

Final Report

Performance Evaluation of Technology Demonstration for Dynamic Underground Stripping with Hydrous Pyrolysis Oxidation (DUS/HPO) Using a Single Well at Beale Air Force Base



Prepared by
Battelle / SteamTech

Prepared for
Naval Facilities Engineering Service Center
1100 23rd Avenue
Port Hueneme, CA 93043



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14. ABSTRACT Dynamic Underground Stripping (DUS) with Hydrous Pyrolysis Oxidation (HPO) Technology was demonstrated using a single well in a trichloroethene (TCE) and tetrachloroethene (PCE) plume at Beale Air Force Base. The performance of the demonstration technology was evaluated to determine the efficiency of TCE/PCE reduction using a single well with HPO process. Primary COC levels were observed for considerable declining trends in the monitoring wells installed in the treatment zone, with up to 85% decline in TCE levels and up to 91% decline in PCE levels. Additionally, the economic analysis showed that single well steam injection/extraction has the potential to be more cost-effective over a conventional treatment, such as pump-and-treat technology.					
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Executive Summary

Because of the limited success with conventional technologies in achieving cost-effective and timely cleanup of groundwater contaminated with chlorinated solvents such as trichloroethylene (TCE) and/or tetrachloroethene (PCE), there has been a strong demand for the development and testing of remediation technologies that rely on physical, chemical, thermal, or biological mechanisms to enhance the removal and/or destruction of these compounds. As part of research efforts to address this demand, the U.S. Department of Energy's (DOE's) Lawrence Livermore National Laboratory (LLNL) has developed and patented an innovative technology called dynamic underground stripping (DUS) with hydrous pyrolysis oxidation (HPO). The DUS/HPO technique relies on both thermal and chemical mechanisms to enhance the remediation and destruction of chlorinated solvents in the subsurface. DUS involves the injection/extraction of steam combined with electrical heating. DUS/HPO involves the injection of air along with the steam. This combination promotes the in situ oxidation of chlorinated solvents to carbon dioxide (CO₂), chloride ions, and water in the presence of sufficient dissolved oxygen (DO) and under high temperatures, which brings about more rapid chemical reactions and higher mass transfer rates.

The United States Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP) has recognized the potential benefit in applying the DUS/HPO technology at many DoD environmental restoration sites, and supported this demonstration and validation effort at Beale Air Force Base (AFB) in Marysville, CA.

Previous applications of this technology have focused primarily on contaminant removal through steam injection and extraction, along with extensive aboveground treatment of the extracted fluids. This demonstration was conducted at a site without a significant dense, nonaqueous-phase liquid (DNAPL) source zone present and was concerned primarily with the in situ destruction of TCE in the dissolved-phase plume at Solid Waste Management Unit (SWMU) 23. The DUS/HPO technique also could be employed as a "polishing" step (after source zone removal has been implemented) to reduce elevated groundwater contaminant levels by several orders of magnitude in order to meet acceptable cleanup criteria (e.g., maximum contaminant levels [MCLs]). Compared to DUS/HPO, other competing chemical oxidation methods (e.g., potassium permanganate injection) may be limited by higher mass transfer limitations and/or poor contact due to displacement of the contaminant during reagent injection.

This demonstration employed a novel mode of DUS/HPO application using a cyclic steam injection and extraction process from a single well, termed the "huff-and-puff" technique. The method involves intermittent operation of the system consisting of active steam/air injection into the subsurface, a passive "soaking" period, which allows the oxygen (O₂)-laden steam to condense and mix with contaminated groundwater in a heated zone, and then active extraction to

recover displaced contaminants and to minimize their migration outside of the target treatment area. The majority of the contaminant is oxidized during the passive “soaking” period. This novel method represents a significant advance over the application of DUS alone, primarily because in situ treatment of the chlorinated solvents results in a reduction in aboveground treatment requirements and costs as follows: (1) contaminants are significantly degraded in situ, which decreases the contaminant levels in the extracted fluids; (2) cyclic steam injection and extraction reduces the volume of extracted fluids; and (3) cyclic operation requires less intensive operation and maintenance of the system. Another potential enhancement to the application of DUS/HPO used in this demonstration is to increase the O₂ delivery rate through the injection of pure O₂ with the steam.

The field application of this technology at Beale AFB was conducted between May and December 2002. Considerable monitoring was conducted before, during, and after the field demonstration, which included three injection/extraction cycles. Groundwater monitoring was conducted through five wells installed in the target treatment zone surrounding the steam injection/extraction well. In addition to the contaminants of concern (COC), indicator groundwater parameters, such as chloride, alkalinity, dissolved oxygen, etc., also were measured. Thermocouples and electrical resistance tomography (ERT) were used to monitor the size of the heated zone. Bromide was injected with the steam as a tracer to evaluate hydraulic control during the demonstration and system operation.

The results of the monitoring indicate that the vendor was successful in heating the target treatment zone, despite some challenges, such as the abundance of finer-grained soils at the site. The radius of the heated zone (above ambient temperatures) was estimated to be as large as 20 ft around the steam injection well based on the thermocouple and ERT measurements. The dissolved oxygen distribution coincided approximately with the heated zone, although the oxygen appeared to have distributed in a wider zone. Therefore, the vendor was successful in creating conditions conducive to HPO.

Primary COC levels declined considerably in the monitoring wells in the treatment zone, with up to 85% decline in TCE levels and up to 91% decline in PCE levels observed. The *cis*-1,2-DCE levels in the treatment zone declined considerably. The analytical results indicated that approximately 64 g of TCE were recovered in the vapor, while the change in groundwater concentrations within the heated radius only, indicate that 52 g of TCE were removed. Therefore, the extraction zone exceeded the thermally heated zone (to above 80 deg C, approximately 14 ft in radius and 15 ft in thickness).

The extent of the bromide tracer in the aquifer was larger than the influence of the heated zone, indicating that mixing and displacement could have caused some migration of dissolved groundwater constituents. The aborted steam injection Cycle 1a, in which steam was injected, but could not be extracted due to a pump failure, could have been one factor in the loss of hydraulic control. Also, chloride levels declined substantially after the treatment. Pre-treatment chloride levels in the treatment zone groundwater were unusually high, possibly because of release of

chloride from the grout used in the injection well construction. Chloride served as a conservative tracer, because contributions from any degrading COCs is minimal; pre-treatment TCE and PCE levels at this site were relatively low and were orders of magnitude below the pre-treatment chloride levels. The average 68% decline in chloride levels indicates that the displacement/mixing caused by the injection/extraction cycles could have caused a dilution of dissolved groundwater constituents, including TCE and PCE. Therefore, it is difficult to conclusively attribute the decline in COC levels in the heated zone to degradation processes, such as HPO or microbial activity.

The economic analysis showed that single well steam injection/extraction has the potential to be more cost-effective over a conventional treatment, such as pump-and-treat technology.

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Contents

	Page
Executive Summary	iii
Figures.....	ix
Tables.....	xi
Acronyms and Abbreviations	xii
1. Introduction.....	1
1.1 Background.....	1
1.2 Objectives of the Demonstration	2
1.3 Regulatory Drivers.....	2
1.4 Stakeholder/End-User Issues	2
2. Site Characterization and Site Background	3
2.1 Site Hydrogeology	3
2.1.1 Geology	3
2.1.2 Hydrogeology.....	3
2.2 Contamination Extent	6
2.3 Aquifer Quality and Geochemistry.....	9
2.3.1 Groundwater Geochemistry and Inorganics.....	9
2.3.2 Groundwater Parameters.....	11
2.4 Current Operations.....	12
3. Technology Description.....	13
3.1 Technology Development and Application	13
3.2 Previous Testing of Technology	13
3.3 Factors Affecting Performance.....	14
3.4 Potential Advantages and Limitations of the Technology.....	15
4. Modeling Results	16
5. Demonstration Design and Site Preparation.....	19
5.1 Subsurface and Aboveground System Design Factors	19
5.2 Demonstration Subsurface Site Preparation	19
5.2.1 Injection/Extraction Well	21
5.2.2 Performance Monitoring Wells.....	22
5.2.3 Temperature Monitoring Strings.....	23
5.2.4 ERT Vertical Electrode Arrays	24
5.2.5 Preparation of Site.....	24

Contents
(Continued)

5.3	Demonstration Aboveground System Setup.....	27
5.3.1	Steam Generator and Steam Injection System	27
5.3.2	Extraction System.....	29
5.3.3	Effluent Treatment System.....	29
5.4	Residual Handling.....	31
6.	Operation and Maintenance	33
6.1	Steam Injection and Extraction System	33
6.2.	Process Monitoring Parameters	36
6.2.1	Flowrate and Flow Volume	36
6.2.2	Pressure and Temperature	38
6.2.3	Contaminant Concentrations	39
7.	Performance Assessment Methodology.....	41
7.1	Performance Objectives	41
7.1.1	In Situ Destruction of COCs by HPO	41
7.1.2	Subsurface Heating around the Injection Well by Steam Injection	43
7.1.2.1	Subsurface Temperature	44
7.1.2.2	ERT Monitoring.....	44
7.1.3	Hydraulic Control and Migration of COC	45
7.2	Aquifer Changes	46
8.	Performance Monitoring Results and Conclusions.....	48
8.1	Cyclic System Operation of Injection and Extraction	48
8.1.1	Steam and Oxygen Injection	48
8.1.2	Extraction	48
8.2	Results of Heat Distribution During the Demonstration.....	51
8.2.1	Temperature Distribution	51
8.2.2	ERT Results.....	53
8.3	Water Balance and Hydraulic Control Issues	63
8.4	Energy Balance	63
8.5	Geochemistry Changes in the Treatment Zone.....	65
8.6	COC Concentrations in Monitoring Wells	70
8.7	Declining COC Levels in the Subsurface: COC Mass Balance	76
8.8	Summary of Conclusions/Lessons Learned.....	79
9.	Economics.....	83
9.1	Cost Reporting	83
9.2	Cost Analysis	85

**Contents
(Continued)**

10. Implementation Issues90

 10.1 Environmental Checklist.....90

 10.1.1 Resource Conservation and Recovery Act and Title 22, Division 4.5 of
 the California Code of Regulations90

 10.1.2 Clean Water Act91

 10.1.3 Safe Drinking Water Act and the California Safe Drinking Water Act.....91

 10.1.4 Clean Air Act.....92

 10.1.5 Occupational Safety and Health Administration Rules.....92

 10.1.6 Other Selected Federal Regulations93

 10.1.7 Other Selected State Regulations93

 10.1.8 Other Selected Local Regulations93

 10.2 Permitting and Waste Disposal Issues94

 10.3 Other Regulatory and End-User Issues.....94

11. References.....96

- Appendix A: Points of Contact
- Appendix B: Well Construction Diagrams
- Appendix C: Performance Monitoring Data
- Appendix D: Modeling in Support of System Design
- Appendix E: Temperature Monitoring Data and ERT Images
- Appendix F: System Operational Data
- Appendix G: Economics
- Appendix H: Demonstration Work Plan

Figures

Figure 2-1. Geologic Cross Section A-A' at SWMU 234

Figure 2-2. Groundwater Level Map Based on August 2001 Groundwater
Level Survey5

Figure 2-3. Map of Historic and Phase I, II, and III Site Characterization Locations
and Contaminant Distribution Map8

Figure 4-1. Calculated Radii of Steam Zone for First Injection Cycle at Various
Intrinsic Permeability Values.....17

Figure 4-2. Calculated Injection Rates for First Injection Cycle for Various Intrinsic
Permeability Values17

Figure 5-1. Demonstration Site Layout	20
Figure 5-2. Design Features of Injection/Extraction Well and Wellhead Completion.....	21
Figure 5-3. Installation of Thermocouples	23
Figure 5-4. Design Features of Performance Monitoring Wells and ERT Borings	25
Figure 5-5. Pictures of Site Equipment.....	26
Figure 5-6. Steam Generation and Injection Schematic Diagram	28
Figure 5-7. Simplified Effluent Treatment System Flow Diagram	30
Figure 6-1. Original Design of SI-01 (background is the steam generator)	37
Figure 6-2. Design Modification to SI-01 (background is the steam generator).....	37
Figure 7-1. Groundwater Being Collected from BAT-06 Monitoring Well	42
Figure 8-1. Steam Injection Rates and Cumulative Volume of Injected Steam.....	49
Figure 8-2. Steam Injection Pressure, Rates, and Oxygen Injection Rates	49
Figure 8-3. Water Balance for Injection and Extraction.....	50
Figure 8-4. Extracted Vapor Rate, Vacuum, and Temperature	51
Figure 8-5. Temperature vs. Depth Profile during Cycle 1a Heating.....	52
Figure 8-7. VEA-5 Temperature Profile from All Depths	55
Figure 8-8. Relative Conductivity Changes from Cross-Boreholes VEA-2 to VEA-5 to VEA-4 (Plane 2-5-4).....	56
Figure 8-9. Cross-Borehole Resistivity Profiles of Planes 5-3 (top) and 2-5-4 (bottom), Showing Upward and Outward Flaring of Area of Increased Conductivity Above Base of Steam Injection Screen Adjacent to VEA-5.....	57
Figure 8-10. Cross-Borehole Profiles of Conductivity Changes in Plane 4-3 (VEA-4 at left, VEA-3 at right), Showing Cyclical Changes during Cycle 1a (top) and Cycle 1b (bottom) Steam Injection Phases	58
Figure 8-11. Cross-Borehole Profiles, Showing Relative Conductivity Changes in ERT Plane 4-3 (VEA-4 at left) during Early Cycle 3 Steam Injection (11/13/2002) and Cool-Down (12/03 – 12/09/2002) Phases	59
Figure 8-12. Cross-Borehole Resistivity Profiling, showing Resistivity Changes Adjacent to VEA-5 (center of plane), with Corresponding Temperatures (°C) Measured Using Thermocouples in VEA-5.....	62
Figure 8-13. Energy Balance and Estimated HPO Reaction Zone Radius.....	64
Figure 8-14. Schematic View with Changes in Average Temperatures, DO, Bromide, and pH Levels	67
Figure 8-15. Schematic View with Changes in Average Alkalinity, Chloride, TDS, and Electrical Conductivity Levels.....	68
Figure 8-16. Schematic View with Changes in Monitoring Well TCE, PCE, and <i>cis</i> - 1,2-DCE Concentrations.....	72
Figure 8-17. Temporal Changes of TCE Concentrations in Groundwater	73
Figure 8-18. Temporal Changes of PCE Concentrations in Groundwater	74
Figure 8-19. Temporal Changes of <i>cis</i> -1,2-DCE Concentrations in Groundwater	75
Figure 8-20. TCE Concentrations in Vapor Phase during Extraction Phases and Estimated Mass Removal.....	77
Figure 8-21. Adsorbed TCE Mass Estimated in HPO Reaction Zone	78

Tables

Table 2-1. Summary of Slug Test Results	6
Table 2-2. Summary of VOC Results in Groundwater from Phase I Characterization (April 2001)	7
Table 2-3. Contamination Results from Phase II Characterization (June 2001) Using the In Situ MIP System.....	10
Table 2-4. Summary of VOC Results in Groundwater from Phase III Characterization (August 2001)	11
Table 2-5. Inorganic Analysis Results in Groundwater from Phase I Characterization (March 2001)	11
Table 2-6. Summary of Field Parameter Results in Groundwater	12
Table 5-1. Summary of Slug Test Results from Steam Injection Well SI-01	22
Table 5-2. Liquid Effluent Limitations for Parameters Specified by CRWQCB	31
Table 5-3. Emitted Vapor Criteria	31
Table 6-1. Timeline for Steam Injection/Extraction Demonstration	34
Table 6-2. Major Equipment and Required Operation Activities	35
Table 6-3. Process Monitoring During Operations	37
Table 6-4. Summary of Liquid Sample Results from L-1	39
Table 7-1. Summary of Performance Criteria.....	41
Table 8-1. Summary Steam Injection.....	48
Table 8-2. Summary of Liquid Extraction	50
Table 8-3. Estimated Heated Volumes and Radius Assuming a 15-ft-Deep Zone.....	64
Table 8-4. Percent Reduction of Average COC Concentrations in Groundwater	71
Table 8-5. Performance Criteria and Summary of Conclusions	82
Table 9-1. Cost Tracking	84
Table 9-2. Basis for DUS/HPO and Pump-and-Treat Cost Estimate	85
Table 9-3. Capital and O&M Costs Projected for Operating a DUS/HPO System.....	86
Table 9-4. Capital and O&M Costs Projected for Operating a Pump-and-Treat System.....	87
Table 9-5. PV Costs of a Pump-and-Treat System	88
Table 10-1. Permit Requirements	95

Acronyms and Abbreviations

AFB	Air Force Base
AGI	American Geological Institute
API	American Petroleum Institute
AQMD	Air Quality Management District
BAAQMD	Bay Area Air Quality Management District
BACT	Best Available Control Technology
BERC	Berkley Environmental Restoration Center
bgs	below ground surface
BTU/hr	British thermal units per hour
CAA	Clean Air Act
CCR	California Code of Regulations
CFR	Code of Federal Regulations
CO ₂	carbon dioxide
COC	contaminant of concern
COD	chemical oxygen demand
CPT	cone penetrometer test
CRWQCB	California Regional Water Quality Control Board
CVOC	chlorinated volatile organic compound
CWA	Clean Water Act
DCE	dichloroethene
DNAPL	dense, nonaqueous-phase liquid
DO	dissolved oxygen
DoD	United States Department of Defense
DOE	United States Department of Energy
DUS	dynamic underground stripping
ERT	electrical resistivity tomography
ESA	Endangered Species Act
ESTCP	Environmental Security Technology Certification Program
GAC	granular activated carbon
gpm	gallons per minute
HAP	hazardous air pollutant
HASP	Health and Safety Plan

HPO	hydrous pyrolysis oxidation
HSA	hollow-stem auger
IDW	investigation-derived waste
KO-2	knockout vessel 2 (liquid-vapor separator)
KO-3	knockout vessel 3 (liquid-vapor separator)
LLNL	Lawrence Livermore National Laboratory
LNAPL	light, nonaqueous-phase liquid
MACT	Maximum Achievable Control Technology
MBAS	methylene blue active substances
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MIP	membrane interface probe
mS/cm	milliSiemens per centimeter
mS/m	milliSiemens per meter
MW	monitoring well
NA	not available
NAAQS	National Ambient Air Quality Standards
NAPL	nonaqueous-phase liquid
NFESC	Naval Facilities Engineering Service Center
NHPA	National Historic Preservation Act
NPV	net present value
O&M	operation and management
ORP	oxidation/reduction potential
OSHA	Occupational Safety and Health Administration
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PID	photoionization detector
ppb	parts per billion (microgram per liter)
ppm	parts per million (milligram per liter)
psi	pounds per square inch
psia	pounds per square inch/area
psig	pounds per square inch gauge
PV	present value
PVC	polyvinyl chloride

RAB	Remediation Advisory Board
RCRA	Resource Conservation and Recovery Act
RWQCB	(California) Regional Water Quality Control Board, Central Valley Region
SCAPS	Site Characterization and Analysis Penetrometer System
scfh	standard cubic feet per hour
S/D	shallow/deep
SDWA	Safe Drinking Water Act
SEE	Steam Enhanced Extraction
SES	SteamTech Environmental Services, Inc.
SIP	State Implementation Plan
STLC	soluble threshold limit concentration
SWMU	Solid Waste Management Unit
SWRCB	State Water Resources Control Board
TCA	trichloroethane
TCE	trichloroethylene
TDS	total dissolved solids
TOC	total organic carbon
TPH-DRO	total petroleum hydrocarbons–diesel-range organics
TPH-GRO	total petroleum hydrocarbons–gasoline-range organics
TPH-MO	total petroleum hydrocarbons–motor oil
TTLC	total threshold limit concentration
USACE	U.S. Army Corps of Engineers
U.S. EPA	U.S. Environmental Protection Agency
VC	vinyl chloride
VEA	vertical electrode array
VOC	volatile organic compound
WET	(California) Waste Extraction Test
µg/L	micrograms per liter



Dynamic Underground Stripping with Hydrous Pyrolysis Oxidation (DUS/HPO) Technology at Beale Air Force Base

Battelle / SteamTech / LLNL

April 7, 2005

1. Introduction

1.1 Background

Because of the limited success with conventional technologies in achieving cost-effective and timely cleanup of groundwater contaminated with chlorinated solvents such as trichloroethylene (TCE) and/or tetrachloroethene (PCE), there has been a strong demand for the development and testing of remediation technologies that rely on physical, chemical, thermal, or biological mechanisms to enhance the removal and/or destruction of these compounds. As a result of research efforts to address this demand, the U.S. Department of Energy's (DOE's) Lawrence Livermore National Laboratory (LLNL) has developed and patented an innovative technology called dynamic underground stripping (DUS) with hydrous pyrolysis oxidation (HPO). The DUS/HPO technique relies on both thermal and chemical mechanisms to enhance the remediation and destruction of chlorinated solvents in the subsurface. DUS involves the injection/extraction of steam combined with electrical heating. DUS/HPO involves the injection of air along with the steam. This combination promotes the in situ oxidation of chlorinated solvents to carbon dioxide (CO₂), chloride ions, and water in the presence of sufficient dissolved oxygen (DO) and under high temperatures, which brings about more rapid chemical reactions and higher mass transfer rates.

1.2 Objectives of the Demonstration

The United States Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP) has recognized the potential benefit in applying the DUS/HPO technology at many DoD environmental restoration sites, and has supported this demonstration and validation effort at Beale Air Force Base (AFB) in Marysville, CA.

Previous applications of this technology have focused primarily on contaminant removal through steam injection and extraction, along with extensive aboveground treatment of the extracted fluids. This demonstration was conducted at a site at Beale AFB without a significant dense, non-aqueous-phase liquid (DNAPL) source zone present and was concerned primarily with the in situ destruction of TCE in the dissolved-phase plume at Solid Waste Management Unit (SWMU) 23. The DUS/HPO technique could be employed as a “polishing” step (after source zone removal has been implemented) to reduce elevated groundwater contaminant levels by several orders of magnitude in order to meet acceptable cleanup criteria (e.g., maximum contaminant levels [MCLs]). Compared to DUS/HPO, other competing chemical oxidation methods (e.g., potassium permanganate injection) may be limited by higher mass transfer limitations and/or poor contact due to displacement of the contaminant during reagent injection.

This particular demonstration employed a novel mode of DUS/HPO application using a cycled steam injection and extraction process from a single well, termed the “huff-and-puff” technique. This method involves intermittent operation of the system consisting of active steam/air injection into the subsurface, a passive “soaking” period, which allows the oxygen (O₂)-laden steam to condense and mix with contaminated groundwater in a heated zone, and then active extraction to recover displaced contaminants and to minimize their migration outside of the target treatment area. The majority of the contaminant is oxidized during the passive “soaking” period. This method represents a significant advance over the application of DUS alone, primarily because in situ treatment of the chlorinated solvents results in a reduction in aboveground treatment requirements and costs as follows: (1) contaminants are significantly degraded in situ, which decreases the contaminant levels in the extracted fluids; (2) cyclic steam injection and extraction reduces the volume of extracted fluids; and (3) cyclic operation requires less intensive operation and maintenance of the system. Another potential enhancement to the application of DUS/HPO considered in this demonstration is to increase the O₂ delivery rate by injecting pure O₂ with the steam.

1.3 Regulatory Drivers

The application of DUS/HPO should result in the rapid in situ destruction of chlorinated solvents in groundwater and should diminish the hazard posed by the contamination and accelerate site closure. Thus, in an overall site remediation scheme, DUS/HPO could follow source zone removal and be used to treat residual contamination in the dissolved-phase plume to meet federal or state MCLs or other risk-based cleanup levels.

1.4 Stakeholder/End-User Issues

This project addresses stakeholder and end-user issues through demonstration and optimization of the single-well DUS/HPO process using a single well. This technical report will serve as a means of technology transfer to other end-users who could benefit from the use of this remediation technology.

2. Site Characterization and Site Background

2.1 Site Hydrogeology

The following section describes the demonstration site's geology and hydrogeology learned from site investigation and characterization efforts.

2.1.1 Geology

A geological cross section through wells at SWMU 23 is shown in Figure 2-1. The site soils are categorized into approximately five hydrostratigraphic units. The first unit, from 0 to 24 ft bgs, consists of a hard, reddish, light brown sandy/silty clay. The second unit, from 24 to 29 ft bgs, consists of a reddish to light brown clay to silty sand and gravel. The third unit, from 29 to 35 ft bgs, is a reddish, light brown sandy/silty clay to clayey sand. The fourth unit is the main water-bearing zone in the area of SWMU 23 and consists of grayish, light brown gravel with silt, sand, and clay from 35 to 45 ft bgs. The bedrock is encountered at approximately 45 ft bgs and consists of a weathered siltstone, which may contain brackish water. Soil boring logs from the well installation are included in Appendix B.

2.1.2 Hydrogeology

From the groundwater level surveys conducted in April and August 2001, the depth to groundwater at the site ranges from approximately 13 to 21 ft bgs. It appears that the aquifer is confined, as the water levels in the wells are higher than the depth of the hard clay layer, which was found at 24 ft bgs. Although indications are that the aquifer is confined, this would have to be confirmed through slug tests in wells screened in the upper clay layer, or through pump tests in the aquifer. The exact nature of the aquifer was not confirmed due to the limited characterization data, but is hypothesized to be semi-confined, as depicted in Figure 2-1. Based on historic potentiometric maps and the groundwater survey on August 20, 2001 (see Figure 2-2), it appears that the overall gradient at the site is towards the southwest.

Slug tests were conducted from wells BAT-01, BAT-02, and BAT-03 in April 2001; and from BAT-4S/D (shallow/deep) and BAT-5S/D in August 2001. The tests consisted of placing a TROLL™ pressure transducer/datalogger and 1.0-inch-diameter by 5-ft-long polyvinyl chloride (PVC) slug within the well. After the water level reached an equilibrium, the slug was removed rapidly. Removal of the slug created approximately 0.45 ft of change in water level within the well. Water level recovery then was monitored for 10 minutes using the TROLL™ pressure transducer/datalogger. The data were downloaded to a notebook computer for analysis. The recovery rates of the water levels were analyzed with the Bouwer (1989), Bouwer and Rice (1976), and Hvorslev (1951) methods for slug tests. Although the Bouwer and Rice method is sometimes used in confined aquifers where the top of the screen is well below the bottom of the confining layer, this method is more suitable for unconfined aquifers. The Hvorslev method is more applicable in confined aquifers, but may fail to account for the effects of a sand pack. Therefore, data interpretation was conducted by both

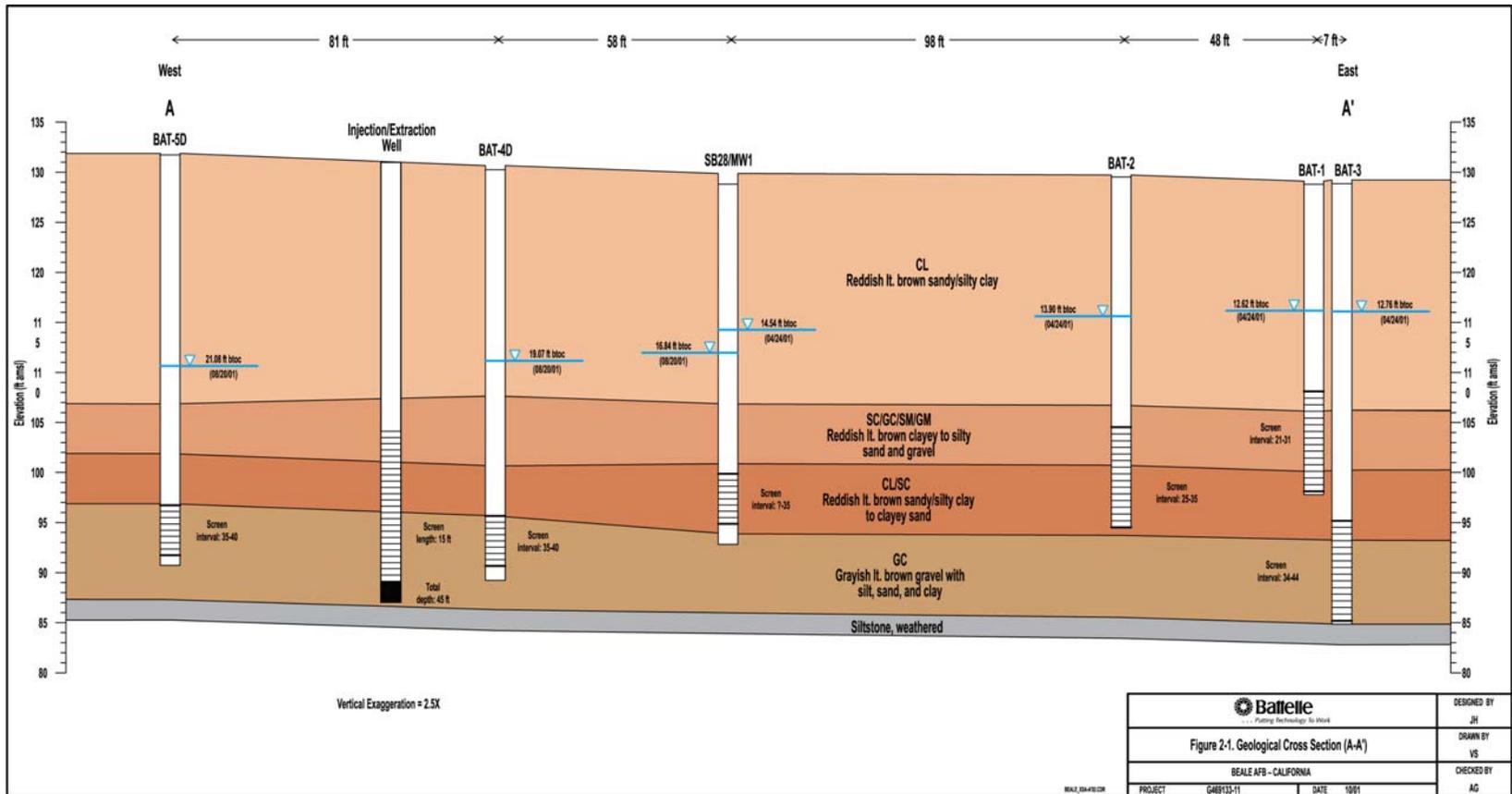


Figure 2-1. Geologic Cross Section A-A' at SWMU 23

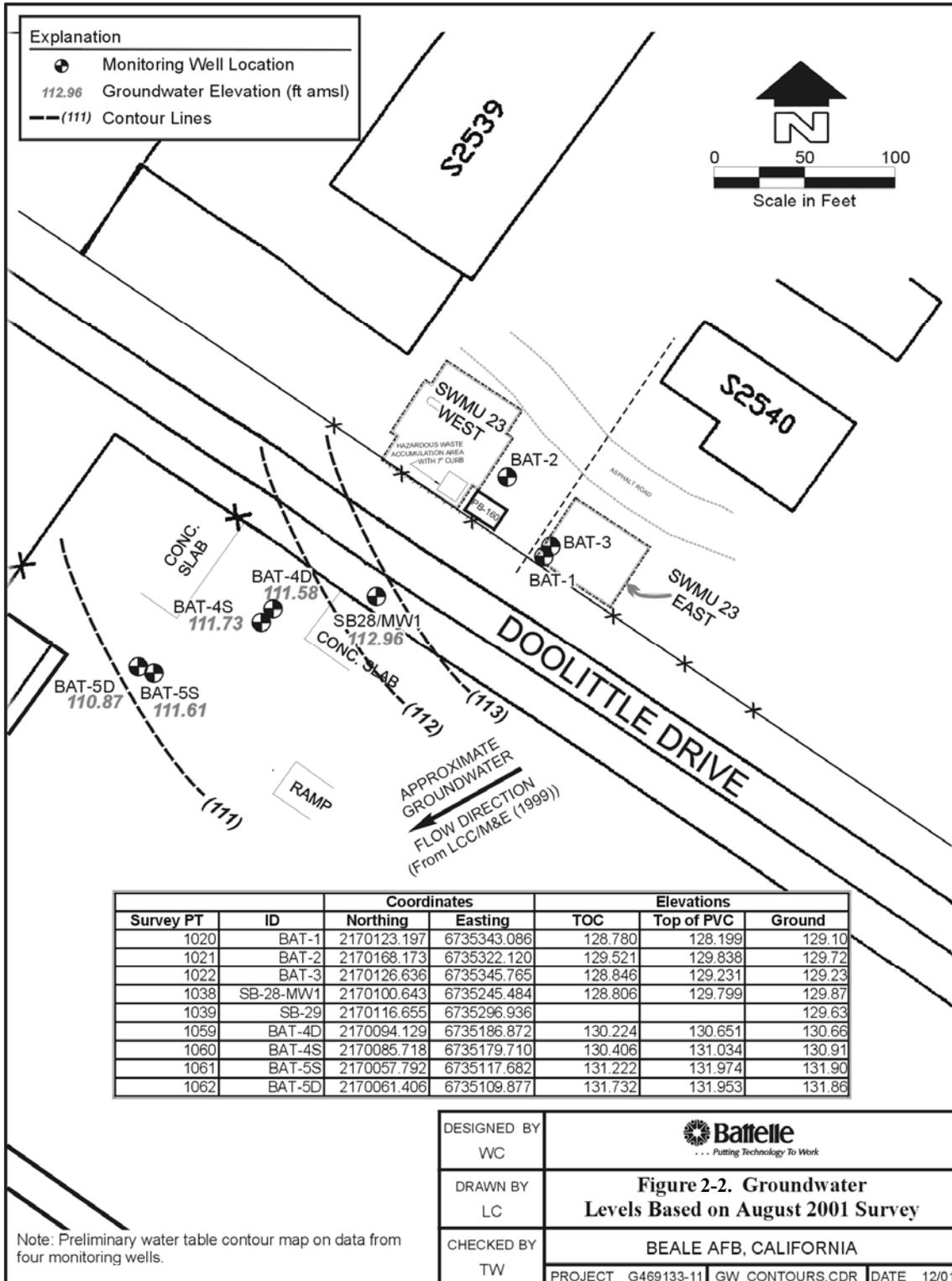


Figure 2-2. Groundwater Level Map Based on August 2001 Groundwater Level Survey

methods. Table 2-1 summarizes the slug test results; graphs were made showing the changes in water level versus time and curve fitted on a semilogarithmic graph (see Appendix B). 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. Water level response showed a good correlation to curve fits. Some early “two-line” responses were evident in the wells, indicating early response from the sand pack followed by response from the aquifer. These data from the slug tests can be found in Appendix B. Overall, the hydraulic conductivity estimates ranged from 0.75 to 14.3 ft/day.

Table 2-1. Summary of Slug Test Results

Well	Well Depth (ft)	Screened Interval		Saturation Thickness (ft)	Well Radius (ft)	Borehole Radius (ft)	Hydraulic Conductivity (ft/day)	
		Top (ft bgs)	Bottom (ft bgs)				Hvorslev	Bouwer and Rice
BAT-01	32	21	31	32	0.0833	0.333	6.4	4.2
BAT-02	35	25	35	32	0.0833	0.333	14.3	6.6
BAT-03	45	35	45	32	0.0833	0.333	3.8	1.4
BAT-4S	30	25	30	30	0.0833	0.333	NA ^(a)	NA ^(a)
BAT-4D	40	35	40	30	0.0833	0.333	1.2	0.75
BAT-5S	30	25	30	30	0.0833	0.333	4.5	1.8
BAT-5D	40	35	40	30	0.0833	0.333	1.3	0.78

(a) Results from well BAT-4S were not recorded due to a malfunction of the TROLL™ data recorder. NA= not available.

Results generated using the Hvorslev method are about 1.3 to 4 times higher than estimates calculated using the Bouwer and Rice method, as might be expected for a confined aquifer. The permeabilities are generally in the range expected from silty sand sediments as seen during drilling. Recovery rates observed during sampling well development also suggest that the aquifer is reasonably productive. As explained earlier, the pump test was not conducted and subsequently the disturbance to the plume was minimized.

Estimates from wells BAT-01 and BAT-02 are similar, because the wells are screened at the same depths. The hydraulic conductivity at BAT-03 is somewhat lower than the ones from the other two nearby wells, suggesting the aquifer sediments differ at the greater depth. At BAT-04 and BAT-05, the hydrostratigraphic layer corresponding to the shallow well BAT-5S had a hydraulic conductivity that was almost twice that of the deeper nested wells BAT-4D and BAT-5D, suggesting the presence of gravel and sand layer. The estimated hydraulic conductivities are generally in the range reported in the literature for silty sands.

2.2 Contamination Extent

Site investigation was to locate the DNAPL source zone, if present, and to determine the optimal location for the HPO demonstration based on the location with the highest TCE/PCE

concentrations in groundwater. Site investigation efforts to date have not identified DNAPL at SWMU 23. TCE concentration levels are relatively low (i.e., generally below 1% of the compound's water solubility), which suggest that a DNAPL source is either absent or minimal.

Based on historical data collected from Hydropunch™ sampling conducted in 1998, the highest TCE level detected at the site was 1,600 micrograms per liter (µg/L) at SB-29 at 25 ft bgs. In general, the concentrations measured in these historic Hydropunch™ locations have not been confirmed with conventional wells. During Phase I (April 2001), Battelle collected groundwater samples from MW-1, BAT-01, BAT-02, and BAT-03. Table 2-2 summarizes VOC results of sampling and analysis in Phase I characterization. The highest TCE level was found in MW-1 at 929 µg/L, and the highest PCE level was found in BAT-03 at 136 µg/L.

Table 2-2. Summary of VOC Results in Groundwater from Phase I Characterization (April 2001)

Well	PCE (µg/L)	TCE (µg/L)	<i>cis</i> -1,2-DCE (µg/L)	<i>trans</i> -1,2-DCE (µg/L)	1,1,1-TCA (µg/L)	VC (µg/L)
BAT-01	105	125	2.63	0.33 J	<1	<1
BAT-02	6.69	58.9	0.52 J	0.2 J	<1	<1
BAT-03	135	2.98	0.19 J	<0.1	<1	<1
BAT-03-DUP	136	2.91	0.20 J	<0.1	<1	<1
MW-1/SB-28	60.7	929	2.01	0.29 J	<1	<1

MW-1 = an existing well south of Doolittle Drive.

EB = quality assurance for equipment rinsate blank.

To gain a better understanding of the nature and extent of the chlorinated volatile organic compounds (CVOCs) contamination in groundwater at SWMU 23, additional site characterization was carried out, which focused on the areas of historically high contamination including the area south of Doolittle Drive and near SB-29 in Doolittle Drive (Figure 2-3). The Navy's Site Characterization and Analysis Penetrometer System (SCAPS) rig was used to complete a near real-time, in situ survey to screen for VOCs. The SCAPS rig is a standard cone penetrometer test (CPT) platform equipped with a membrane interface probe (MIP). The MIP is an in situ helium gas sparge module interfaced with an ion-trap mass spectrometer. The MIP system is certified for the analysis of TCE, PCE, carbon tetrachloride, and several other VOCs such as *cis*-1,2-dichloroethene (DCE), 1,1,1-trichloroethane (TCA), vinyl chloride (VC), etc.

Thirteen CPT punches were performed using the SCAPS system in the area of interest during the Phase II characterization event in June 2001. The punch locations were selected based on likely source areas and migration directions of DNAPL. Sampling began near building PB-160 and continued along a northwest-southeast transect across the SWMU 23 area. These locations were generally low in concentrations (MIP-1 to MIP-3). Sampling then was focused on a potential source near building S2540. TCE concentrations up to 3,100 µg/L were detected at 31.2 ft bgs in

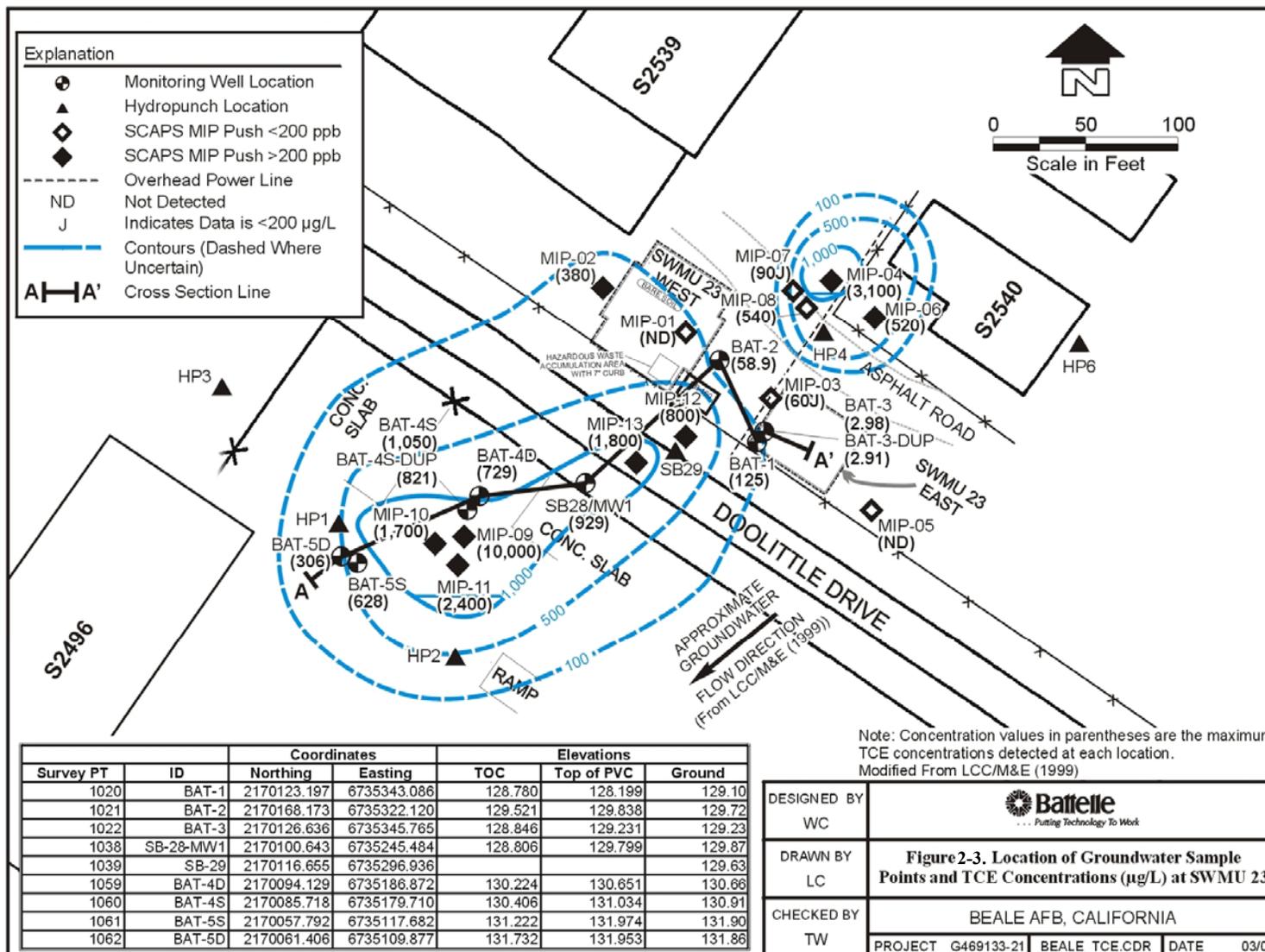


Figure 2-3. Map of Historic and Phase I, II, and III Site Characterization Locations and Contaminant Distribution Map

MIP-04. TCE concentrations measured in MIP-05, MIP-06, MIP-07, and MIP-08 were relatively low, ranging from nondetect to 540 µg/L. Sampling was then aimed at the area south of Doolittle Drive. The results of the MIP investigations indicated that the highest confirmed concentrations were located near MIP-09, MIP-10, and MIP-11 south of Doolittle Drive. TCE levels were measured at levels as high as 10,000 µg/L in this area, and were greater than 200 µg/L at depths of 23 to 37 ft bgs at MIP-09, -10, and -11. PCE also was detected in this zone.

The findings indicate the plume is migrating from the SWMU 23 area, where the source of the contamination was originally suspected two years ago, along the direction of groundwater flow toward the southwest. Although some contamination was detected near building S2540, it was difficult to confirm this result and it may be more indicative of a depleted source zone. Overall, it appeared that the area south of Doolittle Drive (near MIP-09, MIP-10, and MIP-11) was the best location for the DUS/HPO demonstration. Table 2-3 summarizes the highest TCE results including depths at each MIP investigation point. Complete results from the MIP survey locations are provided in Appendix C.

When the demonstration location was identified, a confirmatory investigation was conducted to further corroborate the results of the MIP survey and to obtain more data from the target demonstration area from conventional monitoring wells in August 2001 (Phase III characterization). Activities performed in Phase III characterization included installation of two clustered groundwater monitoring wells (BAT-4S/D and BAT-5S/D) and groundwater sampling and analysis from the new wells. This would corroborate high VOC levels measured by the MIP system using the SCAPS rig. Table 2-4 summarizes VOC results from Phase III sampling and analysis. During Phase III characterization, the highest TCE level (1,050 µg/L) was detected in BAT-4S at a depth of 30 ft bgs. From 30 to 40 ft bgs, TCE concentrations ranged from 306 to 1,050 µg/L, which is approximately 60 to 200 times greater than the groundwater cleanup standard, 5 µg/L, for both federal and California MCLs. The highest TCE hit of 10,000 µg/L from MIP-09 was not corroborated with the sampling results from the nearby conventional monitoring wells. This may be due to the fact that the wells have wider sampling intervals than the MIP probe.

2.3 Aquifer Quality and Geochemistry

This section describes the inorganic chemical measurements and field parameter readings for groundwater collected during March and August 2001.

2.3.1 Groundwater Geochemistry and Inorganics

It was determined that geochemical inorganic analyses were not necessary from the newly installed monitoring wells BAT-451D and -551D. Thus, geochemistry data were only available from Phase I characterization. Cations (calcium [Ca], iron [Fe], magnesium [Mg], manganese [Mn], potassium [K], sodium [Na], and alkalinity [Alk: CaCO₃]) and anions (bromide [Br⁻], chloride [Cl⁻], nitrate [NO₃⁻/NO₂ as N], and sulfate [SO₄²⁻]) were analyzed from background groundwater samples as summarized in Table 2-5. The predominant constituents in the aquifer groundwater include Ca, Mg, Na, Cl, and SO₄²⁻. Other parameters measured were total organic carbon (TOC), total dissolved solids (TDS), and

Table 2-3. Contamination Results from Phase II Characterization (June 2001) Using the In Situ MIP System

Sample ID	Test Type ^(a)	Depth (ft bgs) ^(b)	TCE (µg/L)	PCE (µg/L)	DCE (µg/L)	CHC13 (µg/L)	VC (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Hydrocarbons (µg/L)	M/Z 151+153 ^(c) (µg/L)	M/Z 197+199 (µg/L)
MIP-01	DR	2.4-35.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MIP-02	D	37.5	380	ND	ND	ND	ND	ND	ND	Yes	ND	ND
MIP-03	D	23	60 J	ND	ND	ND	ND	ND	ND	Yes	ND	ND
MIP-04	DR	31.2	3,100	220	ND	ND	ND	ND	ND	Yes	2,400	370
MIP-05	C	0-36.9	ND	240	ND	ND	ND	ND	ND	ND	280	ND
MIP-06	C	0-37.4	520	ND	ND	ND	ND	ND	ND	ND	ND	ND
MIP-07	C	0-40.1	90 J	ND	ND	ND	ND	ND	ND	Yes	ND	ND
MIP-08A	C	0-37.8	540	ND	ND	ND	ND	ND	ND	ND	ND	ND
MIP-09	H	26.3-29.6	10,000	700	ND	ND	ND	ND	ND	ND	ND	ND
MIP-10	H	30.4-33.8	1,700	110 J	ND	ND	ND	ND	ND	ND	ND	ND
MIP-11	H	36.7-40.2	2,400	350	ND	ND	ND	ND	ND	ND	ND	ND
MIP-12	H	26.5-29.9	800	130 J	ND	ND	ND	ND	ND	ND	ND	ND
MIP-13	H	26.8-30.1	1,800	220	ND	ND	ND	ND	ND	ND	ND	ND

Note: Data flagged "J" indicate <200 µg/L, but compound identified present by mass spectrum. ND indicates below detection level of 200 µg/L.

CHC = chlorinated hydrocarbon.

(a) Test types:

D = Discrete static measurement

R = Measured during retraction

C = Continuous measurement

H = Hybrid measurement.

(b) Depth intervals are shown for continuous and hybrid measurements. Contamination within the interval may be variable. The reported concentration is the maximum within the interval.

(c) M/Z 151+153 is likely Freon[®] 113.

Table 2-4. Summary of VOC Results in Groundwater from Phase III Characterization (August 2001)

Well ID	PCE (µg/L)	TCE (µg/L)	<i>cis</i> -1,2-DCE (µg/L)	<i>trans</i> -1,2-DCE (µg/L)	1,1,1-TCA (µg/L)	Vinyl Chloride (µg/L)
BAT-4S	76.3	1,050	2.31	0.25 J	<1.0	<1.0
BAT-4S-DUP	76.7	821	2.19	0.26 J	<1.0	<1.0
BAT-4D	65.6	729	2.2	0.19 J	<1.0	<1.0
BAT-5S	61.6	628	1.36	0.14 J	<1.0	<1.0
BAT-5D	45.1	306	0.55	<1.0	<1.0	<1.0

chemical oxygen demand. Samples for cation analyses were filtered in the field using 0.45-micron (µm) pore size membranes. This procedure was intended to exclude colloidal and suspended forms of particulates in the water samples.

