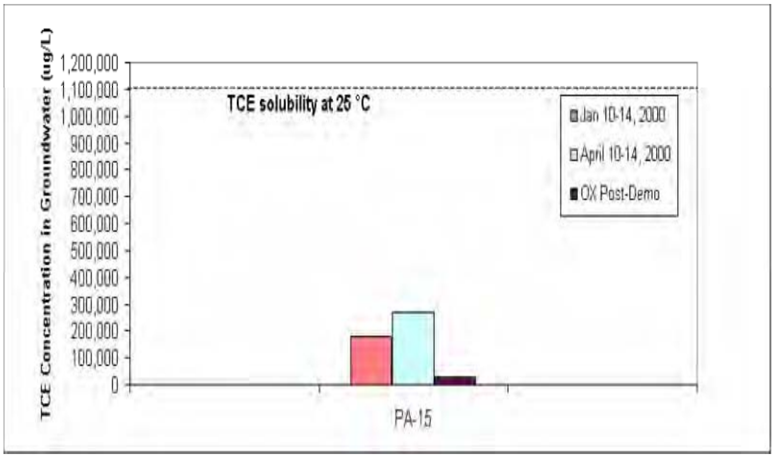

Figure 5-26. Dissolved TCE Levels (µg/L) in Perimeter Well (PA-15) on the Western Side of the ISCO Plot

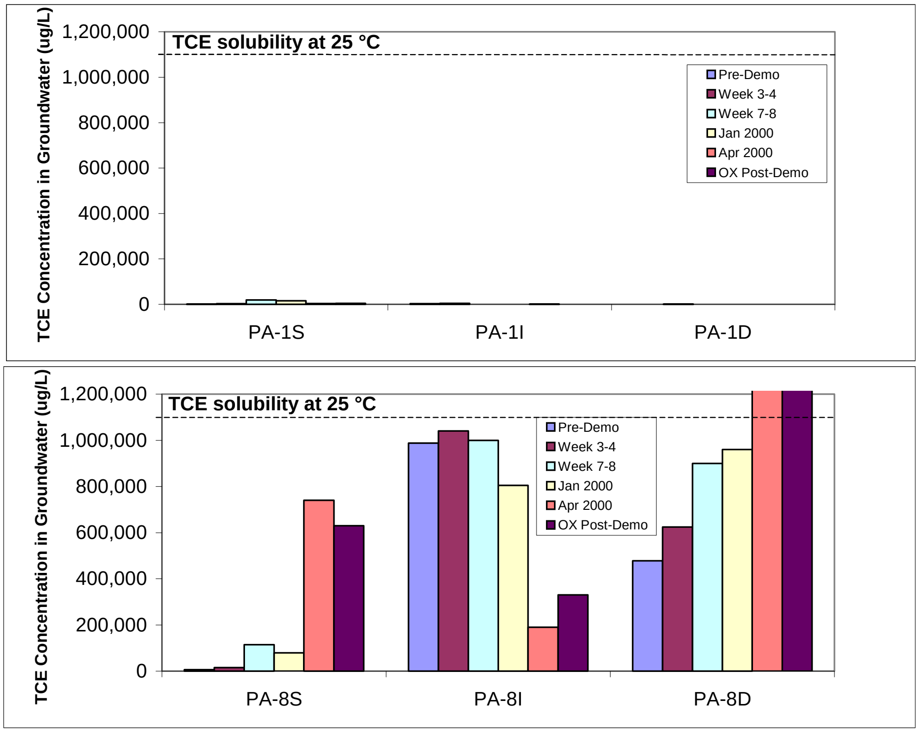

Figure 5-27. Dissolved TCE Levels (µg/L) in Distant Wells (PA-1 and PA-8) on the Northeastern Side of the ISCO Plot

During these hurricanes, it is probable that shallow ground water (laden with TCE) from the plot migrated into a ditch on the northwest side of the plot. Elevated TCE levels were subsequently found in ponded **surface water** samples collected along this ditch by FSU. However, the additional post-demonstration soil cores (LC34B309, LC34B214 and LC34B314) collected along the ditch did not reveal any TCE at DNAPL levels. Therefore, it is likely that the TCE that migrated during the hurricanes was mostly in the dissolved phase and not DNAPL. The ditch is dry during most times of the year and no surface water was present during the post-demonstration monitoring event.

5.3.2.2 Potential for DNAPL Migration to the Lower Clay Unit and Semi-Confined Aquifer

The geologic logs of the three confined aquifer wells are provided in Appendix A. Their locations are shown in

Top Depth	Bottom Depth	PA-1 (mg/kg)	PA-201 (mg/kg)	PA-2 (mg/kg)	PA-202 (mg/kg)	PA-5 (mg/kg)	PA-205 (mg/kg)	LC34B14 (mg/kg)	LC34B214 (mg/kg)	LC34B314 (mg/kg)
0	2	NA	8.6	NA	2	NA	ND	NA	ND	ND
2	4	NA	ND	NA	1	NA	ND	NA	ND	ND
4	6	NA	0.7	NA	ND	NA	ND	NA	ND	ND
6	8	NA	1.2	NA	2	NA	ND	NA	ND	ND
8	10	NA	ND	NA	ND	NA	0.6	NA	ND	5
10	12	NA	ND	NA	2	NA	ND	ND	ND	5
12	14	NA	1.5	NA	1	NA	3.4	ND	ND	6
14	16	NA	4.6	NA	0	2.5	ND	ND	11	12
16	18	NA	0.9	NA	694	1.0	136	ND	4	16
18	20	NA	2.6	4,513	21	5.4	127	ND	1	3
20	22	NA	6.6	316	156	2	41	ND	10	ND
22	24	NA	12.8	275	598	91	27	ND	3	ND
24	26	NA	ND	336	798	193	65	ND	ND	ND
26	28	NA	ND	293	346	125	58	ND	ND	ND
28	30	NA	ND	223	3,858	15	39	ND	ND	ND
30	32	NA	ND	NA	13,100	73	31	ND	ND	ND
32	34	NA	ND	2,570	2,039	1.8	ND	ND	ND	ND
34	36	0.3	ND	814	4,886	NA	ND	ND	ND	ND
36	38	NA	ND	218	681	1.1	6.3	ND	ND	1
38	40	NA	ND	271	416	2.3	19.8	ND	ND	ND
40	42	2.9	ND	2,792	NA	8.2	48.8	ND	NA	ND
42	44	NA	ND	1,096	444	27	5.1	ND	NA	0
44	46	NA	ND	NA	472	8.2	NA	ND	NA	NA

Figure 5-28. Pre- and Post-Demonstration TCE Concentrations (mg/kg) for Resistive Heating Perimeter Soil Samples (page 1 of 3)

Top Depth	Bottom Depth	PA-6 (mg/kg)	PA-206 (mg/kg)	PA-7 (mg/kg)	PA-207 (mg/kg)	PA-8 (mg/kg)	PA-208 (mg/kg)	LC34B17 (mg/kg)	LC34B217 (mg/kg)	LC34B39 (mg/kg)	LC34B239 (mg/kg)
0	2	NA	NA	NA	1.3	NA	3.5	NA	ND	NA	0.8
2	4	NA	1.7	NA	4.1	NA	1.2	NA	ND	NA	0.4
4	6	NA	ND	NA	1.1	NA	0.9	NA	1	NA	0.3
6	8	NA	ND	NA	1.0	NA	ND	NA	1	NA	1.3
8	10	NA	ND	NA	3.8	NA	ND	NA	13	NA	6
10	12	NA	2.3	NA	8.6	NA	0.3	NA	11	NA	12
12	14	NA	1.6	NA	10	NA	ND	NA	14	NA	9
14	16	0.3	0.5	0.5	89	0.9	ND	NA	6	NA	4
16	18	1.9	35	1.4	89	0.5	ND	NA	ND	NA	9
18	20	21	124	0.4	5	1.1	31	NA	ND	NA	16
20	22	83	86	2.9	12	38	32	0.1	8	NA	5
22	24	NA	144	75	2.6	6.3	102	0.0	96	NA	346
24	26	179	202	6.9	ND	175	255	0.0	160	0.1	222
26	28	255	237	46	1.6	77	108	0.0	223	NA	298
28	30	164	233	6.1	1.1	67	32	ND	67	NA	358
30	32	131	81	0.5	29	32	92	ND	27	NA	289
32	34	137	45	0.3	18.4	53	58	ND	NA	NA	314
34	36	112	189	0.1	ND	41	34	ND	ND	NA	247
36	38	39	170	1.2	7.9	1	44	ND	ND	NA	284
38	40	5	214	0.2	ND	2	138	ND	NA	NA	158
40	42	56	71	0.7	ND	21	147	ND	ND	0.1	NA
42	44	74	0.7	NA	ND	95	261	0.062	NA	0.1	267
44	46	33	0.3	0.1	0.8	115	234	0.017	NA	0.2	265

Figure 5-28. Pre- and Post-Demonstration TCE Concentrations (mg/kg) for Resistive Heating Perimeter Soil Samples (page 2 of 3)

Top Depth	Bottom Depth	PA-9 (mg/kg)	PA-209 (mg/kg)	PA-11 (mg/kg)	PA-211 (mg/kg)	PA-12 (mg/kg)	PA-212 (mg/kg)	LC34B09 (mg/kg)	LC34B209 (mg/kg)	LC34B309 (mg/kg)
0	2	NA	NA	NA	3.3	NA	ND	NA	ND	ND
2	4	NA	ND	NA	NA	NA	0.8	NA	ND	ND
4	6	NA	ND	NA	2.5	NA	0.9	NA	1	ND
6	8	NA	ND	NA	3.5	NA	1.0	NA	3	ND
8	10	NA	ND	NA	0.5	NA	1.4	NA	18	ND
10	12	NA	3.6	NA	1	NA	2.2	NA	28	ND
12	14	NA	36	NA	14	NA	ND	NA	50	3
14	16	6	51	NA	27	NA	ND	ND	28	ND
16	18	92	56	NA	32	4	ND	ND	3	ND
18	20	156	81	5.5	3.2	24	ND	ND	23	ND
20	22	188	89	NA	3.4	30	ND	0.001	53	ND
22	24	205	46	207	3,332	31	87	0.004	41	ND
24	26	9.1	37	250	123	154	84	0.069	6	ND
26	28	58.4	ND	228	958	126	305	0.1	1	ND
28	30	14.7	ND	236	186	201	327	0.025	3	ND
30	32	0.6	ND	185	468	NA	307	0.009	1	ND
32	34	0.2	2.9	483	300	130	209	0.007	3	ND
34	36	3.0	1.3	363	208	125	176	ND	ND	ND
36	38	0.1	7.1	142	206	178	314	ND	4	ND
38	40	1.6	61	NA	961	NA	123	ND	ND	ND
40	42	NA	61	NA	2,357	73	149	0.001	ND	ND
42	44	41.7	NA	NA	241	98	97	ND	2	ND
44	46	1.2	NA	NA	NA	196	NA	ND	NA	ND

LC34B2XX and PA-2XX: Post-demonstration characterization coring IDs.
NA: Not available.
ND: Not detected.
Color in the chart represents the soil sample color observed during the soil sample collection.
Solid horizontal lines demarcate the Middle Fine-Grained Unit.

Figure 5-28. Pre- and Post-Demonstration TCE Concentrations (mg/kg) for Resistive Heating Perimeter Soil Samples (page 3 of 3)

Table 5-14. Surface Emissions Results from Resistive Heating Treatment Demonstration

Sample ID	Sample Date	TCE ppb (v/v)	Sample ID	Sample Date	TCE ppb (v/v)
Pre-Demonstration (Baseline Data Sampled from Steam Injection Plot)					
CP-SE-1	11/17/1999	< 0.39	CP-SE-3	11/17/1999	< 0.41
CP-SE-2	11/17/1999	< 0.39			
During Demonstration					
SPH-SE-1	10/08/1999	2.1	SPH-SE-8	01/18/2000	78
SPH-SE-2	10/08/1999	3.6	SPH-SE-9	01/18/2000	35
SPH-SE-3	10/08/1999	2.0	SPH-SE-10	04/11/2000	0.93
SPH-SE-4	10/22/1999	**13,000**	SPH-SE-11	04/11/2000	0.67
SPH-SE-5	10/22/1999	**12,000**	SPH-SE-12	04/11/2000	<0.37
SPH-SE-6	10/22/1999	**13,000**	SPH-SE-13	04/11/2000	**1,300**
SPH-SE-7	01/18/2000	23			
Post-Demonstration					
SPH-SE-21	08/30/2000	<0.42	SPH-SE-27	11/30/2000	**3,100**
SPH-SE-22	08/30/2000	0.61	SPH-SE-28	11/30/2000	**10,000**
SPH-SE-23	08/30/2000	<870	SPH-SE-29	12/01/2000	**11,000**
SPH-SE-24	08/31/2000	500	SPH-SE-30	12/02/2000	9.0
SPH-SE-25	09/01/2000	59	SPH-SE-31	12/02/2000	0.71
SPH-SE-26	09/01/2000	17	SPH-SE-32	12/04/2000	<0.40
Background			*Ambient Air at Shoulder Level*		
DW-SE-1	10/01/1999	< 0.42	SPH-SE-14	05/09/2000	<0.39(a)
DW-SE-2	10/08/1999	< 0.44	SPH-SE-15	05/09/2000	<0.39(a)
DW-SE-3	10/25/1999	0.44	SPH-SE-C27	09/01/2000	<0.88
DW-SE-4	10/22/1999	**6,000**(b)	DW-C1	04/11/2000	2.1(c)
DW-SE-5	01/17/2000	< 0.38	DW-C2	05/09/2000	<0.39
DW-SE-6	04/11/2000	0.43	DW-C3	05/09/2000	<0.39
DW-SE-7	04/11/2000	0.86	DW-11	08/31/2000	13
DW-SE-8	04/11/2000	0.79	DW-12	09/01/2000	<27
DW-SE-36	12/06/2000	<0.40	DW-C21	08/31/2000	0.86(c)
DW-SE-37	12/06/2000	0.49	DW-C22	09/01/2000	<0.58(c)
DW-SE-38	12/07/2000	<0.40			

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 (10/22/1999) was collected immediately after SPH-SE-6 sample (the last sample for the sampling set in October 1999), 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 of cleaning the box with methanol and air dry were adapted to minimize carryover.

(c) A Summa canister was held at shoulder level to collect an ambient air sample to evaluate local background air.

Figure 4-7 in Section 4.3.1. Table 5-15 shows the depths and thicknesses of the Lower Clay Unit (aquitard) and the screened intervals of the wells installed. Figure 5-30 is a geologic cross section across the three test plots showing the varying thickness of the aquitard. The aquitard is thinnest in the resistive heating plot, where it is only around 1.5 ft thick. The thickness of the aquitard increases in the eastward and northward directions.

Split-spoon samples of the Lower Clay Unit show it to be a medium gray-colored clay with moderate to high plasticity. The clay is overlain by a silt zone which in turn is overlain by sand. The entire sand-silt-clay sequence appears to be gradational and fining downward with respect to grain size. In PA-21, the overlying sand and silt intervals appeared to be more contaminated (PID reading over 2,000 ppm). The clay itself was generally less contaminated, but lower PID readings in the clay may be due to the fact that volatilization of organic contaminants in clayey soils occurs more slowly. Sandier soils were encountered directly below the confining unit. Only at the PA-20 well did soils underlying the confining unit appear to be clean.

Soil samples were collected for lab analysis from each split spoon. Care was taken to collect soil samples of each 2-ft interval from the retrieved soil core. Multiple samples were collected in cases where both clays and sand were recovered in a spoon. PID readings exceeded 1,000 ppm (or more) at both the PA-21 and PA-22 locations both above and below the confining unit. Visual observations of clay samples indicated that the clay has low permeability.

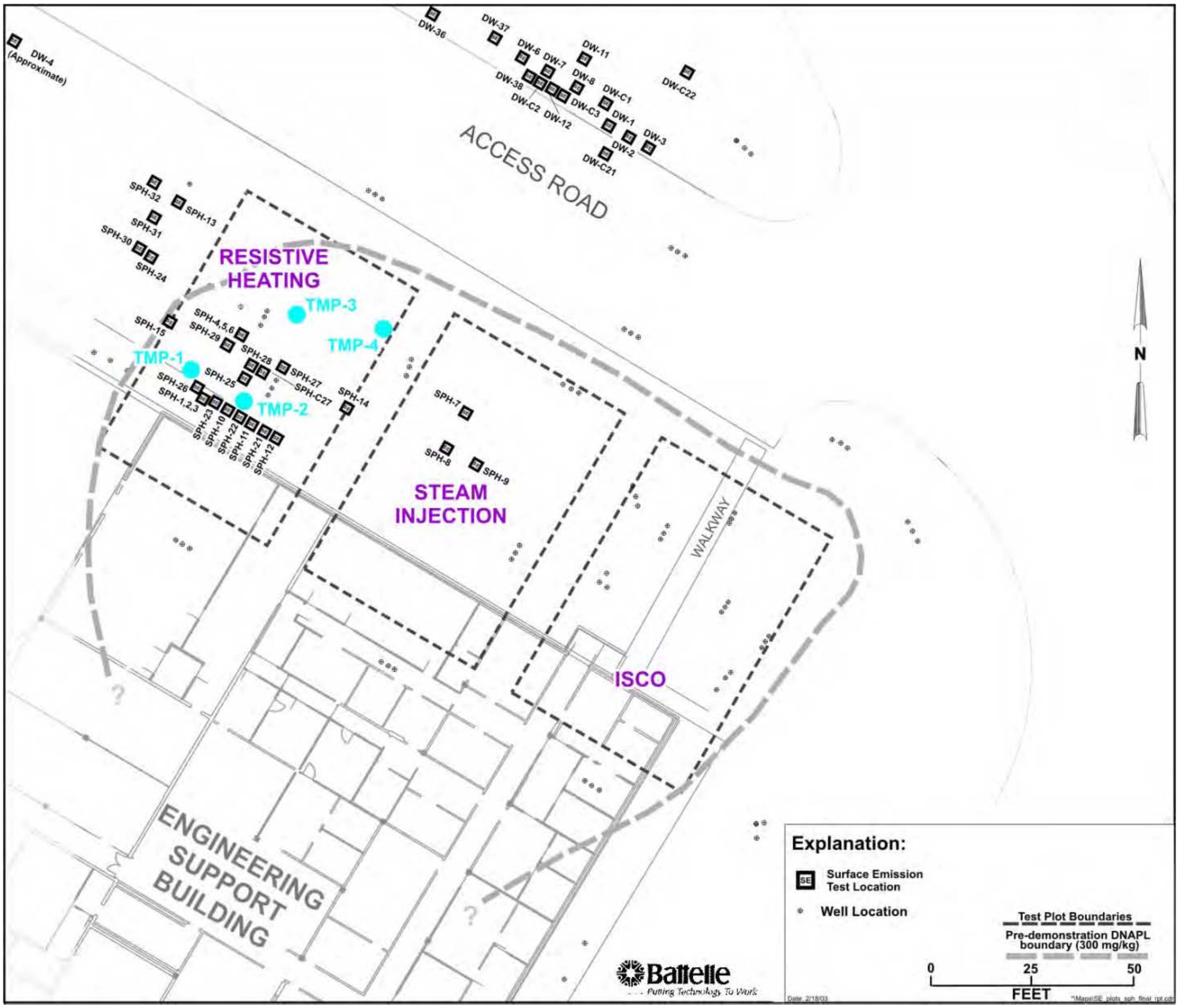

Figure 5-29. Location Map for Surface Emissions Test

Table 5-16 and Figure 5-31 show the vertical distribution of the TCE analysis results of the soil samples collected at depths of approximately 40 to 60 ft bgs; the lower clay unit occurs at approximately 46 ft bgs in the resistive heating plot. The soil borings SB-50, SB-51, and SB-52 are the borings done for wells PA-20, PA-21, and PA-22 (see Figure 4-7 in Section 4.3.1). Soil boring SB-50 was conducted in the parking lot and did not show any concentrations approaching the DNAPL threshold of 300 mg/kg at any depth. Soil boring SB-51 was conducted in the ISCO plot; this boring indicated the presence of DNAPL in the Lower Sand Unit and Lower Clay Unit, but relatively low levels of TCE in the confined aquifer. Soil boring SB-52, in the resistive heating plot, showed the presence of DNAPL in the Lower Clay Unit, the semi-confining unit from the aquifer below; TCE levels were as high as 40,498 mg/kg in the semi-confined aquifer (56-58 ft bgs) at this location. Previously, no monitoring was done in the semi-confining layer or in the semi-confined aquifer before the demonstration because of NASA's concern about breaching the relatively thin aquitard. Subsequently, these three wells were drilled because nonintrusive (seismic) monitoring indicated the possibility of DNAPL being present in the semi-confined aquifer (Resolution Resources, 2000). Because there is no information regarding the state of the confined aquifer before the demonstration, it is unclear whether the DNAPL had migrated to the semi-confined aquifer before

Table 5-15. Confined Aquifer Well Screens and Aquitard Depth

Well ID	Screened Interval (ft bgs)	Depth where Aquitard was Encountered (ft bgs)	Thickness of Aquitard (ft)
PA-20 (North of steam injection plot in parking lot)	55-60	45.5	3
PA-21 (In ISCO plot)	55-60	44.8	2.8
PA-22 (In resistive heating plot)	55-60	45.8	3[(a)]

(a) The confining unit clay contained thin sand lenses. Three ft is the overall thickness, including the interspersed sand lenses. The effective thickness of the aquitard is approximately 1.5 ft.

Table 5-16. TCE Concentrations in Deep Soil Borings 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	
47-47.5			
47.5-48			
48-49	5	46	
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 between the surficial and confined aquifers.

or during the demonstration. Heating could have lowered the surface tension of DNAPL, making it easier to penetrate the Lower Clay Unit. However, given the strong electrical heating achieved in the Lower Sand Unit (of the surficial aquifer) that would tend to volatilize TCE and move it upward, the greater probability is that the DNAPL penetrated the Lower Clay Unit and entered the semi-confined aquifer before the demonstration. Although the Lower Clay Unit is approximately 3 ft thick in other parts of Launch Complex 34, it appears to contain sand lenses that reduce the effective thickness of the aquitard to approximately 1.5 ft near PA-22, under the resistive heating plot. Therefore, the barrier to gradual downward migration over time is geologically weaker in this region.

Table 5-17 summarizes the results of the CVOC analysis of the ground water from the semi-confined aquifer. CVOC measurements were taken on seven occasions over a one-year period to evaluate natural fluctuation. Ground-water samples from the semi-confined aquifer wells reinforce the soil sampling results. High levels of TCE approaching solubility (free-phase DNAPL) were observed in PA-22 where high soil concentrations were also observed (Yoon et al., 2002). In wells PA-20 and PA-21, relatively lower CVOC concentrations were measured, suggesting that the semi-confining clay layer is more competent in these areas and free phase contamination has not migrated into the semi-confined aquifer in this area. Elevated levels of *cis*-1,2-DCE (all three wells) and vinyl chloride (PA-21) also were found in the semi-confined aquifer wells. Overall, CVOC concentrations appear to be relatively stable over time in all three wells, namely, PA-20, PA-21, and PA-22 (see Figure 5-32).

Table 5-18 shows the field parameter measurements in the confined aquifer wells. Based on the relatively low DO and ORP levels, the semi-confined aquifer appears to be anaerobic. The ground water has a neutral-to-slightly-alkaline pH. The temperature was in the range of 26 to 28°C in PA-20 and PA-21, but in PA-22, which is below the resistive heating plot, the temperature during both events was elevated (44 to 49°C). The higher temperature in this well may be due to heat conduction from the resistive heating application in the surficial aquifer, although migration of heated water from the surficial aquifer through the thin Lower Clay Unit cannot be ruled out.

Table 5-19 shows the inorganic measurements in the semi-confined aquifer wells. The geochemical composition of the ground water appears to be relatively constant throughout the semi-confined aquifer, and is similar to that of the surficial aquifer.

Table 5-20 shows slug test results in the semi-confined aquifer wells. Slug tests were performed in July 2001 on the wells PA-20, PA-21, and PA-22. The recovery rates of the water levels were analyzed with the Bouwer (1989), Bouwer and Rice (1976), and Horslev (1951) methods for slug tests. The Bouwer and Rice methods may be used in confined aquifers where the top of the screen is well below the bottom of the confining layer, but are more suitable for unconfined aquifers. The Horslev method is more applicable in confined aquifers,

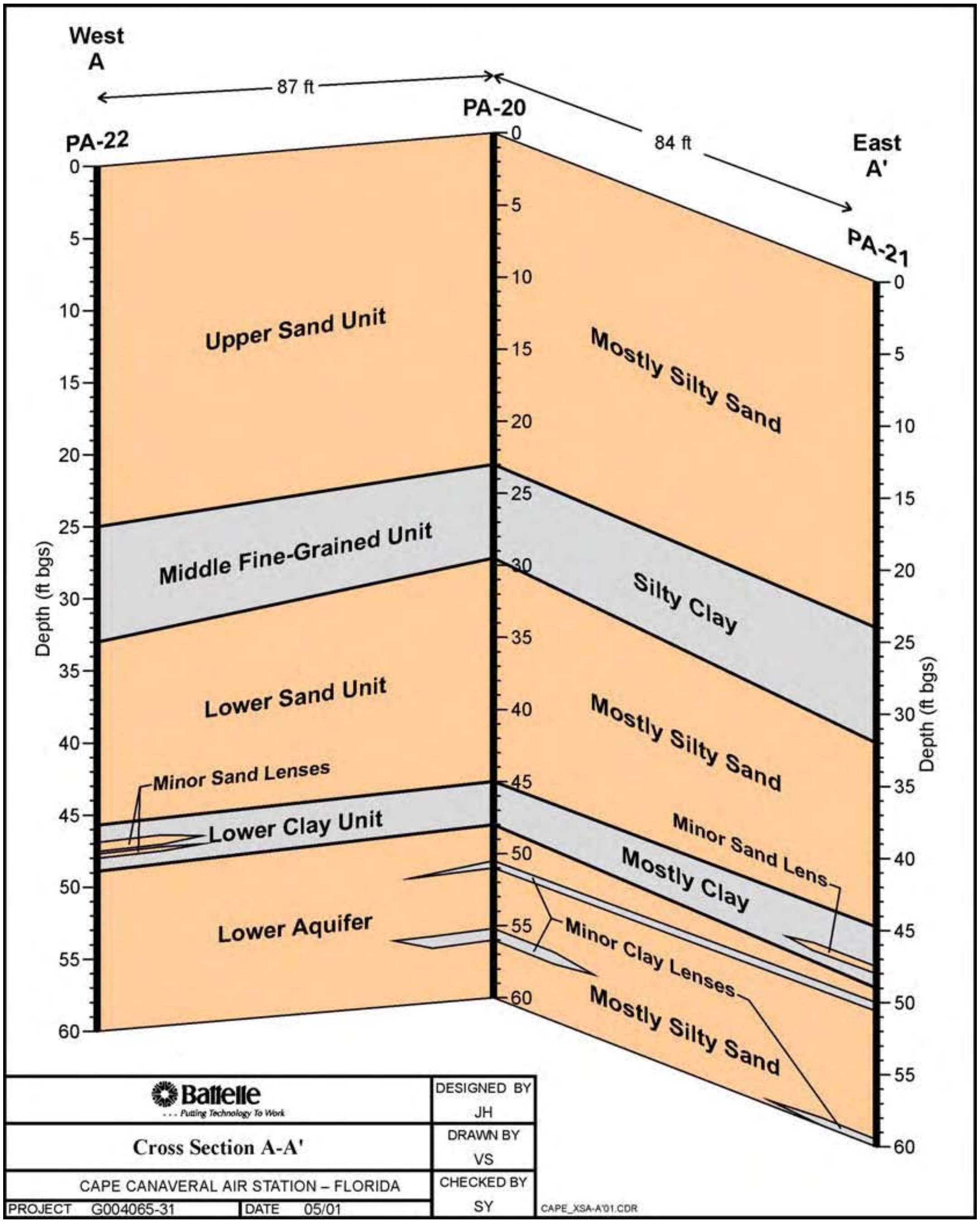

Figure 5-30. Geologic Cross Section Showing Lower Clay Unit and Semi-Confined Aquifer

but may fail to account for the effects of a sand pack. Overall, the hydraulic conductivity (K) estimates range from 0.4 to 29.9 ft/day. The Horslev method results are about two to four times higher than estimates using the Bouwer and Rice method. The replicate tests are similar, except for PA-20, where the Horslev method differed. It appears that the aquifer conductivity near well PA-20 is greater than near PA-21 and PA-22. The conductivity of wells PA-21 and PA-22 is lower and reflects the silty-clayey sands that were observed during drilling. The conductivities in the semi-confined aquifer are similar to the conductivities measured in the surficial aquifer wells.

Figure 5-33 shows the potentiometric map for water levels measured in April 2001 in the new semi-confined aquifer wells near the demonstration test plots at Launch Complex 34. Although very few wells are available to make a positive determination, the water levels measured

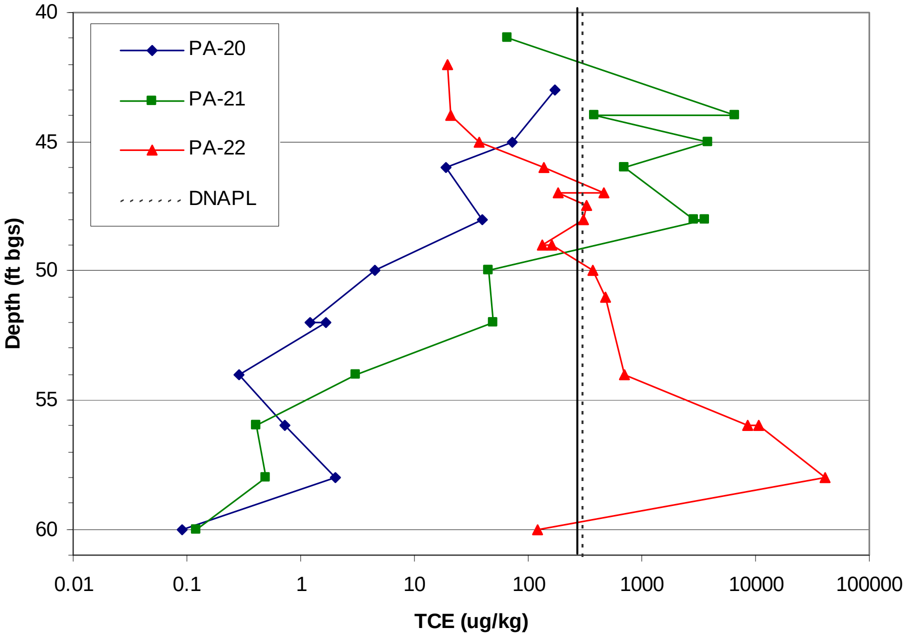

Figure 5-31. TCE Concentrations in Soil with Depth from Semi-Confined Aquifer Soil Borings

Table 5-17. TCE Concentrations in the Semi-Confined Aquifer Wells

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.

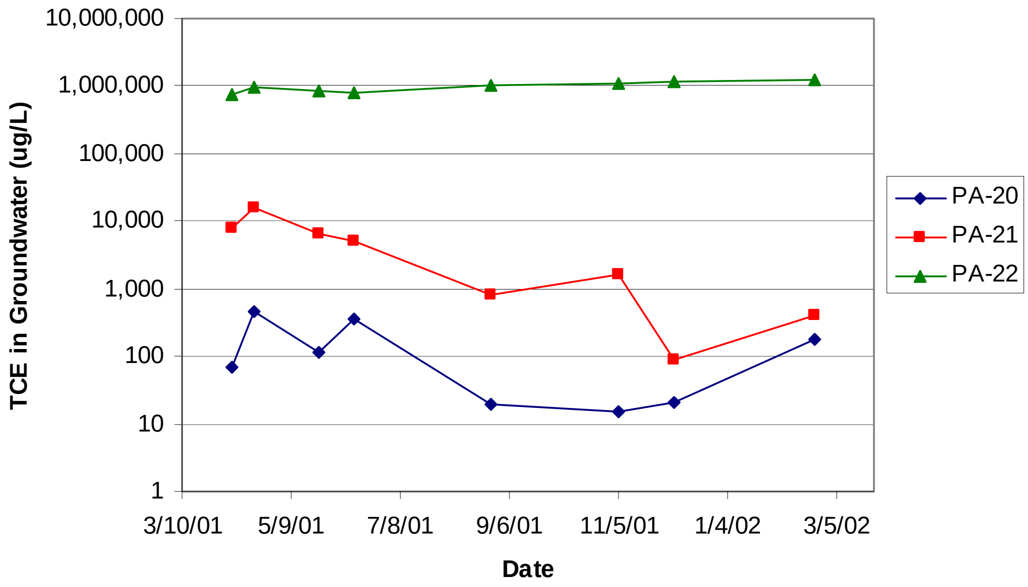

Figure 5-32. TCE Concentration Trend in Ground Water from Semi-Confined Aquifer

Table 5-18. Key Field Parameter Measurements in Semi-Confined Aquifer Wells

Well ID	Date	Temperature (°C)	DO (mg/L)	pH	ORP (mV)
PA-20	04/06/2001	27.2	0.65	7.8	67.4
PA-21	04/06/2001	28.4	0.05	8.84	30.2
PA-22	04/06/2001	48.9	0.36	6.77	39.1
PA-20	06/12/2001	26.2	0.42	7.21	–42.5
PA-21	06/12/2001	26.1	0.47	7.17	–36.5
PA-22	06/12/2001	44.4	0.78	7.25	–33.6

in four semi-confined aquifer wells (PA-20, PA-21, PA-22, and previously existing well IW-2D1, southeast from the test plots) indicate that there is an eastward or northeastward gradient, similar to the regional gradient observed in the surficial aquifer. The gradient and magnitude are summarized in Table 5-21.

Figure 5-34 displays vertical gradients from paired wells between nearby surficial aquifer wells and the newly installed wells (PA-20 to PA-22). A positive vertical gradient suggests upward flow from the deep aquifer to the surficial aquifer, which would inhibit downward migration of contamination. A negative gradient would promote downward migration. As shown in Figure 5-34, it appears that the vertical gradient fluctuates, beginning as an upward gradient when the wells were installed, changing to a downward gradient in the Fall of 2001, and finally recovering to an upward gradient.

In summary, the following were the key results and conclusions from the installation of three semi-confined aquifer wells at Launch Complex 34:

- Use of the two-stage (dual-casing) drilling and completion process led to the installation of three semi-confined aquifer wells that appeared to be sealed from the surficial aquifer above.
- At all three locations, the Lower Clay Unit occurs at approximately 45 ft bgs and is approximately 3 ft thick; at PA-22, located in the resistive heating plot, the Lower Clay Unit was found to contain sand lenses that appeared to reduce the effective thickness of the aquitard.

Table 5-19. Geochemistry of the Confined Aquifer

Well ID	Ca (mg/L)	Fe (mg/L)	Mg (mg/L)	Mn (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Cl (mg/L)	SO_4 (mg/L)	TDS (mg/L)
PA-20	71.8	<0.1	64	0.0145	180	664	114	1,400
PA-20-DUP	69.4	<0.1	62.8	0.0128	168	680	114	1,410
PA-21	74	<0.1	48	<0.01	196	553	134	1,310
PA-22	120	0.109	79.7	0.0534	276	802	122	1,840

Table 5-20. Results for Slug Tests in Semi-Confined Aquifer Wells at Launch Complex 34

Well	Test	Method	K (ft/d)	Response
PA-20	a	Bouwer and Rice	4.1	Good
PA-20	b	Bouwer and Rice	6.9	Good
PA-20	a	Horslev	8.6	Good
PA-20	b	Horslev	29.9	Good
PA-21	a	Bouwer and Rice	0.7	Excellent
PA-21	b	Bouwer and Rice	0.8	Excellent
PA-21	a	Horslev	1.1	Excellent
PA-21	b	Horslev	1.1	Excellent
PA-22	a	Bouwer and Rice	0.4	Excellent
PA-22	b	Bouwer and Rice	0.5	Excellent
PA-22	a	Horslev	1.5	Excellent
PA-22	b	Horslev	1.1	Excellent

- Ground-water sampling in the three semi-confined aquifer wells confirmed that dissolved-phase CVOCs were present in the semi-confined aquifer at all three locations.
- At PA-20, in the parking lot north of the test plots, there was no DNAPL in any of the soil samples.
- At PA-21, in the ISCO plot, soil analysis indicated that DNAPL was present both in the Lower Clay Unit and in the Lower Sand Unit, immediately above the aquitard. No DNAPL was found in the semi-confined aquifer at this location.
- At PA-22 in the resistive heating plot, PID screening and field extraction/laboratory analysis of the soil

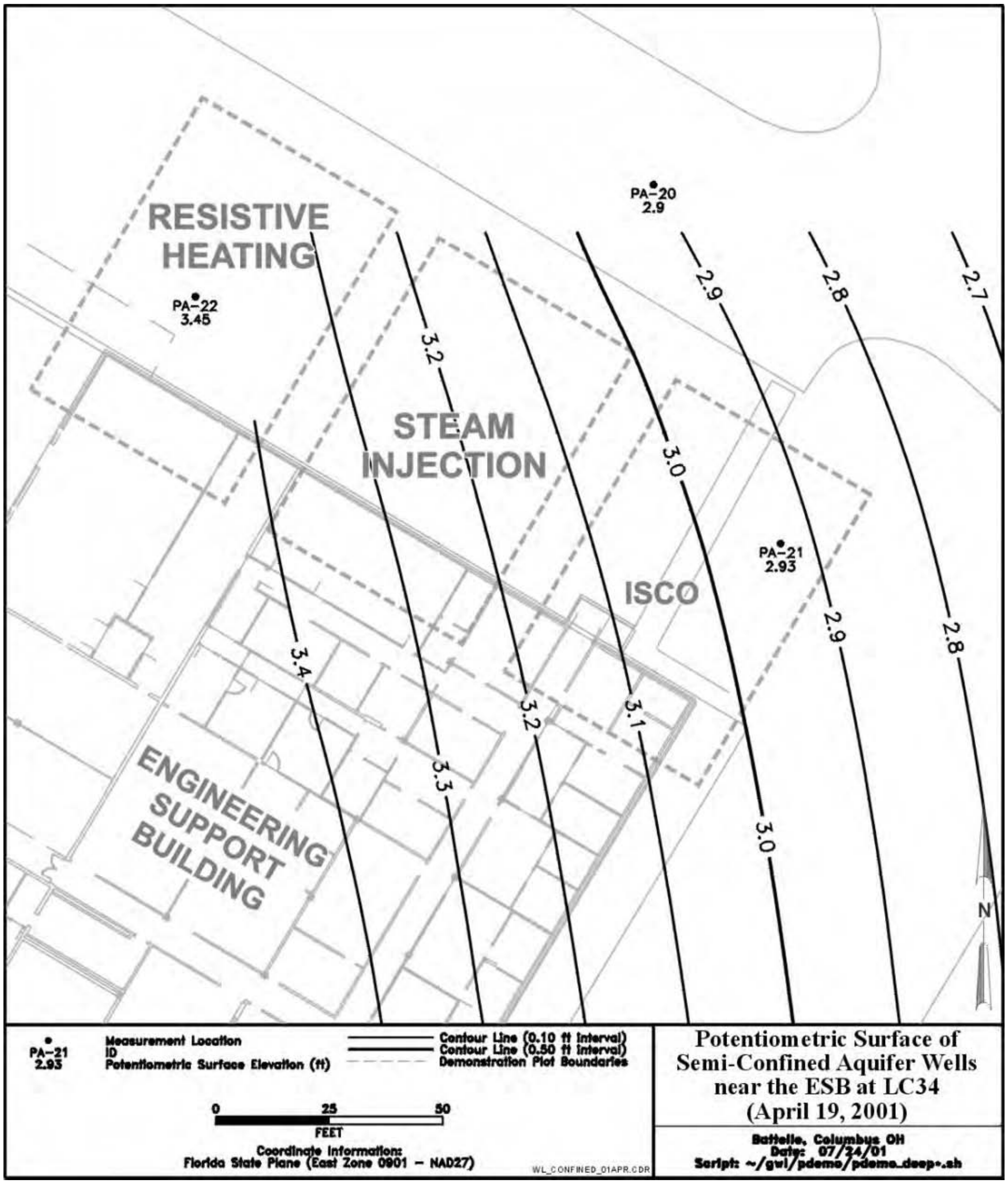

Figure 5-33. Hydraulic Gradient in the Semi-Confined Aquifer (April 19, 2001)

Table 5-21. Summary of Gradient Direction and Magnitude in the Semi-Confined Aquifer

Date	4/19/01	5/24/01	7/2/01	8/28/01	11/8/01	12/4/01	1/21/02	1/25/02	2/20/02
Direction	ENE	E	ENE	SW	NE	NW	ESE	ESE	ENE
	↗	→	↗	↙	↗	↖	↘	↘	↗
Magnitude (ft/ft)	0.0046	0.0056	0.0052	0.0033	0.0028	0.0013	0.0014	0.0013	0.0026

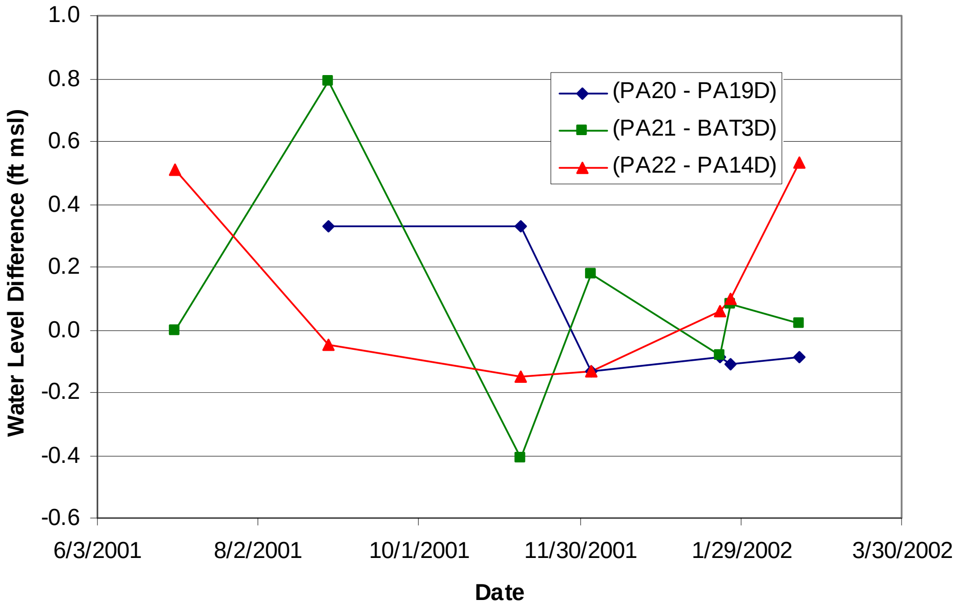

Figure 5-34. Vertical Gradients from the Spatially Neighboring Paired Wells between the Surficial Aquifer and the Semi-Confined Aquifer

samples indicated that DNAPL was present in the Lower Clay Unit and in the semi-confined aquifer, although not in the Lower Sand Unit, immediately above the aquitard. No monitoring was done in the semi-confining layer (Lower Clay Unit) or in the semi-confined aquifer before the demonstration because of NASA's concern about breaching the relatively thin aquitard. Subsequently, these three wells were drilled because nonintrusive (seismic) monitoring indicated the possibility of DNAPL being present in the semi-confined aquifer. Because there is no information regarding the state of the semi-confined aquifer before the demonstration, it is unclear whether the DNAPL had migrated to the confined aquifer before or during the demonstration. However, given the strong electrical heating achieved in the Lower Sand Unit (in the surficial aquifer) which would tend to volatilize TCE upward, the greater probability is that the DNAPL penetrated the Lower Clay Unit before the demonstration. Whereas the Lower Clay Unit is 3 ft thick in other parts of Launch Complex 34, near PA-22 it appears to contain sand lenses that reduce the effective thickness of the aquitard to approximately 1.5 ft. Therefore, the barrier to downward migration is geologically weaker in this region.

- Hydraulic measurements in the semi-confined aquifer indicate an eastward gradient similar to the overlying surficial aquifer. Vertical gradients fluctuate between the semi-confined aquifer and the surficial aquifer.

- As the semi-confined aquifer extends down to approximately 120 ft bgs, additional investigation of the deeper geologic strata would be required to obtain an understanding of the CVOC distribution in the semi-confined aquifer.

5.3.3 Potential TCE Losses during Hot Soil Core Sampling

Even after waiting for three months following the end of resistive heating application to the subsurface, the test plot had cooled down only to 90°C or less (from a maximum of 120°C during heating). Therefore, post-demonstration soil coring had to be conducted while the plot was still hot. To minimize CVOC losses due to volatilization, the following steps were taken:

- Soil coring was started only after steam generation had subsided and the plot had cooled to 90°C or less in all parts.
- As the core barrel was retrieved from the ground, each 2-inch-diameter, 4-ft-long acetate sleeve in the core barrel was capped on both ends and dipped in an ice bath until the core soil was cooled to ambient temperature. The soil core was kept in the ice bath long enough for cooling to occur without breaking the seals at the capped ends.
- Upon reaching ambient temperature, the core sleeve was then uncapped and cut open along its length to collect the soil sample for CVOC analysis.

In order to determine volatilization losses due to the hot soil care, surrogate of 1,1,1-TCA was spiked for a few soil samples as described in Appendix G. Overall, the results show that between 84 and 113% of the surrogate spike was recovered from the soil cores. 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 (see Table G-1 in Appendix G). Slightly less surrogate was recovered from the soil cores spiked prior to cooling, which implies that any losses of 1,1,1-TCA in the soil samples spiked prior to cooling are minimal and acceptable, within the limitations of the field sampling protocol.

5.3.4 Summary of Fate of TCE-DNAPL in the Plot

The change in TCE-DNAPL mass in the plot can be explained by the following pathways:

- *Aboveground recovery*. Vapor sampling conducted by the resistive heating vendor indicates that 1,947 kg of total TCE was recovered in the vapor extraction system. The initial estimate of total TCE mass in the subsurface was 11,313 kg.
- *Degradation by biological or abiotic processes*. There are indications that some TCE may have been degraded due to the heating in the resistive heating plot.
  - The sharp increase in *cis*-1,2-DCE levels in several monitoring wells inside the plot and perimeter indicate the possibility that some TCE may have degraded by reductive dechlorination. Microbial counts in soil and groundwater samples before and after the demonstration indicate that microbial populations survived the heat treatment in most parts of the plot. Recent research (Truex, 2003) indicates that TCE biodegradation rates are accelerated substantially at higher temperatures. Therefore, there is a strong possibility that some of the TCE in the plot has biodegraded to *cis*-1,2-DCE, but that the dechlorination is not yet complete. If TCE degradation to *cis*-1,2-DCE has been hastened, it is unclear as to the time frame over which *cis*-1,2-DCE itself may degrade. Accumulation of *cis*-1,2-DCE shows that the rate of degradation of TCE may be much faster than the rate of *cis*-1,2-DCE degradation.
  - The sharp increase in chloride, which would have been a strong indicator of dechlorination of CVOCs, proved to be inconclusive. Sodium, potassium, sulfate, alkalinity, and TDS increased sharply, concomitant with the increase in chloride—these are all seawater constituents. The possibility that the increase in chloride was caused by saltwater intrusion during the resistive heating application cannot be ruled out.
  - Abiotic processes that may have degraded TCE include reductive dechlorination by the steel shot in the electrodes, hydrolysis, and/or oxidation. Any of these processes could have been promoted by the heating in the plot.
- *Migration to surrounding regions*. It is possible that some TCE, and perhaps DNAPL, may have migrated to regions surrounding the resistive heating plot.
  - Monitoring wells (IW-17S and IW-17I) outside the western perimeter of the plot showed a sustained increase in TCE concentrations during and after the demonstration. TCE was found in transient surface water that appeared along a ditch on the western side of the plot, following the two hurricane events. It is

possible that when the water table rose to the ground surface, the vapor extraction piping in the plot was submerged. Hot water laden with TCE could have migrated westward along the topographic gradient. Another possible obstruction to the TCE vapors being extracted through the extraction pipes and plenum in the vadose zone and ground surface is the Middle Fine-Grained Unit. TCE vapors and steam migrating upwards could preferentially migrate horizontally in the sandy layer under the Middle Fine-Grained Unit rather than through the silty layer above. A limited number of exploratory soil cores collected in the regions surrounding the resistive heating plot after the demonstration did not show any signs of fresh DNAPL deposits.

  - DNAPL appeared in two of the wells (PA-2I and PA-2D) on the eastern side of the plot. It is not clear which of the two technologies, ISCO or resistive heating, caused DNAPL to migrate. ISCO in the neighboring test plot (80 ft away) created strong hydraulic gradient that could potentially displace any mobile DNAPL in the aquifer. Resistive heating generates heat-induced convection gradients that could displace mobile DNAPL or mobilize residual DNAPL. On the other hand, the PA-2 well cluster was installed in a region that was showing dissolved TCE levels close to its solubility before the demonstration. It is possible that DNAPL would have eventually appeared in these wells even if there were no remediation activities at the site.
  - Soil core samples from the vadose zone in the resistive heating did not show any noticeable increase in TCE concentrations.
  - Surface emission tests conducted inside and around the plot on several occasions during and immediately following the resistive heating treatment showed noticeably elevated levels of TCE, compared to background levels. This indicated that the vapor capture system was not as efficient as would be desired and some CVOC vapors were migrating to the atmosphere. On some occasions, steam (and probably CVOC vapors) shot out of the monitoring wells for several seconds during sampling. This is another potential route for CVOC vapors.
  - After the resistive heating and ISCO treatment demonstrations, three wells were installed into the semi-confined aquifer—one in the parking lot to the north (PA-20), one in the ISCO plot (PA-21) and one in the resistive heating plot (PA-22). All three wells showed elevated levels of dissolved TCE, but the levels were especially high in PA-22. Ground water in PA-22 also had elevated temperature (44 to 49°C). It is possible that heat conduction was responsible for elevating the temperature in the semi-confined aquifer below the resistive heating plot, although penetration of heated water from the surficial aquifer through the thin Lower Clay Unit cannot be ruled out. The soil cores collected during the installation of these wells showed the presence of DNAPL in the Lower Clay Unit and semi-confined aquifer below the ISCO plot and below the resistive heating plot, but not under the parking lot, which is outside the suspected DNAPL source zone. DNAPL concentrations were particularly high under the resistive heating plot. Because these wells were installed only after the demonstration, it is unclear as to when the DNAPL migrated to the semi-confined aquifer. The resistive heating treatment heated the base of the aquifer and probably the aquitard fairly well and the buoyancy of the water would probably create vertically upward gradients. On the other hand, the Lower Clay Unit is thinnest in the resistive heating plot (1.5 ft effective thickness versus 3 ft in other parts of Launch Complex 34). It is possible that the DNAPL penetrated the aquitard gradually over time, long before the demonstration.

- *Losses during sampling of hot soil cores*. It is possible that some CVOC losses occurred during post-demonstration sampling of the hot (90°C or less) soil cores. However, tests conducted to determine volatilization losses by spiking hot soil samples with 1,1,1-TCA surrogate indicated that any such losses were minimal. The spike test results show that between 84 and 113% of the surrogate spike was recovered from the soil cores. All precautions had been taken to minimize any such losses. By the time the post-demonstration soil sampling was done, the plot had cooled to 90°C or less, indicating that steam generation had subsided. Each time the soil sample sleeve from the barrel was retrieved from the ground, it was immediately capped at both ends of the sleeve and submerged in an ice bath until the core temperature cooled to ambient.
- In summary, the monitoring indicates that some TCE may have degraded through one or more of several heat-induced degradation mechanisms and/or that some TCE may have migrated from the resistive heating plot through a variety of possible pathways. It also is possible that some of the migrating TCE was DNAPL. The resistive heating

application at Launch Complex 34 generated the desired heating in most parts of the plot, even in difficult spots, such as immediately above the aquitard and under the building. Heating in the shallower regions of the plot was somewhat hampered by the deficiencies of the new electrode design and by the transient diminishing of the vadose zone. Vapor capture and hydraulic control are the biggest challenges that the technology needs to engineer for in future applications, in order to ensure that all the mobilized or volatilized TCE-DNAPL is captured. At Launch Complex 34, a mechanism (such as a pipe) for channeling upward-migrating CVOC vapors past the Middle Fine-Grained Unit would have probably improved vapor capture. Better hydraulic and pneumatic control, as well as better heating, near the water table, vadose zone, and ground surface would have reduced TCE-DNAPL migration potential.

In summary, the TCE in the plot probably was dissipated by the resistive heating treatment through a number of possible pathways, including aboveground vapor recovery and condensation, microbial degradation, and migration to the surrounding regions. The possible buildup and persistence of *cis*-1,2-DCE in the plot, as well as dechlorination to ethenes, due to heat-accelerated biodegradation needs to be studied. Ways of maximizing any such biodegradation and minimizing migration outside the plot need to be determined during future resistive heating applications.

5.4 Operating Requirements and Cost

Section 3 contains a description of the resistive heating treatment 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 ground-water CVOC (primary) measurements and ground-water field parameter (secondary) measurements are described in this section. The results of the QA associated with other ground-water quality (secondary) measurements are described in Appendix G. The focus of the QA is on the critical TCE measurement in soil and ground water, 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 resistive heating 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 x 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 post-demonstration 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 resistive heating technology.
    - Sampling and analysis of duplicate post-demonstration soil cores to determine TCE concentration variability within each grid cell. Two complete cores (SB-204 and SB-304) were collected within about 2 ft of each other in the post-demonstration resistive heating 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 good match between the duplicate cores. This indicated that dividing the resistive heating 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 ground-water samples included:

- Installation and sampling of two well clusters in the 75-ft × 50-ft resistive heating 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 ground-water samples were collected from all resistive heating plot and surrounding wells to better evaluate the generation and migration of chloride, and the presence of potassium ion and potassium permanganate from the ISCO demonstration. One additional soil core was collected during post-demonstration sampling to evaluate the variability within the same grid cell.

All the quality control (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 pre-demonstration soil coring event. These blanks were later added to the QAPP and were prepared during the post-demonstration 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 1 blank per 20 samples (5%). However, as the speed of the soil coring increased, this frequency was found to have fallen slightly short of this ratio. The same rinsing procedure was maintained for the soil core barrel through the pre- and post-demonstration 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 were 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 ground-water 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 ground water 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 extract was sent to the off-site laboratory for CVOC analysis. A surrogate compound was initially selected to be 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 post-demonstration 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 pre-demonstration 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 QA 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 pre-demonstration sampling was greater than 30%, but less than 60%. This indicated that the repeatability of some of the pre-demonstration 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 post-demonstration 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 post-demonstration 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 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 June 23, 1999 (1.8 mg/kg), June 29, 1999 (8.0 mg/kg), and July 16, 1999 (1.2 mg/kg) during the pre-demonstration 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 post-demonstration methanol blanks were below detection.

6.2.2 Field QC Checks for Ground-Water Sampling

QC checks for ground-water 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 ground-water 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 ground-water samples initially consisted of a detergent rinse and two distilled water rinses. However, initial ground-water 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 post-demonstration 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 ground-water 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 Checks

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 ground-water samples were clear, in order to determine accuracy. However, when excess permanganate was present in the samples, as with many post-demonstration 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 Checks for Soil

Analytical accuracy for the soil samples (methanol extracts) analyzed were generally within acceptance limits (70-130%) for the pre-demonstration period (Appendix G, Table G-12). The batch of regular samples on August 22, 1999 had very high levels of TCE (near saturation), which tended to mask the spiked TCE. Matrix spike recoveries were outside this range for three of the MS/MSD samples conducted during the post-demonstration 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. Matrix spike recovery was 208% for one of the matrix spike repetitions on June 1, 2000. 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 post-demonstration periods

Table 6-2. List of Surrogate and Matrix Spike Compounds and Their Target Recoveries for Ground-Water 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. Surrogate and Laboratory Control Sample Compounds and Their Target Recoveries for Soil and Ground-Water Analysis by the Off-Site Laboratory

Surrogate Compound STL	Matrix Spike Compound STL
Dibromofluoromethane (66-137%) 1,2-Dichloroethane – d4 (61-138%) Toluene – d8 (69-132%) Bromofluorobenzene (59-145%)	Vinyl chloride (56-123%) Carbon tetrachloride (60-136%) Benzene (70-122%) 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 Ground Water

Pre- and post-demonstration MS and MSD results for ground water 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 August 3, 1999 and January 14, 2000 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 ground-water 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 ground water (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 organics 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 the ones 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 analysis.

6.4 QA/QC Summary

Given the challenges posed by the typically heterogeneous TCE distribution in a DNAPL source zone, the collected data were a relatively good representation of the TCE distribution in the Launch Complex 34 aquifer before, during, and after the demonstration, for the following reasons:

- 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 post-demonstration confidence intervals (range of TCE mass estimates) that were narrow enough to enable a good judgment of the TCE and DNAPL mass removal achieved by the resistive heating 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 ground-water 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, 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 caused detection limits for TCE, in some cases, to rise to 5 µg/L (instead of 3 µg/L). However, post-demonstration levels of dissolved TCE in many of the monitoring wells in the resistive heating 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 ground-water sampling tubing, TCE levels in field blanks were acceptably low or below detection.

7. Economic Analysis

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

- Application cost of resistive heating at the demonstration site. Costs of the technology application at Launch Complex 34 were tracked by the resistive heating vendor and by MSE, the DOE contractor who subcontracted the vendor.
- Site preparation and waste disposal costs incurred by the owner. NASA and MSE tracked 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 resistive heating cost with the cost of a conventional pump-and-treat system.

7.1 Resistive Heating Treatment Costs

The costs of the resistive heating treatment technology were tracked and reported by both the vendor and MSE, the DOE contractor who subcontracted the vendor. Table 7-1 summarizes the cost breakdown for the treatment. The total cost of the resistive heating demonstration incurred by the vendor was approximately $569,000. 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] by NASA, preliminary characterization by WSRC, detailed characterization by Battelle/TetraTech EM, Inc./U.S. EPA) and the cost of the operating waste disposal (incurred by NASA).

Table 7-1. Resistive Heating Application Cost Summary Provided by Vendor

Cost Item	Actual Cost ($)	Percentage (%)
Design and submittals	45,808	8.0
Mobilization of equipment	63,230	11.0
Temporary utilities setup	7,007	1.2
Air, water, and limited soil analyses	17,806	3.1
Condensate collection and storage	5,175	1.0
Gas/vapor collection system	38,952	6.8
Waste containment	4,620	0.8
Transport/disposal of drill cuttings	39,713	7.0
Resistive heating operations	196,194	34.5
Electricity used	72,484	12.8
Site restoration	5,380	1.0
Demobilization of equipment	58,837	10.3
Final report	13,536	2.5
Total Cost	**568,742**	**100**

Source: CES, 2001.

MSE separately estimated the unit treatment cost for the resistive heating treatment demonstration to be approximately $29/lb of TCE removed, which translates to the treatment cost of approximately $104/yd^3 (MSE, 2002). The estimated unit cost takes consideration of the treated/removed TCE in the plot, not accounting for the remainder of total TCE present in the resistive heating plot.

7.2 Site Preparation and Waste Disposal Costs

Soil cuttings from the hollow-stem auger used for installing the resistive heating electrodes were disposed of off site by the vendor and the costs are shown in Table 7-1. The wastes generated during resistive heating operation were disposed of off site by NASA at a cost of $44,000.

Wastes shipped off site included the spent GAC (sent to Arizona for regeneration), permanganate-impregnated silica (shipped to a nearby landfill), and steam condensate (transported to the on-site wastewater treatment facility).

7.3 Site Characterization and Performance Assessment Costs

This section describes two categories of costs:

- Site characterization costs. These are the costs that a site would incur in an 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 ground-water 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 resistive heating plot and determine the TCE-DNAPL mass removal achieved by resistive heating. 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 ground-water 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.

Performance assessment costs incurred jointly by Battelle and TetraTech EM, Inc., are listed in Table 7-3.

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 ground-water 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
Pre-Demonstration Assessment • Drilling – 12 continuous soil cores, installation of 18 monitoring wells • Soil and ground-water 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 • Ground-water 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
Post-Demonstration Assessment • Drilling – 12 continuous soil cores • Soil and ground-water sampling (36 monitoring wells; collection and field extraction of 300 soil samples) • Laboratory analysis (organic and inorganic analysis) • Field measurements (water quality; hydraulic testing)	$215,000
Total	**$ 663,000**

7.4 Present Value Analysis of Resistive Heating 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 ground-water 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 ground water above ground. This conventional technology is basically a plume control technology and would have to be implemented as long as ground-water contamination exists. Resistive heating technology is an innovative in situ technology that may be comparable to 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 the resistive heating technology, 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 the same 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 resistive heating plot. Recent research (Pankow and Cherry, 1996) indicates that the most efficient pump-and-treat system for source containment would capture all the ground water 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 extraction well pumping at 2 gallons per minute (gpm) is assumed to be sufficient to contain the source in an aquifer where the hydraulic gradient (and therefore, the ground-water flow velocity) is extremely low. This type of minimal containment pumping ensures that the source is contained without having to extract and treat ground water from cleaner surrounding regions, as would be the case in more aggressive conventional pump-and-treat systems. The extracted ground water is treated with an air stripper, polishing carbon (liquid phase), and a catalytic oxidation unit (for air effluent).

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 $57,000 (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 discount rate (real rate of return) 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**.

An equivalent treatment cost for full-scale deployment of the resistive heating technology would be approximately $613,000. This estimate is based on a total resistive heating treatment ($569,000) and waste disposal cost ($44,000) during the demonstration (from Table 7-1 and Section 7-2). Therefore, if the TCE remaining in the resistive heating plot was allowed to attenuate naturally, the total treatment cost with the resistive heating technology would be around **$613,000**. One assumption here is that the full-scale deployment of the resistive heating treatment system would entail design, equipment, and deployment similar to the kind done during the demonstration. If additional equipment or labor is required to install and operate additional/modified vapor capture and/or hydraulic control devices, there may be additional costs involved. Vapor capture and hydraulic control were the two main limitations identified during the demonstration that may require improvements at future implementation sites.

The economics of the resistive heating treatment 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 resistive heating would be recovered in the ninth year, when the PV of the pump-and-treat system exceeds the cost of resistive heating. In addition to a lower PV or life-cycle cost, 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 years or more, 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 the pump-and-treat or plume containment option (without source removal). As seen in Appendix H, the PV of a pump-and-treat system operated for 100 years would be $2,188,000. 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 size 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 resistive heating treatment technology to sites with contaminated ground water 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 resistive heating 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 resistive heating in particular.

8.1.1 Overall Protection of Human Health and the Environment

Resistive heating is protective of human health and environment in both the short and long term. At Launch Complex 34 for example, resistive heating removed more than 10,000 kg of DNAPL contamination from the resistive heating plot, with the possibility of some TCE mass destruction. 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. Vapor extraction and hydraulic control need to be improved to mitigate the potential for TCE-DNAPL migration to the regions surrounding the resistive heating treatment zone.

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.

Compliance with chemical-specific ARARs depends on the efficiency of the resistive heating process at the site and the cleanup goals agreed on by various stakeholders. In general, reasonable **short-term** (DNAPL mass removal) goals are more achievable and should lead to eventual and earlier compliance with long-term ground-water cleanup goals. Achieving **intermediate-term** ground-water 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 ground-water concentrations is observed. However, removal of DNAPL, even if most of the removal takes place from the more accessible pores, would probably result in a weakened plume that may lead to significant risk reduction in the downgradient aquifer. In the **long term**, source treatment should lead to earlier compliance with ground-water cleanup goals at the compliance boundary and earlier dismantling of any interim remedies (e.g., pump-and-treat).

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

8.1.2.1 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

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 resistive heating technology meets several of these criteria relating to a preferred alternative. Resistive heating reduces the volume of contaminants by removing DNAPL from the aquifer; it is possible that the toxicity of contaminants is reduced depending on how much the degradation pathways contribute to contaminant mass removal (see Sections 5.3.1 and 5.3.2). For example, at Launch Complex 34, as described in Section 5.3.1, there was a large increase in chloride in the ground water; some part of the chloride may have been generated by TCE degradation by microbial or abiotic mechanisms. This removal of solvent leads to a considerable reduction in the time it takes for the DNAPL source to fully deplete. 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 ground water over the short term, in the long term, there is faster eventual elimination of ground-water contamination. Section 7.4 shows that resistive heating is cost-effective compared with the conventional alternative of long-term pump and treat.

8.1.2.2 Resource Conservation and Recovery Act (RCRA)

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 ground-water treatment because the contaminated ground water may not be considered hazardous waste while it is still in the aquifer. The contaminated ground water becomes regulated if it is extracted from the ground, as would happen with the conventional alternative of pump and treat. Some aboveground wastes are generated that may require off-site landfill disposal. During the Launch Complex 34 demonstration, soil cuttings (from drilling and installation of resistive heating electrodes) and the permanganate-impregnated silica were shipped to a landfill. The spent GAC was shipped back to the supplier for regeneration.

8.1.2.3 Clean Water Act (CWA)

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. When steam or ground-water extraction is conducted, 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. At Launch Complex 34, no surface water discharge was involved at the demonstration site. Approximately 98,038 gal of condensate was generated during the demonstration. The condensate was run through a liquid-phase GAC, stored, analyzed, and transported to the on-site wastewater treatment plant.

Sometimes, soil or ground-water 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 (SDWA)

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 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 (ACL) 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 usually becomes the cleanup goal.

Although the long-term goal of DNAPL source zone treatment is meeting applicable drinking water standards or other risk-based ground-water cleanup goals agreed on between site owners and regulatory authorities, the short-term objective of resistive heating 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 ground-water 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 ground-water 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 ground-water cleanup targets at the compliance point in the short term. DNAPL mass removal will always lead to faster attainment of ground-water cleanup goals in the long term, as compared to the condition in which no source removal action is taken.

8.1.2.5 Clean Air Act (CAA)

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 (SIP) developed to bring each state in compliance with National Ambient Air Quality Standards (NAAQS).

Pump-and-treat systems often generate air emissions (when an air stripper is used). Source removal technologies that use thermal energy (e.g., steam injection or resistive heating) also may have the potential to generate air emissions, unless adequate controls are implemented. Surface emission tests conducted in the resistive heating plot during and after the demonstration showed TCE emissions that were noticeably above background levels. This indicates that the vapor recovery system needs to be designed for better capture. This is an issue of concern for this technology.

8.1.2.6 Occupational Safety and Health Administration (OSHA)

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 resistive heating are addressed in Section 3.2.3, 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, handling of hot fluids, and high voltage are the main working hazards and are dealt with by using appropriate PPE and trained workers. Monitoring wells should be fitted with pressure gauges and pressure release valves to facilitate sampling during and/or after the resistive heating application. All operating and sampling personnel are required to have completed the 40-hour HAZWOPER training course and 8-hour refresher courses. There were no injuries during the resistive heating demonstration at Launch Complex 34.

8.1.3 Long-Term Effectiveness and Permanence

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

8.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Resistive heating affects treatment by reducing the volume of the contamination and possibly, reducing its toxicity as well (depending on how much the degradation pathway contributes to contaminant mass removal).

8.1.5 Short-Term Effectiveness

Short-term effectiveness of the resistive heating 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 the monitoring wells in the resistive heating plot, but were well above federal or state MCLs. 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 post-treatment ground-water 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 or intermediate term. In the long term, DNAPL mass removal will always shorten the time 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 the resistive heating technology are minimal. Firm ground for setup of the heating equipment (such as electrodes, transformer, cables, etc.) is required. The equipment involved are commercially available, although the electrical transformer and power supply required are relatively large, and may require time to acquire. Setup and shakedown times are relatively high compared to other technologies, such as chemical oxidation. Overhead space available at open sites generally is sufficient for housing the resistive heating equipment. Accessibility to the targeted portion of the contamination under the Engineering Support Building at Launch Complex 34 was relatively good with electrodes inserted from the outside. However, electrodes installed from inside the building may be required to remediate more of the contamination under the building. This may disrupt the use of the building for the period of the treatment. The vendor suggests that electrodes inside the building can be flush-mounted, allowing continued use of the building. In this case, the installation cost would be higher.

8.1.7 Cost

As described in Section 7.4, the cost of the resistive heating treatment technology, implemented at Launch Complex 34, 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 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 resistive heating technology are:

- Operating requirements associated with any contamination further under a building, where angled electrodes are not sufficient and the aquifer has to be accessed from inside the building.
- Need for additional vapor or hydraulic control (e.g., with extraction wells) and any associated need to treat and dispose/reinject extracted fluids. This may be required to ensure that TCE vapors reach the vadose zone, where they can be captured, and are not obstructed by aquifer heterogeneities (such as the Middle Fine-Grained Unit).
- Regions with high unit cost of power.

8.1.8 State Acceptance

The ITRC, a consortium of several states in the United States, is participating in the IDC demonstration through review of reports 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 resistive heating technology's low noise levels and ability to reduce short- and long-term risks posed by DNAPL contamination are expected to promote local community acceptance. Supply of sufficient power and control of air emissions may be issues of concern for communities.

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 the resistive heating treatment demonstration in the 75-ft × 50-ft plot at Launch Complex 34 took about 11 months to complete. The remediation generally is done as a turnkey project by multiple vendors, who will design, build, and operate the resistive heating system. Site characterization, site preparation (utilities, etc.), monitoring, and any waste disposal often are done by the site owner. The resistive heating process is patented, but is commercially available from multiple licensed vendors.

The resistive heating treatment is relatively complex and requires proficient operators trained in this particular technology. Handing of hot fluids and high-voltage electrical equipment may require additional precautions.

8.3 Applicable Wastes

Resistive heating has been applied to remediation of aquifers contaminated with chlorinated solvents, polycyclic aromatic hydrocarbons (PAHs), and petroleum hydrocarbons both in the vadose and saturated zones. Source zones consisting of perchloroethylene (PCE) and TCE in DNAPL or dissolved form, as well as dissolved *cis*-1,2-DCE and vinyl chloride can be addressed by resistive heating.

8.4 Key Features

The following are some of the key features of resistive heating that make it attractive for DNAPL source zone treatment:

- In situ application
- Aboveground use of the site can continue during application
- Uses relatively complex, but commercially available, equipment
- Relatively fast field application time possible, when applied properly
- The heat generated distributes well in the aquifer in both high-permeability and low-permeability zones, 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 could be applied for a shorter duration in the future.

8.5 Availability/Transportability

Resistive heating is commercially available from multiple vendors as a service on a contract basis. All reusable system components can be trailer-mounted for transportation from site to site. Electrodes and other subsurface components usually are left in the ground after resistive heating application.

8.6 Materials Handling Requirements

Resistive heating technology requires hot fluids handling capabilities. Heavy equipment needs to be moved around with forklifts. Drilling equipment is required to install subsurface electrodes. Design and operation of the high-voltage electrical equipment requires specially trained operators.

8.7 Ranges of Suitable Site Characteristics

The following factors should be considered when determining the suitability of a site for the resistive heating treament:

- **Type of contaminants.** Contaminants should be amenable to mobilization, volatilization, or degradation by heat.
- **Site geology.** Resistive heating treatment can heat sandy soils, as well as silts or clays. However, aquifer heterogeneities and preferential flowpaths can make capturing the contaminants in the extraction system more difficult. DNAPL source zones in fractured bedrock also may pose a challenge. Longer application times and higher cost may be involved at sites with a high ground-water flow velocity because of increased rate of heat loss from the treated zone.
- **Soil characteristics.** Both low- and high-permeability soils can be heated by resistive heating treatment.
- **Regulatory acceptance.** Regulatory acceptance is important for this application. Improvements in vapor transport and recovery are necessary to increase acceptance.
- **Site accessibility.** Sites that have no aboveground structures and fewer utilities are easier to remediate with this technology. Presence of buildings or a network of utilities can make the application more difficult.

None of the factors mentioned above necessarily eliminates the resistive heating technology from consideration. Rather, these are factors that may make the application less or more economical.

8.8 Limitations

The resistive heating technology has the following limitations:

- Not all types of contaminants are amenable to heat treatment. In addition, some cocontaminants, such as certain heavy metals, if present, could be mobilized by heating.
- Aquifer heterogeneities can make the application more difficult, necessitating more complex application schemes, greater amounts of heat (or electricity), and/or longer application times. The limitation

lies not so much with the ability of the resistive heating technology to heat the subsurface, but with its ability to transport and capture the contaminant vapors in an efficient manner.

- Some sites may require greater hydraulic control to minimize the spread of contaminants. This may necessitate the use of extraction wells and any associated aboveground treatment.

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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.

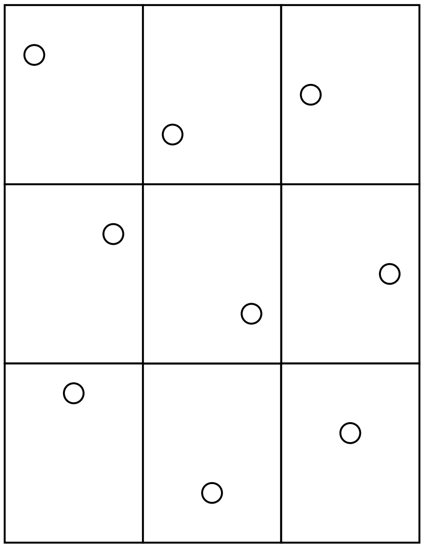


Figure A.1-1. Unaligned Systematic Sampling Design for a 3 × 3 Grid

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 ∀ 22.5º), 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.

- To help fully understand the spatial correlation structure, a variety of experimental semivariogram curves may be generated by subsetting the data into discrete zones, such as different depth horizons. If significant differences are found in the semivariograms they are modeled separately; if not, the data are pooled together into a single semivariogram.
- After the data have been pooled or subsetted accordingly, and the associated experimental semivariograms have been calculated and plotted, a positive-definite analytical model is fitted to each experimental curve. The fitted semivariogram model is then used to input the spatial correlation structure into the subsequent kriging interpolation step.

A.1.2.2 Interpolation Using Ordinary Kriging

Ordinary kriging is a linear geostatistical estimation method which uses the semivariogram function to determine the optimal weighting of the measured TCE values to be used for the required estimates, and to calculate the estimation standard error associated with the estimates (Journel and Huijbregts, 1981). In a sense, kriging is no different from other classical interpolation and contouring algorithms. However, kriging is different in that it produces statistically optimal estimates and associated precision measures. It should be noted that the ordinary kriging variance, while easy to calculate and readily available from most standard geostatistical software packages, may have limited usefulness in cases where local estimates are to be calculated, and the data probability distribution is highly skewed or non-gaussian. The ordinary kriging variance is more appropriately used for global estimates and symmetric or gaussian data distributions. The ordinary kriging variance provides a standard error measure associated with the data density and spatial data arrangement relative to the point or block being kriged. However, the ordinary kriging variance is independent of the data values themselves, and therefore may not provide an accurate measure of local estimation precision.

A.1.2.3 TCE Data Summary

Semivariogram and kriging analyses were conducted on data collected from two test plots; one plot used ISCO technology, and the other used a standard Resistive Heating technology to remove TCE. Each plot was approximately 50 by 75 feet in size, and was sampled via 25 drill holes, half before and half after remediation. The location of each drill hole was recorded by measuring the distance in the northing and easting directions from a designated point on the Cape Canaveral Air Station. The documented coordinates for each drill hole on the ISCO and Resistive Heating plots are defined within Figure A.1-2. The same locations are also shown in Figure A.1-3 after we rotated both plots by 30 degrees and shifted the coordinates in order to produce a posting map that was compatible with the kriging computer software.

Each point within Figures A.1-2 and A.1-3 represents a single drill hole. Recall that pre- and post-remediation TCE measurements were collected in order to analyze the effectiveness of the contaminant removal methods. Thus, the drill holes were strategically placed so that pre and post information could be gathered within a reasonable distance of one another (i.e., the holes were approximately paired). In addition, for both the ISCO and the Resistive Heating plots, an extra or twinned post-remediation hole was drilled (see pre/post pair # 10B and 17B on Figures A.1-2 and A.1-3). Since our approach for the kriging analysis considered the pre- and post-remediation data as independent data sets (see Section 1.0), we included the duplicate holes in our analyses, even though a corresponding pre-remediation hole did not exist.

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.

Tables A.1-3 and A.1-4 provide summary statistics by layer and depth for pre- and post-remediation measurements. The minimum and maximum values provide the overall range of the data; the mean or average TCE measurement estimates (via simple arithmetic averaging) the amount of TCE found within the given layer and depth; and the standard deviation provides a sense of the overall spread of the data. Note that our analyses focus on the three deepest layers, USU, MFGU and LSU.

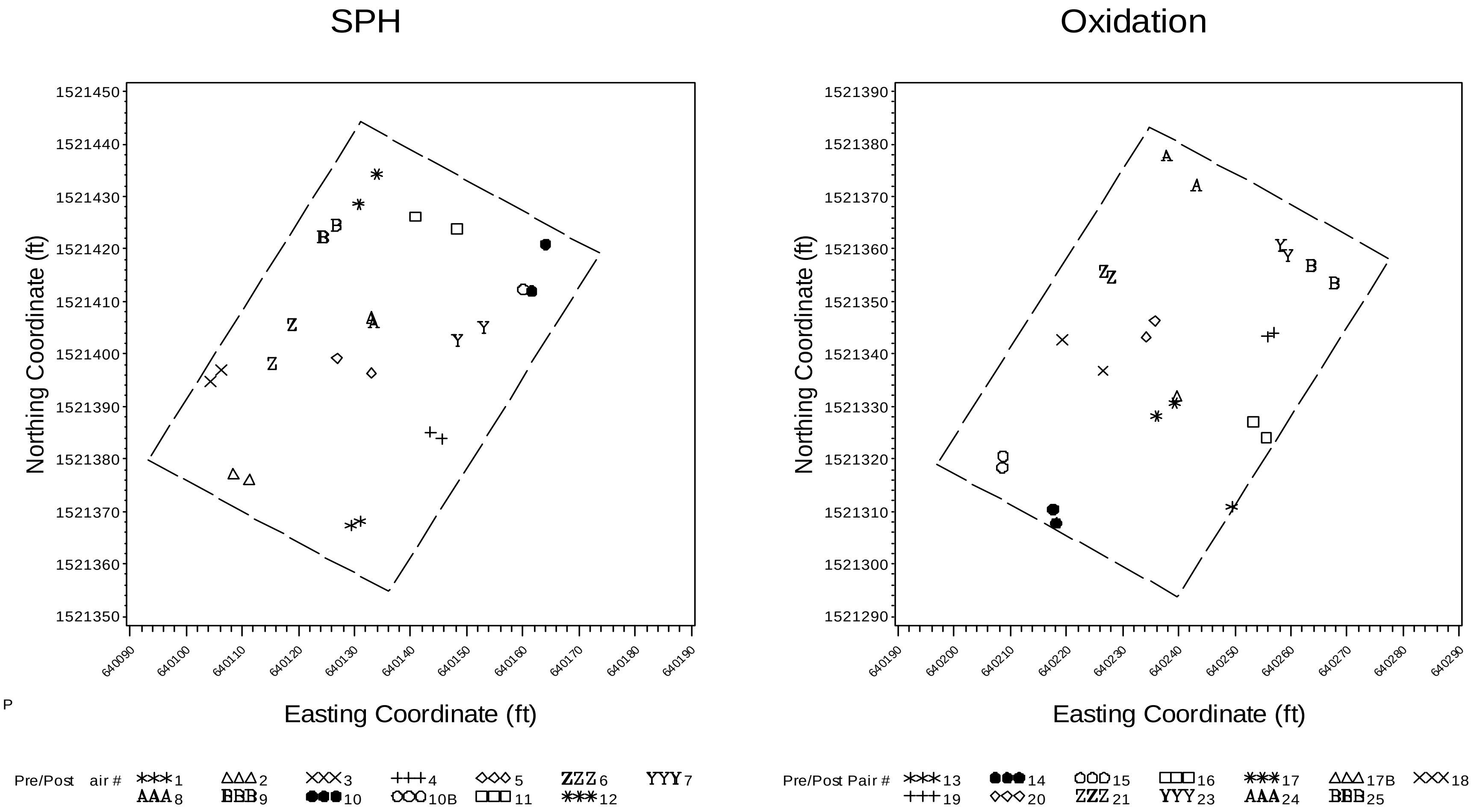


Figure A.1-2. Original Posting Maps of Resistive Heating (SPH) and ISCO plots
(Note that pre/post pair # 13 has two drill holes that are extremely close to one another)

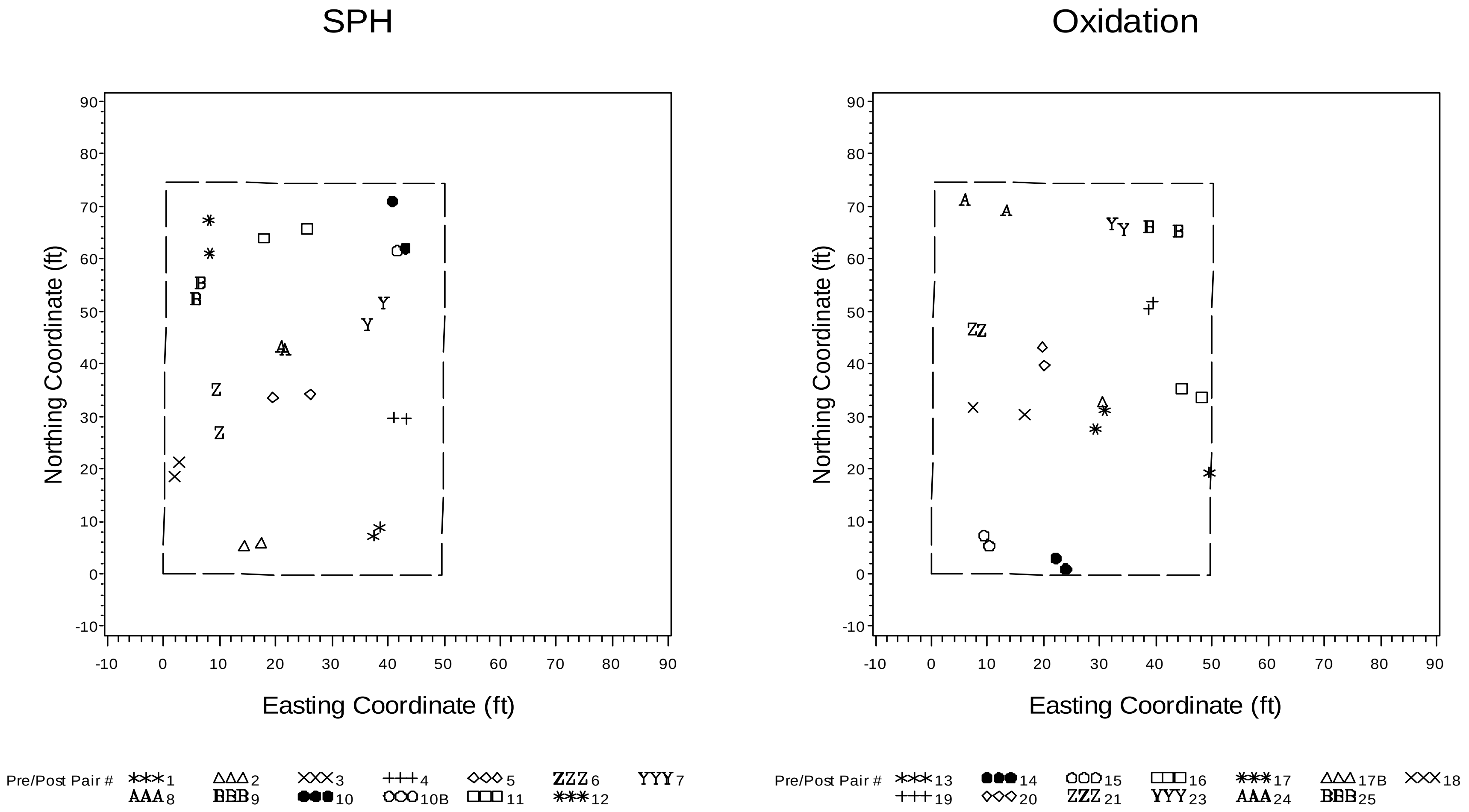


Figure A.1-3. Rotated Posting Maps of Resistive Heating (SPH) and ISCO plots
(Note that pre/post pair # 13 has two drill holes that are extremely close to one another)

Table A.1-3. Summary Statistics for Data Collected From Resistive Heating 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	1	7.78	7.78	7.78	.	2	0.26	0.77	0.51	0.36
	8 to 10	1	5.29	5.29	5.29	.	6	0.25	6.00	2.67	2.62
	6 to 8	6	0.14	9.24	2.01	3.59	12	0.25	6.00	1.84	1.77
	4 to 6	12	0.14	4.63	1.25	1.63	13	0.21	12.00	2.61	3.53
	2 to 4	12	0.10	10.52	1.75	3.16	13	3.00	40.22	9.32	11.22
	0 to 2	10	0.17	48.74	5.26	15.29	3	10.00	72.00	47.67	33.08
	-2 to 0	2	0.20	1.10	0.65	0.64	.	.	.	.	.
	Total	44	0.10	48.74	2.61	7.55	49	0.21	72.00	6.88	14.23
USU	0 to 2	2	0.71	8.84	4.77	5.75	10	5.00	90.00	30.31	27.06
	-2 to 0	9	0.18	12.46	2.27	4.06	12	0.22	114.00	20.85	35.55
	-4 to -2	11	0.18	6.46	1.65	2.09	9	0.22	71.00	18.84	27.65
	-6 to -4	10	0.18	4.01	1.05	1.24	12	0.16	126.00	36.26	47.60
	-8 to -6	13	0.17	121.67	10.73	33.41	12	0.26	197.00	50.52	72.10
	-10 to -8	13	0.20	341.80	51.64	122.88	13	1.00	4295.43	358.08	1183.66
	-12 to -10	11	0.19	1935.01	182.22	581.52	11	0.17	1248.08	154.42	368.78
	-14 to -12	12	0.20	107.82	22.01	32.52	11	5.00	135.00	62.56	45.67
	-16 to -14	10	9.20	1835.15	224.50	569.37	10	4.00	213.00	96.89	80.34
	-18 to -16	5	10.77	259.76	86.43	101.53	2	6.00	64.00	35.00	41.01
	-20 to -18	2	26.27	112.13	69.20	60.71	1	20.00	20.00	20.00	.
	Total	98	0.17	1935.01	60.75	271.45	103	0.16	4295.43	95.78	437.80
MFGU	-14 to -12	1	820.43	820.43	820.43	.	1	3927.05	3927.05	3927.05	.
	-16 to -14	2	292.17	526.14	409.16	165.45	5	12.00	401.30	252.87	150.23
	-18 to -16	5	183.22	9050.90	2192.46	3844.52	12	4.00	5560.77	704.64	1539.34
	-20 to -18	13	26.37	19090.91	3314.22	6670.74	12	13.00	403.00	215.36	159.67
	-22 to -20	10	54.64	541.79	196.80	148.15	8	10.00	319.00	131.66	102.29
	-24 to -22	8	17.00	11085.00	1533.59	3871.12	4	7.00	140.00	55.25	61.99
	-26 to -24	3	2.24	5345.08	1783.27	3084.62	2	3.00	19.00	11.00	11.31
	-28 to -26	2	0.39	0.39	0.39	0.00	2	5.00	23.00	14.00	12.73
	-30 to -28	2	0.20	1.40	0.80	0.85	2	1.00	1.00	1.00	0.00
	-32 to -30	1	0.68	0.68	0.68	.	1	3.00	3.00	3.00	.
	Total	47	0.20	19090.91	1601.61	4152.73	49	1.00	5560.77	358.38	942.46
LSU	-20 to -18	.	.	.	.	.	1	1217.00	1217.00	1217.00	.
	-22 to -20	3	34.76	349.12	186.05	157.51	5	34.00	464.64	233.38	158.60
	-24 to -22	6	4.79	623.63	176.84	231.51	10	20.70	287.00	139.97	101.17
	-26 to -24	9	0.18	1024.58	213.91	332.94	11	35.00	429.15	192.80	145.10
	-28 to -26	11	0.28	23361.76	4599.56	8705.84	12	63.00	473.85	279.32	148.04
	-30 to -28	10	0.23	8061.67	1430.78	2922.44	12	2.00	264.00	143.55	86.98
	-32 to -30	9	0.21	28167.63	3338.38	9314.75	11	9.00	335.08	123.18	107.14
	-34 to -32	12	0.43	33099.93	3357.69	9549.49	12	0.17	511.00	167.27	179.23
	-36 to -34	12	5.75	41043.56	7635.34	15205.72	12	0.19	364.00	144.99	126.21
	-38 to -36	12	11.76	37104.00	6980.34	12891.67	3	2.00	59.00	23.00	31.32
	-40 to -38	1	1.46	1.46	1.46	.	.	.	.	.	.
	Total	85	0.18	41043.56	3696.17	9459.97	89	0.17	1217.00	181.46	176.47

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 30º 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 22.5º.

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 *		
		Average	Lower Bound	Upper Bound	Average	Lower Bound	Upper Bound		Average	Lower Bound	Upper Bound	Average	Lower Bound	Upper Bound
	N	(mg/kg)	(mg/kg)	(mg/kg)	(kg)	(kg)	(kg)	N	(mg/kg)	(mg/kg)	(mg/kg)	(kg)	(kg)	(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

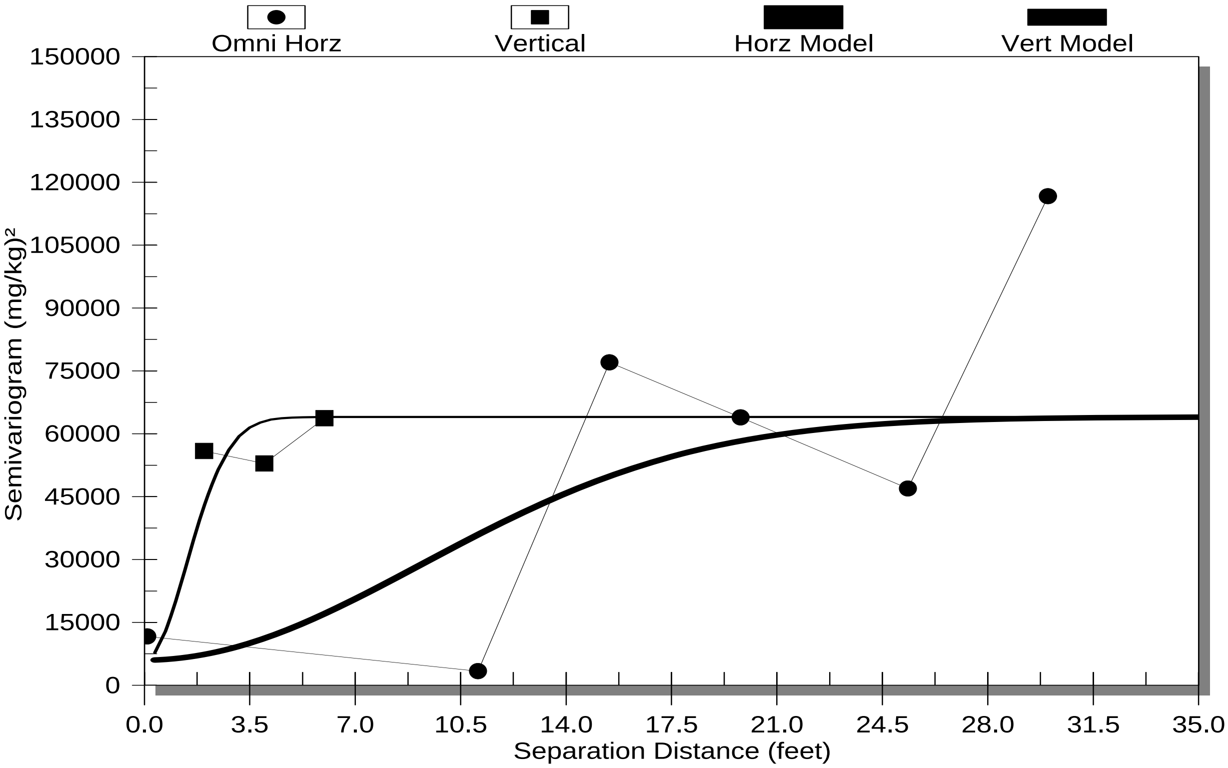


Figure A.1-4. Pre-Remediation TCE Semivariograms for Resistive Heating Plot and USU

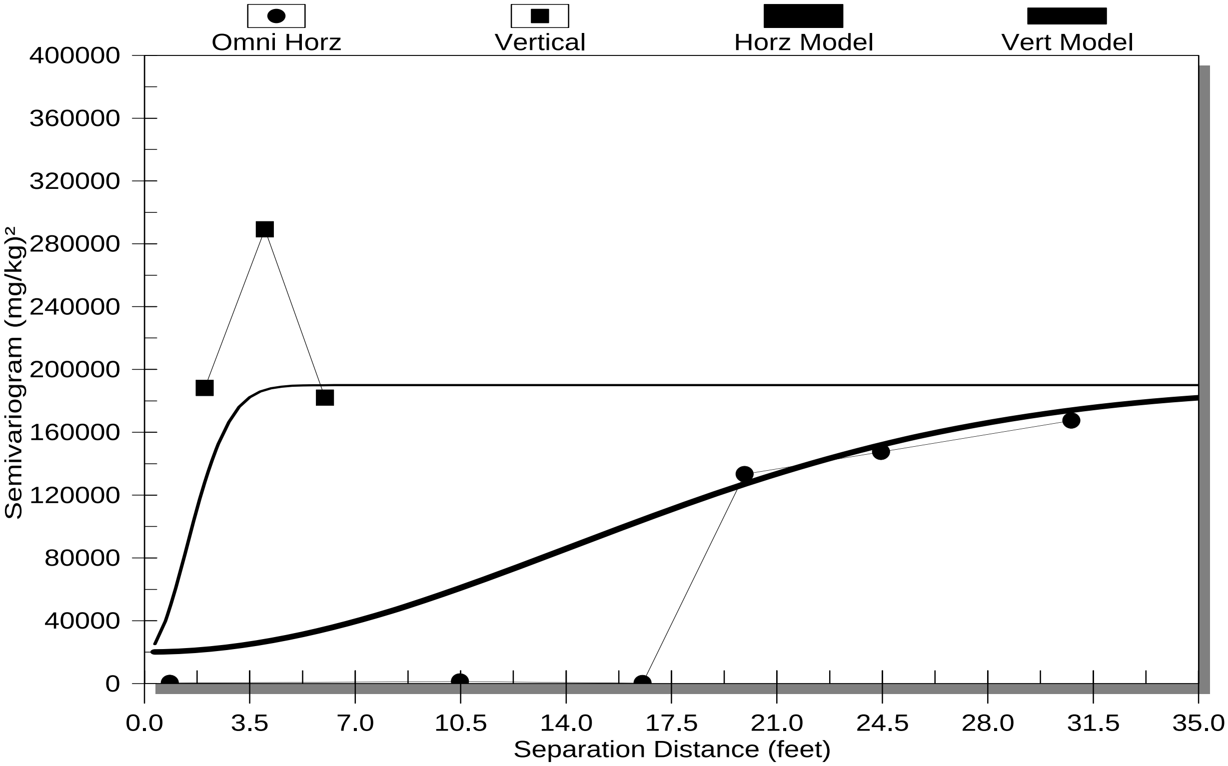


Figure A.1-5. Post-Remediation TCE Semivariograms for Resistive Heating Plot and USU

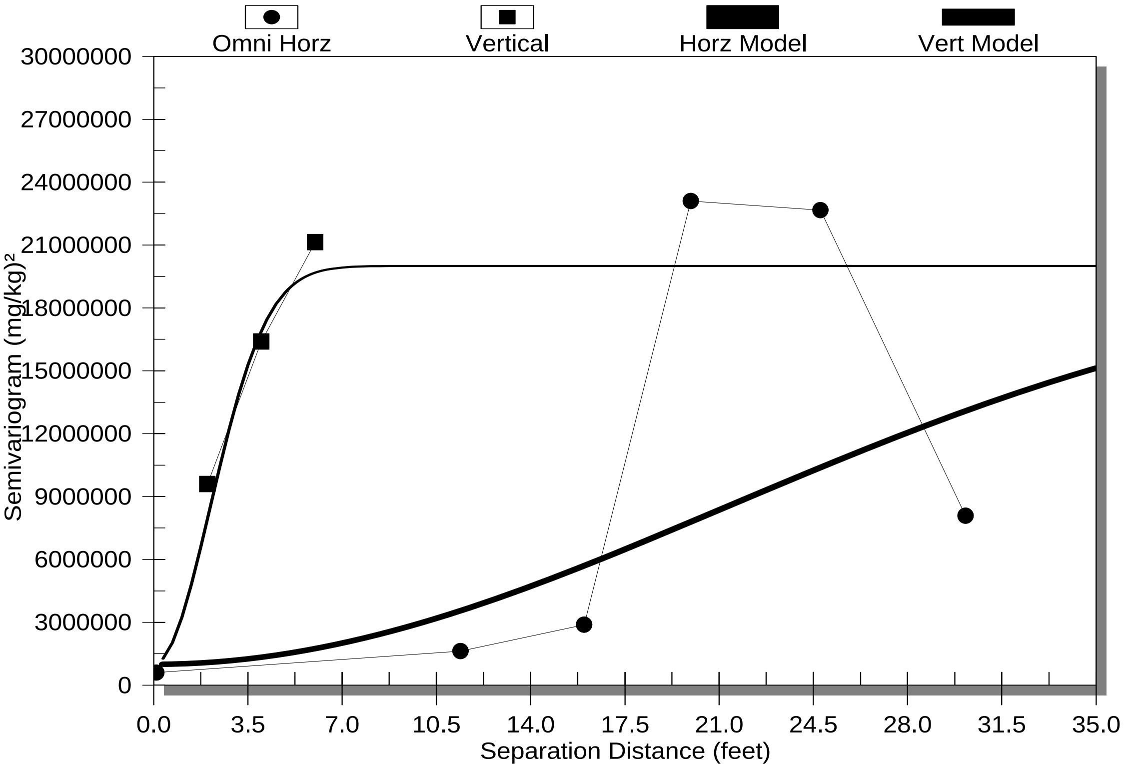


Figure A.1-6. Pre-Remediation TCE Semivariograms for Resistive Heating Plot and MFGU

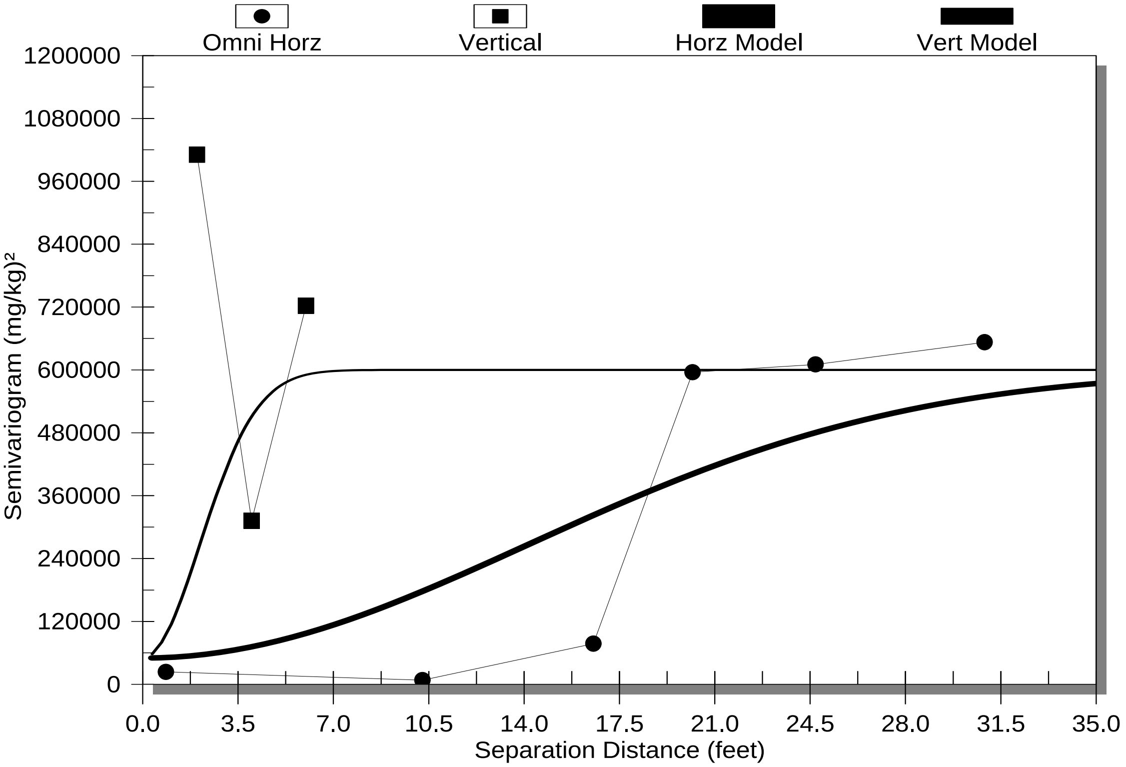


Figure A.1-7. Post-Remediation TCE Semivariograms for Resistive Heating Plot and MFGU

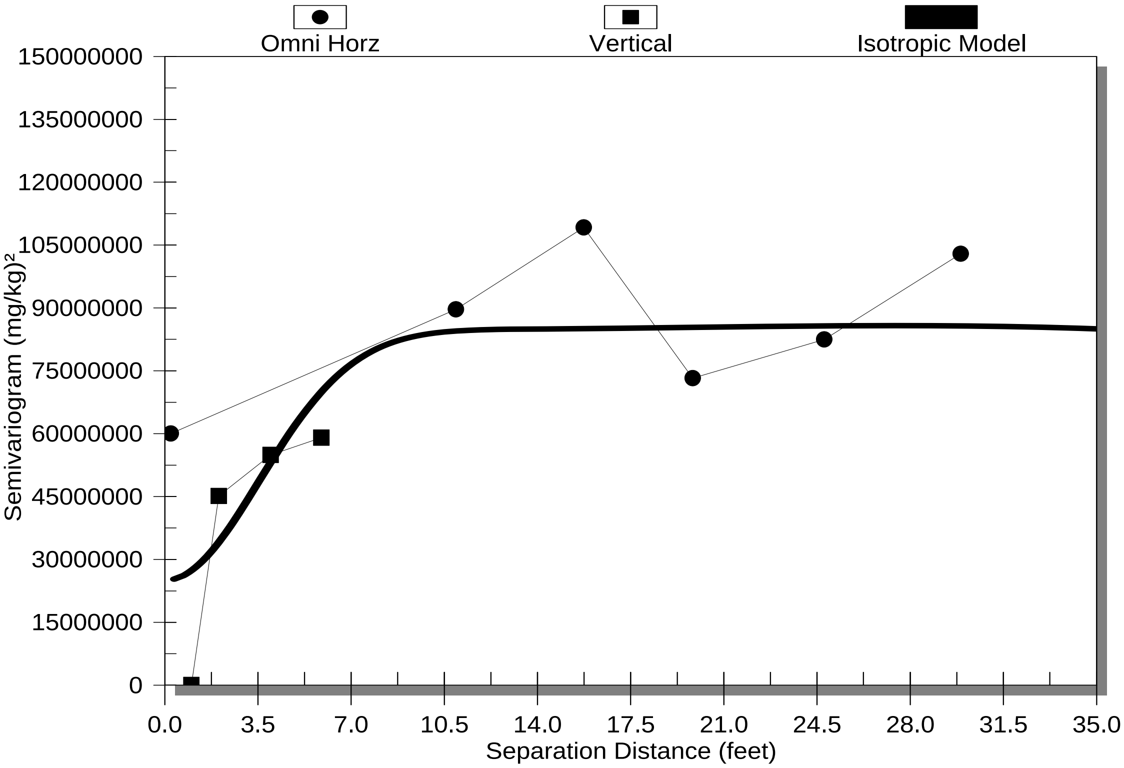


Figure A.1-8. Pre-Remediation TCE Semivariograms for Resistive Heating Plot and LSU

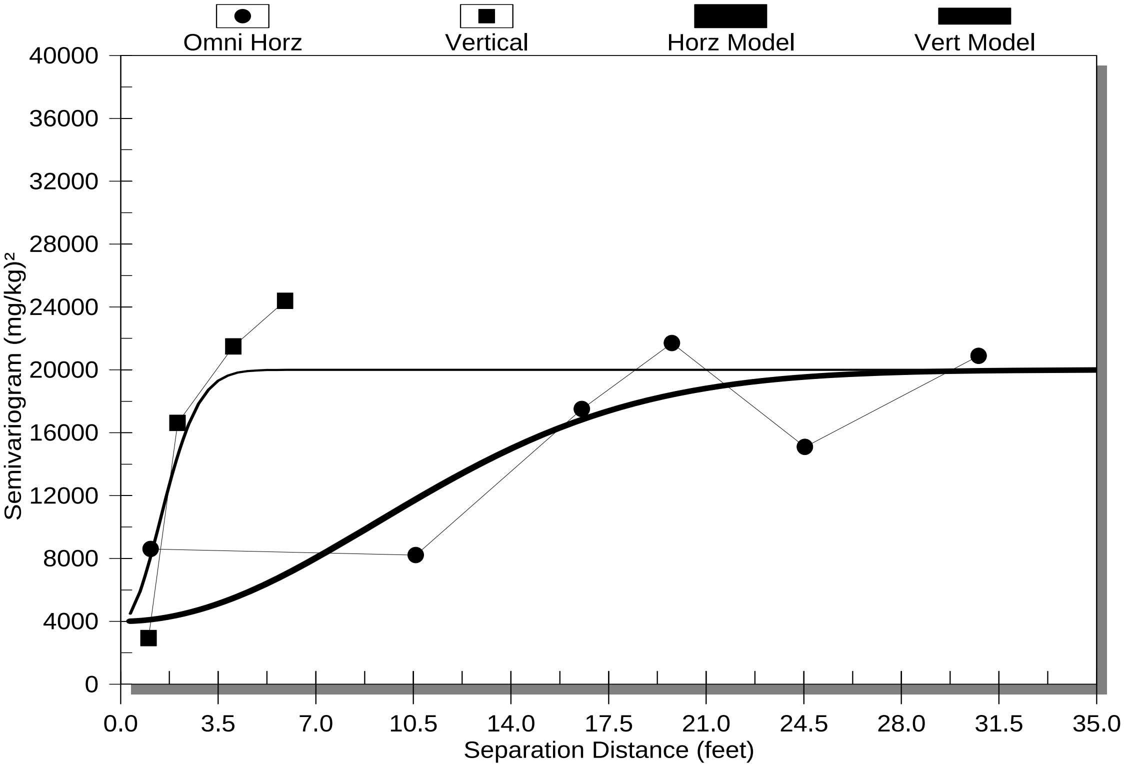


Figure A.1-9. Post-Remediation TCE Semivariograms for Resistive Heating Plot and LSU

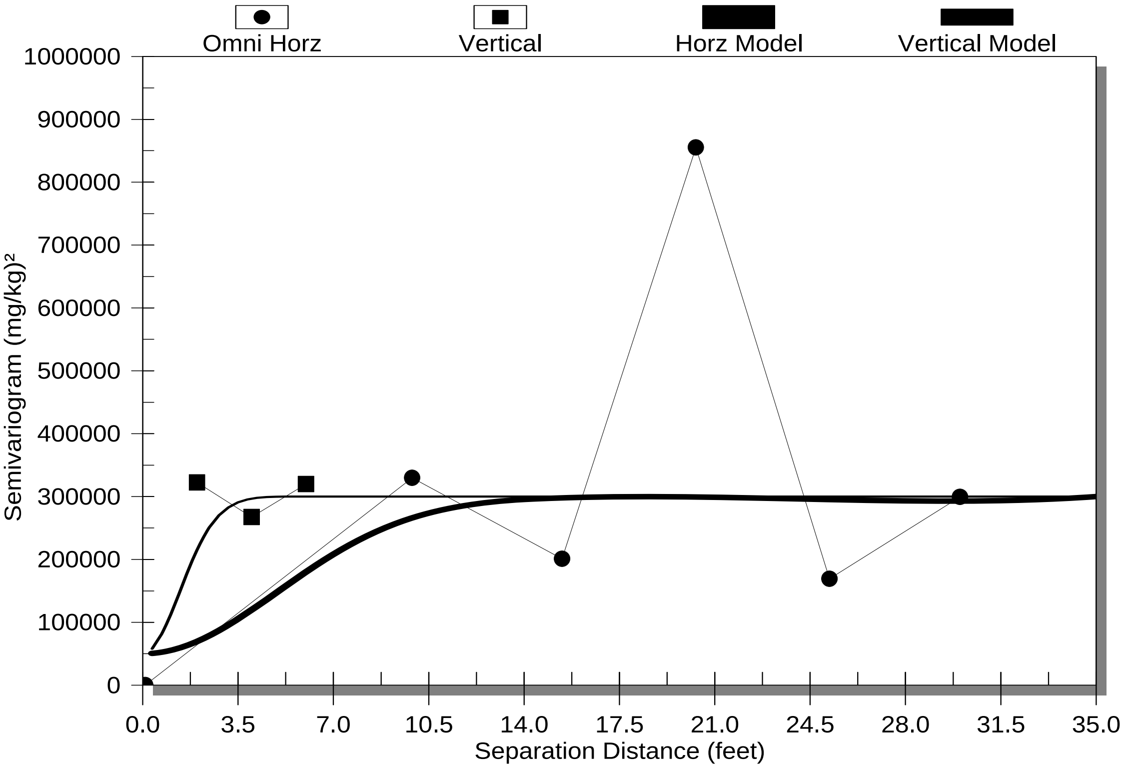


Figure A.1-10. Pre-Remediation TCE Semivariograms for ISCO Plot and USU

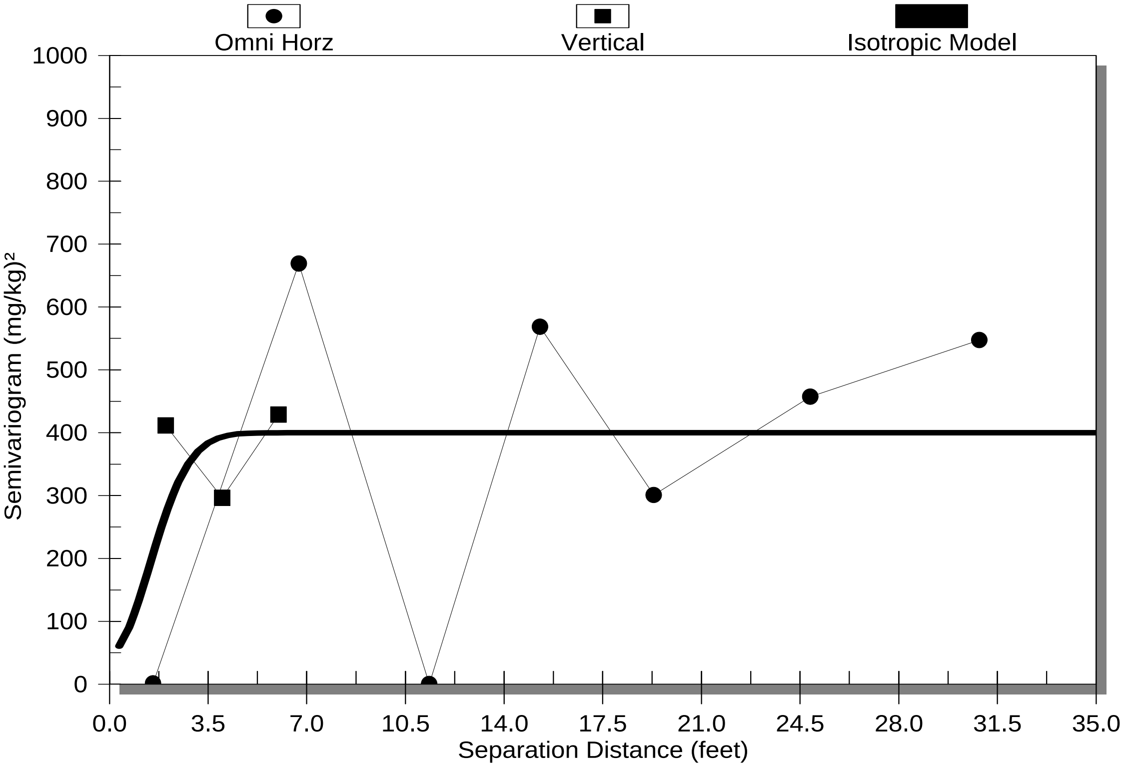


Figure A.1-11. Post-Remediation TCE Semivariograms for ISCO Plot and USU

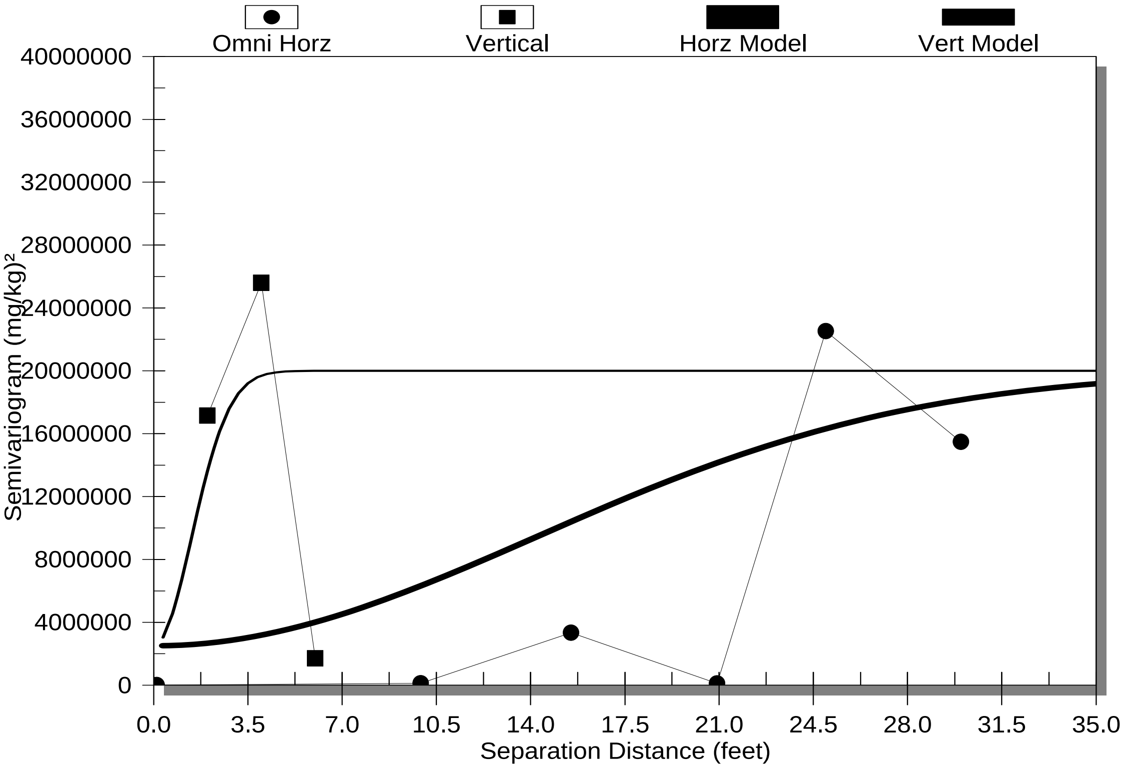


Figure A.1-12. Pre-Remediation TCE Semivariograms for ISCO Plot and MFGU

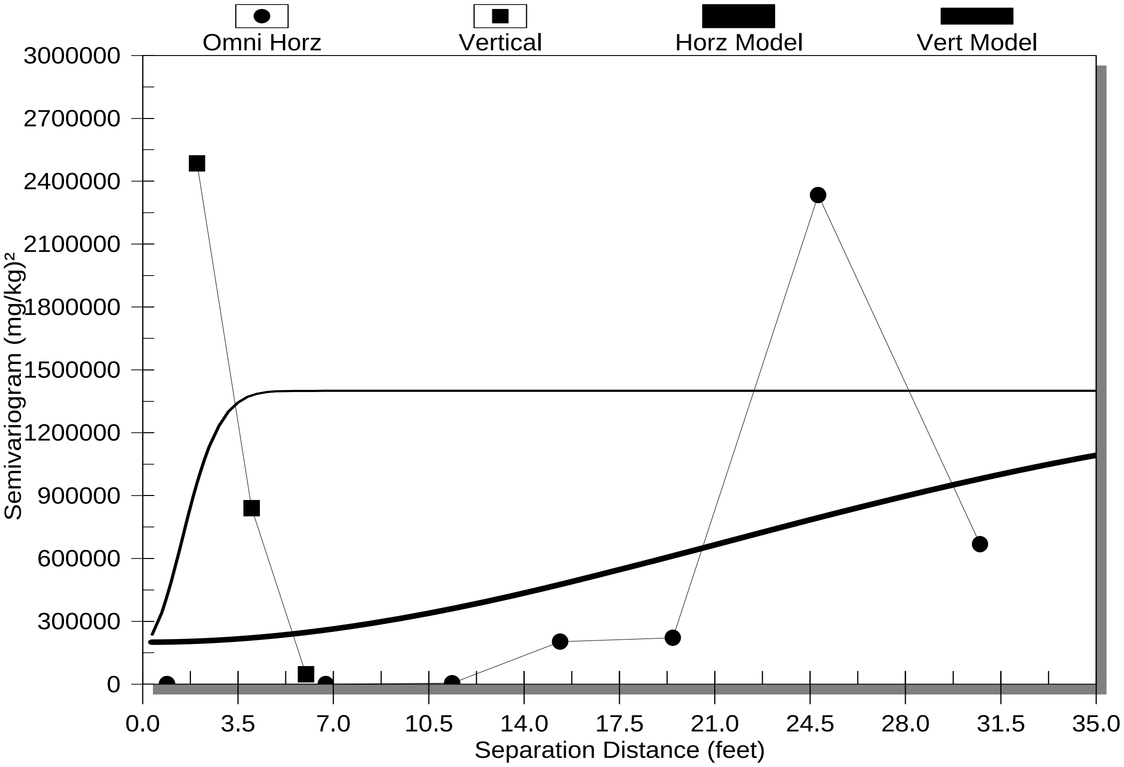


Figure A.1-13. Post-Remediation TCE Semivariograms for ISCO Plot and MFGU

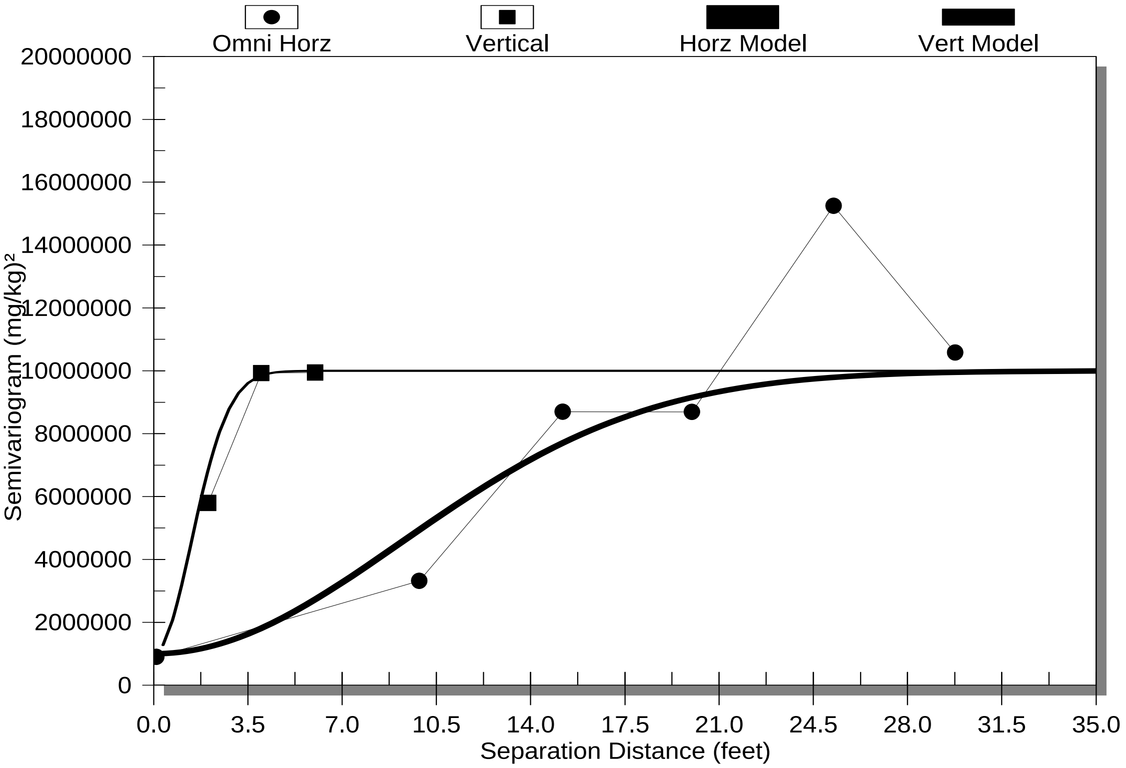


Figure A.1-14. Pre-Remediation TCE Semivariograms for ISCO Plot and LSU

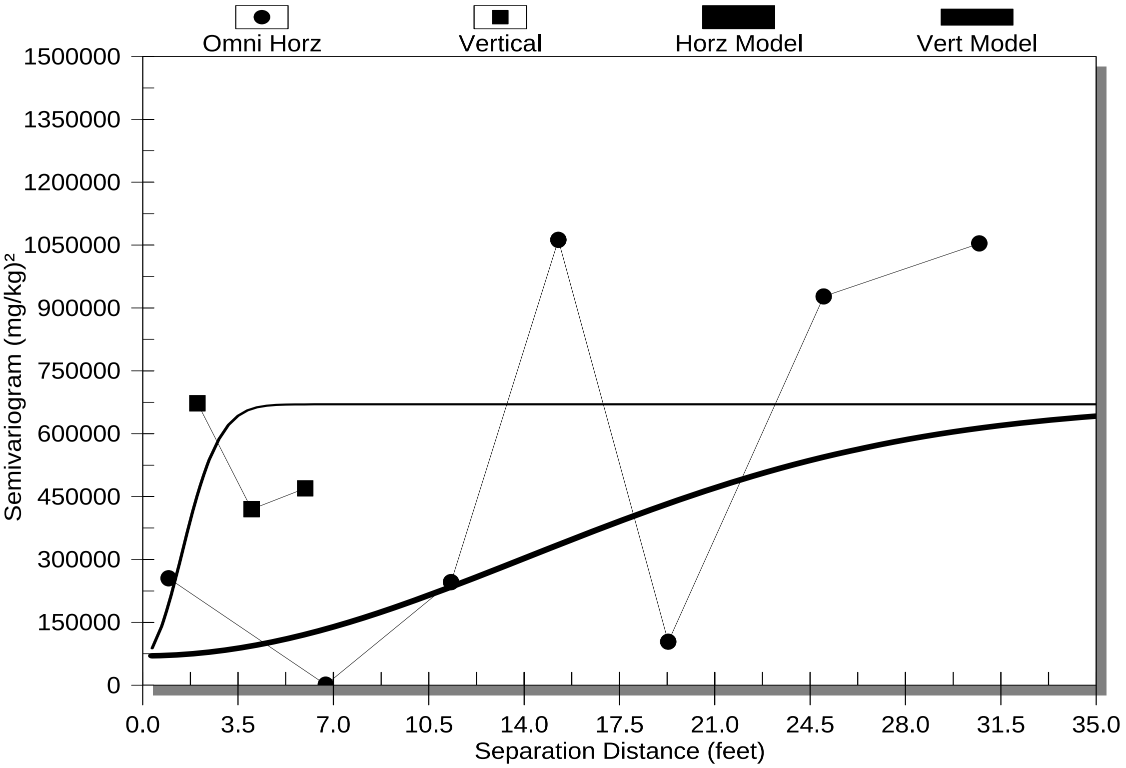


Figure A.1-15. Post-Remediation TCE Semivariograms for ISCO Plot and LSU

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 and Lithologic Logs

B.1 Data Analysis Methods and Results for Slug Tests
B.2 Site Assessment Well Completion Diagrams for Shallow, Intermediate, and Deep Wells
B.3 LC34 IDC Coring Logsheets for Site Assessment Wells
B.4 LC34 IDC Coring Logsheets for Semi-Confined Aquifer Wells

B.1 Data Analysis Methods and Results for the Slug Tests

Slug tests were performed on well clusters PA-13 and PA-14 within the resistive heating plot for pre-demonstration and post-demonstration to determine if the remediation system affected the permeability of the aquifer. 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 1.6 ft of change in water level within the well. Water level recovery was then monitored for 10 minutes using a TROLL pressure transducer/data logger. The data was then downloaded to a notebook computer. Replicate tests were performed for each well.

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. Tests showed very high coefficient of determinations (R^2), with all R^2s above 0.95. The results also showed a very good agreement between the replicate tests. However, in wells PA-14S and PA-14I some unclear response was observed, where the water levels never returned to the original levels or started decreasing again after reaching equilibrium. It should be noted that during the demonstration, the wells became pressurized, and some residual effects of the pressurization may still be present within the resistive heating plot wells.

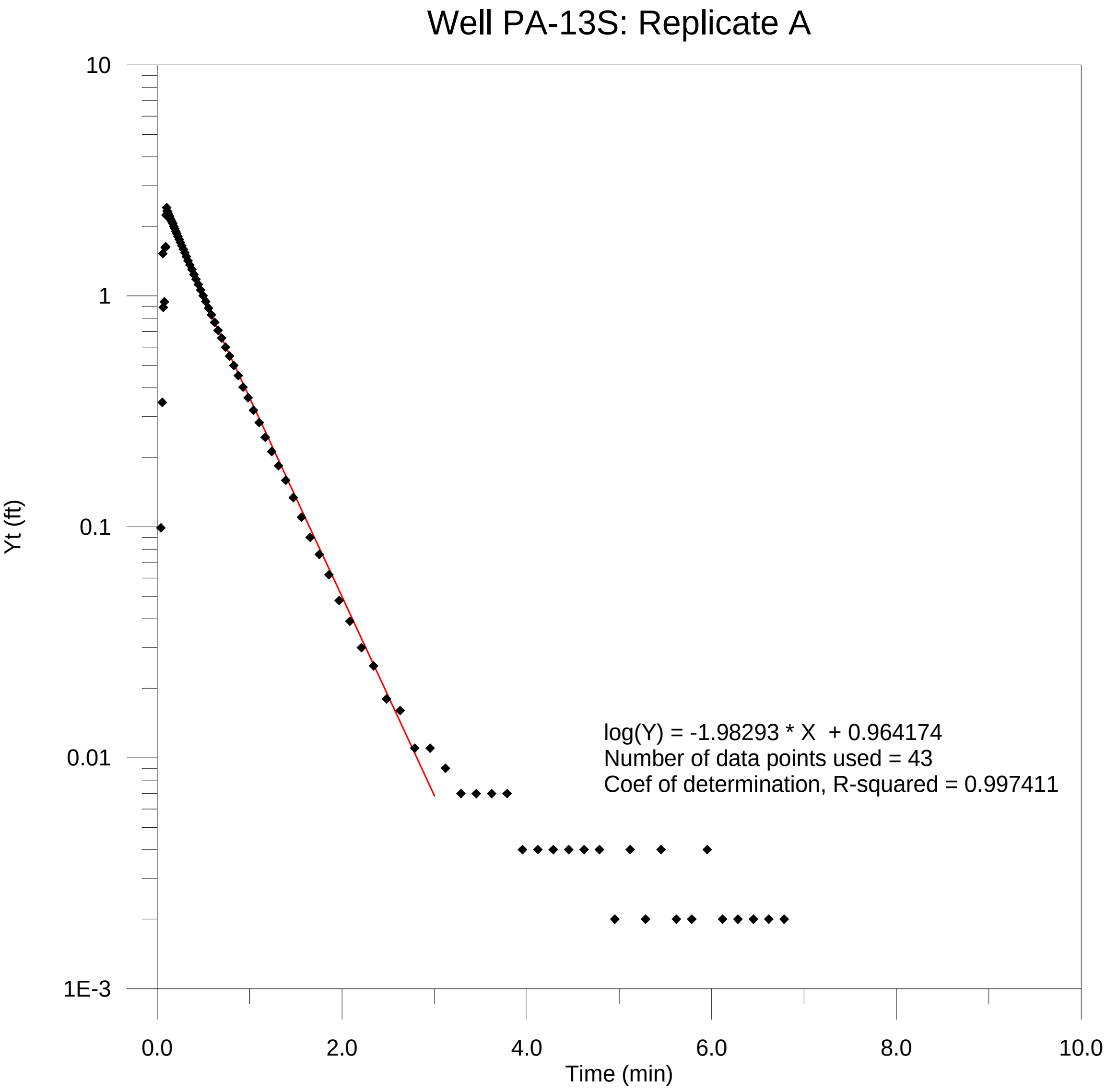
The tests are subject to minor variations. As such, a change of more than a magnitude of order would be required to indicate a change in the permeability of the sediments. Keeping this in mind, no tests showed a substantial change in permeability as shown on Table 1. However, five of the six tests indicated a net increase in permeability. Overall, this would suggest that the resistive heating plot technology had a small effect on the sediments in the test plot, increasing the overall permeability of the plot, but not significantly.

Table 1. Slug Test Results in Resistive Heating Plot

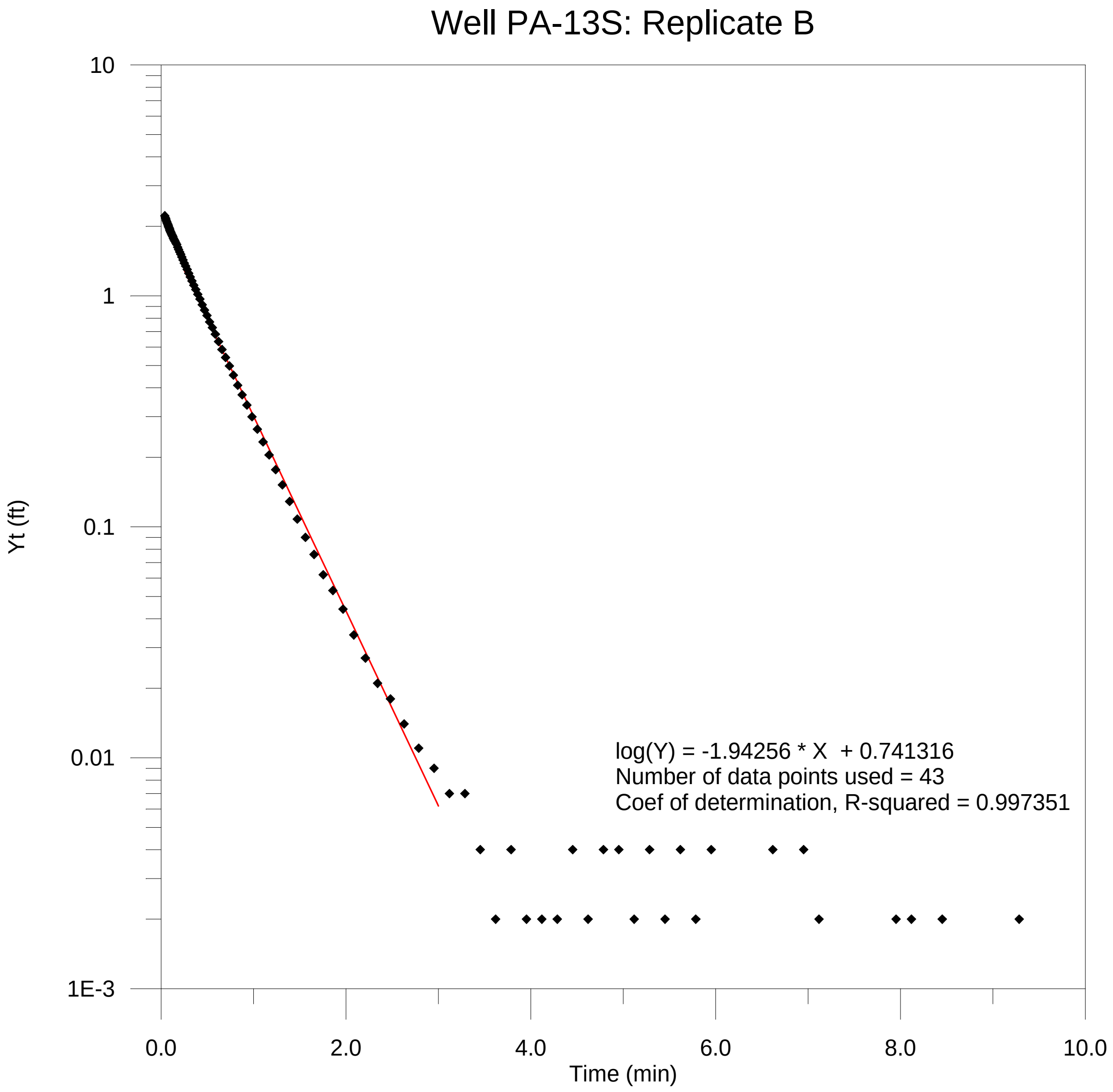
Well	Predemo	Postdemo	Change	Response
PA-13S	14.1	17.4	negligible	excellent
PA-13I	2.4	1.2	(slight decrease)	good
PA-13D	1.1	5.4	(slight increase)	excellent
PA-14S	10.3	23.6	(slight increase)	excellent
PA-14I	4.1	11.4	(slight increase)	good
PA-14D	1.9	7.3	(slight increase)	good

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.