Chloride levels were relatively low and ranged between 13 and 33 mg/L. TDS levels in the background aquifer ranged from 234 to 362 mg/L. TOC was low and below the detection limit of 5 mg/L.

Table 2-5. Inorganic Analysis Results in Groundwater from Phase I Characterization (March 2001)

Well ID	Ca (mg/L)	Fe (mg/L)	Mg (mg/L)	Mn (mg/L)	K (mg/L)	Na (mg/L)	Alk (mg/L)
BAT-01	40.6	<0.1	29.9	0.0398	2.31	22.3	181
BAT-02	40.6	<0.1	29.9	0.0862	2.88	27.2	190
BAT-03	27.6	<0.1	14.9	0.133	2.49	20.0	115

Well ID	Br (mg/L)	Cl (mg/L)	NO ₃ /NO ₂ -N (mg/L)	SO ₄ (mg/L)	TDS (mg/L)	COD (mg/L)	TOC (mg/L)
BAT-01	<2	20.0	7.42	17.5	329	<10	<5
BAT-02	<2	33.1	4.98	22.8	362	<10	<5
BAT-03	<2	13.5	3.35	15.3	234	<10	<5

2.3.2 Groundwater Parameters

CVOC results collected from the monitoring wells in the demonstration area are described above in Section 2.2. Groundwater field parameters (e.g., pH, DO, and oxidation-reduction potential [ORP]) were measured during site characterization Phases I and III and are provided in Table 2-6. A groundwater sample was drawn into a tube at low flow and fed into the flowthrough cell connected to a Horiba U-22[®] water quality instrument, avoiding open air

Table 2-6. Summary of Field Parameter Results in Groundwater

Well ID	Temperature (°C)	pH	ORP (mV)	Conductivity (mS/cm)	DO (mg/L)
<i>Phase I Groundwater Monitoring Data in the Original Proposed Demonstration</i>					
BAT-01	20.98	6.34	211.9	0.763	2.44
BAT-02	21.66	6.33	312.6	0.835	1.50
BAT-03	20.68	6.77	107.1	0.489	3.62
MW-1	22.35	6.21	130	0.689	2.32
<i>Phase III Monitoring Wells in the Demonstration Area</i>					
BAT-04S	21.8	7.16	41	0.52	2.60
BAT-04D	20.9	6.86	14	0.49	3.33
BAT-05S	22.7	7.2	34	0.57	2.10
BAT-05D	22.7	7.02	51	0.54	3.30

BAT-01 to -03 and MW-1 were measured in March 2001.

BAT-04 and -05 cluster samples were measured in August 2001.

contact. Then, the groundwater parameters were measured several times during the course of sample collection from each well until the parameters were stabilized. Thus, the parameters were measured close to the aquifer condition.

The pH levels of groundwater in the aquifer are between 6.2 and 7.2, suggesting that it is neutral. DO levels at the demonstration site south of Doolittle Drive range from 2.1 to 3.3 mg/L, which suggests that groundwater is relatively aerobic in the demonstration area from wells BAT-04 and BAT-05 (i.e., greater than 2 mg/L based on Leeson et al., 2001). The conductivity ranges from 0.49 to 0.57 milliSiemens per centimeter (mS/cm). Temperature of the aquifer groundwater changes slightly seasonally. Temperature readings from spring ranged between 20.9 and 22.7, and summer readings were from 20.9 to 22.7, indicating that there are no significant seasonal fluctuations in groundwater temperature. ORP levels appeared to be unstable with a wide range from 14 to 312.6 mV, and associated pH levels were steady and stable.

2.4 Current Operations

There were no ongoing groundwater remediation activities at SWMU 23 at the time of site preparation and demonstration. Before the demonstration, surface soil contaminated with polychlorinated biphenyls (PCBs) was removed for off-site treatment and disposal in August of 2000. The site was refilled and repaved following the excavation.

3. Technology Description

3.1 Technology Development and Application

Steam enhanced remediation is a technology where steam is injected into the subsurface through wells, and contaminated fluids are extracted for on-site treatment. The fundamentals of steam injection and extraction technology were developed for enhanced oil recovery within the oil industry during the 1960s and 1970s. Several demonstrations of steam injection for contaminant recovery were conducted in the Netherlands in the early 1980s, and at the University of California, Berkeley in the late 1980s (Udell and Stewart, 1989). Later, a process called Steam Enhanced Extraction (SEE), involving steam injection and dual-phase extraction deployed in a specific manner, was patented (Udell et al., 1991). The patented approach involves cessation of steam injection while continuing liquid and vapor extraction. Steam injection was later combined with electrical heating in the process called DUS by LLNL and University of California, and patented (Newmark et al., 1994; Newmark and Aines, 1997; Daily et al., 1995). This process was successfully demonstrated at the Livermore Gasoline Pad site for removal of light, nonaqueous-phase liquid (LNAPL) source trapped below the water table (Newmark et al., 1994).

HPO process is a rapid, in situ remediation technique that destroys subsurface contaminants, such as TCE and other dissolved organic components, with a minimal need for extraction. When steam is injected with air into the target zone, it builds a heated and oxygenated zone in the subsurface, where TCE is oxidized and degraded chemically. When the injection of steam and air is stopped, the steam condenses and contaminated groundwater returns to the heated zone, mixing with the air and condensate. Then, in the presence of heat, TCE is oxidized into carbon dioxide and chloride. This method takes advantage of much more rapid reactions that take place at steam temperature, as well as the large increases in mass transfer rates (dissolution of nonaqueous-phase liquid [NAPL] into the water) which makes contaminants more available for destruction.

LLNL reported a complete mineralization of common contaminants such as polycyclic aromatic hydrocarbons (PAHs) (coal tar and creosote components), chlorinated solvents and oil and gasoline components (Knauss et al., 1997). A detailed study on the kinetics of TCE destruction was also completed (Knauss et al., 1998).

3.2 Previous Testing of Technology

The most noteworthy test of HPO processes in a hydrogeological setting comparable to that found at the demonstration site was conducted by LLNL at the Visalia Pole Yard site in the San Joaquin Valley of California. This study was conducted as part of a successful application of steam stripping (DUS) by Southern California Edison, the site owner (Newmark and Aines, 1998). The disappearance of dissolved oxygen in groundwater, appearance of oxidized daughter products of the contaminants, and production of carbon dioxide bearing a stable carbon isotope

signature more similar to that of the contaminants than of air and soil gases all provided evidence to support the destruction of hydrocarbons, in situ, by HPO.

SteamTech Environmental Services (SES), the technology vendor for this demonstration, is the first commercial licensee of the patented steam and HPO technologies, bringing the technologies to bear on environmental cleanup sites. The vendor performed a field application of the HPO technology for destruction of TCE at Portsmouth, OH. Results for the HPO technology application at the Portsmouth site were encouraging. The elevated carbon dioxide levels in the extracted vapors indicated that HPO reactions were probably important for removing TCE at the site. A total of approximately 1,000 lb of TCE was removed from a small pilot test area through a combination of steam stripping and HPO (SES, 1999; Heron et al., 2000).

Another demonstration of steam injection using the HPO process was performed at the Savannah River site in Aiken, SC. Preliminary data on effluent vapor carbon dioxide levels indicate that a substantial amount of TCE and/or PCE has degraded in situ (IWR, 2001). This field demonstration was involved with the injection of steam and air into multiple screens at three well locations, and liquid and vapor extraction at a central location.

To date, no demonstration of the single-well HPO technology has been conducted other than at Beale AFB. All previous work was involved with multiple wells where dedicated wells were used for either steam injection or extraction. For this demonstration, a single well was used to serve as an injection and extraction in this demonstration. Also, air was injected with steam to increase the oxygen delivery rate and prevent VOC migration in the injected air zone.

In summary, the steam and air injection technology has shown promise at previous demonstrations, with the data indicating that HPO reactions played a major role in the remedial processes at sites where VOC removal by steam stripping was the main focus. Therefore, it was anticipated that HPO reactions might be further optimized by using single well injection-soaking-extraction cycles to minimize VOC migration away from the well, and pure oxygen injection to optimize the reaction rates in the groundwater upon mixing of the steam condensate with the native contaminant of concern (COC)-laden groundwater.

3.3 Factors Affecting Performance

The principal factor affecting performance in the application of this technology is the distribution of permeability. Permeability will govern the radius of influence of steam injected over a screened interval in the injection/extraction well. Redox conditions in the saturated zone at the demonstration site could also impact to performance. Chlorinated solvents such as TCE are commonly more easily degraded under reducing conditions. In addition, should there prove to be significant quantities of reduced minerals in soils within the target volume; these minerals tend to take up coinjected oxygen to encourage HPO, with a consequent loss of available oxygen for destruction of contaminants.

These factors could impact to the overall effectiveness of the process, by limiting the extent of heating or of oxygen addition. In a full-scale cleanup, this would increase the length of time

required for the cleanup, with consequent increases in costs of fuel used, labor, sampling and analyses.

3.4 Potential Advantages and Limitations of the Technology

Advantages:

Low installation cost, as single or few wells would be used for operation.

- Relatively low treatment cost due to minimizing need for extraction and treatment of extracted fluids.
- Level of performance monitoring at an advanced stage may be reduced to temperature and flowrate monitoring along with confirmatory groundwater and soil samples.
- By using fluid injection, the technology preferentially treats the permeable zones in contact with the well, which also are the zones that govern groundwater flowrates and downgradient groundwater quality.
- Environmental remediation and restoration industry is looking for a less aggressive technology that can treat the source of contamination where contamination levels (parts per million [ppm] range) may be several orders of magnitude higher than acceptable levels (i.e., MCL levels in the parts per billion [ppb] range). A single-well scheme can be a source zone technology with less aggression.

Limitations:

- Radius of influence may be small in tight formations where permeability limits the injection rate for steam and oxygen.
- Need to demonstrate that volatilization does not lead to migration of the COCs to the vadose zone or into other regions where they are not extracted in the following extraction phase.
- The HPO technology is limited to COCs that are degradable in heated, oxygenated water under actual field conditions in a time period of less than a few years.
- The creation of an oxygenated, heated zone where the COCs are present in the groundwater may be complicated for volatile COCs that tend to vaporize when heated.
- Formations with reducing conditions may have large chemical oxygen demand (COD), and reduced minerals such as iron sulfide, iron carbonate, or methane may consume the injected oxygen until the COD is overcome. This may dramatically increase the oxygen injection demand.

4. Modeling Results

The technology vendor estimated steam flow and radii of influence for the DUS/HPO treatability study at Beale AFB. The objective of the modeling was to use existing site information to calculate appropriate equipment sizes and to provide an estimate for the size of the footprint affected by the demonstration. Additionally, it was to ensure that the subsurface volume covered by the monitoring program was sufficiently large, such that the risk of fluid migration outside of the demonstration zone could be evaluated and any migration controlled.

Several steam simulator models were published and calibrated to work at several field sites (Heron et al., 2000). The one model user for this demonstration is a modified Marx-Langenheim simulator that was used in enhanced oil recovery for more than 30 years. The model was coupled to a solution of the governing pressure equation for a single injection well. The same simulator was used successfully to predict steam and hot water rates and radii of influence for the following projects:

- Alameda Point, CA (Berkley Environmental Restoration Center, 2000).
- Portsmouth, OH (SES, 1999).
- Sunbeam, TN (SES, no date).

In addition, the same simulator was used as a design tool for the following sites:

- McCormick-Baxter in Stockton, CA (U.S. Army Corps of Engineers [USACE]).
- Wyckoff-Eagle Harbor, Seattle, WA (USACE).
- Guadalupe Sand Dunes, Guadalupe, CA (SES).
- Port of Ridgefield, Vancouver, WA (SES, 2000).

Five intrinsic permeability rates between 0.1 to 5 darcy (10^{-13} to 5×10^{-12} m²) were used for the modeling. It was assumed that the steam zone would become 15 ft thick (screen depths between 25 and 40 ft bgs) at the maximum injection pressure of 20 pounds per square inch gauge (psig). Based on these intrinsic permeability rates and assumptions, radii of the steam zone created for the first steam injection cycle were estimated using the input parameters listed in Appendix D. Calculated radii of the steam zone for different permeability rates were graphed in Figure 4-1. The results indicate that the higher radius of influence for the steam zone is expected in the higher intrinsic permeability. Separately, the steam injection rates were calculated for the duration of the operation period at the same intrinsic permeability rates in Figure 4-2. Figures 4-1 and 4-2 demonstrate the importance of intrinsic permeability that would be used for the demonstration. It is apparent that the permeability controls the injection rate and the radius of influence for the steam injection. The maximum radius of heated influence would be no more than 40 ft (approximately 13 m) at the permeability of 5 darcy when the first injection is applied into the

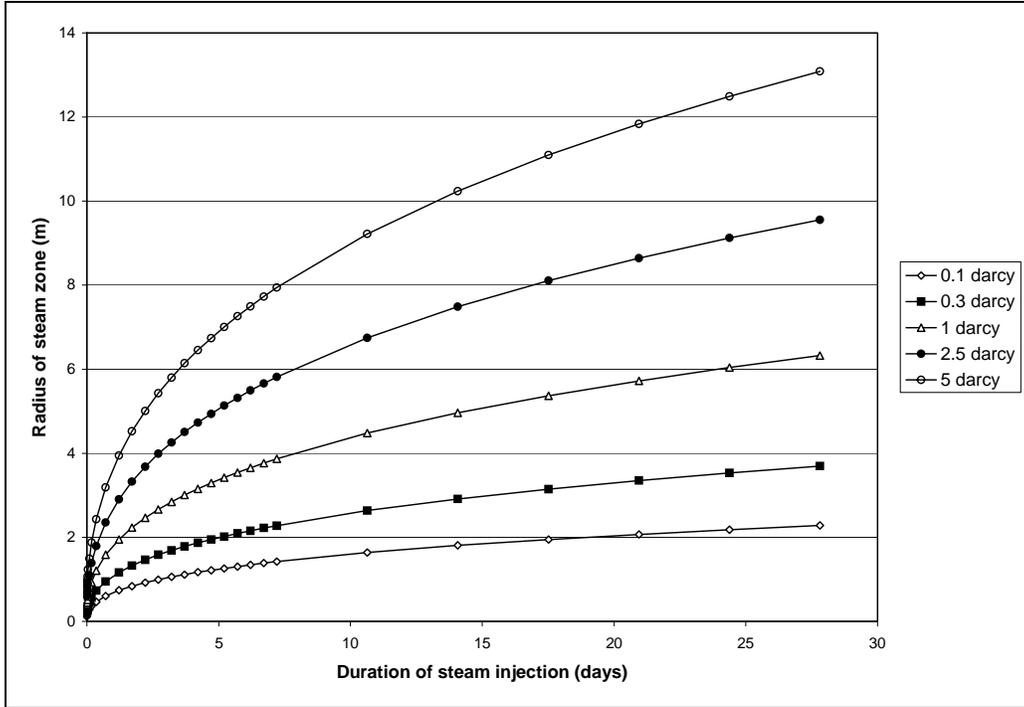


Figure 4-1. Calculated Radii of Steam Zone for First Injection Cycle at Various Intrinsic Permeability Values

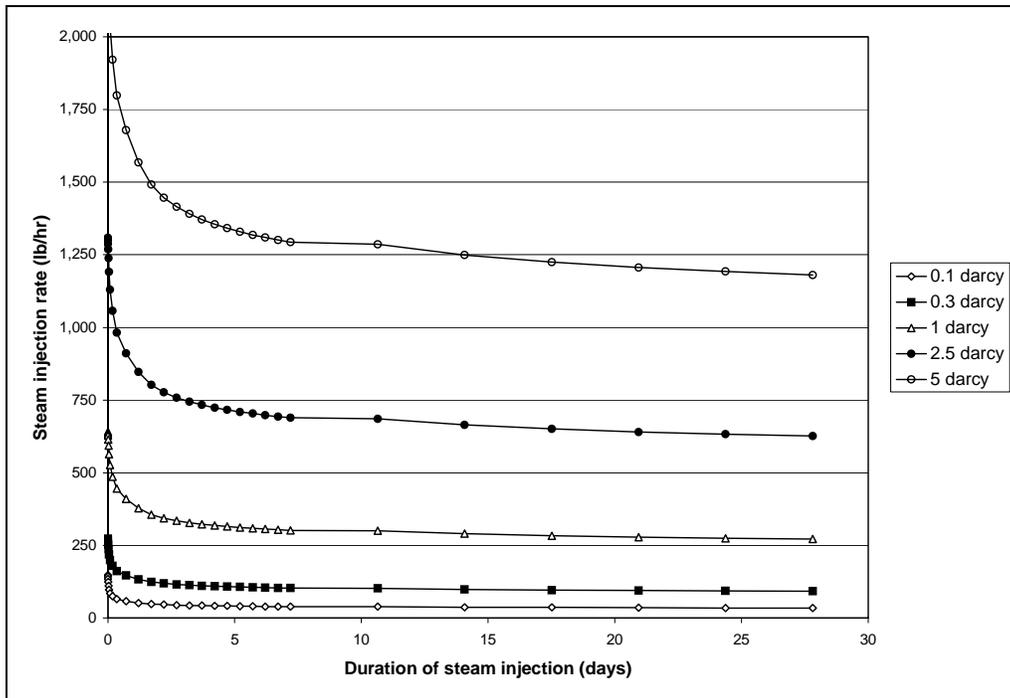


Figure 4-2. Calculated Injection Rates for First Injection Cycle for Various Intrinsic Permeability Values

single injection well. At the same intrinsic permeability, the maximum steam generation rate was determined to be no more than 2,000 lb/hr. However, the actual injection rate should be substantially lower than the steam generation rate.

With the intrinsic permeability data from nearby wells at approximately 1 darcy range, the modeling results also suggest that subsequent cycles expand the radii of influence for both steam and water zones as summarized below:

- Cycle 1. 10 ft steam zone, 14 ft hot water zone.
- Cycle 2. 14 ft steam zone, 17 ft hot water zone.
- Cycle 3. 16 ft steam zone, 20 ft hot water zone.
- Cycle 4. 18 ft steam zone, 22 ft hot water zone.
- Cycle 5. 20 ft steam zone, 25 ft hot water zone.

In conclusion, the modeling results ($k=1$ darcy) helped to determine the maximum radius of influence zone and the injection rate, and indicated that the monitoring zone for the heated zone would extend about 20 to 30 ft from the injection/extraction well. With characterization data (Section 2), the soil in the demonstration site was sufficiently permeable to allow the steam injected to impact contaminant-filled pores within the volume during the proposed period of the demonstration. However, the actual steam and hot water zone would be different from the estimates. As a result, the actual radius of influence of injected steam could be smaller than predicted and thus the contaminant mass impacted would be smaller. Also, more efficient HPO could be achieved using shorter injection and extraction cycles than the longer injection and extraction cycles originally planned and proposed in the demonstration work plan.

In addition to the results from the modeling prediction, the following monitoring approaches were used to prevent escapes of steam and hot condensation during the demonstration:

- In situ monitoring of temperature (using thermocouples) and electrical resistivity (using Electrical Resistivity Tomography [ERT]) in an area larger than the expected heated zone. This monitoring would detect any hot water or steam migration outside of the predicted zone. Detection of hot water migration out of the test area would lead us to extract more aggressively until the impact was under control.
- Successive cycles for which more extraction was planned than injected volume. Document flowrates and volumes of steam injected, liquid and vapor extracted, and the separation of heated fluids in the treatment system.

5. Demonstration Design and Site Preparation

5.1 Subsurface and Aboveground System Design Factors

In order to distribute steam and heat in the subsurface in the most efficient way, the subsurface design for the demonstration considered the following factors: stratigraphy, contamination levels from site characterization, estimated radius of heating influence, and an injection rate of steam and oxygen. In order to monitor temperature and contaminant fluctuations in groundwater, performance monitoring wells were installed in and around the demonstration area in strategically selected monitoring locations.

A single injection/extraction well (SI-01) was located at a point immediately adjacent to the highest contaminated area identified during the site characterization (See Figure 5-1). The injection/extraction well was screened from the base of the unconfined aquifer to a level 15 ft above the unconfined aquifer. The 15-ft long screen was installed over the stratigraphic unit in which the highest contaminant concentration was located. A network of five groundwater monitoring wells (BAT-06 to BAT-10) was positioned along axes radiating out from SI-01 at angles of about 120°. The monitoring network consisted of: (1) a series of three wells extending toward the southwest, roughly along the groundwater flow direction in the unconfined aquifer, and (2) two single wells to the north and east of SI-01. An additional monitoring network for temperature and ERT monitoring was located outside the groundwater monitoring wells in a “5-spot” configuration. Thermocouple strings for the temperature monitoring were placed outside of each monitoring well casing and the injection well casing.

For the aboveground system, the technology vendor used standard surface equipment and techniques previously used at other sites. The standard equipment list included a steam generator, a steam and oxygen delivery system, electric control box, and an extract treatment system. The maximum steam generator rate was determined based on the modeling results (Section 4). The steam and oxygen delivery system consisted of a 12-inch-diameter carbon steel pipe connected from the steam generator to the wellhead of the injection well to deliver a good mixture of steam and oxygen into the subsurface. The wellhead has a device attached to measure steam pressure and flow inside the delivery pipe as well as inside the well casing. The wellhead is also equipped with a temperature monitoring device and a pressure release valve to alleviate excess pressure in the well casing. A combination of proper mixture for steam and oxygen was estimated based on the modeling results mentioned in Section 4.

5.2 Demonstration Subsurface Site Preparation

The details of the subsurface monitoring network construction, including the connection to the base main utility lines, are discussed in this section.

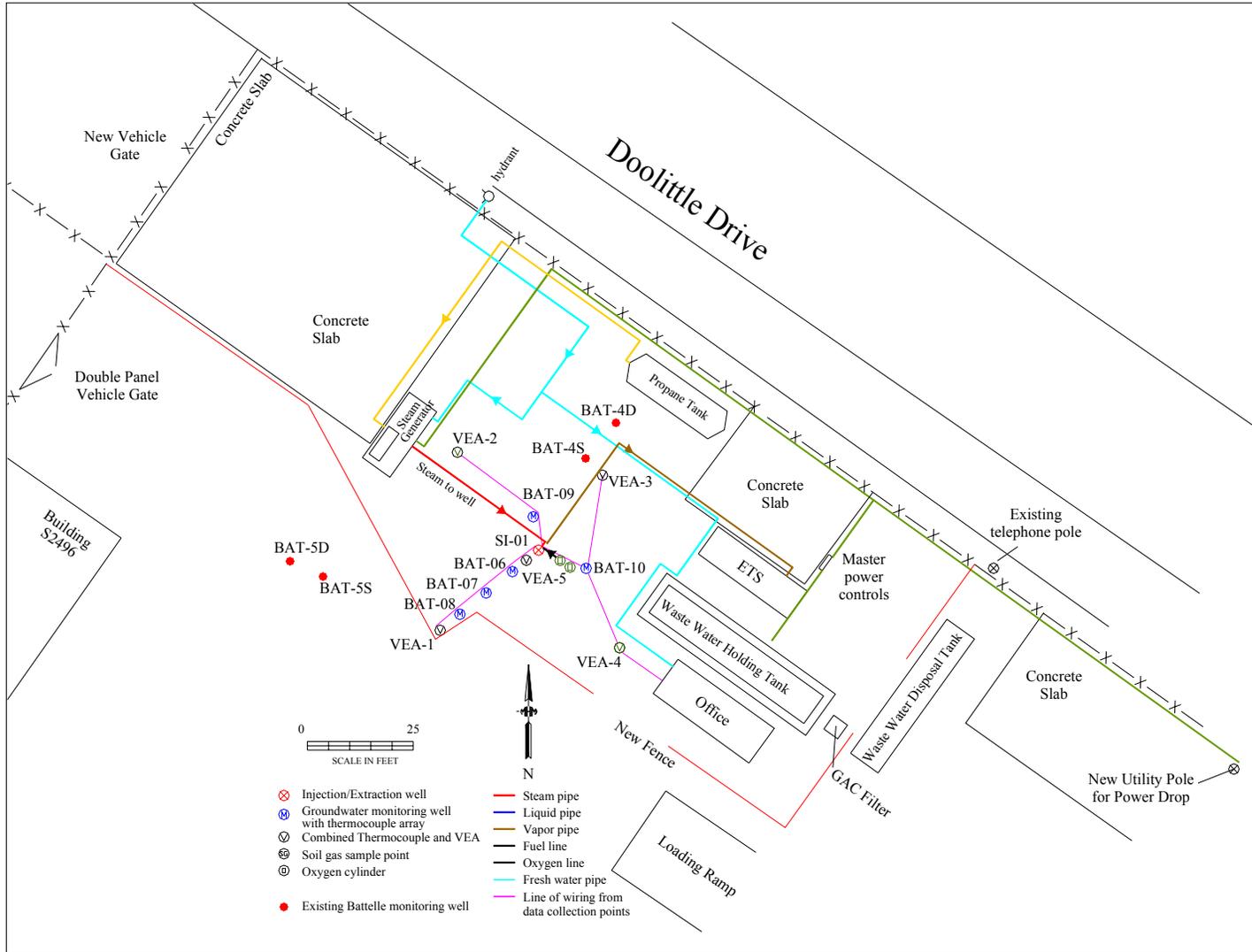


Figure 5-1. Demonstration Site Layout

5.2.1 Injection/Extraction Well

A truck-mounted (DR 10K) hollow-stem auger (HSA) rig was used to install the injection/extraction well SI-01 to a depth of 45 ft bgs at a borehole diameter of 10 inches. Soil samples from the borehole were collected to keep a log of the lithology. Qualitative contamination scanning processes were conducted using a photoionization detector (PID) during drilling with a split-spoon sampler from a depth of 5 ft bgs to 45 ft (total depth). The well was completed with 4-inch black-steel casing, a stainless-steel screen, and a 2-ft black steel sump with a welded endcap. The wire-wound 0.010-inch slot screen was 15 ft in length and extended from 43 to 28 ft bgs. Well construction details are shown in Figure 5-2.

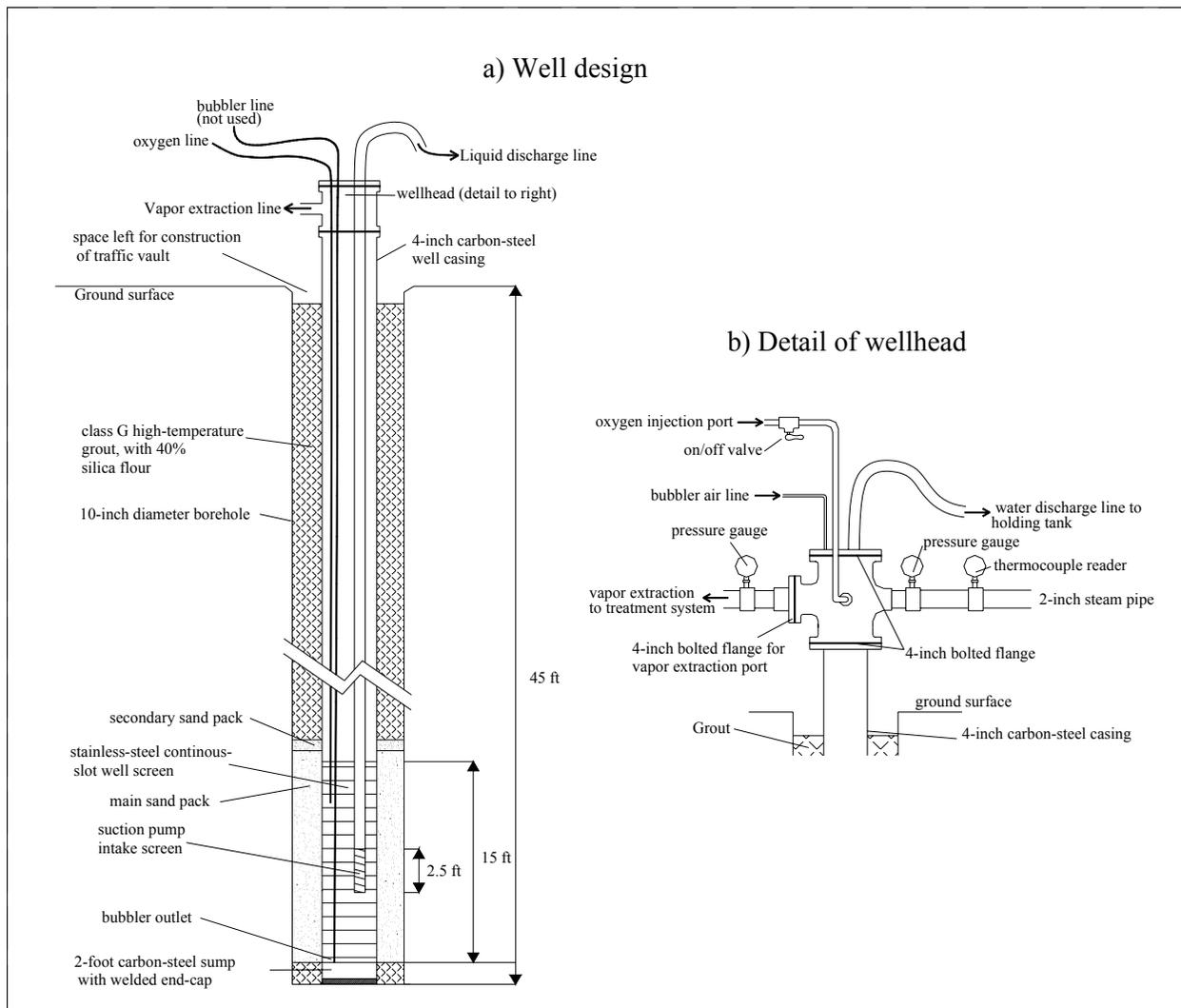


Figure 5-2. Design Features of Injection/Extraction Well and Wellhead Completion

DigiTAM™ temperature sensors, manufactured by McMillan-McGee Corporation, were inserted adjacent to the casing and screen to provide temperature profiling during the well installation. The well sump was set in American Petroleum Institute (API) Class G cement, which was allowed to set before the main sandpack was poured. The main sandpack (RMC 2/12) extended from the top of the sump (43 ft bgs) to 27 ft bgs, where it was overlain by 1 ft of secondary sandpack (RMC 1/20) to act as a seal, in place of bentonite, which would lose its integrity at high temperature. The well annulus was then grouted with Class G cement to within 1.5 ft of surface, to allow for installation of a traffic vault at the completion of demobilization. The completed well was left undisturbed for one week before development. Well development was involved with a surge-and-purge technique, using a 2-inch-diameter submersible Grundfoss® pump, until the extracted water was free of visible sediment.

After the injection/extraction well construction, two falling head slug tests were conducted. A 5-ft-long by 1-inch-diameter PVC slug was used to displace water in the well. Head changes were measured using an In-Situ, Inc., miniTroll™ pressure transducer and data-logger. Hydraulic conductivity was calculated using the Hvorslev and Bouwer and Rice methods described in Section 2.1. The calculated hydraulic conductivity values (summarized in Table 5-1) were comparable to those previously determined at the site for adjacent wells (see Table 2-1) and are probably most directly representative of conditions in the upper part of the screened interval, where the bulk of the steam flow would be expected to occur.

Table 5-1. Summary of Slug Test Results from Steam Injection Well SI-01

Well	Well depth (ft)	Screened Interval		Saturation Thickness (ft)	Hydraulic Conductivity (ft/day)	
		Top (ft bgs)	Bottom (ft bgs)		Hvorslev	Bouwer & Rice
SI-01	45	28	43	25.74	6.77	4.86
SI-01	45	28	43	25.74	6.64	4.49

5.2.2 Performance Monitoring Wells

Performance monitoring wells, designated BAT-06 to -10, were placed to be used as groundwater sampling points before, during and after the demonstration. The monitoring wells were located along three axes set at about 120° to each other and radiating from well SI-01. Each monitoring well was advanced with a HSA to the same depth (45 ft bgs) at each bore-hole with a 7-inch diameter, using a DR 10K truck-mounted rig. Soil sampling was conducted during the well installation from the depths between 20 ft bgs to 45 ft (total depth) as described in Section 5.2.1. The soil sampling was to provide a soil profile corresponding to the screened interval.

Initially, steel casing was planned to be used for the performance monitoring wells. During the well installation, the design was modified per request from Beale AFB to switch to stainless-steel casing. BAT-07 and -08 were installed with carbon steel casing, whereas BAT-06, -09, and -10 were completed with stainless-steel casing. Each performance monitoring well was screened at 18 to 43 ft bgs. DigiTAM™ sensors were installed adjacent to each monitoring well for temperature monitoring.

Well construction materials and development procedures were the same as the injection/extraction well described in Section 5.2.1.

5.2.3 Temperature Monitoring Strings

As discussed in Sections 5.2.1 and 5.2.2, direct temperature tools were installed in each well. The temperature monitoring tools include arrays of thermocouples and microchip sensors.

Each thermocouple tip was spot-welded, then covered in epoxy resin, and wrapped with heat-shrink tubing before the installation. The arrays of Type-K thermocouples were spaced at 5-ft intervals from the surface to 45 ft bgs as shown in Figure 5-3. Any thermocouples with a reading varying more than 1°C from the calibration temperatures of 0 and 100°C were replaced during prefabrication. Direct measurements of the temperature from the subsurface would offer one of the most generous interpretations of the temperature distribution after heat distribution due to the steam injection and extraction processes.



Figure 5-3. Installation of Thermocouples

At the site it was proposed to use microchip temperature sensors manufactured by McMillan-McGee Corporation in each of the monitoring wells and on the injection/extraction well. The sensors originally installed were spaced at 2.5-ft intervals, with the sensor strings attached

directly to the casing by cable ties. During the baseline monitoring, persistent hardware failures in the original sensors compelled the installation of retrofit sensors prefabricated for another site in each of the wells. The retrofit sensors were spaced at 3-ft intervals. The lowest sensor on the sensor string was attached to the end of the stainless-steel groundwater sampling tube at a depth of 42.5 ft bgs. The remainder of the string was kept under slight tension and led out of the monitoring well at a T-joint at the wellhead. Continued unreliability of this model of temperature sensor in all wells led to a final substitution of more robust sensor strings, which were retrofit from another site and spaced at 2.5-ft intervals in wells BAT-07 and BAT-09. Design features of both thermocouple and microchip sensor temperature monitoring strings are shown in Figure 5-4.

5.2.4 ERT Vertical Electrode Arrays

Upon the completion of the wells, additional boring holes were made to equip necessary ERT vertical electrode arrays (VEAs). Five VEAs (VEA-1 to -5) were installed at five spatially distributed locations to capture the heat resistivity and conductivity due to the steam injection and extraction processes. Each boring was advanced by a HSA to a depth of 45 ft bgs with a 7-inch borehole diameter, using the DR 10K truck-mounted rig. Soil samples were not collected or logged during the construction of the VEA installation. The VEA arrays, containing 5-ft spacing electrodes and thermocouples, were prefabricated before the installation. VEAs were suspended in the open boring after the auger barrels had been withdrawn, in order to ensure a vertical orientation. Heat-resistant grouting cement was then tremied into the boring, flush with the ground surface. Detailed design features are shown in Figure 5-4.

5.2.5 Preparation of Site

Access to basic utilities for system operations at the site was provided by Beale AFB. Water to generate steam was supplied from a fire hydrant on Doolittle Drive. A two-stage backflow preventer served to isolate the base water supply system from water used in the operations. Electrical power was provided by extending a spur from the power line lying on the north side of Doolittle Drive across the road to a new utility pole and power drop to a temporary 150 KVA pad transformer which was located in the transportation yard for the duration of the demonstration.

Major pieces of equipment used in steam generation, dual-phase extraction, wastewater holding tanks and disposal units were brought into the site. All items were trailer or skid-mounted and were mobilized to the site. Other equipment included a 5,500-gal propane fuel tank, 6,500-gal mobile wastewater disposal tank, prefabricated vapor-extraction system, 21,000-gal holding tank, and administrative office trailer (see Figure 5-5 for the list of photos).

Once equipment had been placed on-site, the surface infrastructure of the demonstration system was constructed. This involved connection of piping linking well SI-01 to the steam generator, vapor treatment system and holding tank. The oxygen supply line was connected to the injection well SI-01. The oxygen supply line was connected to the subsurface delivery

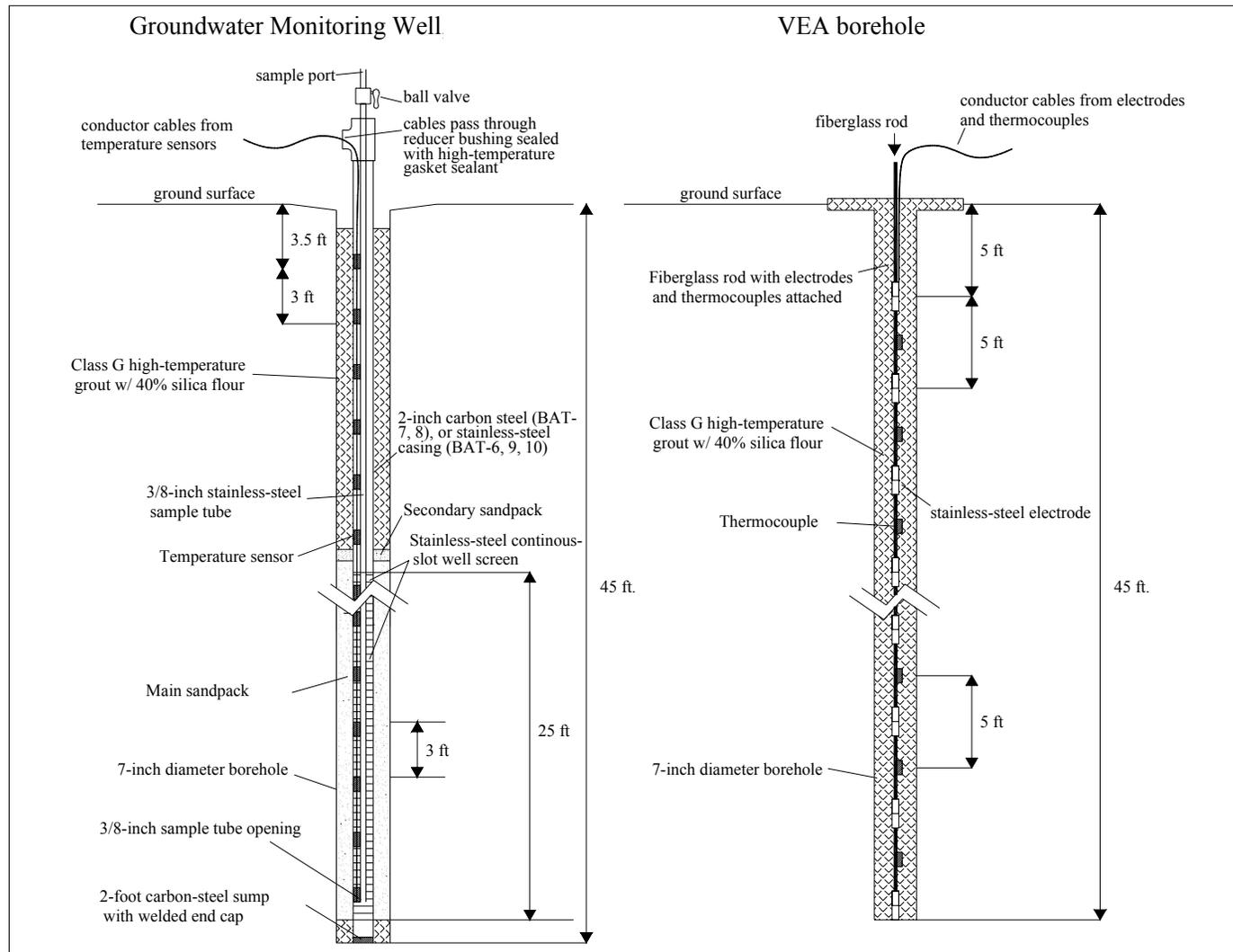


Figure 5-4. Design Features of Performance Monitoring Wells and ERT Borings



(a) 5,500-gal Propane Gas tank



(c) Vapor-Extraction Treatment System



(b) 6,500-gal mobile Wastewater Disposal Tank



(d) 21,000-gal Wastewater Holding Tank

Figure 5-5. Pictures of Site Equipment

system and all electrical wiring. The layout of equipment at the site is shown in Figure 5-1. Subsurface geophysical (i.e., ERT) monitoring equipment installed during the well installation was connected to a data acquisition and processing unit. All the subsurface monitoring equipment units were installed by the technology vendor, SES. The geophysical monitoring equipment was connected by Forest Environmental Services personnel. Upon completion of surface and subsurface installation, background groundwater sampling of each of the monitoring wells and of the injection/extraction well was conducted by Battelle personnel.

5.3 Demonstration Aboveground System Setup

Essential design features for the aboveground systems are summarized in this section.

5.3.1 Steam Generator and Steam Injection System

This section describes site preparation related to the steam generation system and the injection system. Before steam was generated, a water line was connected to the nearest fire hydrant, which belongs to the adjacent base fire station facility. Because the water from the source was rusty, it was fed through a water-softener using an ion-exchange resin before entering the steam generator. This reduced hardness and oxidized particulates (rust) in the water before it was fed into a preheater. In this way, the steam generator required less energy by using water that had been preheated to 70°C.

The steam generator, containing a furnace and a boiler, was in an enclosed trailer, as shown in Figure 5-6. As the modeling suggested, the required steam generation rate was not more than 2,000 lb/hr; the propane-powered generator was selected as the on-site steam generator and was rated at a maximum of 1,725 lb/hr, equal to an energy input of 1.97 million British thermal units per hour (BTU/hr). Although the original design was to use natural gas, which generally has a higher energy production rate than that of propane, the challenge to connect the gas hookup line to the main gas line at the base impeded its use and thus propane gas was used. Subsequently, the total estimated volume of steam generation (about 6,000 gal) would not necessarily require natural gas as a fuel source. The required volume of propane gas was transported from a local supplier and stored in a 5,500-gal tanker trailer on site. The steam generator water supply was obtained from the aforementioned fire hydrant, at the maximum continuous rate of 5 gallons per minute (gpm). Softened, preheated water was fed into the steam generator which was set for the steam pressure at a range of 1 pound per square inch (psi) using an air-powered, oilfield-type pressure regulator. Generated steam was to be delivered to the injection wellhead through carbon steel pipes. Steam pressure was to be maintained between 20 and 25 psi, as the modeling results suggested in Section 4. Steam pressure, temperature, and water quality parameters from the wellhead were designed to be read using standard instruments during regular routine monitoring of the operation. The oxygen injection manifold was connected to the injection wellhead and was designed to adjust the oxygen flowrate to provide the proper amount of oxygen (at 100 ± 50 ppm) into the steam.

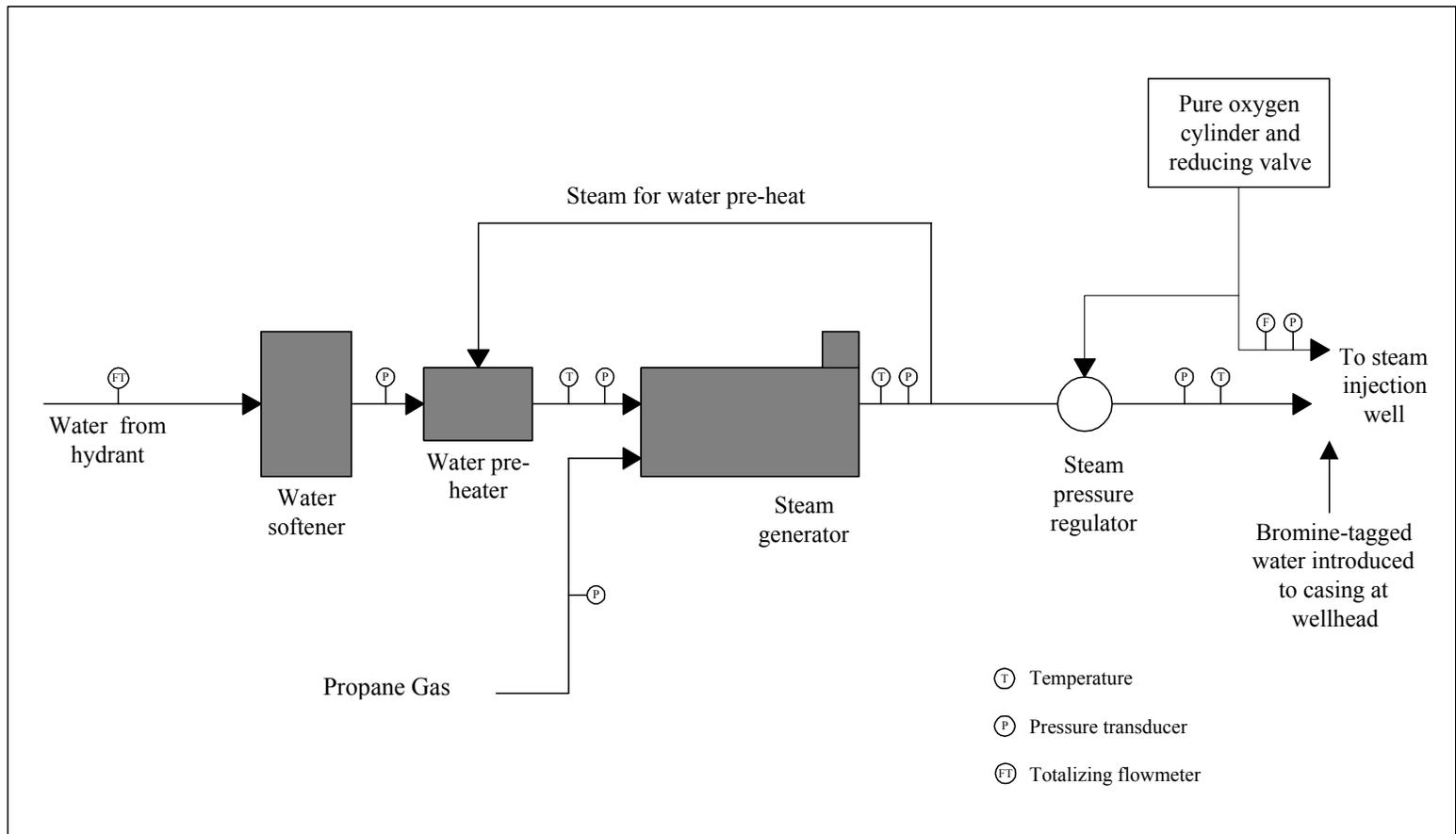


Figure 5-6. Steam Generation and Injection Schematic Diagram

5.3.2 Extraction System

In the final demonstration work plan (Appendix H) submitted to the ESTCP office, the project team proposed that the extraction system was to extract the injected steam and aquifer water using a dedicated pneumatic positive displacement pump. However, considerations to the ease of operation led to the pump design being replaced by a progressive cavity pump. An equipment failure at the beginning of the first extraction phase compelled the removal of the progressive cavity pump. Then the pump was replaced with a suction pump, which used a combination of applied vacuum and airlift to force water from the well (see Section 6-1 for the operation). Vapors were extracted under a vacuum state through a vapor extraction line of the wellhead (Figure 5-2).

5.3.3 Effluent Treatment System

Vapor and liquid effluents were designed to be treated using a series of treatment processes shown in Figure 5-7. The effluent extracted from the extraction well is the combination of escaping vapor subsequent to the steam application in the contaminated groundwater, liquids via the liquid recovery system, and a small amount (less than 700 gal total) of boiler blow-down water to the wastestream.

The extracted vapors were carried to the treatment system through surface piping. The vapors first entered a liquid-vapor separator knockout vessel (KO-2), in which water and fines carried with the vapor were removed from the vapor stream. The vapors then passed through a heat exchanger/condenser, in which their temperature was reduced to below 50°C (120°F). This led to condensation of water vapors and contaminants (the condensable gases). The condensate was then removed from the vapor stream, contained in a second liquid-vapor separator (KO-3), and the gases carried to the vacuum pump. The effluent vapors from the vacuum pump were treated by carbon adsorption through two 200-lb carbon canisters in series before being vented to the atmosphere (see Figure 5-7).

The extraction and treatment system was designed to meet specific discharge and emissions criteria from the designated sample ports of L-2 and V-2 (Figure 5-7) for individual COCs and other parameters. Table 5-2 is the list of parameters and associated discharge limits specified by the California Regional Water Quality Control Board (CRWQCB). Vapor treatment was set to take place at a series of granulated activated carbon (GAC) tanks before discharging air into the atmosphere. It was expected to have a relatively lower concentration of contaminants in the extracted vapor and liquids (the liquids would be mixed and diluted with the injected extra volume of steam). The carbon scrubbing was determined to be sufficient for the vapor treatment. The vapor after the effluent treatment was to meet the discharge loading limits, listed in Table 5-3, set by both State of California Central Valley Region and the Bay Area Air Quality Management District (BAAQMD).

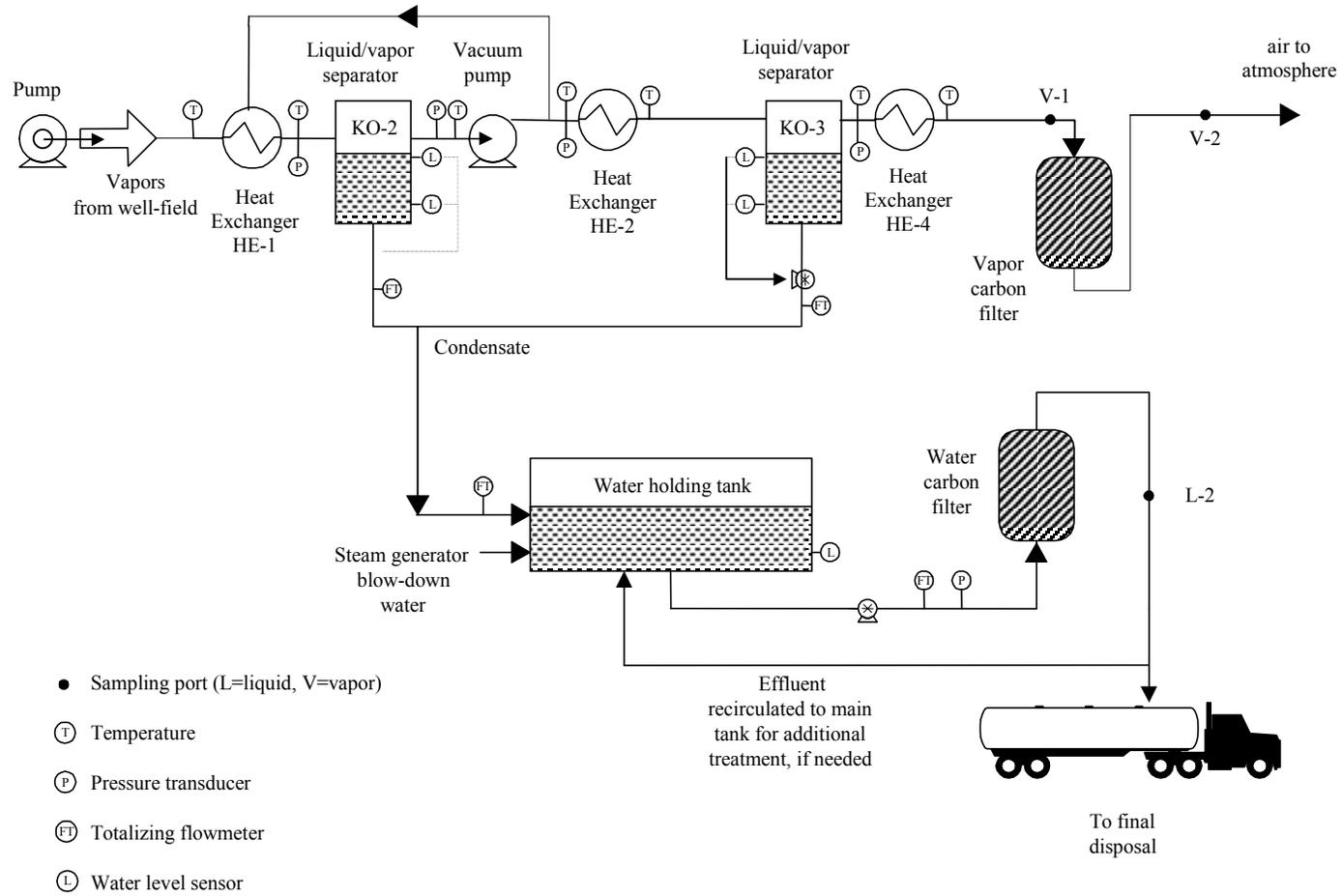


Figure 5-7. Simplified Effluent Treatment System Flow Diagram

Table 5-2. Liquid Effluent Limitations for Parameters Specified by CRWQCB^(a)

Parameter	Target (µg/L)	Sample Point
Ammonia (as N)	1,500	L-2: Liquid discharge point
Barium	1,000	L-2: Liquid discharge point
Boron	1,000	L-2: Liquid discharge point
Copper	13	L-2: Liquid discharge point
Cyanide	5.2	L-2: Liquid discharge point
Mercury	0.012	L-2: Liquid discharge point
Cadmium	1.2	L-2: Liquid discharge point
Methylene blue active substances (MBAS)	500	L-2: Liquid discharge point
Oil and grease	10,000	L-2: Liquid discharge point
TPH-GRO	50	L-2: Liquid discharge point
TPH-MO	100	L-2: Liquid discharge point
TPH-DRO	100	L-2: Liquid discharge point
<i>bis</i> (2-ethylhexyl)phthalate	1.8	L-2: Liquid discharge point
Chloroform	0.5	L-2: Liquid discharge point
1,1,2-trichloroethane	0.5	L-2: Liquid discharge point
<i>trans</i> -1,2-DCE	0.5	L-2: Liquid discharge point
<i>cis</i> -1,2-DCE	0.5	L-2: Liquid discharge point
TCE	0.5	L-2: Liquid discharge point
PCE	0.5	L-2: Liquid discharge point
VC	0.5	L-2: Liquid discharge point

(a) Discharged liquids should not exceed stated target levels.

TPH-DRO = total petroleum hydrocarbons as diesel-range organics.

TPH-GRO = total petroleum hydrocarbons as gasoline-range organics.

TPH-MO = total petroleum hydrocarbons as motor oil.

5.4 Residual Handling

Solid and liquid generated during the site preparation and system setup were contained and stored in 55-gal drums. Several sets of random investigation-derived waste (IDW) samples were collected and analyzed before the discharge when the sample results met the regulatory discharge limits as listed in Table 5-2.

Table 5-3. Emitted Vapor Criteria

Parameter	Trigger Level	Sample Location
TCE	97 lb/year	V-2: Emitted vapor
PCE	33 lb/year	V-2: Emitted vapor
VC	2.5 lb/year	V-2: Emitted vapor

Residuals consisted of extracted water that failed to meet regulatory discharge limits, spent vapor and liquid carbon, and nonhazardous construction and demobilization refuse. After profiling wastewater for the full suite of VOCs and other inorganics including mercury required by the CRWQCB, the wastewater in the tanker trailer was sent off to be disposed of at a licensed hydrocarbon-tainted water disposal facility. Samples from spent carbon were collected and analyzed before disposal at the supplier's facility. Nonhazardous general waste such as paper towels was stored in a 55-gal drum. The drum was hauled to a local landfill in the Marysville area at the end of demonstration.

6. Operation and Maintenance

As explained in Section 4, the HPO process could be more efficient when shorter injection and extraction cycles are applied than the longer injection and extraction cycles originally planned. The original demonstration was to operate for a total of five cycles in an overall work period of 35 calendar days (25 work days). Each cycle consisted of an initial steam injection phase followed by a steam-soaking phase, then a liquid and vapor extraction phase. Each phase was planned to last for two days. Steam injection into the subsurface occurs on Thursdays and Fridays, allowing the soaking phase to occur on weekends (Saturday and Sunday), during which time the site and process equipment would be left unattended. Then, each extraction of liquid and vapor begins on Monday mornings and continues until Thursday morning, when the next steam injection phase would begin. Due to the limited resources over the course of the project, it was determined that the demonstration was modified to reduce the original schedule to a shorter period of operations over 29 calendar days (21 work days), beginning with an initial short heat-up phase, followed by three inject-soak-extract phases as described above. Steam injection started on October 23, 2002; the first extraction phase began on November 4, 2002. The third extraction phase was completed on November 20, 2002. After the demonstration, groundwater monitoring, temperature, and ERT monitoring continued until December 9, 2002. Activities for the operational period are summarized in Table 6-1, with supporting data are included in Appendix F. Details of design changes and major maintenance activities implemented during the operation will be discussed in this section.

6.1 Steam Injection and Extraction System

The steam generator and boiler unit was a single enclosed unit in which a water line was connected to the preheater of the steam generator. The electrically preheated water was fed into the steam generator by the boiler unit. The furnace was turned on only during the steam injection phase of each cycle. Opening a safety valve to release built-up steam in the steam tank was not necessary until steam generation for the injection was completed.

An unexpected difficulty involving liquid extraction out of the injection well was encountered during the first extraction phase. As discussed in Section 5.3.2, a replacement progressive cavity pump instead of a dedicated pneumatic positive displacement pump was drawing only air but no water. The failure of extraction was rectified by pulling the installed pump out of the injection/extraction well and connecting a 6-inch suction tube from the wellhead to a suction pump for the water discharge. Although the flowrate was not controlled due to the intermittent suction mechanism in the suction pump, it was measured for the total volume of liquid extracted in a given amount of time. The liquids removed from the SI-01 well were stored temporarily in a 21,000-gal epoxy-coated tank, fitted with vapor-tight top hatches in order to minimize contaminant loss prior to sampling of the tanks. No provisions for cooling were necessary, as the succeeding step in the treatment process was to remove volatile organics from the water.

Table 6-1. Timeline for Steam Injection/Extraction Demonstration

Start-End Date/Time	Event	Phase	Operation Hours	Comments
May 2002	Pre-demonstration monitoring	—	—	Baseline groundwater monitoring; soil-gas monitoring
October 23, 2002 15:40 October 25, 2002 16:00	Cycle 1a	Injection	48.3 hr	Injection rate: 302 lb/hr Injection volume: 1,753 gal Extraction failed. Treated as Shakedown test.
October 25, 2002 16:00 October 30, 2002 15:20	Downtime	NA	—	Downtime
October 30, 2002 15:20 November 1, 2002 17:45	Cycle 1b Cycle 1b	Injection	46.75 hr	Injection rate: 246 lb/hr Injection volume: 1,380 gal O ₂ injection rate: 32 to 70 scfh Total O ₂ Injected: 248 ft ³
November 1, 2002 17:45 November 4, 2002 23:00		Soaking	77.25 hr	—
November 4, 2002 23:00 November 7, 2002 13:20		Extraction	22.6 hr (discontinuous extraction)	Extraction volume: 1,531 gal (111% of the injected volume for Cycle 1b) SVE: 42.4 hours of operation
November 7, 2002 18:05 November 9, 2002 11:15	Cycle 2	Injection	31.2 hr	Injection rate: 237.8 lb/hr Injection volume: 891 gal O ₂ injection rate: 17 to 22 scfh Total O ₂ Injected: 158 ft ³
November 9, 2002 11:15 November 11, 2002 15:30	Cycle 2	Soaking	28.25 hr	—
November 11, 2002 15:30 November 12, 2002 10:50	Cycle 2	Extraction	19.3hr	Extraction volume: 1,006 gal (113% of the injected volume for Cycle 1b) SVE: 9.2 hours of operation
November 12, 2002 15:55 November 14, 2002 14:45	Cycle 3	Injection	46.3 hr	Injection rate: 279.5 lb/hr Injection volume: 1,554 gal O ₂ injection rate: 10 to 15 scfh Total O ₂ injected: 139 ft ³
November 14, 2002 14:45 November 18, 2002 16:00	Cycle 3	Soaking	97.25 hr	—
November 18, 2002 16:00 November 20, 2002 21:25	Cycle 3	Extraction	53.2 continuous hours	Extraction volume: 1,910 gal (123% of the injected volume for Cycle 1b) SVE: 28.2 hours of operation
December 2-6, 2002	Post-demonstration monitoring	NA	NA	Groundwater monitoring

NA = Not applicable.

The extraction volumes presented in Table 6-1 include both liquid and vapor volumes extracted, as these lines were co-joined after Cycle 1A, due to replacement of the downhole pump with the aboveground suction pump.

The duration of cycle phases varied for several reasons. Issues were experienced during co-air injection during Cycle 1A, and this difficulty was investigated during Cycle 1B with no air or oxygen injection. In subsequent cycles, oxygen was then added. Additionally, the extraction required 25% additional volume of the injected volume. The extraction in Cycle 1b took much longer time than planned due to the unanticipated pump malfunction in the first cycle and its subsequent field implementations, injection rates (and volumes of extraction correspondingly/roughly). This subsequently shortened the period of the injection in Cycle 2 in the same week.

Other service equipment and necessary operational activities are summarized in Table 6-2. Before the final disposal, the water was cleaned of VOCs by simple carbon adsorption using two 200-lb carbon canisters in series.

Table 6-2. Major Equipment and Required Operation Activities

Equipment Description	Function	Design Rating and Specifications	Conditions and Activities
Water supply	Water to steam and treatment system	Max 50 gpm briefly, 5 gpm continuous at 60 psig	Average water usage will be below 5 gpm.
Water softening unit	Supply soft, low O ₂ water to steam generator	10 gpm, TDS < 250 mg/L, DO <0.5 mg/L	Sulfite added to reduce DO levels, pH and TDS adjusted to prevent scale buildup.
Steam pressure regulator and manifold	Reduce pressure to injection pressure	Air-operated pressure regulator valve, condensate spitter, 2-inch steam pipe with orifice plates for steam flow measurement	Orifice plates to be sized during procurement and construction phase.
Liquid-vapor separator, KO-2	Knockout liquid component and fines before cooling	Maximum 2 gpm liquid, 1,000 cfm vapor including steam component	Vessel on the ground to allow for pipe drainage into it.
Vapor line condenser/heat exchanger	Cool vapors to 30-40°C and condense out condensable gases	Maximum cooling capacity 1 × 10 ⁶ (1 million) BTU/hr = 300 kW, maximum condensate flow 2 gpm, effluent temperature <40°C (vapors and liquids)	Ran at much less than full capacity most of the time. Designed for peak performance at time of maximum steam extraction.
Liquid-vapor separator, KO-3	Knockout liquid component and condensate after cooling	2 gpm liquid, 50 scfm noncondensable vapor	Aerosols in vapor stream should be minimized.

Equipment Description	Function	Design Rating and Specifications	Conditions and Activities
Vacuum pump, liquid ring with associated cooling system	Apply vacuum to vapor extraction line, deliver vapor to vapor treatment system at positive pressure	50 scfm, inlet side vacuum 0.5 atm = 7.4 pounds per square inch/area (psia). Outlet side pressure between 1.0 and 1.5 atm absolute. Adjustable.	Continuous check on the suction tube attached to the wellhead.
Water holding tank	Store water for cleaning and discharge	Minimum 20,000 gal	Sufficient to contain the wastewater of a single cycle.

6.2. Process Monitoring Parameters

In this section, process monitoring measured for the system operation will be discussed.

6.2.1 Flowrate and Flow Volume

Routine monitoring of flowrates and cumulative flow was conducted at various sampling ports of the overall steam injection system. During the injection phase of each cycle, the flowrate was measured at the steam generator connection from the water supply and then a cumulative flow was measured at the steam manifold before the steam was injected into the injection well (SI-01). The flow monitoring enabled a determination of the required extraction volume using a flowmeter installed on the injection well (see Figure 6-1). Steam injection rates were measured using a steam orifice plate with differential pressure measurement. The total steam injection rate was calculated using a totalizing flowmeter for each injection phase compared to the total water flow into the steam generator. Liquid extraction rates were estimated for the total volume recorded from SI-01 during each extraction phase. Due to the replacement of the progressive cavity pump with the suction pump (Figure 6-2) as described in Section 5.3.2, it was difficult to quantify the exact extraction rate. However, the totalizing flowmeter was able to quantify the total volume of liquids extracted from SI-01. Other liquid flowrates and total flow were monitored at several locations within the treatment system (see Figure 5-7 and Table 6-3) at least twice during the extraction phase. Totalizing flowmeters were used to measure condensate flowrate and volume at the liquid effluent lines from KO-2 and KO-3 and the total water flowrate to carbon canisters to measure total discharge liquid volume at L-2.



Figure 6-1. Original Design of SI-01 (background is the steam generator)

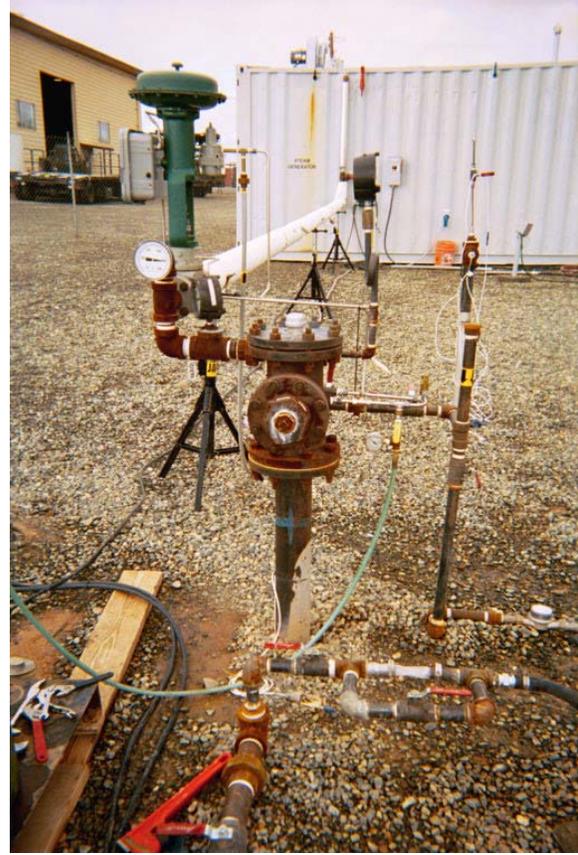


Figure 6-2. Design Modification to SI-01 (background is the steam generator)

Table 6-3. Process Monitoring During Operations

Process Monitoring ^(a)	Monitoring Description	Monitoring Parameters				
		Flow	Temperature	Pressure	Liquid Level	Sample
Water supply	Intake line	NA	NA	P	NA	NA
	Water softener output	NA	NA	P	NA	NA
	Deaerator output	NA	T	P	NA	NA
Steam generator	Gas intake	FR	NA	P	NA	NA
	Clean water intake	FT	T	NA	NA	NA
	Steam output	NA	T	P	NA	NA
Steam manifold	Primary side	NA	NA	P	NA	NA
	Secondary side	FR	NA	P	NA	NA
Steam injection well	Wellhead measurements	NA	T	P	NA	NA
Vapor extraction line	Vapor extraction header	NA	T	P	NA	NA
Liquid extraction line	Downhole pump discharge line	FT	T	NA	NA	NA

Liquid line, treatment system	L-1: extraction well	FT	T	NA	NA	LS
	Water holding tank	NA	T	NA	L	NA
	L-2: GAC outlet (discharge point)	FRT	T	P	NA	LS
Vapor line, treatment system	KO-2 inlet	NA	T	P	NA	NA
	KO-2 liquid outlet	FT	NA	NA	NA	NA
	KO-3 vapor outlet	NA	T	P	NA	NA
	KO-3 liquid outlet	FT	NA	NA	NA	NA
	Vacuum pump output	NA	T	P	NA	NA
	V-1: air drier outlet	FRT	T	P	NA	VS
	V-2: vapor GAC outlet, emission point	NA	NA	NA	NA	VS

(a) Every point is monitored at least twice daily.

FR = flowrate monitoring.

FRT = flowrate and cumulative flow monitoring.

FT = cumulative flow monitoring.

L = Liquid level in the treatment system.

LS = liquid sample.

NA = not available.

P = pressure.

T = temperature monitoring.

VS = vapor sample.

Discharge vapor from the carbon canister tank effluent to the atmosphere was also measured for vapor flowrate and cumulative flow to calculate the total volume. Based on the vapor flowrate and the cumulative flow volume, discharged VOC volume into the atmosphere was quantifiable.

6.2.2 Pressure and Temperature

Pressure and temperature were other important operation parameters. Buildup of excess pressure in any closed system would create a potential shutdown as well as an explosion hazard. Maintaining proper pressures at every closed channel system ensured appropriate operation of the injection and extraction system. It was critical to monitor and record steam pressure at the injection wellhead because the injected steam would not diffuse into the subsurface, and subsequently would create backpressure into the well casing of the steam generator. The detailed sampling points for the pressure are summarized in Table 6-3.

Like pressure monitoring, temperature monitoring was conducted at various parts of the system and recorded manually. The injection phase required temperature monitoring only at the water supply line of ambient water temperature, the steam generator of the elevated temperature at the furnace, and the temperature of the steam in the injection system. Monitoring was conducted three times each day and temperatures recorded for each thermometer. During the extraction phase of each cycle, more frequent temperature monitoring of the liquid extraction system and the liquid treatment system was conducted to maintain the best possible operating conditions. The treatment system was equipped with a shutdown control that would automatically shut off the treatment system to prevent any adverse damage to the system due to less desirable conditions such as high temperature from the extracted liquids

or/and the aforementioned excessive pressure buildup in the closed system. As summarized in Table 6-3, the detailed sampling locations can be found in Figures 5-6 and 5-7. The operation data can be found in Appendix F.

Additionally, subsurface temperature monitoring was conducted using thermocouples in and around each monitoring well in and around the treatment zone. Indirect subsurface monitoring for electrical resistivity was performed using ERT wirelines that were installed in the demonstration treatment area. The temperature monitoring from the thermocouples was to determine whether the steam heated the temperature in the subsurface at every 3-ft interval from the surface to 45 ft bgs. Baseline subsurface temperature monitoring was conducted on October 22, 2002, and continued numerous times throughout the operation period (see Section 8.2). The ERT test was conducted at three different times: in May 2002, in October 2002, and November 2002. A partial equipment failure in an electronics board in the switch box occurred between collection of the initial background dataset in May 2002 and the second background dataset in October 2002. The source of this failure was not identified and remedied until November 13, 2002, resulting in the loss of the first 13 electrodes from the ERT system (affecting all electrodes on VEA-1 and the shallowest four electrodes on VEA-2).

Due to the timing of the equipment failure, VEA-1 could not be used for time-lapse difference calculations (no useable background data for VEA-1 were available). Two sets of background ERT data were collected in May 2002, when the ERT system was initially set up. Another set of background data was collected on October 22, 2002, just prior the initiation of the steaming phase of the project. This dataset was used as a resistivity baseline for the calculation of difference values used in developing time-lapse images of the change in subsurface resistivity and conductivity over time. The subsurface temperature monitoring and the ERT tests were performed to assess data collection and analysis.

6.2.3 Contaminant Concentrations

Four sets of liquid samples were collected from L-1, which was a sample port situated after the water was extracted and before the extracted water was supplied into the treatment system during the extraction phases. The results of the samples from L-1 were measured to determine the residual VOC levels in the aquifer where the HPO process occurred after the steam application. Concentration levels for PCE, *cis*-1,2-DCE, and VC were all below detection as summarized in Table 6-4. TCE levels were well below the baseline concentration of approximately 1,000 µg/L, suggesting that the HPO process was successful.

Table 6-4. Summary of Liquid Sample Results from L-1

Sample Time	PCE	TCE	<i>cis</i> -1,2-DCE	VC
11/18/02 17:00	<2.0	2.54	<1.0	<1.0
11/18/02 17:30	<2.0	5.70	<1.0	<1.0
11/18/02 18:00	<2.0	1.7J	<1.0	<1.0

11/18/02 18:30	<2.0	1.6J	<1.0	<1.0
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The liquids removed from the extraction well (SI-01) were stored temporarily in a 21,000-gal epoxy-coated temporary holding tank (Figure 5-5), fitted with vapor-tight top hatches in order to minimize contaminant loss prior to the sampling of the tanks. No provisions for cooling were necessary, as the succeeding step in the treatment process was to remove volatile organics from the water. Before the final disposal, the liquids stored in the temporary tank were cleaned of VOCs by simple carbon adsorption using two 200-lb carbon canisters in series. Several sets of liquid samples were collected from the L-2 sample port. The samples were analyzed for the list of compounds presented in Table 5-2. When the results met the standards, the water was transferred to a mobile tank via a series of GAC canisters.

Additionally, vapor phase samples were collected and analyzed from the V-2 during each extraction phase. All of the liquid- and vapor-phase concentrations collected from L-1 and V-2, were converted into mass fluxes to establish a total mass balance for the COCs.

7. Performance Assessment Methodology

7.1 Performance Objectives

Battelle and the technology vendor, SES, conducted a performance assessment for the HPO process using a single well. There are three major performance objectives of the DUS/HPO technology demonstration using a single injection/extraction well:

- Destroy COCs by in situ treatment HPO process
- Heat up the aquifer and soil around the injection well by steam injection
- Maintain hydraulic control of the site and prevent migration of contaminants beyond the effective HPO zone.

The first objective, the COC reduction, was the primary objective. The others were secondary objectives. Table 7-1 summarizes the three objectives and descriptions used to evaluate the technology performance.

Table 7-1. Summary of Performance Criteria

Performance Objectives	Description	Primary or Secondary
In situ destruction of COCs in situ by HPO.	To destroy COCs (TCE, PCE, <i>cis</i> -1,2-DCE, vinyl chloride) in situ.	Primary
Heat the soil around the injection well by steam injection.	To heat the soil in the treatment zone to a temperature sufficient for HPO to occur, using steam injected at a single well as the heat source.	Secondary
Maintain hydraulic control of the site and prevent significant migration of COCs beyond the zone of effective HPO.	To extract liquid and vapor from the subsurface at a rate and volume sufficient to ensure that any COCs not destroyed by HPO are recovered.	Secondary

7.1.1 In Situ Destruction of COCs by HPO

The primary objective of this demonstration was to achieve the reduction of groundwater contamination within the demonstration test area using the single well HPO technology.

The post-demonstration COC levels at the end of the demonstration would be significantly lower and the data statistically significant. Three sets of groundwater samples were collected

and analyzed for CVOCs before and after the demonstration from the injection well and other performance monitoring wells. During the groundwater monitoring, it was necessary to use a cooling loop to minimize a volatilization of collected water samples. More importantly, this step was taken as a safety measure to prevent or minimize the potential of spraying pressurized steam and water from the aquifer into the field crew or the surrounding area. Groundwater monitoring included the measurement of field parameters. With the Horiba U-22[®] using a flow-through cell unit, temperatures of purge water were measured simultaneously with pH, DO, ORP, and conductivity prior to the sample collection. However, it was difficult to record precise measurements for some field parameter readings because a water quality instrument, the Horiba[®] U-22, was not designed to handle high-temperature water or heat. Although the measurements were available from field monitoring, some reading results from the instruments used for this demonstration might not be precise due to the afore

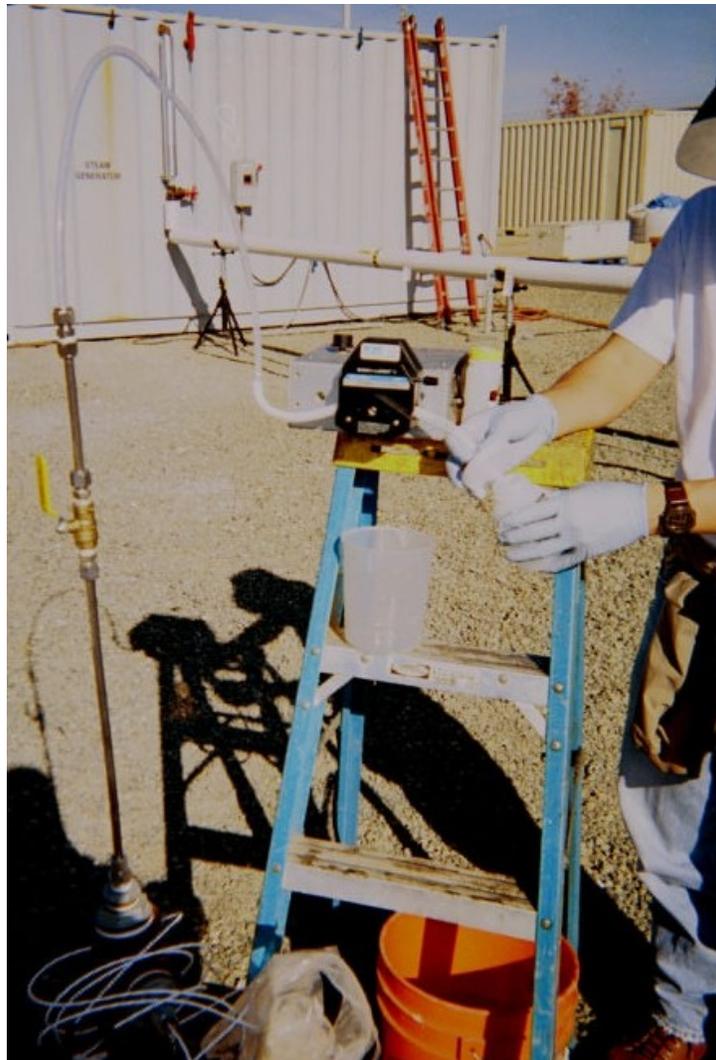
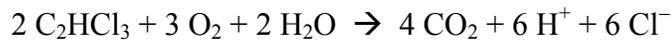


Figure 7-1. Groundwater Being Collected from BAT-06 Monitoring Well

mentioned extreme conditions in the flowthrough cell. Sample collection setup is shown in Figure 7-1. The cooling loop is shown in the left bottom corner, and was cut shorter for the inorganic sampling since the volatilization was not a concern for these samples. Once the samples underwent VOC analysis at an off-site certified laboratory (DHL Analytical, Round Rock, TX), the average concentration levels of CVOCs from three monitoring events were calculated and compared with those from the pre- and post-demonstrations. Although reduction of TCE and PCE levels in groundwater to 5 µg/L (for both TCE and PCE) was desirable, it was not a direct goal or objective of this demonstration due to the heterogeneous site geology.

Knauss et al. (1997) investigated the kinetics of TCE oxidation by HPO and concluded that TCE was readily mineralized into water, chloride, and CO₂. For TCE oxidized by oxygen, the following kinetics will occur:



As TCE is oxidized according to the stoichiometry, CO₂ is produced in gaseous phase as a by-product. Thus, the potential increase of CO₂ levels in the vapor phase were measured in the surface of the demonstration area from soil-gas monitoring points and at the effluent stream of vapor discharged to the atmosphere using a CO₂ analyzer placed in the air stream of the treatment system. Also, chloride is another by-product of the HPO process for TCE reduction. Similar to the CVOC levels, the post-demonstration average chloride level was compared to the pre-demonstration average concentration of chloride, which is an indicator of reduced forms of degrading chlorinated solvents. Calculated percent (%) reduction would be used to determine the overall efficacy of the HPO process using a single well for this demonstration.

7.1.2 Subsurface Heating around the Injection Well by Steam Injection

Another objective was to heat the subsurface surrounding test plot area by injecting steam. As a result of heating the aquifer by the co-air steam injection, the test plot immediately adjacent to the injection well would likely heat as well. Temperature monitoring could be done at the permanently installed thermocouple locations (VEA-1 to -5). Although the modeling results indicated that the injection would achieve the radius of heated influence up to 15 ft, the realistic influence zone that could be achieved was a challenge. Daily temperature data also were collected, especially during the steam soak and extraction phases of each cycle. The ERT monitoring was conducted at the end of each soaking phase after the steam injection and each extraction phase prior to the steam phase of the following cycle. This provided information on the progression of heated zones, the migration of steam in the subsurface, and creation of conditions where HPO reactions may have been favored. However, there was no contiguous direct temperature monitoring equipment installed in the space between monitoring wells and VEAs. Regardless of the lack of the monitoring equipment, the monitoring challenge was overcome by applying and measuring various aspects of electrical resistivities in the aquifer of the demonstration test area. Both ERT and temperature

data were collected daily during the injection cycles to measure the increased temperature in the demonstration area.

7.1.2.1 Subsurface Temperature

Temperature data were collected manually by the technology vendor at intervals set out in the sampling and analysis plan and at additional times, when warranted. Profiles of temperature versus depth were plotted within 24 hours of completion of temperature measurements. Thermocouple arrays were used for direct temperature measurements installed in five VEA boreholes. As discussed in Section 5.2.4, all five VEAs were completed to a depth of 45 ft. Each VEA consisted of nine electrodes spaced 5 ft apart, alternating with nine thermocouples also spaced 5 ft apart. Thermocouple data were collected manually using a portable thermocouple reader. A complete dataset typically could be collected within 30 minutes. Microchip temperature sensors were directly attached to each of the monitoring well casings. Temperature data were downloaded into a datalogger from the temperature sensor chips and then analyzed using DigiTAM™ software. The sensor microchips were originally spaced at 3-ft intervals. The lowest sensor on the sensor string was attached to the end of the stainless-steel groundwater sampling tube at a depth of 42.5 ft bgs. However, during the operation, there was a series of difficulties in temperature recording from the microchips. The continued unreliability of this model of temperature sensor led to a final substitution of more robust sensor strings in all wells. The sensors in the downhole string, which were retrofit from another site of the technology vendor, were spaced at 2.5-ft intervals. This sensor string was lowered to measure the temperatures from wells BAT-07 and BAT-09. These sensor strings were considerably larger and denser than the earlier models and were simply paid out until the lowest sensor rested at the bottom of the sump, at a depth of 45 ft bgs.

7.1.2.2 ERT Monitoring

To examine the expected initial changes of temperature in the subsurface due to the injection of steam in the subsurface, daily ERT data monitoring was conducted during each injection period and each extraction phase thereafter throughout the demonstration. A total of 25 ERT measurements were planned. The original demonstration was intended for five operational cycles. However, the shorter 3-cycle demonstration that was conducted resulted in the collection of only 23 ERT datasets (two pre-treatment sets, three post-treatment sets, and 18 sets during the demonstration cycles).

The ERT technology is a measurement method to evaluate resistivity created by the injected steam and subsequent heated fluid in the aquifer. Consequently, this technology can determine conductivity in the aquifer. Cross-borehole ERT with vertical electrode arrays is principally sensitive to soil clay content, moisture saturation, and temperature. As clay content would be expected to remain constant throughout the demonstration, ERT allowed for mapping of fluid migration processes, heating, and steam migration in the subsurface.

Details of subsurface equipment installation and setup are described in Section 5.2.4. The installation in every horizontal space or vertical depth of the demonstration plot is not economical. Thus, electrode spacing on the VEAs was set at 5-ft centers, resulting in nine electrodes per VEA, and a total of 45 electrodes for the ERT system.

Collection of ERT data was set up using an American Geological Institute (AGI) Supersting™ earth resistivity meter with a 45-electrode switch box. Electrode wires at each borehole were connected to multiconductor cable within a junction box and the multiconductor wire was run to the operations trailer. The 45 electrode wires from the field installation (nine discrete electrodes per VEA) were connected to the switch box panel. A single command file was developed to collect data from all eight of the data panels using a dipole-dipole array. This approach allowed for adequate data density while keeping the time for data collection to a reasonable amount. Two sets of background ERT data were collected in May 2002, when the ERT system was initially set up. Another set of background data was collected on October 22, 2002, just prior the initiation of the steaming phase of the project. The background dataset collected in October 2002 was used as a resistivity baseline for the calculation of difference values used in developing time-lapse images of the change in subsurface resistivity and conductivity over time.

The raw ERT data files were split into six separate data files representing four two-borehole single-ERT panels (1-2, 1-4, 2-3, 4-3) and two three-borehole double-ERT panels (1-5-3 and 2-5-4). Data were subjected to resistivity inversion processing using AGI EarthImager™ software. The AGI EarthImager™ software provides the tools to produce two-dimensional electrical resistance tomography models for multiple boreholes. The software also provides a function to produce percent difference time-lapse images by comparing background model data to current model data to obtain the percent difference in resistivity and conductivity. Percent difference image profiles for each data panel are presented in Appendix E. The percent difference in conductivity, representing the reciprocal of resistivity, is used here as it is directly proportional to soil temperature and saturation.

7.1.3 Hydraulic Control and Migration of COC

Another secondary objective was to maintain hydraulic control during the injection and extraction phases while no excessive amounts of liquids were pulled out to cause a migration of the contaminated plume outside the demonstration plot area. It could be noted first that there was a period of soaking, or “no hydraulic control” applied, with each push-pull steam cycle, as documented in Table 6.1.

First, the net extraction was documented by comparing the cumulative amount of steam injected for each cycle with the cumulative amount of liquids extracted in the subsequent extraction phase. For each extraction phase, a minimum 110% of the injected volume was withdrawn and documented (although less than the 120%, that was accomplished only with the final steam event). The cumulative amount of steam injected was determined based on

both direct measurement of water usage for steam generation and calculated volume based on the direct measurement of steam flowrates at the injection wellhead. The total extracted water was estimated using a totalizer at sampling point L-2 of the effluent treatment system.

$$\text{Volume} = \text{sum} (\text{flowrate} \times \text{period of operation})$$

where the flowrates were instantaneous measurements and the periods were measured between flowrate measuring events. Where a totalizing flowmeter was used, the cumulative flow volumes/masses were read periodically and added to a database.

Bromide is not naturally prevalent in the geologic condition at Beale AFB. Background levels for naturally occurring bromide are below 2 mg/L according to the site characterization assessment (Section 2.3). No elevated level of bromide was detected at Beale AFB. Subsequently there is no known adverse toxicity for bromide. Thus, the project team decided to use it as a conservative tracer that enabled the project team to calculate the mass balance of the amount of the tracer recovered during the injection and extraction operations. A solution of bromide slug was prepared on site prior to the first steam injection phase. Then, the 2-gal volume of tracer solution was added into the injection well just shortly after the steam injection. As the processes of injection, soaking, and extraction progressed, a bigger steam pocket zone was anticipated from the source of the steam injection. Bromide analysis results from groundwater samples collected at L-1 were employed to estimate the total recovery of bromide.

Additionally, CVOC results in the performance assessment wells were used to determine increases of contaminant levels which suggested plume migration due to the technology application.

7.2 Aquifer Changes

The achievement of oxidizing conditions in the groundwater was documented by measuring for DO in the performance assessment wells at the onset of the soaking and extraction phases and in the extracted liquid during the extraction phase. A minimum of 1 mg/L of DO is considered to indicate anaerobic conditions in the groundwater. Where the groundwater temperature is above ambient, a cooling coil was used to reduce the groundwater sample temperature to below 30°C before the DO analysis and to minimize the volatilization during the sample collection. Other groundwater indicator parameters included:

- ORP (expected to increase to above 100 mV) in the heated zone wells
- Dissolved iron (expected to decrease to below 0.1 mg/L) in the heated zone wells
- Methane (expected to decrease to below 0.5 mg/L) in the heated zone wells.

It was important to evaluate the capability of HPO at the field scale for this demonstration. CO₂, alkalinity, and chloride were key parameters of the HPO process. If a substantial amount of COC was degraded, produced CO₂ could lead to carbonate buffering reactions that affect the alkalinity of the groundwater as described in Section 7.1.1. Although it was not anticipated for

measurable change because of relative low concentrations in TCE and PCE contamination in the aquifer, these data were collected to contribute to the overall understanding of the subsurface processes. Alkalinity levels before the demonstration were 115-190 mg/L, which was approximately two orders of magnitude higher than the expected change due to TCE oxidation to CO₂. Chloride concentrations were unlikely to be significantly affected by oxidation of TCE. Background chloride concentration levels vary from 13 to 33 mg/L. Approximately 1 mg/L would be produced if all TCE was oxidized after the treatment with this technology. This estimated chloride level with the complete oxidation of TCE would be compared to the chloride levels analyzed from the field samples.

8. Performance Monitoring Results and Conclusions

8.1 Cyclic System Operation of Injection and Extraction

This section describes the performance evaluation of the injection and extraction operations.

8.1.1 Steam and Oxygen Injection

Steam was injected in each of three cycles (Table 8-1; Figure 8-1). The first cycle was never completed because the extraction of the injected steam was not successful. In addition, a long lapse took place due to the limited resources and permitting issues after the system was constructed and installed in May 2002. This contributed to the failure of the pump installed in the injection/extraction well, SI-01. Thus, the first injection phase was named as Cycle 1a and considered as the shakedown test.

Table 8-1. Summary Steam Injection

Cycles	Average Injection Rate (lb/hr)	Total Steam Injected (gal)	Cumulative Steam Injected (gal)	Total Oxygen Injected (ft ³)
Cycle 1a	302	1,753	1,753	0
Cycle 1b	246	1,380	3,133	248
Cycle 2	238	891	4,024	158
Cycle 3	280	1,554	5,578	139

A total of 5,578 gal of water as steam was injected into the injection well SI-01 for the demonstration. Each injection phase lasted two to three days as shown in Table 6-1. Average steam injection rates were modestly achieved for the demonstration. Injection rates varied from 100 to 600 lb/hr, with an average rate of 250 lb/hr under the injection pressure between 15 and 27 psig without surface excursions or other related problems. Oxygen was coinjected every cycle except for Cycle 1a. Due to the failures of the coinjection of oxygen and the extraction pump during Cycle 1a, as discussed earlier, the complete first cycle was further delayed until November 1, 2002, when Cycle 1b occurred. As listed in Figure 8-2, the injection rate for oxygen was pulsed at rates between 10 and 70 standard cubic feet per hr (scfh). The coinjected oxygen was not quantified for Cycle 2 due to a malfunction of the flowmeter. The total oxygen injected with steam was estimated at between 140 and 250 ft³ in three cycles (see Table 8-1).

8.1.2 Extraction

Liquid was not withdrawn until Cycle 1b because of the malfunction in the extraction pump during Cycle 1a. Each extraction took place at the end of the cycle after the injection and soaking phases. The cumulative volume for liquids extracted from extraction well SI-01 is

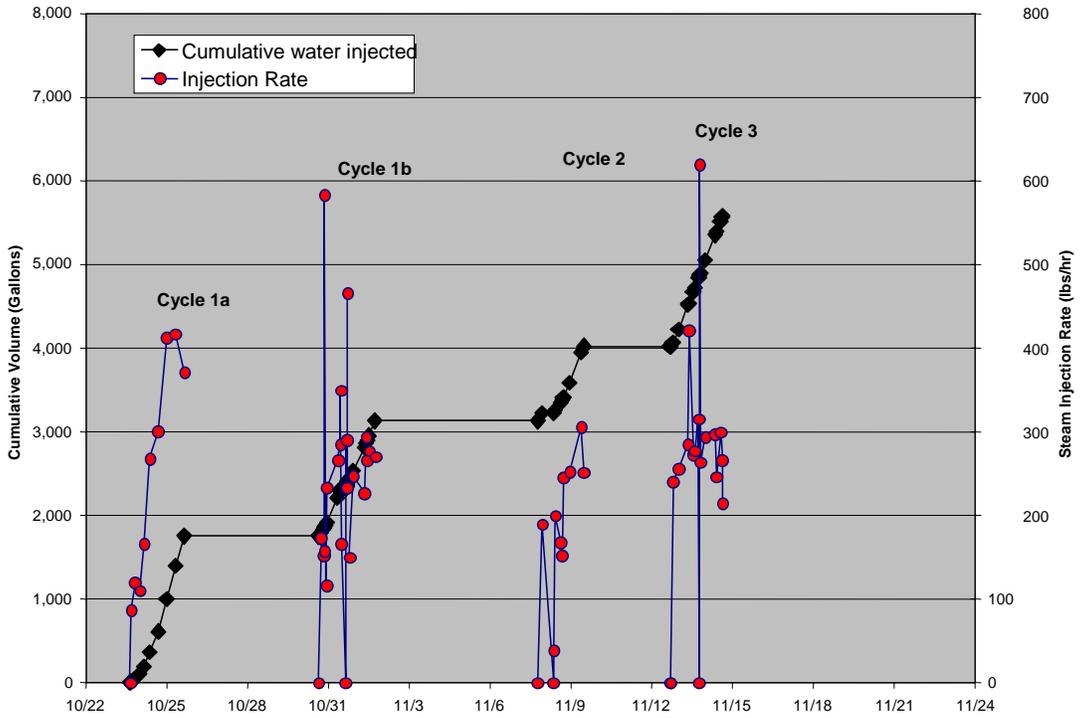


Figure 8-1. Steam Injection Rates and Cumulative Volume of Injected Steam
 Steam injection pressure and rates, and oxygen injection rate

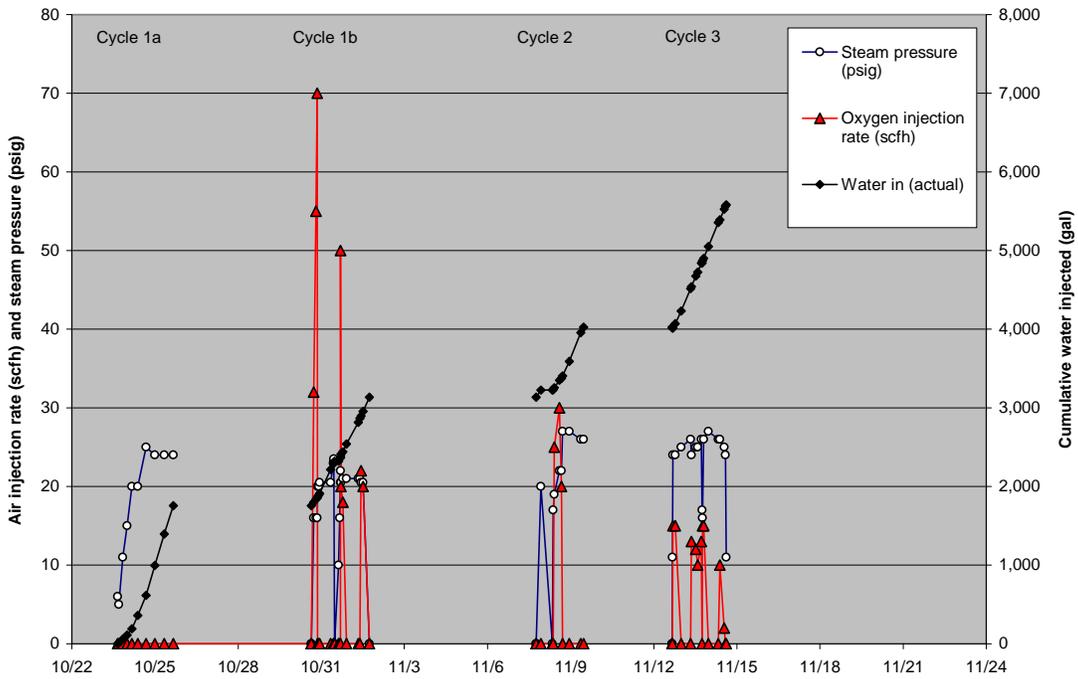


Figure 8-2. Steam Injection Pressure, Rates, and Oxygen Injection Rates

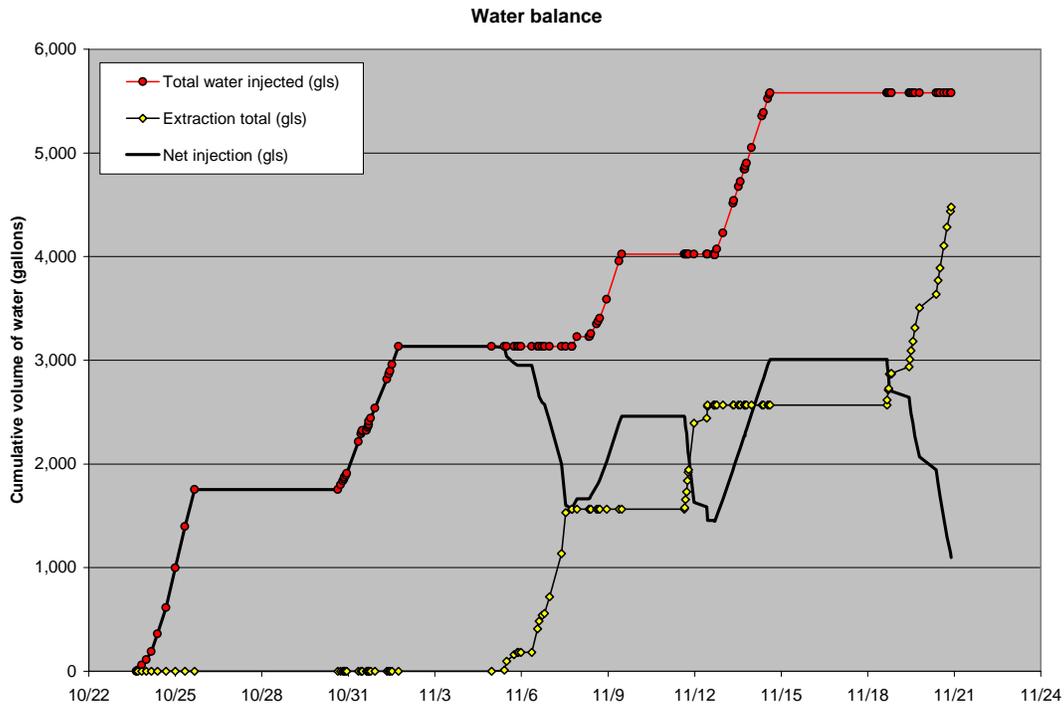


Figure 8-3. Water Balance for Injection and Extraction

Table 8-2. Summary of Liquid Extraction

Cycles	Start	Finish	Average Extraction Rate per Cycle (gpm)	Total Liquids Extracted (gal)	Cumulative Extracted Liquids (gal)
Cycle 1a	NA	NA	0	0	0
Cycle 1b	11/04/02 23:00	11/7/02 12:55	(a)	1,531	1,531
Cycle 2	11/11/02 15:30	11/12/02 10:50	0.87	1,006	2,537
Cycle 3	11/18/02 16:00	11/20/02 21:10	0.48	1,910	4,447

(a) Extraction was discontinuous throughout this period.

summarized in Figure 8-3 and Table 8-2. Liquid extraction rates ranged between 0.4 and 1.0 gpm, which was in the predicted range. The vapor extraction rates are plotted in Figure 8-4. Initially, the vapor extraction rates were relative high at 70 scfm during Cycle 1b, then decreased to approximately 30 scfm during Cycles 2 and 3. In Cycles 2 and 3, vapor extraction rates fluctuated between 5 and 30 scfm at the applied vacuum of 10 to 20 inches Hg. This was a modest vapor extraction rate for the vapor since the air was pumped from much higher depth (approximately 27 ft below top of casing) of the static water table to the wellhead (SI-01).