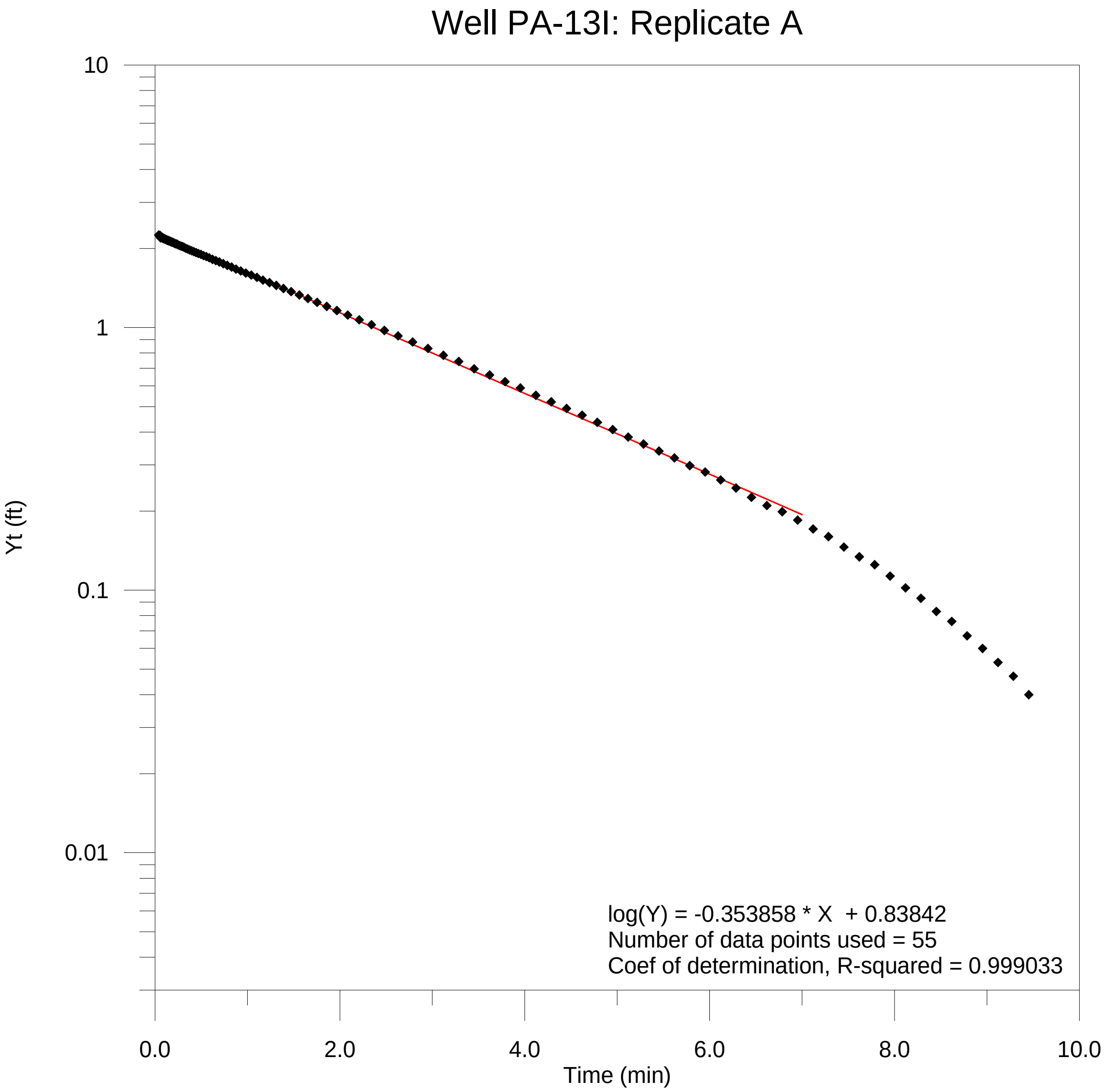
Bouwer, H., 1989, The Bouwer and Rice slug test- an update, Ground Water, v. 27, n.3., pp. 304-309.



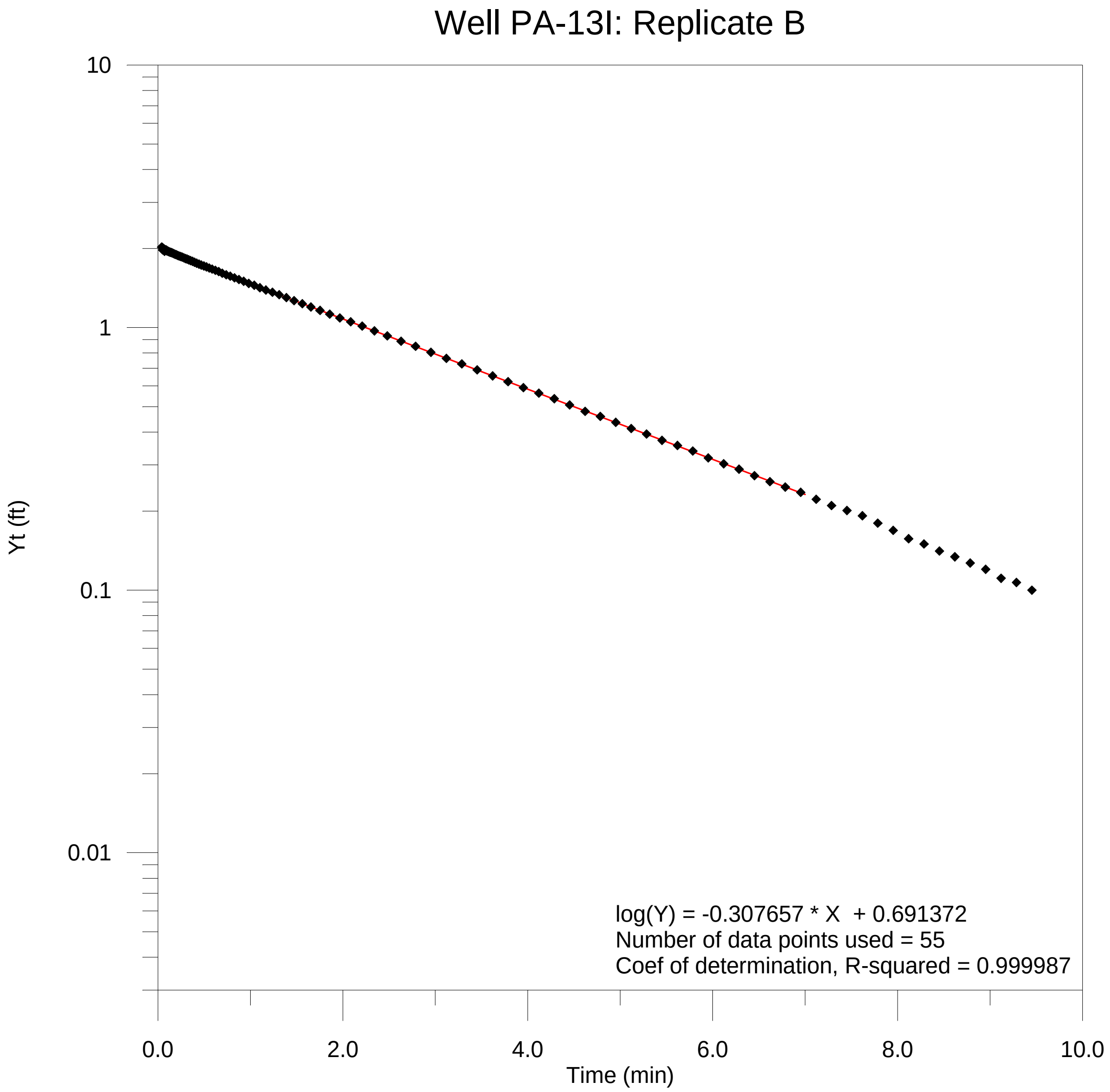
Pre-demonstration Slug Test Results: Well PA-13S.



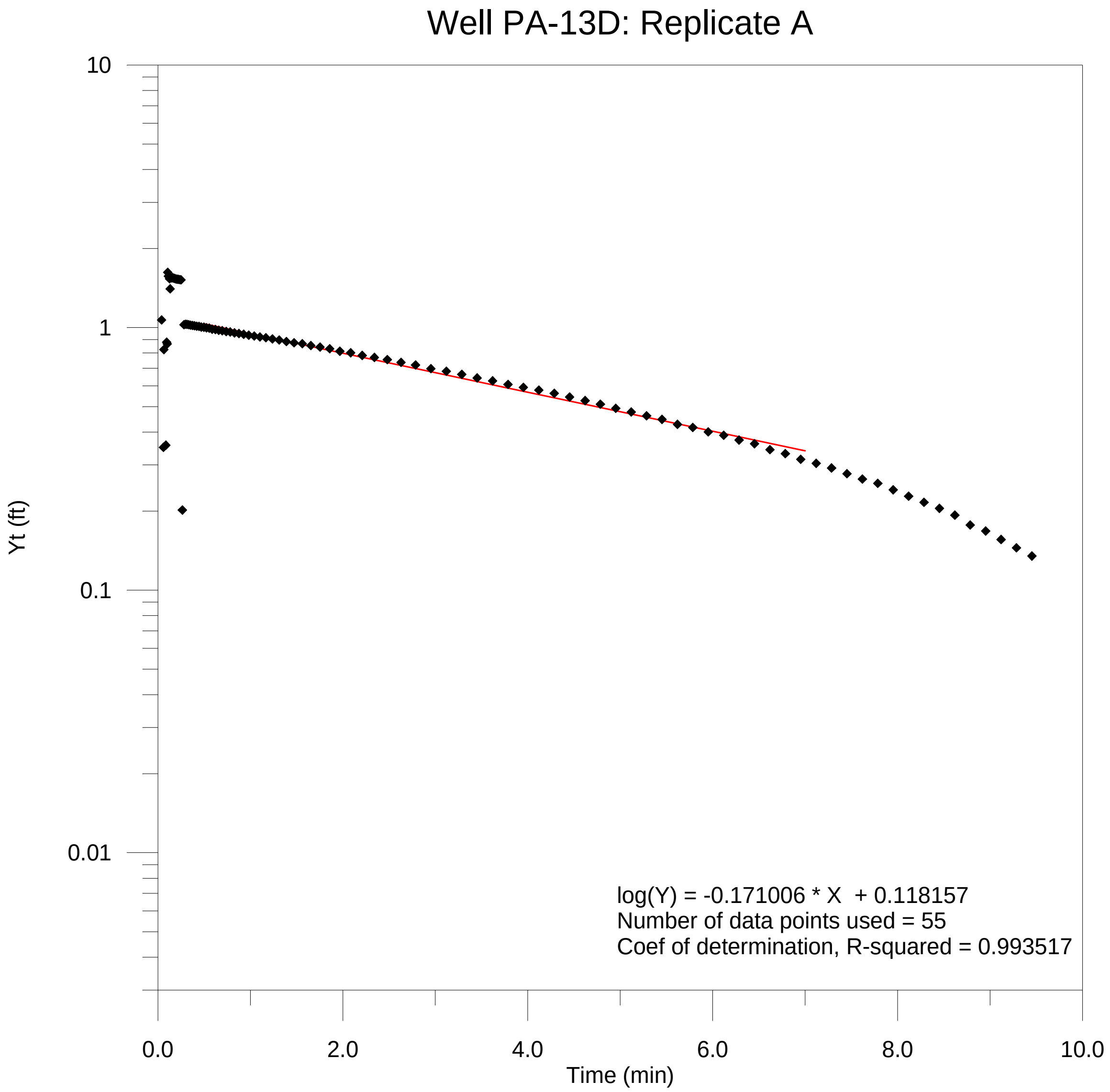
Pre-demonstration Slug Test Results: Well PA-13S.



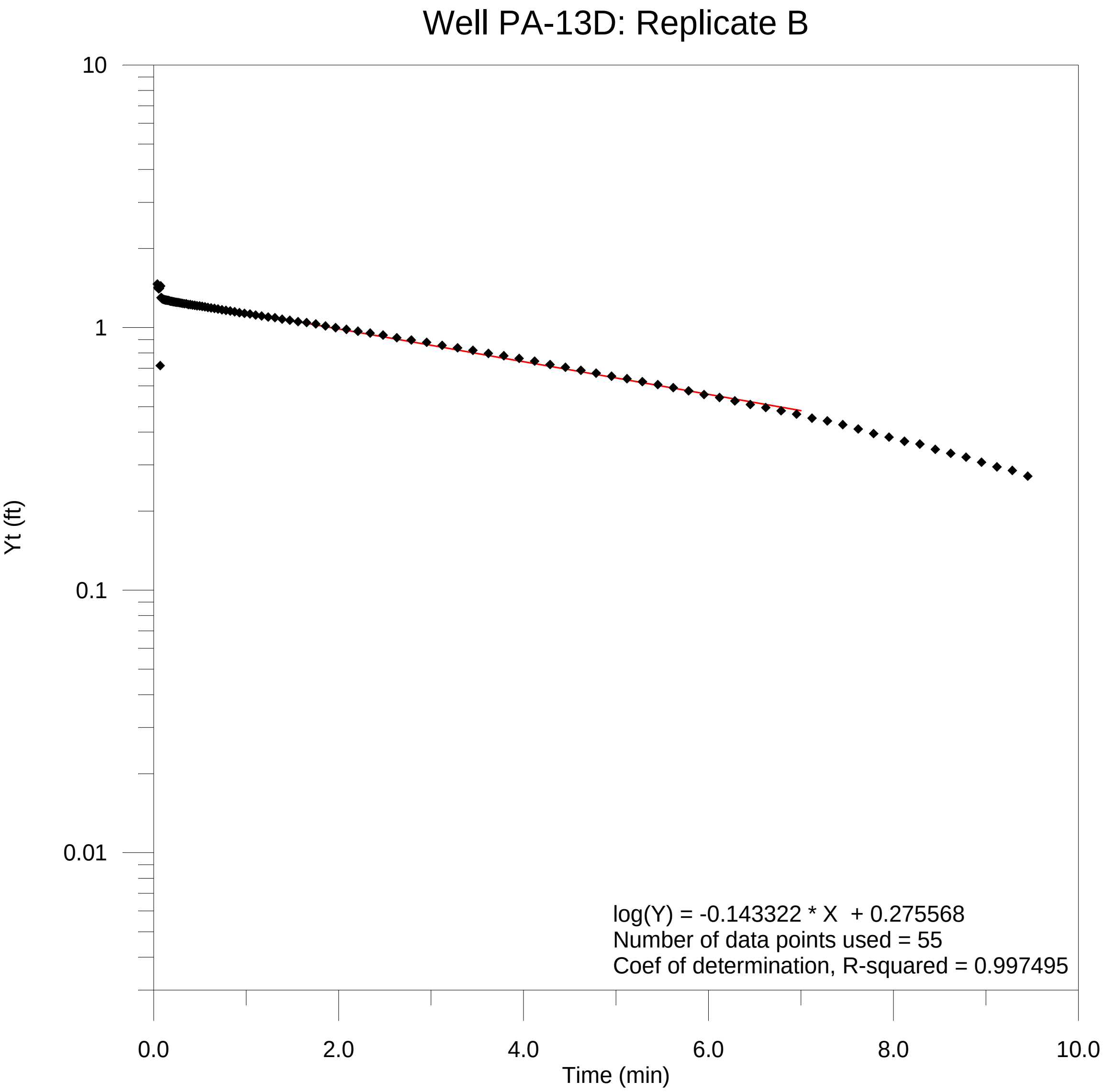
Pre-demonstration Slug Test Results: Well PA-13I.



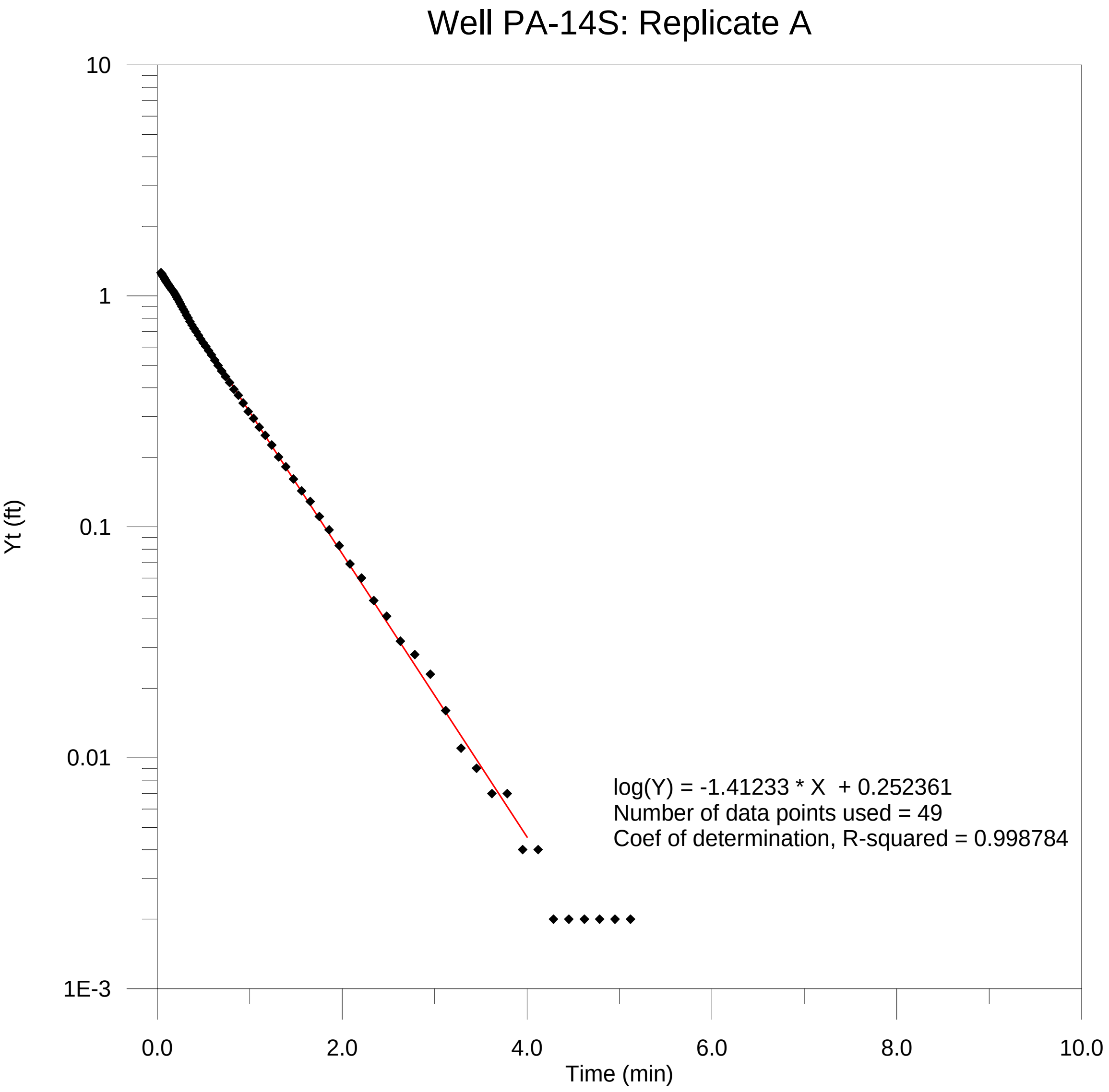
Pre-demonstration Slug Test Results: Well PA-13I.



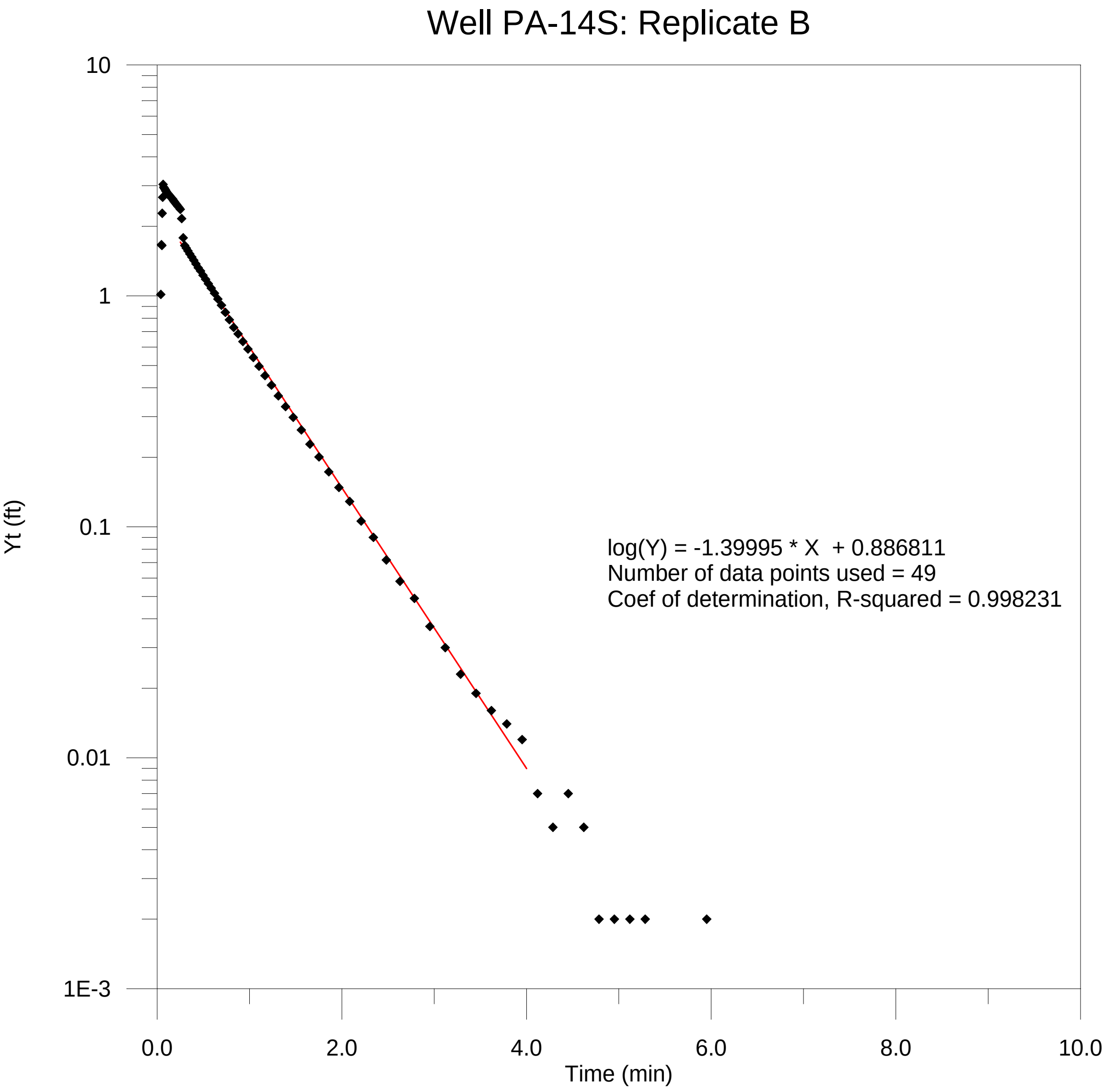
Pre-demonstration Slug Test Results: Well PA-13D.



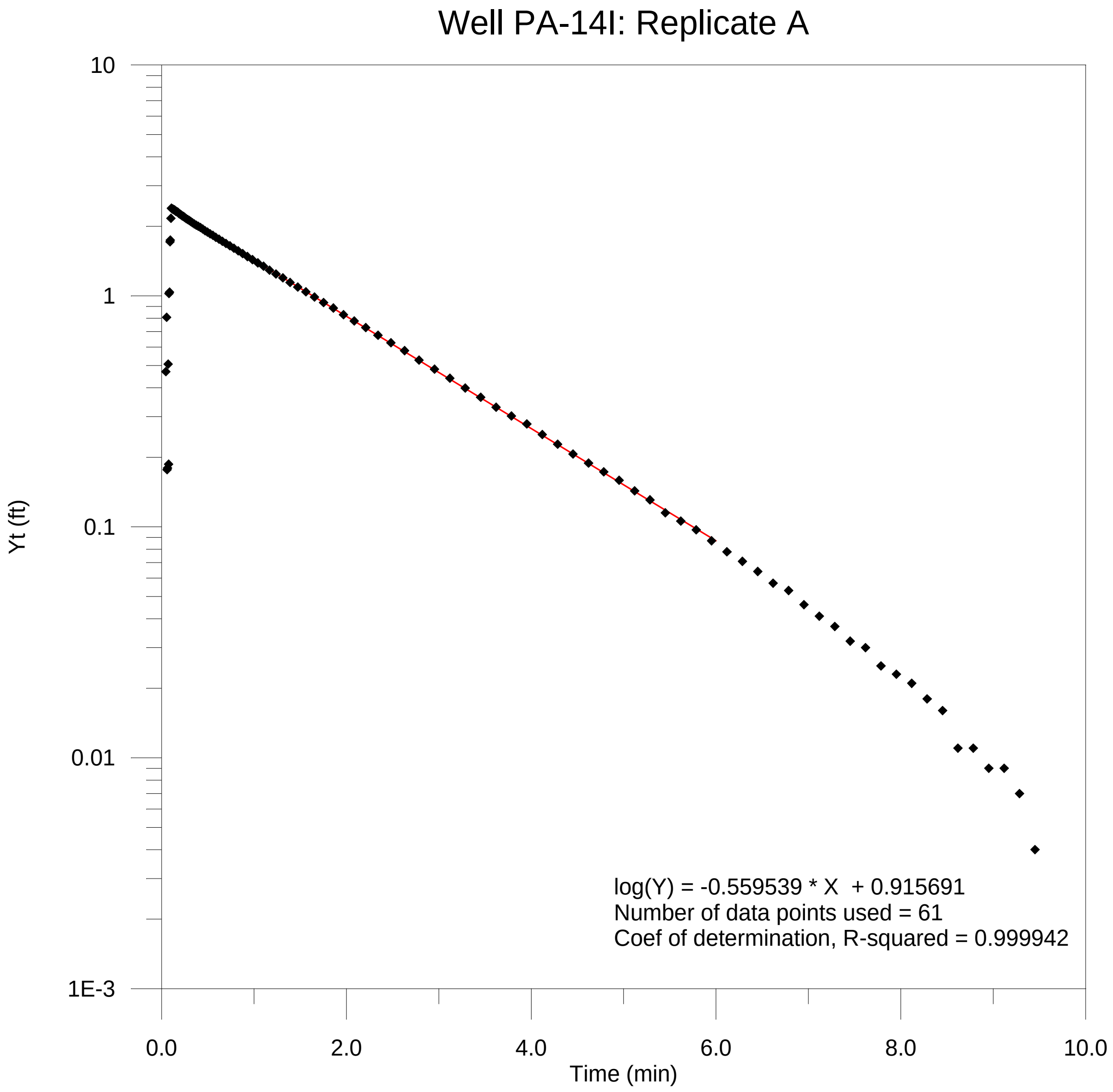
Pre-demonstration Slug Test Results: Well PA-13D.



Pre-demonstration Slug Test Results: Well PA-14S.



Pre-demonstration Slug Test Results: Well PA-14S.



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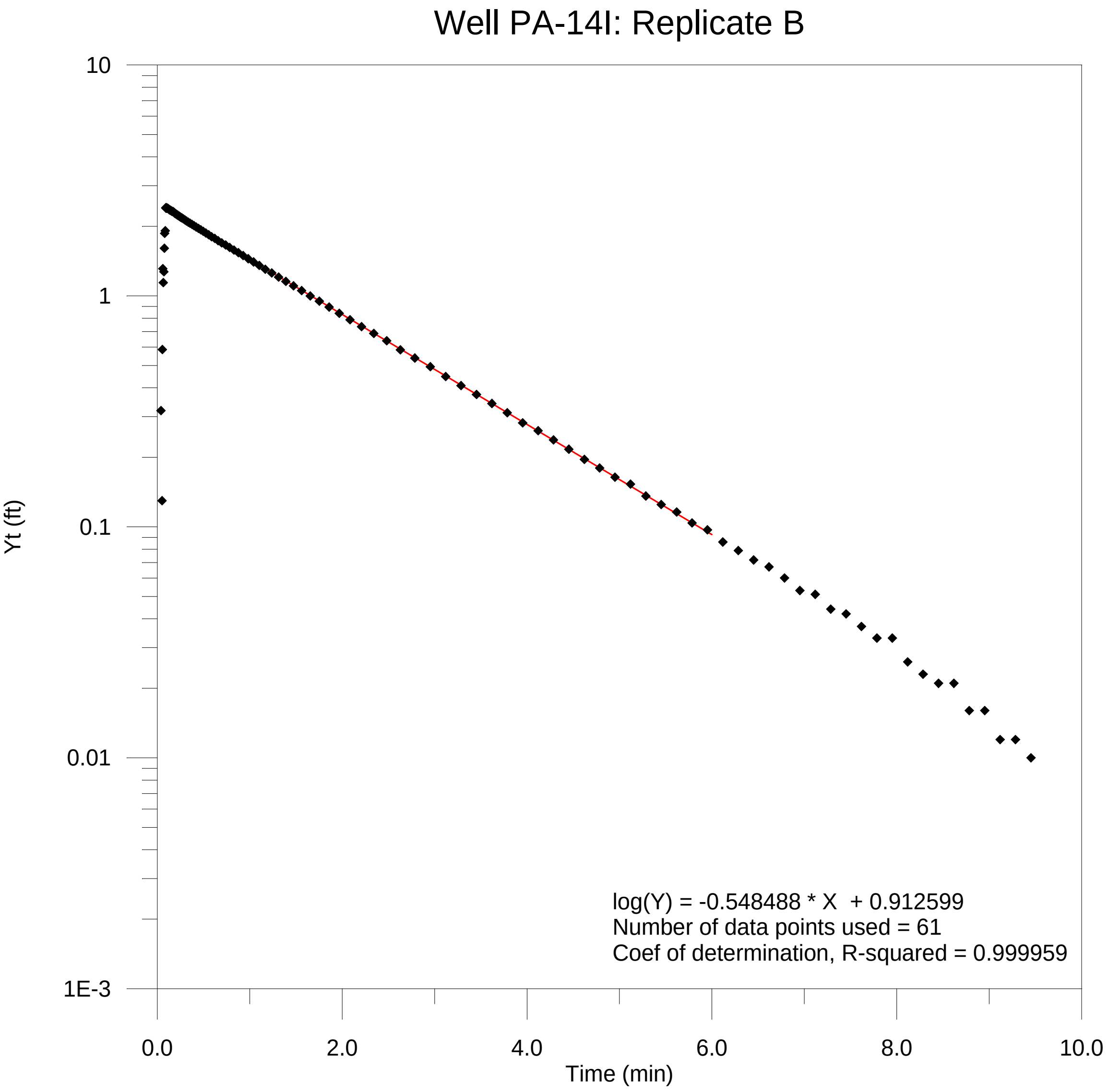
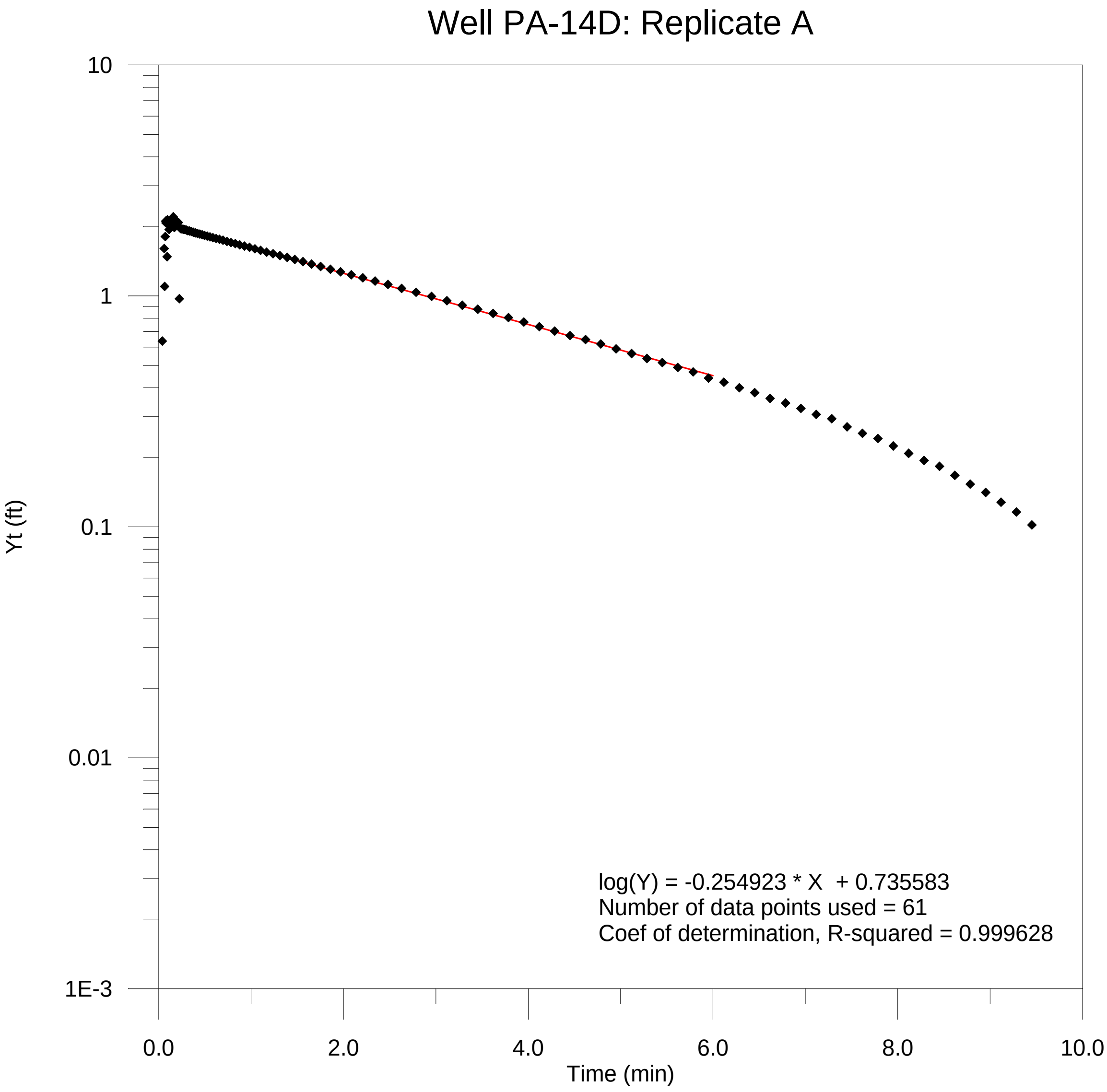


Pre-demonstration Slug Test Results: Well PA-14I.



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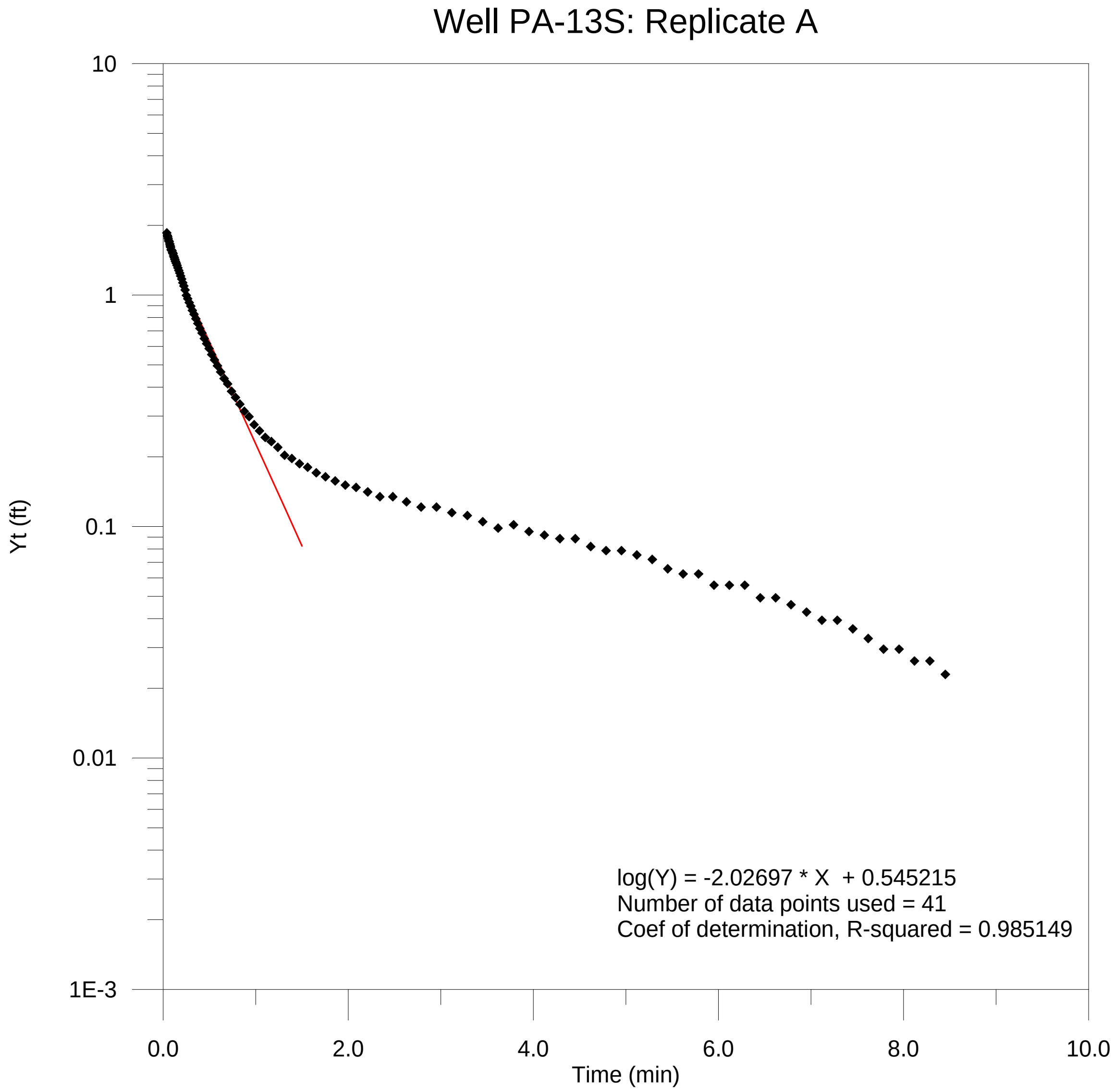
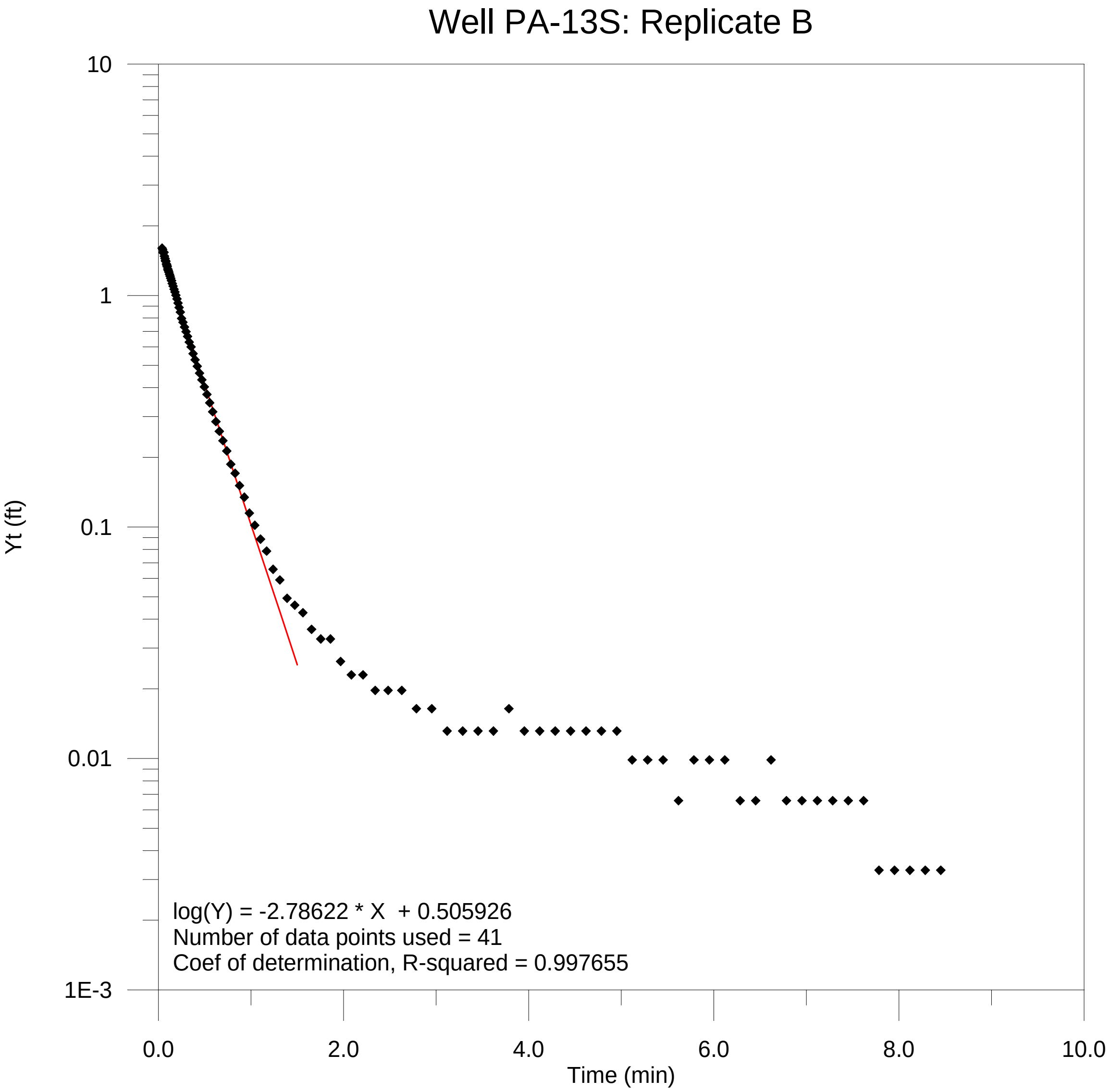
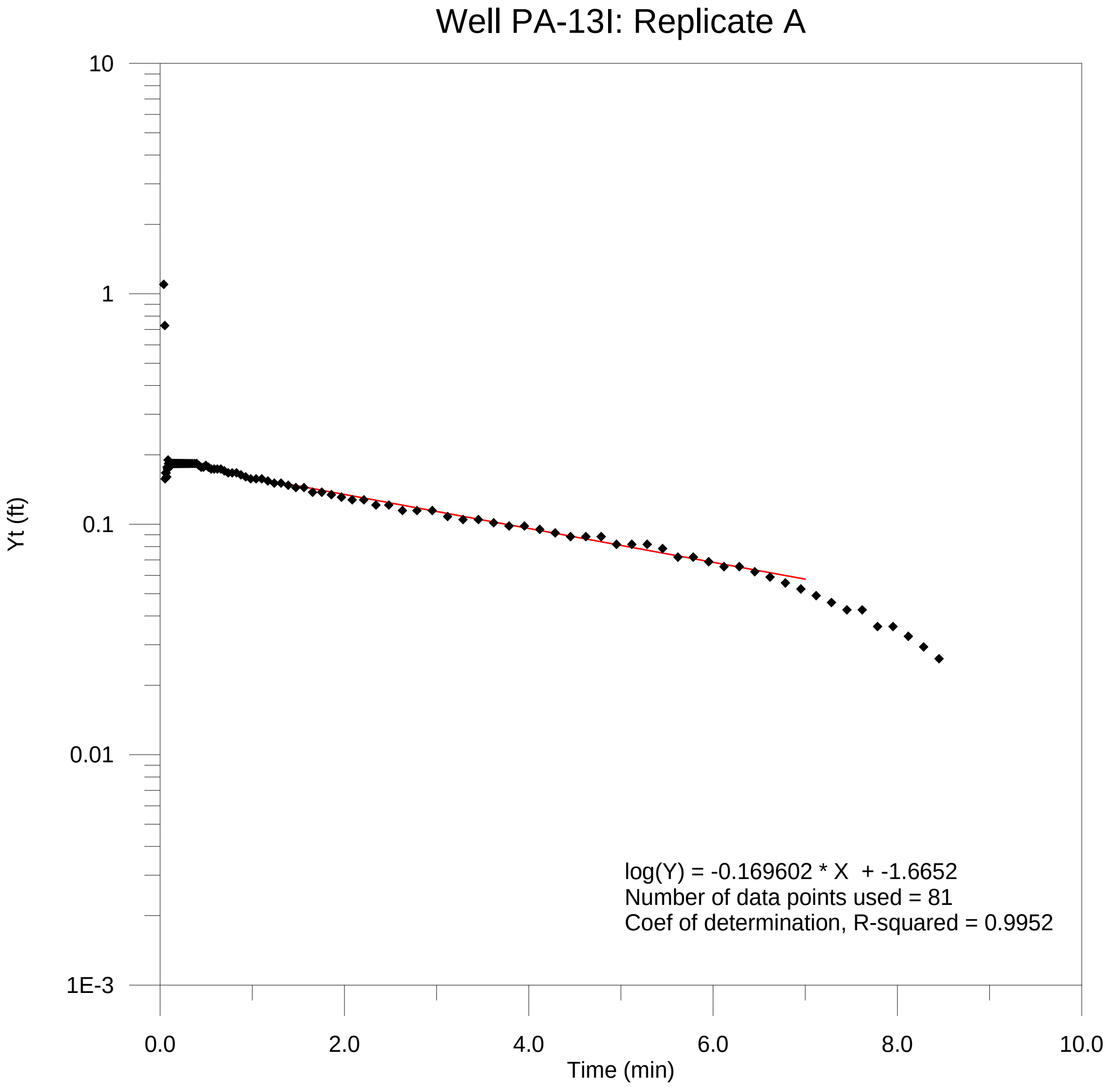


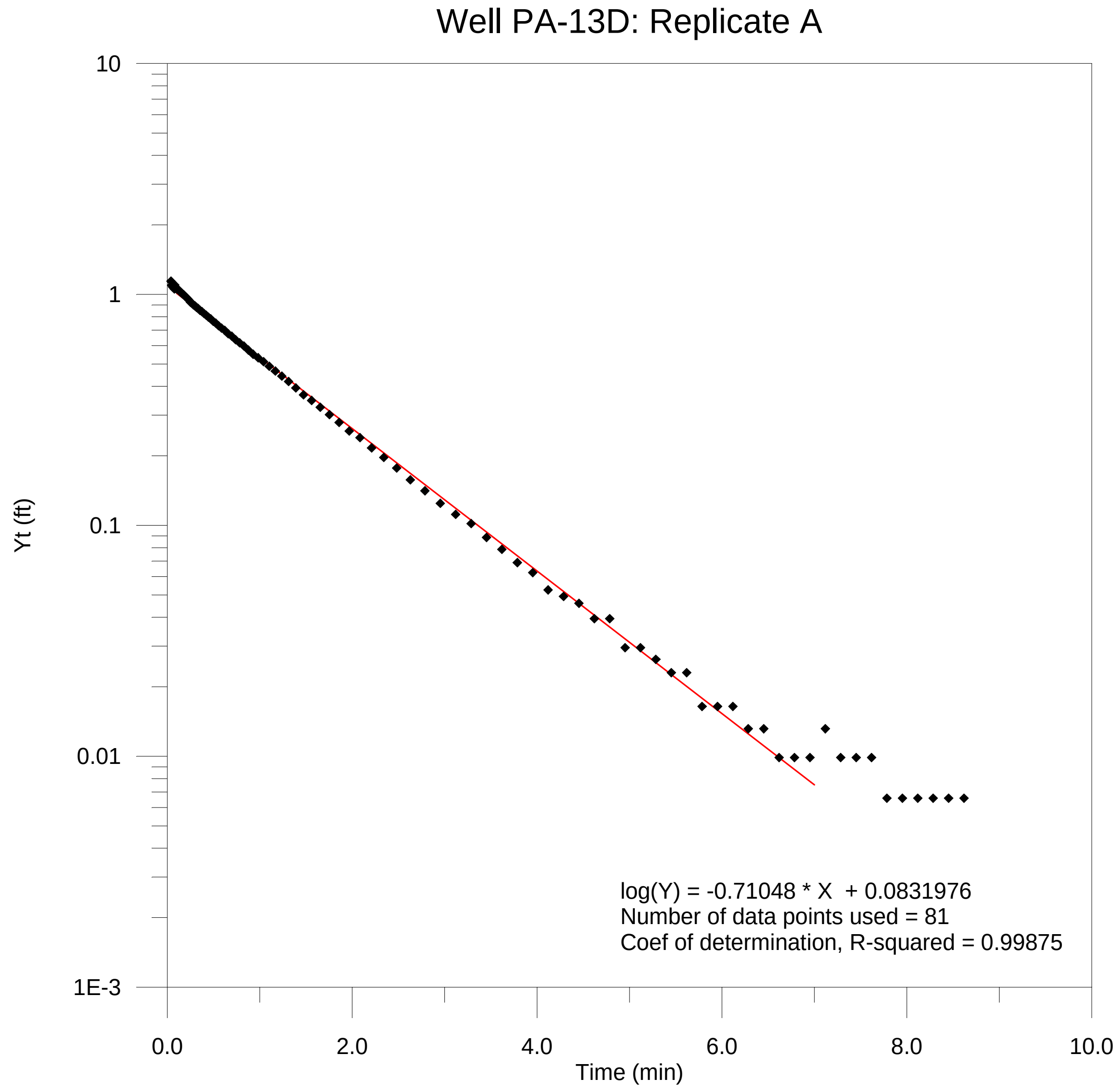
Post-demonstration Slug Test Results: Well PA-13S.



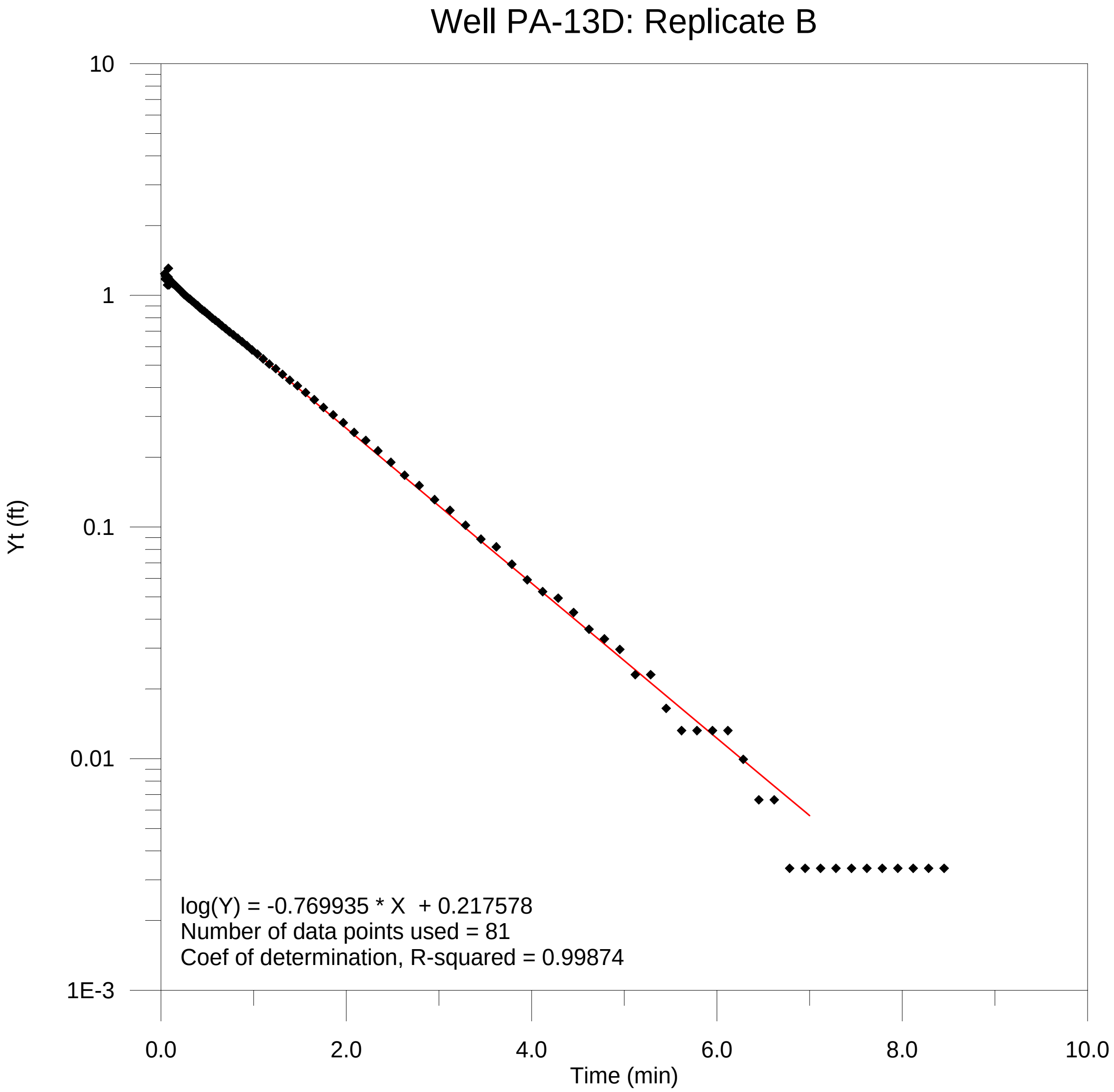
Post-demonstration Slug Test Results: Well PA-13S.



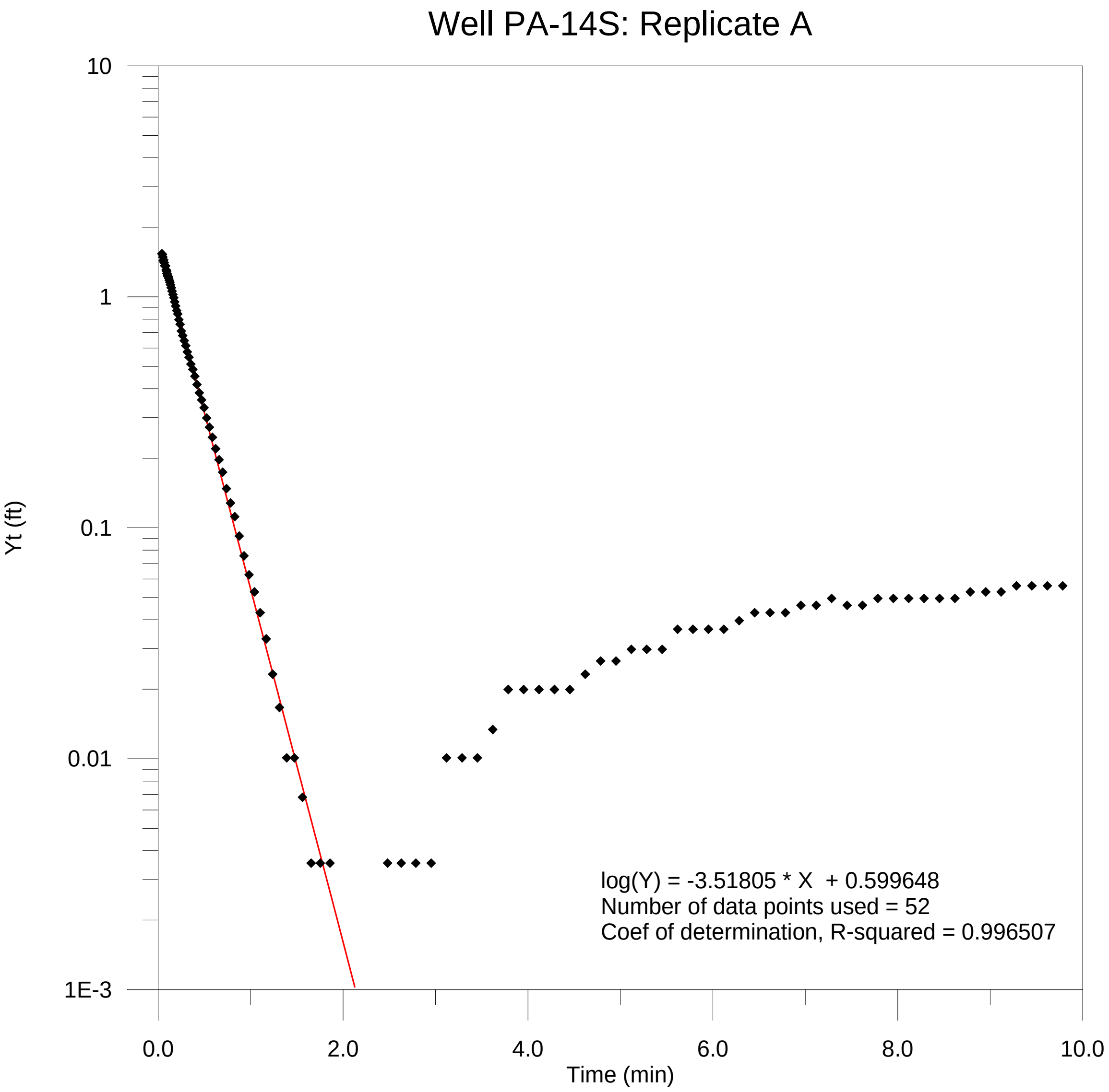
Post-demonstration Slug Test Results: Well PA-13I.



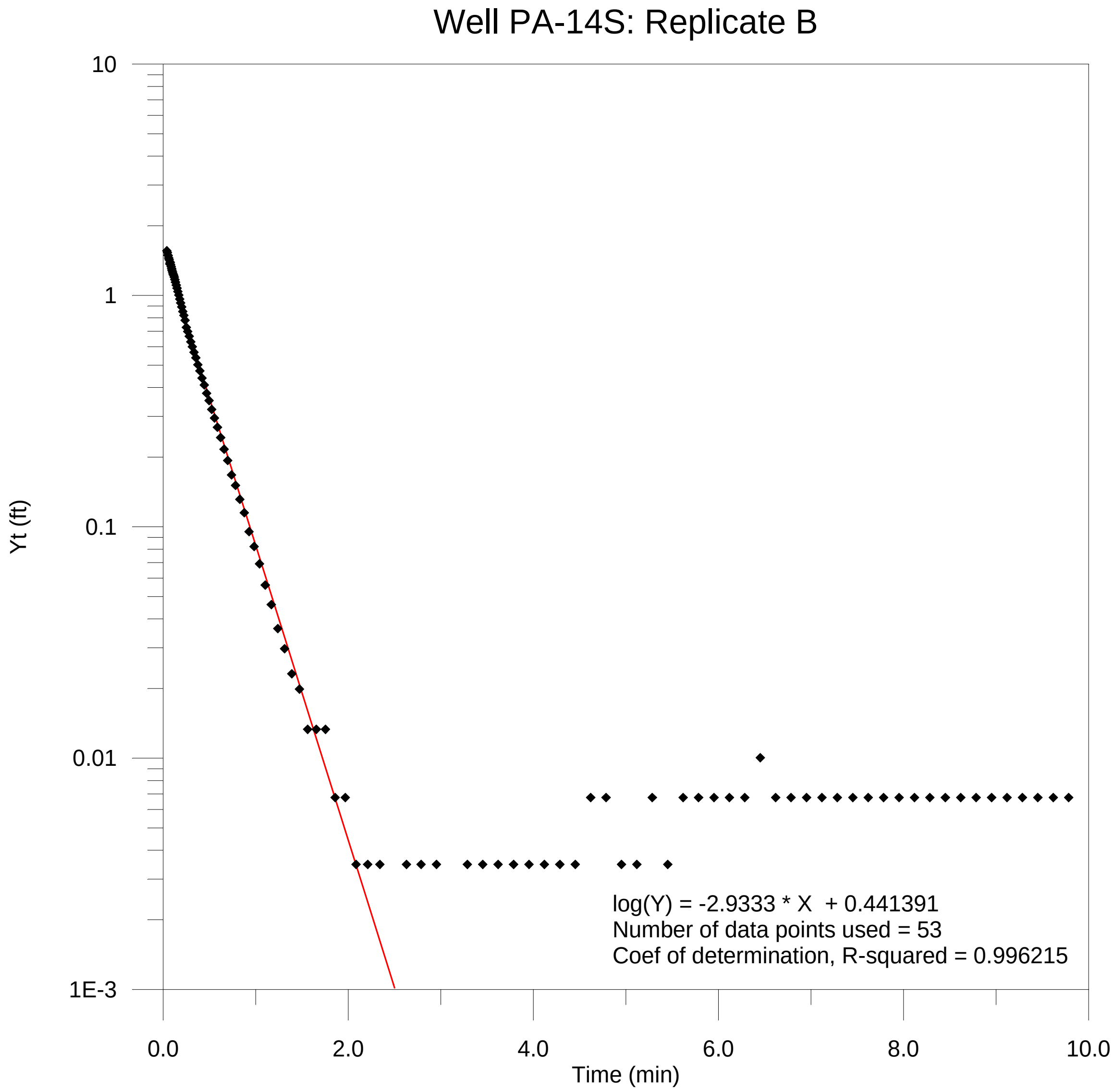
Post-demonstration Slug Test Results: Well PA-13D.



Post-demonstration Slug Test Results: Well PA-13D.



Post-demonstration Slug Test Results: Well PA-14S.