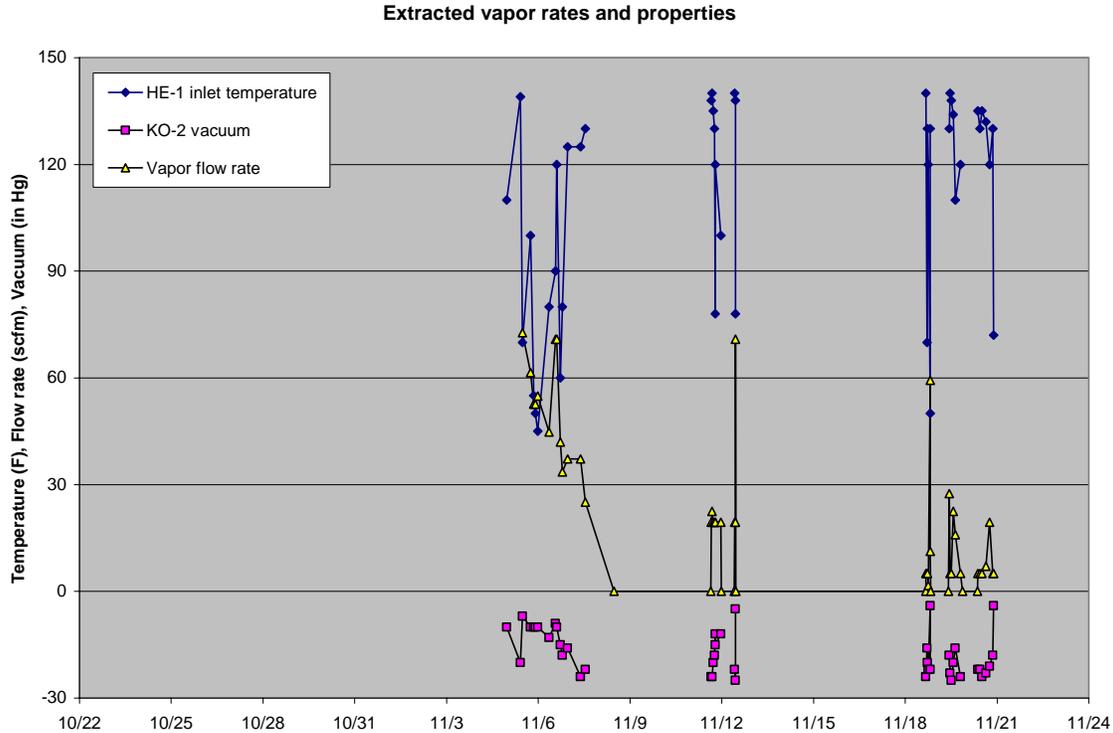


Figure 8-4. Extracted Vapor Rate, Vacuum, and Temperature

8.2 Results of Heat Distribution During the Demonstration

This section will discuss performance assessment results for heat distribution. Primarily, monitoring results of temperature and ERT measurements will be discussed in this section.

8.2.1 Temperature Distribution

Temperature distribution was plotted for temperature monitoring data profiles from each of the ERT borings and thermocouples installed at monitoring, with the exception of the steam injection well (SI-01). Persistent unreliability of the microchip sensors in the temperature thermocouple wires prevented a collection of complete temperature changes. The temperature responses are divided into two groups: (1) some elevated temperature observed at depths greater than 10 ft bgs (VEA-5, BAT-06, -07, -09, and -10); and (2) no discernable heating throughout the demonstration (BAT-08, VEA-1, -2, -3, and -4).

For the unheated group, these thermocouples were located 24 ft and 30 ft from the injection wells for BAT-08 and for VEA-1 to VEA-4, respectively. For the heated group, progressively less heating was observed with an increased distance from SI-01. The thermocouple array VEA-5, which is only 3.75 ft from SI-01, showed an indication of heating up the fastest, as expected. The thermocouple bundle was not installed in the well casing of SI-01. Thus, VEA-5 was the closest direct temperature monitor of the subsurface. The progressive heating of the subsurface during the first steam injection phase (Cycle 1a) is shown in Figure 8-5.

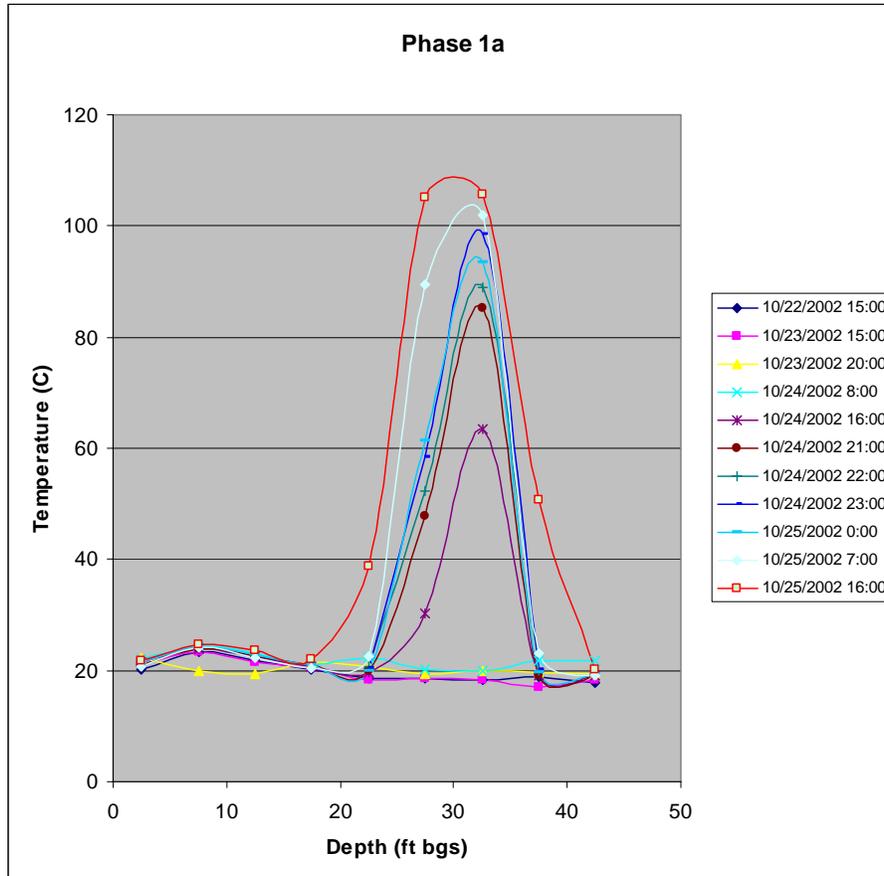


Figure 8-5. Temperature vs. Depth Profile during Cycle 1a Heating

It was apparent that there was essentially no heating outward from the injection well during the initial steam injection. However, upon increasing the injection pressure and rate on the morning of October 24, 2002, a rapid heating process began, reaching 100°C within 24 hours in VEA-5. It appeared that the stratigraphic unit controlled levels of the steam injection rate and heat transfer. The highest temperature observed during Cycle 1a was at the localized depth of 32.5 ft bgs, and the thermocouple adjacent to the top of the injection screen remained significantly cooler (Figure 8-5). Application of continuous steam injection with similar pressures and rates gradually created a broad heated soil zone as steam and hot water conducted more heat in less permeable spatial zones. VEA-5 temperature profiles for the later steam injection phases showed the progressive heating transfer from greater than 20 ft bgs in Cycle 1a to 10-15 ft bgs in Cycle 3 (see Appendix E). Temperature profiles collected during Cycle 3 by the DigiTAM™ microchip sensors in wells BAT-06 and BAT-09 (located at 8 ft from SI-01) showed a similar broad heated zone of soil at close to 100°C between 10 and 35 ft bgs. Those wells (BAT-10 at 12 ft and BAT-07 at 16 ft) lying at greater distances from the injection/extraction well showed clear evidence of limited heating (5-10°C increase)

in a zone extending from 20-35 ft bgs. Heat-up in BAT-07 apparently did not begin until after the final phase of steam injection (Figure 8-6).

Temperature and time plots for various depths in the VEA arrays over the duration of the demonstration showed a contrast between peripheral borings (VEA-1, -2, -3, and -4), indicating very minor variations in temperature throughout the demonstration. Significantly, the variations at all depths closely parallel the variations observed in the shallowest thermocouple (2.5 ft bgs) which would be expected to most closely track variations in air temperature. The rapid decline in temperature from the shallowest thermocouple was observed, as shown in Figure 8-7. It appears that there is a correlation between the elevated temperatures at the end of the steam injection phases and the cool-down temperatures at the end of the extraction phases. It is also readily apparent that the temperature drops between successive steam injection phases were getting smaller and the thicknesses of heated soil between the successive cycles was increasing throughout the demonstration.

8.2.2 ERT Results

Background ERT testing was conducted to measure resistivities in the demonstration site in May 2002. With delays and seasonal variation in the groundwater hydrology and variations in formation saturation, another set of background data were collected a few days prior to the initiation of the steam and/or pumping phase of the project, providing the best results for subsequent differences in ERT imaging.

Previous measurements showed some hydrologic differences that would mask variances in the subsurface heating; thus the background data from October 22, 2002 were used for the development of time-lapse difference images of conductivities (reverse measurement of resistivities). Due to electrode failure in VEA-1, background ERT data for development of difference images were available only for planes 2-3 (from VEA-2 and VEA-3), 4-3 (VEA-4 and VEA-3), 5-3 (VEA-5 and VEA-3), and 2-5-4 (VEA-2 to VEA-5 to VEA-4). The average background resistivity was measured at approximately 250 ohms.

Steam Injection and Extraction Cycle: The percent changes in conductivity profiles for planes 5-3, 2-5-4, and 4-3 in Figures 8-8 to 8-11 reflected the introduction of steam and consequent heating to the formation and groundwater. Positive anomalies represent an increase in conductivity (decreased resistivity) due to the heating and groundwater flow carried away from the heating zone.

The change over time in the distribution of positive anomalies, which represent heating, appeared to be consistent with the steam injection cycle. A strong positive anomaly appeared to be sourced from VEA-5, which was near the steam injection well. This was seen in both planes 5-3 and 2-5-4 (Figures 8-8 and 8-9), which crossed through the center of the study area. In both panels, the conductive anomalies slowly expanded and became stronger over time as steam injection phases continued. However, the expansion of the heated zone appeared to be very slow, away from the steam injection zone.

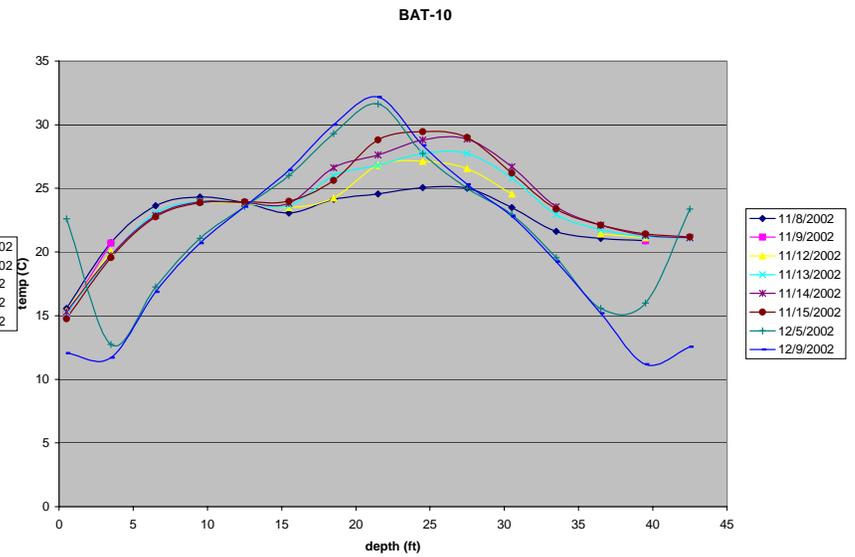
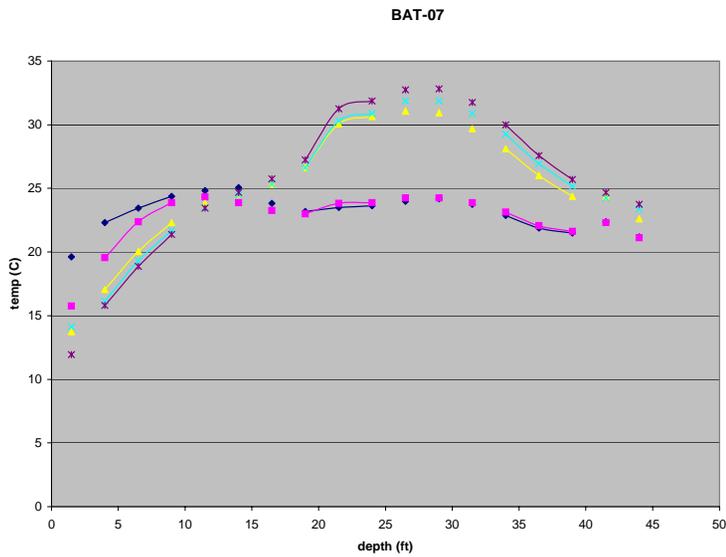
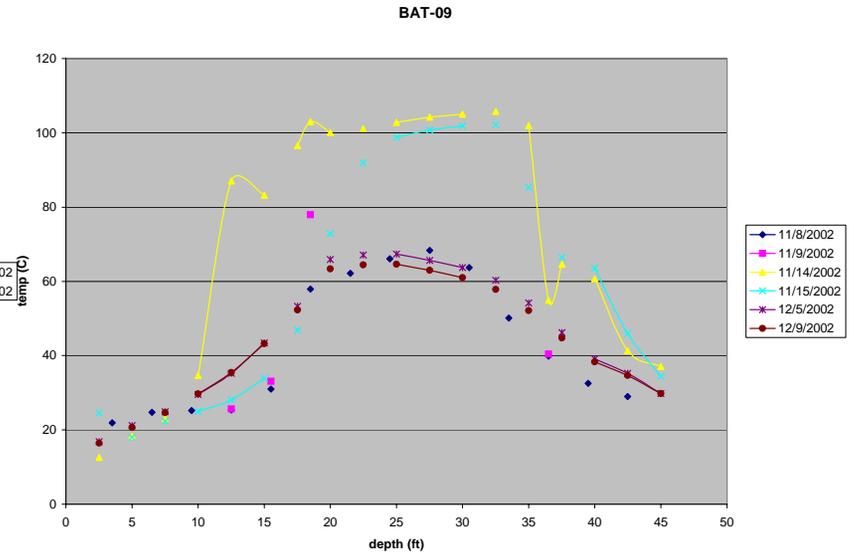
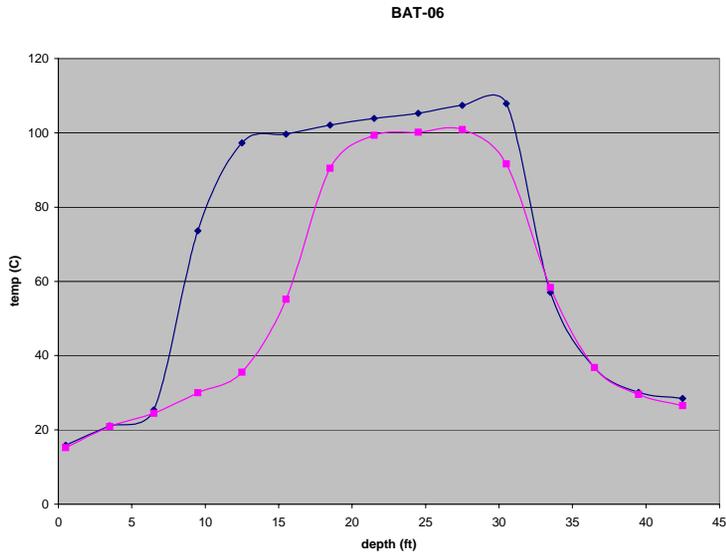


Figure 8-6. Temperature vs. Depth Profiles for Monitoring Wells Showing Heating Effects

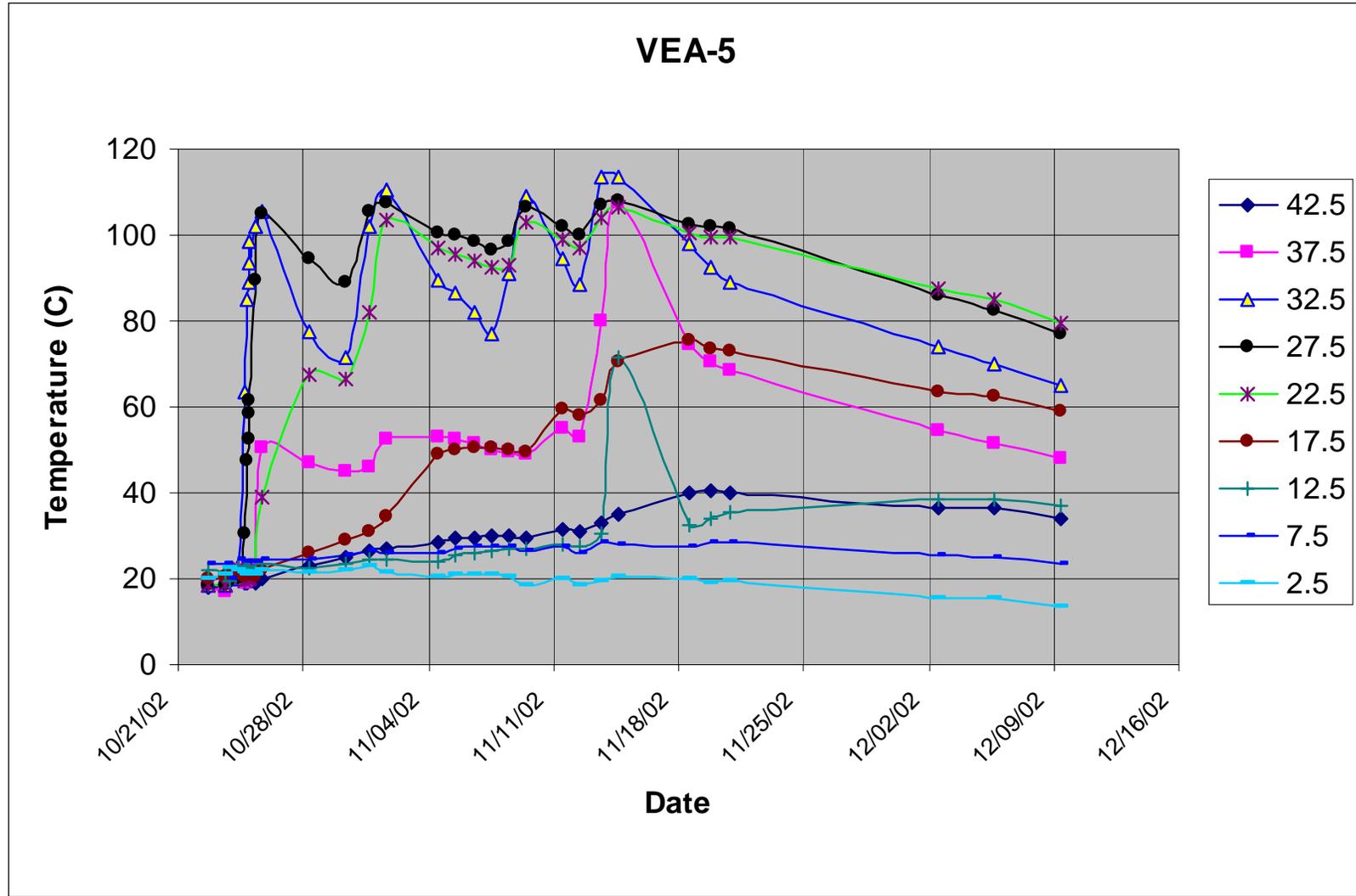


Figure 8-7. VEA-5 Temperature Profile from All Depths

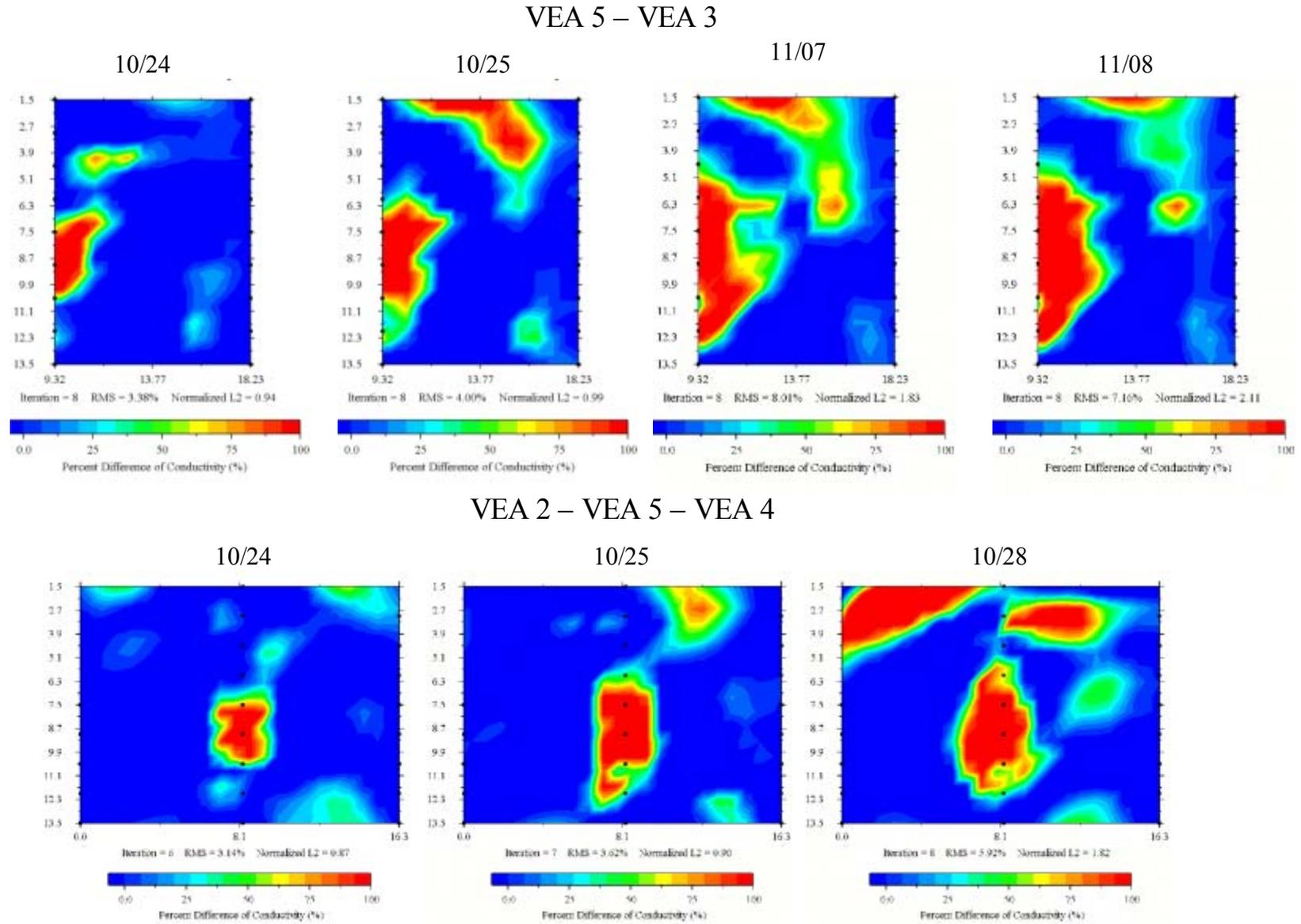


Figure 8-8. Relative Conductivity Changes from Cross-Boreholes VEA-2 to VEA-5 to VEA-4 (Plane 2-5-4)

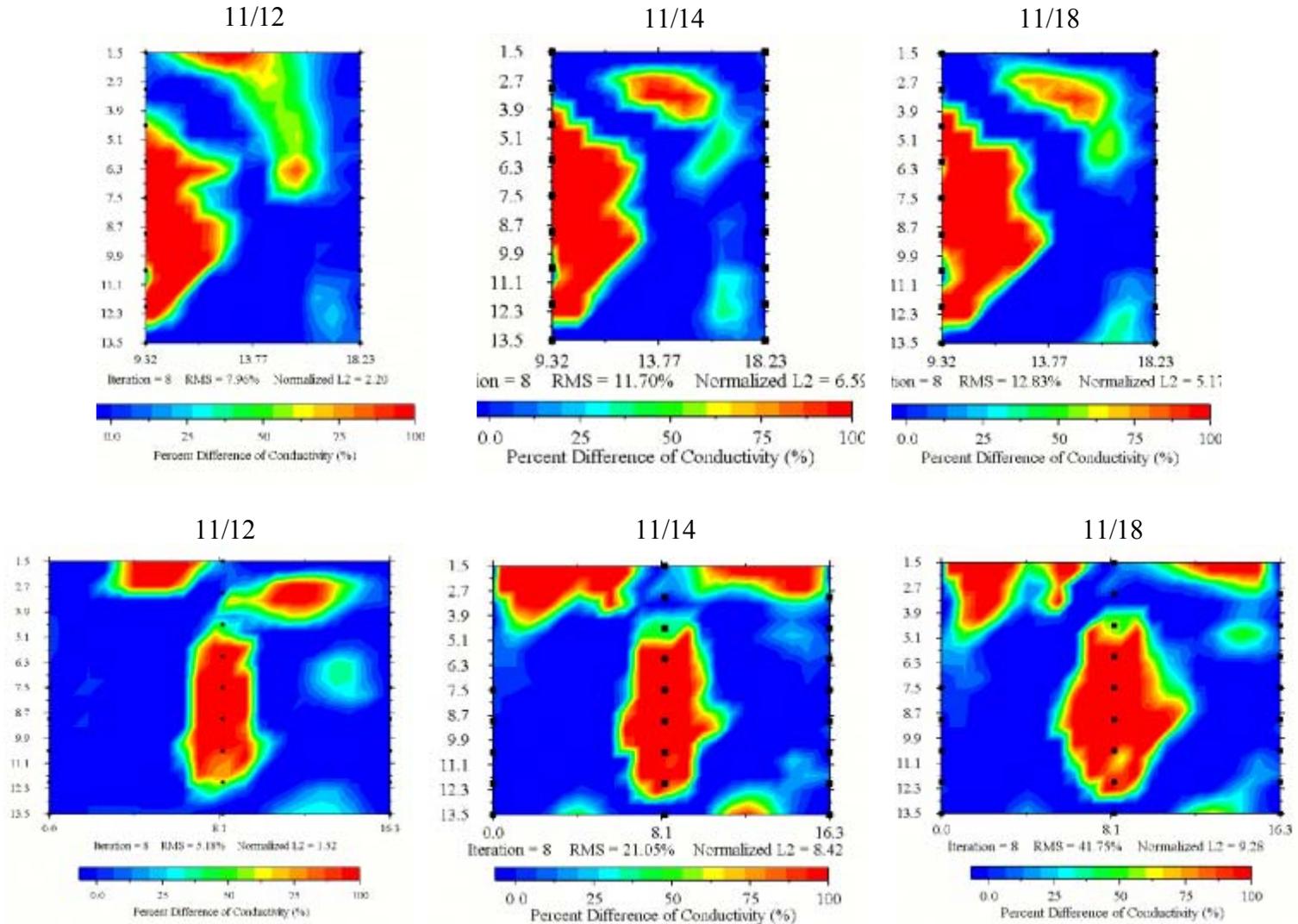


Figure 8-9. Cross-Borehole Resistivity Profiles of Planes 5-3 (top) and 2-5-4 (bottom), Showing Upward and Outward Flaring of Area of Increased Conductivity Above Base of Steam Injection Screen Adjacent to VEA-5

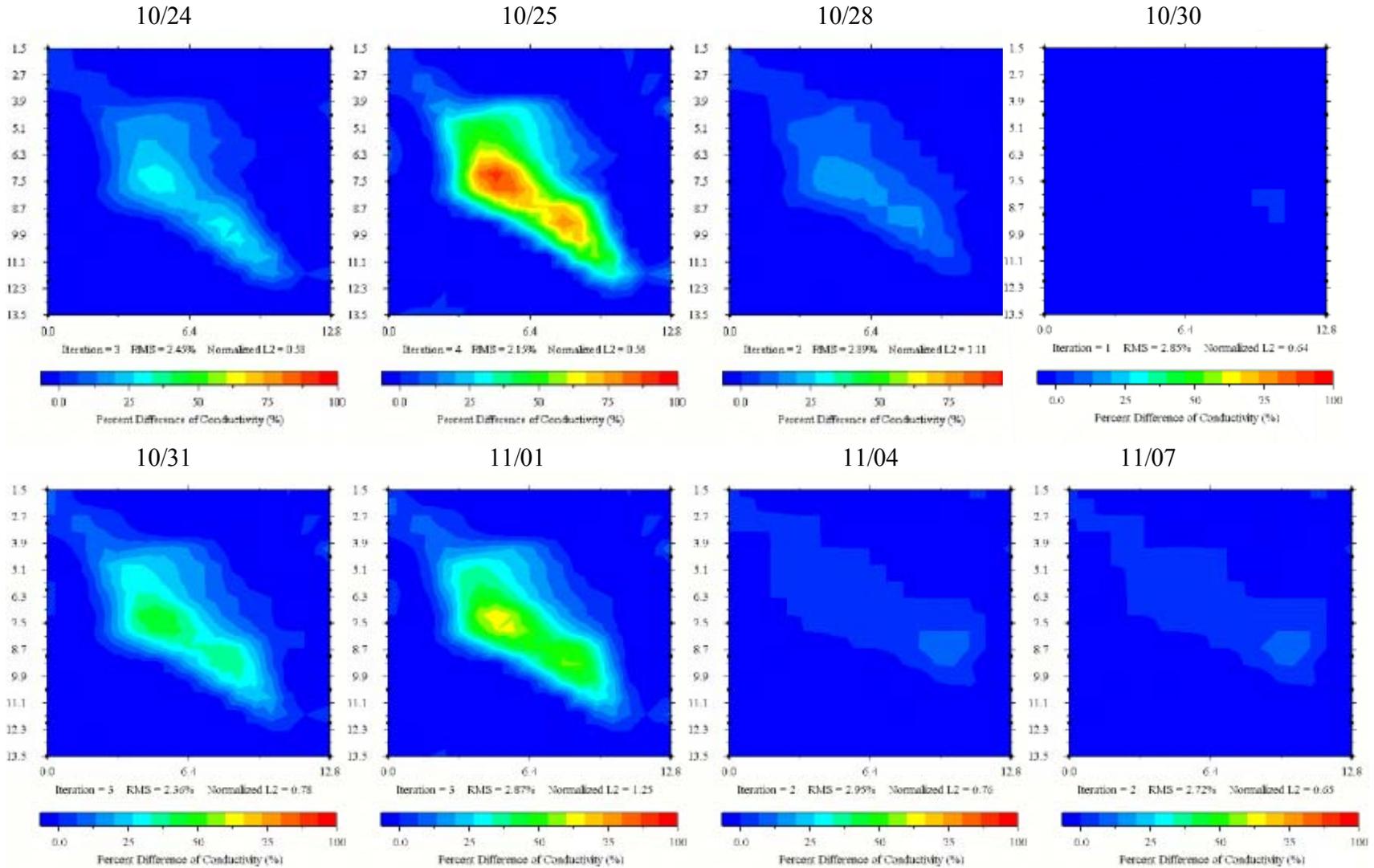


Figure 8-10. Cross-Borehole Profiles of Conductivity Changes in Plane 4-3 (VEA-4 at left, VEA-3 at right), Showing Cyclical Changes during Cycle 1a (top) and Cycle 1b (bottom) Steam Injection Phases

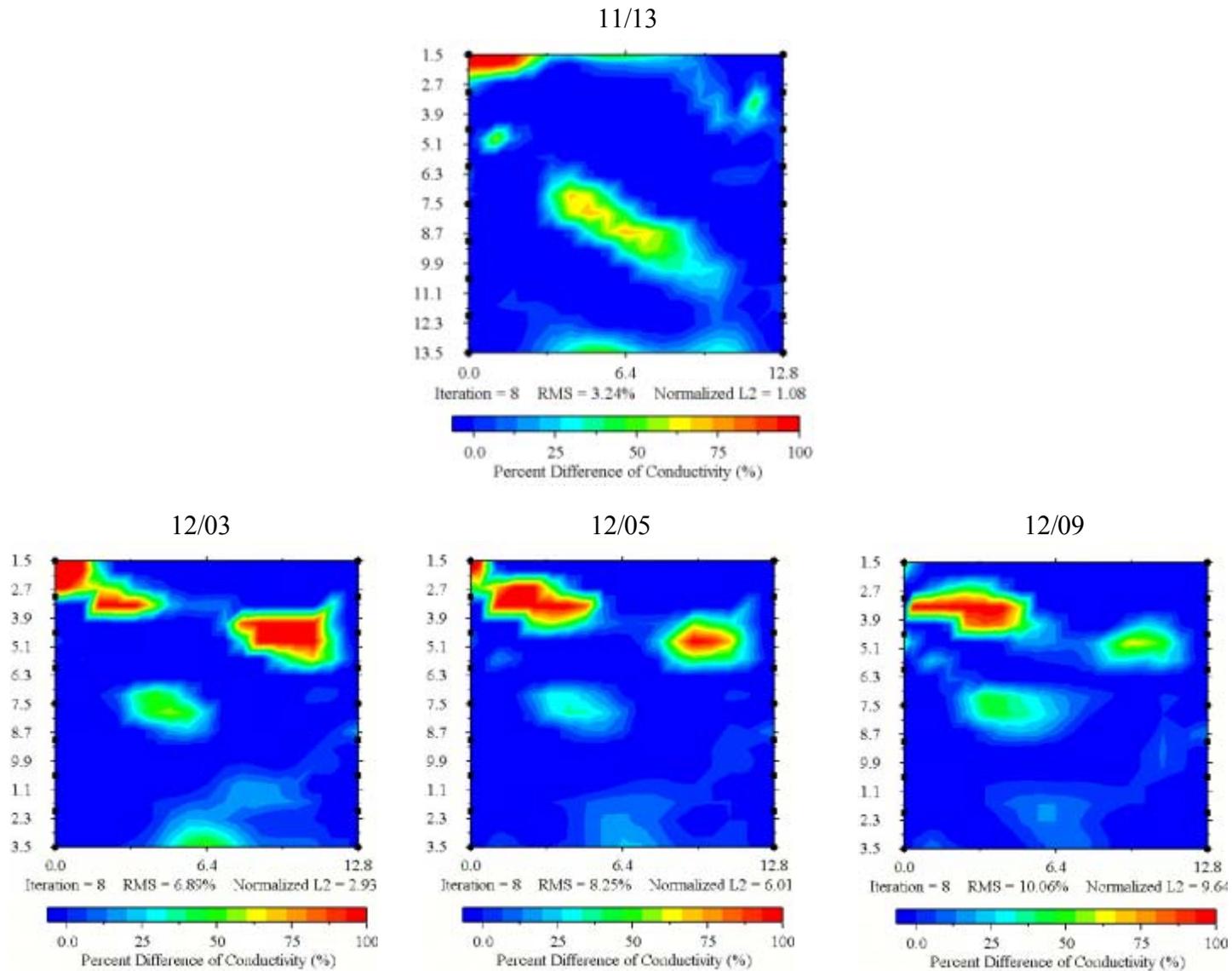


Figure 8-11. Cross-Borehole Profiles, Showing Relative Conductivity Changes in ERT Plane 4-3 (VEA-4 at left) during Early Cycle 3 Steam Injection (11/13/2002) and Cool-Down (12/03 – 12/09/2002) Phases

Starting on November 14, 2002, the full data assessment was possible from the ERT plane 1-5-3. A study of time-lapse differences in conductivities between November 21, 2002 and November 14, 2002 as background, confirmed the outward movement of the heated zone. The plane 1-5-3 difference image for panel 5-3 (Figure 8-9) showed vertical positive anomalies lying to either side of, but away from, VEA-5, suggesting progressive heating outward from the steam injection well. This pattern was also observed in the ERT plane 2-5-4 using data from the same monitoring dates. Conductive anomalies in the difference images near the surface along the ERT plane 2-5-4 might be attributed to the lack of adequate data coverage resulting from the four missing shallow electrodes in VEA-2 as well as the data gap from the surface electrode missing in VEA-4. In both cases, the conductive anomalies were a result of surface water infiltration that caused increases in conductivities.

The outside of the expected heated zone in the demonstration plot was represented by the ERT planes 2-5-3 and 4-3. The ERT plane 2-5-3, the upgradient side of the groundwater flow to the injection well, showed little change in conductivity from background throughout the demonstration. The ERT plane 4-3, east of the injection well, showed a cyclical pattern of increases and decreases in conductivity levels because the ERT plane had a slight direct heating influence on the east side of the injection zone with depths of approximately 4 and 12 m (12 to 36 ft bgs) (Figure 8-10 and Appendix E). Conductivity increased in this plane on October 24 and 25, then decreased to background levels on October 30, 2002. A similar repeated cycle occurred with increases in conductivity levels from October 31 to November 1, 2002, then with drops to background levels on November 4, 2002. The third repeated cycle did not occur again until November 13, 2002 when a much stronger increase in conductivity level occurred by November 14 and continued until November 18 (the start of the extraction phase, Cycle 3). The higher magnitude of this increase in conductivity might have resulted from the infiltration of water from the surface, which is indicated by a positive anomaly at the surface near VEA-4 on November 13, 2002. A further indication of this infiltration effect was noted in the apparent connection of the subsurface anomaly up toward the surface near VEA-4. After November 18, 2002, the anomaly below the water table dissipated, but an anomaly along the shallower zone and above the water table persisted through the last dataset on December 9, 2002.

Regardless of the effect of surface water infiltration due to heavy rain events during the demonstration, the ERT plane 3-4 between VEA-3 and VEA-4 was interpreted as an area of higher permeability and increased groundwater flow. The increased permeability facilitated the movement of heated groundwater from the injection zone. The cyclic pattern observed correlated wells with the steam injection cycle, at least in the first half of the demonstration.

With the full dataset beginning on November 14, 2002, it was possible to assess all of the data from ERT planes 1-2 and 1-4. An examination of time-lapse difference in conductivity for November 21, using November 14 data as background, showed very little if any change. The continuous steam injection over time generally resulted in an initial increase in conductivities as formation water heated up around the injection zone. When groundwater water is replaced by steam, levels of positive conductivity difference would drop as resistivity

increased due to the presence of steam. Note that the ERT data here did not show any transition in the saturated subsurface. This was due to the cyclic pattern of steam injection in this demonstration, which allowed for the heating of groundwater, but not for sufficient heat transfer to transition to steam.

Post-Demonstration Assessment: With the demonstration process completion on November 21, 2002, three follow-up datasets were collected on December 3, 5 and 9, 2002. The change in conductivity plots for ERT planes 5-3 and 2-5-4 showed a gradual dissipation of the anomaly centered at VEA-5 (Figure 8-8). The data reflect the dissipation of heat and reintroduction of ambient groundwater beginning to occur in the heated zone.

Within the perimeter ERT panels, only plane 4-3 showed any indication of change (Figure 8-12). Plane 4-3 showed minor fluctuation in magnitude of a small anomaly located at approximately 7.5-m depth (23 ft bgs). This anomaly was at the same location as noted during the steam injection cycle of the demonstration with a higher permeability zone. An anomaly located at and above the water table (6 to 15 ft bgs) also did persist in plane 4-3, likely indicating that continued influence of surface water infiltration was affected after the heavy rain event on November 13, 2002.

The measurement of temperature conducted throughout the project showed a strong correlation with the ERT data. Significant change in temperature is noted only in VEA-5. ERT planes that included VEA-5 showed a corresponding increase in conductivity, notably between 16- and 38-ft depths (5- to 12-m depth) centered on VEA-5 (Figure 8-12). The depth interval showing increases in conductivity correlated well with the temperature increases, which were also focused in the 16- to 38-ft depth interval, with lower temperatures near the surface and base of the boring.

As the ERT test suggests, for spatial subsurface changes rather than point-based temporal temperature monitoring, the hydraulic movement of heated fluid was enabled between VEA-3 and VEA-4, whereas no change in temperature was noted at the boreholes themselves. The ERT thus provides a broader picture of the subsurface hydrogeology during the heating application, revealing variations in groundwater movement and zones of increased permeability that provided preferred pathways for the movement of heated fluid and steam.

In summary, the maximum values for percent-change in conductivity observed at VEA-5 over the project time period showed increases and decreases in conductivity, which correspond with the cyclic nature of this demonstration for steam injection and extraction. The highest increases and decreases occurred within the injection phases, and decreases in conductivity appeared during the intermediate soaking/extraction phases. It was apparent that the pattern of temperature over time at VEA-5 showed increases and decreases in temperature corresponding to the demonstration phase.

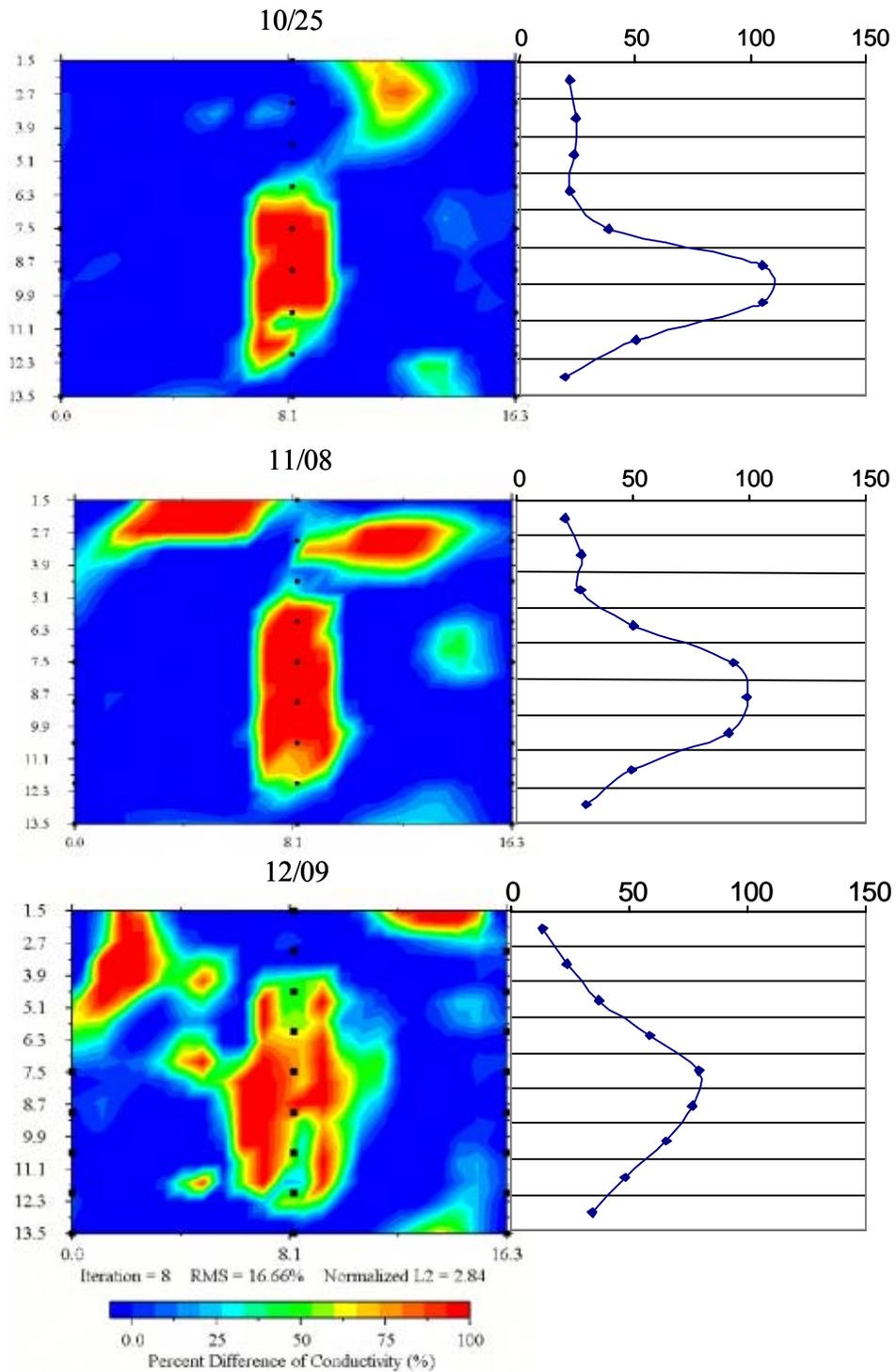


Figure 8-12. Cross-Borehole Resistivity Profiling, showing Resistivity Changes Adjacent to VEA-5 (center of plane), with Corresponding Temperatures (°C) Measured Using Thermocouples in VEA-5

The maximum levels for percent-change in conductivity observed within ERT plane 4-3, over the project time period, showed no increase until the third steam injection phase, where its maximum change occurred. This maximum change corresponds to the maxima noted within the ERT planes containing VEA-5 and the highest values of change observed during the project. It is important to also note that an elevated percent change in conductivity is observed with ERT plane 4-3 during the cool-down phase. This was likely due to continuous movement of heated groundwater outward from the injection zone along the zone of higher permeability shown by ERT plane 4-3.

8.3 Water Balance and Hydraulic Control Issues

The cumulative water volume from the injection and extraction processes is shown in Figure 8-3 and presented in Section 8.1. Figure 8-3 also shows the total addition of water to the subsurface, calculated as the amount injected as steam minus the amount recovered when extracting. The net injection volume for the cycles combined was approximately 5578 gal. This positive net injection resulted from the incomplete injection achieved during Cycle 1a, where the oxygen flow was not provided during the steam injection phase. Subsequently, Cycle 1a was considered as a preheating cycle (shake-down test).

However, the positive net volume of water from the injection could potentially cause a lateral COC migration from SI-01 due to displacement and mixing. A total of 5,578 gal of water (as steam) was injected in the treatment zone and displaced/mixed with the native water. The first 1,753 gal of water injected (Cycle 1a) was not extracted because of pump failure and contributed totally to the dilution of the native water in the treatment zone. The level of dilution experienced in the treatment zone due to the retention of distilled water (steam) in the aquifer is illustrated in the average 68% decline in chloride concentrations in the monitoring wells surrounding the steam injection well. Chloride is a relatively conservative component in the treatment zone as it is not affected by temperature, and the contributions from any COCs is minimal. Therefore, the water retention in the treatment zone due to displacement and mixing could have caused a decline in several groundwater constituents due to dilution.

8.4 Energy Balance

The energy balance for the site is shown in Figure 8-13. It is a theoretical calculation of potential heating volume based upon the actual quantities of steam injected. The energy injected was calculated as the net amount of water injected as steam multiplied by an enthalpy content of 1,100 BTU/lb. The final heating radius calculated assumed completion of all events (1a-3 cycles); more in-depth estimates were not made. Figure 8-13 shows however, the heat storage per cycle as well as the theoretical energy remaining in the extracted fluids. The vapor component of the extracted streams was assumed to be very minimal.

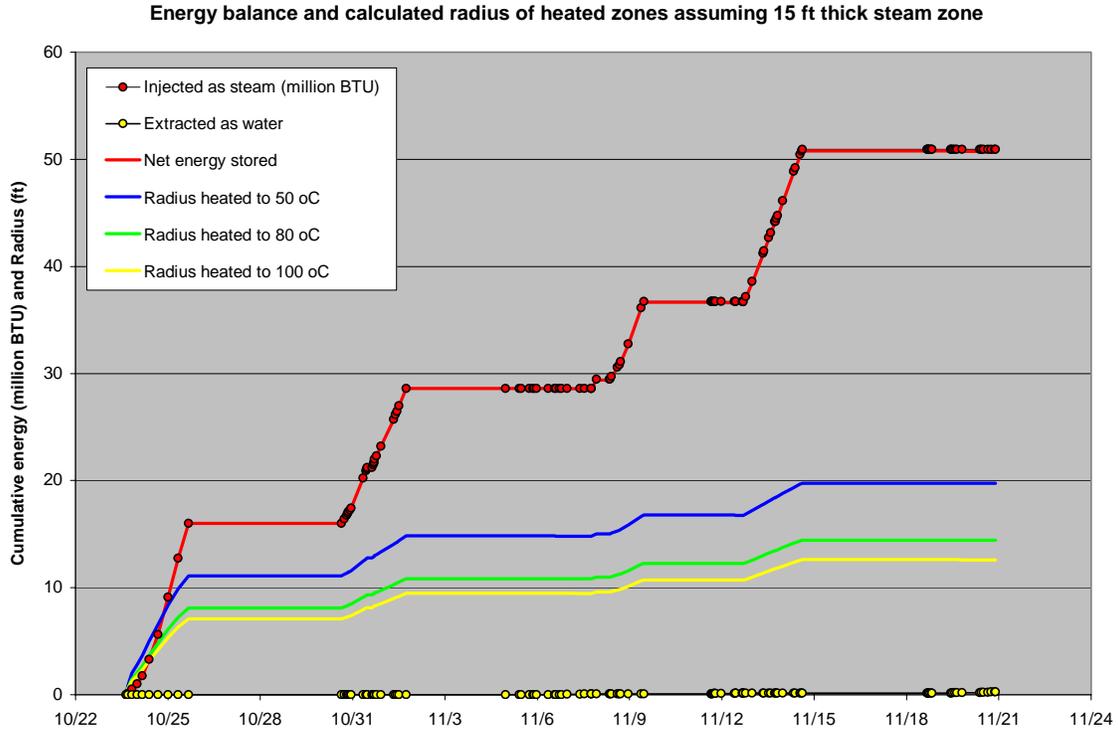


Figure 8-13. Energy Balance and Estimated HPO Reaction Zone Radius

A total net injection was achieved at about 51 million BTU with 5,578 gal of steam injected. Assuming that this energy was used to heat the target area in the subsurface, the following volume of heated area was estimated to be between 277 and 679 yd³, resulting in a radius of heated influence from 12.6 to 19.7 ft (Table 8-3) for an assumed heating thickness of 15 ft. For depths of 20 and 25 ft thickness, the radius of influence would decrease: for example, 11.2 to 12.5 ft for heating to 80 deg C.

Table 8-3. Estimated Heated Volumes and Radius Assuming a 15-ft-Deep Zone

Final Temperature	Heated Volume (yd³)	Radius of Heated Zone (ft)
50°C	679	19.7
80°C	363	14.4
100°C	277	12.6

* Assumes partial displacement of pore water due to steam.

In summary, because the temperature of the heated zone was in the range of 50 to 120°C, the energy balance used for the injection and extraction was kept with the observed heated temperature in the subsurface. The energy balance suggested a theoretical radius of heated influence

(achievable from the energy input of steam injected) to be between 15 and 20 ft from the injection well.

8.5 Geochemistry Changes in the Treatment Zone

A HPO reaction zone was observed from the steam injection of the demonstration as listed:

- Presence of dissolved COCs in the groundwater.
- Elevated temperatures over ambient groundwater were measured.
- Measurable DO in groundwater at or over 0.5 mg/L.

Generally, the hotter the reaction zone is, the higher the expected HPO reaction rate. Subsequent changes in groundwater are expected due to the HPO reactions as well as additions for monitoring purposes:

- Increases in DO, indicating that injected oxygen was solubilized into the groundwater.
- Increases in bromide added as tracer, indicating the extent of injected water and steam.
- Changes in chloride, from background, with increases (if any) indicating thermally induced degradation.
- Increase in alkalinity due to carbonate system equilibrium changes and potential production of inorganic carbon by oxidation of COCs or other organic material in the aquifer.
- Decreases of reduced groundwater species such as methane, sulfide, ferrous iron, and dissolved manganese indicating that aerobic conditions are created.

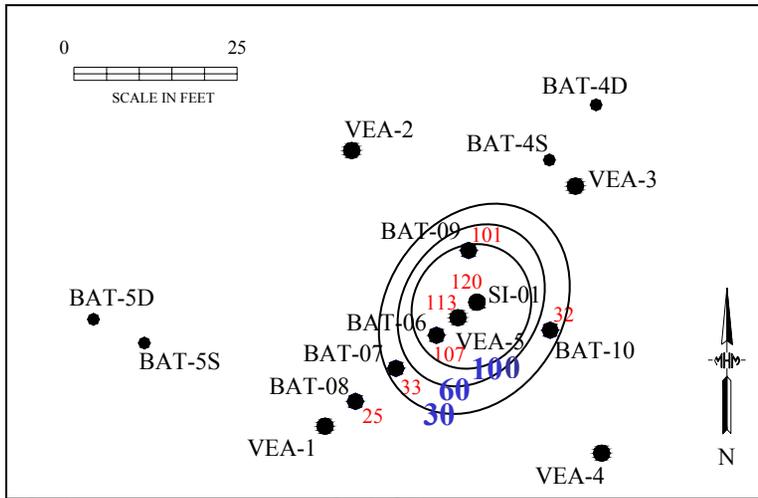
The results of changes in groundwater are summarized in Appendix C. The aforementioned parameters (field parameters bromide, chloride, etc.) were averaged for the pre- and post-demonstrations. The average levels were used to determine geochemistry changes in the treatment zone. Selected parameter changes are illustrated on the well-field maps in Figures 8-14 and 8-15. The following are the summary results observed in the field:

- Substantial increases in groundwater temperatures from BAT-06, -07, -09, and -10. The isocontour lines for the elevated temperatures at 30, 60, and 100°C are shown in Figure 8-14. Approximate radii of the elevated temperature zones were 8, 16, and 20 ft for 100, 60, and 30°C, respectively. Temperatures increased in the direction of BAT-06 and BAT-09, but less so in the direction of BAT-10. This probably indicates the effect of fresh groundwater influx from the upgradient direction. More distant wells, such as BAT-08, BAT-04, and BAT-05 did not show any elevated temperatures, indicating that heating was limited to a radius of

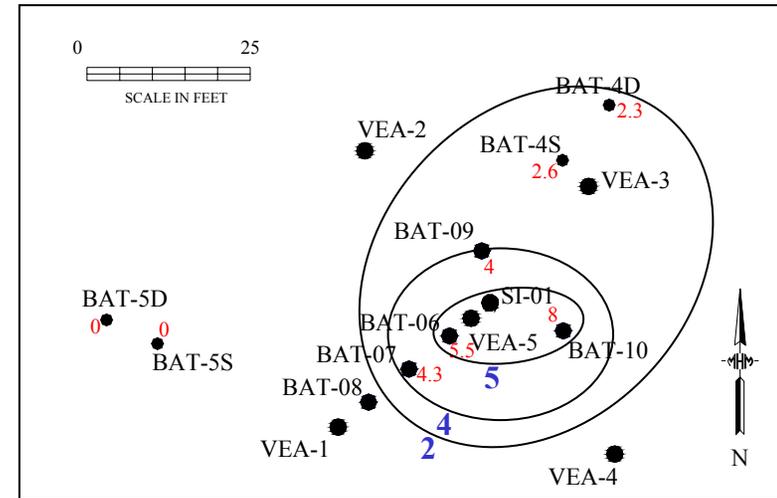
approximately 20 ft around the injection well. This is consistent with the pre-demonstration modeling.

DO levels increased to above 1 mg/L in SI-01, BAT-4S, -4D, -06, -07, -09, and -10 for the demonstration (see Figure 8-14 and Table C-1 in Appendix C). In particular, DO levels for BAT-06 and BAT-10 were noticeably increased, indicating that there may be a preferential flow in the formation as the injected oxygen was traveling through the flow line. The surrounding wells (namely, BAT-5S/D) outside the demonstration target area did not show significant changes and remained anaerobic. The DO level increases for BAT-10, -4S, and -4D were somewhat surprising, because there was no other evidence of changes in those wells. If these DO level increases were real, the radius of the oxygenated zone would be much larger than the heated radius, and there may be an aerobic, cool zone around the heated zone where HPO does not occur. Such a zone could be explained by oxygen bubbling through the condensate zone during injection cycles.

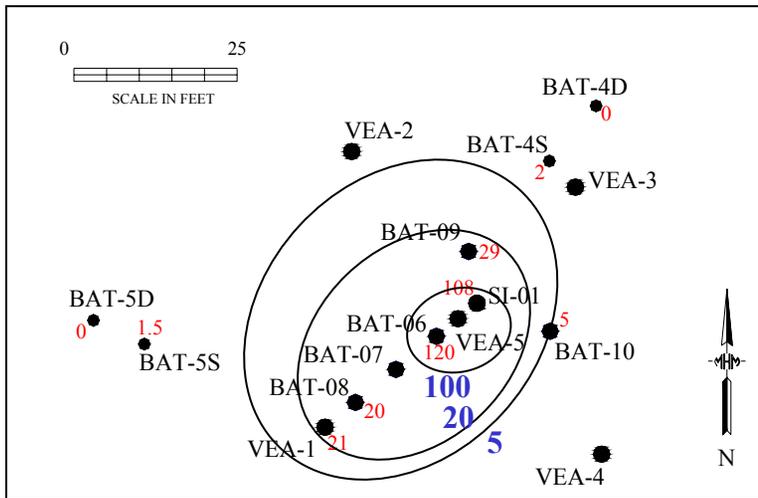
- Bromide concentrations increased in BAT-06, -07, -08, -09, and -10 and showed signs of increase in BAT-4S and -5S (see Figure 8-14 and Table C-3 in Appendix C). Bromide was injected as slugs (with the original concentration of 66,300 mg/L) prior to the steam injection phase of each cycle. Serving as a tracer injected into the injection well SI-01, it was expected that bromide would diffuse out as the condensation of steam spread out in the aquifer. The results from the monitoring wells were used to create isocontour lines in Figure 8-14 showing an elliptical shape stretching farther to the southwest than the heated area. The interpreted area was larger than the heated area and this was approximately the same as the area observed for the increased DO levels. Therefore, the region affected by water displacement (created by the steam injection) was larger than the heated region. This may indicate that the extracted water in the extraction phase potentially was not always equivalent to the steam/water injected. The water balance shown in Figure 8-3 illustrates the fact that the extracted water volume was always less than the injected water (as steam) volume. One anomalous datum was observed in 23L001MW. This well is located about 600 ft away from SI-01 in the downgradient side of the demonstration site. It was highly unlikely that the observed change was related to the injection at SI-01. The bromide was below detection from results in the post-demonstration monitoring. Thus, the bromide datum for the distant well 23L001MW either was anomalous or affected by other factors not directly associated with the steam injection demonstration.
- Chloride concentrations decreased significantly in the wells near SI-01 (see Table C-3 in Appendix C). At the end of the demonstration, all of the wells with concentrations between 10 and 16 mg/L were close to the observed background in the surrounding wells at the site (BAT-4S, -4D, -5S, -5D, and the distant well 23L001MW). The elevated chloride concentrations in BAT-06, -07, -08, -09 and -10 during the May 2002 sampling events could be explained by chloride releases



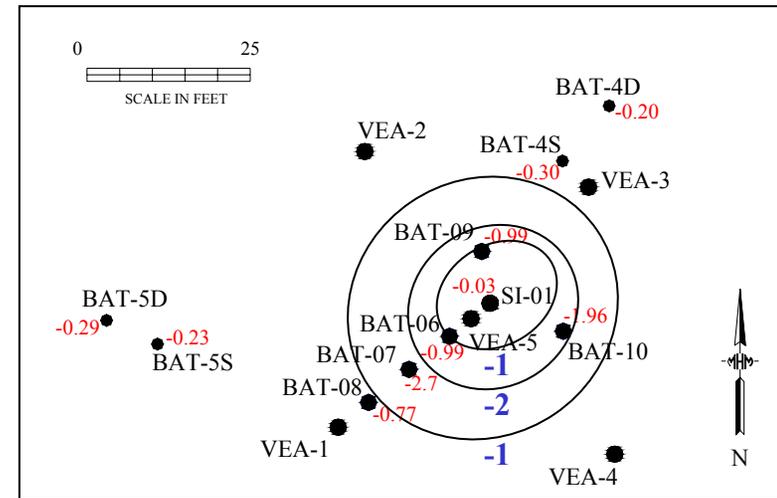
Maximum temperature reached (°C)



Maximum DO increase (mg/L)

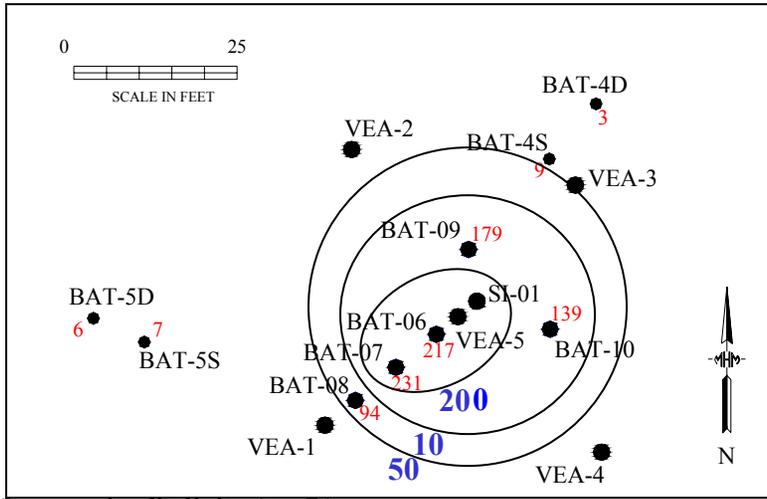


Highest Br⁻ concentration (mg/L)

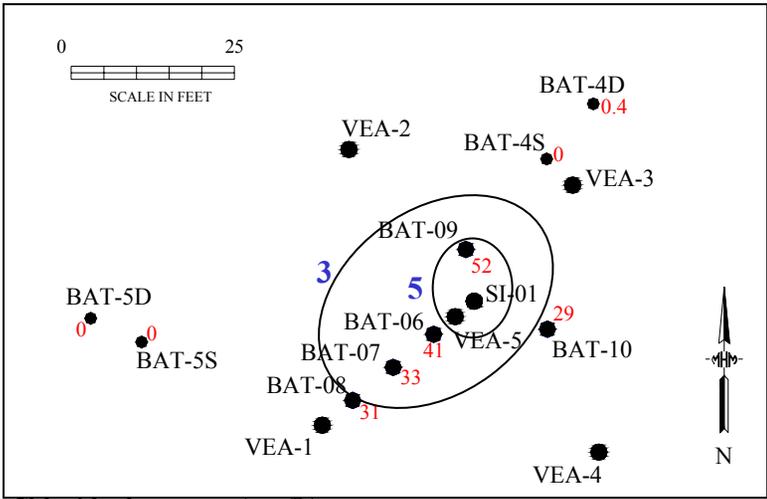


pH change (-)

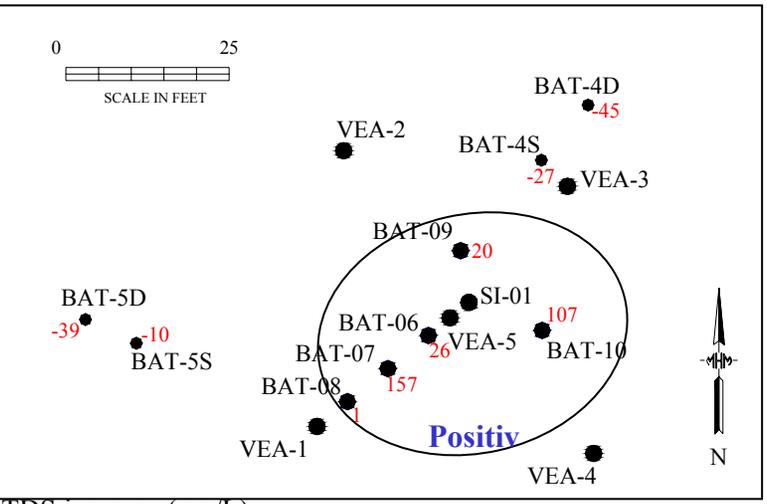
Figure 8-14. Schematic View with Changes in Average Temperatures, DO, Bromide, and pH Levels



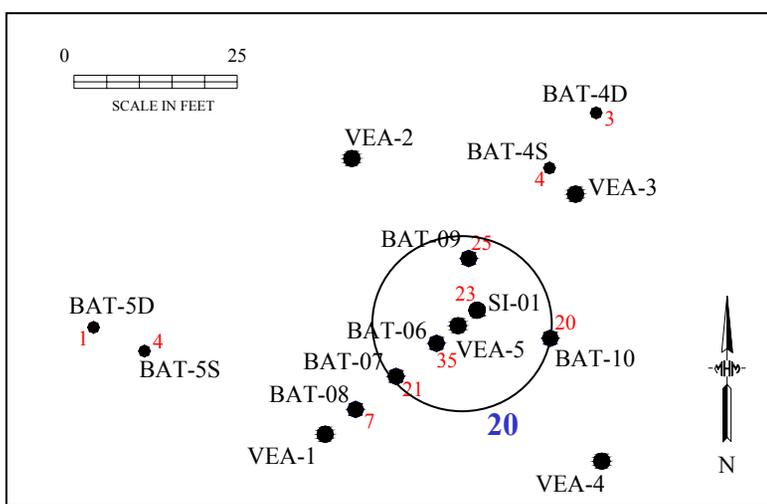
Increase in alkalinity (mg/L)



Chloride decreases (mg/L)



TDS increase (mg/L)



Highest conductivity increase (mS/cm)

Figure 8-15. Schematic View with Changes in Average Alkalinity, Chloride, TDS, and Electrical Conductivity Levels

- from the well construction grout materials during the site preparation including well installation. As cyclic processes for the injection and extraction were applied, the chloride concentrations in these wells dropped to the levels of the surrounding wells, indicating that the water with elevated chloride was pumped out or mixed substantially with groundwater. This indicates that retention of distilled water (steam) in the treatment zone due to displacement/mixing may have contributed to dilution of several groundwater constituents, including the COCs.
- Alkalinity increased substantially in wells BAT-06, -07, -09, and -10 (see Figure 8-15 and Table C-3 in Appendix C). This indicates that the carbonate equilibrium was changed due to the temperature changes in the aquifer. An increase in alkalinity could be attributed to the oxidation of natural organic matter and/or COCs in the heated aquifer under elevated DO.
- pH generally decreased in the wells near SI-01 from 6.31 to 8.54 from the sampling in May 2002 to 5.93 to 7.7 after the demonstration period (see Figure 8-14 and Table C-1 in Appendix C). During the demonstration cycles, pH levels remained relatively constant (6.6 to 8.00) in the wells in the target area, indicating that the groundwater was well buffered. As discussed for the chloride observation earlier, it is believed that the initially higher pH values in these newly installed wells might be due to the well installation and grout curing. As the pulses from the process of the injection and extraction were conducted, the disturbed groundwater was either removed or mixed with the injected water and undisturbed groundwater, in which pH levels were subsequently stabilized.
- Total dissolved solids results from the monitoring conducted prior to and after the demonstration increased only in wells SI-01, BAT-07 and BAT-08, which were heated from 262 to 345 mg/L before the demonstration to 374 to 453 mg/L after the demonstration, and modest decreases were observed in the surrounding wells (see Table C-3 in Appendix C). It is likely that the increases were due to the increase in alkalinity noted in the water.
- Specific conductivity levels increased in BAT-06, -07, -09, and -10 from 39 to 56 mS/meter (mS/m) before the demonstration to 40 to 90 mS/m during the steam application. Then, the specific conductivity levels decreased to background levels (44 to 68 mS/m) after the demonstration. Little change was observed in BAT-08 at approximately 40 to 50 mS/m regardless of the demonstration, which suggested that there was little impact from the steam injection or extraction of the liquids and vapor (see Figure 8-15 and Table C-1 in Appendix C).

- ORP changes observed in all wells during the injection of oxygen are expected to increase as the groundwater becomes aerobic. However, the observation differed from the expectation (see Table C-1 in Appendix C). The ORP levels from 303 to 461 mV before the demonstration in May 2002 decreased to -74 to 221 mV after the demonstration in December 2002, suggesting that a reducing condition was created. It was difficult to attribute why the reducing condition occurred in the aquifer when the aquifer was oxygenated. The geology may be a possibility.
- Methane concentrations were generally very low wherever present; methane concentrations were lowered to near the detection limit at 0.001 mg/L at the end of the demonstration (see Table C-1 in Appendix C). The decrease of methane levels may support the creation of aerobic conditions by the injection of steam and oxygen.
- Dissolved iron and manganese concentrations were generally very low (less than 2 mg/L iron and 0.2 mg/L manganese). No significant trends were observed other than a peak in BAT-06, which occurred prior to the first injection cycle. The iron and manganese concentrations then dropped during the operations phases, indicating the reduced species had been oxidized. This supports the creation of an aerobic reaction zone near SI-01.

In summary, the groundwater composition changes show the creation of a heat-impacted zone around SI-01 that would favor HPO reactions. Based on the observed changes in geochemistry and temperature, the zone was between 15 and 20 ft in diameter, and possibly elongated in the southwest-northeast direction. The pattern was the elongated axis for SI-01, and BAT-06, and BAT-07 within the reaction zone, and the shorter axis covered BAT-09 and BAT-10. There was little change in BAT-4S/D and -5S/D wells. None of them were significant enough to suggest that the HPO reaction created any COC migration outside the target area. Additionally, field parameters including temperature and DO supported the fact that the native condition remained and no significant changes were observed in those wells outside the target area.

8.6 COC Concentrations in Monitoring Wells

One line of evidence for HPO reactions would be the reduction of COCs in the subsurface. In this case, the concentration levels for TCE, PCE, and *cis*-1,2-DCE in groundwater were evaluated for the demonstration target area. Table 8-4 is divided into two groups for both HPO-impacted and nonimpacted well data based on average COC concentration results from pre-demonstration and post-demonstration. The average concentrations for each COC was calculated from all of the monitoring results summarized in Table C-2 of Appendix C. Based on the average TCE reduction rate in each well, Figure 8-16 was prepared to show overall reduction for the aforementioned COCs in the demonstration target area. TCE had the highest concentration in the groundwater prior to the steam injection/extraction process application in the treatment area. After the injection/extraction cycles, the ranges of % reduction for average TCE ranged from 53 to 85% from the groundwater monitoring results in the heat-impacted wells.

The monitoring data with greater reduction of TCE and PCE concentrations corresponded to the elevated temperature (above 30°C) and the increased DO (above 2 mg/L). Average reduction efficiencies in this heat-impacted zone, including wells SI-01, BAT-06, -07, -09, and -10, are the following:

- TCE: 75%
- PCE: 80%
- *cis*-1,2-DCE: 65%.

Table 8-4. Percent Reduction of Average COC Concentrations in Groundwater

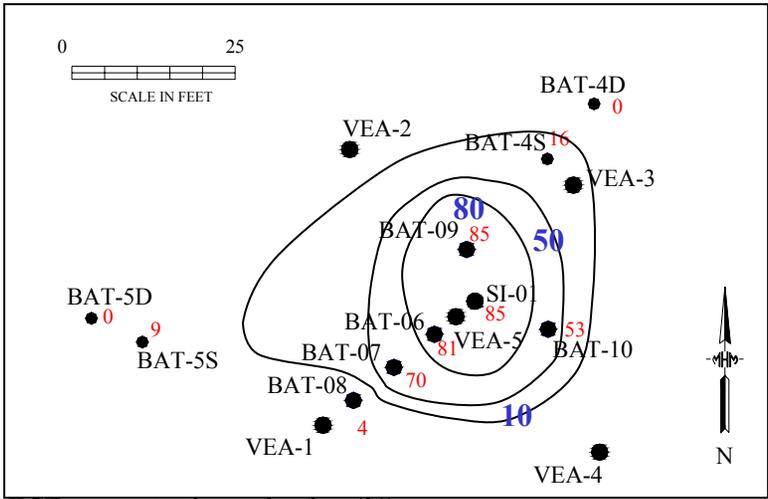
Well	TCE Pre-Demo	TCE Post-Demo	TCE %Reduction ^(a)	PCE Pre-Demo	PCE Post-Demo	PCE %Reduction	DCE Pre-Demo	DCE Post-Demo	<i>cis</i> -1,2-DCE %Reduction ^(a)
<i>Heat-Impacted Results</i>									
SI-01	904	138	85	59	7	88	1.8	0.4	79
BAT-06	761	148	81	50	12	77	1.4	0.4	71
BAT-07	800	238	70	52	11	78	1.4	0.7	53
BAT-09	776	113	85	50	5	91	1.6	0.4	75
BAT-10	414	194	53	41	14	66	0.8	0.4	45
<i>Heat Nonimpacted COC Results</i>									
BAT-08	635	608	4	45	39	13	1.1	1.1	2
BAT-4S	828	695	16	55	48	12	1.7	2.0	-17
BAT-4D	688	688	0	52	47	10	1.6	2.0	-28
BAT-5S	448	409	9	39	33	16	1.0	1.2	-26
BAT-5D	172	178	-4	28	26	7	0.3	0.3	-17

All units are in µg/L.

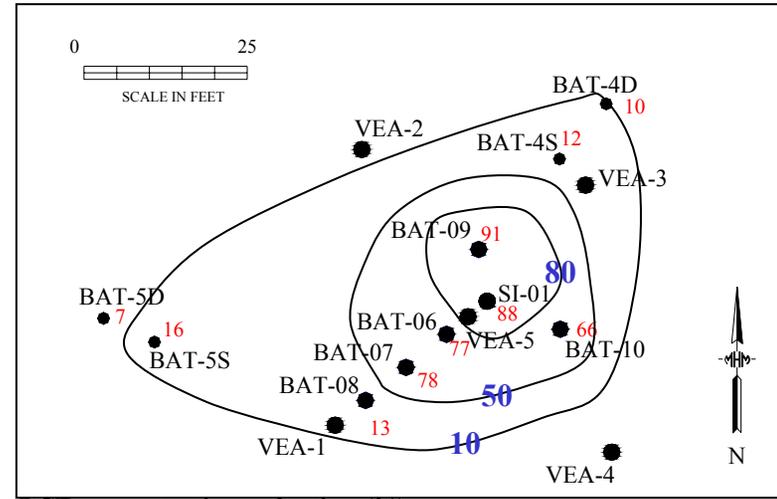
- (a) Negative values indicate an increase in concentration.
- (b) Averaged data represents 3 sampling data sets: see also Section 8.7.

In addition to the average reduction in each well, temporal changes of the TCE, PCE, and *cis*-1,2-DCE concentrations in groundwater are presented in Figures 8-17 to 8-19, respectively. TCE concentrations decreased over the period of the demonstration. TCE changes similarly showed the biggest reduction of the concentration levels after the demonstration. Some of the outer wells showed slight increases in the *cis*-1,2-DCE concentrations, which could suggest enhanced reduction of TCE or PCE. However, because the levels were very close to the detection limits (in the 0.3 to 1.5 mg/L range), the increases were not easy to quantify to determine a significant increase.

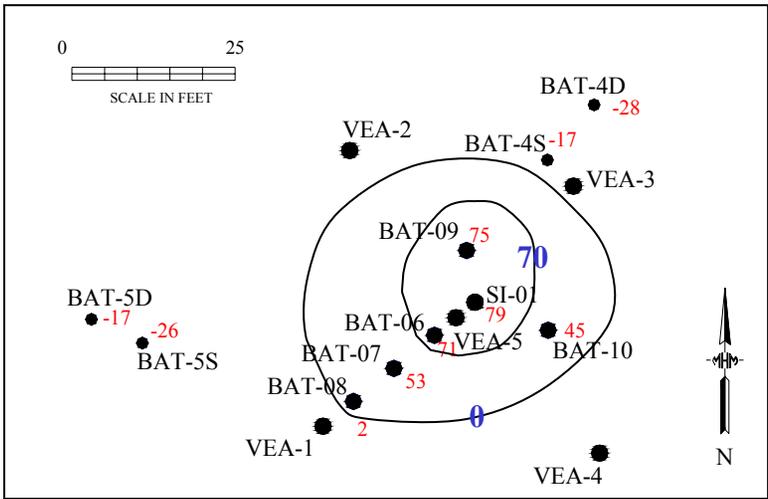
As discussed in Section 8.3 (Water Balance) and Section 8.5 (Geochemistry Changes), one factor in the declining TCE and PCE concentrations could be the dilution effect of the distilled water (as steam) injected into the treatment zone. Although a substantial portion of the injected water was extracted, the resulting displacement/mixing caused the levels of one conservative dissolved constituent (chloride) to decline by 68%. Similar dilution could have been a factor in the TCE and PCE declines observed during the demonstration.



TCE concentration reduction (%)



PCE concentration reduction (%)



cis-1,2-DCE concentration reduction (%)

Figure 8-16. Schematic View with Changes in Monitoring Well TCE, PCE, and *cis*-1,2-DCE Concentrations

PCE concentration in monitoring wells

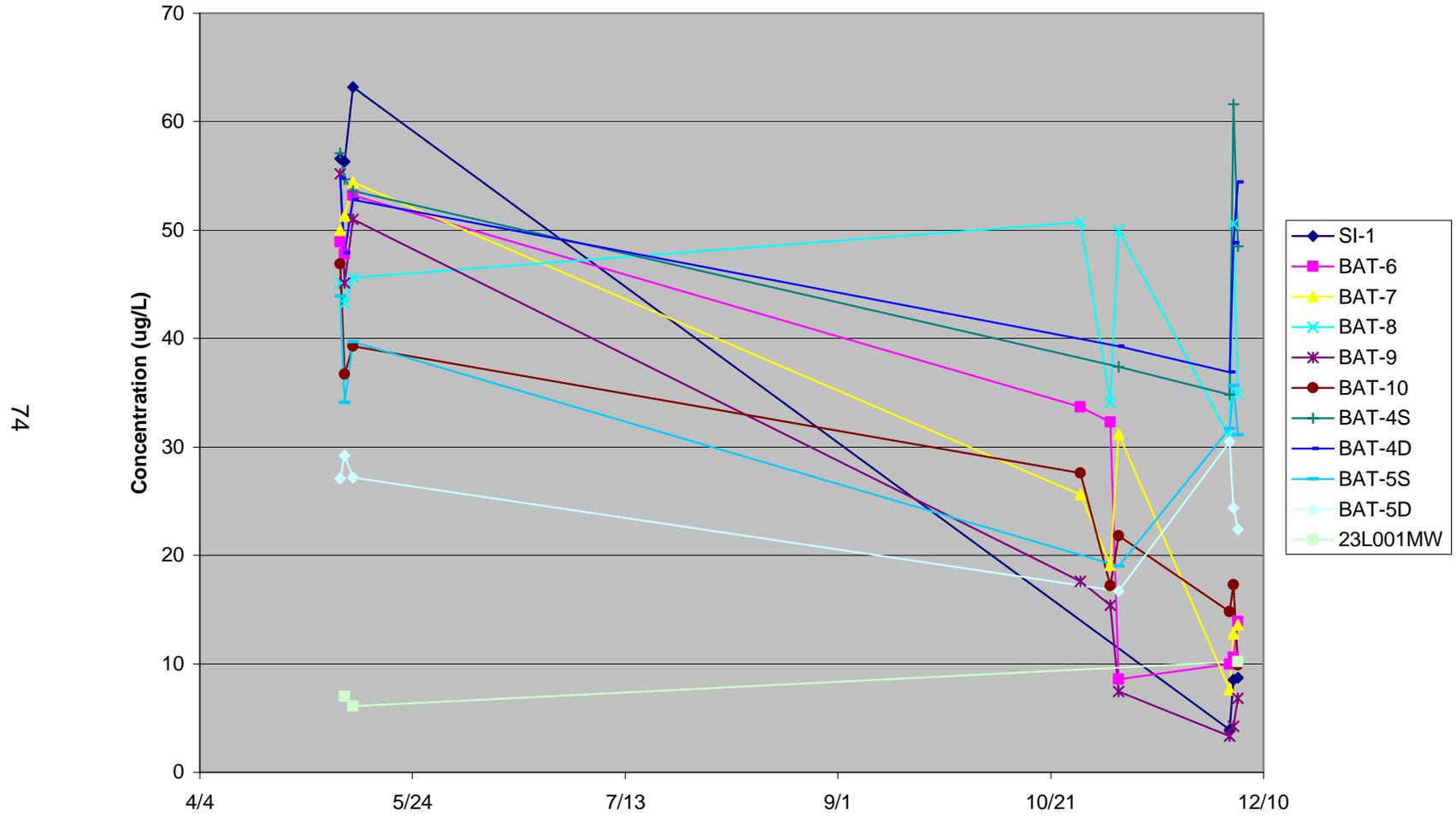


Figure 8-18. Temporal Changes of PCE Concentrations in Groundwater

cis-1,2-DCE concentration in monitoring wells

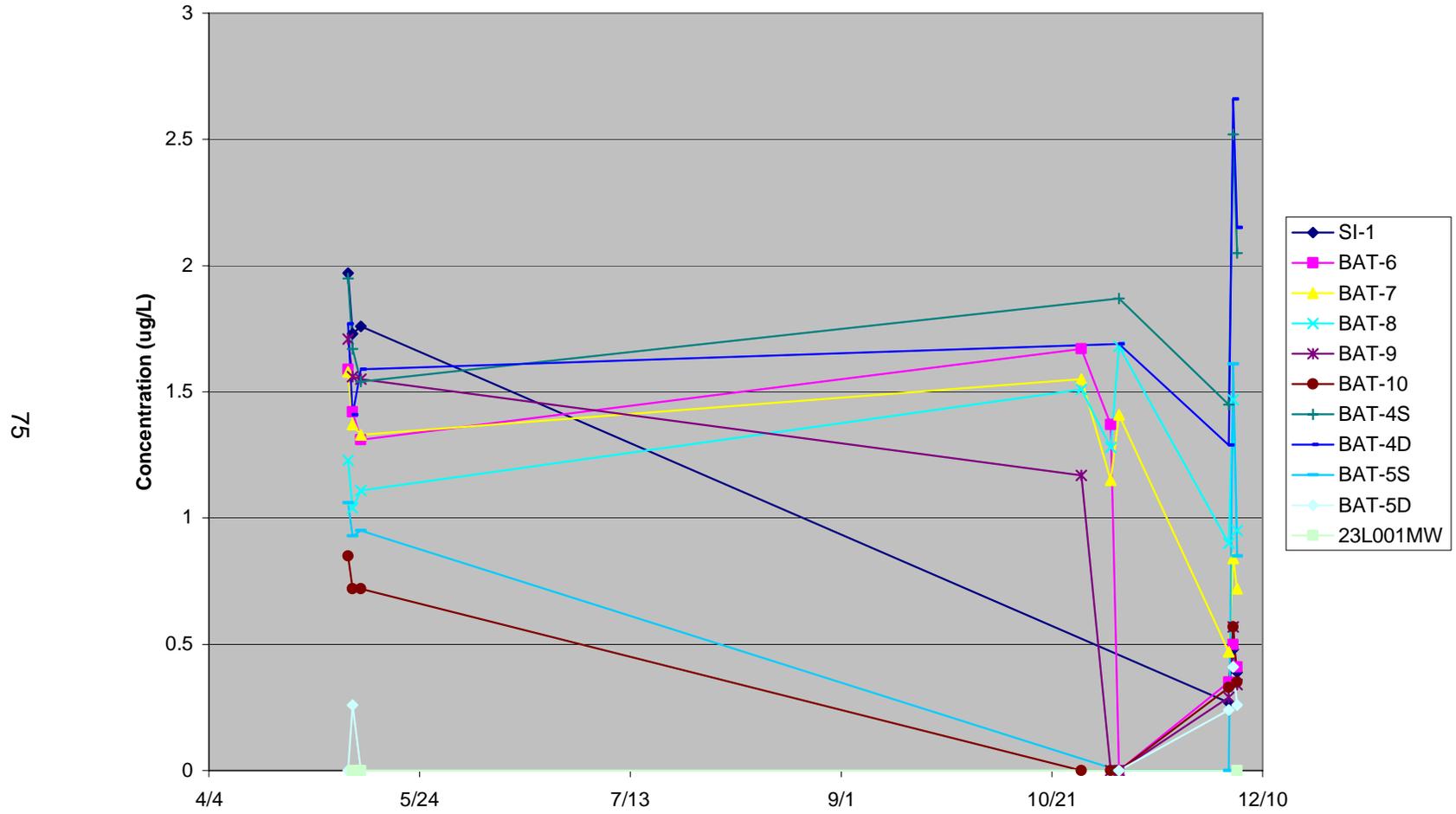


Figure 8-19. Temporal Changes of cis-1,2-DCE Concentrations in Groundwater

8.7 Declining COC Levels in the Subsurface: COC Mass Balance

Reduction of contaminants in the demonstration plot could have occurred with one or multiple mechanisms as follows:

- Dilution due to displacement/mixing generated by the injected steam.
- Degradation via HPO reactions generated by heating and oxygen.
- Biological degradation by enhanced microbial activity at higher temperatures.
- Extraction of groundwater and condensate.
- Displacement of the dissolved plume by injected steam condensate.
- Vaporization during the extraction phase.
- Vaporization from the surface.

It is inherently difficult and challenging to separate the mechanisms, due to factors such as site heterogeneity, limited sampling frequencies, analytical accuracy, and limited monitoring. Nevertheless, the possible mechanisms listed below would follow:

- Dilution due to injected steam. One dissolved constituent in the groundwater, chloride, declined by 68%. This decline is comparable to the decline in COC levels.
- Degradation via HPO reactions. An HPO reaction zone was established by the injection and extraction processes. Approximately 360 yd³ in the subsurface was estimated to be heated to above 80°C at the radius of 14.4 ft around SI-01 with the thickness of 15 ft over depth (see Table 8-3) with the combination of heating cycles. The radial extent was measured to have varied between 8 to 15 ft as shown in Figure 8-14 (p. 67). Similarly, the data from Figures 8-6 and 8-7 shows that a variable heating thickness was achieved during various cycles. Groundwater data from monitoring wells present within this HPO treatment zone, and slightly outside, all showed increased DO, bromide, alkalinity, and significant reduction in COCs. Chloride, which could have been a significant indicator of COC degradation, was not useful at this site because of the relatively low levels of TCE and PCE in the pre-treatment aquifer. Any chloride generated by TCE or PCE degradation would be indistinguishable from the pre-treatment chloride levels, due to dilution effects of steam addition.
- Biological degradation. Even though microbiological tests were not conducted, past demonstration results from other sites indicate that a microbial degradation pathway is not inevitable. Because this demonstration was involved with a dramatic change in subsurface conditions for a short period of time, however, microbial adaptation and degradation for the short demonstration period were not likely to play a major role for this demonstration.
- Extraction of groundwater and condensate. During the extraction phases of each cycle, groundwater and condensate were recovered from SI-01.

- Vaporization from the surface. Vaporization during the injection and soak phases. During these phases, the treatment zone was at substantially elevated temperature. Some COCs could have been volatilized from the groundwater, although the finer-grained soil strata above the sand stringers do not appear to be particularly conducive to gas migration. Volatilization from the surface was not quantified due to limited resources. Vaporization during the extraction phase. The vapor recovered from the SI-01 well that was cooled and passed through the vacuum pump was sampled at the sampling port V-1, the inlet port of a series of GAC tanks at V-1. Figure 8-20 shows the TCE concentrations and the calculated cumulative TCE removal. The cumulative amount of TCE removed as a vapor was estimated at 0.14 lb (64 g), which was very minimal.

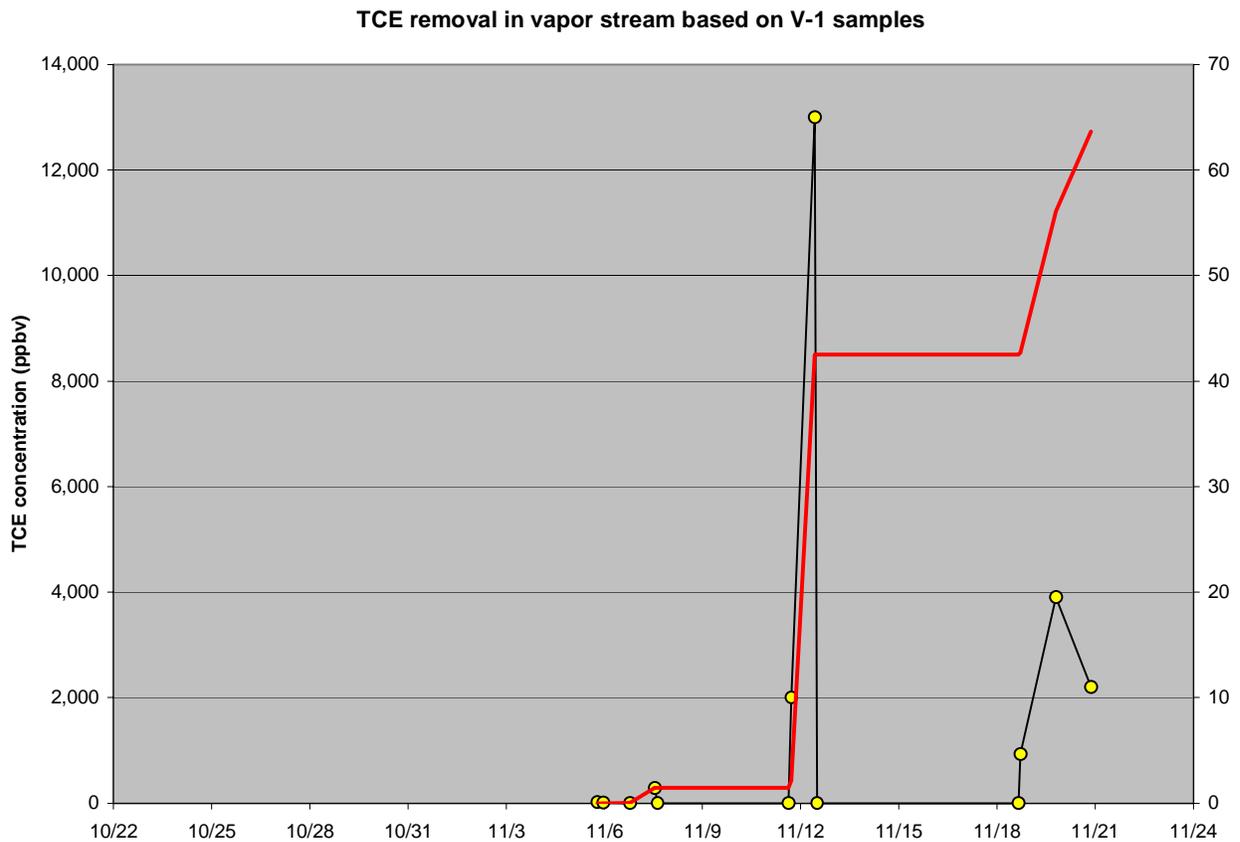


Figure 8-20. TCE Concentrations in Vapor Phase during Extraction Phases and Estimated Mass Removal

Based on the TCE monitoring groundwater data from the wells within the HPO reaction zone (i.e., SI-1 and BAT-6, -7, -9, and -10) from May and December 2002 respectively, the average TCE concentration was reduced from 731 to 166 $\mu\text{g/L}$ in the 14-ft heated radius. Assuming no

sorption, the mass reduction in groundwater within the reaction zone was calculated at 52 g of TCE with the total extraction volume of 92,000 L.

The major uncertainty of constructing a COC mass balance is the adsorbed COCs in the formation. In order to calculate the adsorbed amount, it is necessary to evaluate the organic content of the soil, as well as K_d of the contaminant, which in this case is TCE. The calculations are further complicated because the temperatures change when steam is injected. It was uncertain how K_d changed with this temperature rise.

Figure 8-21 shows the estimated TCE mass that would have remained from TCE that was dissolved and adsorbed into the formation as it was being partitioned. The estimation was calculated based on assumptions from local equilibrium at ambient temperature in the absence of a better estimate ($K_{oc} = 128 \text{ L/kg}$).

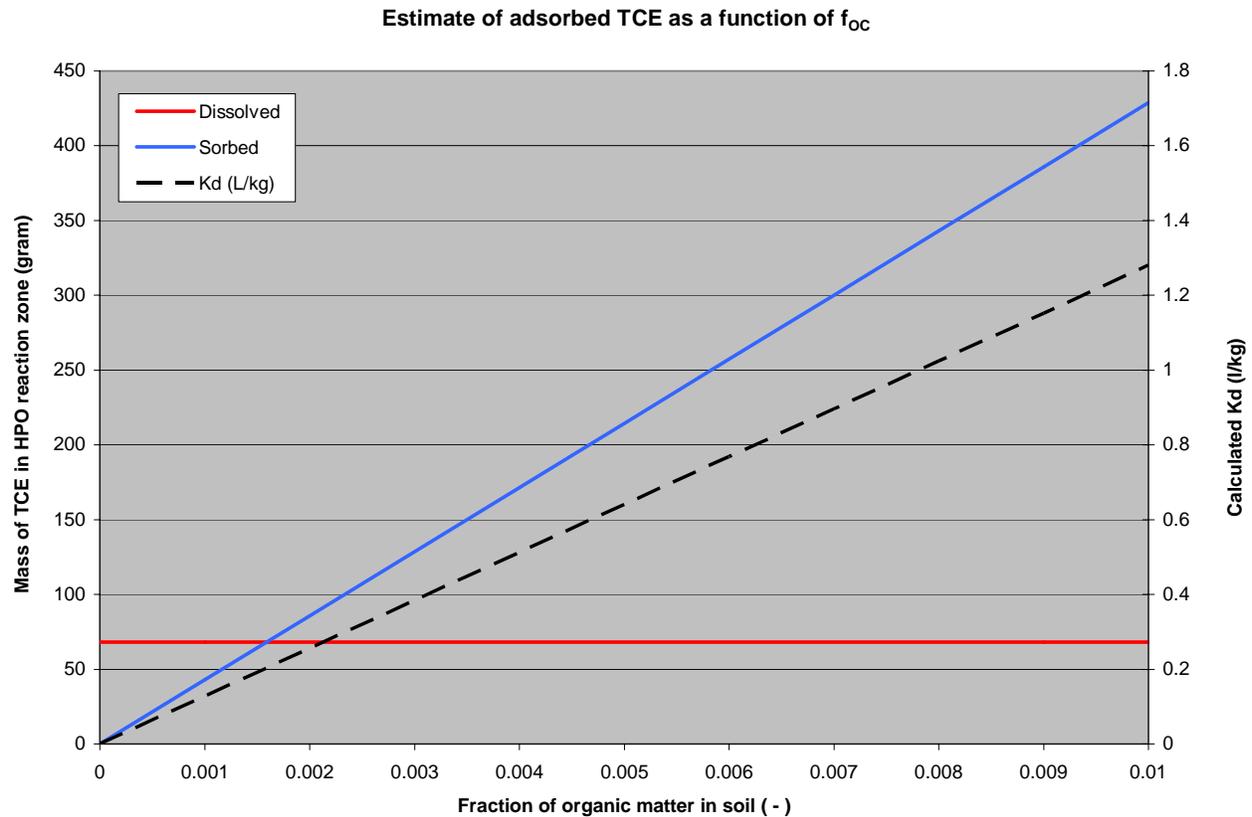


Figure 8-21. Adsorbed TCE Mass Estimated in HPO Reaction Zone

$$K_d = K_{oc} * f_{oc}$$

$$C_{soil} = C_{water} * K_d$$

Where K_d = partition coefficient of TCE in soil [(mg/kg)/(mg/L)]
 K_{oc} = organic carbon partition coefficient [(mg/kg)/(mg/L) = 128L/kg]
 f_{oc} = fraction organic carbon (unitless)
 C_{soil} = sorbed phase TCE concentration in soil (mg/kg)
 C_{water} = dissolved TCE concentration (mg/L).

Two soil samples collected during the site preparation were analyzed for TOC, and both resulted in less than 100 mg/kg, or f_{oc} of less than 0.0001. As shown in Figure 8-21, it is apparent that the adsorbed mass of TCE becomes very important if the fraction of organic matter is larger than 0.001. If the adsorbed TCE mass is significant at the onset of treatment, it also is likely that groundwater treatment leads to desorption of COCs into the dissolved state. In addition, the mass calculated will disappear from the source area and will be degraded.

The COC mass reduction in the vapor phase during the extraction phase was found to be in the same order as the mass reduction in groundwater within the reaction zone. The amount of COCs degraded by HPO reactions could not be quantified. In spite of this small amount and the associated uncertainties, this technology demonstration using a single well has shown a positive remediation capability in a dissolved plume at Beale AFB. The summary of performance criteria to the demonstration is summarized in Table 8-5.

8.8 Summary of Conclusions/Lessons Learned

The field demonstration showed that single-well injection/extraction of steam and oxygen into an aquifer can be effectively used to create a heated treatment zone, in which degradation of COCs is potentially enhanced. The design used for this demonstration required a period without hydraulic control, i.e. a soaking period. Therefore a site with significant contamination could be not selected for the demonstration of this design. Still yet, some issues were encountered in accomplishing adequate hydraulic control during the demonstration. The first batch of injected steam (Cycle 1a) could not be recovered due to pump failure, and similarly, in cycle 1B, which followed, difficulty was met in sustaining extraction (continuously). In all other cycles, a greater amount of hydraulic control was likely achieved, as shown by the data of Tables 6-1 and 8-2, where net extraction volumes exceeded injection volumes. By the groundwater sampling event comparison data, there was no significant increase in TCE levels in the monitoring wells surrounding the heated zone.