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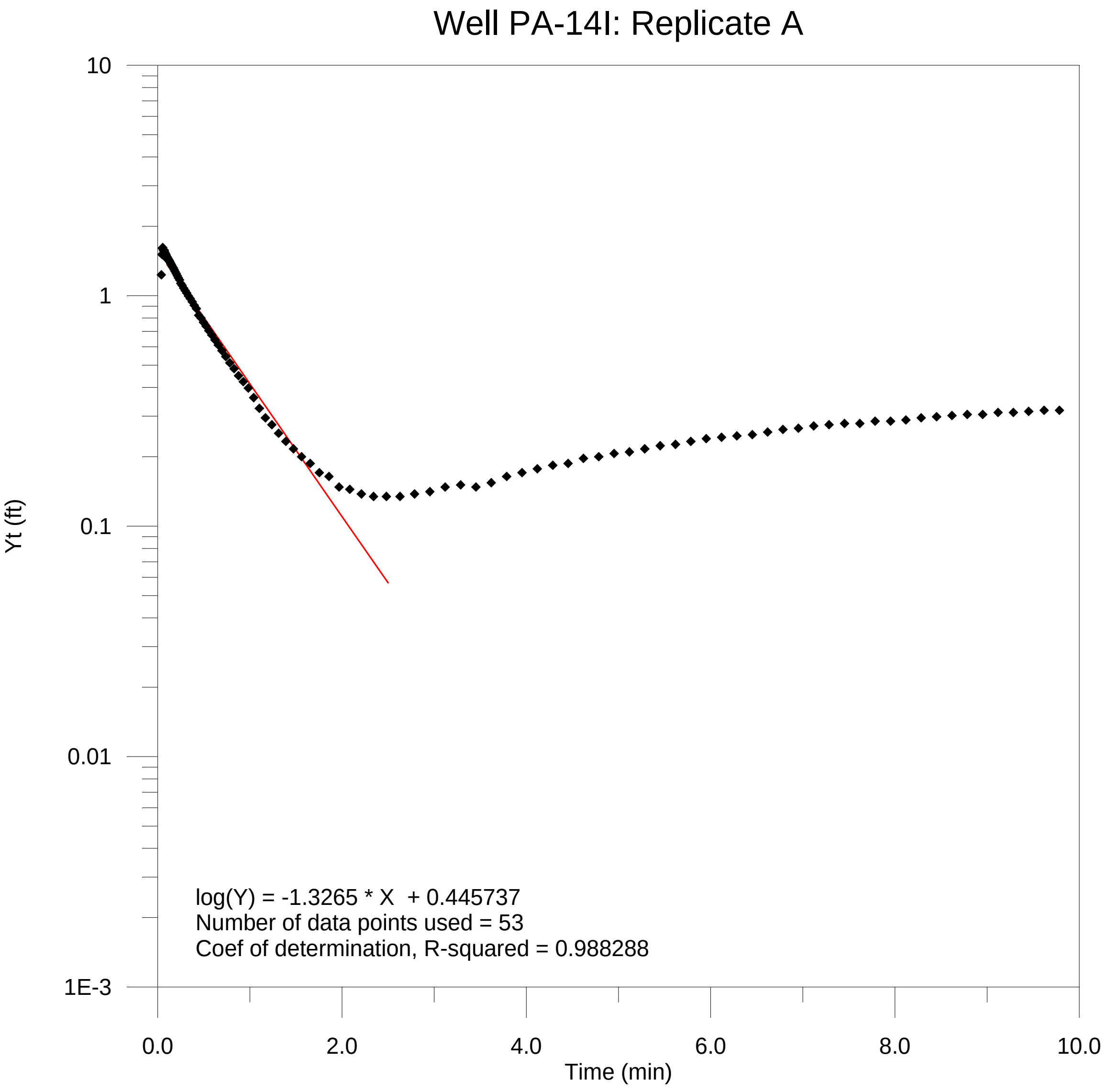
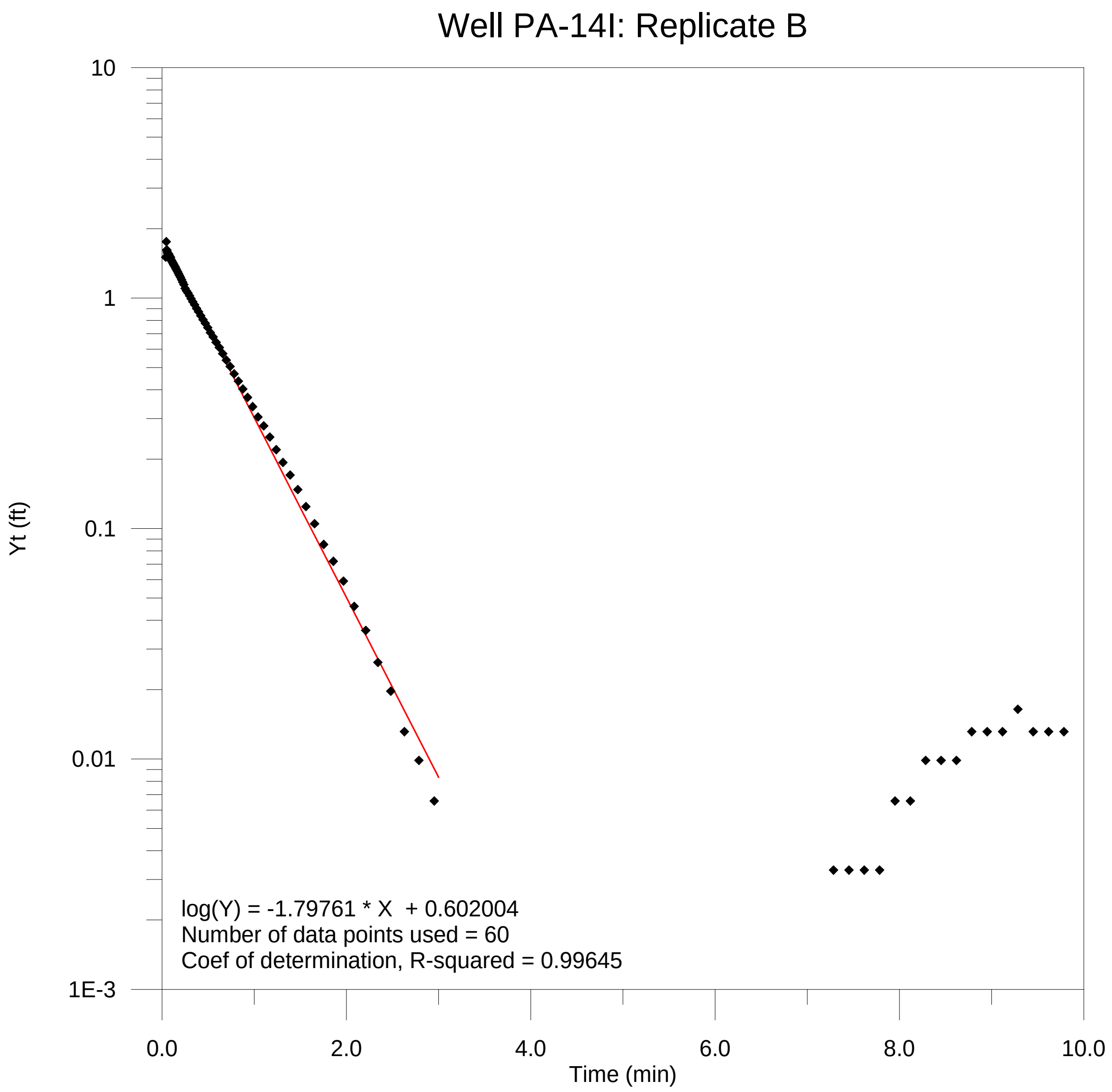
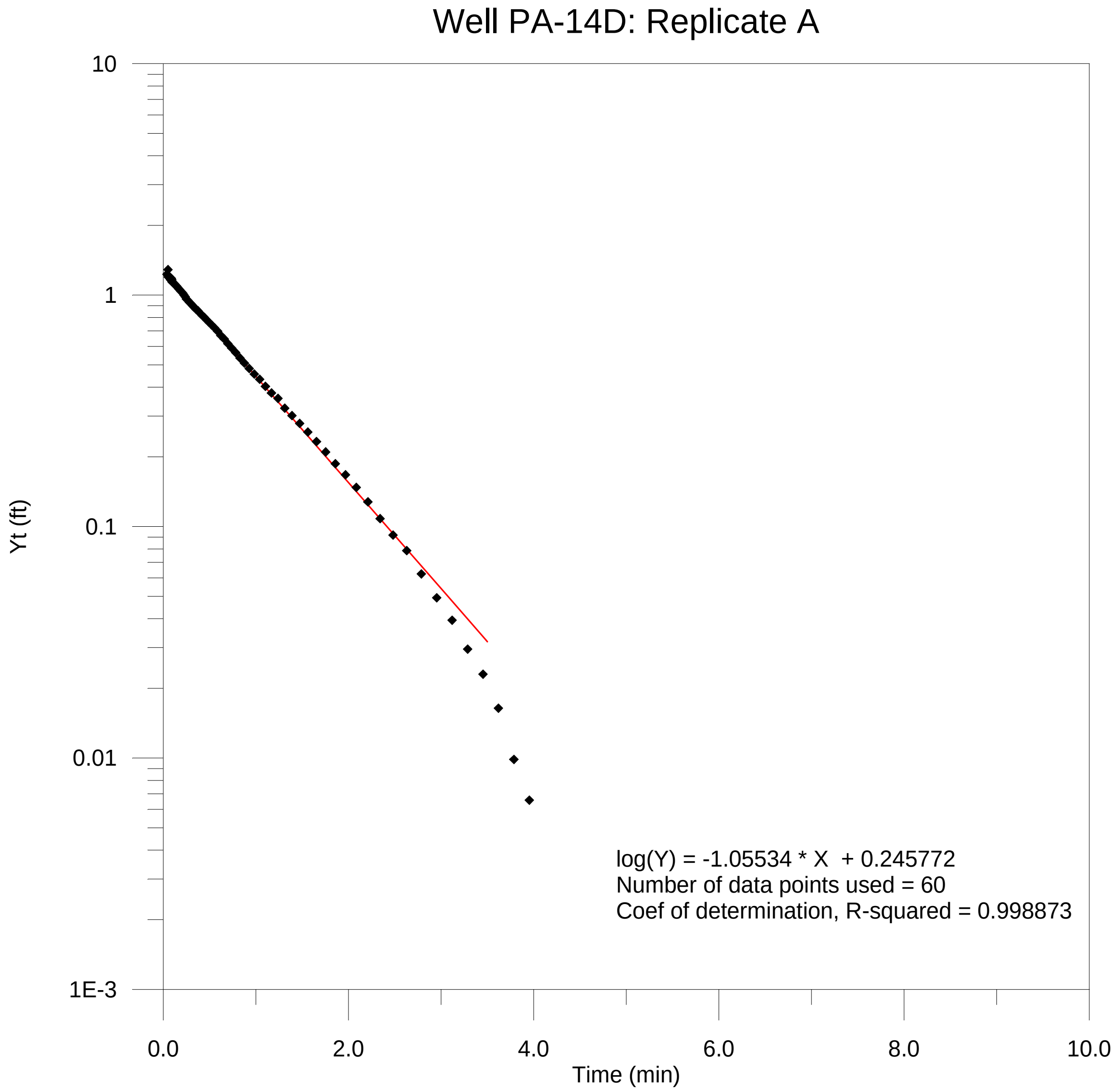


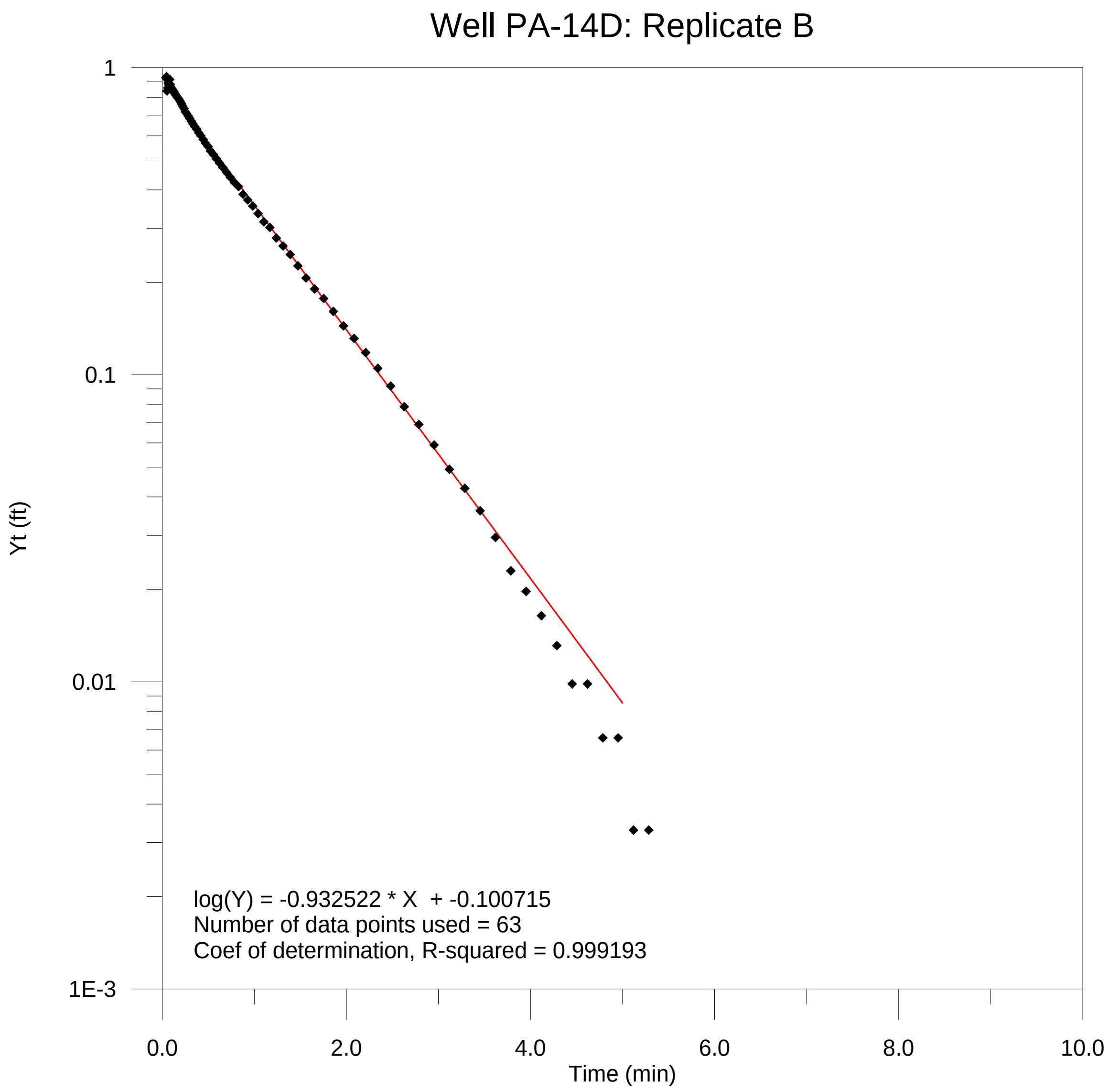
Post-demonstration Slug Test Results: Well PA-14I.



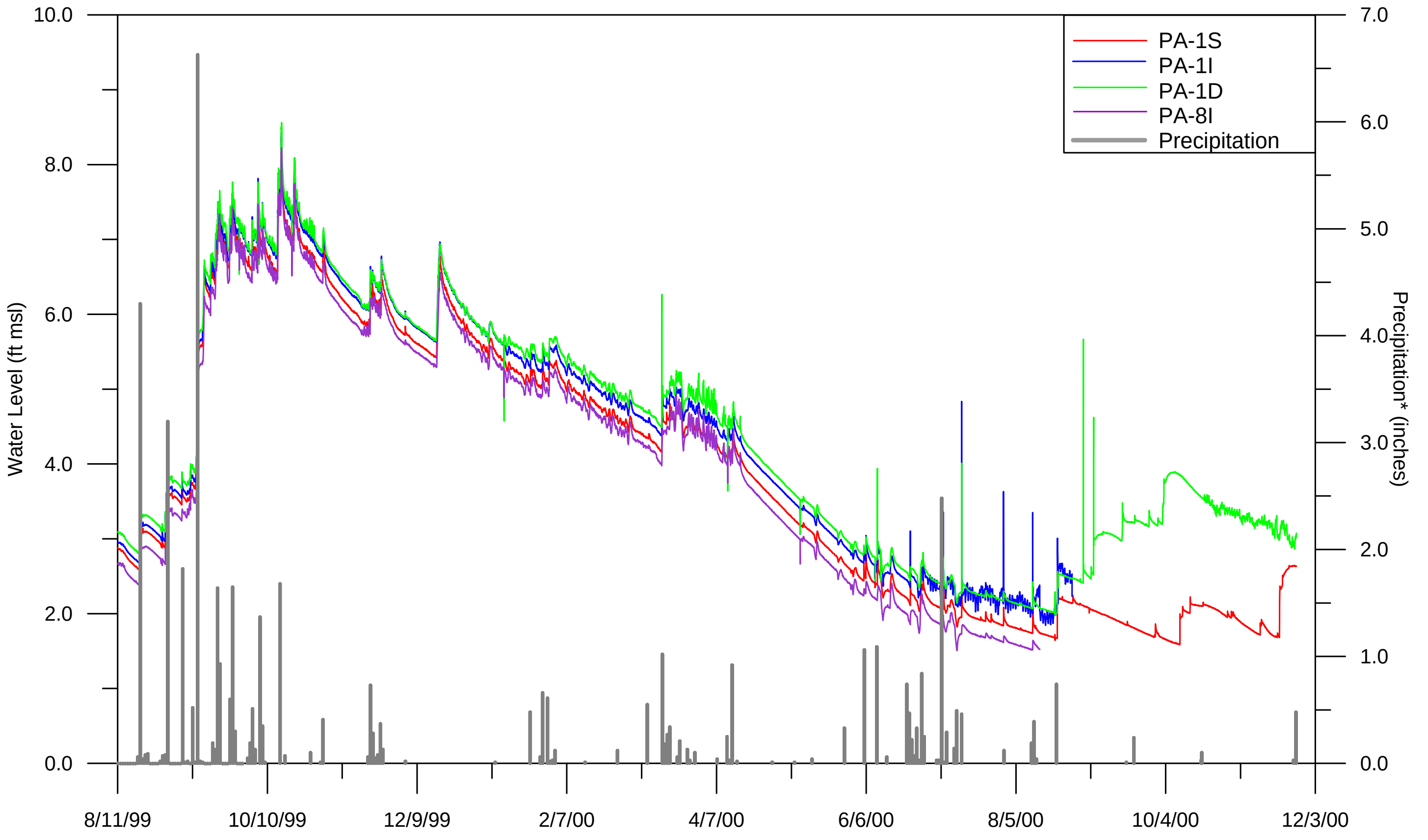
Post-demonstration Slug Test Results: Well PA-14I.



Post-demonstration Slug Test Results: Well PA-14D.



Post-demonstration Slug Test Results: Well PA-14D.



*based on measurements at field mill 30 at Cape Canaveral Air Station

B.2 Site Assessment Well Completion Diagrams for Shallow, Intermediate, and Deep Wells

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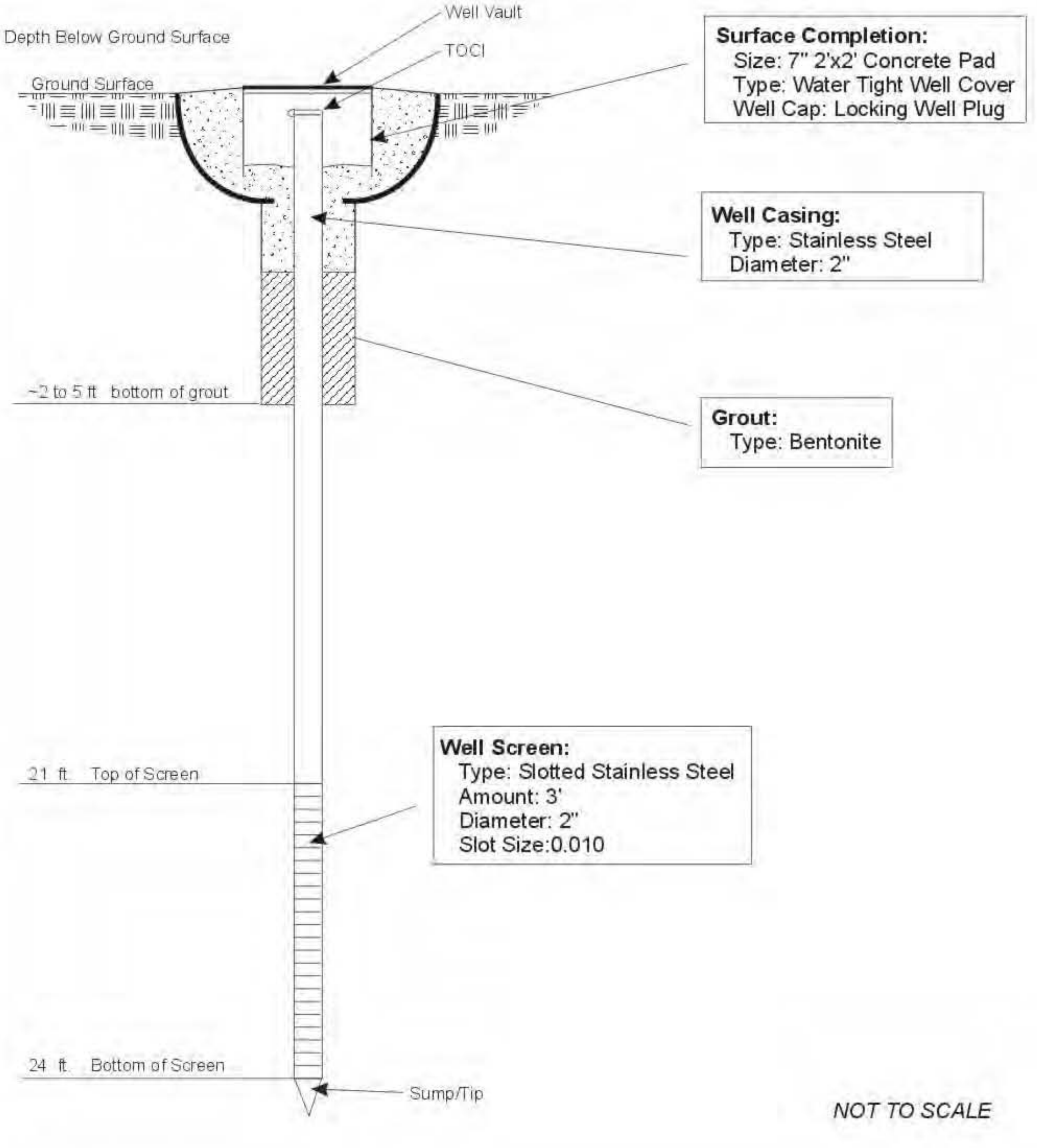
WELL COMPLETION DIAGRAM

Project #: G004065	Site: LC34, CCAS	Well #: Shallow	Northing (NAD 83):
Drilling Contractor:	Rig Type and Drilling Method: Direct Push	Date: 1998-2001	Easting (NAD 83):
Reviewed by: JRS	Driller:	Hydrogeologist: JRS	Surface Elevation (NAVD 88):



Surface Completion:
Size: 7" 2'x2' Concrete Pad
Type: Water Tight Well Cover
Well Cap: Locking Well Plug

Well Casing:
Type: Stainless Steel
Diameter: 2"

Grout:
Type: Bentonite

Well Screen:
Type: Slotted Stainless Steel
Amount: 3'
Diameter: 2"
Slot Size:0.010

NOT TO SCALE

MW-template.CDR

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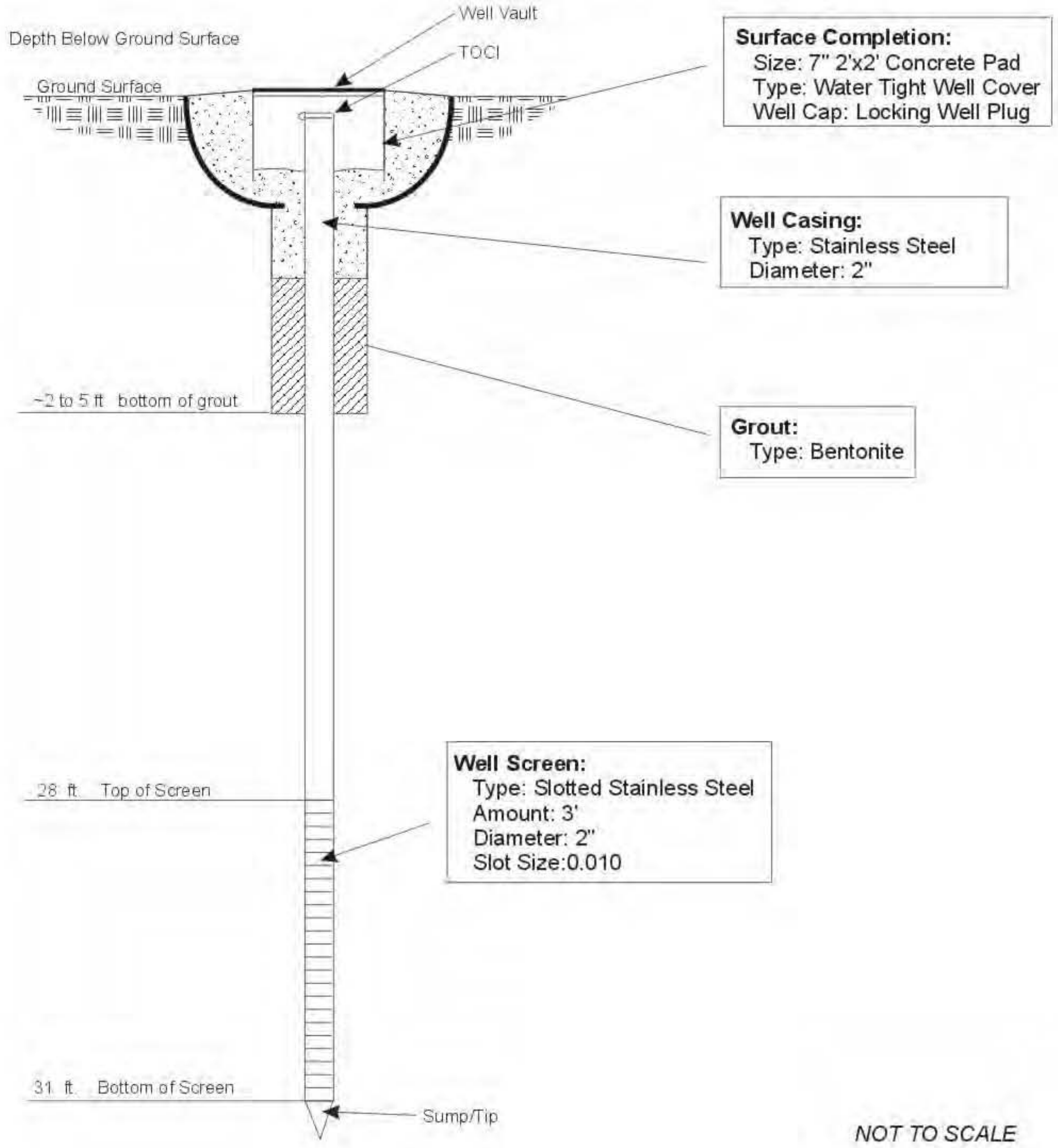
WELL COMPLETION DIAGRAM

Project #: G004065	Site: LC34, CCAS	Well #: Intermediate	Northing (NAD 83):
Drilling Contractor:	Rig Type and Drilling Method: Direct Push	Date: 1998-2001	Easting (NAD 83):
Reviewed by: JRS	Driller:	Hydrogeologist: JRS	Surface Elevation (NAVD 88):



Surface Completion:
Size: 7" 2'x2' Concrete Pad
Type: Water Tight Well Cover
Well Cap: Locking Well Plug

Well Casing:
Type: Stainless Steel
Diameter: 2"

Grout:
Type: Bentonite

Well Screen:
Type: Slotted Stainless Steel
Amount: 3'
Diameter: 2"
Slot Size:0.010

NOT TO SCALE

MW-template.CDR

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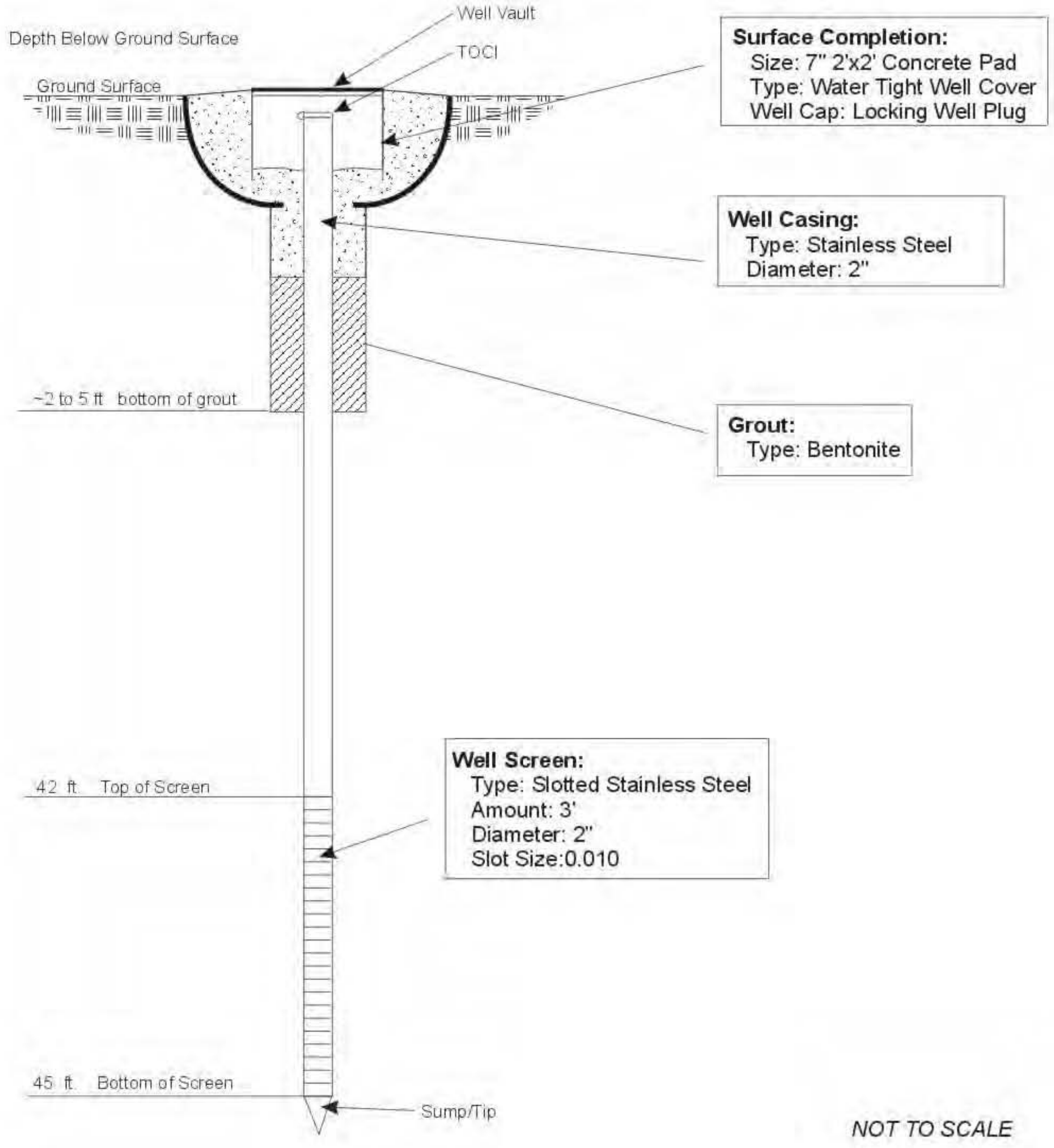
WELL COMPLETION DIAGRAM

Project #: G004065	Site: LC34, CCAS	Well #: Deep	Northing (NAD 83):
Drilling Contractor:	Rig Type and Drilling Method: Direct Push	Date: 1998-2001	Easting (NAD 83):
Reviewed by: JRS	Driller:	Hydrogeologist: JRS	Surface Elevation (NAVD 88):



Surface Completion:
Size: 7" 2'x2' Concrete Pad
Type: Water Tight Well Cover
Well Cap: Locking Well Plug

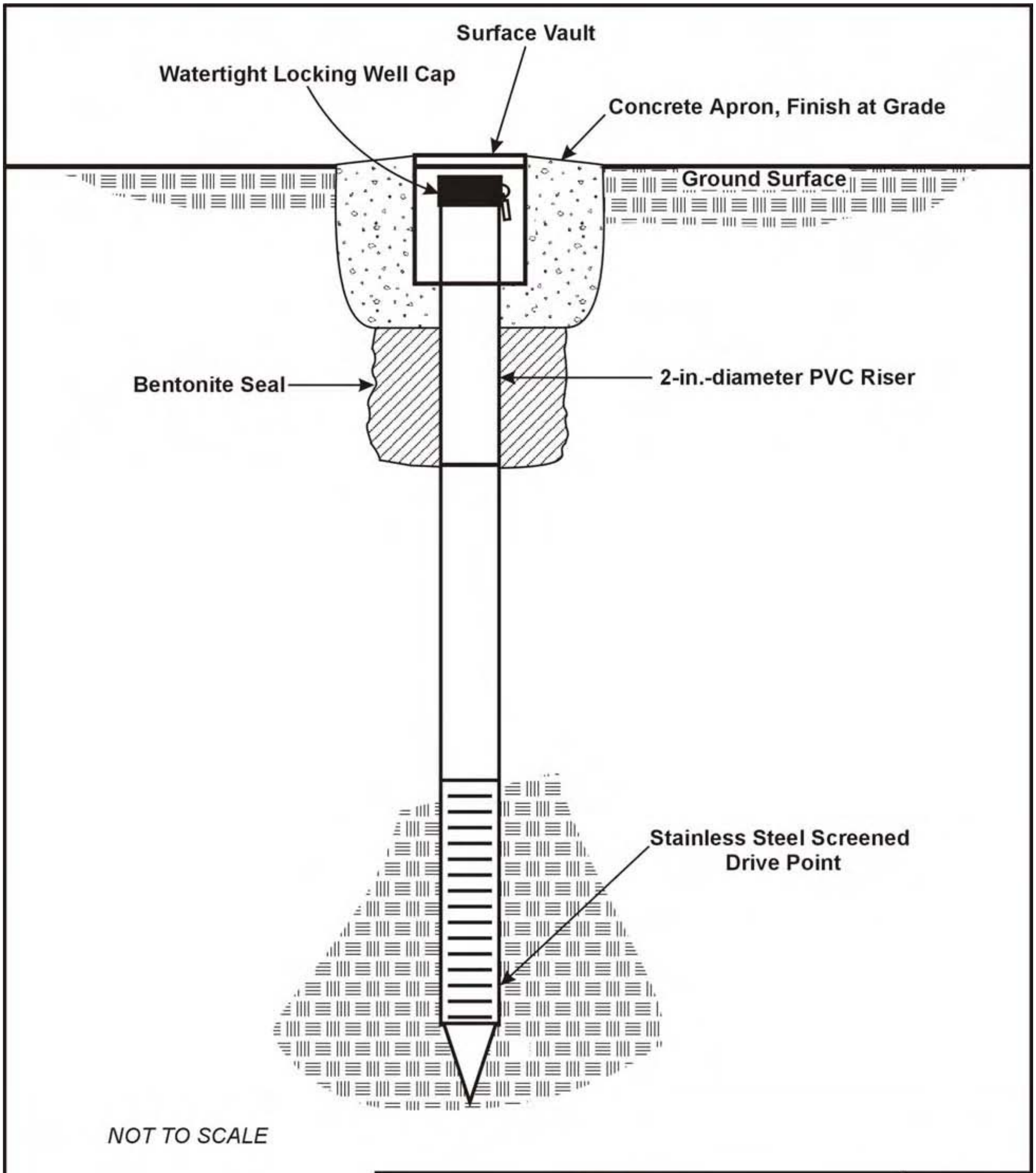
Well Casing:
Type: Stainless Steel
Diameter: 2"

Grout:
Type: Bentonite

Well Screen:
Type: Slotted Stainless Steel
Amount: 3'
Diameter: 2"
Slot Size:0.010

NOT TO SCALE

MW-template.CDR



NOT TO SCALE

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Figure 3-4.
PASC Groundwater Monitoring Well Construction Diagram

CAPE CANAVERAL AIR STATION – FLORIDA

PROJECT G331505-11 DATE 12/98

DESIGNED BY JS
DRAWN BY VS
CHECKED BY TL

DSGWMWCAPE_C01.CDR

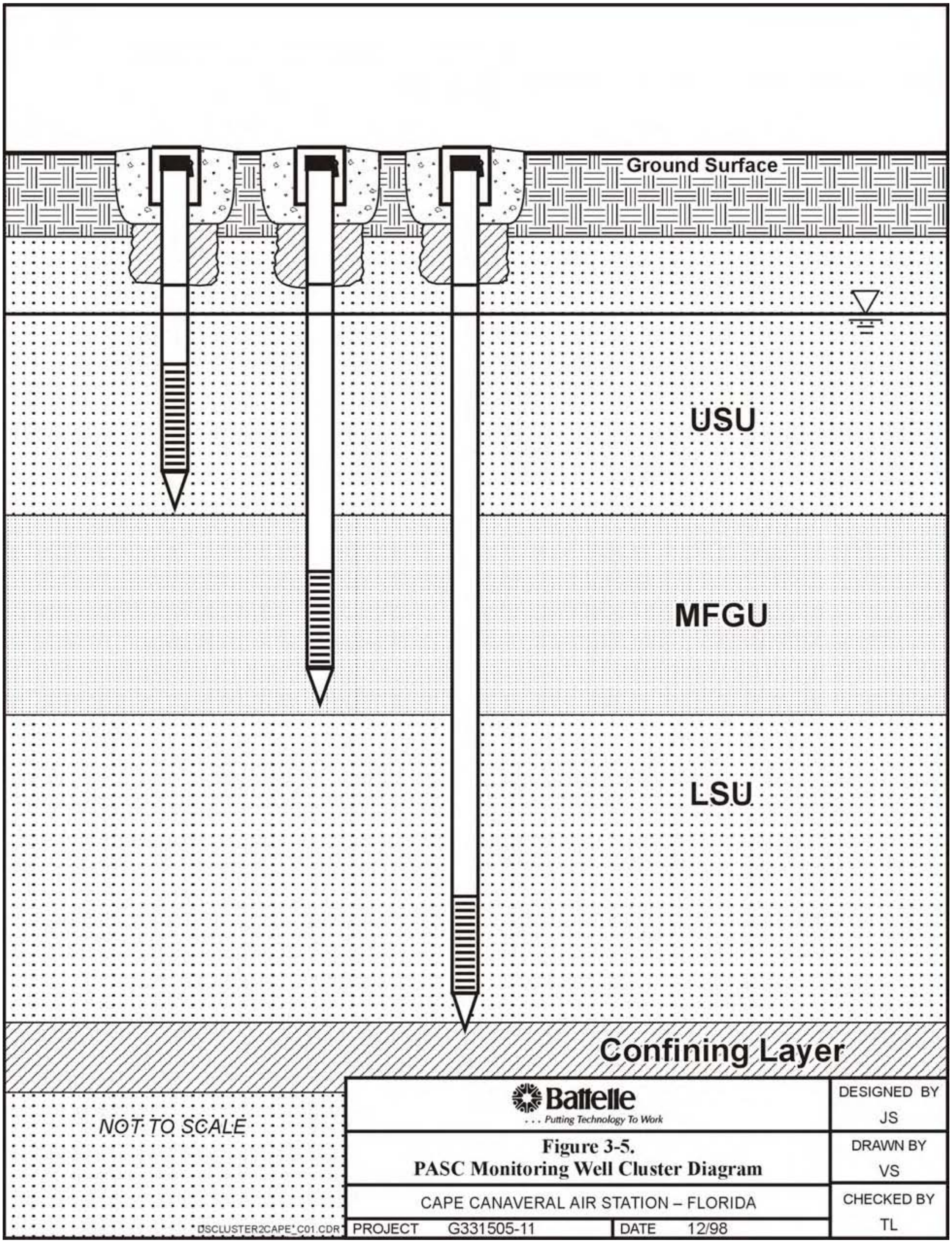

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Figure 3-5.
PASC Monitoring Well Cluster Diagram

CAPE CANAVERAL AIR STATION – FLORIDA

PROJECT G331505-11
DATE 12/98

DESIGNED BY JS
DRAWN BY VS
CHECKED BY TL

B.3 LC34 IDC Coring Logsheets for Site Assessment Wells

LC34 IDC Coring Logsheet

Boring ID **PA-1S**

Date 2/17/99

Location LC34 E. of ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 21.7 to 24.4 ft

Total Depth 26.1 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

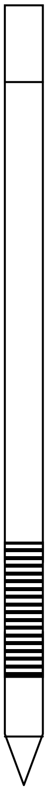
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush vault w/ concrete pad

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post hole loose tan sands	0-5	---	---		PVC riser
No sampling, direct push.	5-26.1	---	---		
					2 2/3 ft screen
					1 ft sump
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 2/17/99

Construction Notes: Completion depths based on previous borings in the area (LC34-B13).

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LC34 IDC Coring Logsheet

Boring ID **PA-1I**

Date 2/19/99

Location LC34 E. of ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 26.6 to 29.3 ft

Total Depth 31 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

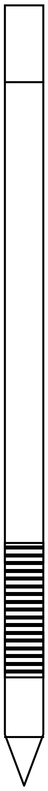
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush vault w/ concrete pad

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post hole loose tan sands	0-4	---	---		PVC riser
No sampling, direct push.	4-31	---	---		
					2 2/3 ft screen
					1 ft sump
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 2/19/99

Construction Notes: Completion depths based on previous borings in the area (LC34-B13).

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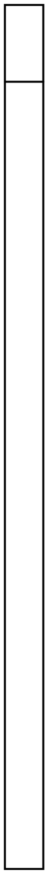
LC34 IDC Coring Logsheet

Boring ID PA-1D

Date 2/18/99

Location LC34, ESB

Boring Diameter	2 3/8 in	Total Depth	46.5 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from 2 to 3 ft
Screen Slot	0.010	Surface Completion	flush vault w/ concrete pad
Screen Length	2 2/3 ft	Drilling Method	CPT
Screen Depth	from 43.3 to 45.9 ft	Driller	John Hoggatt

Lithologic Description	Depth	Sample	USCS	Well	Other
post hole to 4 ft bgs soil, loose tan sands	0-4	---	---		PVC riser
direct push, no sampling	4-25	---	---		
gray fine sand, some silt <30%	25-26.5	PA-1D-26.5	SM		
direct push, no sampling	26.5-35	---	---		
gray fine sand, some silt <30%	35-36	PA-1D-36.5	SM		
gray med to fine sand, shells 40%, some silts	36-36.5	PA-1D-36.5	SW		
gray fine to medium sand, 40-50%, some silts	37-38.5	PA-1D-38.5	SW		
gray med to fine sand, shells < 10%, some silts	39.5-39.8	PA-1D-40.5	SW		
gray med to fine sand, shells 40-50%, some silts	39.8-40.5	PA-1D-40.5	SW		
gray med to fine sand grading into more shell content >50% w/ some silts	41-42.5	PA-1D-42.5	SW		

Logged by: J Sminchak

Completion Date: 2/19/99

Construction Notes: soil sampling 2/18, left tip in hole overnight and completed 2/19/99

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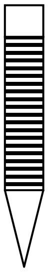
LC34 IDC Coring Logsheet

Boring ID PA-1D

Date 2/18/99

Location LC34 ESB

Lithologic Description	Depth	Sample	USCS	Well	Water Level	Other
gray fine sands, some silts, shell frags finer sands + silts at bottom of sample	43-44.5	PA-1D-44.5	SM			2 2/3 ft screen 6 7/8 in. tip
fine silt and sands, gray, very little shell frags	44.5-45.5	PA-1D-46	ML			
silty gray clay, med. plasticity	45.5-46	PA-1D-46	CL			

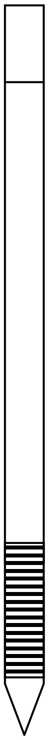
LC34 IDC Coring Logsheet

Boring ID **PA-2S**

Date 2/22/99

Location LC34, ESB

Boring Diameter	2 3/8 in	Total Depth	21 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from 2 to 3 ft
Screen Slot	0.010	Surface Completion	flush vault w/ concrete pad
Screen Length	2 2/3 ft	Drilling Method	CPT
Screen Depth	from 17.7 to 20.3 ft	Driller	John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post hole loose tan sands	0-4	---	---		PVC riser
No sampling, direct push.	4-21	---	---		
					2 2/3 ft screen
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 2/22/99

Construction Notes:

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LC34 IDC Coring Logsheet

Boring ID **PA-2I**

Date 2/22/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 23.7 to 26.3 ft

Total Depth 27 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

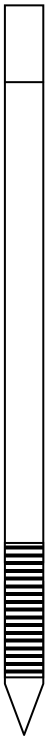
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mounted vault .

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole soil, loose tan sands	0-4	---	---		PVC riser
direct push, no sampling	4-27	---	---		
					2 2/3 ft screen
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 2/22/99

Construction Notes: Two pilot hole pushes and a well push .

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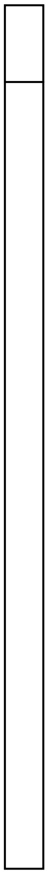
LC34 IDC Coring Logsheet

Boring ID **PA-2D**

Date 2/19/99

Location LC34, ESB

Boring Diameter	2 3/8 in	Total Depth	45 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from 2 to 3 ft
Screen Slot	0.010	Surface Completion	flush vault w/ concrete pad
Screen Length	2 2/3 ft	Drilling Method	CPT
Screen Depth	from 41.7 to 44.3 ft	Driller	John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole to 4 ft bgs soil, loose tan sands	0-4	---	---		PVC riser
direct push, no sampling	4-15	---	---		
medium to fine sand, gray, trace of shell material, wet	15-15.5	PA-2D-16.6	SP		
gray fine sand and silt, trace of shell material	15.5-16.6	PA-2D-16.6	SP		
no recovery	16.6-17	PA-2D-16.6			
gray fine sand and silt, trace shell material	17-17.25	PA-2D-18.5	SP		
gray fine to medium sand, 20-30% shells, 10-20% silts	17.25-18.5	PA-2D-18.5	SP		
no recovery	18.5-19				
gray silty fine sand, trace of shells	19-20	PA-2D-20.5	SP		
gray med to fine to med sand, 50-70% shells, some silts	20-20.5	PA-2D-20.5	SP		

Logged by: J Sminchak

Completion Date: 2/19/99

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID PA-2D

Date 2/20/99

Location LC34 ESB

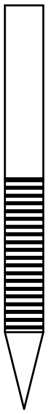
Lithologic Description	Depth	Sample	USCS	Well	Water Level	Other
gray medium to fine sands with abundant shell material >70%	21-21.5	PA-2D-22.5	SW			
gray silty fine sand, little shell material	21.5-22.5	PA-2D-22.5	SP			
gray silty fine sand, little shell material 10-20%	23-24.5	PA-2D-24.5	SP			
graly clayey fine sand	25-26.5	PA-2D-26.5	SM			
gray clayey fine sand, shells <10%	27-28.2	PA-2D-28.5	SM			
gray fine to medium sand, shells <20%	28.2-28.5	PA-2D-28.5	SP			
gray fine silty sand, little % of shells	29-29.5	PA-2D-30.5	SM			
gray fine to medium sand, some silts	29.5-30	PA-2D-30.5	SP			
mostly shells and gray fine sand with trace of silt <10%	30-30.5	PA-2D-30.5	SW			
no recovery (piston on sampler jammed)	31-32.5	PA-2D-30.5				
fine to med. gray sands, 30-40% shells	33.3-34.1	PA-2D-34.5	SW-GM			
silty fine sand to med. sand, some shells	34.1-34.5	PA-2D-34.5	SP			
silty fine sand, little shells	35-35.3	PA-2D-36.5	SM			
clay, medium plasticity	35.3-35.4	PA-2D-36.5	CL			
medium to fine sand, mostly >75% gravel sized shell material	35.4-36.5	PA-2D-36.5	SW			
gray silty fine sand, trace of shell material	37-38.5	PA-2D-38.5	SM			
gray fine silty sand, trace of shell material	39-39.3	PA-2D-40.5	SM			
fine sand, mostly shell frags, trace of silt	39.3-40.5	PA-2D-40.5	SP			

LC34 IDC Coring Logsheet

Boring ID PA-2D

Date 2/20/99

Location LC34 ESB

Lithologic Description	Depth	Sample	USCS	Well	Water Level	Other
fine silty gray sand, with 10-20% shells	41-41.5	PA-2D-42.5	SM			
clay, med plasticity	41.5-41.6	PA-2D-42.5	CL			
fine silty sand with abundant shell fragments	41.6-42.5	PA-2D-42.5	GS-SP			2 2/3 ft screen
fine sand and silts, wet and loose, some shells 20%	43-44.5	PA-2D-44.5	SM			6 7/8 in. tip

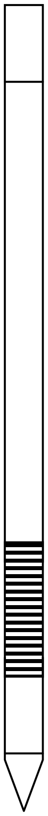
LC34 IDC Coring Logsheet

Boring ID **PA-3S**

Date 2/24/99

Location LC34, ESB

Boring Diameter	2 3/8 in	Total Depth	24 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from 2 to 3 ft
Screen Slot	0.010	Surface Completion	flush mount vault
Screen Length	2 2/3 ft	Drilling Method	CPT
Screen Depth	from 19.6 to 22.3 ft	Driller	John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post hole loose tan sands	0-4	---	---		PVC riser
No sampling, direct push.	4-24	---	---		
					2 2/3 ft screen
					1 ft sump
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 2/24/99

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-3I**

Date 2/24/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 26.1 to 28.7 ft

Total Depth 30.3 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

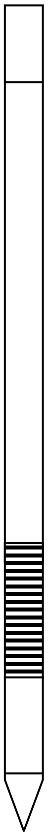
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mounted vault .

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole soil, loose tan sands	0-4	---	---		PVC riser 2 2/3 ft screen 1 ft sump 6 7/8 in. tip
direct push, no sampling	4-30.3	---	---		

Logged by: J Sminchak

Completion Date: 2/24/99

Construction Notes:

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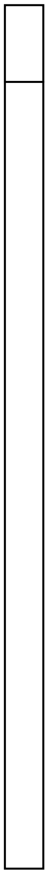
LC34 IDC Coring Logsheet

Boring ID **PA-3D**

Date 2/23/99

Location LC34, ESB

Boring Diameter	2 3/8 in	Total Depth	46.5 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from 2 to 3 ft
Screen Slot	0.010	Surface Completion	flush mount vault
Screen Length	2 2/3 ft	Drilling Method	CPT
Screen Depth	from 42.2 to 44.8 ft	Driller	John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole soil, loose tan sands	0-4	---	---		PVC riser
direct push, no sampling	4-15	---	---		
fine silty sand, gray, 10% shells	15-16.2	PA-2D-16.6	SP		
abundant shells and medium to fine gray sands	16.2-16.5	PA-2D-16.6	SP		
fine gray silty sand, trace shells	17-18.5	PA-2D-16.6	SP		
fine to medium gray sand, 20% shell fragments	19-20. 5	PA-2D-18.5	SP		
fine gray sand, some silts <10% and shells <10%	21-22.5	PA-2D-18.5	SP		
fine gray sand, some silts 10-20% and shell material <10%	23-24.5	PA-2D-18.5	SP		
fine gray sand, some silts and shell and shell material	25-26.5	PA-2D-20.5	SP		
fine gray sand, little silt, 20-30% shell (wet)	27-28.2	PA-2D-20.5	SP		

Logged by: J Sminchak

Completion Date: 2/23/99

Construction Notes: ____

Battelle
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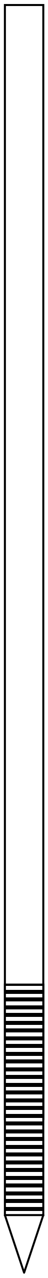
LC34 IDC Coring Logsheet

Date 2/23/99

Boring ID PA-3D

Location LC34 ESB

Lithologic Description	Depth	Sample	USCS	Well	Water Level	Other
shelly layer, mostly shells and fine sand and silts (wet)	28.2-28.5	PA-3D-28.5	SP			
shelly layer, mostly shells and fine sand and silts (wet)	29-29.2	PA-3D-30.5	SP			
fine silty/clayey sand, trace of shells	29.2-30.5	PA-3D-30.5	SM			
abundant shells and fine gray sands and silts 20-30%	31-32.1	PA-3D-32.5	SP-GM			
fine silty sand and 20-30% shells	32.1-32.5	PA-3D-32.5	SM			
fine silty sand and 20-30% shells	33.2-33.6	PA-3D-34.5	SM			
mostly shells and gray fine sand (20%)	33.6-34.5	PA-3D-34.5	SP-GM			
mostly shells and gray fine sand (20%)	35.3-36.3	PA-3D-36.5	SP-GM			
clayey fine sand, med-low plasticity	36.3-36.5	PA-3D-36.5	SC			
abundant shells, fine sands and silts 20-30%, loose wet	37-38.5	PA-3D-38.5	SP-GM			
abundant shells, fine sands and silts 20-30%, loose wet	39-40.5	PA-3D-40.5	SP-GM			
abundant shells, fine sands and silts 20-30%, loose wet	41-42.5	PA-3D-42.5	SP-GM			
fine silty sand and small amount of shells 10%	43.2-43.5	PA-3D-44.5	SM			
fine sand and shell frag 20% wet and loose	43.5-44.5	PA-3D-44.5	SP			2 2/3 ft screen
gray clay with some silt and fine sand, med-low plasticity	45-46.5	PA-3D-46.5	CL			6 7/8 in. tip

LC34 IDC Coring Logsheet

Date 2/26/99

Boring ID **PA-4S**

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 17.7 to 20.4 ft

Total Depth 22 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

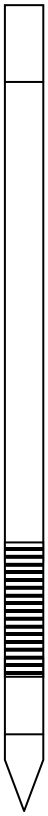
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post hole soil and loose tan sands	0-4	---	---		PVC riser
No sampling, direct push.	4-22	---	---		
					2 2/3 ft screen
					1 ft sump
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 2/26/99

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-4I**

Date 2/26/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 23.7 to 26.4 ft

Total Depth 28 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

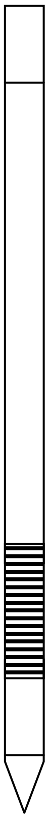
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault .

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole soil and loose tan sands	0-4	---	---		PVC riser
direct push, no sampling	4-28	---	---		
					2 2/3 ft screen
					1 ft sump
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 2/26/99

Construction Notes:

Battelle

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LC34 IDC Coring Logsheet

Boring ID PA-4D

Date 2/25/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 43.2 to 45.9 ft

Total Depth 47.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

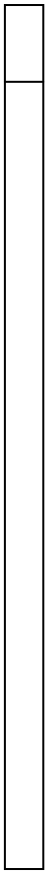
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole soil, loose tan sands	0-4	---	---		PVC riser
direct push, no sampling	4-15	---	---		
silty fine gray sand with 10-20% shells	15-15.3	PA-4D-16.5	SP		
abundant shell frags, some silty fine sand	15.3-16	PA-4D-16.5	SP		
silty fine to medium gray sand, 20-30% shells	16-16.5	PA-4D-16.5	SP		
fine gray sand, with little silt and shells <5%	17-18. 5	PA-4D-18.5	SP		
fine gray sand with more silt 10-20%	19-20.5	PA-4D-20.5	SP		
fine gray sand, with silt 10% and some shell material (well sorted)	21-22.5	PA-4D-22.5	SP		
fine gray sand, with silt 10% and some shell material (well sorted)	23-24.5	PA-4D-24.5	SP		
fine gray sand with 5% silt and shells, well sorted	25-26.5	PA-4D-26.5	SP		

Logged by: J Sminchak

Completion Date: 2/25/99

Construction Notes:

Battelle
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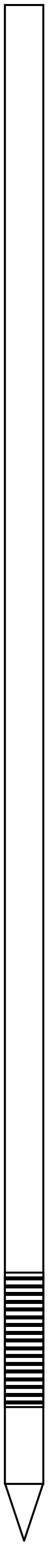
LC34 IDC Coring Logsheet

Boring ID PA-4D

Date 2/23/99

Location LC34 ESB

Lithologic Description	Depth	Sample	USCS	Well	Water Level	Other
fine gray sand and 40% shells with some silts	27-27.4	PA-4D-28.5	SP			
silty fine gray sand, some clay	27.4-28.5	PA-4D-28.5	SM			
fine to med sand with abundant shell material	29-29.4	PA-4D-30.5	SP			
gray silty sand	29.4-30.0	PA-4D-30.5	SM			
wet silty fine sand with 20% shells	30.0-30.5	PA-4D-30.5	SP			
wet silty fine sand with 10-20% shells	31-32	PA-4D-32.5	SP-GM			
abundant shells with gray fine silty sand (10%)	32-32.5	PA-4D-32.5	SP-GM			
abundant shells with gray fine silty sand (10%), wet	33-34.5	PA-4D-34.5	SP-GM			
abundant shells with gray fine silty sand (10%), wet	35-36	PA-4D-36.5	SP			
silty gray sand, some shells	36-36.5	PA-4D-36.5	---			
no recovery	37-38.5	PA-4D-36.5	SP-GM			
abundant shells with gray silty sand	38.5-38.8	PA-4D-40	SP-GM			
fine silty gray sand with 40-50% shells	38.8-39.7	PA-4D-40	SP-GM			
sandy clay with some shells med-low plasticity	39.7-40	PA-4D-40	SC			
abundant shells with fine gray silty sand 30-40%	40.5-42	PA-4D-42	SP-GM			
abundant shells with fine gray silty sand 30%	42.5-44	PA-4D-44	SP-GM			2 2/3 ft screen
silty gray fine sand	44.5-46	PA-4D-46	SP			
clayey sand and silt, some shells	46.5-46.8	PA-4D-47.5	SC			1 ft sump
sandy clay, some shell material	46.8-47.5	PA-4D-47.5	CL			6 7/8 in. tip

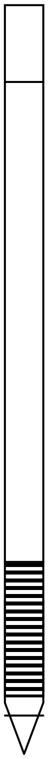
LC34 IDC Coring Logsheet

Boring ID PA-5S

Date 3/1/99

Location LC34, ESB

Boring Diameter	2 3/8 in	Total Depth	17 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from 2 to 3 ft
Screen Slot	0.010	Surface Completion	flush mount vault
Screen Length	2 2/3 ft	Drilling Method	CPT
Screen Depth	from 13.7 to 16.3 ft	Driller	John Hoggatt

Lithologic Description	Depth	Sample	USCS	Well	Other
Post hole loose tan sands	0-5	---	---		PVC riser
No sampling, direct push.	5-17	---	---		
					2 2/3 ft screen
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 3/1/99

Construction Notes:

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LC34 IDC Coring Logsheet

Boring ID **PA-5I**

Date 3/1/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 17.8 to 20.4 ft

Total Depth 22 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

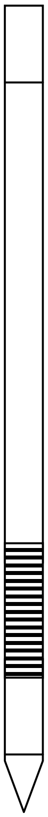
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault .

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole soil and loose tan sands	0-4	---	---		PVC riser 2 2/3 ft screen 1 ft sump 6 7/8 in. tip
direct push, no sampling	4-22	---	---		

Logged by: J Sminchak

Completion Date: 3/1/99

Construction Notes:

Battelle
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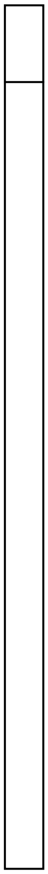
LC34 IDC Coring Logsheet

Boring ID **PA-5D**

Date 2/26/99

Location LC34, ESB

Boring Diameter	2 3/8 in	Total Depth	45.6 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from 2 to 3 ft
Screen Slot	0.010	Surface Completion	flush mount vault
Screen Length	2 2/3 ft	Drilling Method	CPT
Screen Depth	from 42.2 to 44.9 ft	Driller	John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole soil, loose tan sands	0-5	---	---		PVC riser
direct push, no sampling	5-15	---	---		
fine gray sand with 20-30% shell material	15-15.7	PA-5D-16.5	SP		
mostly shell frags with 20-30% fine gray sand	15.7-16.5	PA-5D-16.5	SP		
well graded yellowish-orange fine sand with dark brown mottling (no shells gray plug)	17-18.5	PA-5D-18.5	SP		
gray silty fine sand, well sorted, trace of shell frags	19-20. 5	PA-5D-20.5	SP		
well graded yellowish-orange fine sand with dark brown mottling	21-22.3	PA-5D-20.5	SP		
gray silty fine sand in plug of sampler	22.3-22.5	PA-5D-22.5	SP		
gray silty fine sand, trace of shell fragments	23-24.5	PA-5D-24.5	SP		
gray silty fine sand, trace of shell fragments	25-26.5	PA-5D-26.5	SP		

Logged by: J Sminchak

Completion Date: 2/27/99

Construction Notes:

Battelle
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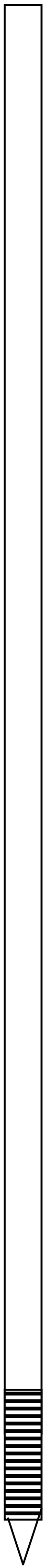
LC34 IDC Coring Logsheet

Boring ID PA-5D

Date 2/27/99

Location LC34 ESB

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Water Level**	**Other**
silty fine gray sand, trace of shell fragments	27-28.1	PA-5D-28.5	SM			
silty fine gray sand, 10% shells	28.1-28.5	PA-5D-28.5	SM			
yellowish-orange fine to medium sand w/ abundant shells (sluff?)	29-30	PA-5D-30.5	SP			
silty fine gray sand, trace of shell fragments	30-30.5	PA-5D-30.5	SM			
abundant shell fragments and fine gray sand, trace silt	31-32.5	PA5-D-32.5	SP-GM			
yellowish orange fine to med. sand w/ abundant shells	33.5-34	PA-5D-34.5	SP			
silty fine gray sand, trace shell frags	34-34.2	PA-5D-34.5	SM			
abundant shells frags. and gray fine sand, trace silt	34.2-34.5	PA-5D-34.5	SP-GM			
silty fine gray sand, trace of clay and shell frags	35-35.4	PA-5D-36.5	SM			
silty gray clay low plasticity, trace sand	35.4-35.9	PA-5D-36.5	CL			
abundant shells, trace of fine silty sand (10%)	35.9-36.5	PA-5D-36.5	SP-GM			
silty gray clay, trace shells med-low plasticity, (1-2" stiff gray plug)	37 - 37.6	PA-5D-38.5	CL-ML			
clayey gray silt, shells 10-20%	37.6-38.5	PA-5D-38.5	SM			
silty gray clay, trace shells med-low plasticity	39-39.3	PA-5D-40.5	CL-ML			
silty-clayey fine sand and shell frags	39.3-39.8	PA-5D-40.5	SP-sM			
silty gray clay, trace shells med-low plasticity	39.8-40.2	PA-5D-40.5	CL-ML			
silty fine sand, mostly shells 60-80%	40.2-40.5	PA-5D-40.5	SP-GM			2 2/3 ft screen
sandy silty gray clay with trace of shell ftags. (some stiffness)	41.5-42	PA-5D-42.5	CL-ML			
silty sandy gray shell frags and shells (75% shells)	42-42.5	PA-5D-42.5	SP-GM			1 ft sump 6 7/8 in. tip
gray fine sand, trace of silt and shells but overall well sorted	43-44.5	PA-5D-44.5	SP			
gray sandy clay, trace of shells	45-46.5	PA-5D-46.5	CL			

LC34 IDC Coring Logsheet

Boring ID **BAT-6S**

Date 7/12/99

Location LC34

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 23 to 26 ft

Total Depth 26.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

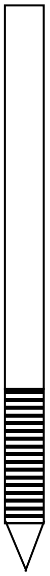
Grout Material bentonite

Grout Depth from 0 to ~2 ft

Surface Completion flush mount

Drilling Method CPT

Driller Ruperto Aquilar

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Direct push- no sampling	0-26.5	---	---		PVC Riser 3 ft screen 0.5 ft tip

Logged by: L. Cumming

Completion Date: 7/12/99

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-6I**

Date 3/2/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 23.5 to 26.2 ft

Total Depth 26.8 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

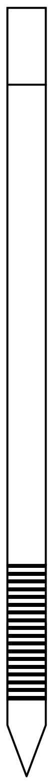
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault .

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole soil and loose tan sands (tar/rock layer at 2 ½ ft)	0-5	---	---		PVC riser
direct push, no sampling	4-26.8	---	---		
					2 2/3 ft screen
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 3/2/99

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-6D**

Date 3/1/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 42 to 44.6 ft

Total Depth 46.2 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole soil, loose tan sands	0-5	---	---		PVC riser
direct push, no sampling	5-15	---	---		
fine gray sand, well sorted, trace of shell material and silts	15-15.7	PA-6D-16.5	SP		
fine gray sand, well sorted, trace of shell material and silts	15.7-16.5	PA-6D-18.5	SP		
fine gray sand, (30-40%) shell fragments	17-18.5	PA-6D-20.5	SP		
fine gray sand with some silt (<10%) and trace shell frag	19-20. 5	PA-6D-20.5	SP		
fine gray sand with some shell frag (10-15%) and trace silt	21-22.3	PA-6D-22.5	SP		
gray silt with fine sand	22.3-22.5	PA-6D-22.5	SM		
no recovery	23-24.5	---	---		
fine gray silty fine sand, trace of shell fragments	25-26.5	PA-6D-26.5	SM		

Logged by: J Sminchak

Completion Date: 3/2/99

Construction Notes: ______

Battelle
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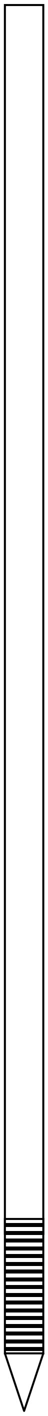
LC34 IDC Coring Logsheet

Boring ID PA-6D

Date 3/2/99

Location LC34 ESB

Lithologic Description	Depth	Sample	USCS	Well	Water Level	Other
silty fine gray sand, trace of shell fragments	27-28	PA-5D-28.5	SM			
gray fine sand with 30-40% shell fragments	28-28.2	PA-5D-28.5	S9			
gray sandy silt, trace of shell fragments	28.2-28.5	PA-5D-30.5	SM			
gray sandy silt, trace of shell fragments	29-29.7	PA-5D-30.5	SM			
fine gray sand with 30-40% shell frags, trace silt	29.7-30.3	PA5-D-32.5	SP			
gray sandy silt, trace of shell fragments	30.3-30.5	PA-5D-34.5	SM			
gray sandy silt, trace of shell fragments	31-31.4	PA-5D-34.5	SM			
abundant shells frags. and gray fine silty sand	31.4-32.5	PA-5D-34.5	SP-GM			
abundant shells frags. and gray fine silty sand	33.5-34.5	PA-5D-36.5	SP-GM			
silty fine gray sand, trace shell frags	35-35.3	PA-5D-36.5	SP			
silty sandy clay, low plast.	35.3-35.6	PA-5D-36.5	SC			
clayey, silty sand w/ shell material 20%	35.6 - 36.5	PA-5D-38.5	SM			
abundant shells w/ silty-fine sands	37-38.5	PA-5D-38.5	SP-SM			
silty clayey fine sand w/ 10-20% shell frags	39.5-39.7	PA-5D-40.5	SP-SM			
abundant large shells + frags in a silty clayey matirix	39.3-40.5	PA-5D-40.5	SP-SM			
clayey silt and fine sand with 20-30% shell frags	41.5-42.5	PA-6D-42.5	SM			2 2/3 ft screen
silty fine gray sand with 10-20% shell frags	43-44.5	PA-6D-44.5	SP			
sandy clay with trace of shell ftags.	45-46.2	PA-6D-46.2	CL			6 7/8 in. tip

LC34 IDC Coring Logsheet

Boring ID **PA-7S**

Date 3/3/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 19 to 21.6 ft

Total Depth 23.25 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

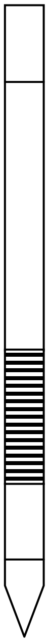
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post hole loose tan sands	0-4	---	---		PVC riser
No sampling, direct push.	4-17	---	---		
fine gray sand, some shell fragments + silts	15-16.5	PA-7D(s)-18.5	SP		
fine gray sand, well sorted, trace shells	17-18.5	PA-7D(s)-18.5	SP		
shell fragments and fine to medium gray sands	19-20.5	PA-7D(s)-20.5	SP-GM		2 2/3 ft screen
abundant shell fragments and fine to coarse gray sands	21-22.5	PA-7D(s)-22.5	SP-GM		1ft sump 6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 3/3/99

Construction Notes: ____________________

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-7I**

Date 3/8/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 23.6 to 26.2 ft

Total Depth 26.8 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

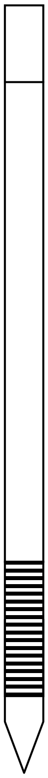
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault .

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
saw 2” asphalt, post hole loose tan sands	0-6	---	---		PVC riser
direct push, no sampling	6-26.8	---	---		
					2 2/3 ft screen
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 3/8/99

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-7D**

Date 3/5/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 41.3 to 43.9 ft

Total Depth 45.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

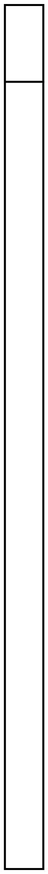
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
saw 2 “ asphalt, post hole soil, loose tan sands	0-5	---	---		PVC riser
direct push, no sampling, continue from PA-7S	5-23	---	---		
fine gray sand, w/ some silts and trace of shell material	23-23.7	PA-6D-16.5	SP		
fine gray silty sand 10% shell material	23.7-24.5	PA-6D-18.5	SP		
<u>shelly</u> fine gray sand	25-25.2	PA-6D-20.5	SP		
fine gray sand, trace shell frags, well sorted	25.2-26.1		SP		
sandy gray silt, trace shell frags	26.1-26.3	PA-6D-22.5	SP		
silty fine gray sand, trace shell frags	27-28.5		SM		
fine gray sand, 5% shells, well sorted	29-29.5	---	---		
silty fine gray sand, trace of shell fragments	29.5-30.5	PA-6D-26.5	SM		

Logged by: J Sminchak

Completion Date: 3/5/99

Construction Notes:

Battelle
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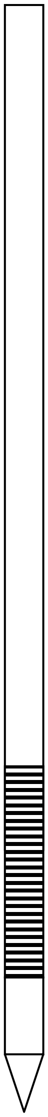
LC34 IDC Coring Logsheet

Boring ID PA-7D

Date 3/5/99

Location LC34 ESB

Lithologic Description	Depth	Sample	USCS	Well	Water Level	Other
silty fine gray sand, trace of shell fragments	31-31.2	PA-7D-32.5	SM			
abundant shells + fragments with silty gray fine sand	31.2-32.5		GM-SM			
abundant coarse shells + frag with fine sand, some silts	33-33.6	PA-7D-34.5	GM			
silty fine gray sand, trace shell frags	33.6-34.5		SM			
shell frags in silty clay matrix (very slight to no stiffness)	35-35.7	PA7D-36.5	SC			
shell fragments in clayey matirx, low plasticity	35.7-36.5		SC			
light gray fine sand, trace shells	37.5-38.5	PA7D-38.5	SP			
abundant shells (70%) in silty fine gray sand matrix	39-39.8	PA7D-40.5	SP-GM			
gray silty fine sand, trace shells (10-15%)	39.8-40.5		SP-GM			
yellowish brown tan fine sand, trace shells	41-41.7	PA7D-42.5	SP			
gray fine to med sand, trace shells	41.7-42.5		SP			2 2/3 ft screen
clayey sand, some stiffness, silty	44 – 44.5	PA7D-45.5	SC			
sandy gray clay, med plasticity	44.5-45.5		CL			1 ft sump 6 7/8 in. tip

LC34 IDC Coring Logsheet

Boring ID **PA-8S**

Date 3/3/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 15.8 to 18.4 ft

Total Depth 20 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

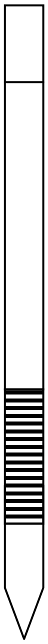
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post hole loose tan sands	0-6	---	---		PVC riser
No sampling, direct push.	4-20	---	---		
					2 2/3 ft screen
					1ft sump 6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 3/3/99

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-8I**

Date 3/8/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 23.6 to 26.2 ft

Total Depth 26.8 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

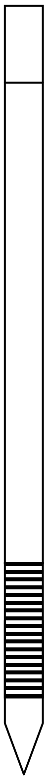
Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault .

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
saw 2” asphalt, post hole loose tan sands	0-6	---	---		PVC riser
direct push, no sampling	6-26.8	---	---		
					2 2/3 ft screen
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 3/8/99

Construction Notes:

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LC34 IDC Coring Logsheet

Boring ID **PA-8D**

Date 3/4/99

Location LC34, ESB

Boring Diameter 2 3/8 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 2 2/3 ft

Screen Depth from 42.3 to 44.9 ft

Total Depth 46.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

Grout Material bentonite chips

Grout Depth from 2 to 3 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
saw 2 " asphalt, post hole soil, loose tan sands	0-6	---	---		PVC riser
direct push, no sampling	6-15	---	---		
fine gray sand, well sorted, trace of shell frags	15-16.5	PA-8D-16.5	SP		
coarse shell fragments (90%) and fine gray sand trace silt	17-18.5	PA-7D-18.5	SP-GM		
fine gray sand, well sorted, 5-10% shell frags.	19-20.5	PA-8D-20.5	SP		
silty fine gray sand, 5-10% shell frags	21-22.5	PA-8D-22.5	SP		
yellowish brown fine sand and shell fragments	23.5-24.3	PA-8D-24.5	SP		
clayey gray silt with some fine sand	24.3-24.5		SM		
silty fine gray sand with 5% shells	25-26.5	PA-8D-26.5	SM		
silty fine gray sand with 5% shells	27-28.3	PA-8D-28.5	SM		

Logged by: J Sminchak

Completion Date: 3/4/99

Construction Notes:

Battelle

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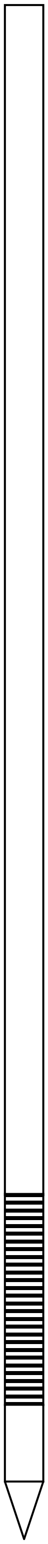
LC34 IDC Coring Logsheet

Boring ID PA-8D

Date 3/4/99

Location LC34 ESB

Lithologic Description	Depth	Sample	USCS	Well	Water Level	Other
sandy silty gray clay	28.3-28.5	PA-8D-28.5	SC			
sandy silty gray clay	29-29.3	PA-8D-30.5	SC			
clayey-silty fine sand with some shell frags (5%)	29.3-30.5		SM			
silty fine gray sand	31-31.1	PA-8D-32.5	SM			
abundant shells w/ silty fine gray sand	31.1-31.3		SP-GM			
mostly shells/fragments with in silty fine gray sands (30-40%)	31.3-32.5		SP			
silty fine gray sand with 20% coarse shell frag	33-33.4	PA-8D-34.5	SP-GM			
mostly shells with silty fine gray sand	33.4-33.8		SP			
gray silty fine sand with trace shell frags	33.8-34.5		SP-GM			
silty-clayey fine sand, trace shells	35-35.6	PA-8D-36.5	SP			
silty clayey fine sand wi 10-20% shells +fragments	35.6-36.5		SM			
shells, shell frags in silty clayey matirx	37-38.5	PA-8D-38.5	SM			
fine gray to brown sand, trace of shell fragments	39-39.7	PA-8D-40.5	GM			
silty clayey fine sand w/ 10-20% shells	39.7-40.3		SP			
sandy-silty clay	40.3-40.5		SP-SM			
silty clayey fine sand w/ 30% shells + shell frags	41-42.5	PA-8D-42.5	SC			
gray silty sand with 20-30% shell frags	43-44	PA-8D-44.5	SM			2 2/3 ft screen
clayey sitl and fine sand	44-44.5	PA-8D-44.5	SM			
sandy gray clay, med-low plasticity	44.7-45.7	PA-8D-45.7	CL			1 ft sump
						6 7/8 in. tip

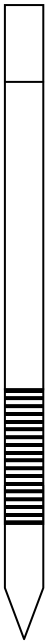
LC34 IDC Coring Logsheet

Boring ID **PA-9S**

Date 3/8/99

Location LC34, ESB

Boring Diameter	2 3/8 in	Total Depth	22.7 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from 2 to 3 ft
Screen Slot	0.010	Surface Completion	flush mount vault
Screen Length	2 2/3 ft	Drilling Method	CPT
Screen Depth	from 18.5 to 21.1 ft	Driller	John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post hole soil, loose tan sands	0-6	---	---		PVC riser
No sampling, direct push.	6-22.7	---	---		
					2 2/3 ft screen
					1ft sump 6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 3/8/99

Construction Notes:

Battelle
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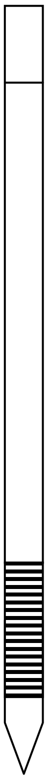
LC34 IDC Coring Logsheet

Boring ID **PA-9I**

Date 3/8/99

Location LC34, ESB

Boring Diameter	2 3/8 in	Total Depth	26.8 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from 2 to 3 ft
Screen Slot	0.010	Surface Completion	flush mount vault .
Screen Length	2 2/3 ft	Drilling Method	CPT
Screen Depth	from 23.6 to 26.2 ft	Driller	John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
saw 2” asphalt, post hole loose tan sands	0-6	---	---		PVC riser
direct push, no sampling	6-26.8	---	---		
					2 2/3 ft screen
					6 7/8 in. tip

Logged by: J Sminchak

Completion Date: 3/8/99

Construction Notes:

.

LC34 IDC Coring Logsheet

Boring ID **PA-9D**

Date 3/6/99

Location LC34, ESB

Boring Diameter	2 3/8 in	Total Depth	45 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from 2 to 3 ft
Screen Slot	0.010	Surface Completion	flush mount vault
Screen Length	2 2/3 ft	Drilling Method	CPT
Screen Depth	from 41.8 to 44.4 ft	Driller	John Hoggatt

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
post hole soil, loose tan sands	0-6	---	---		PVC riser
direct push, no sampling	6-15	---	---		
coarse shell fragments and coarse gray sand	15-16.5	PA-9D-16.5	SP		
fine gray sand, trace shell frags, well sorted	17-18.5	PA-9D-18.5	SP-GM		
fine gray sand, well sorted, trace shell frags.	19-20.5	PA-9D-20.5	SP		
fine gray sand, well sorted, trace shell frags.	21-22.5	PA-9D-22.5	SP		
fine gray sand, well sorted, trace shell frags.	23-24.5	PA-9D-24.5	SP		
light gray fine to med sand and 5-10% shell frags	25-25.4	PA-9D-26.5	SM		
light gray fine to med. sand w/ abundant shells + frags (30-50%)	25.4-25.9		SM		
light gray fine silty sand, trace shell frags	25.9-26.5		SM		

Logged by: J Sminchak

Completion Date: 3/6/99

Construction Notes:

Battelle
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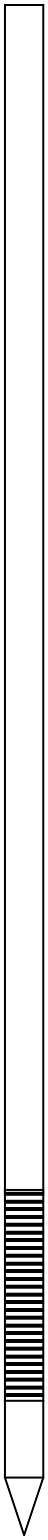
LC34 IDC Coring Logsheet

Boring ID PA-9D

Date 3/6/99

Location LC34 ESB

Lithologic Description	Depth	Sample	USCS	Well	Water Level	Other
silty gray fine sand, trace of shells	27-28.5	PA-9D-28.5	SM			
silty gray fine sand, trace of shells	29-30.5	PA-9D-30.5	SM			
silty clayey fine sand w/ 30% shells	31-31.7	PA-9D-32.5	SM			
mostly shells in a silty fine sand matrix	31.7-32.5		GM			
silty fine sand, trace shells	33-33.5	PA-9D-34.5	SM			
abundant shells in silty fine gray sand matrix	33.5-34		SM-GM			
silty clayey fine gray sand with 20-30% shells	34-34.5		SM			
abundant shells (75%) in a silty matrix w/ fine sand	35-36.5	PA-9D-36.5	GM			
gray clay, trace sands	37-37.5	PA-9D-38.5	CL			
gray sandy silt with 10-20% shells	37.5-37.9		SM			
silty fine sand well sorted	37.9-38.5		SP-SM			
silty fine sand well sorted	39-39.8	PA-8D-40.5	SP-SM			
gray silt with shells 30-40%	39.8-40.2		GM-SM			
sandy clay with 10% shells	40.2-40.5		SC-CL			
silty fine sand, trace shells	42-42.9	PA-9D-43.5	SP-SM			
abundant shells + shell frags (70%) w/ silty fine sand	42.9-43.5		GM			
sandy clay, trace shells	44-45	PA-9D-45.5	CL			2 2/3 ft screen
shells in silty fine sand matrix	45-45.2		GM			
sandy gray clay, low plasticity	45.2-45.5		SC			1 ft sump 6 7/8 in. tip

LC34 IDC Coring Logsheet

Boring ID **PA-10S**

Date 3/18/99

Location LC34, ESB

Boring Diameter 3 1/2 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 18 to 21 ft

Total Depth 22.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

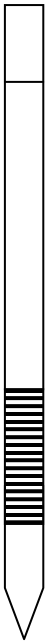
Grout Material bentonite

Grout Depth from ______ to ______ ft

Surface Completion flush mount vault

Drilling Method pneumatic hammer

Driller Rob Hancock (PSI)

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
cement saw 8” concrete, hand-auger loose tan sands	0-6	---	---		PVC riser
No sampling, direct push.	6-22.5	---	---		
					3 ft screen
					1.5 ft sump and tip

Logged by: J Sminchak

Completion Date: 3/18/99

Construction Notes: push sacrificial tip and 3 ½ diameter sections, insert well in hole and let sands collapse

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LC34 IDC Coring Logsheet

Boring ID **PA-10I**

Date 3/18/99

Location LC34, ESB

Boring Diameter 3 1/2 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 23.5 to 26.5 ft

Total Depth 28 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

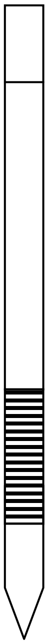
Grout Material bentonite

Grout Depth from ______ to ______ ft

Surface Completion flush mount vault

Drilling Method pneumatic hammer

Driller Rob Hancock (PSI)

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
cement drill 8" concrete, hand-auger loose tan sands	0-6	---	---		PVC riser
No sampling, direct push.	6-28	---	---		
					3 ft screen
					1.5 ft sump and tip

Logged by: J Sminchak

Completion Date: 3/18/99

Construction Notes: push rate increases after 22.5 ft

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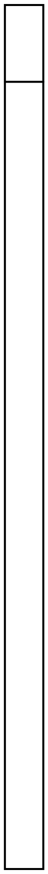
LC34 IDC Coring Logsheet

Boring ID **PA-10D**

Date 3/18/99

Location LC34, ESB

Boring Diameter	3 1/2 in	Total Depth	45 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite chips
Screen Type	stainless steel	Grout Depth	from --- to --- ft
Screen Slot	0.010	Surface Completion	flush mount vault
Screen Length	3 ft	Drilling Method	Pnuematic Hammer
Screen Depth	from 40.5 to 43.5 ft	Driller	Rob Hancock (PSI)

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
cement drill 8”, hand auger loose tan sands	0-6	---	---		PVC riser
direct push, no sampling	6-15	---	---		
no recovery	15-17	---	---		
no recovery	17-18.5	---	---		
silty fine gray sand, trace (5-10%) shell frags.	19-20.5	PA-10D-23.5	SP		
silty fine gray sand, trace (5-10%) shell frags.	21-22.5	PA-10D-25	SP		
silty fine gray sand, trace (5-10%) shell frags.	23-24.5	PA-10D-26.5	SP		
silty fine gray sand, trace (5-10%) shell frags.	25-25.4	PA-10D-28	SP		
skip two ft to prevent sluff from entering sampler	25.4-25.9	---	---		
coarse shell frags (70%) in silty fine gray sand matrix	25.9-26.5	PA-10D-31.5	SP-GM		

Logged by: J Sminchak

Completion Date: 3/25/99

Construction Notes: DI water added to offset heaving sands during soil sampling, switch to 6’ sampling method after 22’ bgs

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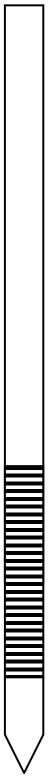
LC34 IDC Coring Logsheet

Boring ID PA-10D

Date 3/18/99

Location LC34 ESB

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Water Level**	**Other**
abundant whole shells (70%) in silty fine sand matrix	31-32.5	PA-10D-33	SP-GM			
abundant whole shells (70%) in silty fine sand matrix	32.5-34	PA-10D-34.5	SP-GM			
abundant whole shells (70%) in silty fine sand matrix	34-36	PA-10D-36	SP-GM			
---	---	---	---			
skip two ft	---	---	---			
coarse shell frags (75%) in gray silty sand matrix	38-39	PA-10D-38.5	SP-GM			
silty-clayey fine gray sand with 30% shells (slight stiffness)	39-40	PA-10-41	SP-SM			
abundant shells in gray fine sand	40-42.5	PA-10D-42.5	SP-GM			3 ft screen
sampler jammed, no further recovery	---	---	---			
						1.5 ft sump and tip

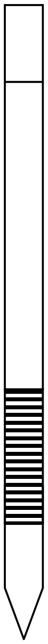
LC34 IDC Coring Logsheet

Boring ID **PA-11S**

Date 3/19/99

Location LC34, ESB

Boring Diameter	3 1/2 in	Total Depth	22.5 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite
Screen Type	stainless steel	Grout Depth	from ____ to ____ ft
Screen Slot	0.010	Surface Completion	flush mount vault
Screen Length	3 ft	Drilling Method	pneumatic hammer
Screen Depth	from 18 to 21 ft	Driller	Rob Hancock (PSI)

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
cement drill 8” cement, hand-auger loose tan sands	0-6	---	---		PVC riser
No sampling, direct push.	6-22.5	---	---		
					3 ft screen
					1.5 ft sump and tip

Logged by: J Sminchak

Completion Date: 3/19/99

Construction Notes: ____________________

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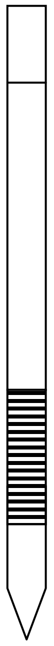
LC34 IDC Coring Logsheet

Boring ID **PA-11I**

Date 3/19/99

Location LC34, ESB

Boring Diameter	3 1/2 in	Total Depth	28 ft
Casing Outer Diameter	2 3/8 in	Sand Pack	---
Casing Inner Diameter	1 7/8 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite
Screen Type	stainless steel	Grout Depth	from ____ to ____ ft
Screen Slot	0.010	Surface Completion	flush mount vault
Screen Length	3 ft	Drilling Method	pneumatic hammer
Screen Depth	from 23.5 to 26.5 ft	Driller	Rob Hancock (PSI)

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
cement saw 8” concrete, hand-auger loose tan sands	0-6	---	---		PVC riser 3 ft screen 1.5 ft sump and tip
No sampling, direct push.	6-28	---	---		

Logged by: J Sminchak

Completion Date: 3/19/99

Construction Notes: middle indoor well cluster

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LC34 IDC Coring Logsheet

Boring ID PA-11D

Date 3/20/99

Location LC34, ESB

Boring Diameter 3 1/2 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 41.0 to 43.5 ft

Total Depth 45 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

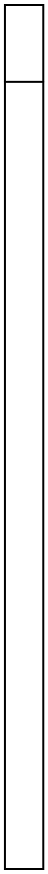
Grout Material bentonite chips

Grout Depth from --- to --- ft

Surface Completion flush mount vault

Drilling Method Pnuematic Hammer

Driller Rob Hancock (PSI)

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
cement drill 8”, hand auger loose tan sands	0-6	---	---		PVC riser
direct push, no sampling	6-15	---	---		
no recovery	15-17.5	---	---		
no recovery	17.5-19.0	PA-11D-19	SP		
silty fine gray sand, trace (5-10%) shell frags.	19.5-22	---	---		
silty fine gray sand, trace (5-10%) shell frags.	22-23.5	PA-11D-23.5	SP		
silty fine gray sand, trace (5-10%) shell frags.	23-24.5	PA-11D-25	SP		
silty fine gray sand, trace (5-10%) shell frags.	24.5-26.5	PA-11D-26.5	SP-SM		
skip two ft to prevent sluff from entering sampler	26.5-28.0	PA-11D-28	SP		
coarse shell frags (70%) in silty fine gray sand matrix	29-30.5	PA-11D-29	SM		

Logged by: J Sminchak

Completion Date: 3/25/99

Construction Notes: DI water added to offset heaving sands during soil sampling, switch to 6’ sampling method after 22’ bgs

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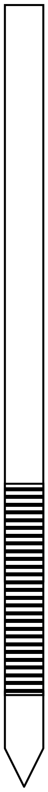
LC34 IDC Coring Logsheet

Boring ID PA-11D

Date 3/20/99

Location LC34 ESB

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Water Level**	**Other**
coarse grained shell frags (90%) w/ fine gray sand	30.5-31.2	PA-11D-30.5	GP			
silty fine gray sand, some clay and shell frags	31.2-32.1	PA-11D-32	SM			
abundant shells in silty fine gray sand matrix	32.1-32.6	PA-11D-33.5	SP-GM			
silty fine gray sand, some clay 5% ans 10-30% shells	32.6-32.9	PA-11D-35	SM			
abundant shells in silty fine gray sand matrix	32.9-33.5	PA-11D-35	SP			
silty fine gray sand w/ 30-50% shell frags (coarse)	33.5-35	PA-11D-35	SP-GM			
silty fine gray sand, wet, trace shells	35-35.5	PA-11-35.5	SP			
shell hach (5% silty fine gray sand)	35.5-37	PA-11D-37	SP-GM			3 ft screen
sampler jammed, no further recovery	---	---	---			1.5 ft sump and tip

LC34 IDC Coring Logsheet

Boring ID **PA-12S**

Date 3/21/99

Location LC34, ESB

Boring Diameter 3 1/2 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 18 to 21 ft

Total Depth 22.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

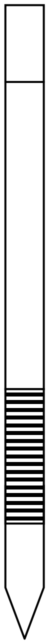
Grout Material bentonite

Grout Depth from ______ to ______ ft

Surface Completion flush mount vault

Drilling Method pneumatic hammer

Driller Rob Hancock (PSI)

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
cement drill 8" concrete, hand auger loose tan to brown sands	0-6	---	---		PVC riser
No sampling, direct push.	6-22.5	---	---		
					2 2/3 ft screen
					1.5 ft sump and tip

Logged by: J Sminchak

Completion Date: 3/21/99

Construction Notes: ______________________

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LC34 IDC Coring Logsheet

Boring ID **PA-12I**

Date 3/21/99

Location LC34, ESB

Boring Diameter 3 1/2 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 24 to 27 ft

Total Depth 28.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

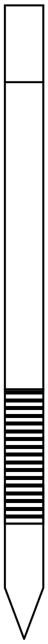
Grout Material bentonite

Grout Depth from ______ to ______ ft

Surface Completion flush mount vault

Drilling Method pneumatic hammer

Driller Rob Hancock (PSI)

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
cement drill 8” concrete, hand-auger loose tan sands	0-6	---	---		PVC riser
No sampling, direct push.	6-28.5	---	---		
					3 ft screen
					1.5 ft sump and tip

Logged by: J Sminchak

Completion Date: 3/21/99

Construction Notes: sand heave forces well from 30’ to 28.5’ during well placement

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LC34 IDC Coring Logsheet

Date 3/22/99

Boring ID **PA-12D**

Location LC34, ESB

Boring Diameter 3 1/2 in

Casing Outer Diameter 2 3/8 in

Casing Inner Diameter 1 7/8 in

Casing Material stainless steel

Screen Type stainless steel

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 40.5 to 43.5 ft

Total Depth 45 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

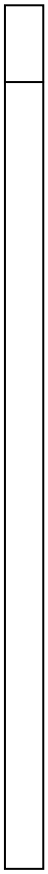
Grout Material bentonite chips

Grout Depth from --- to --- ft

Surface Completion flush mount vault

Drilling Method Pnuematic Hammer

Driller Rob Hancock (PSI)

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
cement drill 8", hand auger loose tan sands	0-6	---	---		PVC riser
direct push, no sampling	6-15	---	---		
tan to yellowish brown fine sand well sorted, some gray fine sands	15.5-17	PA-12D-17.5	SP		
fine gray fine sand, 10-15% shells	17.5-18.2	PA-12D-20	SP		
fine to med. gray sand, 10-25% shell frags	18.2-19	PA-12D-20	SP		
fine gray sand well sorted, trace silt and shell frags	19.5-20.5	PA-12D-21	SP		
fine to med. gray sand, 10-25% shell frags	20.5-21	PA-12D-21	SP		
fine to med. gray sand, 10-25% shell frags	21.5-23	PA-12D-23	SP		
fine gray sand, wet, well sorted, trace shells	23.5-25	PA-12D-25	SP		
fine gray silty sand w/ trace of shell frags (<10% silt)	25.5-27	PA-12D-27	SP		

Logged by: J Sminchak

Completion Date: 3/23/99

Construction Notes: start w/ 2 ft pin-point sampler on

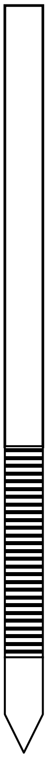
3/22 to 31' bgs, swithc to 6 ft core barrel sampler on 3/23

LC34 IDC Coring Logsheet

Boring ID PA-12D

Date 3/22/99

Location LC34 ESB

Lithologic Description	Depth	Sample	USCS	Well	Water Level	Other
silty fine gray sand, trace shells (10-20% silt)	27.5-29	PA-12D-29	SM			
silty fine gray sand, 30-50% shell frags	32-34	PA-12D-33.5	SM			
silty fine gray sand, some shell frags <10%	34-35	PA-12D-35	SM			
abundant shells w/ silty fine sand (10-20%)	35-36.5	PA-12D-36.5	GM			
silty gray fine sand, w/some clay + shells	36.5-38	PA-12D-38	SM			
overpush no sample	---	---	---			
silty fine gray sand, trace shells	41-42	PA-12D-42.5	SP-SM			
ssilty fine gray sand with 20-40% shells	42-44	PA-12D-44	SM			3 ft screen
abundant shells in silty fine gray sand (30-40%)	44-44.5	PA-12D-44.5	GM			1.5 ft sump and tip

LC34 IDC Coring Logsheet

Boring ID **PA-13S**

Date 7/13/99

Location LC34

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 21 to 24 ft

Total Depth 24.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

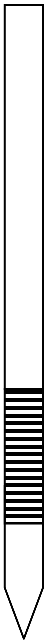
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller R. Aguilar

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
No sampling, direct push.	0-24.5	---	---		PVC riser 3 ft screen 6 in. tip

Logged by: L. Cumming

Completion Date: 7/13/99

Construction Notes:

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LC34 IDC Coring Logsheet

Boring ID **PA-13I**

Date 7/13/99

Location LC34

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 25 to 28 ft

Total Depth 28.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

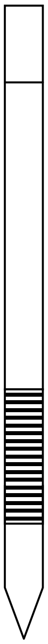
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller R. Aguilar

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
					PVC riser
No sampling, direct push.	0-28.5	---	---		
					3 ft screen
					6 in. tip

Logged by: L. Cumming

Completion Date: 7/13/99

Construction Notes:

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LC34 IDC Coring Logsheet

Boring ID **PA-13D**

Date 7/12/99

Location LC34

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 41 to 44 ft

Total Depth 44.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

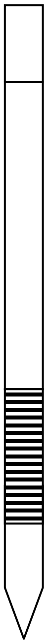
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller R. Aguilar

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
					PVC riser 3 ft screen 6 in. tip
No sampling, direct push.	0-44.5	---	---		

Logged by: L. Cumming

Completion Date: 7/12/99

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-14S**

Date 7/13/99

Location LC34

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 21 to 24 ft

Total Depth 24.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

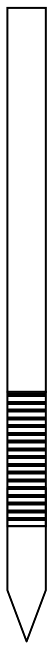
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller R. Aguilar

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
No sampling, direct push.	0-24.5	---	---		PVC riser 3 ft screen 6 in. tip

Logged by: L. Cumming

Completion Date: 7/13/99

Construction Notes:

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LC34 IDC Coring Logsheet

Boring ID **PA-14I**

Date 7/13/99

Location LC34

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 25 to 28 ft

Total Depth 28.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

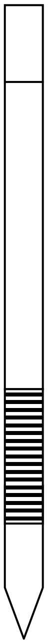
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount vault

Drilling Method CPT

Driller R. Aguilar

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
					PVC riser
No sampling, direct push.	0-28.5	---	---		
					3 ft screen
					6 in. tip

Logged by: L. Cumming

Completion Date: 7/13/99

Construction Notes:

Battelle

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LC34 IDC Coring Logsheet

Boring ID **PA-14D**

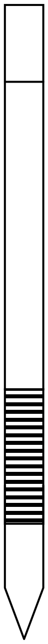
Date 7/13/99

Location LC34

Boring Diameter	2 1/2 in	Total Depth	44.5 ft
Casing Outer Diameter	2 1/2 in	Sand Pack	---
Casing Inner Diameter	2 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	bentonite
Screen Type	stainless steel, slotted	Grout Depth	from 0 to 2 ft
Screen Slot	0.010	Surface Completion	flush mount vault
Screen Length	3 ft	Drilling Method	CPT
Screen Depth	from 41 to 44 ft	Driller	R. Aguilar

Lithologic Description	**Depth**	**Sample**	**USCS**
No sampling, direct push.	0-44.5	---	---

Well



Other

PVC riser

3 ft screen

6 in. tip

Logged by: L. Cumming

Completion Date: 7/13/99

Construction Notes:

Battelle
. . . Putting Technology To Work

LC34 IDC Coring Logsheet

Boring ID **PA-15S**

Date 8/15/99

Location LC34

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/3 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 10 to 15 ft

Total Depth 15.5 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

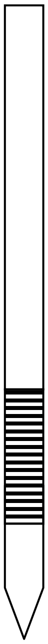
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount vault

Drilling Method Direct Push

Driller

Lithologic Description	Depth	Sample	USCS	Well	Other
No sampling, direct push.	0-15	---	---		3 ft screen 6 in. tip

Logged by:

Completion Date: 8/15/99

Construction Notes:

Battelle
. . . Putting Technology To Work

LC34 IDC Coring Logsheet

Boring ID **PA-16S**

Date 5/26/00

Location Steam Plot

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 21 to 24 ft

Total Depth 24.75 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

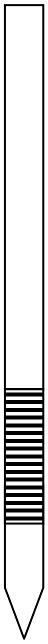
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount pad

Drilling Method CPT

Driller Gregg In-Situ

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Topsoil, loose sand	0-8	---	SP		
Direct push	8-24.75	---	---		
					3 ft screen
					8 in. tip

Logged by: J. Sminchak

Completion Date: 5/26/00

Construction Notes:

Battelle
. . . Putting Technology To Work

LC34 IDC Coring Logsheet

Boring ID **PA-16I**

Date 5/26/00

Location Steam Plot

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 25 to 28 ft

Total Depth 28.75 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

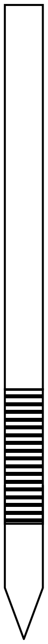
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount pad

Drilling Method CPT

Driller Gregg In-Situ

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Topsoil, loose sand	0-5	---	SP		
Direct push	5-28.75	---	---		
					3 ft screen
					8 in. tip

Logged by: J. Sminchak

Completion Date: 6/2/00

Construction Notes:

LC34 IDC Coring Logsheet

Boring ID **PA-16D**

Date 5/26/00

Location Steam Plot

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 41.25 to 44.25 ft

Total Depth 45 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

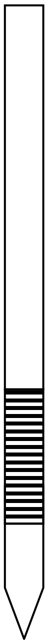
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount pad

Drilling Method CPT

Driller Gregg In-Situ

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Topsoil, loose sand	0-5	---	SP		
Direct push	5-45	---	---		
					3 ft screen
					8 in. tip

Logged by: J. Sminchak

Completion Date: 6/2/00

Construction Notes:

Battelle

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LC34 IDC Coring Logsheet

Date 5/26/00

Boring ID **PA-17S**

Location Steam Plot

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 18 to 21 ft

Total Depth 21 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

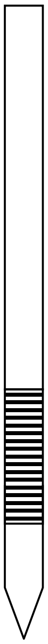
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount pad

Drilling Method CPT

Driller Gregg In-Situ

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Topsoil, loose sand	0-5	---	SP		
Direct push	5-21	---	---		
					3 ft screen
					8 in. tip

Logged by: J. Sminchak

Completion Date: 5/26/00 (8/31/01)

Construction Notes: well casing broken during installation, well not operational, replaced by PSI 8/31/00

. . . Putting Technology To Work

LC34 IDC Coring Logsheet

Boring ID **PA-17I**

Date 6/2/00

Location Steam Plot

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 25 to 28 ft

Total Depth 28.75 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

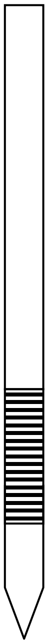
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount pad

Drilling Method CPT

Driller Gregg In-Situ

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Topsoil, loose sand	0-5	---	SP		3 ft screen 8 in. tip
Direct push	5-28.75	---	---		

Logged by: J. Sminchak

Completion Date: 6/2/00

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-17D**

Date 6/2/00

Location Steam Plot

Boring Diameter 2 1/2 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 41.25 to 44.25 ft

Total Depth 45 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

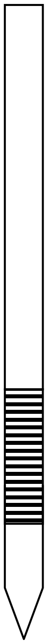
Grout Material bentonite

Grout Depth from 0 to 2 ft

Surface Completion flush mount pad

Drilling Method CPT

Driller Gregg In-Situ

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Topsoil, loose sand	0-5	---	SP		
Direct push	5-45	---	---		
					3 ft screen
					8 in. tip

Logged by: J. Sminchak

Completion Date: 6/3/00

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-18S**

Date 12/11/00

Location ESB

Boring Diameter 4 in

Casing Outer Diameter 2 1/4 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 21 to 24 ft

Total Depth 24 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

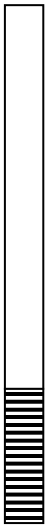
Grout Material cement

Grout Depth from 0 to 2 ft

Surface Completion flush

Drilling Method Vibra-Core

Driller Precision

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post-hole, loose tan sand	0-6	---	SP		3 ft screen
Direct push	6-24	---	---		
(pvc riser)					

Logged by: J. Sminchak

Completion Date: 12/11/00

Construction Notes:

Battelle

. . . Putting Technology To Work

LC34 IDC Coring Logsheet

Boring ID **PA-18I**

Date 12/12/00

Location ESB

Boring Diameter 4 in

Casing Outer Diameter 2 1/4 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 25 to 28 ft

Total Depth 28 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

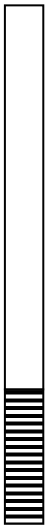
Grout Material cement

Grout Depth from 0 to 2 ft

Surface Completion flush mount

Drilling Method Vibra-Core

Driller Precision

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post-hole, loose tan sand	0-6	---	SP		PVC Riser
Direct push	6-28	---	---		
					3 ft screen

Logged by: J. Sminchak

Completion Date: 12/12/00

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-18D**

Date 12/12/00

Location ESB

Boring Diameter 4 in

Casing Outer Diameter 2 1/4 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 41 to 44 ft

Total Depth 44 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

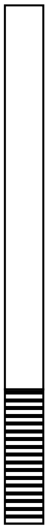
Grout Material cement

Grout Depth from 0 to 2 ft

Surface Completion flush mount

Drilling Method Vibra-Core

Driller Precision

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
Post-hole, loose tan sand	0-6	---	SP		PVC Riser
Direct push	6-44	---	---		
					3 ft screen

Logged by: J. Sminchak

Completion Date: 12/12/00

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID **PA-19S**

Date 2/28/01

Location LC34

Boring Diameter 4 in

Casing Outer Diameter 2 1/2 in

Casing Inner Diameter 2 in

Casing Material stainless steel

Screen Type stainless steel, slotted

Screen Slot 0.010

Screen Length 3 ft

Screen Depth from 20 to 23 ft

Total Depth 23 ft

Sand Pack ---

Sand Pack Depth from --- to --- ft

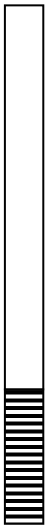
Grout Material cement

Grout Depth from 0 to 5 ft

Surface Completion flush vault

Drilling Method Direct Push

Driller Precision

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
loose tan sand	0-6	---	SP		
Direct push	6-23	---	---		
					3 ft screen

Logged by: J. Sminchak

Completion Date: 2/28/01

Construction Notes:

Battelle
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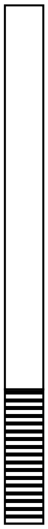
LC34 IDC Coring Logsheet

Boring ID **PA-19I**

Date 2/28/01

Location LC34

Boring Diameter	4 in	Total Depth	28 ft
Casing Outer Diameter	2 1/2 in	Sand Pack	---
Casing Inner Diameter	2 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	cement
Screen Type	stainless steel, slotted	Grout Depth	from 0 to 5 ft
Screen Slot	0.010	Surface Completion	flush vault
Screen Length	3 ft	Drilling Method	Direct Push
Screen Depth	from 25 to 28 ft	Driller	Precision

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
loose tan sand	0-6	---	SP		
Direct push	6-28	---	---		
					3 ft screen

Logged by: J. Sminchak

Completion Date: 2/28/01

Construction Notes:

Battelle
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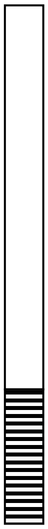
LC34 IDC Coring Logsheet

Boring ID **PA-19D**

Date 2/28/01

Location LC34

Boring Diameter	4 in	Total Depth	45 ft
Casing Outer Diameter	2 1/2 in	Sand Pack	---
Casing Inner Diameter	2 in	Sand Pack Depth	from --- to --- ft
Casing Material	stainless steel	Grout Material	cement
Screen Type	stainless steel, slotted	Grout Depth	from 0 to 45 ft
Screen Slot	0.010	Surface Completion	flush vault
Screen Length	3 ft	Drilling Method	Direct Push
Screen Depth	from 42 to 45 ft	Driller	Precision

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
loose tan sand	0-6	---	SP		
Direct push	6-45	---	---		
					3 ft screen

Logged by: J. Sminchak

Completion Date: 2/28/01

Construction Notes:

Battelle
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LC34 IDC Coring Logsheet

Boring ID PA-20

Date 4/9/01

Location Roadway

Boring Diameter	10 & 5 7/8 in	Total Depth	61 ft
Casing Outer Diameter	6 & 2 in	Sand Pack	20/30
Casing Inner Diameter	in	Sand Pack Depth	from 53 to 61 ft
Casing Material	304 SCH 10 Stainless	Grout Material	type G & silica flour
Screen Type	wirewound 304 Sch 10	Grout Depth	from GS to 51 ft
Screen Slot	0.10	Surface Completion	flush mount vault
Screen Length	5 ft	Drilling Method	mud rotary
Screen Depth	from 55 to 60 ft	Driller	R. Hutchinson

Lithologic Description	Depth	Sample	USCS	Well	Other
sand, med gray, silty, rec 1.1 ft, PID 0.0, 12/14/12/13	41-43	SB50-43	SP		Flush Mount
silt, clayey, med gray, rec 1.0 ft, PID 0.0, 3/2/2/3	43-45	SB50-45	ML		
clay, med plasticity, med. gray, rec. 6”, PID 0.0, 3/3	45-46	SB50-46	CL		46’
clay, plastic, med. gray, wet, rec. 1’, PID 15, 8/9/5/5	47.5-48	SB50-48	CH		
sand,some silt and clay, fine grained, rec. 1.5’, PID 2.0, 10/12/11/12	48.5-48.9		SM		
sand, med grained with some shells, PID 0.0	48.9-50	SB50-50	SP		
sand, fine-med grained with shell frags, rec 2.0, PID 0.0, 10/13/13/15	50-50.5		SW		
clay, soft, wet, plastic, med. gray , PID 0.0	50.5-51	SB50-52	CH		51’ bent. seal (2’)
sand, fine-med grained, shelly zones, med. gray, PID 0.0	51-52	SB50-52B	SP		
sand, w coarse shell fragments, PID 0.0, rec 1.7 or 2.0	52-52.3		Sp		53 sand pack (20/30)
abrupt contact w med grained sand, no shells, silty	52.3-53 53-54	SB50-54	SM SM		

Logged by: C.J. Perry

Completion Date: 4/5/01

Construction Notes: 6-in surface casing set to 46’, 2-in casing screen set at 60’

LC34 IDC Coring Logsheet

Date 4/9/01

Boring ID PA-20

Location Roadway

Lithologic Description	Depth	Sample	USCS	Well	Other
sand, shelly cs fragments, med gray, rec 1.4 or 2.0, PID 0.0, 6/7/7/4	54.6-55.2		SP		55 2-" SS Screen 61' TD
clay, shelly, some silt, soft, wet, med. gray	55.2-56	SB 50-56	CL		
sand, very shelly, med. gray, trace silt and clay, Rec 1.9 of 2.0, PID 0.0, 6/7/7/7	56-58	SB 56-58	SM/SC		
sand, shelly, no fines, med gray, rec. 2.0 of 2.0, PID 0.0, 13/13/15/17	58-60	SB 50-60	SP		
Total Depth (sampled): 60'					
Total Dept (drilled): 61'					
5' x 2" diameter well screen 55-60'					

LC34 IDC Coring Logsheet

Boring ID PA-21

Date 4/9/01

Location ISCO Plot

Battelle
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Boring Diameter	10 & 5 7/8 in	Total Depth	61 ft
Casing Outer Diameter	6 & 2 in	Sand Pack	20/30
Casing Inner Diameter	in	Sand Pack Depth	from 53 to 61 ft
Casing Material	304 SCH 10 Stainless	Grout Material	type G & silica flour
Screen Type	wirewound 304 Sch 10	Grout Depth	from GS to 51 ft
Screen Slot	0.10	Surface Completion	flush mount vault
Screen Length	5 ft	Drilling Method	mud rotary
Screen Depth	from 55 to 60 ft	Driller	R. Hutchinson

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
sand, brn-gray, some silt, med grnd, rec 1.15 of 2, PID 0.0, 11/13/15/20	40-42	SB51-41	SM		Flush Mount
sand, brn-gray, silty,fine grnd., rec 1.3 of 2', PID 2.0, 6/7/8/6	42-44	SB51 .44	SM		
sand, brn, med grnd, grading to silty clay/clay, rec. 2 of 2', PID 2000+, 8/7/4/3	44-44.5	SB51-44B	SM		
silty clay, med. brn gray, wet	44.5-44.75	SB51-45	ML		
clay, med gray, wet, soft	44.75-46	SB51-46	CH		46'
clay, med gray, wet, soft, rec. 1.1 of 2.0, PID 29, 6/7/9/5	47-47.5		CH		
sand, med grained, med gray, massive, shells, PID 2000+	47.5-48	SB-51-48.8	SP		
sand, clayey, mucky, w/ cs shell frags, rec. 2.0 of 2.0, PID 46, 7/8/8/12	48-48.2	SB51-48B	SC		
clay, soft, plastic, wet, med gray, PID 323	48.2-49		CH		
sand, fine-med grnd, massive, med. gray, PID 96	49-50		SP		
sand, med-cs grnd, some silt, rec 1.9 of 2.0, PID 2.0, 7/7/6/6	50-50.3	SB51-50	SM		

Logged by: C.J. Perry

Completion Date: 4/4/01

Construction Notes: 6-in surface casing set to 46', 2-in casing screen set at 60'

LC34 IDC Coring Logsheet

Boring ID PA-21

Battelle . . . Putting Technology To Work

Date 4/9/01

Location ISCO Plot

Lithologic Description	**Depth**	**Sample**	**USCS**	**Well**	**Other**
sand, silty and clayey, shell frags, med gray	50.3-50.6		SC		Type G Cement
sand, fine grnd, massive, med. gray, PID 2.0	50.6-52	SB 51-52	SP		51 Bentonite Seal
sand, silty and clayey, med. gray, shelly, Rec 2.0 of 2.0', PID 34, 7/8/9/10	52-52.8		SM		53
sand, med grnd, fining downward, some shells	52.8-54	SB 51-54	SP		55
sand, w silt and clay, shelly, med gray, rec 2.0 of 2.0', PID 8.0, 5/5/4/6	54-56	SB51-56	SM		2-in Screen 0.0010
sand, fn-med grnd, massive, med gray, rec 2.0 of 2.0, PID =0.0, 4/4/3/5	56-56.6		SP		
sand, w silt and clay, mucky, shelly	56.6-57.6		SM		
sand, fn grnd, tr. silt and clay	57.6-58	SB51-58	SM		
sand, med grnd, slightly silty, shells, rec 2.0 of 2.0', PID 0.0, 6/8/12/16	59-60		SP		60
clayey interval from 59.1-59.5, PID 0.0		SB51-60	SC		TD 61'
Total Dept (Sampled): 60'					
Total Depth (reamed): 61'					
5' x 2" diameter well screen 55-60'					

LC34 IDC Coring Logsheet

Boring ID PA-22
Date 4/9/01
Location Resistive Heating Plot

Boring Diameter 10 & 5 7/8 in
Casing Outer Diameter 6 & 2 in
Casing Inner Diameter ____ in
Casing Material 304 SCH 10 Stainless
Screen Type wirewound 304 Sch 10
Screen Slot 0.10
Screen Length 5 ft
Screen Depth from 55 to 60 ft

Total Depth 61 ft
Sand Pack 20/30
Sand Pack Depth from 53 to 61 ft
Grout Material type G & silica flour
Grout Depth from GS to 51 ft
Surface Completion flush mount vault
Drilling Method mud rotary
Driller R. Hutchinson

Lithologic Description	Depth	Sample	USCS	Well	Other
sand, med grnd, shell frags, gray, rec 1.3 of 2, PID 155, 8/10/13/16	40-42	SB52-42	SP		Flush Mount
sand, med-grnd, med. gray, rec 0.75 of 2', PID 44, 6/7/7/8	42-44	SB52 44	SP		
silt, massive, med gray, grading to clay, rec. 1.4 of 2', PID 102, 8/7/6/5	44.6-45.7	SB52-45	ML		
clay, plastic, med. gray, 3" thick, PID 234	45.7-46	SB52-45	CH		
clay, med gray, plastic, 3/3, PID 381	46-46.9	SB52-47	CH		46'
sand, fine-grnd, med gray, PID 725	46.9-47.2	SB52-47B	SP		
sand, fine grained, silty, shelly, med gray	47.2-.5		SM		
clay, stiff, wet, med gray	47.5-47.7	SB52-47.5	CL		
sand, med-grnd, massive, few shells, med gray	47.7-48	SB52-48	SP		
clay, stiff, mod. wet, shell frags, Rec. 2.0 of 2.0, 6/6/7/8	48-48.9	SB52-49/49B	CL		
sand, fn-med grnd, massive, few shells 1.9 of 2.0	48.9-50	SB52-50	SP		

Logged by: C.J. Perry
Completion Date: 4/5/01

Construction Notes: 6-in surface casing set to 46', 2-in casing screen set at 60'

LC34 IDC Coring Logsheet

Boring ID PA-22

Date 4/9/01

Location Resistive Heating Plot

Lithologic Description	Depth	Sample	USCS	Well	Other
sand, med. grnd, med. gray, some shells, Rec 0.75 of 2.0, PID 20, 7/8/8/9	50-50.75	SB52-51	SP		Type G Cement
sand, med grnd, very shelly, Rec 2.0 of 2.0, PID 20, 6/7/5/8	52-52.9		SP		51 Bentonite Seal
sand, fn-med grnd, silty	52.9-54		SP		53
sand, med grnd, very shelly, loose, wet, PID 80, 7/5/9/9	54-54.2	SB 52-54	SP		55
sand, med. grnd, v. shelly but sandier, PID 1530	54.2-56	SB52-56/56B	SP		2-in Screen 0.0010
sand, med grnd, w/ clay and silt, muckey, shells, 1.7 of 2.0, PID 1200+, 7/7/4/3	56.3-58	SB52-58	SM		
sand, cs grnd, trc silt, v. shelly, loose, rec 2.0 of 2.0, PID 50+, 11/12/14/17	558-58.5		SP		
sand, med grnd, mucky, wet	58.5-59		SP		
sand, med grnd, massive, decreasing shell fragments wit depth	59-60		SP		60
					TD 61’
Total Dept (Sampled): 60’					
Total Depth (reamed): 61’					
5’ x 2” diameter well screen 55-60’					

Appendix C. CVOC Measurements

C.1 TCE Results of Ground-Water Samples
C.2 Other CVOC Results of Ground-Water Samples
C.3 Resistive Heating Pre-Demonstration Soil Sample Results
C.4 Resistive Heating Post-Demonstration Soil Sample Results
Figure C-1. TCE Concentrations and Observed Soil Color Results at the Resistive Heating Plot

Table C-1. TCE Results of Groundwater Samples

	TCE (µg/L)								
	Pre-Demo	**Week 3-4**		**Week 5**		**Week 7-8**		**Jan 10-14, 2000**	
Well ID	**Results**	**Results**	**% Change in Conc.**	**Results**	**% Change in Conc.**	**Results**	**% Change in Conc.**	**Results**	**% Change in Conc.**
Resistive Heating Plot Wells									
PA-13S	1,030,000	1,220,000	18%	476,000	-54%	NA	NA	NA	NA
PA-13S-DUP	1,100,000	1,240,000	13%	NA	NA	NA	NA	NA	NA
PA-13I	1,070,000	1,250,000	17%	268,000	-75%	NA	NA	NA	NA
PA-13D	892,000	1,160,000	30%	380,000	-57%	NA	NA	NA	NA
PA-13D-DUP	730,000	NA	NA	NA	NA	NA	NA	NA	NA
PA-14S	935,000	106,000	-89%	556	>-99%	NA	NA	NA	NA
PA-14I	960,000	75,500	-92%	NA	NA	NA	NA	NA	NA
PA-14D	868,000	482,000	-44%	NA	NA	NA	NA	NA	NA
Resistive Heating Perimeter Wells									
PA-2S	22,900	1,110	-95%	82.6	>-99%	NA	NA	17,400	-24%
PA-2I	1,140,000	720,000	-37%	425,000	-63%	NA	NA	1,100,000	-4%
PA-2I-DUP	NA	NA	NA	475,000	-58%	NA	NA	NA	NA
PA-2D	1,150,000	1,080,000	-6%	1,120,000	-3%	NA	NA	1,250,000	9%
PA-7S	118,000	92,000	-22%	55,000	-53%	NA	NA	39,600	-66%
PA-7I	365,000	486,000	33%	438,000	20%	NA	NA	112,000	-69%
PA-7D	309	19,000	6,049%	23,100	7,376%	NA	NA	160,000	51,680%
PA-10S	162,000	299,000	85%	182,000	12%	NA	NA	182,000	12%
PA-10I	1,100,000	860,000	-22%	458,000	-58%	NA	NA	280,000	-75%
PA-10I-DUP	NA	NA	NA	451,000	-59%	NA	NA	NA	NA
PA-10D	1,120,000	180,000	-84%	825,000	-26%	NA	NA	1,060,000	-5%
PA-10D-DUP	NA	NA	NA	NA	NA	NA	NA	1,120,000	0%
IW-17S	397	468,000	117,784%	494,000	124,333%	NA	NA	77,500	19,421%
IW-17I	15,000	17,400	16%	31,000	107%	NA	NA	152,000	913%
IW-17D	154,000	7,410	-95%	1,180	-99%	NA	NA	630J	>-99%
PA-15	NA	NA	NA	NA	NA	NA	NA	180,000	NA
Distant Wells									
PA-1S	984	2,550	159%	9,690	885%	19,400	1,872%	16,200	1,546%
PA-1I	2,920	4,420	51%	2,310	-21%	288	-90%	140J	-95%
PA-1I-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-1D	172	845	391%	24.1	-86%	24.6	-86%	2.58	>-99%
PA-8S	5,730	15,300	167%	25,800	350%	115,000	1,907%	**79,300**	1,284%
PA-8S-DUP	NA	NA	NA	NA	NA	113,000	1,872%	84,400	1,373%
PA-8I	988,000	1,040,000	5%	1,390,000	41%	1,000,000	1%	805,000	-19%
PA-8D	478,000	625,000	31%	635,000	33%	900,000	88%	960,000	101%
PA-8D-DUP	NA	555,000	16%	NA	NA	NA	NA	NA	NA
PA-11S	865,000	800,000	-8%	790,000	-9%	810,000	-6%	1,090,000	26%
PA-11I	1,060,000	1,280,000	21%	1,200,000	13%	1,190,000	12%	1,200,000	13%
PA-11D	1,010,000	1,240,000	23%	1,030,000	2%	1,250,000	24%	1,180,000	17%

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

Well ID	TCE (µg/L) Apr 10-14, 2000		ISCO Post-Demo		Resistive Heating Post-Demo		June 12, 2001	
	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.	Results	% Change in Conc.
Resistive Heating Plot Wells								
PA-13S	180,000 *	-83%	NA	NA	820,000 D	-20%	758,000	-20%
PA-13S-DUP	170,000 *	-85%	NA	NA	NA	NA	NA	NA
PA-13I	1,300,000 D*	21%	NA	NA	NA	NA	60,200	-94%
PA-13D	3,300 *	>-99%	NA	NA	920,000	3%	794,000	-11%
PA-13D-DUP	NA	NA	NA	NA	910,000	25%	647,000	-11%
PA-14S	9,400 *	>-99%	NA	NA	710,000	-24%	601,000	-36%
PA-14I	46,000 *	-95%	NA	NA	NA	NA	174,000	-82%
PA-14D	68,000 *	-92%	NA	NA	4,200	>-99%	2,730	>-99%
Resistive Heating Perimeter Wells								
PA-2S	6,400	-72%	19,000	-17%	330 J	-99%	NA	NA
PA-2I	1,800,000D	58%	980,000	-14%	970,000	-15%	NA	NA
PA-2I-DUP	1,400,000D	23%	NA	NA	NA	NA	NA	NA
PA-2D	1,300,000D	13%	990,000D	-14%	1,300,000	13%	NA	NA
PA-7S	64,000	-46%	NA	NA	150,000	27%	NA	NA
PA-7I	36,000	-90%	NA	NA	62,000	-83%	NA	NA
PA-7D	33,000	10,580%	NA	NA	<2,500	NA	NA	NA
PA-10S	760,000D	369%	NA	NA	24,000	-85%	NA	NA
PA-10I	740,000D	-33%	NA	NA	750,000	-32%	NA	NA
PA-10I-DUP	NA	NA	NA	NA	870,000	-21%	NA	NA
PA-10D	1,000,000D	-11%	NA	NA	1,100,000	-2%	NA	NA
PA-10D-DUP	NA	NA	NA	NA	NA	NA	NA	NA
IW-17S	Dry	NA	NA	NA	NA	NA	NA	NA
IW-17I	680,000	4,433%	NA	NA	190,000	1,167%	NA	NA
IW-17D	1,600J	>-99%	NA	NA	1,500	-99%	NA	NA
PA-15	270,000D	NA	NA	NA	30,000	NA	NA	NA
Distant Wells								
PA-1S	3,700	276%	4,500	357%	8,000	713%	NA	NA
PA-1I	510J	-83%	<2000	>-99%	<250	-96%	NA	NA
PA-1I-DUP	NA	NA	<2000	>-99%	NA	NA	NA	NA
PA-1D	0.67J	>-99%	2.80	>-99%	<4	-98%	NA	NA
PA-8S	740,000	12,814%	630,000	10,895%	7,600	33%	NA	NA
PA-8S-DUP	NA	NA	NA	NA	NA	NA	NA	NA
PA-8I	190,000	-81%	330,000	-67%	870,000	-12%	NA	NA
PA-8D	1,300,000D	172%	1,800,000D	277%	1,100,000	130%	NA	NA
PA-8D-DUP	NA	NA	NA	NA	NA	NA	NA	NA
PA-11S	970,000	12%	**<5**	>-99%	390,000	-55%	NA	NA
PA-11I	1,200,000D	13%	1,200,000D	13%	790,000	-25%	NA	NA
PA-11D	1,300,000D	29%	1,400,000D	39%	1,300,000	29%	NA	NA

Notes:

Pre-Demo: Sep 3 to 10, 1999.
Week 3-4: Sep 24 to 20, 1999.
Week 5: Oct 6 to 8, 1999.
Week 7-8: Oct 19 to 28, 1999.
ISCO Post-Demo: May 8 to 14, 2000.
Resistive Heating Post-Demo: Nov 27 to Dec 2, 2000.
All units are in µg/L.
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.
*: 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

	cis -1,2-DCE (µg/L)									*trans* -1,2-DCE (µg/L)								
Well ID	**Pre-Demo**	**Week 3-4**	**Week 5**	**Week 7-8**	**Jan 2000**	**Apr 2000**	**ISCO Post-Demo**	**Res Heating Post-Demo**	**June 2001**	**Pre-Demo**	**Week 3-4**	**Week 5**	**Week 7-8**	**Jan 2000**	**Apr 2000**	**ISCO Post-Demo**	**Res Heating Post-Demo**	**June 2001**
Resistive Heating Plot Wells																		
PA-13S	4,400	17,400	350,000	NA	NA	8,900	NA	21,000 J	14,000	<5,000	<10,000	3,000J	NA	NA	<5,000	NA	<25,000	<100
PA-13S-DUP	4,900	16,000	NA	NA	NA	8,200	NA	NA	NA	<5,000	<10,000	NA	NA	NA	<5,000	NA	NA	NA
PA-13I	4,900	<10,000	3,900J	NA	NA	17,000J	NA	NA	9,370	<5,000	<10,000	<5,000	NA	NA	6,200J	NA	NA	16
PA-13D	2,200	5,900J	3,000J	NA	NA	230	NA	18,000 J	52,000	<5,000	<10,000	<5,000	NA	NA	26J	NA	<25,000	<1,000
PA-13D-DUP	<62,000	NA	NA	NA	NA	NA	NA	18,000 J	NA	<42,000	NA	NA	NA	NA	NA	NA	<33,000	NA
PA-14S	5,880	2,090	19J	NA	NA	140J	NA	95,000	73,800	<5,000	<200	<20	NA	NA	<560	NA	<20,000	<1,000
PA-14I	26,000	349	NA	NA	NA	1,700J	NA	NA	80,000	<5,000	<200	NA	NA	NA	<5,000	NA	NA	1,150
PA-14I-DUP	25,500	NA	NA	NA	NA	NA	NA	NA	NA	<5,000	NA	NA	NA	NA	NA	NA	NA	NA
PA-14D	21,900	11,600	NA	NA	NA	1,300J	NA	1,100	2,660	<5,000	<10,000	NA	NA	NA	<4,200	NA	<200	33
PA-14D-DUP	23,200	NA	NA	NA	NA	NA	NA	NA	NA	<5,000	NA	NA	NA	NA	NA	NA	NA	NA
Resistive Heating Perimeter Wells																		
PA-2S	3,020	3,520	2,170	NA	32,800	28,000	19,000	6,000	NA	<500	<20	<20	NA	<1,000	<2,500	<620	<500	NA
PA-2I	5,480	33,600	2,900J	NA	<10,000	7,200J	20,000J	11,000 J	NA	<5,000	<10,000	<5,000	NA	<10,000	<25,000	<25,000	<25,000	NA
PA-2I-DUP	NA	NA	3,600J	NA	NA	12,000J	NA	NA	NA	NA	NA	<5,000	NA	NA	<25,000	NA	NA	NA
PA-2D	2,700	7,400J	3,600J	NA	8,500J	<25,000	<25,000	<33,000	NA	<5,000	<10,000	<5,000	NA	<10,000	<25,000	<25,000	<33,000	NA
PA-7S	22,100	19,200	7,430	NA	8,900	100,000	NA	130,000	NA	<5,000	<10,000	<5,000	NA	<400	<3,300	NA	<12,000	NA
PA-7I	160,000	109,000	73,200	NA	21,400	21,000	NA	170,000	NA	<5,000	<10,000	<5,000	NA	<1,000	290J	NA	<17,000	NA
PA-7D	21	38,000	41,800	NA	54,500	96,000	NA	30,000	NA	2.78	633	<10,000	NA	<10,000	<5,000	NA	<2,500	NA
PA-10S	8,880	5,300J	1,900J	NA	81,000	42,000	NA	19,000	NA	<5,000	<10,000	<2,000	NA	<10,000	<20,000	NA	<1,900	NA
PA-10I	4,700J	6,900J	4,900J	NA	<10,000	50,000	NA	12,000 J	NA	<5,000	<10,000	<10,000	NA	<10,000	<20,000	NA	<42,000	NA
PA-10I-DUP	NA	NA	<10,000	NA	NA	NA	NA	15,000 J	NA	NA	NA	<10,000	NA	NA	NA	NA	<42,000	NA
PA-10D	2,400J	<10,000	<10,000	NA	9,800J	14,000J	NA	23,000 J	NA	<5,000	<10,000	<10,000	NA	<10,000	<25,000	NA	<42,000	NA
PA-10D-DUP	NA	NA	NA	NA	12,300	NA	NA	NA	NA	NA	NA	NA	NA	<10,000	NA	NA	NA	NA
IW-17S	593	15,700	4,640	NA	4,180	Dry	NA	Dry	NA	<20	225	140J	NA	<1,000	Dry	NA	Dry	NA
IW-17I	123,000	7,150	7,950	NA	14,600	50,000	NA	30,000	NA	<5,000	<1,000	<5,000	NA	<1,000	<20,000	NA	<8,300	NA
IW-17D	39,200	18,100	18,600	NA	70,000	65,000	NA	16,000 D	NA	<5,000	150J	251	NA	2,060	1,800J	NA	390	NA
PA-15	NA	NA	NA	NA	39,300	39,000	NA	170,000	NA	NA	NA	NA	NA	<10,000	<5,600	NA	<17,000	NA
Distant Wells																		
PA-1S	1,190	945	5,030	12,800	20,000	29,000	27,000	22,000	NA	38.4	50J	220	484	714	1,400J	1,100J	570 J	NA
PA-1I	32,800	22,100	10,800	8,400	43,900	53,000	48,000	2,400	NA	1,540	1,220	530J	431	1,670	1,500J	1,400J	300	NA
PA-1I-DUP	NA	NA	NA	NA	NA	NA	47,000	NA	NA	NA	NA	NA	NA	NA	NA	1,400J	NA	NA
PA-1D	299	1,100	689	589	1.4J	6.2J	2.9	<4	NA	22.9	64J	32.4	21.9	1.2J	0.46J	0.46J	2.8 J	NA
PA-8S	10,000	9,930	12,000	18,200	<2,000	23,000	32,000	36,000	NA	140J	220	220	352	<2,000	<20,000	<17,000	<2,900	NA
PA-8S-DUP	NA	NA	NA	18,000	<2,000	NA	NA	NA	NA	NA	NA	NA	368	<2,000	NA	NA	NA	NA
PA-8I	36,800	51,000	64,000	104,000	128,000	220,000	210,000	100,000	NA	<5,000	<10,000	<1,000	<10,000	<10,000	<17,000	<10,000	<33,000	NA
PA-8D	36,500	38,600	31,100	20,800	6,600J	11,000J	10,000J	19,000 J	NA	<5,000	<10,000	<2,000	<10,000	<10,000	<20,000	<25,000	<42,000	NA
PA-8D-DUP	NA	32,600	NA	NA	NA	NA	NA	NA	NA	NA	<10,000	NA	NA	NA	NA	NA	NA	NA
PA-11S	4,900J	8,000J	5,400J	5,600J	<10,000	<25,000	<5	8,500 J	NA	<5,000	<10,000	<10,000	<10,000	<10,000	<25,000	<5	<25,000	NA
PA-11I	4,900J	6,900J	5,200J	5,400J	<10,000	5,700J	<25,000	<42,000	NA	<5,000	<10,000	<10,000	<10,000	<10,000	<25,000	<25,000	<42,000	NA
PA-11D	6,180	<10,000	6,700J	<10,000	<10,000	<17,000	<25,000	<42,000	NA	<5,000	<10,000	<10,000	<10,000	<10,000	<17,000	<25,000	<42,000	NA

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	Res Heating Post-Demo	June 2001
Resistive Heating Plot Wells									
PA-13S	<5,000	<10,000	<5,000	NA	NA	<10,000	NA	<50,000	700
PA-13S-DUP	<5,000	<10,000	NA	NA	NA	<10,000	NA	NA	NA
PA-13I	<5,000	<10,000	<5,000	NA	NA	<50,000	NA	NA	<100
PA-13D	<5,000	<10,000	<5,000	NA	NA	21J	NA	<50,000	<1,000
PA-13D	<83,000	NA	NA	NA	NA	NA	NA	<67,000	NA
PA-14S	<5,000	170J	NA	NA	NA	<1,100	NA	10,000 J	6,280
PA-14I	<5,000	100J	NA	NA	NA	<10,000	NA	NA	1,710
PA-14I-DUP	<5,000	NA	NA	NA	NA	NA	NA	NA	NA
PA-14D	<5,000	<10,000	NA	NA	NA	<8,300	NA	32 J	48.7
PA-14D-DUP	<5,000	NA	NA	NA	NA	NA	NA	NA	NA
Resistive Heating Perimeter Wells									
PA-2S	<500	<20	<20	NA	<1,000	2,800J	4,100	650 J	NA
PA-2I	<5,000	<10,000	<5,000	NA	<10,000	<50,000	<50,000	<50,000	NA
PA-2I-DUP	NA	NA	<5,000	NA	NA	<50,000	NA	NA	NA
PA-2D	<5,000	<10,000	<5,000	NA	<10,000	<50,000	<50,000	<67,000	NA
PA-7S	<5,000	<10,000	<5,000	NA	<400	1,200J	NA	13,000 J	NA
PA-7I	<5,000	<10,000	<5,000	NA	<1,000	<3,300	NA	12,000 J	NA
PA-7D	3.3	764	<10,000	NA	<10,000	6,400J	NA	15,000	NA
PA-10S	<5,000	<10,000	<2,000	NA	<10,000	2,500J	NA	4,300	NA
PA-10I	<5,000	<10,000	<10,000	NA	<10,000	<40,000	NA	<83,000	NA
PA-10I-DUP	NA	NA	<10,000	NA	NA	NA	NA	<83,000	NA
PA-10D	<5,000	<10,000	<10,000	NA	<10,000	<50,000	NA	<83,000	NA
PA-10D-DUP	NA	NA	NA	NA	<10,000	NA	NA	NA	NA
IW-17S	<20	292	<200	NA	<1,000	Dry	NA	Dry	NA
IW-17I	<5,000	<1,000	<5,000	NA	<1,000	<40,000	NA	<17,000	NA
IW-17D	<5,000	428	<200	NA	<1,000	3,800J	NA	330	NA
PA-15	NA	NA	NA	NA	<10,000	590J	NA	2,800 J	NA
Distant Wells									
PA-1S	<20	<100	30.3	152	<200	2,400J	2,300J	560 J	NA
PA-1I	1,910	1,700	1,260	1,250	6,260	7,200	6,500	5,100	NA
PA-1I-DUP	NA	NA	NA	NA	NA	NA	6,300	NA	NA
PA-1D	171	338	332	195	12.1	5.1	4.5	76	NA
PA-8S	<200	<200	<20	<200	<2,000	<40,000	<33,000	670 J	NA
PA-8S-DUP	NA	NA	NA	<200	<2,000	NA	NA	NA	NA
PA-8I	<5,000	<10,000	<1,000	<10,000	<10,000	<33,000	<20,000	<67,000	NA
PA-8D	<5,000	<10,000	<2,000	<10,000	<10,000	<40,000	<50,000	<83,000	NA
PA-8D-DUP	NA	<10,000	NA	NA	NA	NA	NA	NA	NA
PA-11S	<5,000	<10,000	<10,000	<10,000	<10,000	<50,000	<10	<50,000	NA
PA-11I	<5,000	<10,000	<10,000	<10,000	<10,000	<50,000	<50,000	<83,000	NA
PA-11D	<5,000	<10,000	<10,000	<10,000	<10,000	<33,000	<50,000	<83,000	NA

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

Notes:
Pre-Demo: Sep 3 to 10, 1999.
Week 3-4: Sep 24 to 20, 1999.
Week 5: Oct 6 to 8, 1999.
Week 7-8: Oct 19 to 28, 1999.
ISCO Post-Demo: May 8 to 14, 2000.
Res Heating Post-Demo: Nov 27 to Dec 2, 2000.
June 2001: June 12, 2001
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.
🟧 Orange 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.