It is possible that mixing/displacement of the clean injected water (steam) and the native aquifer water would have contributed to dilution of dissolved groundwater constituents, including COCs. Therefore, in this demonstration, the observed decline in COC levels could not be conclusively attributed to HPO or other degradation processes (e.g., enhanced microbial activity). The sharp decline in chloride levels in the monitoring wells in the treatment zone is a potential indicator of such dilution. However, the temperature and dissolved oxygen measurements do indicate that conditions conducive to HPO were successfully generated in the treatment zone during this demonstration. The vendor also showed that steam could be injected and extracted from the same well to heat a target aquifer zone, thus expanding the modes of application of the steam

technology. The analytical results indicated that approximately 64 g of TCE were recovered in the vapor, while the change in groundwater concentrations within the heated radius only, indicate that 52 g of TCE were removed. Therefore, the extraction zone exceeded the thermally heated zone (to above 80 deg C, approximately 14 ft in radius and 15 ft in thickness).

A problem encountered during the demonstration was the drying out of the aquifer region immediately adjacent to the extraction well during pumping, especially when the aquifer contains tighter soils. It became necessary to turn off the pump overnight during the extraction cycle, so that the pump was not operating unsupervised. Although this does not appear to have caused any noticeable loss of hydraulic control, continuous 24-hour operation during the extraction stage is desirable and could be ensured at other sites, either by selecting suitable pumps or extracting at as slow a rate as possible.

It should be recognized that an intrinsic part of the design of this demonstration was the cyclic application of injection, soaking, and extraction. Three cycling applications were planned, and four were completed due to a major equipment problem encountered in the first cycle (1a). The inventors (LLNL) did not intend that this cyclic application be used in heavily contaminated source zones because of the release of hydraulic control, during the waiting or soaking period. Proper measures should be taken in such NAPL contamination environments to ensure hydraulic containment of contamination plumes, and unintended movements of NAPL to below or beyond the treatment areas. It will be emphasized that continuous extraction is really required for steam implementation in a highly contaminated zone, rather than the three-part steam injection, soak, extraction performed herein, due to discontinuation of heating and release of hydraulic controls (i.e., pumping) during the wait period. These were done to study a hypothesis and mechanism of hydrous pyrolysis oxidation (HPO), previously observed to account for contaminant losses and removals in the remediation of other NAPL plumes (being remediated with steam, but not in this TYPE of configuration). Note that the inventors envisioned that this type of single-well injection-extraction system primarily to plumes or to source zones that had previously been subjected to more aggressive thermal or other treatment.

In the light of some of the challenges faced during this demonstration, the following can be incorporated into future applications of this technology:

- ❑ The progressive cavity pump failed to extract steam during the first (shakedown) Cycle 1a. It had to be replaced with a suction pump that performed well. In the future, when a newly-designed system (such as this single-well injection-extraction system) is used for the first time, a shakedown test needs to be done off-site to verify that the equipment can do what it is supposed to be doing.
- ❑ Clays and silts could potentially be mobilized with the heating pressure. This may cause clogging of pores in some parts of the aquifer. Post-treatment slug tests and other hydraulic measurements should be conducted to evaluate this possibility.
- ❑ The modeling conducted for this demonstration design was for a single injection-extraction event, of media with a homogeneous (single-value) permeability, for which several values over a range of darcy values were assumed. In a scale-up technology

application, or even for a single-well application, the modeling simulations can encompass a more realistic stratigraphy (multiple permeabilities with depth and radial variation), and sequential steam applications and subsequent extractions, changing porosity, as DNAPL or contaminant is removed.

Table 8-5. Performance Criteria and Summary of Conclusions

Performance Criteria	Expected Performance (pretest)	Performance Confirmation Method	Added Methods	Results and Conclusions
1. In situ destruction of COCs by HPO	Statistically significant COC decrease within treatment zone	Groundwater sampling	Maps of groundwater compositional changes used to document reaction zone. Mass balance.	COC concentrations in the target area were reduced substantially, between 65 and 80% for <i>cis</i> -1,2-DCE, TCE, and PCE for a short period. For TCE, an estimated minimum of 64 g was removed from the dissolved plume within the extraction zone, as vapor. The groundwater mass balance showed that 52 g of TCE were removed from the 14 ft radius heated to at least 80 deg C. The criterion was met, that the technology is effective in reducing COC concentrations, but it could not be positively confirmed that HPO was the dominant mechanism because of other contributing factors, such as dilution.
2. Heat the soil around SI-01 by steam injection	Heat to 80°C or above	Temperature and ERT data	Energy balance calculations	Created a radius of heated zone of up to 20 ft, above ambient, with a 15 ft thickness, heating about 370 yd ³ . Confirmed temperature data from wells and VEA-5 within the heated zone. ERT profiles and Digitam™ data from VEA-1, -2, -3, and -4 supported the energy balance calculations that indicated that the steam did not heat the soil or groundwater more than 20 ft away from SI-01. This criterion was met 100%.
3. Maintain hydraulic control and prevent significant migration of COCs beyond the zone of effective HPO	Net extraction. Br recovery. No increases in COC concentrations in groundwater. No COC increases in soil gas. No dilution of conservative groundwater constituents.	Water balance, Br tracer study, groundwater sampling, chloride sampling	Net water volume estimation.	Did not extract more water than injected overall. COC monitoring showed no spreading. The fact that the post-treatment Br footprint was larger than the heated zone footprint indicates that some displacement/mixing with the surrounding groundwater occurred. The aborted Cycle 1a, in which steam was injected but not extracted, could be one reason for some loss of hydraulic control.

9. Economics

This section discusses the cost considerations involved in the application of DUS/HPO. Discussed in the following sections are cost reporting for the demonstration, and cost analysis including a cost comparison.

9.1 Cost Reporting

In this section, costs associated with the demonstration at Beale AFB are divided into three subcategories: startup costs, capital costs, and operating costs.

Startup costs include mobilization, including designing the system, site preparation, and a preliminary site investigation. The technology vendor (SES) designed the system, in cooperation with Battelle, including: modeling, drafting, and production of draft and final versions of the conceptual design. The costs associated with numerous telephone conference calls and meetings at the site are included in the startup costs. The site investigation included a CPT investigation to determine the nature and extent of VOC contamination in the groundwater and the best location for the demonstration.

Capital costs include installation, shakedown testing, and off-site process equipment fabrication and testing at the vendor's facility. Installation activities include filing of dig and drilling permits, purchase of monitoring well construction materials, renting equipment required for well boring and installation, and characterizing the wells and boring, including PID screening of soil cuttings and aquifer tests. On-site preparation costs consisted of the site preparation during surface construction (wellhead completion and surface piping runs), in addition to rental costs of process equipment prior to the construction. Off-site construction and testing costs were incurred during the construction and testing of process equipment (vapor skid and downhole pump).

Operating costs include: a transformer rental; labor for performance monitoring and daily operation (Battelle, an on-site technician, and SES); consumables and supplies; sampling and analyses (i.e., groundwater/process water, off-gas, and waste analyses); and waste disposal. Consumables and supplies that were purchased for this project include health and safety materials, and sampling materials. Because this technology creates extreme temperatures in the groundwater, safety materials to handle this hazard were purchased including face shields and high-temperature gloves. Sampling materials included Teflon[®] tubing and Viton[®] tubing, groundwater sample filters for cations (dissolved metals), and calibration solutions and gases. Other performance monitoring costs incurred by the technology vendor included equipment rental and subcontracted labor for ERT data collection and processing and rental of equipment for PID screening of vapor and liquid streams.

Other costs that were incurred by the project that are not fitted into another category are costs that were incurred by data reduction/reporting and by standby costs. There were three periods of inactivity during which costs that were necessarily incurred were imposed for administrative reasons:

- The period from 5/23/02 until 6/28/02, during which time final access arrangements to the site were made.
- The period from 6/29/02 until 10/07/02, during which a “stop work” order was in place pending contractual changes.

Table 9-1. Cost Tracking

Cost Category	Subcategory	Details	Cost
Startup Costs	Mobilization	Proposal/Work Plan	\$57,400
		SES – system design	\$20,150
	Site Characterization	CPT investigation/well installation	\$26,335
		Materials (sampling and health and safety)	\$3,650
		Groundwater analyses	\$2,600
		Waste analyses	\$1,600
		Battelle labor	\$72,550
Capital Costs	Installation	Surveyor	\$4,640
		Permits	\$835
		Materials (sampling and health and safety)	\$2,225
		Groundwater analyses	\$8,660
		Battelle – construction labor	\$32,250
		SES – construction/equipment mobilization	\$183,250
Operating Costs	Ancillary Equip. Rental	Transformer rental	\$7,700
	Supervision	Project management	\$9,800
	Operating Labor	Battelle O&M labor	\$48,500
		On-site labor	\$9,065
		Steam Tech O&M labor	\$64,150
	Consumables/Supplies	Health and safety and misc. materials	\$1,200
		Sampling materials	\$7,000
	Sampling and Analysis	Groundwater/process water analyses	\$18,600
		Off-gas analyses	\$5,000
		SES – performance monitoring	\$10,800
Waste analyses		\$7,600	
Offsite Disposal	Waste disposal	\$8,150	
Demobilization	Demob Costs	SES – demobilization	\$196,250
Other	Standby Costs	SES – standby	\$89,180
	Reporting	Final Report	\$20,550
		SES – reporting	\$11,250
Total Technology Costs:			\$930,160

- The period after completion of operations, during which rental equipment costs were incurred when the technology vendor was unable to demobilize from the site because of funding and personnel difficulties.

A total of approximately 360 yd³ of the aquifer was treated with the DUS/HPO technology. Concentrations of the target compounds were reduced by 65 to 80%, on average (cis-DCE to PCE) with an estimated 52 g of TCE removed from the dissolved plume within the 15 ft thickness reaction zone. The entire cost of the demonstration, including some costs that should not be considered technology costs, was \$2,584 per cubic yard.

9.2 Cost Analysis

There has been limited success with conventional technologies in achieving cost-effective and timely cleanup of groundwater contaminated with chlorinated solvents. A source zone reduction/removal technology including DUS/HPO generally involves a considerable up-front capital cost, but the remediation by the technology can be completed much quicker than a conventional technology (such as pump and treat), reducing long-term operating costs and overall project costs. Pump-and-treat systems also have initial capital requirements, but are relatively lower in up-front capital cost. The difficulty is that most pump-and-treat programs require decades of operation, increasing net present value (NPV) estimates, and reducing reliability of such estimates. In addition, downgradient aquifer quality may not be controlled by the pump-and-treat technology due to the residual contamination that will go under dissolution in the aquifer, which creates further contamination. Thus, most technical experts agree that pump-and-treat project timelines that extend beyond a few decades are likely to be little more than guesses.

The site conditions used for the cost estimate for DUS/HPO and pump and treat are shown in Table 9-2 and Table G-1 in Appendix G. Tables 9-3 and 9-4 list the capital investment costs and annual and periodic operating costs for both the DUS/HPO system and a pump-and-treat system, respectively, using a similar contamination condition as listed in Table 9-2, i.e., demonstration site condition, and by implementing the demonstration single well scale or radial influence in time series mode for the entire contamination zone.

A more detailed cost summary of capital investment for a pump-and-treat system is presented in Table G-2 in Appendix G. Because of the assumed concentration, it may require a catalytic oxidizer and air stripper before discharge into the atmosphere. Total estimated cost is

Table 9-2. Basis for DUS/HPO and Pump-and-Treat Cost Estimate

Parameter	Value
Number of wells	4
Soil type (in aquifer)	Gravel with silt, sand, and clay layers
Contaminant type	<10 mg/L TCE, <0.7 mg/L PCE
Contaminated area, radius of influence	Oval, 100 ft by 200 ft
Depth to groundwater	15 ft
Depth to base of groundwater contamination	45 ft

Expected treatment period (DUS/HPO using single well)	0.5 year
Expected treatment period (pump and treat using four wells)	30 years

Table 9-3. Capital and O&M Costs Projected for Operating a DUS/HPO System

Item	Description	Basis	Cost
<i>Startup Costs</i>			
Mobilization	Design plan, engineering, modeling	Data analysis of site characterization data; hydrogeologic modeling; engineering design; work plan	\$150,000
Site characterization	Field investigation, laboratory analyses	CPT pushes for geologic mapping and temporary wells; analyses of water samples for VOCs and chloride; slug tests	\$150,000
<i>Capital Costs</i>			
System construction	4 injection/extraction wells; process system construction and testing; equipment mobilization	DUS/HPO system construction	\$125,000
Performance monitoring construction	Thirty stainless-steel monitoring wells installed for monitoring plume movement and 8 soil-gas monitoring points	Installation of wells for aquifer monitoring	\$120,000
<i>Operating Costs</i>			
System operation	Per each single push-pull well event in series: Operate 3 cycles with first cycle –2 weeks steam injection, 1 week soak, and 1 week extraction. The other 2 cycles – 1 week injection, 1 week soak, and 1 week extraction	Labor, energy consumption, materials	\$900,000
Performance monitoring	30 wells during and after test (VOCs, chloride, water levels); 8 soil-gas monitoring points during each cycle; wastewater samples; data analysis and reporting	Labor, materials, analytical; reporting	\$170,000

approximately \$295,000 considering the size of the contaminated plume. The pump-and-treat system requires annual operation and monitoring before discharge at approximately \$50,000 and \$12,000, respectively. The system costs the site owner \$62,500 annually. In addition to the annual O&M costs, periodic maintenance may be necessary every five and ten years as summarized in Table 9-4 for the conventional technology.

Typically, present value (PV) or discounted cashflow analysis is used to determine the life-cycle cost of a technology. PV cost represents the amount of money that would have to be set aside today to cover all the capital investment and O&M costs occurring in the present and future. Table 9-5 and Table G-3 in Appendix G show the PV costs of the pump-and-treat system.

$$PV_{\text{technology}} = \text{Capital Investment} + PV_{\text{annual O\&M costs over life of the new technology}} \quad (9-1)$$

Table 9-4. Capital and O&M Costs Projected for Operating a Pump-and-Treat System

Item	Description	Basis	Cost
<i>Startup Costs</i>			
Mobilization	Design plan, engineering, modeling	Data analysis of site characterization data; hydrogeologic modeling; engineering design; work plan	\$70,400
Site characterization	Fieldwork, Laboratory analyses	CPT pushes for geologic mapping and temporary wells; analyses of water samples for VOCs and inorganics; slug tests	\$75,000
<i>Capital Costs</i>			
System construction	Installation of six 4-inch-diameter extraction wells; air stripper; catalytic oxidizer; polishing carbon; shed; piping	Groundwater extraction and treatment system	\$100,000
Performance monitoring construction	15 PVC aquifer wells installed for monitoring plume movement	Installation of PVC wells for aquifer monitoring	\$50,000
<i>Operating Costs</i>			
System operation	Keeping pump-and-treat system operational	Labor, energy consumption, materials	\$50,500
Performance monitoring	Quarterly, 15 wells (VOCs, inorganics, water levels) and monthly air stripper influent and effluent samples	Labor, materials, analytical	\$12,000
Annual Operating Cost			
<i>Maintenance (once every 10 years)</i>			
10-year periodic maintenance	Overhaul systems	Overhaul air stripper; catalytic oxidizer	\$104,500
<i>Maintenance (once every 5 years)</i>			
5-year periodic maintenance	Replace consumables	Replace pumps, air compressor, blower, catalyst replacement	\$76,000

Capital investment does not have to be discounted back to the present because this investment occurs up front (time t=0). The term $PV_{\text{annual O\&M costs over life of the new technology}}$ represents the annual O&M costs over several years of operation, adjusted for the time value of money. This adjustment is done by dividing each year's O&M costs by a factor that incorporates a discount rate (r),

as shown in Equations 9-2 and 9-3. The discount rate incorporates the combined effort of inflation, productivity, and risk. In other words, the discount rate accounts for the fact that any cost that is postponed into future years frees up money that can be put to productive use and provides a rate of return equal to the discount rate (r).

Table 9-5. PV Costs of a Pump-and-Treat System

Year	Pump-and-Treat		
	Annual Cost *	PV of Annual Cost	Cumulative PV of Annual Cost
0	\$294,846	\$294,846	\$294,846
1	\$62,015	\$60,267	\$355,113
2	\$62,015	\$58,569	\$413,682
3	\$62,015	\$56,918	\$470,600
4	\$62,015	\$55,314	\$525,914
5	\$76,070	\$65,938	\$591,852
6	\$62,015	\$52,240	\$644,092
7	\$62,015	\$50,768	\$694,859
8	\$62,015	\$49,337	\$744,197
9	\$62,015	\$47,947	\$792,143
10	\$104,405	\$78,445	\$870,588
11	\$62,015	\$45,282	\$915,871
12	\$62,015	\$44,006	\$959,877
13	\$62,015	\$42,766	\$1,002,642
14	\$62,015	\$41,561	\$1,044,203
15	\$76,070	\$49,543	\$1,093,746
16	\$62,015	\$39,251	\$1,132,997
17	\$62,015	\$38,145	\$1,171,142
18	\$62,015	\$37,070	\$1,208,211
19	\$62,015	\$36,025	\$1,244,236
20	\$104,405	\$58,940	\$1,303,177
21	\$62,015	\$34,023	\$1,337,200
22	\$62,015	\$33,064	\$1,370,264
23	\$62,015	\$32,132	\$1,402,396
24	\$62,015	\$31,227	\$1,433,623
25	\$76,070	\$37,224	\$1,470,848
26	\$62,015	\$29,491	\$1,500,339
27	\$62,015	\$28,660	\$1,528,999
28	\$62,015	\$27,853	\$1,556,852
29	\$62,015	\$27,068	\$1,583,920
30	\$104,405	\$44,285	\$1,628,205

*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

$$PV_{\text{annual O\&M costs}} = \sum \frac{\text{O \& M cost in Year } t}{(1+r)^t} \quad (9-2)$$

$$PV_{\text{annual O\&M costs}} = \frac{\text{O \& M cost in Year 1}}{(1+r)^1} + \frac{\text{O \& M cost in Year 2}}{(1+r)^2} + \dots + \frac{\text{O \& M cost in Year } n}{(1+r)^n} \quad (9-3)$$

As shown in Equation 9-3, O&M costs are incurred gradually over several years, so a smaller amount of money can be set aside today (for example, in a bank deposit that provides a rate of return (r) to cover future O&M costs). As time goes by, the denominator for the relevant t becomes greater, and the PV of that year's O&M cost becomes less, so fewer dollars have to be set aside today (in a separate investment that provides a rate of return (r) to cover the O&M costs of the future).

A total time period of 30 years (n = 30) is typically used for the long-term evaluation of pump-and-treat remediation costs. A real discount rate of 2.9% was used in the PV calculations. The long-term evaluation for the DUS/HPO technology using a single well may be more cost-effective compared to the pump-and-treat technology after the ninth year and thereafter.

In conclusion, although capital and startup costs for DUS/HPO typically are larger than for pump-and-treat alone, DUS/HPO is likely a more cost-effective technology for DNAPL cleanup in the long term because of the reduction of contaminants in time and operating costs. Pump-and-treat is a slow process requiring many years of operation before the contaminant is removed, because it is limited by extraction and treatment capacity. At many sites, pump-and-treat operations are simply used to control the spread of contaminants (source containment) with no realistic expectation of cleaning the site's contamination source area. In this way, pump and treat, even when used in conjunction with other technologies, invariably represents a long-term cost, and an associated long-term environmental liability.

10. Implementation Issues

10.1 Environmental Checklist

This section provides a brief description of the federal regulations that are potentially applicable to the implementation of the DUS/HPO demonstration project at Beale, AFB. The state of California regulations and local permitting requirements for the DUS/HPO system also are discussed.

10.1.1 Resource Conservation and Recovery Act and Title 22, Division 4.5 of the California Code of Regulations

The goal of Resource Conservation and Recovery Act (RCRA) is to regulate hazardous waste management activities. Solid wastes generated during the DUS/HPO project may be hazardous and therefore managed under the RCRA or state of California RCRA program. Solid wastes that may be generated include soil cuttings, spent GAC, and other solid wastes associated with monitoring (e.g., tubing, paper towels, etc.). Hazardous waste is defined as materials that contain those constituents listed in RCRA Subtitle C or materials that exhibit hazardous characteristics, including ignitability, corrosivity, reactivity, and toxicity. In addition to these rules, certain RCRA provisions will require corrective action when point-of-compliance wells at SWMUs are above the permitted groundwater protection standards. The corrective action requirements of RCRA are extensive and a complete discussion of the regulatory implications is beyond the scope of this work plan. The RCRA regulations are included in 40 Code of Federal Regulations (CFR) Parts 240-282.

The following is a list of potential responsibilities generated by RCRA requirements:

- Perform corrective action at out-of-compliance solid waste management units.
- Identify, characterize, and label hazardous waste.
- Manifest hazardous waste for off-site disposal.
- Maintain required records and documentation.
- Ensure that land disposal restrictions are followed.
- Ship wastes within mandated time limits.

The state of California “Environmental Health Standards for the Management of Hazardous Waste,” set forth in Title 22 California Code of Regulations [CCR], Division 4.5 (CCR Title 22, Division 4.5), were approved by the U.S. EPA as a component of the federally authorized state of California RCRA program. Therefore, the regulations of CCR Title 22, Division 4.5 are the source of RCRA-related federal regulations. A waste determined not to be a RCRA hazardous waste may still be considered a state-regulated, non-RCRA hazardous waste because the state is more stringent in determining its hazardous waste classifications. CCR Title 22, §66261.24(a) (2) lists the total threshold limit concentrations (TTLCs) and the soluble threshold limit concentrations (STLCs) for non-RCRA hazardous waste. The state

applies its own leaching procedure, the California Waste Extraction Test (WET), which uses a different acid reagent and has a different dilution factor (tenfold). In addition, other state requirements that may be broader in scope than the federal RCRA program and should be consulted include the solid waste classifications at CCR Title 27, § 20210, 20220, and 20230.

10.1.2 Clean Water Act

The Clean Water Act (CWA) sets surface water quality standards and permit requirements for the treatment and discharge of wastewater and stormwater. The CWA is applicable to this DUS/HPO remediation project because liquid wastes will be treated and disposed of via a sewer hookup or other method to the Beale AFB wastewater treatment facility. The base treats the combined water from surface water and general sewer water generated from normal activities.

The groundwater extracted during the DUS/HPO project did not require a permit to discharge into the base sewer line; however, it must meet the appropriate standards (Table 5-2) set by the CRWQCB Central Valley Region before discharge. Before sewer discharge, the analytical results from the treated water must be submitted to the base environmental engineer and CRWQCB. Then, the discharge should be approved by the appropriate base authority and the water board.

Liquid wastes generated at DUS/HPO sites included recovered groundwater, monitoring well purge water, decontamination water, and knock-out tank condensate from the vapor extraction system. The CWA regulations are included in 40 CFR Parts 100-136, 140, 230-233, 401-471, and 501-503. All federal, state, and local standards for discharges were followed.

10.1.3 Safe Drinking Water Act and the California Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) sets standards for the permissible level of contaminants in drinking water and establishes treatment standards for drinking water supply systems. If the affected groundwater at a site is a current or potential drinking water source, then the full-scale corrective action may have to meet MCLs or maximum contaminant level goals (MCLGs) for protection of the groundwater source. The SDWA regulations are included in 40 CFR Parts 141-149. However, because this project is a demonstration project, cleanup levels have not been defined and MCLs are more applicable to the full-scale corrective action.

The following is a list of potential responsibilities generated by SDWA requirements:

- Meet MCLs or MCLGs to protect groundwater source and achieve site closure.

In addition to the SDWA, the California Safe Drinking Water Act (California Health and Safety Code, Division 5, Part 1, Chapter 7) sets MCLs for drinking water. Some state MCLs can be more stringent than corresponding federal MCLs. The federal and state MCLs for TCE are both set at 5 µg/L.

10.1.4 Clean Air Act

The Clean Air Act (CAA) regulates point source and mobile source emissions and sets ambient air quality standards. For this DUS/HPO demonstration project, off-gas treatment will be required and will involve the control of VOC emissions via GAC adsorption from two process streams: (1) the vapor extraction system and (2) the water-holding tank. Several CAA requirements will be relevant to the operation of the GAC unit(s) and any discharges of regulated pollutants from these two points. If VOC emissions from the water-holding tank are below certain allowable limits, a certificate of exemption may be appropriate and the VOC off-gas from the tank may be directly discharged to the atmosphere. In addition, the boiler used to generate the steam for injection is fueled by natural gas and will therefore have emission limits for combustion-related pollutants (e.g., particulate matter, SO₂, NO_x, and carbon monoxide).

The permit to construct and operate the DUS/HPO system will be issued by the Feather River Air Quality Management District (AQMD). The Feather River AQMD is authorized to issue these permits and in doing so must make sure that the emission limits set by the permit comply with all local and state regulations, along with certain CAA provisions. Only Title I and Title III of CAA are likely to directly impact the DUS/HPO demonstration project. Title I of the Act requires states to identify areas that have not achieved National Ambient Air Quality Standards (NAAQS) for certain critical air pollutants. If the project is in a nonattainment area, it may be subject to additional emission control standards as outlined in the State Implementation Plan (SIP). Title III of the act specifies point source standards for hazardous air pollutants (HAPs). For all sources that emit HAPs, the U.S. EPA sets Maximum Achievable Control Technology (MACT) standards. The CAA regulations are included in 40 CFR Parts 50-99.

The following is a list of potential responsibilities generated by CAA requirements:

- Obtain the necessary permits for construction and operation of the remediation system (or the appropriate certificate of exemption).
- Maintain emissions of all regulated pollutants within permitted levels.
- Comply with State Implementation Plan requirements.
- Maintain all required records and documentation.

10.1.5 Occupational Safety and Health Administration Rules

The Occupational Safety and Health Administration (OSHA) requires that all work performed on a hazardous waste site be in compliance with a site-specific HASP as described in 29 CFR 1910.120. A site-specific HASP was prepared and attached in Appendix H. The site-specific HASP also includes all hazards associated with the site and remediation activities.

10.1.6 Other Selected Federal Regulations

Other federal regulations and executive orders that could apply to remediation projects under certain limited conditions include the Endangered Species Act (ESA), Executive Order Number 11988, Floodplain Management, Executive Order Number 11990, Protection of Wetlands, and the National Historic Preservation Act (NHPA). However, because the demonstration area for the DUS/HPO component installation is located at a developed industrial area (Transportation Yard) at the Beale AFB, any of the above federal laws or executive orders do not apply.

10.1.7 Other Selected State Regulations

Several other state regulations may apply to the administration of the DUS/HPO project, including the following:

- State Water Resources Control Board (SWRCB) Resolution 68-16, Policy with respect to maintaining high quality of waters in California (Water Code Section 13140) which requires that water quality remain protective of all beneficial uses and requires cleanup to backgroundwater quality or to lowest technically and economically feasible concentrations.
- California Title 23 (CCR, Division 3, Chapter 15, Article 5, Section 2550), which sets standards for corrective action of waste management units and establishes water quality protection standards and requires cleanup levels greater than background to be the lowest economically and technologically achievable.
- SWRCB Resolution 92-49, Policies and procedures for investigation and cleanup and abatement of discharges under Water Code Section 13304 (Water Code Section 13307), which establishes policies and procedures for the oversight of investigations and cleanup and abatement activities resulting from discharges of waste that affect or threaten water quality.

Because the DUS/HPO project is a demonstration project and not a full-scale corrective action, it is unlikely that the above regulations are directly applicable to project implementation. However, they could be considered relevant and appropriate.

10.1.8 Other Selected Local Regulations

Other local regulations that apply to the administration of the DUS/HPO project include soil boring/well installation permits. Beale AFB is located in Yuba County, CA, which requires permits for all subsurface installations. The steam injection/extraction well and all ground-water monitoring wells require a boring/well permit. In addition, the proper base authority should be notified prior to installation activities and base personnel should mark the location of all subsurface utilities prior to installation of the remediation system.

10.2 Permitting and Waste Disposal Issues

As discussed above, several permits will be needed for proper implementation of the DUS/HPO demonstration project. The permit required and corresponding issuing agency are summarized in Table 10-1. Additionally, waste generated during the DUS/HPO project must be handled in compliance with all appropriate federal, state, and local regulations. The waste generated was disposed of according to the guidelines listed above.

10.3 Other Regulatory and End-User Issues

No other outstanding regulatory issues have been identified at this time. Base personnel and the appropriate regulatory authorities were apprised of the progress of the demonstration project as needed. There is currently an additional push-pull operation planned at the same site with the Air Force's own funding, because the benefits from this demonstration are very useful to the further investigation and application in the dissolved contaminated plume. During the demonstration, the technology demonstration plan was presented to the members of the Remediation Advisory Board (RAB) meeting at the demonstration site. Other than federal and state regulatory agencies, no other public meetings are planned for the coordination of other public participation efforts. The technology transfer tools learned from this demonstration will be available through Naval Facilities Engineering Service Center (NFESC) and will be used to the full extent to promote a better understanding of the advantages and limitations associated with the implementation of DUS/HPO. The tools available for technology transfer include the NFESC Web page, technical abstracts and journal articles, and technology transfer newsletters and fact sheets.

Table 10-1. Permit Requirements

Type	Permits Required	Permit Agency	Comments
<i>During Site Preparation</i>			
Well Permits/Dig Permit/Utility Clearance	Yes	Yuba County/Beale AFB.	Not applicable
Fuel Supply/ hookup	No	Approved by Beale AFB.	Will be provided by Beale AFB
Water Supply	No	Approved by Beale AFB.	Will be provided by Beale AFB; maximum 50 gpm briefly, 5 gpm continuous at 60 psig
Power Supply	No	Approved by Beale AFB.	Will be provided by Beale AFB; 110V and 150 A, 3-phase 480 V
Gas Boiler	Yes	Submit a boiler application to Feather River AQMD (controlled by AP-42); (1) NO _x emission test, (2) test of Best Available Control Technology (BACT), which is available from manufacturer	For boiler: 2.5 × 10 ⁶ BTU/hr, ~2,500 lb/hr, 135°C, 30 psig For NO _x test: NO _x <25 lb/day at startup
Pure O ₂ Tank	No	No approval required.	5 cylinders (1,250 ft ³)
<i>During Treatment (Extracted Water)</i>			
Treated Water Discharge	No	Approved by Beale AFB upon results of water analysis of RCRA before discharge. Monthly progress report to Environmental Office at Beale AFB.	Up to 14,000 gal in a 3-day period.
Residual Liquid (well development and aquifer testing)	No	Approved by Beale AFB upon results of water analysis of RCRA before discharge. Monthly progress report to Environmental Office at Beale AFB.	505 ft ³ (3,763 gal)
Air Discharge from Boiler	Yes	Feather River AQMD; required for analysis of CO ₂ and NO _x .	NO _x <25 lb/day
Extracted Vapor Discharge	Yes	Feather River AQMD; daily for 3 weeks and weekly thereafter by a handheld monitoring unit.	216,000 scfm (maximum)
Water Holding Tank Air Discharge	Yes	Feather River AQMD.	To be determined. May be eligible for certificate of exemption.
<i>After Treatment</i>			
Extracted Groundwater	No	Approved by Beale AFB upon results of water analysis of RCRA before discharge. Monthly progress report to Environmental office at Beale AFB.	7,000 gal
Residual Liquid	No	Approved by Beale AFB upon results of water analysis of RCRA before discharge. Monthly progress report to Environmental Office at Beale AFB.	Not available

11. References

- Berkley Environmental Restoration Center. 2000. *Steam Enhanced Extraction Demonstration at Site 5, Alameda Point*. Field Feasibility Demonstration for the U.S. Navy, DO-9. University of California at Berkeley. Berkeley, CA.
- Bouwer, H., and R.C. Rice. 1976. "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Complete or Partially Penetrating Wells." *Water Resources Research*, 12, 423-428.
- Bouwer, H. 1989. "The Bouwer and Rice Slug Test – An Update." *Groundwater*, 27(3): 304-309.
- Daily, W.D., A.L. Ramirez, R.L. Newmark, K.S. Udell, H.M. Buettner, and R.D. Aines. 1995. Dynamic Underground Stripping: Steam and Electric Heating for In Situ Decontamination of Soils and Groundwater. U.S. Patent # 5,449,251.
- Heron, G., D. LaBrecque, D. Beadle, and H.J. Sowers. 2000. "Steam Stripping/Hydrous Pyrolysis Oxidation for In-Situ Remediation of a TCE DNAPL Spill." Presentation at the May 2000 Battelle Conference on Chlorinated and Recalcitrant Compounds, Monterey, CA. In proceedings volume C2-5, pp. 149-156.
- Hvorslev, M.J. 1951. *Time Lag and Soil Permeability in Groundwater Observations*. U.S. Army Corps of Engineers Waterways Experiment Station Bulletin 36. Vicksburg, Miss.
- Integrated Water Resources, Inc. 2001. "Field Demonstration of Steam Injection and Hydrous Pyrolysis Oxidation at the Savannah River Site, Aiken, South Carolina." Presentation at 2001 International Containment and Remediation Technology Conference and Exhibition, Orlando, FL, June 10-13.
- Knauss, K., R.D. Aines, M.J. Dibley, R.N. Leif, and D.A. Mew. 1997. *Hydrous Pyrolysis/Oxidation: In-Ground Thermal Destruction of Organic Contaminants*. UCRL-JC-126636, Lawrence Livermore National Laboratory, CA.
- Knauss, K., M. Dibley, R. Leif, D. Mew, and R. Aines. 1998. "Aqueous Oxidation of Trichloroethene (TCE): A Kinetic and Thermodynamic Analysis." Paper presented at the 1998 First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, May 18-21. LLNL Report #UCRL-JC-129932.

Leeson, A., P.C. Johnson, R.L. Johnson, R.E. Hinchee, and D.B. McWhorter. 2001. *DUS/HPO Design Paradigm*. Prepared for Battelle, Columbus, OH.

Newmark, R.L. et al. 1994. *Demonstration of Dynamic Underground Stripping at the LLNL Gasoline Spill Site*. Final Report UCRL-ID-116964, Vol. 1-4. Lawrence Livermore National Laboratory, Livermore, California.

Newmark, R.L., and R.D. Aines. 1997. *Dumping Pump and Treat: Rapid Cleanups Using Thermal Technology*. Lawrence Livermore National Laboratory Report UCRL-JC-126637, Livermore, California.

SES, see SteamTech Environmental Services.

SteamTech Environmental Services. 1999. *Steam Stripping and Hydrous Pyrolysis Pilot Project for the Portsmouth Gaseous Diffusion Plant, Portsmouth, Ohio*. Final report for DOE # DOE/OR/11-3032&D1.

SteamTech Environmental Services. 2000. *Steam Enhanced Remediation of the Port of Ridgefield Lake River Industrial Site (Former Pacific Wood Treating Facility): Conceptual Design and Schedule*.

Udell, K.S., and L. Stewart. 1989. *Field Study of In Situ Steam Injection and Vacuum Extraction for Recovery of Volatile Organic Solvents*. UCB-SEEHRL Report No. 89-2, University of California, Berkeley.

Udell, K.S. et al. 1991. U.S. Patent # 5,018,576.

Appendix A Points of Contact

Name	Organization Name/Address	Phone/Fax/E-mail	Role in Project
Andrea Leeson	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	(703) 696-2118, Phone (703) 696-2114, fax Andrea.Leeson@osd.mil	ESTCP Cleanup Program Manager
Charles Reeter	NFESC, Code ESC 414 1100 23rd Street Port Hueneme, CA 93043- 4370	(805) 982-4991, Phone (805) 982-4304, Fax charles.reeter@navy.mil	Navy Project Lead Manager
Kathy Greene Laura Yeh	NFESC, Code ESC 411 1100 23rd Street Port Hueneme, CA 93043- 4370	(805) 982-5284/1660, Phone (805) 982-4304, Fax	Navy Project Co- Managers
Marc Garcia	9 CES/CEV 6601 B Street Beale AFB, CA 95903-1708	(530) 634-2606, Phone (530) 634-2845, Fax Marcelo.Garcia@beale.af.mil	Beale AFB Environmental Engr. Site Owner
Celso Sabiniano	9 CES/CEV 6601 B Street Beale AFB, CA 95903-1708	(530) 634-2832, Phone (530) 634-2845, Fax Celso.Sabiniano@beale.af.mil	Beale AFB Environmental Engr. Site support
Roger Aines	Earth and Environmental Sciences L-219 LLNL Livermore, CA 94550	(925) 423-7184, phone (925) 422-0208, fax aines@llnl.gov	Technology Inventor
Robin Newmark	Earth and Environmental Sciences Directorate L-208 LLNL Livermore, CA 94550	(925) 423-3644, phone (925) 422-3925, fax newmark@llnl.gov	Technology Inventor
Arun Gavaskar	Battelle 505 King Ave. Columbus, OH 43201	(614) 424-3403, phone (614) 424-3667, fax Gavaskar@battelle.org	Co-Principal Investigator, Project Manager
Sam Yoon	Battelle 505 King Ave. Columbus, OH 43201	(614) 424-4569, phone (614) 458-4569, fax Yoon@battelle.org	Co-Principal Investigator, Deputy Project Manager
Steven Carroll	SteamTech 2761 Randolph Drive Reno, NV 89502	(775) 348-8189, phone (775) 826-6841, fax carroll@steamtech.com	Technology Licensee, Vendor-Project Manager
Gorm Heron	SteamTech 4750 Burr Street Bakersfield, CA 93308	(661) 322-6478, phone (661) 322-6552, fax heron@steamtech.com	Technology Licensee, Vendor-Technical Engineer

Coring LogsheetBoring ID BAT-1Date 4/18/01Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>32</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u>RMC 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>18</u> to <u>32</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>3</u> to <u>15</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>10</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>21</u> to <u>31</u> ft	Driller	<u>Precision Sampling</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Post hole dig- Red sandy clay, little gravel, fine (see photo)	0-5	NA	NA	-	-
No cores collected from 5-20. Wet at 8 ft	5-20	NA	NA	-	-
Lt brown silty clay, little sand, mottled, black organic specs, hard, med. plasticity 12-16-22	20-21.5	NS	CL	100	0
As above to soft clay, wet, to lt brown silty clay, mottled, black org. specs, hard 11-18-32	21.5-23	NS	CL	80	0
Silty clay with sand, soft, wet, to clayey med. sand, little gravel. loose to dense 8-12-26	23-24.5	NS	SC	100	0
Clayey coarse sand and fine gravel, trace gravel, subrounded, to sandy clay, mottled, stiff, to clayey sand, loose-dense to sandy clay, mottled, stiff 12-17-22	24.5-26	BAT-1 24.5-26	GC/ SC/CL	100	0
No recovery 10-14-17	26-27.5	NS	NA	-	-
Lt brown, clayey med. sand, trace fine gravel, subrounded, at bottom, wet 4-8-14	27.5-29	NS	SC	100	0
As above at top 3 inches to silty/sandy clay, mottled, black org. specs, hard, med plastic 8-9-14	29-31.5	NS	SC/ CL	100	0
Silty/sandy clay (less sand than above), mottled, black org. specs, hard, med. plasticity 4-8-12	30.5-32	NS	CL	25	0
End Coring					

Logged by: L. CummingCompletion Date: 4/18/01

Construction Notes: 18 inch sampler
0.2" ID, 140 lb hammer, bailed bore-
hole prior to setting well (~50 gallons)

Coring Logsheet

Boring ID BAT-2



Date 4/17/01

Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>35</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u>RMC 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>22</u> to <u>36</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>3</u> to <u>18.8</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>10</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>25</u> to <u>35</u> ft	Driller	<u>Precision Sampling</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Push augers to 20 ft prior to collecting cores. Caliche/hard pan layer observed @10-11 ft. Cuttings- red brown clay, silt, sand, gravel	0-10	NA	NA	-	-
Hit water ~ 10 ft	10-20	NA	NA	-	-
Lt brown sandy/silty clay, mottled, hard. Moist 38-50 for 5"	20-21.5	NS	CL	90	0
Lt brown sandy/silty clay, mottled, hard, black organic specs, moist (see photo) 24-74 for 5"	21.5-23	NS	CL	100	0
As above to m-c sand with silt and clay, loose, wet. 22-44-48	23-24.5	BAT-2-23-24.5	CL/SM	100	0.2
Lt. brown m-c sand, little silt and clay, little fine gravel, subangular to subrounded, loose, wet. 12-13-15	24.5-26	BAT-1 24.5-26	SP	50	0.1
As above to lt. brown fine gravel, subangular-subrounded, with sand and clay, wet, to silty/sandy clay, mottled.	26-27.5	NS	GM/SC	75	0
Lt brown, clayey gravel to sandy clay, mottled, trace fine gravel, to clayey fine gravel to silty/sandy clay, mottled	27.5-29	NS	GM/CL GC/CL	100	0
Lt. brown silty clay with medium to coarse sand to lt. brown silty clay, little med-coarse sand, hard, med plasticity 11-22-48	29-31.5	NS	CL	100	0
Lt. brown sandy clay, soft, wet, with lt. brown silty clay, little med-coarse sand to lt. brown clayey fine-med. sand 24-54-53	30.5-32	NS	CL/SC	100	0
Lt. brown clayey fine-med. sand to lt. brown silty clay with fine-med sand, hard, med. plasticity 7-28-39	32-33.5	NS	CL/SC	100	0

Logged by: L. Cumming

Completion Date: 4/18/01

Construction Notes: 18" split spoon sampler, no liner or sand catcher. Bailed ~50 gallons prior to setting well

Coring LogsheetBoring ID BAT-3Date 4/16/01Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>45.5</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u>RMC 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>31</u> to <u>44.5</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>3</u> to <u>29</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>10</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>34</u> to <u>44</u> ft	Driller	<u>Precision Sampling</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Hand augered with post hole digger 0-5 ft, gravel at surface, red sandy clay, little fine gravel	0-5	NA	NA	-	-
Red brown to red lt. brown clay and gravel with sand, stiff, dry 8-29->50	5-6.5	BAT-3-5-6.5	CL-GC	100	NA
Red to lt. brown clay with silt/sand, stiff, hard, dry 18-50	6.5-8	BAT-3-6.5-8	CL	80	0
Lt. brown sandy clay, hard, dry	8-9.5	BAT-3-8-9.5	CL	50	0.1
Lt. brown silty clay, little coarse sand, v stiff - hard, dry. Advance augers to 15 ft. 80 for 4 inches	9.5-11	BAT-3-9.5-11	CL	25	0.0
Lt. brown silty clay, mottled, little coarse sand, stiff, hard, dry to moist, black organic specs. 10-18-21	15-16.5	BAT-3-15-16.5	CL	75	0
As above 15-65 for 5"	16.5-18	BAT-3-16.5-18	CL	75	0
As above 13-21-48	18-19.5	BAT-3-18-19.5	CL	100	0
As above	19.5-21	BAT-3-19.5-21	CL	100	0
As above	21-22.5	BAT-3-21-22.5	CL	100	0
Lt. brown silty clay with fine sand, mottled, med. stiff to stiff, very moist 10-12-14	22.5-24	BAT-3-22.5-24	CL/SC	100	0

Logged by: L. CummingConstruction Notes: 18" split spoonCompletion Date: 4/17/01sampler, 0.2" ID, no liner or sand catcherForemost Mobile Rig. Pulled augers and then augered to depth to reduce amount of mud in hole prior to setting well.