Table C-3. Resistive Heating Predemonstration Soil Sample Results (mg/Kg)

		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	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-1-593	SB-1-2	0	2	213	182	163	6,400	7.8	<410	ND	<410	ND		ND
SB-1-594	SB-1-4	2	4	214	192	180	4,700	5.3	<380	ND	<380	ND		ND
SB-1-595	SB-1-6	4	6	213	244	225	270	0.3	<270	ND	<270	ND		ND
SB-1-596	SB-1-8	6	8	214	192	169	2,200	2.8	<400	ND	<400	ND		ND
SB-1-597	SB-1-10	8	10	193	152	123	7,400	10.5	<500	ND	<500	ND		ND
SB-1-598	SB-1-12	10	12	214	189	151	6,000	8.8	<450	ND	<450	ND		ND
SB-1-599	SB-1-14	12	14	192	215	169	7,900	12.5	<320	ND	<320	ND		ND
SB-1-600	SB-1-18	16	18	193	266	212	2,500	4.0	<310	ND	<310	ND		ND
SB-1-601	SB-1-20	18	20	193	209	157	72,000	121.7	<3,300	ND	<3,300	ND		ND
SB-1-602	SB-1-22	20	22	213	229	174	190,000	314.6	<11,000	ND	<11,000	ND		ND
SB-1-603	SB-1-24	22	24	192	254	201	1,200,000	1,935.0	<79,000	ND	<79,000	ND		ND
SB-1-604	SB-1-26	24	26	214	254	187	460,000	820.4	<17,000	ND	<17,000	ND		ND
SB-1-605	SB-1-28	26	28	193	239	164	260,000	526.1	<12,000	ND	<12,000	ND		ND
SB-1-606	SB-1-30	28	30	213	162	111	520,000	940.6	<20,000	ND	<20,000	ND		ND
SB-1-607	SB-1-32	30	32	192	160	121	12,000,000	19,090.9	<1,000,000	ND	<1,000,000	ND		ND
SB-1-608	SB-1-32B	30	32	192	198	158	11,000,000	16,656.6	<630,000	ND	<630,000	ND		ND
SB-1-609	SB-1-34	32	34	213	233	177	210,000	349.1	<8,200	ND	<8,200	ND		ND
SB-1-610	SB-1-36	34	36	214	334	235	300,000	623.6	<18,000	ND	<18,000	ND		ND
SB-1-611	SB-1-38	36	38	193	220	155	540,000	1,024.6	<24,000	ND	<24,000	ND		ND
SB-1-612	SB-1-40	38	40	213	229	160	3,100,000	5,874.2	<180,000	ND	<180,000	ND		ND
SB-1-613	SB-1-42	40	42	214	216	162	3,400,000	5,677.3	<140,000	ND	<140,000	ND		ND
SB-1-614	SB-1-44	42	44	214	241	183	220,000	368.3	<11,000	ND	<11,000	ND		ND
SB-1-615	SB-1-46	44	46	193	232	168	18,000,000	33,099.9	<1,700,000	ND	<1,700,000	ND		ND
SB-1-616	SB-1-48	46	48	214	203	140	20,000,000	37,537.4	<800,000	ND	<800,000	ND		ND
SB-1-617	SB-1-BLANK	MeOH Blank Sample		154	0	0	<250	ND	<250	ND	<250	ND		ND
SB-2-510	SB-2-6	4	6	192	141	134	1,600	1.7	660	0.7	<450	ND		ND
SB-2-511	SB-2-8	6	8	189	221	199	580	0.7	310	0.4	<280	ND		ND
SB-2-512	SB-2-10	8	10	212	203	168	300 J	0.4	300 J	0.4	<400	ND		ND
SB-2-513	SB-2-12	10	12	192	216	183	510	0.7	<300	ND	<300	ND		ND
SB-2-514	SB-2-14	12	14	187	335	279	<300	ND	<300	ND	<300	ND		ND
SB-2-515	SB-2-16	14	16	192	191	157	770	1.1	290 J	0.4	<390	ND		ND
SB-2-516	SB-2-18	16	18	189	214	269	1,300	0.7	380	0.2	<310	ND		ND
SB-2-517	SB-2-20	18	20	188	195	150	1,200	1.9	260 J	0.4	<330	ND		ND
SB-2-518	SB-2-20B	18	20	213	238	188	1,600	2.5	250 J	0.4	<320	ND		ND
SB-2-519	SB-2-22	20	22	192	281	226	1,000	1.6	560	0.9	<310	ND		ND
SB-2-520	SB-2-24	22	24	189	295	229	29,000	50.4	<1,600	ND	<1,600	ND		ND
SB-2-521	SB-2-26	24	26	190	296	213	54,000	107.8	<3,500	ND	<3,500	ND		ND
SB-2-522	SB-2-28	26	28	192	277	207	160,000	292.2	<8,400	ND	<8,400	ND		ND
SB-2-523	SB-2-30	28	30	189	286	205	230,000	458.4	<12,000	ND	<12,000	ND		ND
SB-2-524	SB-2-32	30	32	191	332	254	160,000	294.5	<11,000	ND	<11,000	ND		ND
SB-2-525	SB-2-34	32	34	190	221	174	110,000	174.3	<4,500	ND	<4,500	ND		ND
SB-2-526	SB-2-36	34	36	189	277	223	110,000	175.7	<4,400	ND	<4,400	ND		ND
SB-2-527	SB-2-38	36	38	186	263	186	220,000	439.9	<8,800	ND	<8,800	ND		ND
SB-2-528	SB-2-40	38	40	191	176	116	280,000	558.3	<10,000	ND	<10,000	ND		ND
SB-2-529	SB-2-42	40	42	192	264	224	3,500	5.0	<290	ND	<290	ND		ND

Table C-3. Resistive Heating Predemonstration Soil Sample Results (mg/Kg) (Continued)

Analytical Sample ID	Sample ID	Sample Depth (ft) Top Depth	Bottom Depth	MeOH (g)	Wet Soil Weight (g)	Dry Soil Weight (g)	TCE Result in MeOH (µg/L)	TCE Result in Dry Soil (mg/kg)	*cis* -1,2-DCE Result in MeOH (µg/L)	*cis* -1,2-DCE Result in Dry Soil (mg/kg)	*trans* -1,2-DCE Result in MeOH (µg/L)	*trans* -1,2-DCE Result in Dry Soil (mg/kg)	Vinyl Chloride Result in MeOH (µg/L)	Vinyl Chloride Result in Dry Soil (mg/kg)
SB-2-530	SB-2-44	42	44	190	297	236	150,000	249.4	<4,500	ND	<4,500	ND		ND
SB-2-531	SB-2-46	44	46	190	312	240	140,000	251.0	<6,500	ND	<6,500	ND		ND
SB-2-532	SB-2-47	45.5	47	190	294	202	19,000,000	41,043.6	<730,000	ND	<730,000	ND		ND
SB-2-533	SB-2-47B	45.5	47	190	352	239	5,200,000	12,213.4	<250,000	ND	<250,000	ND		ND
SB-2-534	SB-2-BLANK	MeOH Blank Sample		190	0	0	<250	ND	<250	ND	<250	ND		ND
SB-3-487	SB-3-2	0	2	189	190	174	7,800	9.2	720	0.9	<310	ND		ND
SB-3-488	SB-3-4	2	4	186	193	175	720	0.9	270	0.3	<250	ND		ND
SB-3-489	SB-3-6	4	6	189	160	145	120 J	0.1	<370	ND	<370	ND		ND
SB-3-490	SB-3-8	6	8	190	133	115	200 J	0.3	<450	ND	<450	ND		ND
SB-3-491	SB-3-10	8	10	194	174	142	240 J	0.3	<350	ND	<350	ND		ND
SB-3-492	SB-3-12	10	12	192	224	176	210 J	0.3	<250	ND	<250	ND		ND
SB-3-493	SB-3-14	12	14	190	207	164	210 J	0.3	<250	ND	<250	ND		ND
SB-3-494	SB-3-16	14	16	188	238	197	410	0.6	180 J	0.3	<250	ND		ND
SB-3-495	SB-3-18	16	18	192	188	149	870	1.3	270 J	0.4	<320	ND		ND
SB-3-496	SB-3-20	18	20	188	186	150	670	1.0	160 J	0.2	<320	ND		ND
SB-3-497	SB-3-22	20	22	191	203	158	5,600	8.9	410	0.7	<250	ND		ND
SB-3-498	SB-3-26	24	26	190	243	178	100,000	183.2	9,200	16.9	<5,000	ND		ND
SB-3-499	SB-3-28	26	28	186	205	150	57,000	100.9	27,000	47.8	<3,100	ND		ND
SB-3-500	SB-3-28B	26	28	188	239	176	60,000	108.8	27,000	49.0	<3,100	ND		ND
SB-3-501	SB-3-30	28	30	188	243	189	21,000	34.8	27,000	44.7	<1,800	ND		ND
SB-3-502	SB-3-32	30	32	192	207	164	3,100	4.8	21,000	32.4	<1,000	ND		ND
SB-3-503	SB-3-34	32	34	191	209	166	11,000	17.0	22,000	33.9	<1,000	ND		ND
SB-3-504	SB-3-36	34	36	188	185	133	16,000 E	28.4	45,000 E	79.9	240 J	0.42 J		ND
SB-3-504	SB-3-36	34	36	188	185	133	20,000 D	35.5	51,000 D	90.6	<320	ND		ND
SB-3-505	SB-3-38	36	38	193	213	152	760 J	1.4	32,000	59.0	<1,000	ND		ND
SB-3-506	SB-3-42	40	42	190	186	147	18,000	27.5	22,000	33.6	<1,300	ND		ND
SB-3-507	SB-3-44	42	44	190	204	150	66,000	115.3	22,000	38.4	<2,500	ND		ND
SB-3-508	SB-3-46	44	46	191	228	181	130,000	204.1	6,200	9.7	<6,200	ND		ND
SB-3-508	SB-3-46	44	46	191	228	181	140,000	219.7	5,400	8.5	<5,000	ND		ND
SB-3-509	SB-3-BLANK	MeOH Blank Sample			0	0	<250	ND	<250	ND	<250	ND		ND
SB-4-124	SB-4-2	0	2	188	131	116	<450	ND	<450	ND	<450	ND		ND
SB-4-125	SB-4-4	2	4	193	126	115	4,000	4.6	960	1.1	<480	ND		ND
SB-4-126	SB-4-6	4	6	192	153	140	4,400	5.1	<400	ND	<400	ND		ND
SB-4-127	SB-4-8	6	8	189	110	95	39,000	48.7	<1,600	ND	<1,600	ND		ND
SB-4-128	SB-4-10	8	10	190	176	146	170 J	0.2	<340	ND	<340	ND		ND
SB-4-129	SB-4-12	10	12	192	135	108	3,200	4.6	140 J	0.2	<450	ND		ND
SB-4-130	SB-4-14	12	14	190	190	156	NA	NA	NA	NA	NA	NA		NA
SB-4-131	SB-4-16	14	16	190	114	NA	5,300 1	8.3	360 J,1	0.6	<530	ND		ND
SB-4-132	SB-4-18	16	18	192	133	109	4,700	6.5	1,100	1.5	<460	ND		ND
SB-4-133	SB-4-20	18	20	197	108	89	4,500	6.0	320 J	0.4	<580	ND		ND
SB-4-134	SB-4-22	20	22	195	203	166	30,000	43.6	<1,000	ND	<1,000	ND		ND
SB-4-135	SB-4-22B	20	22	187	145	119	39,000	54.1	<1,600	ND	<1,600	ND		ND
SB-4-136	SB-4-24	22	24	191	178	141	40,000	60.3	<1,700	ND	<1,700	ND		ND
SB-4-137	SB-4-26	24	26	191	165	131	6,100,000	9,050.9	<18,000	ND	<18,000	ND		ND

Table C-3. Resistive Heating Predemonstration Soil Sample Results (mg/Kg) (Continued)

		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**	**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-4-138	SB-4-28	26	28	194	169	124	110,000	184.7	<5,200	ND	<5,200	ND		ND
SB-4-139	SB-4-30	28	30	187	109	82	110,000	167.3	<3,900	ND	<3,900	ND		ND
SB-4-140	SB-4-32	30	32	189	283	217	7,200,000 E	12,668.9	<120,000	ND	<120,000	ND		ND
SB-4-140	SB-4-32	30	32	189	283	217	6,300,000 D	11,085.3	<120,000	ND	<120,000	ND		ND
SB-4-141	SB-4-34	32	34	195	151	120	77,000	112.3	<2,000	ND	<2,000	ND		ND
SB-4-142	SB-4-36	34	36	190	141	113	70,000	100.2	<2,100	ND	<2,100	ND		ND
SB-4-143	SB-4-38	36	38	190	168	118	160,000	287.7	<7,100	ND	<7,100	ND		ND
SB-4-144	SB-4-40	38	40	195	197	150	520,000	847.5	<16,000	ND	<16,000	ND		ND
SB-4-145	SB-4-42	40	42	193	238	179	92,000	159.7	<31,000	ND	<31,000	ND		ND
SB-4-146	SB-4-44	42	44	195	291	229	100,000	167.5	<4,200	ND	<4,200	ND		ND
SB-4-147	SB-4-46	44	46	188	210	159	18,000,000	30,222.8	<1,200,000	ND	<1,200,000	ND		ND
SB-4-148	SB-4-BLANK	MeOH Blank Sample			0	0	<250	ND	<250	ND	<250	ND		ND
SB-5-415	SB-5-2	0	2	196	113	101	<550	ND	<550	ND	<550	ND		ND
SB-5-416	SB-5-4	2	4	187	146	127	<400	ND	<400	ND	<400	ND		ND
SB-5-417	SB-5-6	4	6	190	222	195	<250	ND	<250	ND	<250	ND		ND
SB-5-418	SB-5-8	6	8	187	131	110	<450	ND	<450	ND	<450	ND		ND
SB-5-419	SB-5-10	8	10	187	170	138	<350	ND	<350	ND	<350	ND		ND
SB-5-420	SB-5-12	10	12	190	158	128	210 J	0.3	<380	ND	<380	ND		ND
SB-5-421	SB-5-14	12	14	193	175	145	<350	ND	<350	ND	<350	ND		ND
SB-5-422	SB-5-16	14	16	190	197	163	<250	ND	<250	ND	<250	ND		ND
SB-5-423	SB-5-18	16	18	194	135	108	<450	ND	<450	ND	<450	ND		ND
SB-5-424	SB-5-20	18	20	192	189	143	3,200 R	5.2	910	1.5	<320	ND		ND
SB-5-425	SB-5-20B	18	20	189	151	120	2,700 R	4.0	650	1.0	<400	ND		ND
SB-5-426	SB-5-22	20	22	189	178	144	19,000 R	27.7	360 J	0.5	<670	ND		ND
SB-5-427	SB-5-24	22	24	188	168	138	1,300,000	1,835.2	<44,000	ND	<44,000	ND		ND
SB-5-428	SB-5-26	24	26	192	227	170	150,000	259.8	<12,000	ND	<12,000	ND		ND
SB-5-429	SB-5-28	26	28	191	228	165	15,000,000 E	27,564.0	<120,000	ND	<120,000	ND		ND
SB-5-429	SB-5-28	26	28	191	228	165	3,200,000 D	5,880.3	<120,000	ND	<120,000	ND		ND
SB-5-430	SB-5-30	28	30	191	169	121	310,000	541.8	<12,000	ND	<12,000	ND		ND
SB-5-431	SB-5-32	30	32	193	246	186	520,000	901.5	<17,000	ND	<17,000	ND		ND
SB-5-432	SB-5-34	32	34	192	196	150	3,300,000	5,345.1	<100,000	ND	<100,000	ND		ND
SB-5-433	SB-5-36	34	36	189	173	134	15,000,000	23,361.8	<340,000	ND	<340,000	ND		ND
SB-5-433	SB-5-36	34	36	189	173	134	13,000,000	20,246.9	<340,000	ND	<340,000	ND		ND
SB-5-434	SB-5-38	36	38	193	189	127	4,100,000	8,061.7	<130,000	ND	<130,000	ND		ND
SB-5-435	SB-5-40	38	40	188	207	146	15,000,000	28,167.6	<360,000	ND	<360,000	ND		ND
SB-5-436	SB-5-42	40	42	192	209	145	3,400,000	6,534.3	<100,000	ND	<100,000	ND		ND
SB-5-437	SB-5-45	43	45	190	222	164	24,000,000 E	42,405.1	<250,000	ND	<250,000	ND		ND
SB-5-437	SB-5-45	43	45	190	222	164	21,000,000 D	37,104.5	<250,000	ND	<250,000	ND		ND
SB-5-438	SB-5-BLANK	MeOH Blank Sample			0	0	4,400 1	6.9	<250	ND	<250	ND		ND
SB-6-197	SB-6-2	0	2	189	136	128	<250	ND	<250	ND	<250	ND		ND
SB-6-198	SB-6-4	2	4	189	118	106	<250	ND	<250	ND	<250	ND		ND
SB-6-199	SB-6-6	4	6	190	115	102	<250	ND	<250	ND	<250	ND		ND
SB-6-200	SB-6-8	6	8	190	113	95	<250	ND	<250	ND	<250	ND		ND
SB-6-201	SB-6-10	8	10	189	132	107	<250	ND	<250	ND	<250	ND		ND

Table C-3. Resistive Heating Predemonstration Soil Sample Results (mg/Kg) (Continued)

		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	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-6-202	SB-6-12	10	12	189	196	161	<250	ND	<250	ND	<250	ND		ND
SB-6-203	SB-6-14	12	14	191	128	103	<250	ND	<250	ND	<250	ND		ND
SB-6-204	SB-6-16	14	16	192	151	127	<250	ND	<250	ND	<250	ND		ND
SB-6-205	SB-6-18	16	18	187	176	148	1,400	1.9	<250	ND	<250	ND		ND
SB-6-206	SB-6-20	18	20	191	155	120	<250	ND	<250	ND	<250	ND		ND
SB-6-207	SB-6-22	20	22	190	170	140	2,800	3.9	<250	ND	<250	ND		ND
SB-6-208	SB-6-24	22	24	188	228	230	19,000	18.6	<2,000	ND	<2,000	ND		ND
SB-6-209	SB-6-26	24	26	192	181	149	7,600	10.8	<620	ND	<620	ND		ND
SB-6-210	SB-6-28	26	28	189	218	163	40,000	69.1	<5,000	ND	<5,000	ND		ND
SB-6-211	SB-6-30	28	30	189	188	136	31,000	54.6	6,900	12.2	<2,500	ND		ND
SB-6-212	SB-6-32	30	32	189	150	115	11,000	17.0	9,500	14.7	<620	ND		ND
SB-6-213	SB-6-32B	30	32	188	163	124	11,000	17.5	8,700	13.8	<620	ND		ND
SB-6-214	SB-6-36	34	36	185	207	169	7,700	11.4	7,800	11.5	<620	ND		ND
SB-6-215	SB-6-38	36	38	189	228	164	11,000	20.5	17,000	31.6	<2,000	ND		ND
SB-6-216	SB-6-40	38	40	188	176	112	5,300	11.2	19,000	40.0	<2,000	ND		ND
SB-6-217	SB-6-42	40	42	191	215	161	11,000	18.8	21,000	36.0	<2,000	ND		ND
SB-6-218	SB-6-44	42	44	186	123	99	4,100	5.8	11,000	15.4	<620	ND		ND
SB-6-219	SB-6-46	44	46	188	135	105	210,000	313.1	<12,000	ND	<12,000	ND		ND
SB-6-220	SB-6-BLANK	MeOH Blank Sample			0	0	<250	ND	<250	ND	<250	ND		ND
SB-7-100	SB-7-2	0	2	192	149	132	500	0.6	<410	ND	<410	ND		ND
SB-7-101	SB-7-4	2	4	190	164	149	120 J	0.1	<370	ND	<370	ND		ND
SB-7-102	SB-7-6	4	6	189	162	134	<370	ND	<370	ND	<370	ND		ND
SB-7-103	SB-7-8	6	8	191	195	150.2	<250	ND	<250	ND	<250	ND		ND
SB-7-104	SB-7-10	8	10	189	146	117	690	1.0	<410	ND	<410	ND		ND
SB-7-105	SB-7-12	10	12	190	198	106.4	0	0.0	<250	ND	<250	ND		ND
SB-7-106	SB-7-14	12	14	189	135	106.2	<440	ND	<440	ND	<440	ND		ND
SB-7-107	SB-7-16	14	16	190	151	124	150 J	0.2	<400	ND	<400	ND		ND
SB-7-108	SB-7-18	16	18	190	116	95	0	0.0	<520	ND	<520	ND		ND
SB-7-109	SB-7-20	18	20	191	131	46.8	2,400	9.7	520	2.1	<460	ND		ND
SB-7-110	SB-7-22	20	22	188	152	120	21,000	31.1	560 J	0.8	<780	ND		ND
SB-7-111	SB-7-26	24	26	190	127	93.8	90,000	143.1	1,500 J	2.4	<2,400	ND		ND
SB-7-112	SB-7-28	26	28	192	159	96	150,000	330.0	2,000 J	4.4	<3,800	ND		ND
SB-7-113	SB-7-30	28	30	190	140	98	80,000	139.5	18,000	31.4	<2,100	ND		ND
SB-7-114	SB-7-32	30	32	190	134	97	76,000	125.4	5,400	8.9	<2,200	ND		ND
SB-7-115	SB-7-34	32	34	189	140	108.1	60,000	90.8	11,000	16.7	<2,100	ND		ND
SB-7-116	SB-7-36	34	36	189	148	111.6	88,000	139.2	10,000	15.8	<3,400	ND		ND
SB-7-117	SB-7-38	36	38	187	75	40.9	120,000	260.2	11,000	23.8	<5,300	ND		ND
SB-7-118	SB-7-40	38	40	183	68	50.9	48,000	70.1	2,200	3.2	<1,700	ND		ND
SB-7-119	SB-7-40B	38	40	189	325	251.8	63,000	112.8	2,800 J	5.0	<3,600	ND		ND
SB-7-120	SB-7-43	41	43	189	115	81.3	130,000	216.7	<5,200	ND	<5,200	ND		ND
SB-7-121	SB-7-45	43	45	189	187	138.7	5,200,000	8,802.5	<110,000	ND	<110,000	ND		ND
SB-7-122	SB-7-BLANK	MeOH Blank Sample			0	0	<250	ND	<250	ND	<250	ND		ND
SB-8-342	SB-8-2	0	2	193	84	78	290 J	0.3	<730	ND	<730	ND		ND
SB-8-343	SB-8-4	2	4	191	81	73	170 J	0.2	<740	ND	<740	ND		ND

Table C-3. Resistive Heating Predemonstration Soil Sample Results (mg/Kg) (Continued)

		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	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-8-344	SB-8-6	4	6	190	186	169	<320	ND	<320	ND	<320	ND		ND
SB-8-345	SB-8-8	6	8	196	128	104	830 R	1.1	<480	ND	<480	ND		ND
SB-8-346	SB-8-10	8	10	191	139	106	330 J	0.5	<430	ND	<430	ND		ND
SB-8-347	SB-8-12	10	12	194	134	111	600 R	0.8	<460	ND	<460	ND		ND
SB-8-348	SB-8-14	12	14	191	53	45	940 J	1.2	<1,100	ND	<1,100	ND		ND
SB-8-349	SB-8-16	14	16	189	119	91	430 J	0.6	190 J	0.3	<500	ND		ND
SB-8-350	SB-8-16B	14	16	189	105	80	130,000 E	193.2	650	1.0	<570	ND		ND
SB-8-350	SB-8-16B	14	16	189	105	80	230,000 D	341.8	650	1.0	<570	ND		ND
SB-8-351	SB-8-18	16	18	188	122	90	310 J	0.5	<490	ND	<490	ND		ND
SB-8-352	SB-8-20	18	20	191	133	111	1,300 R	1.7	190 J	0.3	<450	ND		ND
SB-8-353	SB-8-22	20	22	189	175	136	140,000	217.3	<5,700	ND	<5,700	ND		ND
SB-8-354	SB-8-24	22	24	192	167	120	190,000	329.1	<9,100	ND	<9,100	ND		ND
SB-8-355	SB-8-26	24	26	191	201	143	180,000	329.8	<5,000	ND	<5,000	ND		ND
SB-8-356	SB-8-28	26	28	190	80	62	130,000	183.6	1,900 J	2.7	<5,000	ND		ND
SB-8-357	SB-8-30	28	30	188	148	115	120,000	181.5	2,600 J	3.9	<5,000	ND		ND
SB-8-358	SB-8-32	30	32	190	173	133	100,000	157.5	5,200	8.2	<5,000	ND	<9,900	ND
SB-8-359	SB-8-34	32	34	191	159	109	160,000	294.5	19,000	35.0	<7,600	ND	<15,000	ND
SB-8-360	SB-8-36	34	36	188	176	121	60,000	112.8	36,000	67.7	<3,400	ND	<6,800	ND
SB-8-361	SB-8-38	36	38	189	164	125	89,000	140.9	15,000	23.7	<3,600	ND	<7,300	ND
SB-8-362	SB-8-42	40	42	189	227	170	120,000	208.6	5,500 J	9.6	<6,200	ND	<12,000	ND
SB-8-363	SB-8-44	42	44	190	183	154	4,900,000	6,711.5	<220,000	ND	<220,000	ND	<440,000	ND
SB-8-364	SB-8-BLANK	MeOH Blank Sample			0	0	280 1	0.4	<250	ND	<250	ND	<500	ND
SB-9-221	SB-9-2	0	2	189	94	86	<250	ND	<250	ND	<250	ND	<500	ND
SB-9-222	SB-9-4	2	4	189	111	98	710	0.9	1,900	2.3	<250	ND	<500	ND
SB-9-223	SB-9-6	4	6	188	173	143	<250	ND	440	0.6	<250	ND	<500	ND
SB-9-224	SB-9-8	6	8	187	220.7	187	<250	ND	610	0.8	<250	ND	<500	ND
SB-9-225	SB-9-9.5	7.5	9.5	188	212.9	170	4,200	6.5	<500	ND	<500	ND	<1,000	ND
SB-9-226	SB-9-11.5	9.5	11.5	189	126.6	104	370	0.5	<250	ND	<250	ND	<500	ND
SB-9-227	SB-9-13.5	11.5	13.5	191	126.3	102	<250	ND	<250	ND	<250	ND	<500	ND
SB-9-228	SB-9-15.5	13.5	15.5	191	133.3	98	490	0.8	2,000	3.2	<250	ND	<500	ND
SB-9-229	SB-9-17.5	15.5	17.5	189	170.7	140	270	0.4	390	0.6	<250	ND	<500	ND
SB-9-230	SB-9-19.5	17.5	19.5	188	221.1	171	3,200	5.2	<500	ND	<500	ND	<1,000	ND
SB-9-231	SB-9-21.5	19.5	21.5	190	204.6	165	8,500	12.7	<1,000	ND	<1,000	ND	<2,000	ND
SB-9-232	SB-9-21.5B	19.5	21.5	190	232.2	165	7,500	14.3	<1,000	ND	<1,000	ND	<2,000	ND
SB-9-233	SB-9-23.5	21.5	23.5	187	198	147	17,000	29.1	2,000	3.4	<2,000	ND	<4,000	ND
SB-9-234	SB-9-25.5	23.5	25.5	189	188.4	148	17,000	26.3	5,200	8.0	<2,000	ND	<4,000	ND
SB-9-235	SB-9-27.5	25.5	27.5	188	186.3	135	48,000	84.3	14,000	24.6	<3,100	ND	<6,200	ND
SB-9-236	SB-9-29.5	27.5	29.5	188	233.8	181	18,000	29.8	12,000	19.9	<2,000	ND	<7,500	ND
SB-9-237	SB-9-31.5	29.5	31.5	188	199.4	157	1,600	2.5	7,700	12.0	<1,000	ND	<2,000	ND
SB-9-238	SB-9-33.5	31.5	33.5	190	207	163	<500	ND	4,500	7.0	<500	ND	<1,000	ND
SB-9-239	SB-9-35.5	33.5	35.5	185	116	83	850	1.4	250	0.4	<250	ND	<500	ND
SB-9-240	SB-9-37.5	35.5	37.5	188	166.2	119	<250	ND	670	1.2	<250	ND	<500	ND
SB-9-241	SB-9-39.5	37.5	39.5	189	134.2	99	2,100	3.4	2,200	3.5	<250	ND	<500	ND
SB-9-242	SB-9-42	40	42	188	170.1	132	33,000	51.1	<3,100	ND	<3,100	ND	<6,200	ND
SB-9-243	SB-9-44	42	44	187	195	135	35,000	66.8	<3,800	ND	<3,800	ND	<7,500	ND

Table C-3. Resistive Heating Predemonstration Soil Sample Results (mg/Kg) (Continued)

		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	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-9-244	SB-9-BLANK	MeOH Blank Sample			0	0	<250	ND	<250	ND	<250	ND	<500	ND
SB-10-004	SB-10-2	0	2	191	244.2	225.9	<250	ND	<250	ND	<250	ND	<500	ND
SB-10-005	SB-10-4	2	4	190	204.2	193	<250	ND	<250	ND	<250	ND	<500	ND
SB-10-006	SB-10-6	4	6	191	330.2	279.8	<250	ND	<250	ND	<250	ND	<500	ND
SB-10-007	SB-10-7.5	6	7.5	191	134.2	117	3,100	3.9	<250	ND	<250	ND	<500	ND
SB-10-008	SB-10-9.5	7.5	9.5	191	174.2	151.8	2,200	2.8	<250	ND	<250	ND	<500	ND
SB-10-009	SB-10-11.5	9.5	11.5	190	154.2	111.8	<250	ND	<250	ND	<250	ND	<500	ND
SB-10-010	SB-10-13.5	11.5	13.5	186	341.2	271.8	1,100	1.9	<250	ND	<250	ND	<500	ND
SB-10-036	SB-10-15.5	13.5	15.5	189	256.2	205	<250	ND	<250	ND	<250	ND	<500	ND
SB-10-037	SB-10-17.5	15.5	17.5	188	313.1	241	<250	ND	<250	ND	<250	ND	<500	ND
SB-10-038	SB-10-19.5	17.5	19.5	188	227.2	190	480	0.7	<250	ND	<250	ND	<500	ND
SB-10-039	SB-10-21.5	19.5	21.5	188	278.2	222	19,000 E	30.9	<250	ND	<250	ND	<500	ND
SB-10-039	SB-10-21.5	19.5	21.5	188	278.2	222	19,000 D	30.9	<250	ND	<250	ND	<500	ND
SB-10-040	SB-10-23.5	21.5	23.5	189	222.2	178	62,000 E	95.5	<250	ND	<250	ND	<500	ND
SB-10-040	SB-10-23.5	21.5	23.5	189	222.2	178	60,000 D	92.4	<250	ND	<250	ND	<500	ND
SB-10-041	SB-10-25.5	23.5	25.5	188	179.2	142	69,000 E	104.3	<250	ND	<250	ND	<500	ND
SB-10-041	SB-10-25.5	23.5	25.5	188	179.2	142	70,000 D	105.8	<250	ND	<250	ND	<500	ND
SB-10-042	SB-10-27.5	25.5	27.5	188	204.2	147	54,000	97.8	11,000	19.9	<250	ND	<500	ND
SB-10-043	SB-10-29.5	27.5	29.5	189	182.2	152	29,000	40.3	16,000	22.2	<250	ND	<500	ND
SB-10-044	SB-10-29.5B	27.5	29.5	189	239.2	203	25,000	35.1	15,000	21.1	<250	ND	<500	ND
SB-10-045	SB-10-31.5	29.5	31.5	192	157.2	126	3,300	4.8	9,100 E	13.2	<250	ND	<500	ND
SB-10-045	SB-10-31.5	29.5	31.5	192	157.2	126	<250	ND	9,500	13.8	<250	ND	<500	ND
SB-10-046	SB-10-33.5	31.5	33.5	195	316	216	<250	ND	2,600	5.8	<250	ND	<500	ND
SB-10-047	SB-10-35.5	33.5	35.5	191	236	174	<250	ND	250	0.4	<250	ND	<500	ND
SB-10-049	SB-10-37.5	35.5	37.5	189	190.2	142	<250	ND	1,800	3.0	<250	ND	<500	ND
SB-10-050	SB-10-39.5	37.5	39.5	194	249	198.3	8,800	13.9	14,000	22.2	<250	ND	<500	ND
SB-10-051	SB-10-41.5	39.5	41.5	192	208.2	155.5	7,400	12.6	3,200	5.5	<250	ND	<500	ND
SB-10-052	SB-10-43.75	41.75	43.75	192	221	167.1	15,000	25.4	<250	ND	<250	ND	<500	ND
SB-10-053	SB-10-44.75	42.75	44.75	192	201	146.8	5,600 E	9.8	1,200	2.1	<250	ND	<500	ND
SB-10-053	SB-10-44.75	42.75	44.75	192	201	146.8	6,700 E	11.8	<250	ND	<250	ND	<500	ND
SB-10-054	SB-10-BLANK	MeOH Blank Sample			0	0	<250	ND	<250	ND	<250	ND	<500	ND
SB-11-174	SB-11-2	0	2	188	111	98	3,400	4.1	<250	ND	<250	ND	<500	ND
SB-11-175	SB-11-4	2	4	191	150	143	2,600	2.8	<250	ND	<250	ND	<500	ND
SB-11-176	SB-11-6	4	6	192	161	142	1,700	2.1	<250	ND	<250	ND	<500	ND
SB-11-177	SB-11-8	6	8	189	145	120	2,000	2.7	<250	ND	<250	ND	<500	ND
SB-11-178	SB-11-9.5	7.5	9.5	185	93	74	540	0.7	<250	ND	<250	ND	<500	ND
SB-11-179	SB-11-11.5	9.5	11.5	188	166	136	790	1.1	<250	ND	<250	ND	<500	ND
SB-11-180	SB-11-13.5	11.5	13.5	196	197	146	<250	ND	<250	ND	<250	ND	<500	ND
SB-11-181	SB-11-15.5	13.5	15.5	194	139	107	770	1.2	<250	ND	<250	ND	<500	ND
SB-11-182	SB-11-17.5	15.5	17.5	194	229	177	1,000	1.6	<250	ND	<250	ND	<500	ND
SB-11-183	SB-11-19.5	17.5	19.5	188	150	112	<250	ND	<250	ND	<250	ND	<500	ND
SB-11-184	SB-11-21.5	19.5	21.5	191	281	223	5,600	9.2	<1,000	ND	<1,000	ND	<2,000	ND
SB-11-185	SB-11-25.5	23.5	25.5	189	161	109	50,000	94.2	3,300	6.2	<3,100	ND	<6,200	ND
SB-11-186	SB-11-25.5B	23.5	25.5	188	126	122	25,000	26.4	<2,000	ND	<2,000	ND	<4,000	ND

Table C-3. Resistive Heating Predemonstration Soil Sample Results (mg/Kg) (Continued)

		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	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-11-187	SB-11-27.5	25.5	27.5	189	255	100	36,000	167.1	8,900	41.3	<5,000	ND	<10,000	ND
SB-11-188	SB-11-29.5	27.5	29.5	188	127	NA	31,000 1	48.8	13,000 1	20.5	<2,000	ND	<4,000	ND
SB-11-189	SB-11-31.5	29.5	31.5	188	224	171	26,000	43.7	22,000	36.9	<2,000	ND	<4,000	ND
SB-11-190	SB-11-33.5	31.5	33.5	191	223	172	13,000	21.4	19,000	31.2	<2,000	ND	<4,000	ND
SB-11-191	SB-11-35.5	33.5	35.5	190	164	113	1,100	2.0	15,000	27.6	<1,000	ND	<2,000	ND
SB-11-192	SB-11-37.5	35.5	37.5	189	150	109	0	0.0	2,800	4.7	<250	ND	<500	ND
SB-11-193	SB-11-39.5	37.5	39.5	189	216	161	250	0.4	3,600	6.2	<250	ND	<500	ND
SB-11-194	SB-11-42.5	40.5	42.5	179	152	113	22,000	36.0	2,300	3.8	<2,000	ND	<4,000	ND
SB-11-195	SB-11-44.5	42.5	44.5	187	129	81	23,000	46.0	1,800	3.6	<1,200	ND	<2,500	ND
SB-11-196	SB-11-BLANK	MeOH Blank Sample			0	0	<250	ND	<250	ND	<250	ND	<500	ND
SB-12-077	SB-12-2	0	2	193	166	148	<370	ND	<370	ND	<370	ND	<730	ND
SB-12-078	SB-12-4	2	4	191	118	92	<510	ND	<510	ND	<510	ND	<1,000	ND
SB-12-079	SB-12-6	4	6	189	206	157	<250	ND	<250	ND	<250	ND	<500	ND
SB-12-080	SB-12-9.5	7.5	9.5	192	266	211	<250	ND	<250	ND	<250	ND	<500	ND
SB-12-081	SB-12-11.5	9.5	11.5	194	196	157	1,600	2.4	<310	ND	<310	ND	<630	ND
SB-12-082	SB-12-13.5	11.5	13.5	193	133	NA	230 J, 1	0.4	<460	ND	<460	ND	<920	ND
SB-12-083	SB-12-15.5	13.5	15.5	190	163	127.2	<370	ND	160 J	0.2	<370	ND	<740	ND
SB-12-084	SB-12-19.5	17.5	19.5	195	91	69.2	<680	ND	510 J	0.7	<680	ND	<1,400	ND
SB-12-085	SB-12-21.5	19.5	21.5	193	181	141	9,900	15.3	1,600	2.5	<340	ND	<670	ND
SB-12-086	SB-12-23.5	21.5	23.5	195	107	77	25,000	40.1	4,200	6.7	<1,200	ND	<2,300	ND
SB-12-087	SB-12-25.5	23.5	25.5	192	160	109.8	61,000	112.1	13,000	23.9	<1,900	ND	<3,800	ND
SB-12-088	SB-12-27.5	25.5	27.5	195	214	155	47,000	84.5	20,000	36.0	<1,700	ND	<3,300	ND
SB-12-089	SB-12-27.5B	25.5	27.5	192	127	80	130,000	256.9	10,000	19.8	<4,800	ND	<9,600	ND
SB-12-090	SB-12-29.5	27.5	29.5	192	182	136.9	18,000 D	29.6	23,000 D	37.8	470	0.8	<670	ND
SB-12-090	SB-12-29.5	27.5	29.5	192	182	136.9	17,000 E	27.9	22,000 E	36.1	<330	ND	<670	ND
SB-12-091	SB-12-31.5	29.5	31.5	191	146	114	1,500	2.2	12,000	17.9	170 J	0.3 J	<830	ND
SB-12-092	SB-12-33.5	31.5	33.5	189	216	179.9	270	0.4	7,200	10.3	<250	ND	<500	ND
SB-12-093	SB-12-35.5	33.5	35.5	193	130	91	120 J	0.2	910	1.6	<470	ND	<940	ND
SB-12-094	SB-12-37.5	35.5	37.5	190	230	158.6	340	0.7	460	0.9	<250	ND	<500	ND
SB-12-095	SB-12-39.5	37.5	39.5	193	150	119.5	360 J	0.5	280 J	0.4	<410	ND	<810	ND
SB-12-096	SB-12-41.5	39.5	41.5	187	223	165.9	9,200	16.1	3,000	5.3	<330	ND	<660	ND
SB-12-098	SB-12-43.5	41.5	43.5	194	184	124.9	19,000	36.5	3,700	7.1	<670	ND	<1,300	ND
SB-12-099	SB-12-45.5	43.5	45.5	191	185	119.4	700	1.5	360	0.7	<320	ND	<650	ND
SB-12-123	SB-12-BLANK	MeOH Blank Sample			0	0	<250	ND	<250	ND	<250	ND	<500	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. Resistive Heating Postdemonstration Soil Sample Results (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-201-2	0	2	12/8/2000	198	153	131	370	1	<250	ND	<250	ND	<500	ND
SB-201-4	2	4	12/8/2000	197	198	196	1,400	2	<250	ND	<250	ND	<500	ND
SB-201-6	4	6	12/8/2000	194	151	148	1,700	3	<250	ND	<250	ND	<500	ND
SB-201-8	6	8	12/8/2000	208	168	165	880	1	<250	ND	<250	ND	<500	ND
SB-201-10	8	10	12/9/2000	190	204	177	12,000	18	730	1	<500	ND	<1,000	ND
SB-201-12	10	12	12/9/2000	199	266	218	9,500	13	15,000	21	<1,000	ND	<2,000	ND
SB-201-14	12	14	12/9/2000	196	151	128	<830	ND	12,000	25	<830	ND	<1,700	ND
SB-201-16	14	16	12/9/2000	196	165	141	<830	ND	11,000	21	<830	ND	<1,700	ND
SB-201-18	16	18	12/9/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-201-20	18	20	12/11/2000	199	281	234	<500	ND	7,400	9	<500	ND	<1,000	ND
SB-201-22	20	22	12/11/2000	195	238	204	20,000	28	1,600	2	<1,000	ND	<2,000	ND
SB-201-24	22	24	12/11/2000	198	216	183	39,000	60	<1,800	ND	<1,800	ND	<3,600	ND
SB-201-26	24	26	12/11/2000	201	195	166	2,300,000	3,927	<100,000	ND	<100,000	ND	<200,000	ND
SB-201-28	26	28	12/11/2000	198	205	166	230,000	401	<12,000	ND	<12,000	ND	<25,000	ND
SB-201-30	28	30	12/11/2000	201	218	169	260,000	467	<17,000	ND	<17,000	ND	<33,000	ND
SB-201-32	30	32	12/11/2000	203	179	166	200,000	325	<10,000	ND	<10,000	ND	<20,000	ND
SB-201-32-DUP	30	32	12/11/2000	203	179	144	190,000	385	<8,300	ND	<8,300	ND	<17,000	ND
SB-201-34	32	34	12/11/2000	202	197	164	120,000	211	<8,300	ND	<8,300	ND	<17,000	ND
SB-201-36	34	36	12/11/2000	198	199	167	150,000	254	<8,300	ND	<8,300	ND	<17,000	ND
SB-201-38	36	38	12/11/2000	195	169	137	130,000	265	<10,000	ND	<10,000	ND	<20,000	ND
SB-201-40	38	40	12/11/2000	204	187	155	170,000	318	<3,300	ND	<3,300	ND	<6,700	ND
SB-201-42	40	42	12/11/2000	193	142	119	83,000	186	<3,600	ND	<3,600	ND	<7,100	ND
SB-201-44	42	44	12/11/2000	190	141	125	71,000	146	<3,600	ND	<3,600	ND	<7,100	ND
SB-201-46	44	46	12/11/2000	194	235	186	230,000	364	<8,300	ND	<8,300	ND	17,000	27
SB-201-48	46	48	12/11/2000	199	197	167	160,000	270	<6,200	ND	<6,200	ND	<12,000	ND
SB-201-76	Lab Blank		12/9/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-201-80	Lab Blank		12/12/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-201-81	Lab Blank		12/12/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-202-2	0	2	12/8/2000	196	122	122	<250	ND	<250	ND	<250	ND	<500	ND
SB-202-4	2	4	12/8/2000	196	122	123	<250	ND	<250	ND	<250	ND	<500	ND
SB-202-6	4	6	12/8/2000	188	178	170	2,000	3	<250	ND	<250	ND	<500	ND
SB-202-8	6	8	12/8/2000	191	155	146	3,900	7	<250	ND	<250	ND	<500	ND
SB-202-10	8	10	12/9/2000	202	234	201	28,000	40	<2,000	ND	<2,000	ND	<4,000	ND
SB-202-12	10	12	12/9/2000	205	257	222	22,000 D	29	5,800	8	<250	ND	<500	ND
SB-202-14	12	14	12/9/2000	185	206	173	6,100	9	5,600	9	<250	ND	<500	ND
SB-202-16	14	16	12/9/2000	189	206	173	1,200	2	5,500	9	<500	ND	<1,000	ND
SB-202-18	16	18	12/9/2000	201	235	195	35,000	53	4,900	7	<1,000	ND	<2,000	ND
SB-202-18-DUP	16	18	12/9/2000	205	249	206	19,000	28	3,600	5	<720	ND	<1,400	ND
SB-202-20	18	20	12/9/2000	202	190	160	62,000	111	3,700	7	<2,000	ND	<4,000	ND
SB-202-22	20	22	12/9/2000	199	191	167	2,600,000	4,295	<210,000	ND	<210,000	ND	<420,000	ND
SB-202-24	22	24	12/9/2000	196	221	186	820,000	1,248	<50,000	ND	<50,000	ND	<100,000	ND
SB-202-26	24	26	12/9/2000	202	268	230	80,000	102	<5,000	ND	<5,000	ND	<10,000	ND
SB-202-28	26	28	12/9/2000	198	213	178	220,000	353	<12,000	ND	<12,000	ND	<25,000	ND

Table C-4. Resistive Heating Postdemonstration Soil Sample Results (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-202-30	28	30	12/9/2000	197	227	174	3,200,000	5,561	<210,000	ND	<210,000	ND	<420,000	ND
SB-202-32	30	32	12/9/2000	194	214	175	240,000	390	<12,000	ND	<12,000	ND	<25,000	ND
SB-202-34	32	34	12/9/2000	186	214	169	280,000	465	<12,000	ND	<12,000	ND	<25,000	ND
SB-202-36	34	36	12/9/2000	192	264	233	87,000	102	<5,000	ND	<5,000	ND	<10,000	ND
SB-202-38	36	38	12/9/2000	189	284	211	290,000	429	<16,000	ND	<16,000	ND	<31,000	ND
SB-202-40	38	40	12/9/2000	187	212	***181***	320,000	474	<17,000	ND	<17,000	ND	<33,000	ND
SB-202-42	40	42	12/9/2000	195	227	192	170,000	250	12,000	18	<10,000	ND	<20,000	ND
SB-202-44	42	44	12/9/2000	204	195	164	190,000	335	<10,000	ND	<10,000	ND	<20,000	ND
SB-202-46	44	46	12/9/2000	201	216	189	5,300	8	<250	ND	<250	ND	<500	ND
SB-202-75	Lab Blank		12/9/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-202-77	Lab Blank		12/11/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
RINSATE-13	EQ		12/9/2000	NA	NA	NA	<1	ND	<1	ND	<1	ND	<2	ND
SB-203-2	0	2	11/17/2000	203	95	91	430	1	<250	ND	<250	ND	<500	ND
SB-203-4	2	4	11/17/2000	204	127	120	<250	ND	<250	ND	<250	ND	<500	ND
SB-203-6	4	6	11/17/2000	194	143	131	390	1	<250	ND	<250	ND	<500	ND
SB-203-8	6	8	11/17/2000	196	139	125	1,300	3	<250	ND	<250	ND	<500	ND
SB-203-10	8	10	11/17/2000	197	189	157	50,000	90	2,300	4	<2,000	ND	<4,000	ND
SB-203-12	10	12	11/17/2000	204	205	178	71,000	114	<3,000	ND	<3,000	ND	<5,900	ND
SB-203-14	12	14	11/17/2000	187	145	142	36,000	61	5,300	9	<1,500	ND	<3,000	ND
SB-203-16	14	16	11/17/2000	187	165	116	51,000	126	11,000	27	<2,000	ND	<4,000	ND
SB-203-18	16	18	11/17/2000	195	183	148	51,000	97	16,000	30	<2,500	ND	<5,000	ND
SB-203-20	18	20	11/17/2000	195	175	142	36,000	71	17,000	34	<1,200	ND	<2,500	ND
SB-203-22	20	22	11/17/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-203-24	22	24	11/17/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-203-26	24	26	11/17/2000	193	226	180	160,000	258	22,000	35	<8,300	ND	<17,000	ND
SB-203-28	26	28	11/17/2000	193	212	165	140,000	247	27,000	48	<5,000	ND	<10,000	ND
SB-203-30	28	30	11/17/2000	192	206	164	700,000	1,217	25,000	43	<25,000	ND	<50,000	ND
SB-203-32	30	32	11/17/2000	192	206	140	130,000	287	19,000	42	<5,000	ND	<10,000	ND
SB-203-34	32	34	11/17/2000	200	171	145	29,000	56	5,900	11	<1,000	ND	<2,000	ND
SB-203-36	34	36	11/17/2000	196	179	155	44,000	77	3,300	6	<1,800	ND	<3,600	ND
SB-203-38	36	38	11/17/2000	199	188	144	150,000	308	18,000	37	<6,200	ND	<12,000	ND
SB-203-38-DUP	36	38	11/17/2000	194	170	125	130,000	302	17,000	40	<4,200	ND	<8,300	ND
SB-203-40	38	40	11/17/2000	201	187	134	81,000	186	14,000	32	<3,600	ND	<7,100	ND
SB-203-44	42	44	11/17/2000	201	276	225	25,000	34	1,000	1	<1,000	ND	<2,000	ND
SB-203-46	44	46	11/17/2000	191	227	191	28,000 D	41	<500	ND	<500	ND	<1,000	ND
SB-203-056	Lab Blank		11/20/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-203-EB	EQ		11/20/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND
SB-204-2	0	2	11/16/2000	194	117	100	510	1	<250	ND	<250	ND	<500	ND
SB-204-4	2	4	11/16/2000	193	145	143	1,500	3	<250	ND	<250	ND	<500	ND
SB-204-6	4	6	11/16/2000	194	148	144	<250	ND	<250	ND	<250	ND	<500	ND
SB-204-8	6	8	11/16/2000	194	120	113	2,100	5	<250	ND	<250	ND	<500	ND
SB-204-10	8	10	11/17/2000	193	220	184	3,800	6	2,700	4	<250	ND	<500	ND
SB-204-12	10	12	11/17/2000	193	224	185	21,000	32	1,200	2	<720	ND	<1,400	ND

Table C-4. Resistive Heating Postdemonstration Soil Sample Results (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-204-14	12	14	11/17/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-204-16	14	16	11/17/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-204-18	16	18	11/17/2000	193	212	174	12,000	19	380	1	<250	ND	<500	ND
SB-204-20	18	20	11/17/2000	194	234	194	1,500	2	760	1	<250	ND	<500	ND
SB-204-22	20	22	11/17/2000	194	247	208	61,000	83	<2,000	ND	<2,000	ND	<4,000	ND
SB-204-24	22	24	11/17/2000	201	164	135	50,000	105	<1,500	ND	<1,500	ND	<2,900	ND
SB-204-24-DUP	22	24	11/17/2000	202	149	128	47,000	102	<1,500	ND	<1,500	ND	<3,000	ND
SB-204-26	24	26	11/17/2000	197	218	172	140,000	240	5,500	9	<5,000	ND	<10,000	ND
SB-204-28	26	28	11/17/2000	192	216	175	120,000	195	4,900	8	<4,600	ND	<9,100	ND
SB-204-30	28	30	11/17/2000	201	252	194	250,000	403	<10,000	ND	<10,000	ND	<20,000	ND
SB-204-32	30	32	11/17/2000	199	288	242	160,000	197	<6,200	ND	<6,200	ND	<12,000	ND
SB-204-34	32	34	11/17/2000	194	237	196	180,000	263	<6,200	ND	<6,200	ND	<12,000	ND
SB-204-36	34	36	11/17/2000	192	231	181	110,000	178	<4,600	ND	<4,600	ND	<9,100	ND
SB-204-38	36	38	11/17/2000	193	231	176	250,000	425	<10,000	ND	<10,000	ND	<20,000	ND
SB-204-40	38	40	11/17/2000	193	192	162	82,000	139	<3,300	ND	<3,300	ND	<6,600	ND
SB-204-43	41	43	11/17/2000	195	264	214	280,000	388	<10,000	ND	<10,000	ND	<20,000	ND
SB-204-45	43	45	11/17/2000	194	304	229	260,000	364	<10,000	ND	<10,000	ND	<20,000	ND
SB-204-055	Lab Blank		11/17/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<12,000	ND
SB-204-EB	EQ		11/17/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND
SB-205-2	0	2	11/17/2000	193	81	79	1,900	6	<250	ND	<250	ND	<500	ND
SB-205-4	2	4	11/17/2000	195	168	161	820	1	<250	ND	<250	ND	<500	ND
SB-205-6	4	6	11/17/2000	192	137	135	6,400	12	<250	ND	<250	ND	<500	ND
SB-205-8	6	8	11/17/2000	192	93	88	1,600	5	<250	ND	<250	ND	<500	ND
SB-205-10	8	10	11/20/2000	193	106	88	3,300	10	1,700	5	<250	ND	<500	ND
SB-205-12	10	12	11/20/2000	193	113	97	3,800	10	550	1	<250	ND	<500	ND
SB-205-14	12	14	11/20/2000	192	164	140	9,000	17	2,400	5	<250	ND	<500	ND
SB-205-16	14	16	11/20/2000	193	143	119	54,000	122	<1,200	ND	<1,200	ND	<2,500	ND
SB-205-18	16	18	11/20/2000	198	165	138	98,000	197	<2,000	ND	<2,000	ND	<4,000	ND
SB-205-20	18	20	11/20/2000	203	129	100	31,000	89	<830	ND	<830	ND	<1,700	ND
SB-205-22	20	22	11/20/2000	194	149	121	27,000	61	<830	ND	<830	ND	<1,700	ND
SB-205-24	22	24	11/20/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-205-26	24	26	11/20/2000	194	149	143	100,000	176	2,800	5	<2,500	ND	<5,000	ND
SB-205-26B	24	26	11/20/2000	194	169	127	78,000	177	<2,500	ND	<2,500	ND	<5,000	ND
SB-205-28	26	28	11/20/2000	193	270	181	96,000	177	3,000	6	<2,000	ND	<4,000	ND
SB-205-30	28	30	11/20/2000	199	270	233	82,000	102	2,500	3	<2,500	ND	<5,000	ND
SB-205-32	30	32	11/20/2000	202	195	159	82,000	150	2,500	5	<2,000	ND	<4,000	ND
SB-205-34	32	34	11/20/2000	200	198	165	81,000	140	2,100	4	<1,800	ND	<3,600	ND
SB-205-36	34	36	11/20/2000	207	184	160	36,000	64	1,000	2	<1,000	ND	<2,000	ND
SB-205-38	36	38	11/20/2000	205	185	148	73,000	146	<2,500	ND	<2,500	ND	<5,000	ND
SB-205-40	38	40	11/20/2000	195	174	142	120,000	236	2,700	5	<2,500	ND	<5,000	ND
SB-205-42	40	42	11/20/2000	194	210	176	61,000	97	2,100	3	<1,200	ND	<2,500	ND
SB-205-45	43	45	11/20/2000	193	214	181	84,000	129	<2,000	ND	<2,000	ND	<4,000	ND
SB-205-057	Lab Blank		11/20/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND

Table C-4. Resistive Heating Postdemonstration Soil Sample Results (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-205-058	Lab Blank		11/20/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-205-EB	EQ		11/20/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND
SB-206-2	0	2	11/20/2000	193	56	57	1,300	6	<250	ND	<250	ND	<500	ND
SB-206-4	2	4	11/20/2000	196	133	129	<250	ND	<250	ND	<250	ND	<500	ND
SB-206-6	4	6	11/20/2000	204	142	135	2,900	6	<250	ND	<250	ND	<500	ND
SB-206-8	6	8	11/20/2000	202	149	137	1,700	3	<250	ND	<250	ND	<500	ND
SB-206-10	8	10	11/21/2000	193	158	139	29,000	55	<1,200	ND	<1,200	ND	<2,500	ND
SB-206-12	10	12	11/21/2000	194	164	140	36,000	69	<1,800	ND	<1,800	ND	<3,600	ND
SB-206-14	12	14	11/21/2000	207	162	135	33,000	71	2,000	4	<1,800	ND	<3,600	ND
SB-206-16	14	16	11/21/2000	204	215	181	47,000	76	2,900	5	<2,000	ND	<4,000	ND
SB-206-18	16	18	11/21/2000	199	165	133	77,000	164	5,300	11	<3,600	ND	<7,100	ND
SB-206-20	18	20	11/21/2000	199	213	190	82,000	119	5,700	8	<4,200	ND	<8,300	ND
SB-206-22	20	22	11/21/2000	203	333	278	200,000	224	17,000	19	<8,300	ND	<17,000	ND
SB-206-24	22	24	11/21/2000	194	177	167	88,000	135	8,500	13	<3,100	ND	<6,200	ND
SB-206-26	24	26	11/21/2000	195	124	102	81,000	213	5,600	15	<4,200	ND	<8,300	ND
SB-206-26-DUP	24	26	11/21/2000	195	121	99	65,000	177	4,700	13	<3,600	ND	<7,100	ND
SB-206-28	26	28	11/21/2000	195	170	141	120,000	235	7,100	14	<6,200	ND	<12,000	ND
SB-206-30	28	30	11/21/2000	195	177	147	56,000	105	<3,600	ND	<3,600	ND	<7,100	ND
SB-206-32	30	32	11/21/2000	201	153	134	42,000	86	<2,500	ND	<2,500	ND	<5,000	ND
SB-206-34	32	34	11/21/2000	207	193	163	35,000	63	9,100	16	<1,800	ND	<3,600	ND
SB-206-36	34	36	11/21/2000	195	210	182	23,000	35	5,800	9	<1,500	ND	<2,900	ND
SB-206-38	36	38	11/21/2000	197	222	182	62,000	99	6,100	10	<2,500	ND	<5,000	ND
SB-206-40	38	40	11/21/2000	193	171	145	48,000	89	7,400	14	<1,800	ND	<3,600	ND
SB-206-43	41	43	11/21/2000	203	179	150	78,000	149	3,700	7	<3,600	ND	<7,100	ND
SB-206-45	43	45	11/21/2000	202	246	210	91,000	126	4,900	7	<4,200	ND	<8,300	ND
SB-206-059	Lab Blank		11/20/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-206-060	Lab Blank		11/21/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-206-EB	EQ		11/21/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND
SB-207-2	0	2	11/16/2000	204	97	94	<250	ND	<250	ND	<250	ND	<500	ND
SB-207-4	2	4	11/16/2000	200	160	155	290	0.48	<250	ND	<250	ND	<500	ND
SB-207-6	4	6	11/16/2000	192	146	130	2,900	6	<250	ND	<250	ND	<500	ND
SB-207-8	6	8	11/16/2000	203	253	213	44,000	61	<1,800	ND	<1,800	ND	<3,600	ND
SB-207-10	8	10	11/16/2000	206	202	173	<500	ND	7,900	13	<500	ND	<1,000	ND
SB-207-10-DUP	8	10	11/16/2000	202	143	122	<250	ND	3,400	8	<250	ND	<500	ND
SB-207-12	10	12	11/16/2000	204	194	154	<720	ND	16,000	31	<720	ND	<1,400	ND
SB-207-14	12	14	11/16/2000	194	202	168	<250	ND	710	1	<250	ND	<500	ND
SB-207-16	14	16	11/16/2000	199	136	119	660	1	650	1	<250	ND	<500	ND
SB-207-18	16	18	11/16/2000	193	232	195	570	1	530	1	<250	ND	<500	ND
SB-207-20	18	20	11/16/2000	195	246	208	<250	ND	1,600	2	<250	ND	<500	ND
SB-207-22	20	22	11/16/2000	193	188	156	33,000	58	<1,200	ND	<1,200	ND	<2,500	ND
SB-207-24	22	24	11/16/2000	193	207	173	53,000	85	<1,800	ND	<1,800	ND	<3,600	ND
SB-207-26	24	26	11/16/2000	192	246	172	280,000	516	<12,000	ND	<12,000	ND	<25,000	ND
SB-207-28	26	28	11/16/2000	210	283	217	240,000	367	<10,000	ND	<10,000	ND	<20,000	ND

Table C-4. Resistive Heating Postdemonstration Soil Sample Results (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-207-30	28	30	11/16/2000	193	196	152	98,000	186	<4,600	ND	<4,600	ND	<9,100	ND
SB-207-32	30	32	11/16/2000	202	205	175	120,000	196	<4,600	ND	<4,600	ND	<9,100	ND
SB-207-34	32	34	11/16/2000	156	223	152	220,000	389	<10,000	ND	<10,000	ND	<20,000	ND
SB-207-36	34	36	11/16/2000	240	185	145	170,000	403	<6,200	ND	<6,200	ND	<12,000	ND
SB-207-38	36	38	11/16/2000	193	222	177	97,000	159	<4,200	ND	<4,200	ND	<8,400	ND
SB-207-40	38	40	11/16/2000	193	213	183	55,000	82	<2,500	ND	<2,500	ND	<5,000	ND
SB-207-42	40	42	11/16/2000	199	293	193	280,000	511	<12,000	ND	<12,000	ND	<25,000	ND
SB-207-44	42	44	11/16/2000	204	275	219	190,000	273	<6,200	ND	<6,200	ND	<12,000	ND
SB-207-054	Lab Blank		11/16/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-207-EB	EQ		11/16/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND
SB-208-2	0	2	11/15/2000	192	134	130	820	2	370	1	<250	ND	<500	ND
SB-208-4	2	4	11/15/2000	196	181	177	1,000	1	<250	ND	<250	ND	<500	ND
SB-208-6	4	6	11/15/2000	194	170	156	2,900	5	530	1	<250	ND	<500	ND
SB-208-8	6	8	11/15/2000	187	156	133	37,000	72	<2,500	ND	<2,500	ND	<5,000	ND
SB-208-10	8	10	11/15/2000	191	176	154	<250	ND	1,100	2	<250	ND	<500	ND
SB-208-12	10	12	11/15/2000	206	188	164	<250	ND	470	1	<250	ND	<500	ND
SB-208-14	12	14	11/15/2000	193	154	125	11,000	24	830	2	<500	ND	<1,000	ND
SB-208-16	14	16	11/15/2000	197	188	163	3,700	6	380	1	<250	ND	<500	ND
SB-208-18	16	18	11/15/2000	196	252	215	20,000	27	1,700	2	<720	ND	<1,400	ND
SB-208-20	18	20	11/15/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-208-22	20	22	11/15/2000	198	240	192	21,000	33	3,500	5	<1,000	ND	<2,000	ND
SB-208-24	22	24	11/15/2000	197	227	186	7,700	12	1,500	2	<380	ND	<770	ND
SB-208-26	24	26	11/15/2000	196	289	204	18,000	29	4,100	7	<720	ND	<1,400	ND
SB-208-28	26	28	11/15/2000	191	212	153	16,000	31	3,800	7	<720	ND	<1,400	ND
SB-208-30	28	30	11/16/2000	192	150	74	8,000	34	1,500	6	<250	ND	<500	ND
SB-208-32	30	32	11/16/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-208-34	32	34	11/16/2000	197	228	179	31,000	52	4,000	7	<1,000	ND	<2,000	ND
SB-208-36	34	36	11/16/2000	196	199	151	32,000	63	4,000	8	<1,000	ND	<2,000	ND
SB-208-38	36	38	11/16/2000	203	310	248	1,400	2	490	1	<250	ND	<500	ND
SB-208-40	38	40	11/16/2000	204	235	201	7,600	11	770	1	<250	ND	<500	ND
SB-208-40-DUP	38	40	11/16/2000	195	247	214	8,600	11	890	1	<250	ND	<500	ND
SB-208-42	40	42	11/16/2000	199	265	220	3,100	4	420	1	<250	ND	<500	ND
SB-208-44	42	44	11/16/2000	204	277	232	40,000	52	2,800	4	<1,800	ND	<3,600	ND
SB-208-45	43	45	11/16/2000	191	254	202	110,000	160	6,000	9	<4,600	ND	<9,100	ND
SB-208-052	Lab Blank		11/15/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-208-EB	EQ		11/16/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND
SB-209-2	0	2	11/15/2000	202	115	110	<250	ND	290	1	<250	ND	<500	ND
SB-209-4	2	4	11/15/2000	194	75	71	<250	ND	<250	ND	<250	ND	<500	ND
SB-209-6	4	6	11/15/2000	203	171	147	2,000	4	600	1	<250	ND	<500	ND
SB-209-8	6	8	11/15/2000	190	191	173	3,600	5	1,600	2	<250	ND	<500	ND
SB-209-10	8	10	11/15/2000	203	223	193	550	1	2,400	4	<250	ND	<500	ND
SB-209-12	10	12	11/15/2000	194	166	145	540	1	1,300	2	<250	ND	<500	ND
SB-209-14	12	14	11/15/2000	195	188	154	2,500	5	9,600	18	<250	ND	<500	ND

Table C-4. Resistive Heating Postdemonstration Soil Sample Results (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-209-16	14	16	11/15/2000	200	172	139	1,800	4	5,800	12	<500	ND	<1,000	ND
SB-209-18	16	18	11/15/2000	199	232	191	8,600	13	16,000	25	<1,200	ND	<2,500	ND
SB-209-18B	16	18	11/15/2000	189	163	138	3,000	6	5,900	11	<500	ND	<1,000	ND
SB-209-20	18	20	11/15/2000	199	178	149	1,700	3	12,000	23	<1,000	ND	<2,000	ND
SB-209-22	20	22	11/15/2000	195	172	133	13,000	28	7,400	16	<500	ND	<1,000	ND
SB-209-24	22	24	11/15/2000	193	222	182	22,000	34	9,500	15	<720	ND	<1,400	ND
SB-209-26	24	26	11/15/2000	201	249	191	39,000	64	36,000	59	<1,200	ND	<2,500	ND
SB-209-28	26	28	11/15/2000	193	230	190	24,000	36	20,000	30	<1,200	ND	<2,500	ND
SB-209-30	28	30	11/15/2000	193	240	197	19,000	28	19,000	28	<1,000	ND	<2,000	ND
SB-209-32	30	32	11/15/2000	192	263	233	9,400	11	9,700	11	<720	ND	<1,400	ND
SB-209-34	32	34	11/15/2000	193	236	197	13,000	19	5,300	8	<500	ND	<1,000	ND
SB-209-36	34	36	11/15/2000	193	224	171	3,100	5	10,000	17	<720	ND	<1,400	ND
SB-209-38	36	38	11/15/2000	193	224	194	52,000	74	2,300	3	<1,800	ND	<3,600	ND
SB-209-40	38	40	11/15/2000	193	236	172	30,000	54	<1,200	ND	<1,200	ND	<2,500	ND
SB-209-42	40	42	11/15/2000	192	272	206	51,000	77	<1,800	ND	<1,800	ND	<3,600	ND
SB-209-44	42	44	11/15/2000	200	295	232	38,000	52	<1,200	ND	<1,200	ND	<2,500	ND
SB-209-EB	EQ		11/15/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND
SB-210-2	0	2	11/13/2000	192	113	109	<250	ND	<250	ND	<250	ND	<500	ND
SB-210-4	2	4	11/13/2000	198	127	125	<250	ND	<250	ND	<250	ND	<500	ND
SB-210-6	4	6	11/13/2000	191	107	95	1,200	3	<250	ND	<250	ND	<500	ND
SB-210-8	6	8	11/13/2000	193	135	114	11,000	26	910	2	<250	ND	<500	ND
SB-210-10	8	10	11/13/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-210-12	10	12	11/13/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-210-14	12	14	11/13/2000	199	287	241	<250	ND	420	1	<250	ND	<500	ND
SB-210-16	14	16	11/13/2000	191	117	101	2,200	6	<250	ND	<250	ND	<500	ND
SB-210-18	16	18	11/13/2000	190	131	111	NA	NA	NA	NA	NA	NA	NA	NA
SB-210-20	18	20	11/13/2000	198	314	263	8,700	10	340	0	<250	ND	<500	ND
SB-210-22	20	22	11/13/2000	194	201	164	52,000	90	<1,800	ND	<1,800	ND	<3,600	ND
SB-210-24	22	24	11/13/2000	194	253	202	31,000	46	1,000	1	<1,000	ND	<2,000	ND
SB-210-26	24	26	11/13/2000	191	243	196	180,000	265	<6,200	ND	<6,200	ND	<12,000	ND
SB-210-26B	24	26	11/13/2000	198	224	183	120,000	191	<5,000	ND	<5,000	ND	<10,000	ND
SB-210-28	26	28	11/13/2000	200	357	281	100,000	117	3,400	4	<2,500	ND	<5,000	ND
SB-210-30	28	30	11/13/2000	195	317	255	140,000	170	13,000	16	<3,600	ND	<7,200	ND
SB-210-32	30	32	11/14/2000	190	215	163	160,000	287	5,000	9	<5,000	ND	<10,000	ND
SB-210-34	32	34	11/14/2000	202	281	224	150,000	209	<6,200	ND	<6,200	ND	<12,000	ND
SB-210-36	34	36	11/14/2000	199	240	167	220,000	428	<10,000	ND	<10,000	ND	<20,000	ND
SB-210-38	36	38	11/14/2000	194	187	150	140,000	264	<5,000	ND	<5,000	ND	<10,000	ND
SB-210-40	38	40	11/14/2000	198	287	222	170,000	242	<7,200	ND	<7,200	ND	<14,000	ND
SB-210-42	40	42	11/14/2000	200	264	206	170,000	257	<7,200	ND	<7,200	ND	<14,000	ND
SB-210-44	42	44	11/14/2000	182	192	140	50,000	101	4,600	9	<2,500	ND	<5,000	ND
SB-210-46	44	46	11/14/2000	194	163	129	27,000	59	2,100	5	<1,200	ND	<2,500	ND
SB-210-EB	EQ		11/14/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND
SB-210B-2	0	2	11/27/2000	193	144	139	1,600	3	<250	ND	<250	ND	<500	ND

Table C-4. Resistive Heating Postdemonstration Soil Sample Results (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-210B-4	2	4	11/27/2000	198	122	114	1,000	2	<250	ND	<250	ND	<500	ND
SB-210B-6	4	6	11/27/2000	199	160	134	11,000	23	1,600	3	<460	ND	<910	ND
SB-210B-8	6	8	11/27/2000	200	193	159	11,000	20	3,700	7	<500	ND	<1,000	ND
SB-210B-10	8	10	11/27/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-210B-12	10	12	11/27/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-210B-14	12	14	11/27/2000	203	174	149	<250	ND	<250	ND	<250	ND	<500	ND
SB-210B-16	14	16	11/27/2000	208	165	139	<250	ND	<250	ND	<250	ND	<500	ND
SB-210B-18	16	18	11/27/2000	193	208	176	700	1	<250	ND	<250	ND	<500	ND
SB-210B-20	18	20	11/27/2000	208	184	153	2,900	6	310	1	<250	ND	<500	ND
SB-210B-22	20	22	11/27/2000	192	161	137	8,200	16	250	0	<250	ND	<500	ND
SB-210B-24	22	24	11/27/2000	205	216	177	29,000	49	<1,200	ND	<1,200	ND	<2,500	ND
SB-210B-26	24	26	11/27/2000	194	224	169	320,000	569	<12,000	ND	<12,000	ND	<25,000	ND
SB-210B-28	26	28	11/27/2000	192	237	194	210,000	310	<8,300	ND	<8,300	ND	<17,000	ND
SB-210B-30	28	30	11/27/2000	191	195	163	46,000	77	4,600	8	<1,800	ND	<3,600	ND
SB-210B-32	30	32	11/27/2000	190	192	168	17,000	27	3,200	5	<830	ND	<1,700	ND
SB-210B-32B	30	32	11/27/2000	190	171	151	12,000	21	2,400	4	<500	ND	<1,000	ND
SB-210B-34	32	34	11/27/2000	187	200	150	180,000	344	<8,300	ND	<8,300	ND	<17,000	ND
SB-210B-36	34	36	11/27/2000	192	169	133	150,000	315	<8,300	ND	<8,300	ND	<17,000	ND
SB-210B-38	36	38	11/27/2000	194	205	177	80,000	124	<4,200	ND	<4,200	ND	<8,300	ND
SB-210B-40	38	40	11/27/2000	194	195	164	130,000	219	<8,300	ND	<8,300	ND	<17,000	ND
SB-210B-42	40	42	11/27/2000	191	193	162	140,000	236	<6,200	ND	<6,200	ND	<12,000	ND
SB-210B-44	42	44	11/27/2000	191	190	145	150,000	297	<8,300	ND	<8,300	ND	<17,000	ND
SB-061-A	Lab Blank		11/28/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
RINSATE-1	EQ		11/27/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND
SB-211-2	0	2	11/14/2000	192	66	66	1,600	6	<250	ND	<250	ND	<500	ND
SB-211-4	2	4	11/14/2000	195	67	60	410	2	<250	ND	<250	ND	<500	ND
SB-211-6	4	6	11/14/2000	194	119	107	1,300	3	<250	ND	<250	ND	<500	ND
SB-211-8	6	8	11/14/2000	194	233	94	12,000	49	1,300	5	<500	ND	<1,000	ND
SB-211-10	8	10	11/14/2000	194	233	197	470	1	3,700	5	<250	ND	<500	ND
SB-211-12	10	12	11/14/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-211-14	12	14	11/14/2000	197	210	177	<830	ND	9,500	15	<830	ND	<1,700	ND
SB-211-16	14	16	11/14/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
SB-211-18	16	18	11/14/2000	199	249	209	1,600	2	4,500	6	<250	ND	<500	ND
SB-211-20	18	20	11/14/2000	202	193	169	1,800	3	1,400	2	<250	ND	<500	ND
SB-211-22	20	22	11/14/2000	200	226	190	9,000	14	8,800	13	<830	ND	<1,700	ND
SB-211-24	22	24	11/14/2000	200	181	151	4,400	8	5,700	11	<500	ND	<1,000	ND
SB-211-26	24	26	11/14/2000	197	207	177	2,300	4	2,400	4	<250	ND	<500	ND
SB-211-28	26	28	11/14/2000	197	219	186	8,300	13	8,700	13	<250	ND	<500	ND
SB-211-30	28	30	11/14/2000	205	190	137	140,000	319	9,500	22	<5,000	ND	<10,000	ND
SB-211-32	30	32	11/14/2000	195	201	178	67,000	102	3,200	5	<2,500	ND	<5,000	ND
SB-211-32B	30	32	11/14/2000	195	163	144	50,000	92	<2,500	ND	<2,500	ND	<5,000	ND
SB-211-34	32	34	11/14/2000	195	163	161	51,000	79	10,000	15	<1,800	ND	<3,600	ND
SB-211-36	34	36	11/14/2000	207	196	163	39,000	71	6,700	12	<1,200	ND	<2,500	ND

Table C-4. Resistive Heating Postdemonstration Soil Sample Results (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-211-38	36	38	11/14/2000	199	265	238	12,000	14	4,200	5	<250	ND	<500	ND
SB-211-40	38	40	11/14/2000	202	197	182	5,800	9	1,400	2	<250	ND	<500	ND
SB-211-42	40	42	11/14/2000	202	317	255	1,300	2	3,000	4	<250	ND	<500	ND
SB-211-44	42	44	11/14/2000	196	218	189	<250	ND	530	1	<250	ND	<500	ND
SB-211-50	Lab Blank		1/14/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-211-EB	EQ		11/14/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND
SB-212-2	0	2	11/14/2000	163	131	126	<250	ND	<250	ND	<250	ND	<500	ND
SB-212-4	2	4	11/14/2000	191	142	121	1,600	3	<250	ND	<250	ND	<500	ND
SB-212-6	4	6	11/14/2000	197	140	135	5,300	10	640	1	<250	ND	<500	ND
SB-212-8	6	8	11/14/2000	194	161	132	5,600	12	2,300	5	<250	ND	<500	ND
SB-212-10	8	10	11/14/2000	198	138	117	7,100	16	2,500	6	<250	ND	<500	ND
SB-212-12	10	12	11/14/2000	191	257	220	<250	ND	3,900	5	<250	ND	<500	ND
SB-212-14	12	14	11/14/2000	197	150	129	660	1	1,400	3	<250	ND	<500	ND
SB-212-16	14	16	11/14/2000	196	178	152	790	1	8,000	14	<500	ND	<1,000	ND
SB-212-18	16	18	11/14/2000	200	195	164	<380	ND	5,100	9	<380	ND	<770	ND
SB-212-20	18	20	11/14/2000	193	193	153	2,600	5	22,000	41	<1,800	ND	<3,600	ND
SB-212-22	20	22	11/14/2000	195	199	169	2,200	4	14,000	23	<1,000	ND	<2,000	ND
SB-212-24	22	24	11/14/2000	191	237	182	3,400	6	45,000	73	<3,100	ND	<6,200	ND
SB-212-26	24	26	11/14/2000	193	211	163	11,000	20	44,000	79	<3,100	ND	<6,200	ND
SB-212-28	26	28	11/14/2000	191	325	263	8,600	10	54,000	62	<3,600	ND	<7,200	ND
SB-212-30	28	30	11/14/2000	193	244	206	5,400	7	33,000	45	<2,500	ND	<5,000	ND
SB-212-32	30	32	11/15/2000	192	188	157	1,900	3	22,000	38	<1,800	ND	<3,600	ND
SB-212-34	32	34	11/15/2000	193	224	190	16,000	23	25,000	37	<1,800	ND	<3,600	ND
SB-212-36	34	36	11/15/2000	199	159	132	290	1	950	2	<250	ND	<500	ND
SB-212-36-DUP	34	36	11/15/2000	194	164	134	630	1	1,500	3	<250	ND	<500	ND
SB-212-38	36	38	11/15/2000	193	201	165	1,600	3	5,200	9	<380	ND	<770	ND
SB-212-40	38	40	11/15/2000	199	263	223	<250	ND	<250	ND	<250	ND	<500	ND
SB-212-42	40	42	11/15/2000	190	300	221	520	1	260	0	<250	ND	<500	ND
SB-212-44	42	44	11/15/2000	195	216	162	1,000	2	390	1	<250	ND	<500	ND
SB-212-45	43	45	11/15/2000	199	216	159	4,300	8	670	1	<250	ND	<500	ND
SB-212-051	Lab Blank		11/15/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-212-EB	EQ		11/15/2000	NA	NA	NA	1		<1	ND	<1	ND	<2	ND

NA: Not available.