Coring Logsheet

Boring ID BAT-3



Date 4/17/01

Location Beale AFB, CA

Lithologic Description	Depth	Sample	USCS	Well	Other
Lt. brown clayey coarse sand to fine gravel, trace coarse gravel, dense 10-12-14	24-25.5	BAT-3-24-25.5	SC	100	0
Lt. brown coarse sand with clay, trace gravel, moist 8-10-12	25.5-27	BAT-3-25.5-27	SC	100	0
Lt. brown coarse sand with clay, trace to little gravel, moist, wet 8-10-12	27-28.5	BAT-3-27-28.5	SC	100	0
Lt. brown clayey sand, moist to lt. brown silty clay, little sand, mottled, stiff, med. plasticity.	28.5-30	BAT-3-28.5-30	SC/CL	100	0
Lt. brown silty clay, mottled, hard	30-31.5	BAT-3-30-31.5	CL	100	0
As above to sandy clay/clayey f-m sand, trace coarse sand, med. Plasticity	31.5-33	BAT-3-31.5-33	CL/SC	100	0
Lt. brown sandy clay, med. stiff, to lt. brown clayey f - m sand, low plasticity to lt. brown sandy clay, med. Stiff	33-34.5	BAT-3-33-34.5	CL/S C/CL	100	0
Lt. brown sand and clay, med. stiff, moist, fine-med sand 11-22-46	34.5-36	BAT-3-34.5-36	SC/CL	100	0
Lt. grayish brown (less red than above) clay and fine to very coarse gravel, subangular, hard to stiff, moist 11-27-53	36-37.5	BAT-3-36-37.5	GC	100	0
Lt. gray-br, fine-coarse gravel with clay, subangular to subrounded, wet. 100 blows per 5 inches	37.5-39	BAT-3-37.5-39	GC	100	0
Lt. grayish brown fine to coarse gravel with clay, gravel up to 3 inch long, hard. 100 blows per 5 inches	39-41.5	BAT-3-39-41.5	GC	100	0
Push augers to pass cobbles.	40.5-43	NS	-	-	-
Lt. brown, fine to coarse gravel, with silt, sand and clay. Loose to dense. Bottom 4 inches siltstone, mottled, brown streaks. 17-54	43.5-45	BAT-3-43.5-45	GC	100	0
End Coring					

Coring LogsheetBoring ID BAT-4SDate 8/14/01Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>31</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u># 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>23</u> to <u>31</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>2</u> to <u>23</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>5</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>25</u> to <u>30</u> ft	Driller	<u>West Hazmat</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Rocky dark brown silty clay	0-5	---	CL	ctg	0
Red-brown silty clay	5-10	---	CL	ctg	0
Red-brown to tan silty clay and sand.	10-15	---	CL	ctg	0
Red-brown silty clay, moist	15-20	---	CL	ctg	0
Red-brown silty clay, moist, stiff	20-25	---	CL	ctg	0
Red-brown clay to red-brown silty coarse sand, wet (8-13-35)	25-26.5	BAT-4S-26.5	CL-SM	100	0
Stiff, mottled gray-red clay to silty-clayey medium sand, wet (12-8-41)	28-5-30	BAT-4S-30	CL-SM	100	0

Logged by: J. SminchakCompletion Date: 8/14/01**Construction Notes:**

1 ft sand sump, 2 ft of bentonite pellets between sand pack and grout, ~25 gallons of grout

Coring LogsheetBoring ID BAT-4DDate 8/14/01Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>41</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u># 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>33</u> to <u>41</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>2</u> to <u>33</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>5</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>35</u> to <u>40</u> ft	Driller	<u>West Hazmat</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Silty red-brown clay to tan sand, silt, and gravel (moist)	0-5	(SS)	CL-GC	100	0
Tan to red clayey silt (42/1.5')	5-10	(SS)	SM	100	0
Mottled tan to red-brown silty clay, moist (31/1.5')	10-15	(SS)	CL	100	0
Mottled tan to red-brown silty clay, stiff, moist (50/1.5')	15-20	(SS)	CL	100	0
Silty clayey coarse sand to clay, wet (29/1.5')	20-25	(SS)	SM-CL	100	0
Mottled silty clay and sand, tan to gray (41/1.5')	25-30	(SS)	SC	100	0
Silty red-brown sand to silty clay, wet, stiff (35/1.5)	30-35	(SS)	SC-CL	100	0
Silty red-brown sand and clay, wet (41/1.5')	35-36.5	BAT-5D-36.5	SC	100	0
Gravelly, silty sand, very wet, loose, poor recovery (38/1.5')	38.5-40	BAT-5D-40	SM-GM	5	0

Logged by: J. SminchakCompletion Date: 8/14/01

Construction Notes:

1 ft sand sump, 2 ft of bentonite pellets between sand pack and grout, ~40 gallons of grout

Coring Logsheet

Boring ID BAT-5S



Date 8/13/01

Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>31</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u># 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>23</u> to <u>31</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>2</u> to <u>23</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>5</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>25</u> to <u>30</u> ft	Driller	<u>West Hazmat</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Red-brown clayey silt, sand, and stones	0-5	---	SC-CL	ctg	0
Red-brown silty clay, dry.	5-10	---	CL	ctg	0
Red-brown silty clay, moist.	10-15	---	CL	ctg	0
Red-brown silty clay, moist	15-20	---	CL	ctg	0
Red-brown silty clay, some sand, moist, stiff	20-25	---	CL	ctg	0
Red-brown silty clay moist (10-20-30)	25-26.5	BAT-5S-26.5	CL	100	0
Mottled red black silty sand, moist (13-20-25)	28-5-30	BAT-5S-30	SM	100	0
Red-brown silty-clayey sand, moist to wet	30-31	---	SM	ctg	0
(water at 25'? slowly seeps in a depth)					

Logged by: J. Sminchak

Completion Date: 8/13/01

Construction Notes:

1 ft sand sump, 2 ft of bentonite pellets between sand pack and grout, ~25 gallons of grout

Coring LogsheetBoring ID BAT-5DDate 8/13/01Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>41</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u># 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>32</u> to <u>41</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>2</u> to <u>32</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>5</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>35</u> to <u>40</u> ft	Driller	<u>West Hazmat</u>

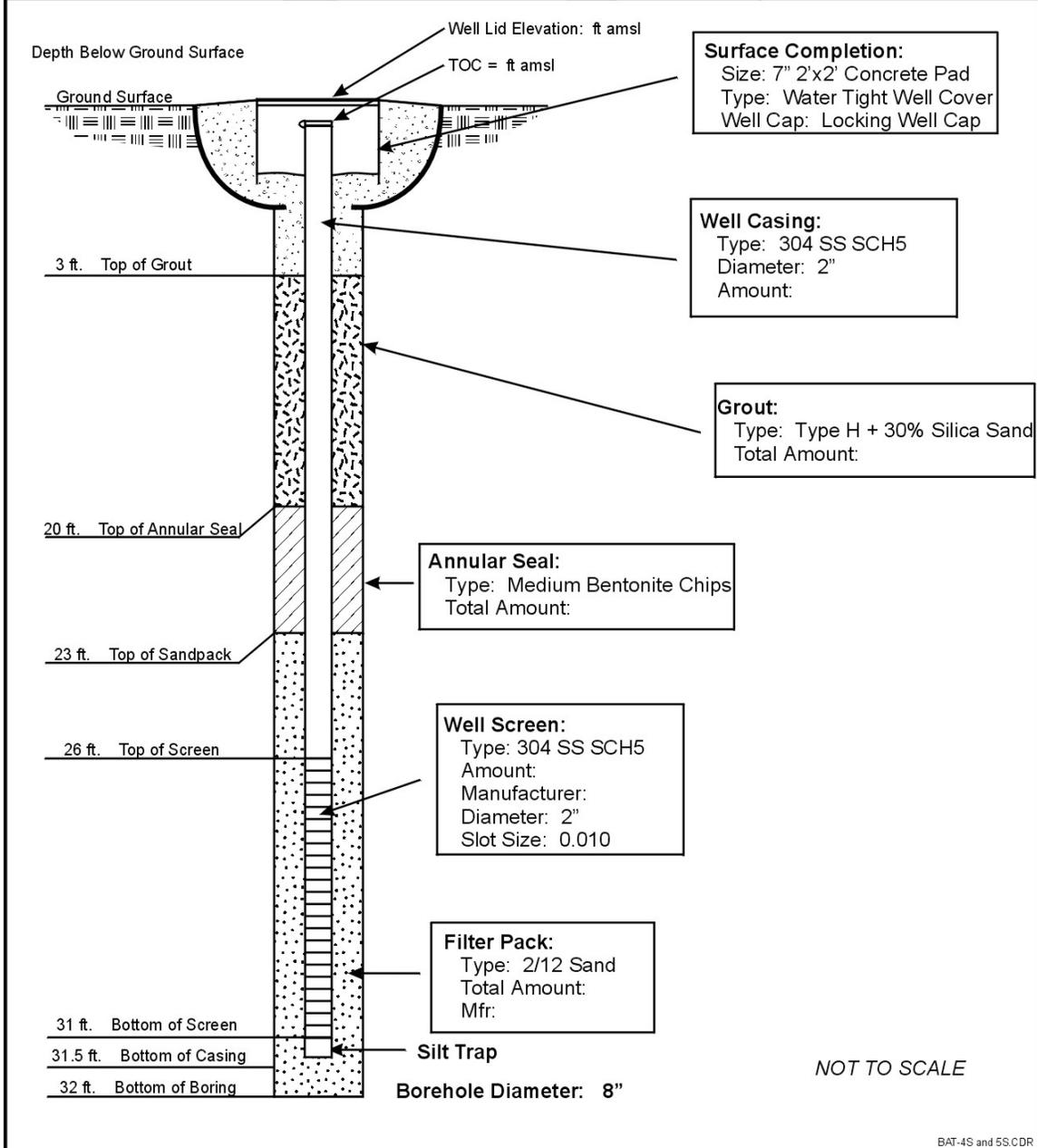
Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Rocky red-brown clayey silt, dry	0-5	---	SC	ctg	0
Red-brown silty clay, some sand/gravel, dry.	5-10	---	SC	ctg	0
Brown to red-brown sandy silt and clay, dry.	10-15	---	SM-CL	ctg	0
Red-brown silty clay, some sand, moist	15-20	---	CL	ctg	0
Red-brown silty clay, some sand, moist, stiff	20-25	---	CL	ctg	0
Red-brown silty clay to sandy silt, moist	25-30	---	SC-SM	ctg	0
Red-brown silty clay, some sand, mottled, moist-wet.	30-35	---	CL	ctg	0
Brown-tan silty, clayey fine sand, wet (12-20-30).	35-36.5	BAT-5D-36.5	SM	100	0
Brown tan silty fine sand, wet, some gravel (10-22-23).	38.5-40	BAT-5D-40	SC-GC	100	0
Brown-tan silty fine sand with some gravel.	40-41	---	SM-GC	ctg	0

Logged by: J. SminchakCompletion Date: 8/13/01**Construction Notes:**

1 ft sand sump, 2 ft of bentonite pellets between sand pack and grout, ~25 gallons of grout

WELL COMPLETION DIAGRAM

Project #: G469133-11	Site: Beale AFB SWMU 23	Well #: BAT-4S/5S	Northing (NAD 83):
Drilling Contractor: West HAZMAT	Rig Type and Drilling Method: HSA	Date: Aug 2001	Easting (NAD 83):
Reviewed by: Sam Yoon	Driller:	Hydrogeologist: Joel Sminchak	Surface Elevation (NAVD 88):



BAT-4S and 5S.CDR

WELL COMPLETION DIAGRAM

Project #: G469133-11	Site: Beale AFB SWMU 23	Well #: BAT-4D/5D	Northing (NAD 83):
Drilling Contractor: West HAZMAT	Rig Type and Drilling Method: HSA	Date: Aug 2001	Easting (NAD 83):
Reviewed by: Sam Yoon	Driller:	Hydrogeologist: Joel Sminchak	Surface Elevation (NAVD 88):

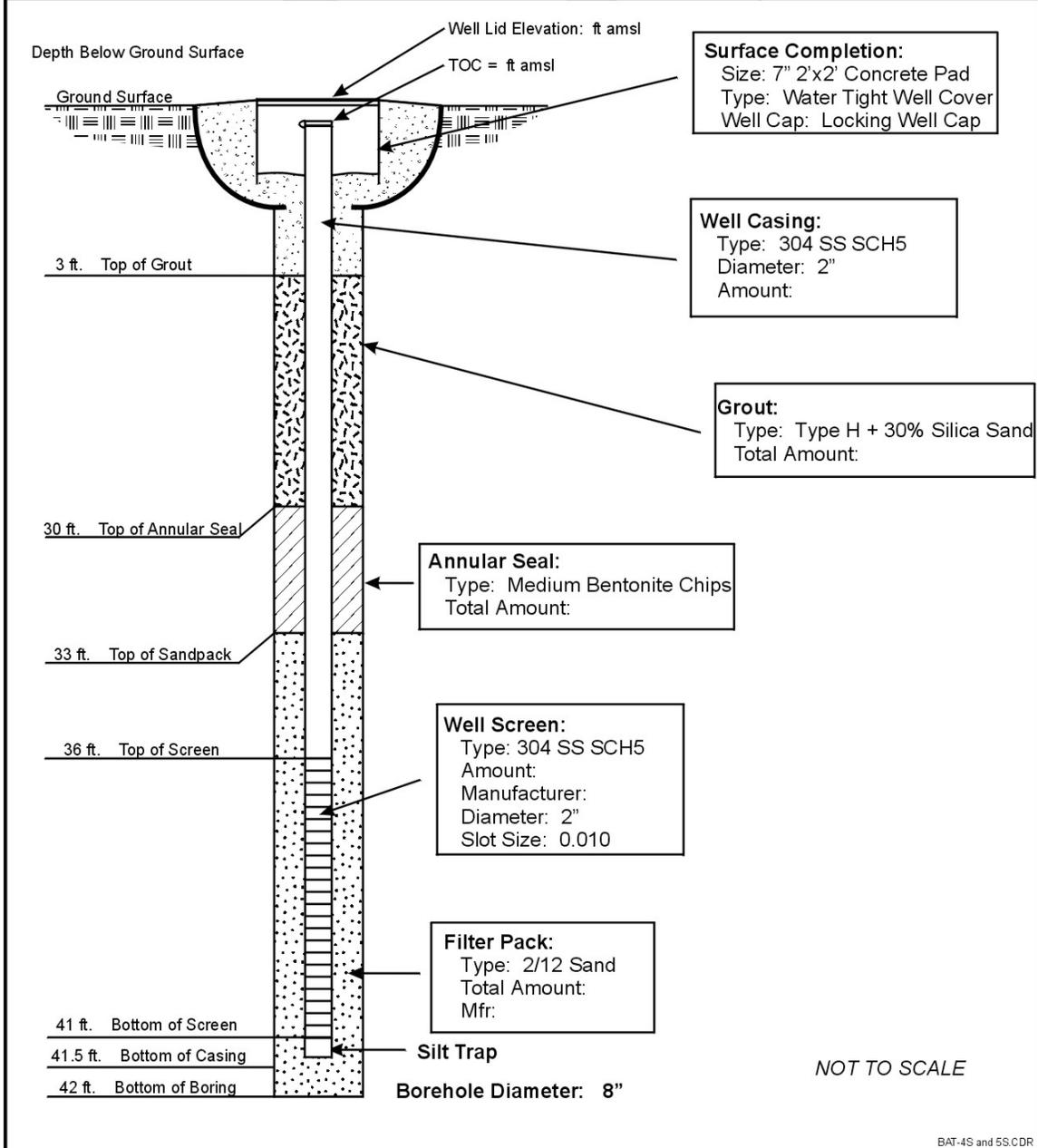


Table C-1. Results of Field Parameters in Groundwater

Well ID	Temperature (°C)									
	5/7/2002	5/8/2002	5/9/2002	5/10/2002	10/28/2002	11/4/2002	11/6/2002	12/2/2002	12/3/2002	12/3/2002
SI-1	22.8	21.8	NA	21.1	NA	NA	NA	57.0	53.1	53.9
BAT-6	23.1	22.2	NA	21.3	29.6	42.1	40.7	43.3	46.1	47.2
BAT-7	22.3	24.3	NA	21.5	23.2	22.7	21.7	27.4	26.3	26.7
BAT-8	23.0	22.5	NA	21.8	20.2	24.1	22.2	21.6	21.3	21.9
BAT-9	22.2	21.5	NA	21.7	34.4	51.6	46.4	45.2	46.2	34.1
BAT-10	21.8	22.8	NA	21.9	24.1	22.7	22.8	31.0	29.5	29.9
BAT-4S	22.3	20.4	NA	21.6	NA	NA	21.0	21.3	21.3	21.6
BAT-4D	21.5	20.4	NA	21.7	NA	NA	20.1	20.3	20.7	20.7
BAT-5S	22.8	22.4	NA	22.6	NA	NA	22.7	20.6	21.3	21.0
BAT-5D	22.8	23.1	NA	22.6	NA	NA	22.0	21.0	21.1	21.0
23L001MW	NA	24.0	26.3	NA	NA	NA	NA	NA	NA	NA

Well ID	DO (mg/L)									
	5/7/2002	5/8/2002	5/9/2002	5/10/2002	10/28/2002	11/4/2002	11/6/2002	12/2/2002	12/3/2002	12/4/2002
SI-1	0.00	0.00	NA	0.00	NA	NA	NA	2.26	4.87	3.95
BAT-6	0.00	0.00	NA	0.00	0.46	5.50	1.16	2.51	1.19	1.01
BAT-7	0.00	0.00	NA	0.00	1.12	0.00	0.00	2.28	4.25	1.17
BAT-8	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BAT-9	0.00	0.00	NA	0.00	0.22	2.63	1.25	3.51	3.98	2.03
BAT-10	0.00	0.01	NA	0.00	0.00	>8.0	>8.0	>8.0	>8.0	>8.0
BAT-4S	2.13	0.00	NA	0.00	NA	NA	2.62	0.80	0.39	0.51
BAT-4D	0.00	0.00	NA	0.00	NA	NA	0.00	2.36 (?)	0.00	0.00
BAT-5S	0.09	1.39	NA	0.13	NA	NA	0.00	0.00	0.00	0.00
BAT-5D	0.00	0.00	NA	0.00	NA	NA	0.00	0.00	0.00	0.00
23L001MW	NA	4.50	4.38	NA	NA	NA	NA	NA	NA	NA

Well ID	pH									
	5/7/2002	5/8/2002	5/9/2002	5/10/2002	10/28/2002	11/4/2002	11/6/2002	12/2/2002	12/3/2002	12/4/2002
SI-1	7.50	7.31	NA	7.04	NA	NA	NA	7.63	6.78	7.70
BAT-6	7.99	7.46	NA	7.65	6.92	6.66	6.78	6.73	6.69	6.78
BAT-7	9.60	9.45	NA	9.07	6.66	6.89	6.85	6.95	6.63	6.81
BAT-8	8.54	8.41	NA	8.25	7.88	8.00	7.82	7.86	7.57	7.69
BAT-9	8.48	7.45	NA	7.49	6.87	6.74	6.74	7.38	6.73	6.81
BAT-10	8.77	8.48	NA	8.21	6.88	6.87	6.81	6.66	6.60	6.75
BAT-4S	6.44	6.36	NA	6.31	NA	NA	6.30	5.93	6.06	6.31
BAT-4D	6.38	6.37	NA	6.33	NA	NA	6.32	6.16	6.06	6.32
BAT-5S	6.39	6.40	NA	6.32	NA	NA	6.40	6.11	6.06	6.31
BAT-5D	6.77	6.57	NA	6.49	NA	NA	6.66	6.46	6.24	6.43
23L001MW	NA	6.57	6.65	NA	NA	NA	NA	NA	NA	NA

Well ID	ORP (mV)									
	5/7/2002	5/8/2002	5/9/2002	5/10/2002	10/28/2002	11/4/2002	11/6/2002	12/2/2002	12/3/2002	12/4/2002
SI-1	359	351	NA	316	NA	NA	NA	29	39	19
BAT-6	343	349	NA	298	186	323	189	128	29	1
BAT-7	253	245	NA	226	260	193	193	132	54	-39
BAT-8	317	306	NA	276	202	141	121	12	-74	-93
BAT-9	324	343	NA	314	243	189	201	155	32	-27
BAT-10	304	303	NA	285	250	226	221	204	73	53
BAT-4S	390	387	NA	355	NA	NA	227	206	63	17
BAT-4D	467	367	NA	354	NA	NA	228	221	29	-5
BAT-5S	413	401	NA	361	NA	NA	212	147	44	6
BAT-5D	392	385	NA	348	NA	NA	202	93	5	-20
23L001MW	NA	389	369	NA	NA	NA	NA	NA	NA	NA

Table C-1. Results of Field Parameters in Groundwater (Continued)

Well ID	Conductivity (mS/m)									
	5/7/2002	5/8/2002	5/9/2002	5/10/2002	10/28/2002	11/4/2002	11/6/2002	12/2/2002	12/3/2002	12/4/2002
SI-1	41	42	NA	43	NA	NA	NA	58	55	65
BAT-6	56	56	NA	53	85	90	80	50	55	55
BAT-7	50	48	NA	43	64	66	67	62	67	68
BAT-8	43	43	NA	43	40	40	44	44	49	50
BAT-9	51	50	NA	47	74	60	58	45	48	48
BAT-10	39	39	NA	38	58	58	57	56	59	59
BAT-4S	46	47	NA	47	NA	NA	48	46	50	51
BAT-4D	44	46	NA	47	NA	NA	44	27	48	49
BAT-5S	48	48	NA	48	NA	NA	50	51	52	52
BAT-5D	52	52	NA	51	NA	NA	47	52	51	53
23L001MW	NA	43	42	NA	NA	NA	NA	NA	NA	NA

Yellow shading denotes that the measured level has changed significantly since the baseline.

DO readings from BAT-10 on Nov 4 and 6 may be elevated due to the excessive O₂ injected during the cycle 1b.

The excessive O₂ may be present near the depths of the monitoring well screen.

Table C-2. Results of Target CVOCs in Groundwater (Continued)

Well ID	<i>trans</i> -1,2-DCE (ug/L)										
	5/7/02	5/8/02	5/10/02	10/28/02	11/4/02	11/6/02	11/11/02	11/12/02	12/2/02	12/3/02	12/4/02
SI-1	<1.0	<1.0	<1.0	NA	NA	NA	NA	NA	<1.0	<1.0	<1.0
SI-1-DUP	NA	NA	<1.0	NA	NA	NA	NA	NA	NA	NA	NA
BAT-6	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	NA	NA	<1.0	<1.0	<1.0
BAT-6-DUP	<1.0	NA	NA	NA	NA	NA	NA	NA	<1.0	<1.0	NA
BAT-7	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	NA	NA	<1.0	<1.0	<1.0
BAT-7-DUP	NA	NA	NA	<1.0	NA	NA	NA	NA	NA	NA	NA
BAT-8	<1.0	<1.0	<1.0	<1.0	<1.0	0.21J	NA	NA	<1.0	<1.0	<1.0
BAT-9	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	NA	NA	<1.0	<1.0	<1.0
BAT-9-DUP	NA	NA	NA	NA	<1.0	NA	NA	NA	NA	NA	<1.0
BAT-10	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	NA	NA	<1.0	<1.0	<1.0
BAT-4S	<1.0	<1.0	<1.0	NA	NA	0.2J	NA	NA	0.22J	0.26J	0.20J
BAT-4S-DUP	NA	<1.0	NA	NA	NA	0.21J	NA	NA	NA	NA	NA
BAT-4D	0.2J	<1.0	<1.0	NA	NA	0.2J	NA	NA	0.21J	0.33J	0.24J
BAT-5S	<1.0	<1.0	<1.0	NA	NA	<1.0	NA	NA	<1.0	0.21J	<1.0
BAT-5D	<1.0	<1.0	<1.0	NA	NA	<1.0	NA	NA	<1.0	<1.0	<1.0
23L001MW	NA	<1.0	<1.0	NA	NA	NA	NA	NA	NA	NA	<1.0

Well ID	Vinyl Chloride										
	5/7/02	5/8/02	5/10/02	10/28/02	11/4/02	11/6/02	11/11/02	11/12/02	12/2/02	12/3/02	12/4/02
SI-1	<1.0	<1.0	<1.0	NA	NA	NA	NA	NA	<1.0	<1.0	<1.0
SI-1-DUP	NA	NA	<1.0	NA	NA	NA	NA	NA	NA	NA	NA
BAT-6	<1.0	<1.0	<1.0	NA	<1.0	<1.0	NA	NA	<1.0	<1.0	<1.0
BAT-6-DUP	<1.0	NA	NA	NA	NA	<1.0	NA	NA	<1.0	<1.0	NA
BAT-7	<1.0	<1.0	<1.0	NA	<1.0	NA	NA	NA	<1.0	<1.0	<1.0
BAT-7-DUP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BAT-8	<1.0	<1.0	<1.0	NA	<1.0	<1.0	NA	NA	<1.00	<1.0	<1.0
BAT-9	<1.0	<1.0	<1.0	NA	<1.0	<1.0	NA	NA	<1.00	<1.0	<1.0
BAT-9-DUP	NA	NA	NA	NA	<1.0	NA	NA	NA	NA	NA	<1.0
BAT-10	<1.0	<1.0	<1.0	NA	<1.0	<1.0	NA	NA	<1.0	<1.0	<1.0
BAT-4S	<1.0	<1.0	<1.0	NA	NA	<1.0	NA	NA	<1.00	<1.0	<1.0
BAT-4S-DUP	NA	<1.0	NA	NA	NA	<1.0	NA	NA	NA	NA	NA
BAT-4D	<1.0	<1.0	<1.0	NA	NA	<1.0	NA	NA	<1.0	<1.0	<1.0
BAT-5S	<1.0	<1.0	<1.0	NA	NA	<1.0	NA	NA	<1.0	<1.0	<1.0
BAT-5D	<1.0	<1.0	<1.0	NA	NA	<1.0	NA	NA	<1.0	<1.0	<1.0
23L001MW	NA	<1.0	<1.0	NA	NA	NA	NA	NA	NA	NA	<1.0

NA: Not available.

May-02 Baseline Monitoring	
10/28/02 Cycle 1A Injection	12/2/02 Post-monitoring 1
11/4/02 Cycle 1B Injection	12/3/02 Post-monitoring 2
11/6/02 Cycle 1 Extraction	12/4/02 Post-monitoring 3

Table C-3. Results of Inorganics in Groundwater (Continued)

Well ID	Manganese (ug/L)								
	5/7/02	5/8/02	5/10/02	10/28/02	11/4/02	11/6/02	12/2/02	12/3/02	12/4/02
SI-1	43.7	48.5	57.6	NA	NA	NA	<10	12	<10
SI-1-DUP	NA	NA	57	NA	NA	NA	NA	NA	NA
BAT-6	<10.0	15	<10.0	146	104	NA	10.4	<10	<10
BAT-6-DUP	<10.0	NA	NA	NA	NA	NA	NA	NA	NA
BAT-7	<10.0	<10.0	<10.0	20.3	23.3	19.1	20.6	18	20
BAT-7-DUP	NA	NA	NA	20.7	NA	NA	NA	NA	NA
BAT-8	<10.0	<10.0	<10.0	<10.0	<10	<10.0	<10.0	<10	<10
BAT-9	<10.0	<10.0	<10.0	61.4	18.2	13.9	28	31.2	35
BAT-9-DUP	NA	NA	NA	NA	19.9	NA	NA	NA	NA
BAT-10	<10.0	<10.0	<10.0	15.1	10.4	<10.0	14.7	14.1	14.6
BAT-4S	21.2	17.2	NA	15.1	NA	<10.0	<10	NA	NA
BAT-4S-DUP	NA	16.6	NA	NA	NA	<10.0	NA	NA	NA
BAT-4D	128	70.3	NA	NA	NA	94.5	59.8	NA	NA
BAT-5S	<10.0	<10.0	NA	NA	NA	25.7	<10	NA	NA
BAT-5D	145	97	NA	NA	NA	183	156	NA	NA
23L001MW	NA	NA	NA	NA	NA	NA	NA	NA	NA

Well ID	Methane (mg/L)								
	5/7/02	5/8/02	5/10/02	10/28/02	11/4/02	11/6/02	12/2/02	12/3/02	12/4/02
SI-1	0.00358	0.00412	0.00969	NA	NA	NA	<0.001	<0.001	<0.001
SI-1-DUP	NA	NA	0.00988	NA	NA	NA	NA	NA	NA
BAT-6	0.00416	0.0105	0.0168	0.0153	0.00277	<0.001	<0.001	<0.001	<0.001
BAT-6-DUP	0.00484	NA	NA	NA	NA	NA	NA	NA	NA
BAT-7	0.00768	0.0113	0.0136	0.00109	<0.001	<0.001	<0.001	<0.001	<0.001
BAT-7-DUP	NA	NA	NA	0.00525	NA	NA	NA	NA	NA
BAT-8	0.00138	0.00218	0.00186	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
BAT-9	0.0347	0.0341	0.039	0.00134	<0.001	NA	<0.001	<0.001	<0.001
BAT-9-DUP	NA	NA	NA	NA	<0.001	NA	NA	NA	NA
BAT-10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
BAT-4S	<0.001	<0.001	NA	NA	NA	0.00148	<0.001	NA	NA
BAT-4S-DUP	NA	<0.001	NA	NA	NA	<0.001	NA	NA	NA
BAT-4D	<0.001	<0.001	NA	NA	NA	<0.001	<0.001	NA	NA
BAT-5S	<0.001	<0.001	NA	NA	NA	<0.001	<0.001	NA	NA
BAT-5D	<0.001	<0.001	NA	NA	NA	<0.001	<0.001	NA	NA

Well ID	Alkalinity (mg/L)								
	5/7/02	5/8/02	5/10/02	10/28/02	11/4/02	11/6/02	12/2/02	12/3/02	12/4/02
SI-1	144	140	155	NA	NA	NA	74.6	73.1	83.2
SI-1-DUP	NA	NA	151	NA	NA	NA	NA	NA	NA
BAT-6	123	147	151	264	364	312	160	156	158
BAT-6-DUP	129	NA	NA	NA	NA	NA	NA	NA	NA
BAT-7	50.5	33.1	39.2	247	264	260	254	248	253
BAT-7-DUP	NA	NA	NA	257	NA	NA	NA	NA	NA
BAT-8	83.8	90.2	102	152	152	163	180	184	179
BAT-9	77.5	101	92.7	272	217	204	130	127	137
BAT-9-DUP	NA	NA	NA	NA	224	NA	NA	NA	NA
BAT-10	73.9	91.6	103	226	244	224	229	231	229
BAT-4S	170	178	NA	NA	NA	176	179	NA	NA
BAT-4S-DUP	NA	180	NA	NA	NA	176	NA	NA	NA
BAT-4D	168	171	NA	NA	NA	156	164	NA	NA
BAT-5S	181	185	NA	NA	NA	188	188	NA	NA
BAT-5D	207	201	NA	NA	NA	177	194	NA	NA

Table C-3. Results of Inorganics in Groundwater (Continued)

Well ID	TDS (mg/L)				TOC (mg/L)		
	5/7/02	5/8/02	5/10/02	12/2/02	5/7/02	5/8/02	12/2/02
SI-1	262	295	291	453	<5.0	<5.0	6
SI-1-DUP	NA	NA	311	NA	NA	NA	NA
BAT-6	345	360	340	374	<5.0	<5.0	1.3
BAT-6-DUP	355	NA	NA	NA	<5.0	NA	NA
BAT-7	290	273	266	433	<5.0	<5.0	1.2
BAT-7-DUP	NA	NA	NA	NA	NA	NA	NA
BAT-8	288	285	310	295	<5.0	<5.0	1.7
BAT-9	331	327	295	338	<5.0	<5.0	3
BAT-9-DUP	NA	NA	NA	NA	NA	NA	NA
BAT-10	276	270	262	376	<5.0	<5.0	2.1
BAT-4S	311	338	NA	298	<5.0	<5.0	1
BAT-4S-DUP	NA	332	NA	NA	NA	<5.0	NA
BAT-4D	297	360	NA	284	<5.0	<5.0	2.3
BAT-5S	309	343	NA	316	<5.0	<5.0	<1
BAT-5D	348	349	NA	310	<5.0	<5.0	<1

NA: Not available.

Table C-4. Results of Bromide Tracer Test from L-1

	Sample Date & Time	Cum. Time (min)	Br (mg/L)	Extraction Volume (gals)
L-1-005-0075	11/18/02 16:30	0	450	75
L-1-010-0144	11/18/02 17:00	30	900	144
L-1-015-0174	11/18/02 17:30	60	772	174
L-1-020-0190	11/18/02 18:00	90	742	190
L-1-025-0215	11/18/02 18:30	120	709	215
L-1-030-0251	11/18/02 19:00	150	650	251
L-1-035-0271	11/18/02 19:30	180	648	271
L-1-040-0320	11/18/02 18:00	90	601	320
L-1-045-0366	11/19/02 10:30	1080	566	366
L-1-050-0440	11/19/02 11:00	1110	427	440
L-1-055-0490	11/19/02 11:30	1140	394	490
L-1-060-0530	11/19/02 12:00	1170	362	530
L-1-068-0570	11/19/02 12:50	1220	326	570
L-1-075-0610	11/19/02 13:30	1260	302	610
L-1-087-0690	11/19/02 14:40	1330	274	690
L-1-093-0750	11/19/02 15:20	1370	258	750
L-1-105-0810	11/19/02 16:30	1440	237	810
L-1-117-0870	11/19/02 17:40	1510	214	870
L-1-130-0930	11/19/02 19:00	1590	203	930
L-1-140-1000	11/20/02 8:00	2370	186	1000
L-1-158-1100	11/20/02 9:15	2445	172	1100
L-1-170-1200	11/20/02 10:30	2520	137	1200
L-1-184-1300	11/20/02 11:55	2605	132	1300
L-1-195-1400	11/20/02 13:00	2670	121	1400
L-1-213-1500	11/20/02 14:50	2780	99.6	1500
L-1-225-1600	11/20/02 16:00	2850	98.7	1600
L-1-243-1700	11/20/02 17:50	2960	96.7	1700
L-1-260-1800	11/20/02 19:30	3060	96	1800
L-1-277-1900	11/20/02 21:10	3160	90.2	1900
L-1-800-3000	11/20/02 21:50	3200	98.8	3000
L-1-900-4000	11/20/02 22:00	3210	92	4000

Bromide Tracer Test

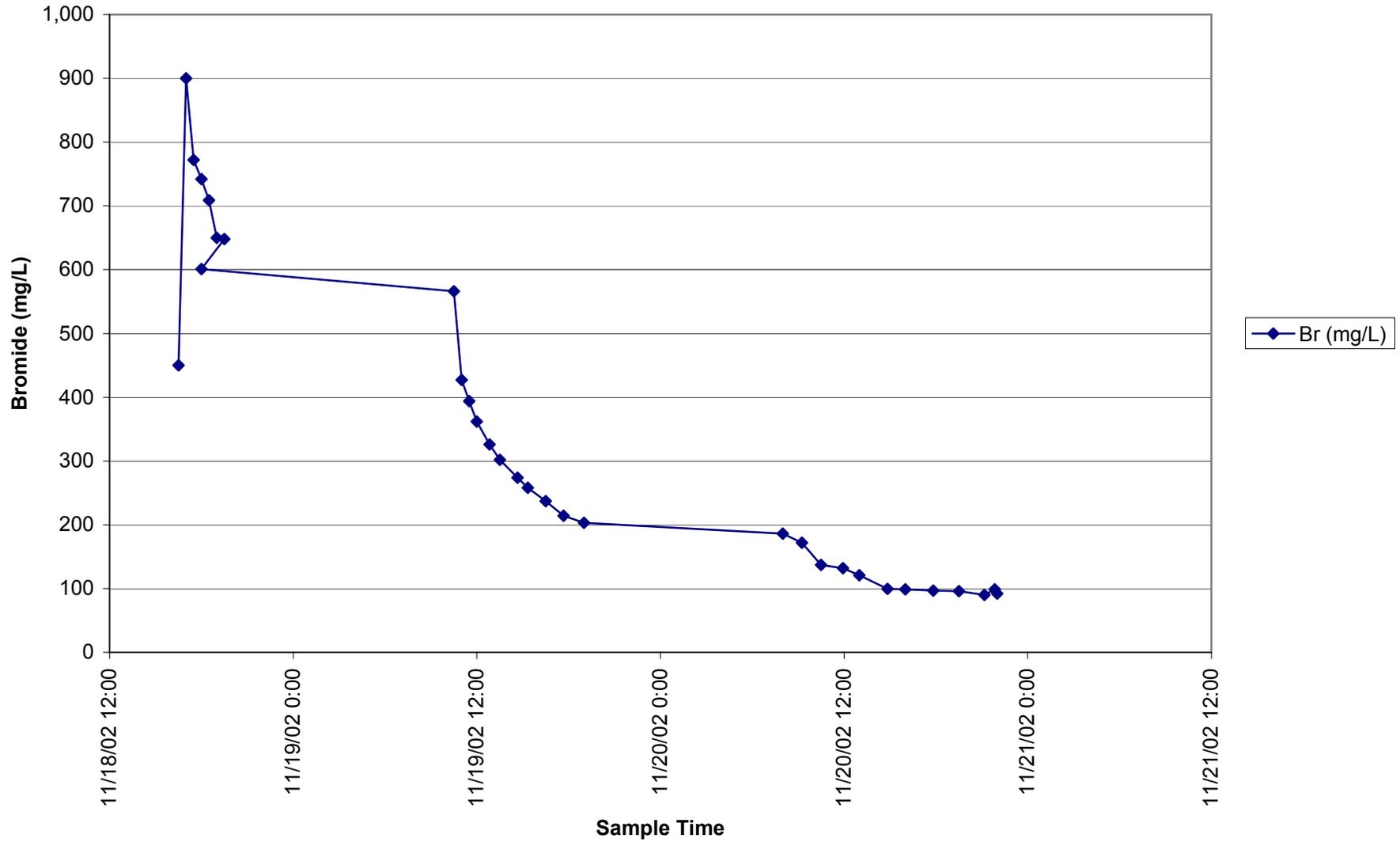


Figure C-1. Bromide Tracer Test Results



STEAMTECH
ENVIRONMENTAL SERVICES, INC.

4750 BURR STREET
BAKERSFIELD, CA 93308
661.322.6478 • FAX: 661.322.6552
Website: www.steamtech.com

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Modeling in Support of the Beale AFB DUS/HPO Study

Steamtech made estimates of the steam flow and radius of influence for the DUS/HPO treatability study at Beale AFB. The objective was to use existing site information to calculate appropriate equipment sizes, and to provide an estimate for the size of the footprint affected by the test. A special objective was to ensure that the subsurface volume covered by the monitoring program was sufficiently large, such that the risk of migration of fluids outside of the test zone can be evaluated and any migration controlled.

The steam simulator models used are published and calibrated to several field sites (Heron et al. 2000). It is a modified Marx-Langenheim simulator (used in enhanced oil recovery for 30+ years coupled to a solution of the governing pressure equation for a single injection well. The same simulator was used successfully to predict steam and hot water rates and radii of influence for the following projects:

- Alameda Point, CA (BERC, 2000).
- Portsmouth, OH (SteamTech, 1999).
- Sunbeam, TN (SteamTech, unpublished).

In addition, the same simulator was used as a design tool for the following sites:

- McCormick-Baxter in Stockton, CA (USACE).
- Wyckoff-Eagle Harbor, Seattle, WA (USACE).
- Guadalupe Sand Dunes, Guadalupe, CA (SteamTech).
- Port of Ridgefield, Vancouver, WA (SteamTech, 2000).

For the Beale project, the achievable steam injection rates for the injection well were estimated for 5 scenarios using the input parameters listed in Table 1 (these are based on general site information), and calculation results are given in Figure 1 (calculated steam zone radius for the first cycle) and 2 (achieved steam injection rate for the first cycle).

Figures 1 and 2 show the importance of intrinsic permeability for the achievable steam injection rate and radius estimated for a well screened from 25 to 40 ft below grade, assuming that the steam zone becomes 15 ft thick and the maximum injection pressure is 20 psig. The intrinsic permeability was varied from 0.1 to 5 darcy (10^{-13} to 5×10^{-12} m²). It is apparent that the permeability controls the injection rate and therefore also the radius of influence for the injection well.

In conclusion, it was decided that a steam generator sized for a maximum steam production rate in the 2,000 lbs/hr range was acceptable. Actual injection rates are expected to be substantially lower than this.

Data from nearby wells indicate that the intrinsic permeability is in the 1 darcy range. Therefore, Steam Tech calculated the following best-guess radii of influence for each of the projected injection cycles:

- Cycle 1. 10 ft steam zone, 14 ft hot water zone.
- Cycle 2. 14 ft steam zone, 17 ft hot water zone.
- Cycle 3. 16 ft steam zone, 20 ft hot water zone.
- Cycle 4. 18 ft steam zone, 22 ft hot water zone.
- Cycle 5. 20 ft steam zone, 25 ft hot water zone.

It was concluded that a reasonable monitoring zone would extend about 20 to 30 ft around the injection-extraction well.

It should be noted that these estimates are preliminary, and that the actual steam and hot water zones may not follow such simplified numbers. The method used to ensure that steam and hot condensate will not escape the site during the operational cycles are the following:

- In-situ monitoring of temperature (using thermocouples) and electrical resistivity (using Electrical Resistivity Tomography) in an area larger than the expected heated zone. This monitoring would detect any hot water or steam migration outside of the predicted zone. Detection of hot water migration out of the test area would lead us to extract more aggressively until the impact was under control.
- Successive cycles for which we will extract more water than we injected in the injection cycles. This will be documented based on flow rates and volumes of steam injected, water and vapor extracted, and the separation of heated fluids in the treatment system.

In conclusion, the size of the impacted area will be tightly monitored and controlled, so that heated fluids do not escape the test area.

Reference

- BERC (2000). Steam Enhanced Extraction Demonstration at Site 5, Alameda Point. Field Feasibility Demonstration for the US Navy, DO-9. Berkeley Environmental Restoration Center, University of California at Berkeley. Berkeley, CA. Final report in preparation.
- Heron, T.; Heron, G.; Udell, K.S. (2000): Tools for designing Steam Enhanced Remediation Systems. Presentation at the May 2000 Battelle Conference on Chlorinated and Recalcitrant Compounds, Monterey, CA.

SteamTech Environmental Services (1999): Steam Stripping and Hydrous Pyrolysis Pilot Project for the Portsmouth Gaseous Diffusion Plant, Portsmouth, Ohio. Final report for DOE # DOE/OR/11-3032&D1.

SteamTech Environmental Services (2000): Steam Enhanced Remediation of the Port of Ridgefield Lake River Industrial Site (Former Pacific Wood Treating Facility): Conceptual Design and Schedule.

Table 1. Input parameters for the steam injection rate estimates.

Parameter	Symbol	Unit	Value	Range
Thickness of steamed layer	h	m	4.5	
Density of soil	d_s	kg/m^3	2650	
Porosity of steamed layer	ρ		0.35	
Absolute permeability of soil	k_s	m^2	1E-12	0.1 to 5 times this value
Heat capacity of soil	c_{pr}	J/(kg K)	1152	
Initial water saturation	S_w		1	
Ambient pressure in aquifer	P_{amb}	Pa	116150	
Density of water	d_w	kg/m^3	1000	
Ambient water temperature	T_{amb}	K	288	
Heat capacity of water	c_{pw}	J/(kg K)	4187	
Overall heat capacity	c_{psw}	J/(kg K)	2200	
Overburden thermal conductivity	k	J/(s m K)	1.3	
Overburden thermal diffusivity	a	m^2/s	0.00000018	
Radius of injection well	r_w	m	0.05	
Maximum steam injection pressure	P_w	Pa	204061	
Relative permeability of steam	k_{rs}		1	
Steam viscosity	μ_s	kg/(m s)	1.30E-05	
Temperature of steam	T_s	K	394	
Delta T	$T_s - T_{amb}$	K	106	
Heat of condensation	λ_h	J/kg	2666000	
Time since start of injection	t	s		
Steam mass flow rate	\dot{m}	kg/s		
Volume of steam zone	V	m^3		
Gas constant	R	J/(mole K)	8.314	
Initial radius of steam zone	r_{si}	m	0.0525	
Mole mass of water	M_w	kg/mole	0.018	
Density of steam	d_{steam}	kg/m^3	1.1	
Depth to top of injection screen	$D_{inj,scr.}$	m.b.g	7.5	
Length of injection screen	$L_{inj,screen}$	m	4.5	
Aquifer hydraulic head	D_{gwt}	m.b.g	6	

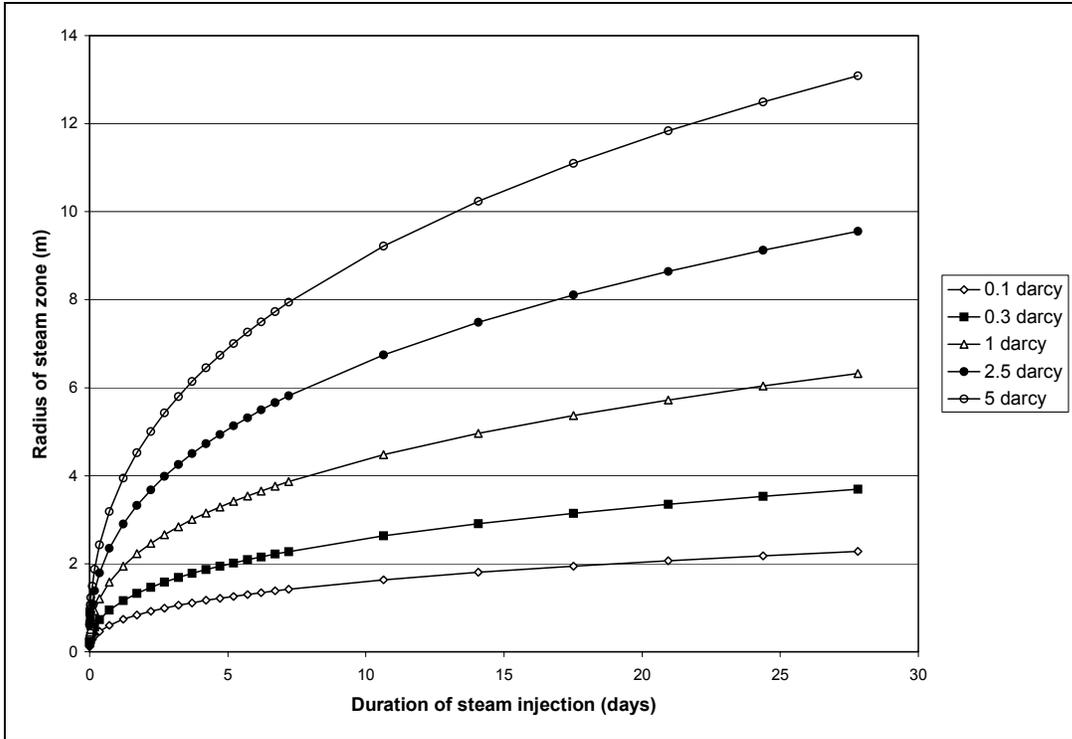


Figure 1. Calculated steam zone radius for the first injection cycle for 5 different values of intrinsic permeability.

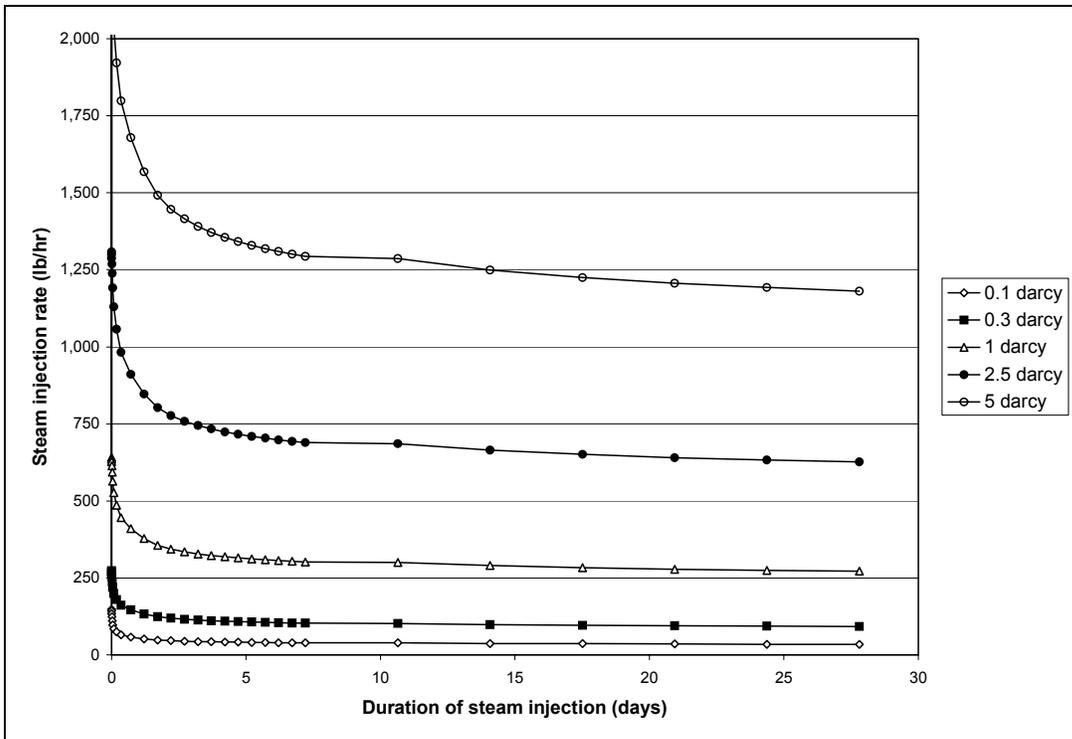


Figure 2. Calculated steam injection rates for the first injection cycle for 5 different values of intrinsic permeability.