ND: Not detected.

NR: No recovery.

EQ: Equipment rinsate blank.

J: Result was estimated but below the reporting limit.

D: Result was quanitified after dilution.

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

Top Depth	*Bottom Depth*	*Pre-Demo SB1*	*Post-Demo SB201*	*Pre-Demo SB2*	*Post-Demo SB202*	*Pre-Demo SB3*	*Post-Demo SB203*	*Pre-Demo SB4*	*Post-Demo SB204*
0	2	8	0.8	NA	ND	9.2	1	ND	1
2	4	5	1.8	NA	ND	0.9	ND	4.6	3
4	6	0.3	2.9	1.7	2.9	0.1 J	1	5.1	ND
6	8	3	1.4	0.7	6.7	0.3 J	3	48.7	5
8	10	11	18	0.4 J	40.2	0.3 J	90	0.2 J	6
10	12	9	13	0.7	29.2	0.3 J	114	4.6	32
12	14	12	ND	ND	9.4	0.3 J	61	NA	NA
14	16	NA	ND	1.1	1.9	0.6	126	8.3	NA
16	18	4	NA	0.7	53	1.3	97	6.5	19
18	20	122	ND	2.5	111	1.0	71	6.0	2
20	22	315	28	2	4,295	8.9	NA	54.1	83
22	24	1,935	60	50	1,248	NA	NA	60	105
24	26	820	3,927	108	102	183	258	9,051	240
26	28	526	401	292	353	109	247	185	195
28	30	941	467	458	5,561	35	1,217	167	403
30	32	19,091	385	295	390	5	287	12,669	197
32	34	349	211	174	465	17	56	112	263
34	36	624	254	176	102	35.5 D	77	100	178
36	38	1,025	265	440	429	1.4 J	308	288	425
38	40	5,874	318	558	474	27	302	848	139
40	42	5,677	186	5	250	115	186	160	388
42	44	368	146	249	335	204	34	167	364
44	46	33,100	364	251	8	220	41	30,223	NA
46	48	37,537	270	41,044	NA	NA	NA	NA	NA

Top Depth	*Bottom Depth*	*Pre-Demo SB5*	*Post-Demo SB205*	*Pre-Demo SB6*	*Post-Demo SB206*	*Post-Demo SB7*	*Post-Demo SB207*	*Pre-Demo SB8*	*Post-Demo SB208*
0	2	ND	6	ND	6	0.6	ND	0.3 J	2
2	4	ND	1	ND	ND	0.1	0	0.2 J	1
4	6	ND	12	ND	6	ND	6	ND	5
6	8	ND	5	ND	3	ND	61	1.1	72
8	10	ND	10	ND	55	1.0	ND	0.5 J	ND
10	12	0.3 J	10	ND	69	0.0	ND	0.8	ND
12	14	ND	17	ND	71	ND	ND	1.2 J	24
14	16	ND	122	ND	76	0.2	1	342	6
16	18	ND	197	1.9	164	0.0	1	0.5 J	27
18	20	5.2	89	ND	119	10	ND	1.7	NA
20	22	27.7	61	3.9	224	31	58	217	33
22	24	1,835	NA	18.6	135	NA	85	329	12
24	26	260	177	10.8	213	143	516	330	29
26	28	5,880	177	69.1	235	330	367	184	31
28	30	542	102	54.6	105	140	186	182	34
30	32	902	150	17.0	86	125	196	157	NA
32	34	5,345	140	17.5	63	91	389	294	52
34	36	23,362	64	11.4	35	139	403	113	63
36	38	8,062	146	20.5	99	260	159	141	2
38	40	28,168	236	11.2	89	113	82	NA	11
40	42	6,534	97	18.8	149	217	511	209	4
42	44	37,104	129	5.8	126	8,802	273	6,711	52
44	46	NA	NA	313.1	NA	NA	NA	NA	160

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

Top Depth	Bottom Depth	Pre-Demo SB9	Post-Demo SB209	Pre-Demo SB10	Post-Demo SB210	Pre-Demo SB10B	Post-Demo SB210B	Pre-Demo SB11	Post-Demo SB211
0	2	ND	ND	ND	ND	SB10B	3	4.1	6
2	4	0.9	ND	ND	ND	Duplicate	2	2.8	2
4	6	ND	4	ND	3		23	2.1	3
6	8	ND	5	3.9	26		20	2.7	49
8	10	6.5	1	2.8	NA		NA	0.7	1
10	12	0.5	1	ND	NA		NA	1.1	NA
12	14	ND	5	1.9	ND		ND	ND	ND
14	16	0.8	4	ND	6		ND	1.2	NA
16	18	0.4	13	ND	NA		1	1.6	2
18	20	5	3	0.7	10		6	ND	3
20	22	14	28	30.9	90		16	9.2	14
22	24	29	34	92.4	46		49	NA	8
24	26	26	64	106	265		569	94	4
26	28	84	36	98	117		310	167	13
28	30	30	28	40.3	170		77	49	319
30	32	2.5	11	4.8	287		27	43.7	102
32	34	ND	NA	ND	209		344	21.4	79
34	36	1.4	5	ND	428		315	2.0	71
36	38	ND	74	ND	264		124	0.0	14
38	40	3.4	54	13.9	242		219	0.4	9
40	42	51	77	12.6	257		236	36.0	2
42	44	67	52	25.4	101		297	46.0	ND
44	46	NA	NA	11.8	59		NA	NA	NA

Top Depth	Bottom Depth	Pre-Demo SB12	Post-Demo SB212
0	2	ND	ND
2	4	ND	3
4	6	ND	10
6	8	NA	12
8	10	ND	16
10	12	2.4	ND
12	14	0.4 J	1
14	16	ND	1
16	18	NA	ND
18	20	ND	5
20	22	15.3	4
22	24	40.1	6
24	26	112.1	20
26	28	256.9	10
28	30	29.6	7
30	32	2.2	3
32	34	0.4	23
34	36	0.2 J	1
36	38	0.7	3
38	40	0.5 J	ND
40	42	16.1	1
42	44	36.5	2
44	46	1.5	8

NA: Not available.

ND: Not detected.

Solid horizontal lines demarcate MFGU. Tan and gray colors are the observed colors from soil samples.

Appendix D. Inorganic and Other Aquifer Parameters

Tables D-1 to D-7

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	Rest Heat Post-Demo	Jul 2001	Pre-Demo	Week 3-4	Week 7-8	Jan. 2000	Apr 2000	ISCO Post-Demo	Rest Heat Post-Demo	Jul 2001
Resistive Heating Plot Wells																
PA-13S	6.87	6.29	NA	NA	7.04	NA	6.31	6.77	-107.9	-83.7	NA	NA	-286.1	NA	-106.80	-17.10
PA-13I	7.38	7.81	NA	NA	8.41	NA	NA	7.44	-73.9	-146.8	NA	NA	-82.5	NA	NA	-68.40
PA-13D	7.24	7.98	NA	NA	8.50	NA	6.54	6.29	-105.8	-71.4	NA	NA	-111.6	NA	-97.00	-237.50
PA-14S	7.13	9.15	NA	NA	6.72	NA	7.59	6.73	-129.6	-196.3	NA	NA	-208.0	NA	-43.80	-17.70
PA-14I	7.51	8.89	NA	NA	6.62	NA	NA	7.06	-118.3	-151.9	NA	NA	-260.1	NA	NA	-88.50
PA-14D	7.45	7.57	NA	NA	NA	NA	6.76	6.31	-141.7	-58.5	NA	NA	-231.0	NA	-249.90	-221.30
Resistive Heating Plot Perimeter Wells																
PA-2S	6.94	7.37	NA	7.50	6.90	6.62	6.98	NA	-58.3	-138.5	NA	-97.6	-277.7	-153.1	-114.20	NA
PA-2I	7.30	6.50	NA	7.50	6.77	6.75	6.85	NA	-31.9	-68.9	NA	-127.0	-102.6	-134.7	-102.50	NA
PA-2D	7.27	6.99	NA	7.46	4.10?	7.00	6.80	NA	-89.8	-163.6	NA	-132.0	-75.7	-112.6	-77.10	NA
PA-7S	6.86	6.59	NA	7.14	6.60	NA	6.59	NA	-82.5	-111.2	NA	-121.6	-157.0	NA	-110.00	NA
PA-7I	7.31	7.26	NA	7.51	6.85	NA	6.77	NA	-33.9	-80.3	NA	-120.4	-89.4	NA	-73.60	NA
PA-7D	7.49	7.00	NA	7.14	7.81	NA	6.78	NA	-56.1	-144.0	NA	-127.9	-58.3	NA	-163.20	NA
PA-10S	6.78	6.72	NA	6.98	6.63	NA	7.16	NA	-119.5	-99.2	NA	-142.8	-121.9	NA	-149.00	NA
PA-10I	6.86	6.72	NA	6.81	6.63	NA	7.05	NA	-129.7	-99.8	NA	-132.4	-125.2	NA	-122.40	NA
PA-10D	7.37	6.48	NA	6.87	7.04	NA	7.74	NA	-131.1	46.2	NA	-125.4	-89.4	NA	-104.50	NA
IW-17S	6.79	5.93	NA	7.85	Dry	NA	Dry	NA	-12.4	-29.5	NA	-122.3	Dry	NA	Dry	NA
IW-17I	7.41	6.92	NA	6.83	6.20	NA	6.61	NA	-12.3	-96.6	NA	-132.5	-76.9	NA	-106.90	NA
IW-17D	7.39	NA	NA	8.43	7.56	NA	7.41	NA	-115.8	-242.3	NA	-144.5	-85.7	NA	-156.60	NA
PA-15	NA	NA	NA	6.86	6.37	NA	6.30	NA	NA	NA	NA	-154.1	-190.4	NA	-76.40	NA
Distant Wells																
PA-1S	7.58	7.79	7.65	8.15	7.54	7.29	7.35	NA	-57.4	1.6	148.2	43.4	-55.0	-117.1	-128.20	NA
PA-1I	7.72	8.39	NM	8.27	7.64	7.60	7.32	NA	-13.3	-19.5	54.8	-94.6	3.1	-65.3	-234.90	NA
PA-1D	7.57	7.88	7.90	7.97	7.52	7.50	6.94	NA	-112.2	-13.4	-762.4	-124.8	-66.8	-90.1	-213.00	NA
PA-8S	6.93	7.08	7.22	6.87	6.66	6.54	6.95	NA	-96.2	-61.8	-115.9	209.6	-33.4	-58.4	-134.90	NA
PA-8I	7.27	7.41	7.52	7.43	7.21	7.16	6.53	NA	-6.6	4.3	-31.8	109.5	-99.2	-114.8	-76.20	NA
PA-8D	7.45	7.66	7.73	7.85	6.86	6.78	6.80	NA	-19.0	9.0	-50.7	87.0	-123.8	-52.8	-110.90	NA
PA-11S	7.02	6.95	6.75	7.45	6.37	NM	8.14	NA	-124.8	-77.8	-76.0	-152.1	-71.3	NM	14.20	NA
PA-11I	7.11	7.25	7.07	7.24	7.01	6.22	7.23	NA	-136.4	-93.9	-133.5	-127.2	-86.0	-75.9	-145.00	NA
PA-11D	7.55	7.69	7.41	7.71	7.45	7.46	7.77	NA	-136.3	-73.2	-96.7	-156.4	-143.9	-133.3	-123.40	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	Rest Heat Post-Demo	Jul 2001	Pre-Demo	Week 3-4	Week 7-8	Jan. 2000	Apr 2000	ISCO Post-Demo	Rest Heat Post-Demo	Jul 2001
Resistive Heating Plot Wells																
PA-13S	0.28	0.86	NA	NA	0.22	NA	0.63	0.84	26.12	43.74	NA	NA	43.71	NA	36.35	36.06
PA-13I	0.27	0.91	NA	NA	0.07	NA	NA	1.11	27.36	30.93	NA	NA	31.12	NA	NA	35.51
PA-13D	0.62	2.21	NA	NA	0.02	NA	0.81	0.30	27.26	44.51	NA	NA	40.86	NA	51.66	41.34
PA-14S	0.31	0.10	NA	NA	0.34	NA	0.60	0.55	26.94	30.29	NA	NA	53.97	NA	41.19	36.23
PA-14I	0.40	0.77	NA	NA	0.15	NA	NA	0.99	27.70	39.99	NA	NA	38.29	NA	NA	37.25
PA-14D	0.10	1.13	NA	NA	0.24	NA	NA	0.35	27.29	43.32	NA	NA	37.70	NA	31.59	41.36
Resistive Heating Plot Perimeter Wells																
PA-2S	0.84	0.42	NA	NA	0.46	0.34	0.41	NA	27.00	27.45	NA	21.57	42.07	34.61	35.19	NA
PA-2I	0.48	0.79	NA	NA	0.39	0.45	0.55	NA	27.03	27.43	NA	24.66	26.68	32.22	36.42	NA
PA-2D	0.80	0.29	NA	NA	0.36	0.68	0.96	NA	26.36	27.80	NA	23.15	30.91	33.29	36.88	NA
PA-7S	0.52	0.41	NA	NA	1.02	NA	0.84	NA	28.84	28.60	NA	29.42	49.21	NA	33.10	NA
PA-7I	0.43	0.58	NA	NA	1.46	NA	0.64	NA	28.53	28.74	NA	26.77	36.14	NA	31.35	NA
PA-7D	0.43	0.73	NA	NA	NA	NA	0.41	NA	28.08	28.33	NA	28.29	39.63	NA	32.42	NA
PA-10S	0.54	0.96	NA	NA	1.24	NA	1.57	NA	23.67	36.77	NA	29.95	45.76	NA	39.87	NA
PA-10I	0.54	0.76	NA	NA	0.85	NA	2.57	NA	23.71	30.73	NA	32.16	32.95	NA	42.08	NA
PA-10D	0.89	0.46	NA	NA	1.47	NA	NA	NA	23.76	29.88	NA	32.10	33.60	NA	39.80	NA
IW-17S	0.46	2.46	NA	NA	Dry	NA	Dry	NA	28.39	40.76	NA	44.32	Dry	NA	Dry	NA
IW-17I	0.47	0.79	NA	NA	0.73	NA	0.47	NA	27.01	29.37	NA	37.25	39.02	NA	28.87	NA
IW-17D	0.34	0.81	NA	NA	0.34	NA	0.42	NA	26.85	28.05	NA	30.45	40.30	NA	47.62	NA
PA-15	NA	NA	NA	NA	0.27	NA	0.52	NA	NA	NA	NA	36.75	32.57	NA	35.15	NA
Distant Wells																
PA-1S	0.43	0.58	1.11	0.18	0.42	0.37	0.51	NA	26.96	27.25	27.62	26.03	24.46	24.96	25.91	NA
PA-1I	0.49	0.41	0.33	1.23	0.64	0.41	0.41	NA	27.60	30.42	27.49	26.10	25.27	25.73	25.92	NA
PA-1D	0.23	0.51	0.39	1.43	0.48	0.48	0.50	NA	27.09	27.43	27.38	25.94	25.64	26.39	25.64	NA
PA-8S	0.69	0.40	0.30	NA	0.47	0.38	1.03	NA	28.91	28.74	27.97	25.55	24.96	26.32	27.53	NA
PA-8I	0.68	0.87	0.51	NA	0.48	0.36	0.94	NA	28.65	28.51	27.58	25.28	25.60	26.40	27.54	NA
PA-8D	0.73	0.56	0.84	NA	0.55	0.68	0.68	NA	27.67	27.78	27.43	25.15	25.76	26.13	26.46	NA
PA-11S	0.47	0.54	0.67	NA	0.50	NM	2.15	NA	24.82	25.58	26.15	25.45	24.83	NM	27.66	NA
PA-11I	0.21	0.66	1.20	NA	0.52	0.56	NA	NA	25.29	25.87	26.01	25.14	24.75	25.80	27.26	NA
PA-11D	0.54	1.09	2.38	NA	0.60	0.66	NA	NA	24.64	25.43	25.51	24.83	24.53	25.12	26.04	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	Rest Heating Post-Demo	Jul 2001	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Rest Heating Post-Demo	Jul 2001
Resistive Heating Plot Wells																
PA-13S	89.1	113.3	NA	NA	10.9	NA	190.2	255.9	0.884	1.013	NA	NA	125.90	NA	4.78	1.51
PA-13I	123.1	50.2	NA	NA	214.5	NA	NA	204.6	0.926	0.991	NA	NA	146.40	NA	NA	1.50
PA-13D	91.2	125.6	NA	NA	185.4	NA	200.0	35.5	3.384	2.663	NA	NA	377.80	NA	29.05	0.47
PA-14S	67.4	0.7	NA	NA	89.0	NA	253.2	255.3	0.776	1.187	NA	NA	251.60	NA	4.03	1.35
PA-14I	78.7	45.1	NA	NA	36.9	NA	NA	184.5	1.171	4.457	NA	NA	272.50	NA	NA	1.49
PA-14D	55.3	138.5	NA	NA	66.0	NA	47.1	51.7	2.836	2.771	NA	NA	224.40	NA	18.18	0.75
Resistive Heating Plot Perimeter Wells																
PA-2S	138.7	58.5	NA	199.4	19.3	143.9	182.8	NA	0.669	0.579	NA	2.762	84.69	3.33	2.93	NA
PA-2I	165.1	128.1	NA	170.0	194.4	162.3	194.5	NA	0.900	1.439	NA	1.723	93.10	3.09	3.10	NA
PA-2D	107.2	33.4	NA	165.0	221.3	184.4	219.9	NA	3.108	0.663	NA	4.294	146.60	5.48	7.67	NA
PA-7S	114.5	85.8	NA	175.4	140.0	NA	187.0	NA	0.854	0.932	NA	1.678	48.07	NA	2.14	NA
PA-7I	163.1	116.7	NA	176.6	207.6	NA	223.4	NA	1.704	1.335	NA	1.887	60.81	NA	2.21	NA
PA-7D	140.9	53.0	NA	169.1	238.7	NA	133.8	NA	2.562	1.840	NA	3.060	39.63	NA	3.93	NA
PA-10S	77.5	97.8	NA	154.2	175.1	NA	148.0	NA	0.804	0.817	NA	3.245	66.59	NA	3.24	NA
PA-10I	67.3	97.2	NA	164.6	171.8	NA	174.6	NA	0.953	0.893	NA	1.980	48.10	NA	2.26	NA
PA-10D	65.9	243.2	NA	171.6	207.6	NA	192.5	NA	3.125	1.414	NA	6.474	121.90	NA	5.19	NA
IW-17S	184.6	167.5	NA	174.7	NA	NA	Dry	NA	0.783	1.333	NA	2.475	Dry	NA	NA	NA
IW-17I	184.7	100.4	NA	164.5	220.1	NA	190.1	NA	2.202	0.835	NA	2.160	111.90	NA	2.01	NA
IW-17D	81.2	-45.3	NA	152.5	211.3	NA	140.4	NA	2.607	2.197	NA	5.720	116.30	NA	4.81	NA
PA-15	NA	NA	NA	142.9	106.6	NA	220.6	NA	NA	NA	NA	4.041	76.05	NA	3.14	NA
Distant Wells																
PA-1S	139.6	198.6	345.2	340.4	242.0	NA	168.8	NA	0.355	0.389	1.221	1.375	1.26	1.39	1.57	NA
PA-1I	183.7	177.5	251.8	202.4	300.1	231.7	62.10	NA	0.676	0.450	0.860	1.861	1.93	1.73	1.30	NA
PA-1D	84.8	183.6	-565.4	172.2	230.2	206.9	84.00	NA	2.225	1.347	4.449	5.392	4.76	4.79	2.32	NA
PA-8S	100.8	135.2	81.1	506.6	263.6	238.6	162.10	NA	0.746	0.666	1.373	5.615	4.92	5.11	4.42	NA
PA-8I	190.4	201.3	165.2	406.5	197.8	182.2	220.80	NA	1.043	1.029	2.688	3.572	3.92	3.81	6.29	NA
PA-8D	178	206.0	146.3	384.0	173.2	244.2	186.10	NA	2.600	2.328	5.216	5.752	7.53	7.22	5.61	NA
PA-11S	72.2	119.2	121.0	144.9	225.7	NA	311.2	NA	0.829	0.737	1.534	1.517	187.20	NM	7.12	NA
PA-11I	60.6	103.1	63.5	169.8	211.0	221.1	152.00	NA	0.878	0.750	1.773	1.848	67.76	11.92	10.73	NA
PA-11D	60.7	123.8	100.3	140.6	153.1	163.7	173.60	NA	2.881	2.474	5.635	6.103	121.60	5.52	5.23	NA

Pre-Demo: Sep 3 to 10, 1999.
Week 3-4: Sep 24 to 20, 1999.
Week 7-8: Oct 19 to 28, 1999.
ISCO Post-Demo: May 8 to 14, 2000.
Resistive Heating Post-Demo: Nov 27 to Dec 2, 2000.
NA: Not available.

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

Compound	**Iron (mg/L)**								**Manganese (mg/L)**								**Potassium (mg/L)**				
SMCL	**0.3 mg/L**								**0.05 mg/L**								**NA**				
Well ID	**Pre-Demo**	**Week 3-4**	**Week 7-8**	**Jan 2000**	**Apr 2000**	**ISCO Post-Demo**	**Restv Heating Post-Demo**	**Jul 2001**	**Pre-Demo**	**Week 3-4**	**Week 7-8**	**Jan 2000**	**Apr 2000**	**ISCO Post-Demo**	**Restv Heating Post-Demo**	**Jul 2001**	**Pre-Demo**	**Apr 2000**	**ISCO Post-Demo**	**Restv Heating Post-Demo**	**Jul 2001**
Resistive Heating Plot Wells																					
PA-13S	2.6	NA	NA	NA	0.24	NA	0.52	0.15	0.963	NA	NA	NA	0.038	NA	0.079	0.071	<5.0	29.1	NA	126	174
PA-13I	0.33	NA	NA	NA	0.4	NA	NA	0.45	0.023	NA	NA	NA	0.065	NA	NA	0.11	12.5	29.7	NA	NA	48.5
PA-13D	<0.05	NA	NA	NA	0.49	NA	<0.25	0.13	<0.015	NA	NA	NA	<0.015	NA	0.13	0.16	20.2	46.4	NA	136	85.5
PA-14S	0.78	NA	NA	NA	0.43	NA	<0.25	<0.05	0.022	NA	NA	NA	0.015	NA	<0.015	<0.015	NA	18.6	NA	9.8	42.6
PA-14I	11.4	NA	NA	NA	8.9	NA	NA	<0.05	1.1	NA	NA	NA	0.17	NA	NA	<0.015	NA	34.1	NA	NA	14.2
PA-14D	0.31	NA	NA	NA	0.38	NA	<0.25	<0.05	0.02	NA	NA	NA	0.028	NA	<0.075	0.021	NA	34.4	NA	143	93.9
Resistive Heating Plot Perimeter Wells																					
PA-2S	1.4	7.00	NA	2.5	0.82	2.7	0.96	NA	0.067	0.072	NA	0.06	0.072	0.071	0.054	NA	NA	99.3	145	NA	NA
PA-2I	0.28	0.62	NA	3.6	2.2	1.6	1.4	NA	0.03	0.066	NA	0.12	0.098	0.048	0.1	NA	NA	19.4	79.5	NA	NA
PA-2I-DUP	NA	NA	NA	NA	2.5	NA	NA	NA	NA	NA	NA	NA	0.096	NA	NA	NA	NA	19.3	NA	NA	NA
PA-2D	9.72	4.20	NA	0.96	4.6	1.1	0.27	NA	1	0.093	NA	0.033	0.098	0.036	0.039	NA	NA	69	40.6	NA	NA
PA-7S	1.2	2.40	NA	4.2	9.8	NA	7.2	NA	0.037	0.068	NA	0.068	0.15	NA	0.074	NA	NA	6.5	NA	NA	NA
PA-7I	<0.05	<0.05	NA	0.26	0.52	NA	0.73	NA	0.03	0.026	NA	0.02	0.043	NA	0.077	NA	NA	13.6	NA	NA	NA
PA-7D	<0.05	1.70	NA	1.6	0.24	NA	0.53	NA	0.028	0.039	NA	0.03	0.054	NA	0.11	NA	NA	29.4	NA	NA	NA
PA-7D-Dup	NA	NA	NA	NA	NA	NA	0.64	NA	NA	NA	NA	NA	NA	NA	0.11	NA	NA	NA	NA	NA	NA
PA-10S	4.8	3.50	NA	4.5	4.5	NA	1.3	NA	0.11	0.039	NA	0.044	0.047	NA	0.029	NA	NA	61.6	NA	NA	NA
PA-10I	12.6	9.50	NA	8.3	3.8	NA	3.5	NA	0.13	0.120	NA	0.12	0.059	NA	0.062	NA	NA	<5	NA	NA	NA
PA-10I-Dup	NA	NA	NA	NA	NA	NA	3.7	NA	NA	NA	NA	NA	NA	NA	0.063	NA	NA	NA	NA	NA	NA
PA-10D	1.2	0.69	NA	0.69	0.3	NA	<0.05	NA	0.029	0.063	NA	0.044	0.021	NA	<0.015	NA	NA	19.2	NA	NA	NA
PA-10D-DUP	NA	NA	NA	0.68	NA	NA	NA	NA	NA	NA	NA	0.044	NA	NA	NA	NA	NA	NA	NA	NA	NA
IW-17S	0.16	3.20	NA	0.099	NS^2	NA	NS^2	NA	0.035	0.088	NA	<0.015	NS^2	NA	NS^2	NA	NA	NS^2	NA	NA	NA
IW-17I	<0.05	1.30	NA	3.2	18.7	NA	2.5	NA	0.068	0.068	NA	0.066	0.16	NA	0.047	NA	NA	8.9	NA	NA	NA
IW-17D	0.24	NA	NA	<0.050	<0.05	NA	0.39	NA	0.053	NA	NA	<0.015	0.024	NA	0.025	NA	NA	24.7	NA	NA	NA
PA-15	NA	NA	NA	<0.050	2.5	NA	5.1	NA	NA	NA	NA	<0.015	0.084	NA	0.11	NA	NA	22.9	NA	NA	NA
Distant Wells																					
PA-1S	0.12	<0.05	<0.05	3.3	0.2	0.45	0.86	NA	<0.015	<0.015	<0.015	0.039	0.015	0.019	0.052	NA	NA	7.3	24.4	NA	NA
PA-1I	<0.05	<0.05	<0.05	0.082	<0.05	<0.05	0.7	NA	<0.015	<0.015	<0.015	<0.015	0.018	0.017	0.13	NA	NA	20.7	22.4	NA	NA
PA-1I-DUP	NA	NA	NA	NA	NA	<0.05	NA	NA	NA	NA	NA	NA	NA	0.019	NA	NA	NA	NA	24	NA	NA
PA-1D	0.11	0.12	0.16	0.15	<0.05	<0.05	0.48	NA	0.037	0.040	0.037	0.026	0.021	0.021	0.12	NA	NA	12.8	13.2	NA	NA
PA-1D-Dup	NA	NA	NA	NA	NA	NA	0.54	NA	NA	NA	NA	NA	NA	NA	0.12	NA	NA	NA	NA	NA	NA
PA-8S	1.9	1.60	2.1	0.16	2.7	4.1	5.6	NA	0.092	0.099	0.095	77.6	4	3.8	1.2	NA	NA	253	277	NA	NA
PA-8S-DUP	NA	NA	2	0.46	NA	NA	NA	NA	NA	NA	0.095	80.7	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-8I	0.23	0.14	<0.05	0.57	0.7	4	4	NA	0.028	0.027	0.028	0.19	0.13	0.43	0.34	NA	NA	16.3	17.8	NA	NA

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

Compound	Iron (mg/L)								Manganese (mg/L)								Potassium (mg/L)				
SMCL	0.3 mg/L								0.05 mg/L								NA				
Well ID	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Restv Heating Post-Demo	Jul 2001	Pre-Demo	Week 3-4	Week 7-8	Jan 2000	Apr 2000	ISCO Post-Demo	Restv Heating Post-Demo	Jul 2001	Pre-Demo	Apr 2000	ISCO Post-Demo	Restv Heating Post-Demo	Jul 2001
PA-8D	<0.05	<0.05	<0.05	0.46	0.31	0.46	2.1	NA	0.029	0.022	<0.015	0.045	0.054	0.11	0.36	NA	NA	21.4	24.5	NA	NA
PA-8D-DUP	NA	<0.05	NA	NA	NA	NA	NA	NA	NA	0.026	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-11S	4.8	3.70	3.3	3.1	22.6	<0.1	<0.05	NA	0.075	0.061	0.053	0.046	0.22	342	0.81	NA	NA	524	1,590	NA	NA
PA-11I	0.9	3.10	1.9	2.2	1.3	38.8	7.4	NA	0.028	0.034	0.043	0.028	0.062	0.27	0.048	NA	NA	10.4	511	NA	NA
PA-11D	2.4	0.60	0.92	0.57	0.9	0.46	0.45	NA	0.026	0.019	0.023	0.019	0.022	0.019	<0.015	NA	NA	19.7	22.6	NA	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.

Shading denotes that the concentration has increased by more than 25 % and exceeded the SMCL.

Shading denotes that the concentration has increased at least doubled over pre-demonstration range in LC34 wells.

1. Sample was not collected due to excess amount of KMnO4 in the flush mount.
2. Sample was not collected because the well was dry.

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

SMCL	Chloride (mg/L)						TDS (mg/L)					
	250 mg/L						500 mg/L					
Well ID	Pre-Demo	Jan 2000	Apr 2000	ISCO Post-Demo	Rest Heat Post-Demo	Jul 2001	Pre-Demo	Jan 2000	Apr 2000	ISCO Post-Demo	Rest Heat Post-Demo	Jul 2001
Resistive Heating Plot Wells												
PA-13S	38	NA	NA	NA	383	277	583	NA	NA	NA	1,750	1,190
PA-13S-DUP	NA	NA	NA	NA	NA	291	587	NA	NA	NA	NA	1,180
PA-13I	66.2	NA	NA	NA	NA	233	NA	NA	NA	NA	NA	925
PA-13D	10.6	NA	NA	NA	4,800	3,610	NA	NA	NA	NA	10,600	8,360
PA-14S	37.4	NA	NA	NA	141	101	548	NA	NA	NA	1,330	772
PA-14I	123	NA	NA	NA	NA	156	724	NA	NA	NA	NA	870
PA-14I-DUP	NA	NA	NA	NA	NA	NA	712	NA	NA	NA	NA	NA
PA-14D	774	NA	NA	NA	3,520	4,790	1,980	NA	NA	NA	7,220	10,700
PA-14D DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Resistive Heating Plot Perimeter Wells												
PA-2S	NA	NA	NA	247	243	NA	NA	NA	NA	NA	915	NA
PA-2I	NA	NA	NA	234	191	NA	NA	NA	NA	NA	1,050	NA
PA-2D	NA	NA	NA	695	960	NA	NA	NA	NA	NA	2,720	NA
PA-7S	NA	NA	NA	NA	119	NA	NA	NA	NA	NA	657	NA
PA-7I	NA	NA	NA	NA	143	NA	NA	NA	NA	NA	752	NA
PA-7D	NA	NA	NA	NA	531	NA	NA	NA	NA	NA	1,260	NA
PA-7D-DUP	NA	NA	NA	NA	522	NA	NA	NA	NA	NA	1,270	NA
PA-10S	NA	NA	NA	NA	342	NA	NA	NA	NA	NA	1,040	NA
PA-10I	NA	NA	NA	NA	130	NA	NA	NA	NA	NA	789	NA
PA-10I-DUP	NA	NA	NA	NA	128	NA	NA	NA	NA	NA	777	NA
PA-10D	NA	NA	NA	NA	701	NA	NA	NA	NA	NA	1,580	NA
IW-17S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IW-17I	NA	NA	NA	NA	73.7	NA	NA	NA	NA	NA	663	NA
IW-17D	NA	NA	NA	NA	640	NA	NA	NA	NA	NA	1,350	NA
PA-15	NA	NA	NA	NA	190	NA	NA	NA	NA	NA	975	NA
Distant Wells												
PA-1S	9.8	33.9	51.6	60.3	56.8	NA	205	326	413	470	583	NA
PA-1I	66.2	92.6	122	105	66.6	NA	424	442	550	513	496	NA
PA-1I-DUP	NA	NA	NA	111	NA	NA	NA	NA	NA	542	NA	NA
PA-1D	627	588	639	639	327	NA	1,380	1,400	1,410	1,490	1,200	NA
PA-1D-Dup	NA	NA	NA	NA	313	NA	NA	NA	NA	NA	1,180	NA
PA-8S	24.2	265	266	273	101	NA	445	1,960	1,710	1,800	1,600	NA
PA-8S-DUP	NA	279	NA	NA	NA	NA	NA	2,050	NA	NA	NA	NA
PA-8I	119	284	418	439	504	NA	706	977	1,210	1,240	2,200	NA
PA-8D	774	822	819	788	640	NA	1,410	1,490	2,550	2,520	1,910	NA
PA-8D-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-11S	36.7	34.1	678	397	357	NA	531	403	2,760	4,710	2,900	NA
PA-11I	49	48.5	248	1230	635	NA	549	557	1,140	4,500	3,790	NA
PA-11D	819	749	771	756	737	NA	1,540	1,510	1,820	1,750	1,670	NA
PA-11D-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	1,760	NA	NA

Pre-Demo: Sep 3 to 10, 1999.
Week 3-4: Sep 24 to 20, 1999.
Week 7-8: Oct 19 to 28, 1999.
ISCO Post-Demo: May 8 to 14, 2000.
Resistive Heating Post-Demo: Nov 27 to Dec 2, 2000.
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.

Table D-4. Other Parameter Results of Groundwater Samples

	Cations (mg/L)									Anions (mg/L)								
	Calcium			Magnesium			Sodium			NO_3-NO_2			Sulfate			Alk as $CaCO_3$		
Well ID	Pre-Demo	Post-Demo	Jul 2001	Pre-Demo	Post-Demo	July 2001	Pre-Demo	Post-Demo	Jul 2001	Pre-Demo	Post-Demo	July 2001	Pre-Demo	Post-Demo	July 2001	Pre-Demo	Post-Demo	Jul 2001
Resistive Heating Plot Wells																		
PA-13S	143	233	97.4	23.4	54.4	40	23.9	161	113	<0.1	<0.1	<0.1	74	169	123	479	588	424
PA-13I	70.1	NA	153	54	NA	76.5	33.1	NA	96.7	<0.1	NA	<0.1	64.8	NA	150	351	NA	243
PA-13D	113	819	647	113	51.4	75	369	2,070	1,530	<0.1	<0.1	0.21	78.3	166	139	410	231	268
PA-14S	97.4	6.6	55.3	37.4	<1	10.6	17.4	467	138	<0.1	<0.1	<0.1	39	37.1	18.6	337	898	388
PA-14I	60.3	NA	13.6	73.7	NA	1.2	120	NA	258	<0.1	NA	<0.1	104	NA	30	465	NA	434
PA-14D	93.1	1,060	662	90.3	30	30.2	325	3,130	2,490	<0.1	<0.1	<0.1	68.3	117	163	343	421	394
Resistive Heating Plot Perimeter Wells																		
PA-2S	NA	77.7	NA	NA	2.6	NA	NA	NA	NA	NA	<0.1	NA	NA	57.7	NA	NA	323	NA
PA-2I	NA	205	NA	NA	18.8	NA	NA	NA	NA	NA	0.11	NA	NA	149	NA	NA	467	NA
PA-2D	113	186	NA	NA	229	NA	NA	NA	NA	NA	0.75	NA	NA	146	NA	NA	663	NA
PA-7S	NA	184	NA	NA	5.9	NA	NA	NA	NA	NA	<0.1	NA	NA	<5	NA	NA	420	NA
PA-7I	NA	166	NA	NA	26.7	NA	NA	NA	NA	NA	<0.1	NA	NA	<10	NA	NA	439	NA
PA-7D	NA	104	NA	NA	38.1	NA	NA	NA	NA	NA	<0.1	NA	NA	36.7	NA	NA	272	NA
PA-7D-DUP	NA	103	NA	NA	31.7	NA	NA	NA	NA	NA	<0.1	NA	NA	36.6	NA	NA	273	NA
PA-10S	NA	138	NA	NA	11	NA	NA	NA	NA	NA	<0.1	NA	NA	<10	NA	NA	335	NA
PA-10I	NA	186	NA	NA	11.8	NA	NA	NA	NA	NA	<0.1	NA	NA	85.4	NA	NA	356	NA
PA-10I-DUP	NA	193	NA	NA	12.2	NA	NA	NA	NA	NA	<0.1	NA	NA	86.2	NA	NA	355	NA
PA-10D	NA	71.7	NA	NA	71.6	NA	NA	NA	NA	NA	<0.1	NA	NA	68.4	NA	NA	293	NA
IW-17S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IW-17I	NA	144	NA	NA	17.6	NA	NA	NA	NA	NA	<0.1	NA	NA	33.7	NA	NA	475	NA
IW-17D	NA	72.2	NA	NA	64.2	NA	NA	NA	NA	NA	<0.1	NA	NA	57.3	NA	NA	212	NA
PA-15	NA	202	NA	NA	10.7	NA	NA	NA	NA	NA	<0.1	NA	NA	62.4	NA	NA	520	NA
Distant Wells																		
PA-1S	NA	128	NA	NA	8.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	310	NA
PA-1I	NA	83.2	NA	NA	19.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	255	NA
PA-1D	NA	119	NA	NA	29.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	230	NA
PA-1D-DUP	NA	117	NA	NA	28.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	234	NA
PA-8S	NA	51	NA	NA	11.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	840	NA
PA-8I	NA	202	NA	NA	190	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	933	NA
PA-8D	NA	151	NA	NA	152	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	632	NA
PA-11S	NA	38	NA	NA	32.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	811	NA
PA-11I	NA	126	NA	NA	40.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	923	NA
PA-11D	NA	92.8	NA	NA	100	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	306	NA

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

	Chromium (mg/L)			Nickel (mg/L)			BOD (mg/L)			TOC (mg/L)		
Well ID	**Pre-Demo**	**Post-Demo**	**Jul 2001**	**Pre-Demo**	**Post-Demo**	**Jul 2001**	**Pre-Demo**	**Post-Demo**	**Jul 2001**	**Pre-Demo**	**Post-Demo**	**Jul 2001**
Resistive Heating Plot Wells												
PA-13S	NA	NA	NA	NA	NA	NA	20	32.4	25.8	5.6	44.8	39.6
PA-13I	NA	NA	NA	NA	NA	NA	<3	NA	3.3	7.1	NA	14.9
PA-13D	NA	NA	NA	NA	NA	NA	13.2	360	360	39.6	300	273
PA-14S	NA	NA	<0.010	NA	NA	<0.040	<3	42	22.2	5.7	34.7	18.7
PA-14I	NA	NA	<0.010	NA	NA	<0.040	8.9	NA	3.7	23.4	NA	8.9
PA-14D	NA	NA	<0.010	NA	NA	<0.040	6	288	560	9	270	326
Resistive Heating Plot Perimeter Wells												
PA-2S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-2I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-2D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-7S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-7I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-7D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-7D-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-10S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-10I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-10I-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-10D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IW-17S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IW-17I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IW-17D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Distant Wells												
PA-1S	NA	NA	<0.010	NA	NA	<0.040	NA	NA	NA	NA	NA	NA
PA-1I	NA	NA	<0.010	NA	NA	<0.040	NA	NA	NA	NA	NA	NA
PA-1D	NA	NA	<0.010	NA	NA	<0.040	NA	NA	NA	NA	NA	NA
PA-8S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-8I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-8D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-11S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-11I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PA-11D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes:

Pre-Demo: Sep 3 to 10, 1999.

Post-Demo: Nov 27 to Dec 2, 2000.

NA: Not available.

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

Table D-5. 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
OX-SE-21	8/29/2000	16	SPH-SE-13	4/11/2000	1,300
OX-SE-22	8/29/2000	130	SPH-SE-21	8/30/2000	<0.42
OX-SE-23	8/30/2000	180	SPH-SE-22	8/30/2000	1
Steam Injection Plot			SPH-SE-23	8/30/2000	<870
CP-SE-1	11/17/1999	< 0.39	SPH-SE-24	8/31/2000	500
CP-SE-2	11/17/1999	< 0.39	SPH-SE-25	9/1/2000	59.00
CP-SE-3	11/17/1999	< 0.41	SPH-SE-26	9/1/2000	17
SI-SE-4	1/18/2000	12	SPH-SE-27	11/30/2000	3,100
SI-SE-5	1/18/2000	13	SPH-SE-28	11/30/2000	10,000
SI-SE-6	1/18/2000	13	SPH-SE-29	12/1/2000	11,000
SI-SE-7	4/11/2000	2.2	SPH-SE-30	12/2/2000	9
SI-SE-8	4/11/2000	11	SPH-SE-31	12/2/2000	1
SI-SE-9	4/11/2000	2.7	SPH-SE-32	12/4/2000	<0.40
SI-SE-33	12/4/2000	1.2	***Background***		
SI-SE-34	12/5/2000	1.1	DW-SE-1	10/1/1999	< 0.42
SI-SE-35	12/5/2000	<0.40	DW-SE-2	10/8/1999	< 0.44
Ambient Air at Shoulder Level			DW-SE-3	10/25/1999	0.44
SPH-SE-14	5/9/2000	<0.39[a]	DW-SE-4	10/22/1999	6,000[b]
SPH-SE-15	5/9/2000	<0.39[a]	DW-SE-5	1/17/2000	< 0.38
SPH-SE-C27	9/1/2000	<0.88	DW-SE-6	4/11/2000	0.43
DW-C1	4/11/2000	2.1[c]	DW-SE-7	4/11/2000	0.86
DW-C2	5/9/2000	<0.39	DW-SE-8	4/11/2000	0.79
DW-C3	5/9/2000	<0.39	DW-SE-36	12/6/2000	<0.40
DW-C21	8/31/2000	0.86[c]	DW-SE-37	12/6/2000	0.49
DW-C22	9/1/2000	<0.58[c]	DW-SE-38	12/7/2000	<0.40

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 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.

Table D-6. TOC Results of Soil Samples

Pre-Demo			Post-Demo		
Sample ID	SW9060 (mg/kg)	Walkley-Black (mg/kg)	Sample ID	SW9060 (mg/kg)	Walkley-Black (mg/kg)
Resisitve Heating Plot					
SB-5-28TOC	NA	<0.20	SB-204-18TOC	10,500	<100
SB-5-38TOC	NA	<0.20	SB-204-30TOC	16,800	686
SB-5-45TOC	NA	<0.20	SB-204-40TOC	12,200	202
SB-5-45TOCB	NA	<0.20	SB-211-22TOC	7,740	<167
SB-8-24TOC	NA	0.20	SB-211-30TOC	11,100	603
SB-8-32TOC	NA	<0.20	SB-211-40TOC	18,000	986
SB-8-38TOC	NA	0.29	NA	NA	NA

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

Table D-7. CVOC Results of Perimeter Soil Cores

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	**Top Depth**	**Bottom Depth**	**Sample Date**	**MeOH (g)**	**Wet Soil Weight (g)**	**Dry Soil 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)**
DB-1-266	0	2	8/30/2000	193	165	153	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-267	2	4	8/30/2000	192	139	121	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-268	4	6	8/30/2000	192	181	150	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-269	6	8	8/30/2000	193	285	236	<250	ND	1,600	2.36	<250	ND	<500	ND
DB-1-270	10	12	8/30/2000	192	225	186	930	1.41	1,200	1.77	<250	ND	<500	ND
DB-1-271	12	14	8/30/2000	192	309	260	460	0.52	430	0.63	<250	ND	<500	ND
DB-1-272	14	16	8/30/2000	193	160	137	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-273	16	18	8/30/2000	194	140	119	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-274	16	18	8/30/2000	192	150	128	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-275	18	20	8/30/2000	193	216	174	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-276	20	22	8/30/2000	190	216	168	<250	ND	<250	ND	<250	ND	520	0.81
DB-1-277	22	24	8/30/2000	193	311	232	<250	ND	<250	ND	<250	ND	1,600	2.57
DB-1-278	24	26	8/30/2000	191	256	196	<250	ND	<250	ND	<250	ND	1,200	1.89
DB-1-279	26	28	8/30/2000	191	296	233	<250	ND	<250	ND	<250	ND	1,500	2.30
DB-1-280	28	30	8/30/2000	192	231	186	<250	ND	<250	ND	<250	ND	750	1.13
DB-1-281	30	32	8/30/2000	191	315	230	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-282	32	34	8/30/2000	189	249	174	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-283	34	36	8/30/2000	192	236	178	1,200	2.03	<250	ND	<250	ND	<500	ND
DB-1-284	36	38	8/30/2000	194	255	204	460	0.67	<250	ND	<250	ND	<500	ND
DB-1-285	38	40	8/30/2000	193	294	239	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-286	Blank		8/30/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-287	Blank		8/31/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
DB-1-288	Blank		8/31/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
PA-201-1	0	2	8/14/2000	198	184	185	6,400	8.6	<250	ND	<250	ND	<500	ND
PA-201-2	2	4	8/14/2000	185	195	189	<250	ND	<250	ND	<250	ND	<500	ND
PA-201-3	4	6	8/14/2000	184	220	209	560	0.7	<250	ND	<250	ND	<500	ND
PA-201-103	6	8	8/21/2000	194	230	205	920	1.2	<250	ND	<250	ND	<500	ND
PA-201-104	8	10	8/21/2000	193	334	285	<250	ND	<250	ND	<250	ND	<500	ND
PA-201-105	10	12	8/21/2000	195	257	222	<250	ND	<250	ND	<250	ND	<500	ND
PA-201-106	12	14	8/21/2000	193	239	205	1,100	1.5	290	0.42	<250	ND	<500	ND
PA-201-107	14	16	8/21/2000	187	260	218	3,600	4.6	1,900	2.77	<250	ND	<500	ND
PA-201-108	16	18	8/21/2000	192	301	254	820	0.9	1,300	1.89	<250	ND	<500	ND
PA-201-109	18	20	8/21/2000	193	251	205	1,800	2.5	2,500	3.73	<250	ND	<500	ND
PA-201-110	20	22	8/21/2000	195	213	177	1,300	2.1	2,300	3.38	<250	ND	<500	ND
PA-201-111	20	22	8/21/2000	194	243	199	4,500	6.5	3,800	5.65	<250	ND	<500	ND
PA-201-112	22	24	8/21/2000	196	293	237	10,000	12.8	7,800	11.72	<500	ND	<1,000	ND

Table D-7. CVOC Results of Perimeter Soil Cores (Continued)

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Wet Soil Weight (g)	Dry Soil 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)
PA-201-113	24	26	8/21/2000	192	358	280	<1,000	ND	16,000	24.71	<1,000	ND	<2,000	ND
PA-201-114	26	28	8/21/2000	194	334	258	<1,200	ND	20,000	31.21	<1,200	ND	<2,500	ND
PA-201-115	28	30	8/21/2000	194	351	291	<500	ND	16,000	23.55	<500	ND	1,400	2.06
PA-201-116	30	32	8/21/2000	195	363	301	<250	ND	7,600	11.19	<250	ND	1,000	1.47
PA-201-117	32	34	8/21/2000	195	347	271	<360	ND	5,600	8.66	<360	ND	760	1.18
PA-201-118	34	36	8/21/2000	193	264	196	<250	ND	1,500	2.42	<250	ND	<500	ND
PA-201-119	36	38	8/21/2000	194	284	200	<250	ND	550	0.93	<250	ND	<500	ND
PA-201-120	38	40	8/21/2000	193	290	214	<250	ND	<250	ND	<250	ND	<500	ND
PA-201-121	40	42	8/21/2000	190	313	246	<250	ND	<250	ND	<250	ND	<500	ND
PA-201-122	42	44	8/21/2000	192	381	293	<250	ND	<250	ND	<250	ND	<500	ND
PA-201-123	44	46	8/21/2000	192	248	184	<250	ND	<250	ND	<250	ND	<500	ND
PA-201-320	Blank		9/1/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
PA-202-2	0	2	12/12/2000	199	121	121	990	2	<250	ND	<250	ND	<500	ND
PA-202-4	2	4	12/12/2000	195	163	160	480	1	<250	ND	<250	ND	<500	ND
PA-202-6	4	6	12/12/2000	197	125	112	<250	ND	<250	ND	<250	ND	<500	ND
PA-202-8	6	8	12/12/2000	193	126	110	660	2	<250	ND	<250	ND	<500	ND
PA-202-10	8	10	12/12/2000	203	141	121	<250	ND	<250	ND	<250	ND	<500	ND
PA-202-12	10	12	12/12/2000	199	173	148	880	2	<250	ND	<250	ND	<500	ND
PA-202-14	12	14	12/12/2000	193	177	154	520	1	<250	ND	<250	ND	<500	ND
PA-202-16	14	16	12/12/2000	203	184	152	250	0	420	1	<250	ND	<500	ND
PA-202-18	16	18	12/12/2000	195	188	159	400,000	694	<25,000	ND	<25,000	ND	<50,000	ND
PA-202-20	18	20	12/12/2000	199	191	161	12,000	21	<500	ND	<500	ND	<1,000	ND
PA-202-22	20	22	12/12/2000	197	163	136	77,000	156	<5,000	ND	<5,000	ND	<10,000	ND
PA-202-24	22	24	12/12/2000	202	141	117	250,000	598	<12,000	ND	<12,000	ND	<25,000	ND
PA-202-26	24	26	12/12/2000	189	186	142	400,000	798	<25,000	ND	<25,000	ND	<50,000	ND
PA-202-28	26	28	12/12/2000	198	185	149	180,000	346	<10,000	ND	<10,000	ND	<20,000	ND
PA-202-28-DUP	26	28	12/12/2000	200	192	156	170,000	315	<10,000	ND	<10,000	ND	<20,000	ND
PA-202-30	28	30	12/12/2000	194	230	187	2,500,000 D	3,858	<25,000	ND	<25,000	ND	<50,000	ND
PA-202-32	30	32	12/12/2000	198	210	176	8,100,000 D	13,100	<120,000	ND	<120,000	ND	<250,000	ND
PA-202-34	32	34	12/12/2000	197	258	188	1,200,000	2,039	<62,000	ND	<62,000	ND	<120,000	ND
PA-202-36	34	36	12/12/2000	192	185	141	2,400,000 D	4,886	<17,000	ND	<17,000	ND	<33,000	ND
PA-202-38	36	38	12/12/2000	192	223	164	370,000	681	<21,000	ND	<21,000	ND	<42,000	ND
PA-202-40	38	40	12/12/2000	195	222	176	250,000	416	<12,000	ND	<12,000	ND	<25,000	ND
PA-202-43	41	43	12/12/2000	197	254	207	310,000	444	<17,000	ND	<17,000	ND	<33,000	ND
PA-202-45	43	45	12/12/2000	198	198	147	230,000	472	<12,000	ND	<12,000	ND	<25,000	ND
PA-202-EB	EQ		12/12/2000	NA	NA	NA	20		<1	ND	<1	ND	<2	ND

Table D-7. CVOC Results of Perimeter Soil Cores (Continued)

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	**Top Depth**	**Bottom Depth**	**Sample Date**	**MeOH (g)**	**Wet Soil Weight (g)**	**Dry Soil 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)**
PA-202-11	0	2	8/14/2000	193	240	223	<250	ND	<250	ND	<250	ND	<500	ND
PA-202-12	2	4	8/14/2000	191	173	169	620	0.90	<250	ND	<250	ND	<500	ND
PA-202-13	4	6	8/14/2000	186	200	191	<250	ND	<250	ND	<250	ND	<500	ND
PA-202-180	6	8	8/24/2000	193	230	195	<250	ND	<250	ND	<250	ND	<500	ND
PA-202-181	8	10	8/24/2000	193	347	295	2,600	2.6	870	1.25	<250	ND	<500	ND
PA-202-182	12	14	8/24/2000	194	276	228	640	0.8	540	0.80	<250	ND	<500	ND
PA-202-183	16	18	8/24/2000	192	292	240	6,600	8.1	2,000	2.96	<250	ND	<500	ND
PA-202-184	18	20	8/24/2000	192	197	72	9,400	48.0	940	2.82	<250	ND	<500	ND
PA-202-185	20	22	8/24/2000	193	338	295	150,000	146.1	<4,200	ND	<4,200	ND	<8,400	ND
PA-202-186	22	24	8/24/2000	193	357	238	74,000	113.0	<2,500	ND	<2,500	ND	<5,000	ND
PA-202-325	Blank		9/1/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
PA-207-94	0	2	8/19/2000	193	185	181	980	1.3	600	0.77	<250	ND	<500	ND
PA-207-95	2	4	8/19/2000	193	174	147	2,200	4.1	<250	ND	<250	ND	<500	ND
PA-207-96	4	6	8/19/2000	193	183	168	710	1.1	<250	ND	<250	ND	<500	ND
PA-207-145	6	8	8/22/2000	196	176	153	540	1.0	<250	ND	<250	ND	<500	ND
PA-207-146	8	10	8/22/2000	196	229	199	2,700	3.8	590	0.84	<250	ND	<500	ND
PA-207-147	10	12	8/22/2000	199	261	223	6,600	8.6	1,200	1.72	<250	ND	<500	ND
PA-207-148	12	14	8/22/2000	193	172	152	5,800	10.1	2,400	3.35	<250	ND	<500	ND
PA-207-149	14	16	8/22/2000	192	210	179	58,000	88.8	8,400	12.09	<2,100	ND	<4,200	ND
PA-207-150	16	18	8/22/2000	193	253	214	67,000	88.7	7,800	11.29	<3,600	ND	<7,200	ND
PA-207-151	18	20	8/22/2000	193	272	235	4,100	4.9	15,000	21.35	<1,000	ND	<2,000	ND
PA-207-152	20	22	8/22/2000	195	271	230	9,900	12.4	16,000	23.11	<1,200	ND	<2,500	ND
PA-207-153	22	24	8/22/2000	194	251	197	1,700	2.6	8,700	13.40	<620	ND	1,700	2.62
PA-207-154	24	26	8/22/2000	195	306	239	<620	ND	8,200	12.68	<620	ND	2,700	4.17
PA-207-155	26	28	8/22/2000	193	219	169	900	1.6	3,700	5.78	<250	ND	<500	ND
PA-207-156	28	30	8/22/2000	195	245	198	760	1.1	2,200	3.31	<250	ND	<500	ND
PA-207-157	30	32	8/22/2000	193	240	203	21,000	29.1	6,100	8.83	<1,000	ND	<2,000	ND
PA-207-158	32	34	8/22/2000	194	249	222	15,000 D	18.4	3,200	4.44	<250	ND	<500	ND
PA-207-159	34	36	8/22/2000	194	178	133	<1,000	ND	15,000	24.06	<1,000	ND	<2,000	ND
PA-207-160	34	36	8/22/2000	193	162	121	<830	ND	13,000	20.86	<830	ND	<1,700	ND
PA-207-161	36	38	8/22/2000	194	199	157	4,300	7.9	7,800	11.96	<500	ND	<1,000	ND
PA-207-162	38	40	8/22/2000	192	303	242	<250	ND	570	0.87	<250	ND	<500	ND
PA-207-163	40	42	8/22/2000	192	245	197	<250	ND	<250	ND	<250	ND	<500	ND
PA-207-164	41.5	43.5	8/22/2000	192	256	194	<250	ND	<250	ND	<250	ND	<500	ND
PA-207-165	43	45	8/22/2000	193	214	157	410	0.8	<250	ND	<250	ND	<500	ND
PA-207-318	Blank		9/1/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND

Table D-7. CVOC Results of Perimeter Soil Cores (Continued)

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	**Top Depth**	**Bottom Depth**	**Sample Date**	**MeOH (g)**	**Wet Soil Weight (g)**	**Dry Soil 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)**
PA-208-97	0	2	8/19/2000	194	211	203	2,800	3.5	<250	ND	<250	ND	<500	ND
PA-208-98	2	4	8/19/2000	194	214	210	970	1.2	<250	ND	<250	ND	<500	ND
PA-208-99	4	6	8/19/2000	194	187	180	630	0.9	<250	ND	<250	ND	<500	ND
PA-208-124	6	8	8/21/2000	195	313	274	<250	ND	<250	ND	<250	ND	<500	ND
PA-208-125	8	10	8/21/2000	193	312	265	<250	ND	<250	ND	<250	ND	<500	ND
PA-208-126	10	12	8/21/2000	197	326	253	270	0.3	350	0.54	<250	ND	<500	ND
PA-208-127	12	14	8/21/2000	196	297	271	<250	ND	<250	ND	<250	ND	<500	ND
PA-208-128	14	16	8/21/2000	192	248	207	<380	ND	6,000	8.78	<380	ND	<770	ND
PA-208-129	16	18	8/21/2000	193	195	169	<250	ND	1,900	2.70	<250	ND	<500	ND
PA-208-130	18	20	8/21/2000	193	302	255	27,000	30.8	4,900	7.11	<1,000	ND	<2,000	ND
PA-208-131	20	22	8/21/2000	195	232	200	23,000	32.1	4,200	5.99	<1,000	ND	<2,000	ND
PA-208-132	22	24	8/21/2000	193	301	243	82,000	102.0	14,000	21.06	<4,200	ND	<8,300	ND
PA-208-133	24	26	8/21/2000	193	301	233	190,000	254.7	29,000	45.17	<6,200	ND	<12,000	ND
PA-208-134	24	26	8/21/2000	191	267	205	110,000	163.0	19,000	29.80	<4,200	ND	<8,300	ND
PA-208-135	26	28	8/21/2000	191	293	221	76,000	107.9	56,000	89.13	<3,100	ND	<6,200	ND
PA-208-136	28	30	8/21/2000	192	383	298	29,000	31.9	55,000	85.31	<4,200	ND	<8,300	ND
PA-208-137	30	32	8/21/2000	192	239	196	63,000	91.9	12,000	17.82	<2,100	ND	<4,200	ND
PA-208-138	32	34	8/21/2000	194	338	285	55,000	57.6	13,000	18.87	<2,500	ND	<5,000	ND
PA-208-139	34	36	8/21/2000	194	337	245	25,000	34.4	39,000	64.01	<2,500	ND	<5,000	ND
PA-208-140	36	38	8/21/2000	195	276	190	25,000	43.8	23,000	39.52	<1,200	ND	<2,500	ND
PA-208-141	38	40	8/21/2000	193	260	191	84,000	137.8	16,000	26.03	<2,500	ND	<5,000	ND
PA-208-142	40	42	8/21/2000	194	275	203	94,000	147.1	7,600	12.32	<4,200	ND	<8,300	ND
PA-208-143	41.5	43.5	8/21/2000	192	305	216	170,000	261.3	<8,300	ND	<8,300	ND	<17,000	ND
PA-208-144	43	45	8/21/2000	194	239	173	130,000	234.1	<6,200	ND	<6,200	ND	<12,000	ND
PA-208-319	Blank		9/1/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
PA-211-207	0	2	8/25/2000	194	232	228	3,000	3.3	<250	ND	<250	ND	<500	ND
PA-211-208	2	4	8/25/2000	194	257	248	NA	0.0	NA	NA	NA	NA	NA	NA
PA-211-209	4	6	8/25/2000	194	241	233	2,300	2.5	<250	ND	<250	ND	<500	ND
PA-211-210	6	8	8/25/2000	195	217	205	2,800	3.5	<250	ND	<250	ND	<500	ND
PA-211-211	8	10	8/25/2000	190	171	152	290	0.5	<250	ND	<250	ND	<500	ND
PA-211-212	10	12	8/25/2000	195	166	143	530	1.0	340	0.49	<250	ND	<500	ND
PA-211-213	12	14	8/25/2000	195	253	217	11,000	14.3	2,300	3.29	<420	ND	<850	ND
PA-211-214	14	16	8/25/2000	194	226	190	18,000	26.7	1,400	2.04	<620	ND	<1,200	ND
PA-211-215	16	18	8/25/2000	192	188	155	18,000	32.1	770	1.14	<620	ND	<1,200	ND
PA-211-216	18	20	8/25/2000	193	221	178	2,000	3.2	<250	ND	<250	ND	<500	ND
PA-211-217	20	22	8/25/2000	193	268	231	2,800	3.4	<250	ND	<250	ND	<500	ND

Table D-7. CVOC Results of Perimeter Soil Cores (Continued)

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Wet Soil Weight (g)	Dry Soil 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)
PA-211-218	22	24	8/25/2000	197	264	225	2,600,000	3,332.2	<120,000	ND	<120,000	ND	<250,000	ND
PA-211-219	24	26	8/25/2000	191	218	180	79,000	122.8	<4,200	ND	<4,200	ND	<8,400	ND
PA-211-220	26	28	8/25/2000	191	219	188	660,000	957.6	<25,000	ND	<25,000	ND	<50,000	ND
PA-211-221	28	30	8/28/2000	193	148	127	89,000	185.9	<3,100	ND	<3,100	ND	<6,200	ND
PA-211-222	30	32	8/28/2000	193	201	163	270,000	467.6	<12,000	ND	<12,000	ND	<25,000	ND
PA-211-223	32	34	8/28/2000	251	261	251	230,000	300.3	<12,000	ND	<12,000	ND	<25,000	ND
PA-211-224	34	36	8/28/2000	195	209	167	120,000	207.5	<5,000	ND	<5,000	ND	<10,000	ND
PA-211-225	36	38	8/28/2000	196	201	174	130,000	205.5	<6,200	ND	<6,200	ND	<12,000	ND
PA-211-226	38	40	8/28/2000	192	317	252	750,000	916.8	<42,000	ND	<42,000	ND	<83,000	ND
PA-211-227	38	40	8/28/2000	194	401	318	930,000	960.9	<50,000	ND	<50,000	ND	<100,000	ND
PA-211-228	40	42	8/28/2000	195	270	209	1,600,000	2,356.6	<72,000	ND	<72,000	ND	<140,000	ND
PA-211-229	42	44	8/28/2000	193	300	240	190,000	240.9	<10,000	ND	<10,000	ND	<20,000	ND
PA-211-314	Blank		9/1/2000	NA	NA	NA	370	0.5	<250	ND	<250	ND	<500	ND
LC34B214-2	0	2	12/13/2000	191	106	104	<250	ND	<250	ND	<250	ND	<500	ND
LC34B214-4	2	4	12/13/2000	198	156	145	<250	ND	<250	ND	<250	ND	<500	ND
LC34B214-6	4	6	12/13/2000	191	135	121	<250	ND	260	1	<250	ND	<500	ND
LC34B214-8	6	8	12/13/2000	196	162	141	<250	ND	1,100	2	<250	ND	<500	ND
LC34B214-10	8	10	12/13/2000	201	122	108	<250	ND	12,000	30	<250	ND	<500	ND
LC34B214-12	10	12	12/13/2000	198	111	92	<250	ND	11,000 D	32	<250	ND	<500	ND
LC34B214-14	12	14	12/13/2000	202	190	161	<250	ND	17,000 D	30	<250	ND	<500	ND
LC34B214-16	14	16	12/13/2000	200	190	160	6,200	11	15,000 D	27	<250	ND	<500	ND
LC34B214-18	16	18	12/13/2000	192	245	205	2,600	4	150,000 D	207	<250	ND	<500	ND
LC34B214-20	18	20	12/13/2000	198	109	96	540	1	6,500	18	<250	ND	<500	ND
LC34B214-20-DUP	18	20	12/13/2000	200	120	103	560	1	7,300	19	<250	ND	<500	ND
LC34B214-22	20	22	12/13/2000	195	166	133	4,700	10	12,000	25	<250	ND	<500	ND
LC34B214-24	22	24	12/13/2000	194	209	160	1,500	3	3,800	7	<250	ND	<500	ND
LC34B214-26	24	26	12/13/2000	194	219	171	<500	ND	6,600	11	<500	ND	<1,000	ND
LC34B214-28	26	28	12/13/2000	203	191	153	<380	ND	7,000	13	<380	ND	<770	ND
LC34B214-30	28	30	12/13/2000	198	247	209	<380	ND	6,600	9	<380	ND	<770	ND
LC34B214-32	30	32	12/13/2000	193	147	121	<250	ND	3,500	8	<250	ND	<500	ND
LC34B214-34	32	34	12/13/2000	191	151	120	<250	ND	1,400	3	<250	ND	<500	ND
LC34B214-36	34	36	12/13/2000	194	231	175	<250	ND	1,200	2	<250	ND	<500	ND
LC34B214-39	37	39	12/13/2000	197	199	155	<250	ND	<250	ND	<250	ND	<500	ND
LC34B214-41	39	41	12/13/2000	189	270	216	<250	ND	<250	ND	<250	ND	<500	ND
LC34B214-87	Lab Blank		12/13/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
LC34B214-88	Lab Blank		12/13/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND

Table D-7. CVOC Results of Perimeter Soil Cores (Continued)

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Wet Soil Weight (g)	Dry Soil 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)
LC34B214-EB	EQ		12/13/2000	NA	NA	NA	<1	ND	<1	ND	<1	ND	<2	ND
LC34B314-2	0	2	12/14/2000	194	124	122	<250	ND	<250	ND	<250	ND	<500	ND
LC34B314-4	2	4	12/14/2000	199	147	138	<250	ND	820	2	<250	ND	<500	ND
LC34B314-6	4	6	12/14/2000	199	112	104	<250	ND	<250	ND	<250	ND	<500	ND
LC34B314-8	6	8	12/14/2000	197	183	169	<250	ND	350	1	<250	ND	<500	ND
LC34B314-10	8	10	12/14/2000	189	194	166	3,100	5	12,000	19	<830	ND	<1,700	ND
LC34B314-12	10	12	12/14/2000	195	149	126	1,900	4	7,200	15	<250	ND	<500	ND
LC34B314-12-DUP	10	12	12/14/2000	204	172	145	2,500	5	9,200	18	<250	ND	<500	ND
LC34B314-14	12	14	12/14/2000	199	170	141	2,900	6	14,000 D	28	<250	ND	<500	ND
LC34B314-16	14	16	12/14/2000	198	217	182	7,500	12	20,000 D	31	<250	ND	<500	ND
LC34B314-18	16	18	12/14/2000	199	227	186	10,000	16	15,000	24	<380	ND	<770	ND
LC34B314-20	18	20	12/14/2000	193	150	126	1,300	3	3,800	8	<250	ND	<500	ND
LC34B314-22	20	22	12/15/2000	192	137	110	<250	ND	2,700	7	<250	ND	<500	ND
LC34B314-24	22	24	12/15/2000	190	220	178	<250	ND	4,300	7	<250	ND	<500	ND
LC34B314-26	24	26	12/15/2000	197	281	226	<250	ND	6,700	9	<250	ND	<500	ND
LC34B314-28	26	28	12/15/2000	197	282	155	<250	ND	7,300	18	<250	ND	<500	ND
LC34B314-30	28	30	12/15/2000	196	200	152	<250	ND	2,900	6	<250	ND	<500	ND
LC34B314-32	30	32	12/15/2000	183	216	171	<250	ND	1,300	2	<250	ND	<500	ND
LC34B314-34	32	34	12/15/2000	195	222	145	<250	ND	1,200	3	<250	ND	<500	ND
LC34B314-36	34	36	12/15/2000	201	132	107	<250	ND	<250	ND	<250	ND	<500	ND
LC34B314-38	36	38	12/15/2000	200	234	165	380	1	<250	ND	<250	ND	<500	ND
LC34B314-40	38	40	12/15/2000	203	230	183	<250	ND	<250	ND	<250	ND	<500	ND
LC34B314-42	40	42	12/15/2000	199	252	196	<250	ND	<250	ND	<250	ND	<500	ND
LC34B314-44	42	44	12/15/2000	207	205	164	4,400	8	<250	ND	<250	ND	<500	ND
LC34B314-91$^{1)}$	Lab Blank		12/15/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
LC34B314-92	Lab Blank		12/15/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
LC34B314-EB	EQ		12/15/2000	NA	NA	NA	0.82 J	NA	<1	ND	<1	ND	<2	ND
LC34B214-14	0	2	8/14/2000	192	194	187	<250	ND	<250	ND	<250	ND	<500	ND
LC34B214-15	2	4	8/14/2000	190	172	163	<250	ND	<250	ND	<250	ND	<500	ND
LC34B214-16	4	6	8/14/2000	188	202	189	<250	ND	<250	ND	<250	ND	<500	ND
LC34B214-170	6	8	8/23/2000	193	198	171	7,300	11.6	1,700	2.42	<250	ND	<500	ND
LC34B214-171	8	10	8/23/2000	195	215	185	13,000	19.5	1,400	2.00	<500	ND	<1,000	ND
LC34B214-172	10	12	8/23/2000	195	260	221	16,000	20.7	4,400	6.35	<830	ND	<1,700	ND
LC34B214-173	12	14	8/23/2000	193	237	203	12,000	16.5	3,300	4.73	<500	ND	<1,000	ND
LC34B214-174	12	14	8/23/2000	196	223	191	9,800	14.4	2,500	3.58	<360	ND	<720	ND
LC34B214-175	14	16	8/23/2000	193	189	149	<1,000	ND	12,000	18.41	<1,000	ND	<2,000	ND

Table D-7. CVOC Results of Perimeter Soil Cores (Continued)

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Wet Soil Weight (g)	Dry Soil 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)
LC34B214-176	16	18	8/23/2000	193	239	206	590	0.8	9,300	13.26	<500	ND	<1,000	ND
LC34B214-324	Blank		9/1/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
LC34B217-2	0	2	12/14/2000	199	192	187	<250	ND	<250	ND	<250	ND	<500	ND
LC34B217-4	2	4	12/14/2000	195	176	171	<250	ND	<250	ND	<250	ND	<500	ND
LC34B217-6	4	6	12/14/2000	193	192	189	910	1	270	0	<250	ND	<500	ND
LC34B217-8	6	8	12/14/2000	194	142	137	670	1	250	0	<250	ND	<500	ND
LC34B217-10	8	10	12/14/2000	196	142	121	5,700	13	3,300	7	<250	ND	<500	ND
LC34B217-12	10	12	12/14/2000	193	129	110	4,700	11	3,800	9	<250	ND	<500	ND
LC34B217-14	12	14	12/14/2000	195	160	135	7,000	14	4,300	9	<380	ND	<770	ND
LC34B217-16	14	16	12/14/2000	202	118	99	2,300	6	5,100	14	<500	ND	<1,000	ND
LC34B217-18	16	18	12/14/2000	193	184	156	<500	ND	19,000	33	<500	ND	<1,000	ND
LC34B217-20 1)	18	20	12/14/2000	195	154	125	<250	ND	17,000 D	38	<250	ND	<500	ND
LC34B217-22	20	22	12/14/2000	193	207	171	4,700	8	31,000	51	<1,800	ND	<3,600	ND
LC34B217-24	22	24	12/14/2000	193	188	146	49,000	96	8,600	17	<1,800	ND	<3,600	ND
LC34B217-26	24	26	12/14/2000	198	198	157	86,000	160	<3,600	ND	<3,600	ND	<7,100	ND
LC34B217-28	26	28	12/14/2000	188	208	156	120,000	223	7,100	13	<4,200	ND	<8,300	ND
LC34B217-30	28	30	12/14/2000	192	197	154	36,000	67	18,000	33	<1,200	ND	<2,500	ND
LC34B217-32	30	32	12/14/2000	191	129	104	10,000	26	12,000	31	<830	ND	<1,700	ND
LC34B217-32-DUP	30	32	12/14/2000	198	163	135	13,000	27	16,000	33	<830	ND	<1,700	ND
LC34B217-34	32	34	12/14/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
LC34B217-36	34	36	12/14/2000	187	275	203	<250	ND	3,900	6	<250	ND	<500	ND
LC34B217-38	36	38	12/14/2000	189	246	146	<250	ND	650	2	<250	ND	<500	ND
LC34B217-40	38	40	12/14/2000	NA	NR	NR	NA	NA	NA	NA	NA	NA	NA	NA
LC34B217-42	40	42	12/14/2000	194	196	156	<250	ND	<250	ND	<250	ND	<500	ND
LC34B217-44	42	44	12/14/2000	190	191	156	<250	ND	<250	ND	<250	ND	<500	ND
LC34B217-90	Lab Blank		12/14/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
LC34B217-93	Lab Blank		12/14/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
LC34B217-EB	EQ		12/14/2000	NA	NA	NA	<1	ND	<1	ND	<1	ND	<2	ND
LC34B217-100	0	2	8/19/2000	194	175	173	3,400	5	<250	ND	<250	ND	<500	ND
LC34B217-101	2	4	8/19/2000	195	203	201	<250	ND	<250	ND	<250	ND	<500	ND
LC34B217-102	4	6	8/19/2000	193	221	211	<250	ND	<250	ND	<250	ND	<500	ND
LC34B217-166	6	8	8/23/2000	196	193	165	250	0.4	<250	ND	<250	ND	<500	ND
LC34B217-167	8	10	8/23/2000	193	241	201	620	1	340	0.50	<250	ND	<500	ND
LC34B217-168	10	12	8/23/2000	194	255	223	12,000	15	1,400	1.97	<360	ND	<720	ND
LC34B217-169	12	14	8/23/2000	192	236	202	9,500	13	760	1.09	<250	ND	<500	ND
LC34B217-316	Blank		9/1/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND

Table D-7. CVOC Results of Perimeter Soil Cores (Continued)

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Wet Soil Weight (g)	Dry Soil 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)
LC34B239-230	0	2	8/28/2000	196	158	157	480	1	<250	ND	<250	ND	<500	ND
LC34B239-231	2	4	8/28/2000	192	201	198	320	0.4	<250	ND	<250	ND	<500	ND
LC34B239-232	4	6	8/28/2000	191	288	281	330	0.3	<250	ND	<250	ND	<500	ND
LC34B239-233	6	8	8/28/2000	193	159	154	800	1	<250	ND	<250	ND	<500	ND
LC34B239-234	8	10	8/28/2000	194	206	177	4,000	6	2,500	3.57	<250	ND	<500	ND
LC34B239-235	10	12	8/28/2000	194	256	219	9,200	12	10,000	14.35	<500	ND	<1,000	ND
LC34B239-236	12	14	8/28/2000	193	197	171	5,400	9	11,000	15.60	<500	ND	<1,000	ND
LC34B239-237	14	16	8/28/2000	191	234	200	2,900	4	5,900	8.47	<500	ND	<1,000	ND
LC34B239-238	16	18	8/28/2000	193	176	147	4,900	9	7,300	10.68	<250	ND	<500	ND
LC34B239-239	18	20	8/28/2000	192	261	206	11,000	16	880	1.35	<500	ND	<1,000	ND
LC34B239-240	20	22	8/29/2000	196	232	197	3,300	5	880	1.27	<250	ND	<500	ND
LC34B239-241	22	24	8/29/2000	239	187	185	210,000	346	<6,200	ND	<6,200	ND	<12,000	ND
LC34B239-242	22	24	8/29/2000	193	202	161	150,000	266	<5,000	ND	<5,000	ND	<10,000	ND
LC34B239-243	24	26	8/29/2000	192	184	150	120,000	222	<3,600	ND	<3,600	ND	<7,100	ND
LC34B239-244	26	28	8/29/2000	193	285	225	220,000	298	<6,200	ND	<6,200	ND	<12,000	ND
LC34B239-245	28	30	8/29/2000	193	323	249	280,000	358	<8,300	ND	<8,300	ND	<17,000	ND
LC34B239-246	30	32	8/29/2000	193	325	264	250,000	289	<8,300	ND	<8,300	ND	<17,000	ND
LC34B239-247	32	34	8/29/2000	193	332	261	260,000	314	<10,000	ND	<10,000	ND	<20,000	ND
LC34B239-248	34	36	8/29/2000	192	240	197	170,000	247	<5,000	ND	<5,000	ND	<10,000	ND
LC34B239-249	36	38	8/29/2000	197	312	245	220,000	284	6,600	10.16	<6,200	ND	<12,000	ND
LC34B239-250	38	40	8/29/2000	195	272	234	130,000	158	<4,200	ND	<4,200	ND	<8,300	ND
LC34B239-251	42	44	8/29/2000	192	363	287	240,000	267	<6,200	ND	<6,200	ND	<12,000	ND
LC34B239-252	44	46	8/29/2000	195	290	231	200,000	265	<6,200	ND	<6,200	ND	<12,000	ND
LC34B239-253	Blank		8/29/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-28-254	0	2	8/29/2000	194	188	185	930	1	<250	ND	<250	ND	<500	ND
SB-28-255	2	4	8/29/2000	192	201	196	710	0.9	<250	ND	<250	ND	<500	ND
SB-28-256	4	6	8/29/2000	195	307	300	640	0.5	<250	ND	<250	ND	<500	ND
SB-28-257	6	8	8/29/2000	194	190	179	<250	ND	<250	ND	<250	ND	<500	ND
SB-28-258	8	10	8/29/2000	193	169	164	<250	ND	<250	ND	<250	ND	<500	ND
SB-28-259	8	10	8/29/2000	194	160	147	<250	ND	<250	ND	<250	ND	<500	ND
SB-28-260	10	12	8/29/2000	193	217	183	<250	ND	410	0.60	<250	ND	<500	ND
SB-28-261	12	14	8/29/2000	191	269	229	290	0.4	900	1.30	<250	ND	<500	ND
SB-28-262	14	16	8/29/2000	193	248	170	630	1	270	0.47	<250	ND	<500	ND
SB-28-263	16	18	8/29/2000	193	176	149	<250	ND	270	0.39	<250	ND	<500	ND
SB-28-264	18	20	8/29/2000	192	229	190	4,500	7	3,600	5.30	<250	ND	<500	ND
SB-28-265	20	22	8/29/2000	193	243	204	47,000	65	3,000	4.37	<1,200	ND	<2,500	ND

Table D-7. CVOC Results of Perimeter Soil Cores (Continued)

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	**Top Depth**	**Bottom Depth**	**Sample Date**	**MeOH (g)**	**Wet Soil Weight (g)**	**Dry Soil 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-28-317	Blank		9/1/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
SB-28B-289	0	2	8/31/2000	195	99	101	<250	ND	<250	ND	<250	ND	<500	ND
SB-28B-290	2	4	8/31/2000	192	125	121	<250	ND	<250	ND	<250	ND	<500	ND
SB-28B-291	4	6	8/31/2000	193	128	127	<250	ND	<250	ND	<250	ND	<500	ND
SB-28B-292	6	8	8/31/2000	196	126	121	<250	ND	<250	ND	<250	ND	<500	ND
SB-28B-293	8	10	8/31/2000	197	167	146	<250	ND	<250	ND	<250	ND	<500	ND
SB-28B-294	10	12	8/31/2000	196	191	163	17,000	29	1,800	2.59	<1,000	ND	<2,000	ND
SB-28B-295	12	14	8/31/2000	195	113	104	15,000	37	<1,000	ND	<1,000	ND	<2,000	ND
SB-28B-296	14	16	8/31/2000	192	200	167	36,000	60	<1,700	ND	<1,700	ND	<3,400	ND
SB-28B-297	16	18	8/31/2000	192	298	252	3,900,000	4,473	<100,000	ND	<100,000	ND	<200,000	ND
SB-28B-298	18	20	8/31/2000	193	100	86	240,000	721	<12,000	ND	<12,000	ND	<25,000	ND
SB-28B-299	20	22	8/31/2000	191	261	220	3,400,000	4,370	<100,000	ND	<100,000	ND	<200,000	ND
SB-28B-300	22	24	8/31/2000	195	197	159	130,000	233	<6,200	ND	<6,200	ND	<12,000	ND
SB-28B-301	24	26	8/31/2000	196	305	236	180,000	242	<6,200	ND	<6,200	ND	<12,000	ND
SB-28B-302	26	28	8/31/2000	196	189	149	150,000	290	<6,200	ND	<6,200	ND	<12,000	ND
SB-28B-303	28	30	8/31/2000	196	216	167	230,000	409	<12,000	ND	<12,000	ND	<25,000	ND
SB-28B-304	30	32	8/31/2000	195	197	155	370,000	689	<25,000	ND	<25,000	ND	<50,000	ND
SB-28B-305	32	34	8/31/2000	190	188	155	140,000	247	<5,000	ND	<5,000	ND	<10,000	ND
SB-28B-306	34	36	8/31/2000	194	120	105	1,300,000	3,226	<42,000	ND	<42,000	ND	<84,000	ND
SB-28B-307	36	38	8/31/2000	195	107	92	500,000	1,423	<17,000	ND	<17,000	ND	<33,000	ND
SB-28B-308	36	38	8/31/2000	192	163	129	580,000	1,246	<25,000	ND	<25,000	ND	<50,000	ND
SB-28B-309	38	40	8/31/2000	199	256	196	190,000	302	<6,200	ND	<6,200	ND	<12,000	ND
SB-28B-310	40	42	8/31/2000	91	429	276	210,000	204	<8,300	ND	<8,300	ND	<17,000	ND
SB-28B-311	42	44	8/31/2000	191	208	167	110,000	186	<5,000	ND	<5,000	ND	<10,000	ND
SB-28B-312	44	46	8/31/2000	195	174	142	93,000	183	<6,200	ND	<6,200	ND	<12,000	ND
SB-28B-313	Blank		8/31/2000	NA	NA	NA	440	0.8	<250	ND	<250	ND	<500	ND
LC34B209-2	0	2	12/12/2000	196	117	114	<250	ND	<250	ND	<250	ND	<500	ND
LC34B209-4	2	4	12/12/2000	195	101	93	<250	ND	<250	ND	<250	ND	<500	ND
LC34B209-6	4	6	12/12/2000	200	151	126	550	1	<250	ND	<250	ND	<500	ND
LC34B209-8	6	8	12/12/2000	192	158	129	1,200	3	300	1	<250	ND	<500	ND
LC34B209-10	8	10	12/12/2000	195	211	176	11,000	18	18,000	29	<500	ND	<1,000	ND
LC34B209-12	10	12	12/12/2000	195	183	151	15,000	28	12,000	22	<1,000	ND	<2,000	ND
LC34B209-14	12	14	12/12/2000	205	142	***115***	20,000	50	13,000	32	<1,000	ND	<2,000	ND
LC34B209-16	14	16	12/12/2000	196	166	137	14,000	28	13,000	26	<830	ND	<1,700	ND
LC34B209-18	16	18	12/12/2000	200	134	115	1,300	3	1,400 D	3	<250	ND	<500	ND
LC34B209-20	18	20	12/12/2000	204	136	110	8,800	23	13,000 D	34	<250	ND	<500	ND

Table D-7. CVOC Results of Perimeter Soil Cores (Continued)

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	**Top Depth**	**Bottom Depth**	**Sample Date**	**MeOH (g)**	**Wet Soil Weight (g)**	**Dry Soil 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)**
LC34B209-22	20	22	12/12/2000	190	258	202	36,000	53	14,000	21	<2,000	ND	<4,000	ND
LC34B209-24	22	24	12/12/2000	198	269	211	28,000	41	9,900	14	<1,500	ND	<2,900	ND
LC34B209-26	24	26	12/13/2000	197	233	182	3,400	6	3,600	6	<250	ND	<500	ND
LC34B209-28	26	28	12/13/2000	199	137	118	350	1	1,300	3	<250	ND	<500	ND
LC34B209-30	28	30	12/13/2000	199	284	226	2,300	3	12,000	16	<250	ND	710	1.0
LC34B209-32	30	32	12/13/2000	198	241	202	1,000	1	8,200	12	<250	ND	720	1.0
LC34B209-34	32	34	12/13/2000	199	159	121	1,200	3	5,600	13	<250	ND	<500	ND
LC34B209-36	34	36	12/13/2000	199	179	120	<250	ND	8,600	22	<250	ND	1,000	2.6
LC34B209-38	36	38	12/13/2000	198	235	187	2,500	4	<250	ND	<250	ND	<500	ND
LC34B209-38B	36	38	12/13/2000	192	246	192	1,900	3	<250	ND	<250	ND	<500	ND
LC34B209-40	38	40	12/13/2000	190	232	189	<250	ND	<250	ND	<250	ND	<500	ND
LC34B209-43	41	43	12/13/2000	194	244	180	<250	ND	<250	ND	<250	ND	<500	ND
LC34B209-45	43	45	12/13/2000	202	165	120	920	2	<250	ND	<250	ND	<500	ND
LC34B209-85	Lab Blank		12/12/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
LC34B209-86	Lab Blank		12/13/2000	NA	NA	NA	870		<250	ND	<250	ND	<500	ND
LC34B209-EB	EQ		12/12/2000	NA	NA	NA	<1	ND	<1	ND	<1	ND	<2	ND
LC34B309-2	0	2	12/13/2000	197	127	123	<250	ND	<250	ND	<250	ND	<500	ND
LC34B309-4	2	4	12/13/2000	200	134	129	<250	ND	<250	ND	<250	ND	<500	ND
LC34B309-6	4	6	12/13/2000	191	157	147	<250	ND	<250	ND	<250	ND	<500	ND
LC34B309-8	6	8	12/13/2000	188	142	119	<250	ND	2,900	6	<250	ND	<500	ND
LC34B309-10	8	10	12/13/2000	201	165	133	<500	ND	8,700	19	<500	ND	<1,000	ND
LC34B309-12	10	12	12/13/2000	196	139	113	<830	ND	12,000	29	<830	ND	<1,700	ND
LC34B309-14	12	14	12/13/2000	192	137	111	1,100	3	13,000	32	<830	ND	<1,700	ND
LC34B309-16	14	16	12/13/2000	199	161	133	<500	ND	9,800	21	<500	ND	<1,000	ND
LC34B309-18	16	18	12/13/2000	196	138	117	<830	ND	15,000	35	<830	ND	<1,700	ND
LC34B309-20	18	20	12/13/2000	205	125	100	<830	ND	12,000	34	<830	ND	<1,700	ND
LC34B309-22	20	22	12/13/2000	194	183	153	<250	ND	2,700	5	<250	ND	<500	ND
LC34B309-24	22	24	12/13/2000	206	204	168	<250	ND	3,700	7	<250	ND	<500	ND
LC34B309-26	24	26	12/13/2000	203	295	230	<500	ND	7,900	11	<500	ND	<1,000	ND
LC34B309-28	26	28	12/13/2000	198	220	176	<500	ND	8,500	14	<500	ND	<1,000	ND
LC34B309-30	28	30	12/13/2000	183	246	193	<250	ND	6,300	9	<250	ND	<500	ND
LC34B309-32	30	32	12/13/2000	180	160	137	<250	ND	1,100	2	<250	ND	<500	ND
LC34B309-34	32	34	12/13/2000	215	214	163	<250	ND	350	1	<250	ND	<500	ND
LC34B309-36	34	36	12/13/2000	201	180	139	<250	ND	<250	ND	<250	ND	<500	ND
LC34B309-36-DUP	34	36	12/13/2000	191	119	96	<250	ND	<250	ND	<250	ND	<500	ND
LC34B309-38	36	38	12/13/2000	191	155	108	<250	ND	<250	ND	<250	ND	<500	ND

Table D-7. CVOC Results of Perimeter Soil Cores (Continued)

	Sample Depth (ft)						TCE		*cis* -1,2-DCE		*trans* -1,2-DCE		Vinyl Chloride	
Analytical Sample ID	Top Depth	Bottom Depth	Sample Date	MeOH (g)	Wet Soil Weight (g)	Dry Soil 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)
LC34B309-40	38	40	12/13/2000	199	198	147	<250	ND	<250	ND	<250	ND	<500	ND
LC34B309-42	40	42	12/13/2000	190	243	189	<250	ND	<250	ND	<250	ND	<500	ND
LC34B309-44	42	44	12/13/2000	193	232	181	<250	ND	<250	ND	<250	ND	<500	ND
LC34B309-89	Lab Blank		12/14/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
LC34B309-90	Lab Blank		12/14/2000	NA	NA	NA	<250	ND	<250	ND	<250	ND	<500	ND
LC34B309-EB	EQ		12/14/2000	NA	NA	NA	<1	ND	<1	ND	<1	ND	<2	ND

NA: Not available.

ND: Not detected.

NR: No recovery.

EQ: Equipment rinsate blank.

1) Sample LC34B217-20 was originally analyzed within holding time criteria but the results were not withing 20% of the calibration range. *cis* -1,2-DCE was reanalyzed and the result was from the new analysis.

J: Result was estimated but below the reporting limit.

D: Result was quanitified after dilution.

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

Appendix E. Microbiological Assessment

E.1 Microbiological Evaluation Work Plan
E.2 Microbiological Evaluation Sampling Procedure
E.3 Microbiological Evaluation Results

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:

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

<u>Phase 2 (Sep ‘00 – Sep ’01)</u>
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^{o}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*		
		Freeze, store	***Ambient, 24 hrs***		2x250 g	*NA*		
	Steam Injection	Freeze, store	***Ambient, 24 hrs***		2x250 g	*NA*		
ISCO		Freeze, store	***Ambient, 24 hrs***		2x250 g	*NA*		
Control	*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

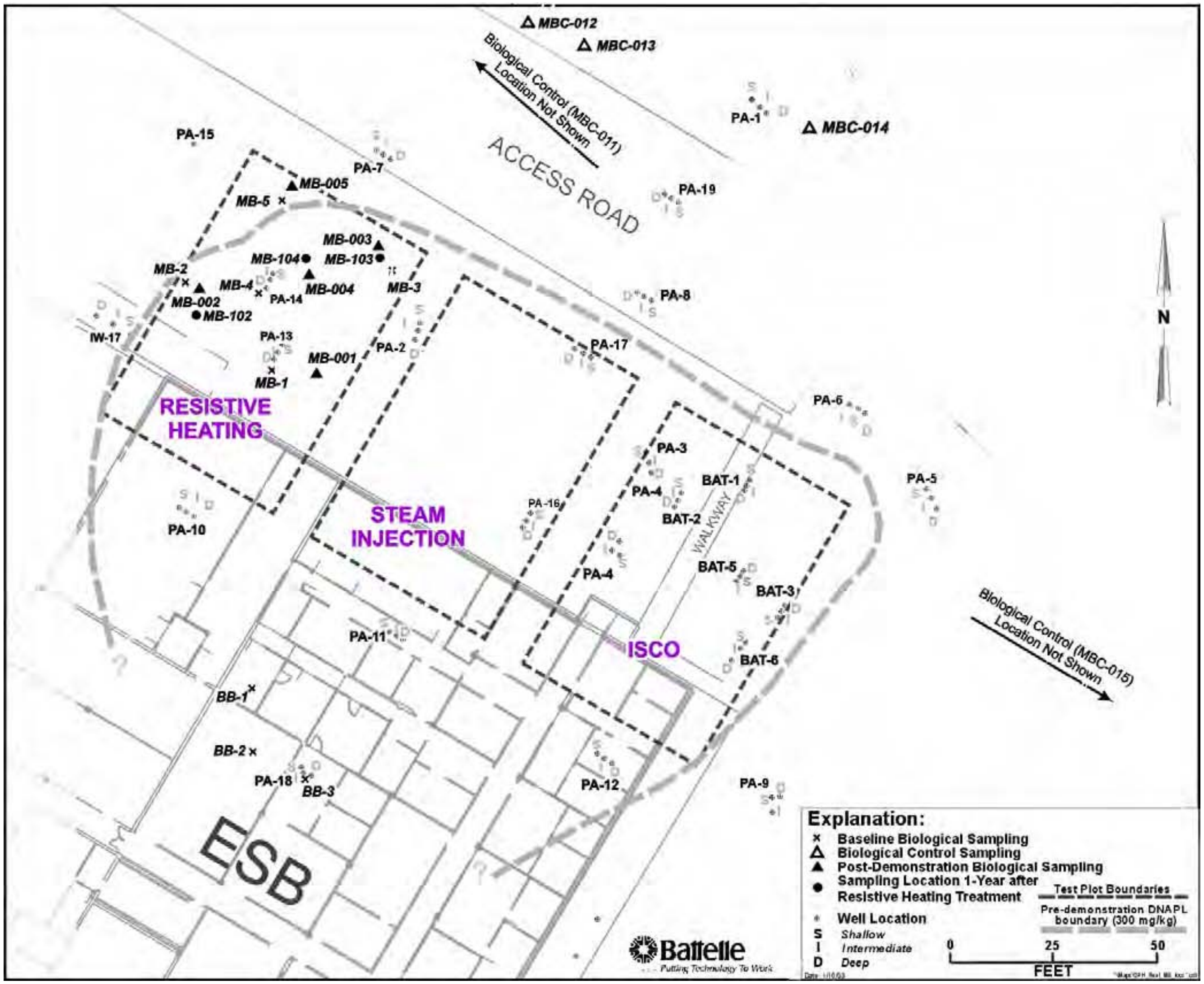

Figure 2. Map of Biological Sampling Location at LC34

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 and resistive heating plots. The predemonstration baseline results were taken from the sampling conducted in the Steam 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.

Microbiological analysis of soil and groundwater samples was conducted to evaluate the effect of resistive heating treatment on the microbial community. Samples were collected before and after (8 months after) the resistive heating treatment 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 Tables E-1 and E-2.

Table 5-20 (see Section 5) summarizes the soil analysis results. The geometric mean typically is the mean of the five samples collected in each stratigraphic unit in the plot. The 8 months of time that elapsed since the end of resistive heating treatment application and collection of the microbial samples may have given time for microbial populations to re-establish. The Middle Fine-Grained Unit experienced some reduction in microbial populations that persisted until the sampling after the of resistive heating treatment application. It could be that microbial populations were reduced immediately after the demonstration, however, if this phenomenon did occur the populations were re-established in the following 8 months. In the capillary fringe and in the Upper Sand Unit, microbial populations appeared to have increased by an order of magnitude. The persistence of these microorganisms despite the autoclave-like conditions in the of resistive heating plot may have positive implications for biodegradation of any TCE residuals following the of resistive heating treatment.

Table E-1. Results of Microbial Counts of Soil Samples

Sample ID	Top Depth ft bgs	Bottom Depth ft bgs	Aerobic Plate Counts CFU/g or MPN/g	Anaerobic Viable Counts Cells/g or MPN/g	BacLight Counts %live/%dead
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
Control Samples, Untreated (April 2001)					
MBC-011	7	7.5	15,848,932	7,943,282	94/06
MBC-011	20	20.5	25,119	10,000	86/14
MBC-011	24.5	25	3,981	2,512	88/12
MBC-011	41.5	41.75	25,119	79,433	89/11
MBC-011	41.75	42	25,119	10,000	80/20

Table E-1. Results of Microbial Counts of Soil Samples (Continued)

Sample ID	Top Depth ft bgs	Bottom Depth ft bgs	Aerobic Plate Counts CFU/g or MPN/g	Anaerobic Viable Counts Cells/g or MPN/g	BacLight Counts %live/%dead
MBC-012	20.5	21	1,995	794	95/05
MBC-012	24.5	25	19,953	31,623	91/09
MBC-012	41	41.5	126	158	98/02
MBC-013	6.5	7	1,000,000	316,228	47/53
MBC-013	10	10.5	15,849	25,119	80/20
MBC-013	20.5	21	6,310	1,585	100/0
MBC-013	24	24.5	631	1,259	76/24
MBC-013	41.5	42	2,512	2,512	73/27
MBC-214	32	32.5	501,187	316,228	90/10
MBC-214	40	40.5	79,433	10,000	96/04
MBC-015	6.5	7	316,228	1,584,893	100/0
MBC-015	20.5	21	39,811	5,012	82/18
MBC-015	24	24.5	794	1,585	85/15
MBC-015	41.5	42	6,310	12,589	94/06
Resistive Heating Plot, Treated T=8 months after (April 2001)					
MB-001	7.5	8	6,309,573	12,589,254	52/48
MB-001	20.5	21	1,258,925	15,848,932	68/32
MB-001	29.5	30	<316.2	251	72/28
MB-001	39	39.5	25,119	50,119	76/24
MB-002	7.5	8	63,096	79,433	27/73
MB-002	19.5	20	100	126	30/70
MB-002	25	25.5	<316.2	251	57/43
MB-002	41.5	42	2,512	501	29/71
MB-003	5.5	6	7,943,282	6,309,573	44/56
MB-003	6	6.5	10,000,000	15,848,932	25/75
MB-003	21.5	22	1,258,925	794,328	32/68
MB-003	24	24.5	125,893	1,995,262	49/51
MB-003	41	41.5	158	251	95/05
MB-004	6	6.5	630,957	501,187	27/73
MB-004	21.5	22	100	1,259	09/91
MB-004	25	25.5	10,000	5,012	44/56
MB-004	41	41.5	158	31,623	46/54
MB-005	6.5	7	63,095,734	10,000,000	43/57
MB-005	20.5	21	794	316	56/44
MB-005	24.5	25	1,585	3,162	95/05
MB-005	41.5	42	<316.2	251	100/0
Resistive Heating Plot, Treated, T=18 months after (June 2002)					
MB-102	6	6.5	8,500	480	54/46
MB-102	15	15.5	4,800	4,800	72/28
MB-102	32	32.5	480	48,000	57/43
MB-102	40	40.5	85	48	54/46
MB-103	6.5	7	480	420	62/37
MB-103	15	15.5	19	48	52/48
MB-103	30	30.5	150	4,800	35/65
MB-103	40	40.5	190	480	22/78

Table E-1. Results of Microbial Counts of Soil Samples (Continued)

Sample ID	Top Depth ft bgs	Bottom Depth ft bgs	Aerobic Plate Counts CFU/g or MPN/g	Anaerobic Viable Counts Cells/g or MPN/g	BacLight Counts %live/%dead
MB-104	9	9.5	850	850	50/50
MB-104	15	15.5	48	5	67/33
MB-104	30	30.5	4.6	4.6	45/55
MB-104	40	40.5	190	19	45/55

bgs: Below ground surface.

CFU: Colony-forming units (roughly, number of culturable cells).

MPN: Most probable number.

Table E-2. Results of Microbial Counts Groundwater Samples

Sample ID	Aerobic Plate Counts	Anaerobic Viable Counts	BacLight Counts
	CFU/mL or MPN/mL	Cells/mL or MPN/mL	%live/%dead
Control Samples, Untreated, Distant Wells			
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
Resistive Heating Plot Wells, Treated, T=0 (January 2001)			
PA-13S	<31.62	31.62	48/52
PA-13D	<31.62	<1.78	66/34
PA-14S	<31.62	158.49	38/62
PA-14D	<31.62	<1.78	97/03
Resistive Heating Plot Perimeter Wells, T=0 (June 2000)			
PA-15	<31.62	25	18/82
PA-15-DUP	<31.62	<1.78	09/91
IW-17I	<31.62	316	46/54
IW-17D	<31.62	2	59/41
Resistive Heating Plot Wells, Treated, T=18 months after (June 2002)			
PA-13S	220,000	9	64/36
PA-13I	48,000	92	33/67
PA-13D	3,000	1	73/27
PA-14S	48,000	5	70/30
PA-14I	48,000	3	59/41
PA-14D	48	48	35/64

NA: Not available.

CFU: Colony-forming units (roughly, number of culturable cells).

MPN: most probable number.

Appendix F. Surface Emissions Testing Methods and Procedures

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 steam 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.

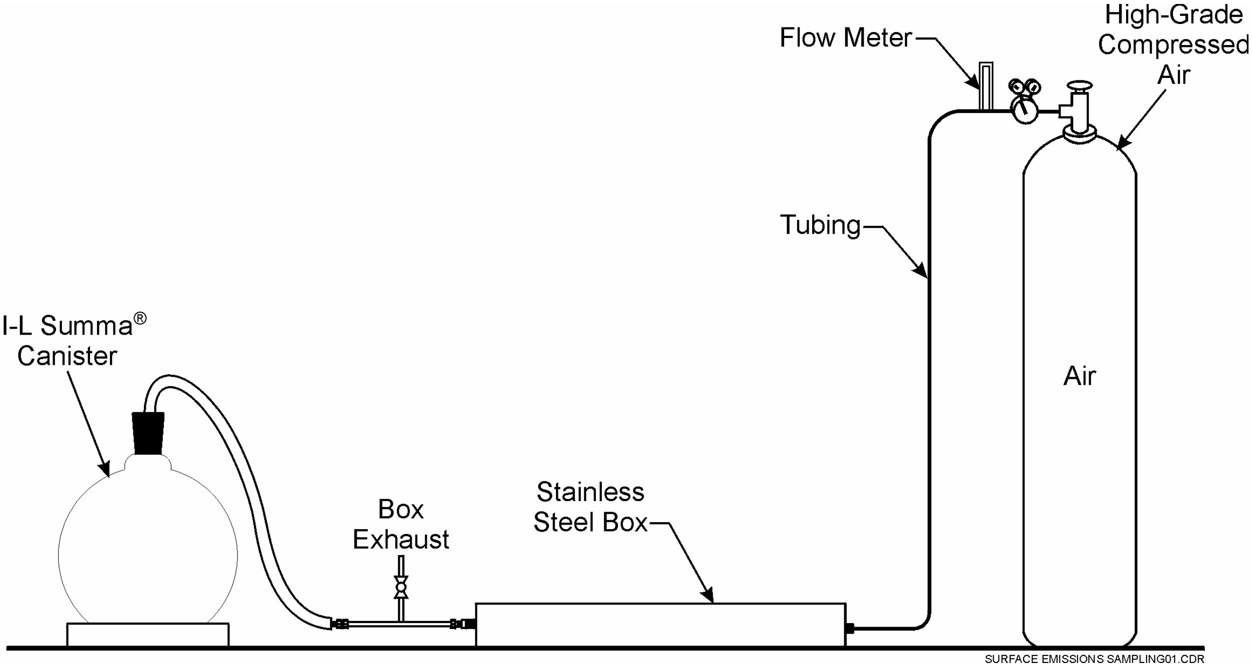

Figure F-1. Schematic Diagram of the Surface Emissions Sampling System

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):

$$F = CV_r/S \tag{F-1}$$

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. Suface Emissions Results from the Resisitve Heating Plot

Sample ID	Sample Date	TCE ppb (v/v)
Resistive Heating Plot		
Pre-Demonstration (Baseline Data)		
CP-SE-1	11/17/1999	<0.39
CP-SE-2	11/17/1999	<0.39
CP-SE-3	11/17/1999	<0.41
During Demonstration		
SPH-SE-1	10/8/1999	2.1
SPH-SE-2	10/8/1999	3.6
SPH-SE-3	10/8/1999	2
SPH-SE-4	10/22/1999	13,000
SPH-SE-5	10/22/1999	12,000
SPH-SE-6	10/22/1999	13,000
SPH-SE-7	1/18/2000	23
SPH-SE-8	1/18/2000	78
SPH-SE-9	1/18/2000	35
SPH-SE-10	4/11/2000	0.93
SPH-SE-11	4/11/2000	0.67
SPH-SE-12	4/11/2000	<0.37
SPH-SE-13	4/11/2000	1,300
Post-Demonstration		
SPH-SE-21	8/30/2000	<0.42
SPH-SE-22	8/30/2000	1
SPH-SE-23	8/30/2000	<870
SPH-SE-24	8/31/2000	500
SPH-SE-25	9/1/2000	59.00
SPH-SE-26	9/1/2000	17
SPH-SE-27	11/30/2000	3,100
SPH-SE-28	11/30/2000	10,000
SPH-SE-29	12/1/2000	11,000
SPH-SE-30	12/2/2000	9
SPH-SE-31	12/2/2000	1
SPH-SE-32	12/4/2000	<0.40
Ambient Air at Shoulder Level		
SPH-SE-14	5/9/2000	<0.39[a]
SPH-SE-15	5/9/2000	<0.39[a]
SPH-SE-C27	9/1/2000	<0.88
DW-C1	4/11/2000	2.1[b]
DW-C2	5/9/2000	<0.39
DW-C3	5/9/2000	<0.39
DW-11	8/31/2000	13
DW-12	9/1/2000	<27
DW-C21	8/31/2000	0.86[b]
DW-C22	9/1/2000	<0.58[b]

Table F-1. Suface Emissions Results from the Resisitve Heating Plot (Continued)

Sample ID	Sample Date	TCE ppb (v/v)
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[c]
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
DW-SE-36	12/6/2000	<0.40
DW-SE-37	12/6/2000	0.49
DW-SE-38	12/7/2000	<0.40

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 w/o using an air collection box.

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

[c.] 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.

Appendix G. Quality Assurance/ Quality Control Information

Tables G-1 to G-22

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 20ºC 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 20ºC). 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 50-95ºC to below 20ºC (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.

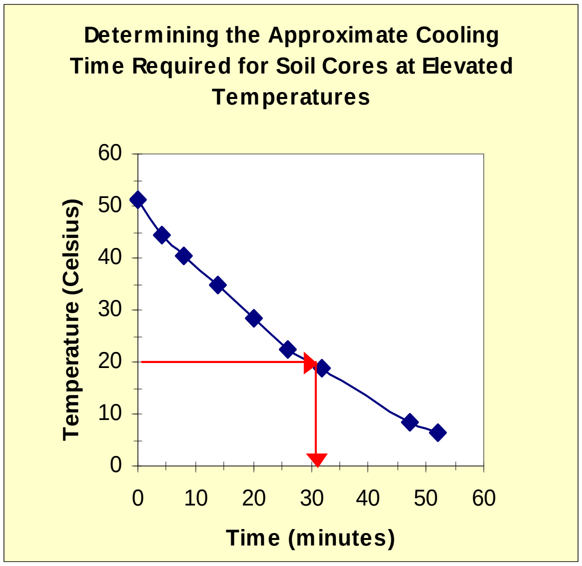

FIGURE G-2. Determining the length of time required to cool a soil core.

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

Resistive Heating Treatment Plot Field Duplicate Soil Samples **QA/QC Target Level < 30.0 %**				**Total Number of Soil Samples Collected = 291 (Pre-) 309 (Post-)** **Total Number of Field Duplicate Samples Analyzed = 10 (Pre-) 13 (Post-)**			
Pre-Demonstration				**Post-Demonstration**			
Sample ID	**Sample Date**	**Result (mg/kg)**	**RPD (%)**	**Sample ID**	**Sample Date**	**Result (mg/kg)**	**RPD (%)**
SB-10-29.5	06/23/1999	40.3	12.90	SB-210-26	11/13/2000	265	27.92
SB-10-29.5 DUP		35.1		SB-210-26 DUP		191	
SB-11-25.5	06/25/1999	94.2	71.97[(b)]	SB-211-32	11/14/2000	102	9.80
SB-11-25.5 DUP		26.4		SB-211-32 DUP		92	
SB-7-40	06/25/1999	70.1	60.91[(b)]	SB-209-18	11/15/2000	13	53.85[(a)]
SB-7-40 DUP		112.8		SB-209-18 DUP		6	
SB-4-22	06/26/1999	43.6	24.08	SB-212-36	11/15/2000	1.0	0.0
SB-4-22 DUP		54.1		SB-212-36 DUP		1.0	
SB-9-21.5	06/27/1999	12.7	12.60	SB-208-40	11/16/2000	11	0.0
SB-9-21.5 DUP		14.3		SB-208-40 DUP		11	
SB-6-32	06/27/1999	17.0	2.94	SB-207-10	11/16/2000	0.0	0.0
SB-6-32 DUP		17.5		SB-207-10 DUP		0.0	
SB-5-20	06/29/1999	5.2	23.08	SB-203-38	11/17/2000	308	1.95
SB-5-20 DUP		4.0		SB-203-38 DUP		302	
SB-3-28	06/30/1999	100.9	7.83	SB-204-24	11/17/2000	105	2.86
SB-3-28 DUP		108.8		SB-204-24 DUP		102	
SB-2-20	06/30/1999	1.9	31.58[(a)]	SB-205-26	11/20/2000	176	0.57
SB-2-20 DUP		2.5		SB-205-26 DUP		177	
SB-1-32	07/01/1999	19,090.9	12.75	SB-206-26	11/21/2000	15	13.33
SB-1-32 DUP		16,656.6		SB-206-26 DUP		13	
				SB-210B-32	11/27/2000	27	22.22
				SB-210B-32 DUP		21	
				SB-202-18	12/09/2000	53	47.17[(c)]
				SB-202-18 DUP		28	
				SB-201-32	12/11/2000	325	18.46
				SB-201-32 DUP		385	

(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 due to this duplicate being used as a surrogate sample.

(c) 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 = 309
Total Number of Field Samples Analyzed = 12

Post-Demonstration Rinsate Blank Samples

Sample ID	Sample Date	Result (ug/L)	Comments
SB-210-EB	11/14/2000	<1.0	Met QA/QC Target Criteria
SB-211-EB	11/14/2000	<1.0	Met QA/QC Target Criteria
SB-212-EB	11/15/2000	<1.0	Met QA/QC Target Criteria
SB-209-EB	11/15/2000	<1.0	Met QA/QC Target Criteria
SB-207-EB	11/16/2000	<1.0	Met QA/QC Target Criteria
SB-208-EB	11/16/2000	<1.0	Met QA/QC Target Criteria
SB-204-EB	11/17/2000	<1.0	Met QA/QC Target Criteria
SB-210B-EB	11/27/2000	<1.0	Met QA/QC Target Criteria
SB-203-EB	11/20/2000	<1.0	Met QA/QC Target Criteria
SB-205-EB	11/20/2000	<1.0	Met QA/QC Target Criteria
SB-206-EB	11/21/2000	<1.0	Met QA/QC Target Criteria
SB-202-EB	12/09/2000	<1.0	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

Resistive Heating Methanol Blank Soil Extraction QA/QC Samples **QA/QC Target Level < 1.0 mg/kg**				**Total Number of Soil Samples Collected = 291 (Pre-) 309 (Post-)** **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-10-Blank	06/23/1999	<0.250	Met QA/QC Target Criteria	SB-211-Blank	11/14/2000	<0.250	Met QA/QC Target Criteria
SB-12-Blank	06/24/1999	<0.250	Met QA/QC Target Criteria	SB-212-Blank	11/15/2000	<0.250	Met QA/QC Target Criteria
SB-11-Blank	06/25/1999	<0.250	Met QA/QC Target Criteria	SB-208-Blank	11/15/2000	<0.250	Met QA/QC Target Criteria
SB-7-Blank	06/25/1999	<0.250	Met QA/QC Target Criteria	SB-207-Blank	11/16/2000	<0.250	Met QA/QC Target Criteria
SB-4-Blank	06/26/1999	<0.250	Met QA/QC Target Criteria	SB-204-Blank	11/17/2000	<0.250	Met QA/QC Target Criteria
SB-6-Blank	06/27/1999	<0.250	Met QA/QC Target Criteria	SB-203-Blank	11/20/2000	<0.250	Met QA/QC Target Criteria
SB-9-Blank	06/27/1999	<0.250	Met QA/QC Target Criteria	SB-205-Blank	11/20/2000	<0.250	Met QA/QC Target Criteria
SB-8-Blank	06/28/1999	<0.250	Met QA/QC Target Criteria	SB-205-Blank	11/20/2000	<0.250	Met QA/QC Target Criteria
SB-5-Blank	06/29/1999	6.9(a)	See footnote.	SB-206-Blank	11/20/2000	<0.250	Met QA/QC Target Criteria
SB-2-Blank	06/30/1999	<0.250	Met QA/QC Target Criteria	SB-206-Blank	11/21/2000	<0.250	Met QA/QC Target Criteria
SB-3-Blank	06/30/1999	<0.250	Met QA/QC Target Criteria	SB-201-Blank	12/09/2000	<0.250	Met QA/QC Target Criteria
SB-1-Blank	07/01/1999	<0.250	Met QA/QC Target Criteria	SB-202-Blank	12/09/2000	<0.250	Met QA/QC Target Criteria
				SB-202-Blank	12/11/2000	<0.250	Met QA/QC Target Criteria
				SB-201-Blank	12/12/2000	<0.250	Met QA/QC Target Criteria
				SB-201-Blank	12/12/2000	<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-5-2 through SB-5-45

Table G-7. Results and Precision of the Field Duplicate Samples Collected During the Pre- and Post-Demonstration Groundwater Sampling

Resistive Heating Treatment Plot Field Duplicate Groundwater Samples QA/QC Target Level < 30.0 %				**Total Number of Groundwater Samples Collected = 46 (Pre-) 42 (Post-) Total Number of Field Duplicate Samples Analyzed = 4**			
Pre-Demonstration				**Post-Demonstration**			
Sample ID	**Sample Date**	**Result (ug/L)**	**RPD (%)**	**Sample ID**	**Sample Date**	**Result (ug/L)**	**RPD (%)**
PA-13S	09/03/1999	1,030,000	6.80	PA-13D	11/27/2000	920,000	1.09
PA-13S DUP		1,100,000		PA-13D DUP		910,000	
PA-13D	09/05/1999	892,000	18.16	PA-10I	11/29/2000	750,000	16.00
PA-13D DUP		730,000		PA-10I DUP		870,000	

Table G-8. Results and Precision of the Field Duplicate Samples Collected During Resistive Heating Demonstration Groundwater Sampling

Resistive Heating 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-8D	09/29/1999	625,000	11.86	PA-10D	01/10/2000	1,060,000	5.66
PA-8D DUP		555,000		PA-10D DUP		1,120,000	
PA-2I	10/06/1999	425,000	11.76	PA-13S	04/10/2000	180,000	5.56
PA-2I DUP		475,000		PA-13S DUP		170,000	
PA-10I	10/08/1999	458,000	1.53	PA-2I	04/12/2000	1,800,000	22.22
PA-10I DUP		451,000		PA-2I DUP		1,400,000	
PA-8S	10/20/1999	115,000	1.75				
PA-8S DUP		113,000					

Table G-9. Rinsate Blank Results for Groundwater Samples Collected for the Resistive Heating Pre-and Post-Demonstration Groundwater Sampling

Resistive Heating Pre-Demonstration Groundwater QA/QC Samples **QA/QC Target Level < 3.0 ug/L**			**Total Number of Samples Collected = 46 (Pre-) 42 (Post-)** **Total Number of Rinsate Blank Samples Analyzed = 3**		
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.	11/29/2000	8.5[(a)]	Met QA/QC Target Criteria
08/05/1999	227.0	Before switching to disposal tubing.	11/30/2000	<1.0	Met QA/QC Target Criteria
08/07/1999	58.3	Before switching to disposal tubing.	12/01/2000	0.46	Met QA/QC Target Criteria
08/10/1999	2,980.0	Before switching to disposal tubing.			
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-13D and PA-13D DUP were collected prior to the field blank, PA-7S, PA-7I and PA-7D 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 Resistive Heating Demonstration Groundwater Sampling

Resistive Heating 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 Resistive Heating Demonstration Soil and Groundwater Sampling

Total Number of Samples Collected = 600 (Soil) 242 (Groundwater) (a)
Total Number of Field Samples Analyzed = 14

Resistive Heating 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-10	05/23/2000	<5.0	Met QA/QC target criteria.
Trip Blank-2	01/05/2000	<1.0	Met QA/QC target criteria.	Trip Blank-11	05/24/2000	<5.0	Met QA/QC target criteria.
Trip Blank-3	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-4	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-5	04/13/2000	<1.0	Met QA/QC target criteria.	Trip Blank-14	06/01/2000	<5.0	Met QA/QC target criteria.
Trip Blank-6	05/09/2000	<1.0	Met QA/QC target criteria.	Trip Blank-15	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-16	06/02/2000	<5.0	Met QA/QC target criteria.
Trip Blank-8	05/19/2000	<5.0	Met QA/QC target criteria.	Trip Blank-17	12/01/2000	<5.0	Met QA/QC target criteria.
Trip Blank-9	05/22/2000	<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 Resistive Heating Pre-Demonstration Soil Sampling

Resistive Heating Treatment Plot MS/MSD Samples QA/QC Target Level Recovery % = 70 – 130 % QA/QC Target Level < 30.0 %			Total Number of Soil Samples Collected = 291 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 Resistive Heating Post-Demonstration Soil Sampling

Resistive Heating Treatment Plot MS/MSD Samples QA/QC Target Level Recovery % = 70 – 130 % QA/QC Target Level < 30.0 %			Total Number of Soil Samples Collected = 309 Total Number of MS/MSD Samples Analyzed = 25		
Post-Demonstration					
Sample Date	**TCE Recovery (%)**	**RPD (%)**	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**
11/18/2000	95	3.2	11/30/2000	85	0.64
	108			87	
11/19/2000	100	5.3	12/13/2000	111	0.68
	83			109	
11/20/2000	108	2.0	12/14/2000	93	0.34
	105			93	
11/21/2000	105	0.92	12/14/2000	86	2.9
	101			95	
11/21/2000	82	12.0	12/15/2000	80	4.2
	122			91	
11/22/2000	102	9.6	12/15/2000	121	7.3
	74			101	
11/24/2000	109	0.20	12/16/2000	109	1.3
	108			105	
11/24/2000	107	1.5	12/17/2000	91	0.99
	101			89	
11/27/2000	96	8.8	12/18/2000	103	2.6
	126			96	
11/27/2000	110	2.1	12/20/2000	110	7.0
	102			102	
11/28/2000	122	0.28	12/21/2000	100	5.3
	121			105	
11/29/2000	107	0.93	12/21/2000	91	3.0
	102			93	
11/29/2000	93	2.4			
	101				

Table G-14. Spike Recovery Values for Soil Laboratory Control Spike Samples Collected for Resistive Heating Pre-Demonstration

Resistive Heating Treatment Plot LCS/LCSD Samples **QA/QC Target Level Recovery % = 70 – 130 %** **QA/QC Target Level < 30.0 %**			**Total Number of Soil Samples Collected = 291** **Total Number of LCS/LCSD Samples Analyzed = 22**		
Pre-Demonstration					
Sample Date	**TCE Recovery (%)**	**RPD (%)**	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**
06/28/1999	110	4.6	07/06/1999	91	2.0
	105			93	
06/30/1999	121	2.4	07/06/1999	118	0.48
	124			117	
06/30/1999	109	0.46	07/07/1999	112	0.73
	108			113	
07/01/1999	122	1.9	07/08/1999	104	0.36
	120			104	
07/02/1999	94	1.6	07/09/1999	89	5.0
	95			94	
07/02/1999	92	0.91	07/09/1999	110	1.5
	93			111	
07/02/1999	107	2.5	07/12/1999	116	4.9
	110			111	
07/02/1999	118	3.6	07/13/1999	116	0.25
	114			116	
07/04/1999	92	3.9	07/14/1999	110	0.6
	96			110	
07/05/1999	110	0.88	07/21/1999	110	2.4
	109			112	
07/06/1999	117	0.76	07/24/1999	117	0.6
	118			117	

Table G-15. Spike Recovery Values for Soil Laboratory Control Spike Samples Collected for Resistive Heating Post-Demonstration

Resistive Heating Treatment Plot LCS/LCSD Samples **QA/QC Target Level Recovery % = 70 – 130 %** **QA/QC Target Level < 30.0 %**			**Total Number of Soil Samples Collected = 309** **Total Number of LCS/LCSD Samples Analyzed = 15**		
Post-Demonstration					
Sample Date	**TCE Recovery (%)**	**RPD (%)**	**Sample Date**	**TCE Recovery (%)**	**RPD (%)**
11/18/2000	111	3.60	12/14/2000	91	2.20
	107			89	
11/20/2000	109	0.92	12/14/2000	93	0.34
	110			93	
11/21/2000	106	6.60	12/16/2000	94	9.57
	113			103	
11/24/2000	117	0.23	12/17/2000	105	10.48
	117			94	
11/27/2000	106	5.66	12/18/2000	94	1.06
	112			93	
11/28/2000	105	0.34	12/20/2000	104	13.46
	105			90	
11/29/2000	113	11.50	12/21/2000	88	2.27
	100			90	
12/12/2000	102	8.82			
	93				

Table G-16. Method Blank Samples Analyzed During Resistive Heating Pre-Demonstration Soil Sampling

Resistive Heating Pre-Demonstration Soil QA/QC Samples QA/QC Target Level < 1.0 mg/kg			Total Number of Samples Collected = 291 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 Resistive Heating Post-Demonstration Soil Sampling

Resistive Heating Pre-Demonstration Soil QA/QC Samples **QA/QC Target Level < 1.0 mg/kg**			**Total Number of Samples Collected = 309** **Total Number of Method Blank Samples Analyzed = 29**		
Post-Demonstration Method Blanks					
Analysis Date	**TCE Concentration (mg/kg)**	**Comments**	**Analysis Date**	**TCE Concentration (mg/kg)**	**Comments**
11/18/2000	<0.250	Met QA/QC Target Criteria	12/13/2000	<0.250	Met QA/QC Target Criteria
11/18/2000	<0.250	Met QA/QC Target Criteria	12/14/2000	<0.250	Met QA/QC Target Criteria
11/20/2000	<0.250	Met QA/QC Target Criteria	12/14/2000	<0.250	Met QA/QC Target Criteria
11/20/2000	<0.250	Met QA/QC Target Criteria	12/14/2000	<0.250	Met QA/QC Target Criteria
11/21/2000	<0.250	Met QA/QC Target Criteria	12/15/2000	<0.250	Met QA/QC Target Criteria
11/21/2000	<0.250	Met QA/QC Target Criteria	12/15/2000	<0.250	Met QA/QC Target Criteria
11/23/2000	<0.250	Met QA/QC Target Criteria	12/16/2000	<0.250	Met QA/QC Target Criteria
11/24/2000	<0.250	Met QA/QC Target Criteria	12/16/2000	<0.250	Met QA/QC Target Criteria
11/27/2000	<0.250	Met QA/QC Target Criteria	12/17/2000	<0.250	Met QA/QC Target Criteria
11/27/2000	<0.250	Met QA/QC Target Criteria	12/18/2000	<0.250	Met QA/QC Target Criteria
11/28/2000	<0.250	Met QA/QC Target Criteria	12/20/2000	<0.250	Met QA/QC Target Criteria
11/28/2000	<0.250	Met QA/QC Target Criteria	12/20/2000	<0.250	Met QA/QC Target Criteria
11/29/2000	<0.250	Met QA/QC Target Criteria	12/21/2000	<0.250	Met QA/QC Target Criteria
11/30/2000	<0.250	Met QA/QC Target Criteria	12/21/2000	<0.250	Met QA/QC Target Criteria
12/12/2000	<0.250	Met QA/QC Target Criteria			

Table G-18. Spike Recovery and Precision Values for Matrix Spike Samples Analyzed During Resistive Heating Demonstration Groundwater Sampling

Resistive Heating Treatment Plot Groundwater QA/QC
QA/QC Target Level Recovery % = 70 – 130 %
QA/QC Target Level RPD < 30.0 %

Resistive Heating 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

Resistive Heating Treatment Plot Groundwater QA/QC QA/QC Target Level Recovery % = 70 – 130 % QA/QC Target Level RPD < 30.0 %				Total Number of Samples Collected = 46 (Pre-) 42 (Post-) Total Number of Matrix Spike Samples Analyzed = 12			
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	DQWR31AC-LCS	12/06/2000	96	2.8
LCSD-990805		122		DQWR31AD -LCSD		93	
LCS-990806	08/06/1999	107	3.1	DQTDH1AC-LCS	12/05/2000	93	1.7
LCSD-990806		111		DQTDH1AD -LCSD		95	
LCS-990807	08/07/1999	113	0.4	DQMKE1AC-LCS	12/01/2000	98	1.8
LCSD-990807		113		DQMKE1AD -LCSD		97	
LCS-990809	08/09/1999	109	2.0	DQQ031AC-LCS	12/04/2000	91	1.2
LCSD-990809		106		DQQ031ACD-LCSD		92	
LCS-990810	08/10/1999	111	2.5				
LCSD-990810		109					
LCS-990811	08/11/1999	112	3.8				
LCSD-990811		108					
LCS-990812	08/12/1999	106	0.6				
LCSD-990812		105					
LCS-990813	08/13/1999	98	4.0				
LCSD-990813		102					

Table G-20. Spike Recovery and Precision Values for Laboratory Control Spike Samples Analyzed During Resistive Heating Demonstration Groundwater Sampling

Resistive Heating 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 Resistive Heating Pre-Demonstration Groundwater Sampling

Resistive Heating Pre- and Post-Demo Groundwater QA/QC Samples **QA/QC Target Level < 3.0 ug/L**			**Total Number of Samples Collected = 46 (Pre-) 42 (Post-)** **Total Number of Method Blank Samples Analyzed = 13**		
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	12/01/2000	<1.0	Met QA/QC Target Criteria
08/06/1999	<2.0	Met QA/QC Target Criteria	12/04/2000	<1.0	Met QA/QC Target Criteria
08/07/1999	<2.0	Met QA/QC Target Criteria	12/06/2000	<1.0	Met QA/QC Target Criteria
08/08/1999	<2.0	Met QA/QC Target Criteria	12/05/2000	<1.0	Met QA/QC Target Criteria
08/09/1999	<2.0	Met QA/QC Target Criteria			
08/10/1999	<2.0	Met QA/QC Target Criteria			
08/11/1999	<2.0	Met QA/QC Target Criteria			
08/12/1999	<2.0	Met QA/QC Target Criteria			
08/09/1999	<1.0	Met QA/QC Target Criteria			

Table G-22. Method Blank Samples Analyzed During Resistive Heating Demonstration Groundwater Sampling

Resistive Heating Demonstration Groundwater QA/QC Samples **QA/QC Target Level < 3.0 ug/L**			**Total Number of Samples Collected = 154** **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			

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 resistive heating plot. Because the groundwater flow in this area is generally to the northeast, the DNAPL source could be contained by installing one or more extraction wells on the northeast side of the resistive heating 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 the resistive heating 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 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. The air effluent is treated with a catalytic oxidation unit before discharge.

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.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.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.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.

$$PV_{\text{P\&T costs}} = \sum \frac{\text{Annual Cost in Year t}}{(1 + r)^{t}} \qquad \text{Equation (H-1)}$$

$$PV_{\text{P\&T costs}} = \text{Capital Investment} + \frac{\text{Annual cost in Year 1}}{(1 + r)^{1}} + \ldots + \frac{\text{Annual cost in Year n}}{(1 + r)^{n}}$$

Equation (H-2)

Table H-3 shows the PV calculation for P&T based on Equation H-1. In Equation H-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 H-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 $2,188,000.

Table H-1. Pump & Treat (P&T) System Design Basis

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
Stack	10	ft	$2	$20	2 inch, PVC, lead out of housing
Catalytic Oxidizer	1	ea	$65,000	$65,000	
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 (catalytic oxidizer	2,200	10E6 Btu	$6.00	$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 influent	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-Year Operation

	P&T		
Year	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