Table E-1. Temperature Monitoring Data from VEA-1

VEA-1	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
10/22/2002	19.6	18.9	20.5	19.4	20.1	25	23	24.5	23.3
10/23/2002	20.2	19.5	18.9	19.5	19.5	21.3	23.6	24.5	22.1
10/24/2002 8:00	18.8	18.7	19	19.2	19.3	20.5	22.3	23.9	21.9
10/24/2002 16:00	19.5	19.4	19.5	19.5	19.9	24.5	22.9	24.7	22.3
10/25/2002 16:00	21.4	21.2	21.1	20	22.3	23	23.9	24.3	24
10/28/2002 8:00	17.5	17.9	18.3	18.4	19.1	20	21.3	23.1	20.5
10/30/2002 10:00	19.3	19.6	19.7	19.4	20	21.2	22.5	24.3	20.6
10/31/2002 17:30	19.4	19.6	19.5	19.6	20.1	21.3	23.1	23.8	20.8
10/28/2002 8:00	17.5	17.9	18.3	18.4	19.1	20	21.3	23.1	20.5
10/30/2002 10:00	19.3	19.6	19.7	19.4	20	21.2	22.5	24.3	20.6
10/31/2002 17:30	19.4	19.6	19.5	19.6	20.1	21.3	23.1	23.8	20.8
11/1/2002 16:30	19.8	19.7	19.6	19.8	20.4	21.6	23.1	24.2	21
11/4/2002 13:30	19.9	19.7	19.9	19.8	20.5	21.1	23.3	23.7	19.8
11/5/2002 13:00	18.6	18.7	18.6	18.6	19.4	19.9	22	22.5	18.8
11/6/2002 14:00	19.6	19.8	19.7	20	20.6	21.3	22.9	23.6	19.6
11/8/2002 13:35	19.2	18.9	19.2	18.9	19.8	20.9	22.4	22.7	18.8
11/9/2002 10:20	18.6	18.7	18.6	18.8	19.2	20.4	22.1	22.6	18.2
11/11/2002 13:00	18.8	18.3	18.3	18.8	19.1	20.3	21.7	22.1	17.4
11/12/2002 11:45	18.2	18.5	18.3	18.3	19.1	19.6	20.9	21.7	16.8
11/13/2002 17:30	19.3	19.1	19.6	19.6	20.1	21	23	22.7	18.8
11/14/2002 15:40	19.1	19.5	19.5	19.4	20	21.2	22.3	22.1	17.5
11/18/2002 13:00	18.8	18.4	19.1	19.2	19.8	20.8	22.3	21.3	16.4

Table E-2. Temperature Monitoring Data from VEA-2

VEA-2	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
10/22/2002	19.4	19.7	18.7	19.5	20.8	20.2	22.8	24.4	22.8
10/23/2002	19.3	19.6	19	19.5	19.6	21	22.3	23.6	23
10/24/2002 8:00	18.7	18.7	18.7	18.6	19	19.8	21.6	23.4	22
10/24/2002 16:00	19	19.3	19.4	19.6	19.9	20.6	22.4	24	22.7
10/25/2002 16:00	20.5	20.1	20.6	20.5	20.6	21.3	23.2	25	22.9
10/28/2002 8:00	16.6	17.3	17.1	17.2	18.2	18.7	20.5	22.1	19.6
10/30/2002 10:00	19.5	19.2	19.2	19.1	19.5	20.5	22.1	23.5	21
10/31/2002 17:30	19.2	19.6	19.4	19.4	18.8	20.4	21.9	23.3	20.4
11/1/2002 16:30	19.9	19.9	19.7	19.8	20.2	21.2	22.6	23.8	21
11/4/2002 13:30	19.3	18.4	18.9	19	19	20.9	21.3	21.8	19.2
11/5/2002 13:00	18.7	18.7	19	18.8	18.9	20.1	21.5	22.7	18.8
11/6/2002 14:00	18.9	19.1	18.9	19.2	19.4	20.6	22.2	22.9	18.9
11/8/2002 14:00	18.8	18.8	18.8	19	19.2	20.4	21.6	21.9	17.9
11/9/2002 10:20	18.5	18.9	18.1	18.9	19.1	19.9	21.9	22.2	17.9
11/11/2002 13:00	18.7	18.7	18.1	18.9	19.1	19.7	21.4	21.1	16.9
11/12/2002 11:45	18.4	18.3	18.2	18.5	18.8	19.7	20.9	20.9	16.6
11/13/2002 17:30	19	18.8	18.5	18.8	19.1	20.2	21.4	21.3	17
11/14/2002 15:40	19.2	19	19.4	19.4	19.5	21	22.1	21.9	17.5
11/18/2002 13:00	19.2	18.9	18.8	19.3	19.6	20.3	21.3	20.6	16.1

Table E-3. Temperature Monitoring Data from VEA-3

VEA-3	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
10/22/2002	19	19.3	19.4	18.9	19.7	21.5	23	23.8	22.5
10/23/2002	19.2	19.1	19.5	19.2	18.9	20.4	23.1	24.6	21.6
10/24/2002 8:00	18.7	18.8	18.7	18.7	19.3	20.4	22.2	23.7	21.5
10/24/2002 16:00	18.8	18.7	18.8	18.8	19.4	20.5	22.2	23.7	21.5
10/25/2002 16:00	19.8	19.9	19.9	20.4	20.7	22.5	23.6	24.9	22.1
10/28/2002 8:00	17.6	17.6	17.6	17.5	17.6	18.8	21.2	22.4	19.1
10/30/2002 10:00	18.1	18.1	18.2	18	18.7	19.8	21.5	22.7	19.1
10/31/2002 17:30	19.5	19.4	19.1	19.7	20.1	21.5	22.6	23.8	20.3
11/1/2002 16:30	19.5	19.2	19.4	19.1	20.1	20.9	22.7	23.8	19.6
11/4/2002 13:30	18.7	18.7	18.8	19.2	19.3	20.7	21.8	22.7	18.7
11/5/2002 13:00	18.3	19	19.3	19.3	19.5	20.9	22.6	23.1	18.6
11/6/2002 14:00	18.4	18.8	18.8	18.7	19.6	20.7	22.1	22.5	17.9
11/8/2002 14:00	18.8	19.3	18.6	19	19	20.8	22.2	22	17.5
11/9/2002 10:20	17.9	17.9	17.4	18.2	18.4	19.5	21.3	21.3	16.3
11/11/2002 13:00	18.4	19.2	19.3	19.3	19.3	21.2	22.4	22.2	16.7
11/12/2002 11:45	18	18.5	18.6	18.7	18.8	20.3	21.3	21.2	16
11/13/2002 17:30	18.8	18.6	18.8	18.8	19.3	20.5	22	21.4	15.8
11/14/2002 15:40	19.4	19	19	19.6	19.8	20.8	21.8	21.4	16.6
11/18/2002 13:00	18.6	19	19.2	19.5	19.9	21.5	21.7	21.1	15.3

Table E-4. Temperature Monitoring Data from VEA-4

VEA-4	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
10/22/2002	18.8	19	18.2	18.6	19.2	19.5	22.1	22.8	21.1
10/23/2002	17.9	18.9	19.4	17.5	18.8	20	20.1	22.2	21
10/24/2002 8:00	19.2	19.3	19.3	19.5	19.6	20.9	22.2	23.5	21.7
10/24/2002 16:00	19	19.1	19.3	19.1	19.6	20.4	21.7	23.3	20.9
10/25/2002 16:00	19.8	19.9	19.9	19.7	20.4	21.7	21.7	24.4	19.9
10/28/2002 8:00	18.5	18.5	18.6	18.7	19	19.9	21.3	22.8	19.6
10/30/2002 10:00	19.3	18.6	18.9	19	19.6	20	22.1	22.2	20.1
10/31/2002 17:30	19.7	19.6	19.5	20	20.2	21	22.2	22.8	19.9
11/1/2002 16:30	18.8	18.8	18.8	19.3	19.5	20.6	21.1	22.6	18.9
11/4/2002 13:30	17.6	17.9	17.6	16.6	17.9	18.9	19.5	20.6	16.7
11/5/2002 13:00	18.4	18.6	18.6	18.4	18.9	20.2	21	21.6	17.8
11/6/2002 14:00	18.9	18.8	18.8	19.1	19.4	20.1	21.3	21.8	17.9
11/8/2002 14:00	18.7	19	19	19	19.1	20.2	21.5	21.5	17.6
11/9/2002 10:20	18.9	18.5	18.4	18.6	18.9	19.9	21.5	20.9	17.5
11/11/2002 13:00	17.9	18.2	17.8	17.9	18.7	19.9	20.6	20.9	16.4
11/12/2002 11:45	17.7	18.1	17.9	18.2	18.4	19.8	20.6	20.8	16.1
11/13/2002 17:30	19	18.9	19.1	19.3	19.6	20.2	21.6	21	16.2
11/14/2002 15:40	18.4	18.6	18.7	18.9	19.4	20.2	21.5	21	16.4
11/18/2002 13:00	18	18.5	17.5	18.4	18.3	20.5	20.3	20.4	15.5

Table E-5. Temperature Monitoring Data from VEA-5

VEA-5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
10/22/2002 15:00	17.9	18.9	18.4	18.6	18.6	20.2	21.9	23.4	20.1
10/23/2002 15:00	18.3	17.1	18.4	18.6	18.4	20.4	21.4	23.3	21.2
10/23/2002 20:00	19.4	19.6	20	19.5	20.7	21.4	19.4	19.8	22.3
10/24/2002 8:00	21.7	21.8	20	20.2	22.4	20.9	23.1	24.5	22
10/24/2002 16:00	19	19.1	63.4	30.3	19.7	20.6	22.6	24	21.5
10/24/2002 21:00	19	19	85.2	47.7	19.9	20.9	22.6	24	21.1
10/24/2002 22:00		20	89	52.3	20.6				
10/24/2002 23:00		20.1	98.4	58.5	20.4				
10/25/2002 0:00	19.4	19.6	93.5	61.3	20	20.9	22.9	24.2	21.4
10/25/2002 7:00	19.2	23	102	89.6	22.5	20.5	22.3	24.1	20.8
10/25/2002 16:00	20.2	50.7	105.7	105.2	38.8	22	23.7	24.6	21.9
10/28/2002 8:00	23.1	46.9	77.4	94.5	67.5	26	22.3	24.5	21.6
10/30/2002 10:00	25.2	45.2	71.4	88.9	66.4	29	23.3	25.3	22
10/31/2002 17:30	26.7	45.9	102.1	105.6	82.2	31	24.6	26.4	22.8
11/1/2002 16:30	27.2	52.4	110.5	107.6	103.4	34.4	24.6	26.1	21.7
11/4/2002 13:30	28.3	52.9	89.6	100.7	96.9	48.9	24	26.1	20.4
11/5/2002 13:00	29.4	52.6	86.5	100.1	95.6	49.8	25.5	27.1	21
11/6/2002 14:00	29.6	51.6	81.9	98.7	94.2	50.3	26.1	27.6	21.1
11/7/2002 13:40	30	49.9	76.9	96.3	92.4	50.3	26.7	27.7	21.1
11/8/2002 13:30	29.9	49.6	91.1	98.4	92.8	49.9	27	27.6	20.5
11/9/2002 10:20	29.3	49	108.9	106.4	103	49.7	26.9	26.7	18.5
11/11/2002 13:00	31.3	54.8	94.6	102.1	99.1	59.5	28.2	27.3	20.2
11/12/2002 11:45	31.1	52.9	88.6	99.8	97.1	57.9	27.7	25.9	18.6
11/13/2002 17:30	33.1	80.2	113.7	107.1	104.1	61.7	30.6	28.5	19.5
11/14/2002 15:40	34.9	107.5	113.4	108.1	106.3	70.7	71.5	28.2	20.4
11/18/2002 13:00	40.1	74.5	97.8	102.7	100.5	75.4	32.7	27.6	20.1
11/19/2002 19:55	40.4	70.6	92.7	102.1	99.4	73.6	34	28.6	18.9
11/20/2002 20:30	40.1	68.4	88.8	101.6	99.4	73.1	35.6	28.7	19.4

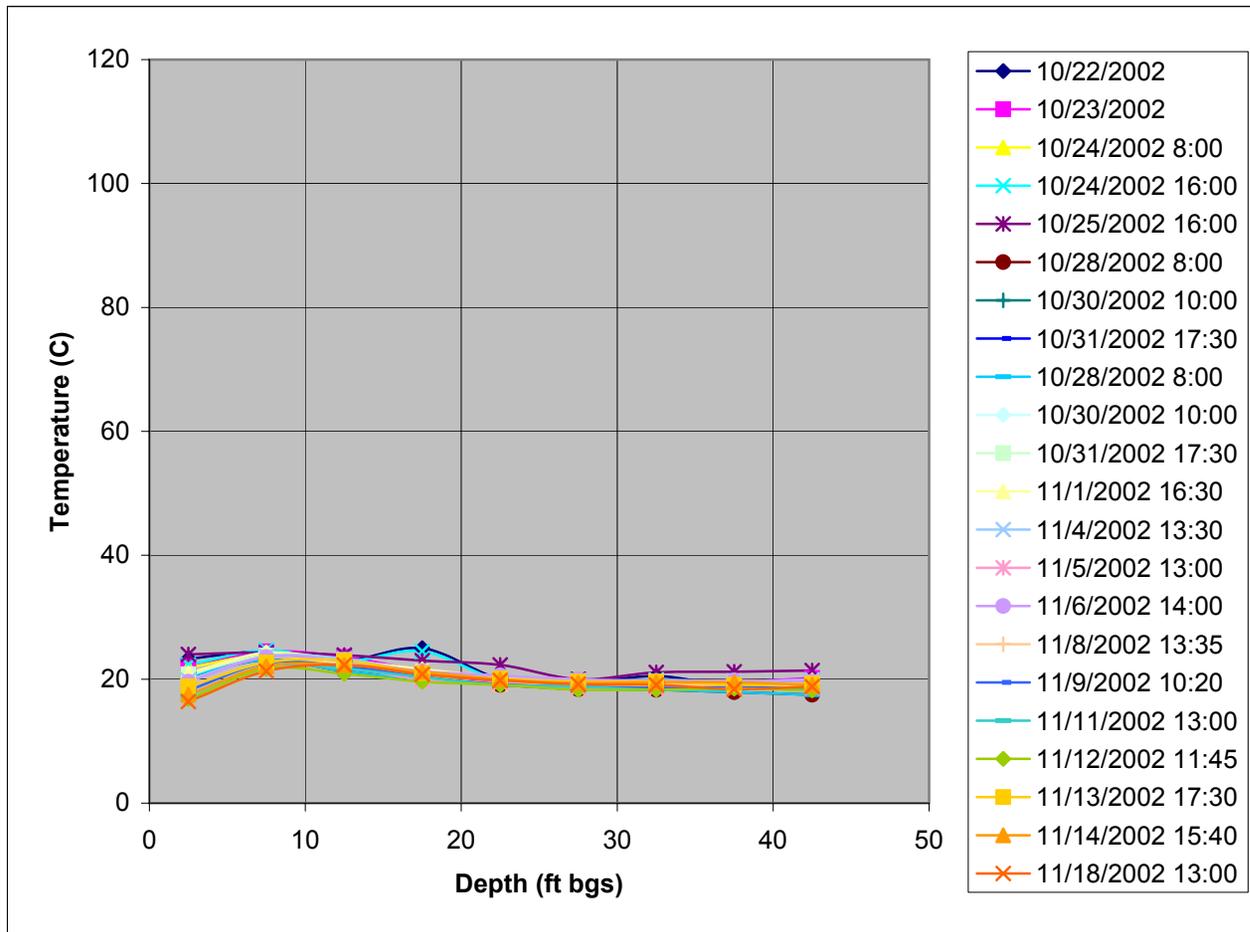


Figure E-1. Temperature Profile from VEA-1

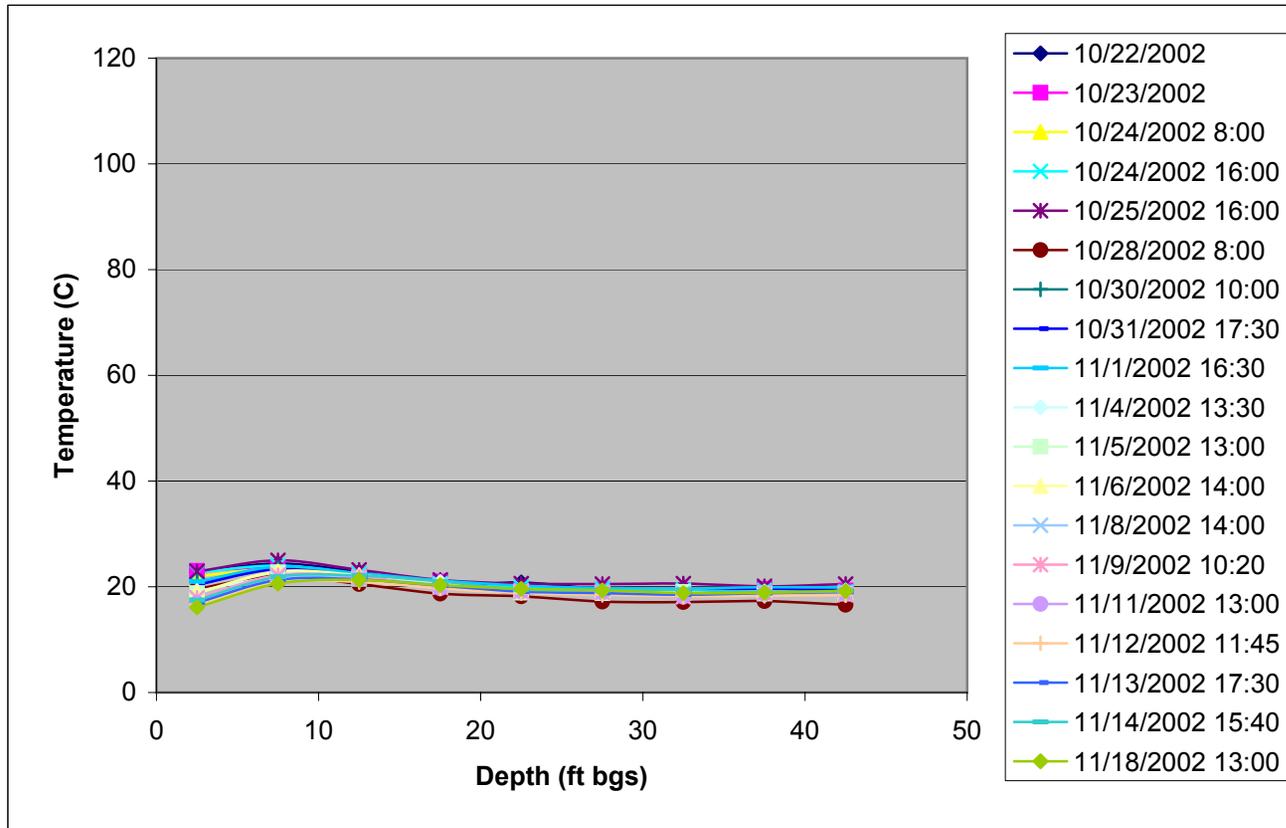


Figure E-2. Temperature Profile from VEA-2

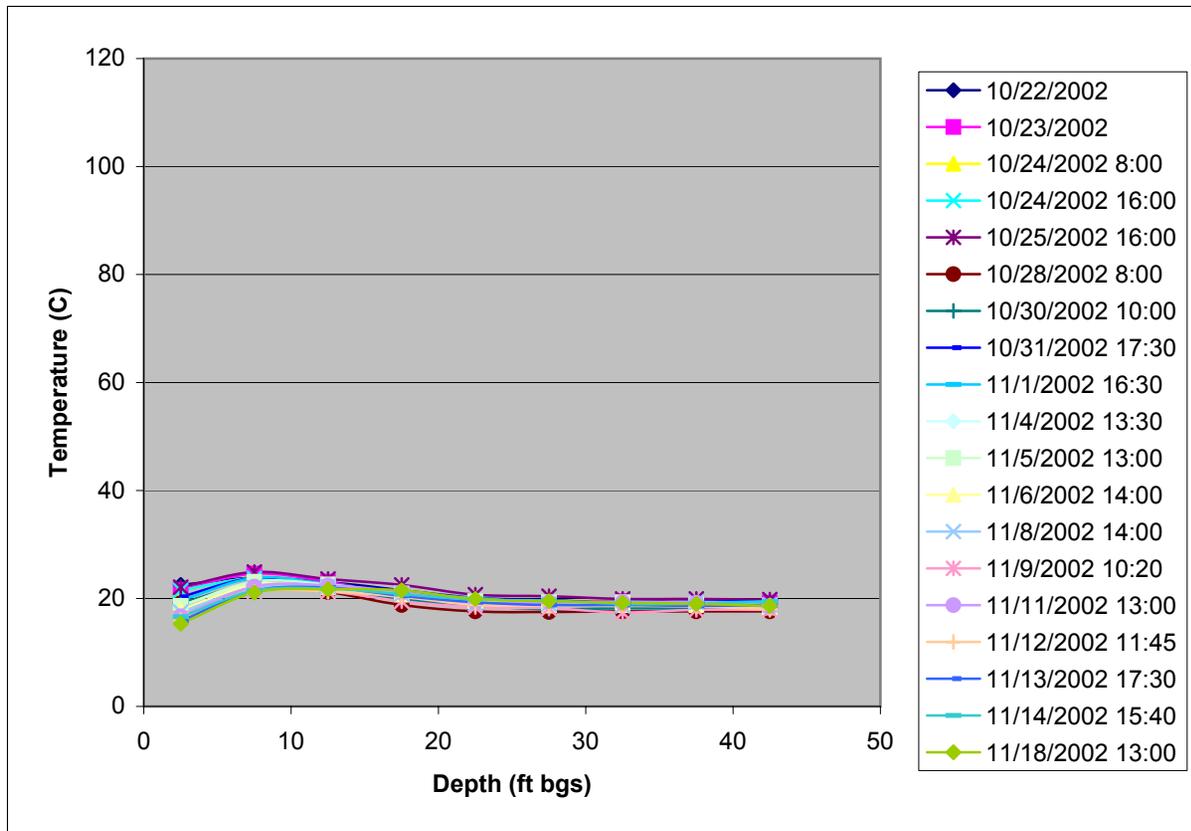


Figure E-3. Temperature Profile from VEA-3

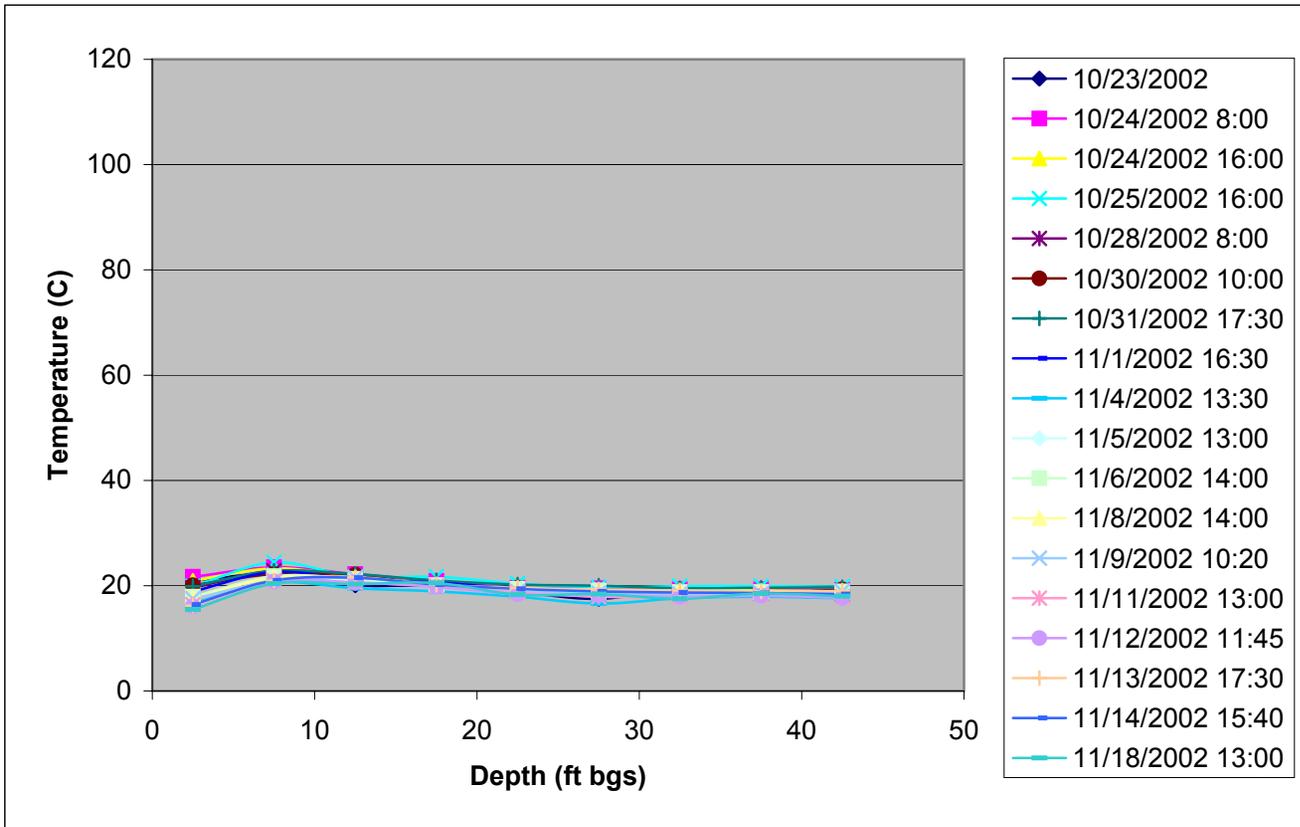


Figure E-4. Temperature Profile from VEA-4

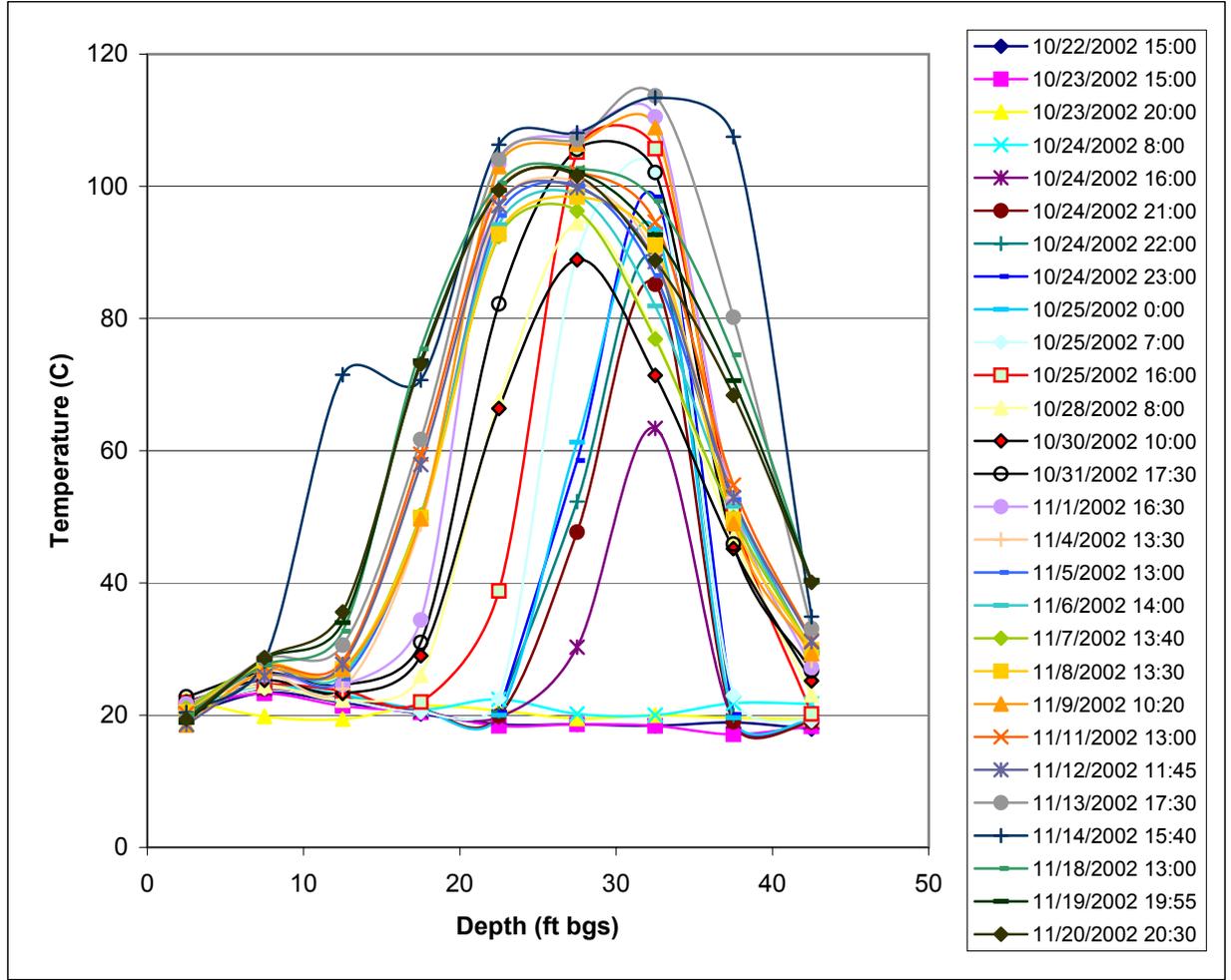


Figure E-5. Temperature Profile from VEA-5

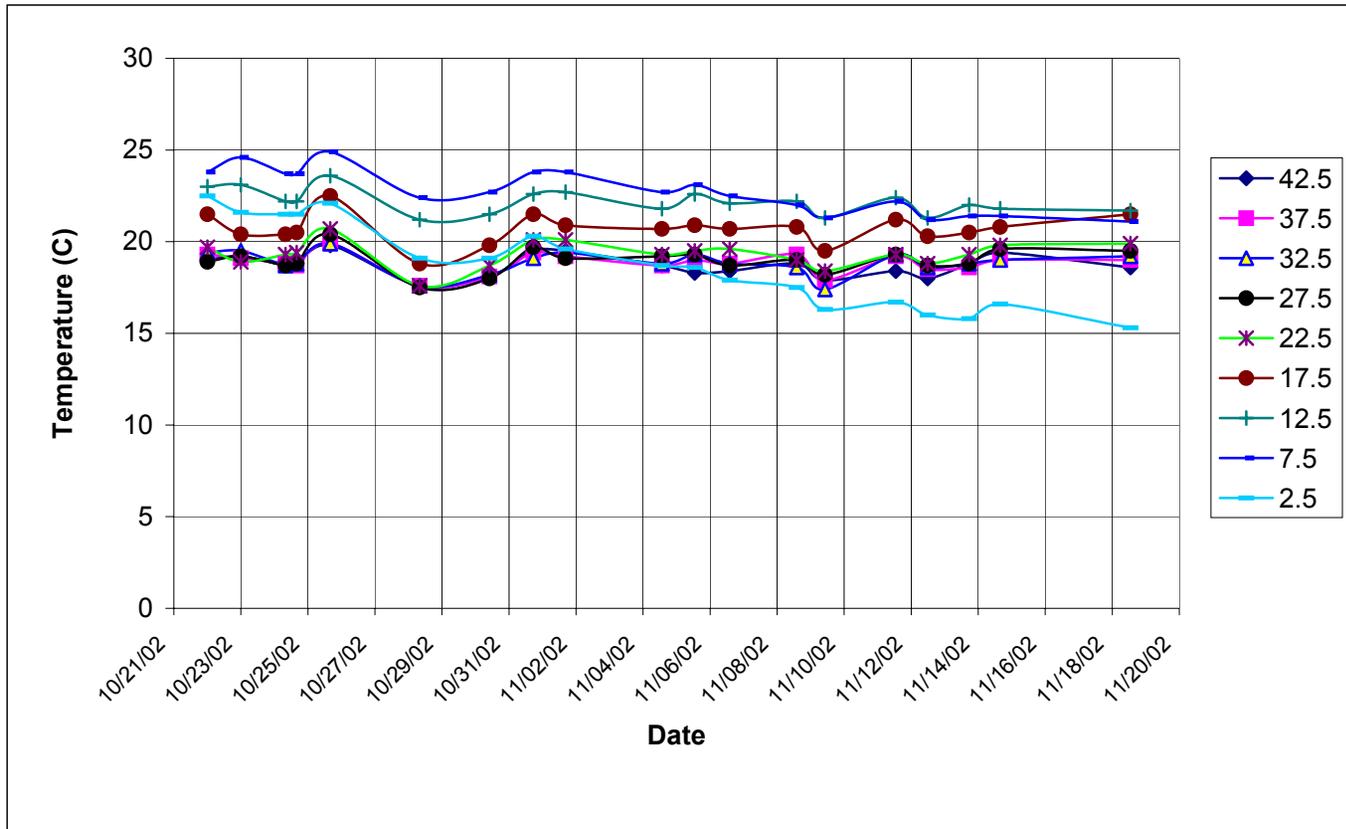


Figure E-6. Temperature Profile over the Period of Demonstration from VEA-1

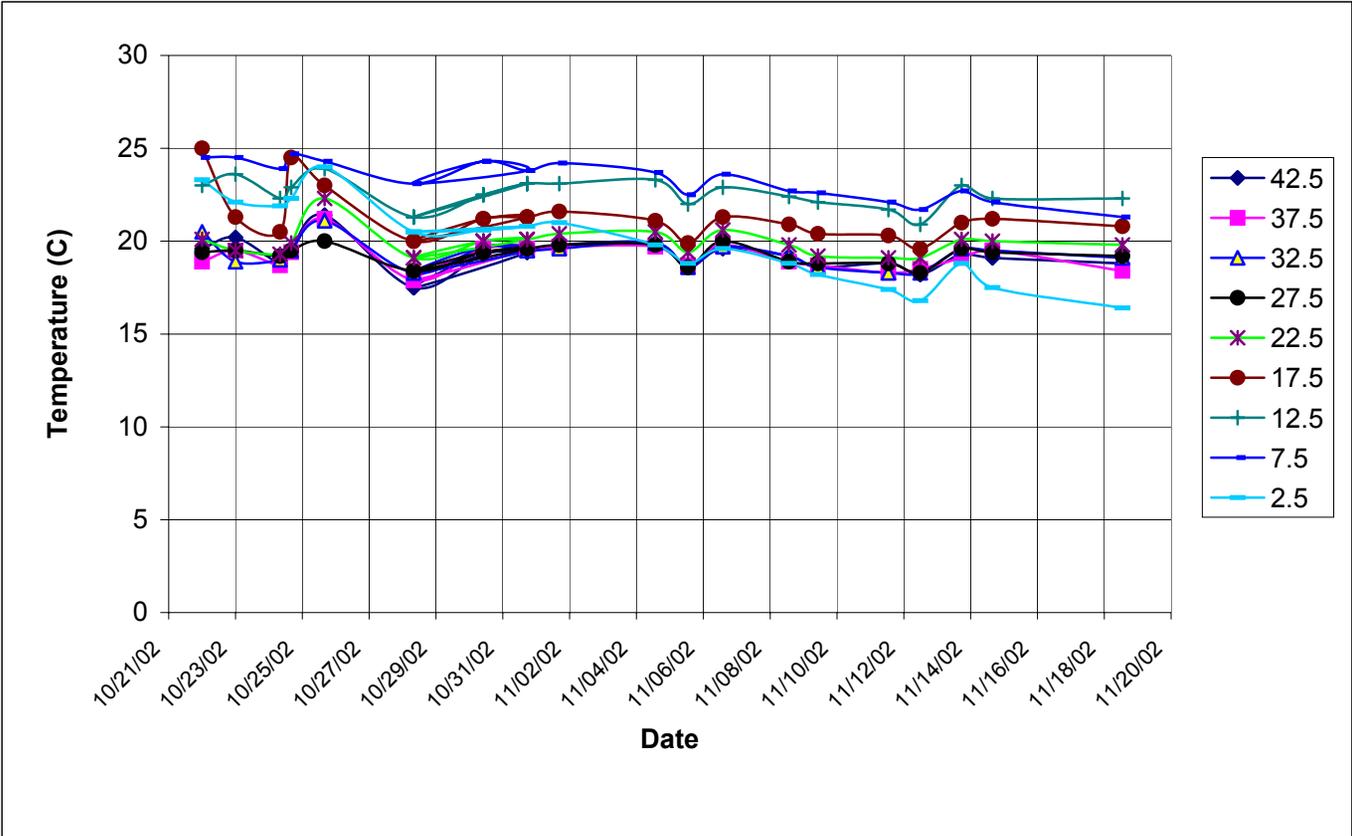


Figure E-7. Temperature Profile over the Period of Demonstration from VEA-2

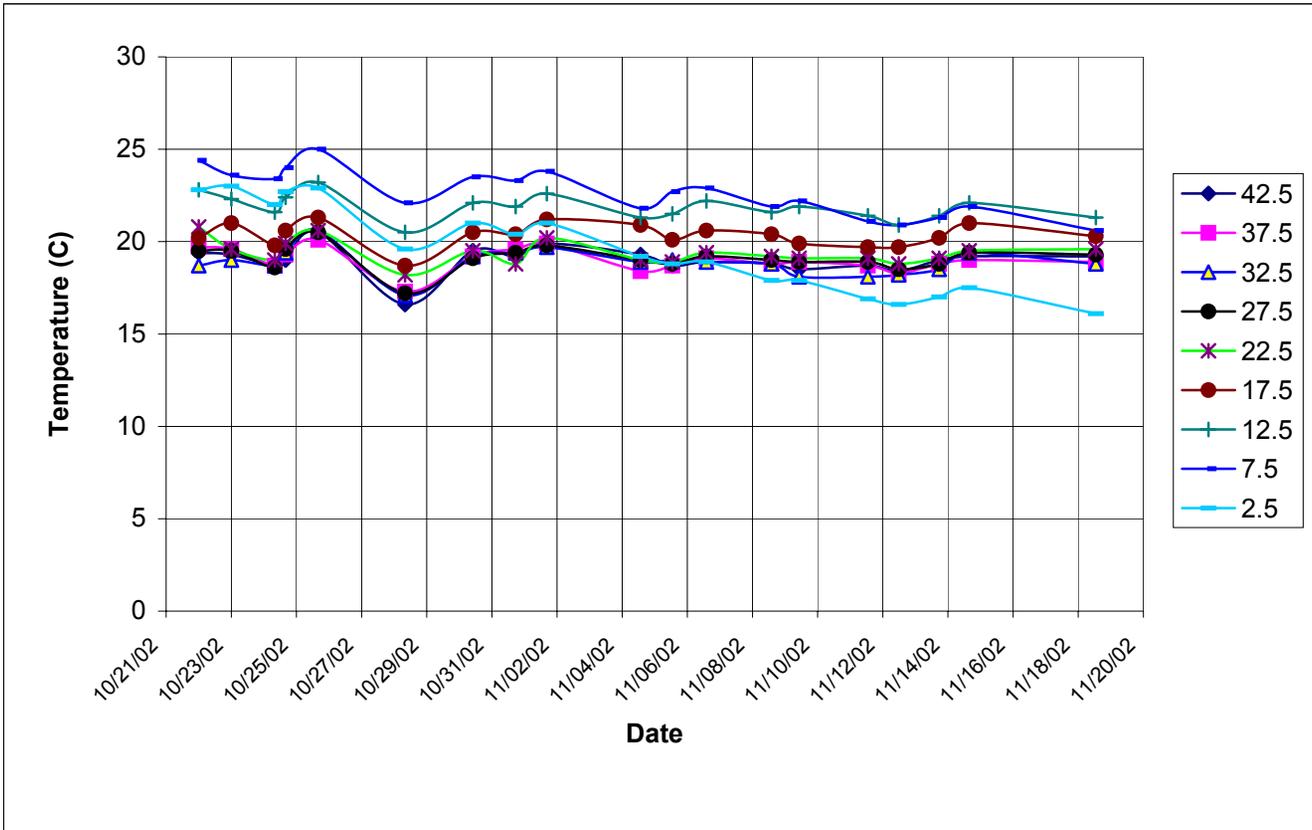


Figure E-8. Temperature Profile over the Period of Demonstration from VEA-3

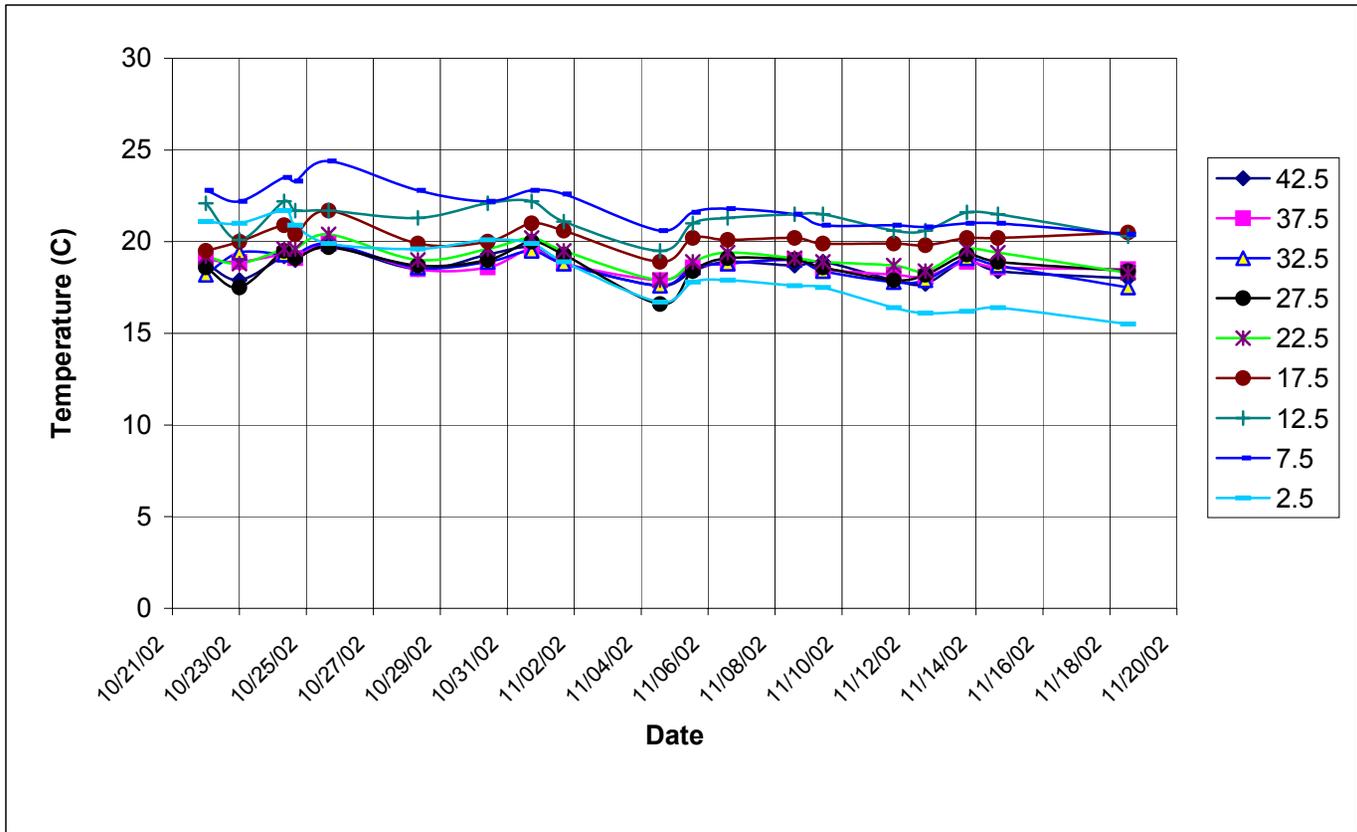


Figure E-9. Temperature Profile over the Period of Demonstration from VEA-4

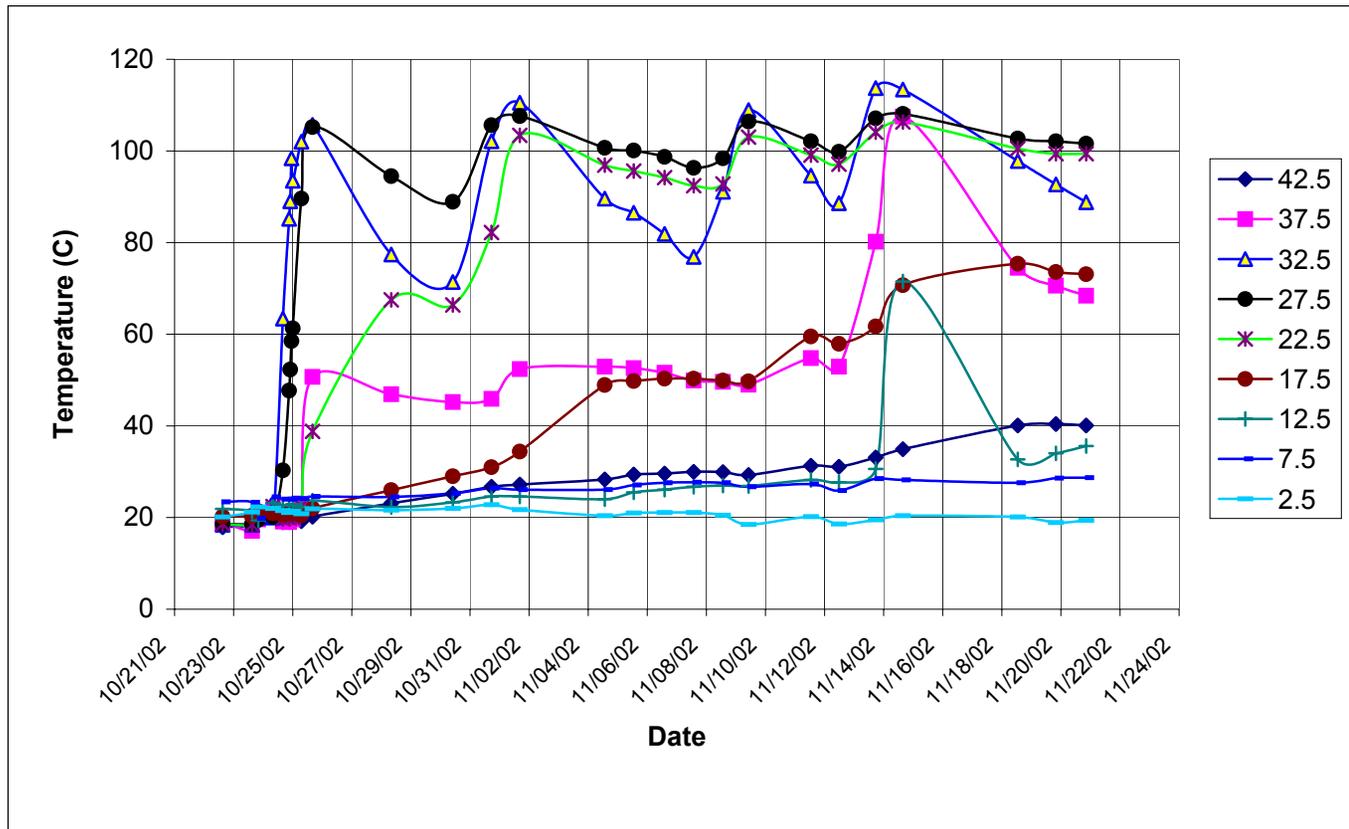
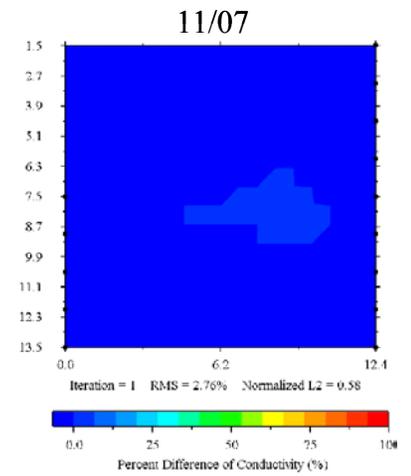
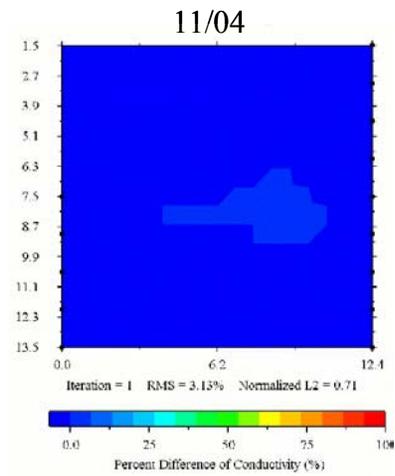
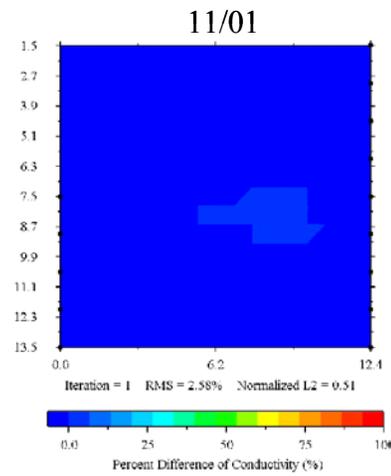
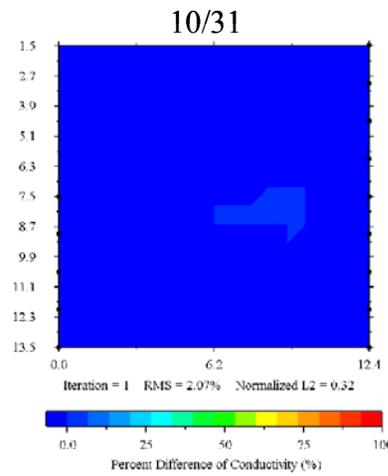
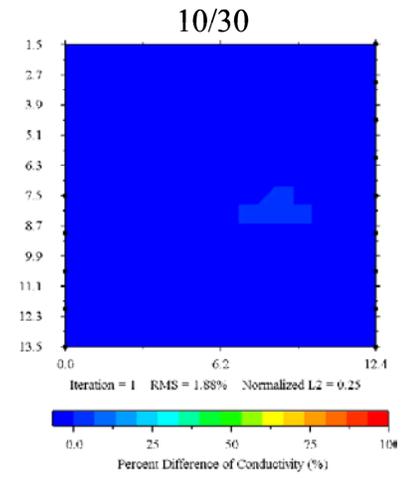
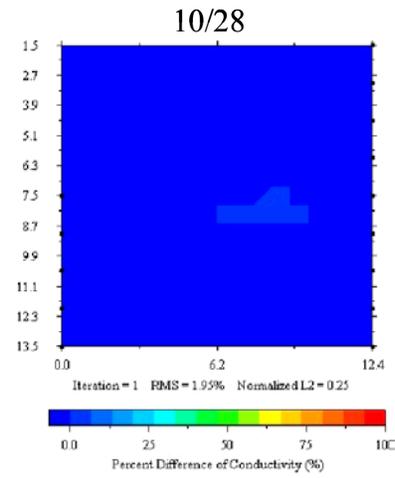
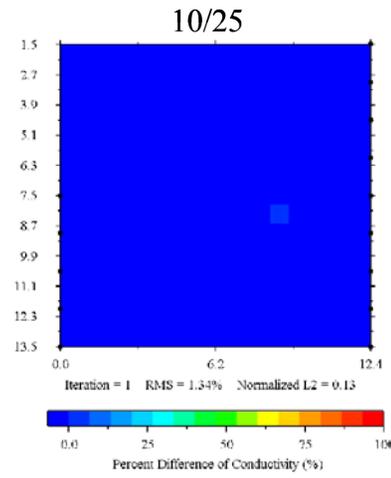
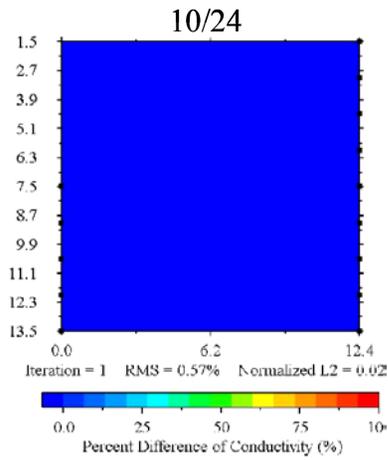


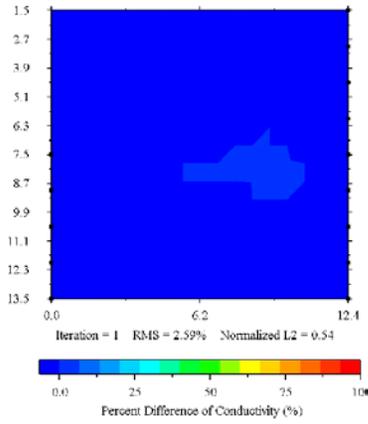
Figure E-10. Temperature Profile over the Period of Demonstration from VEA-5

VEA 2 – VEA 3

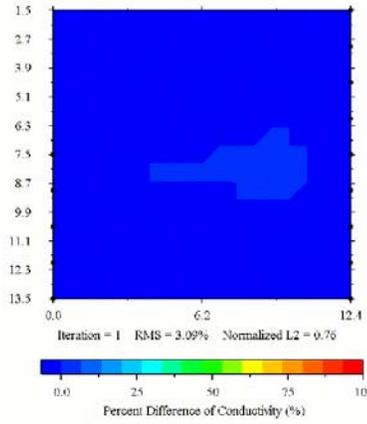


VEA 2 – VEA 3

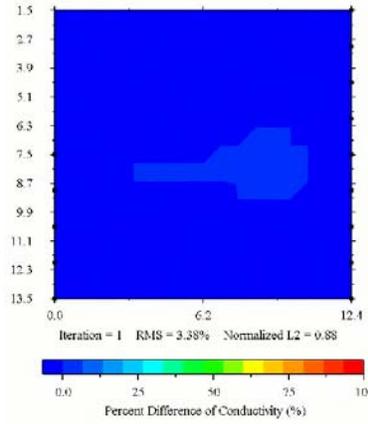
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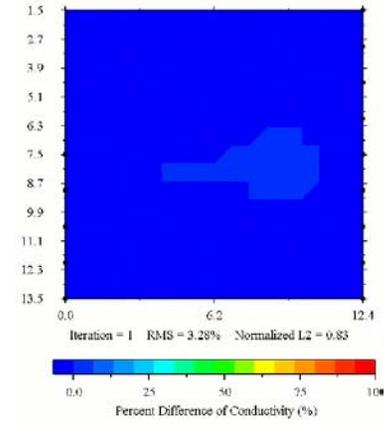
11/09



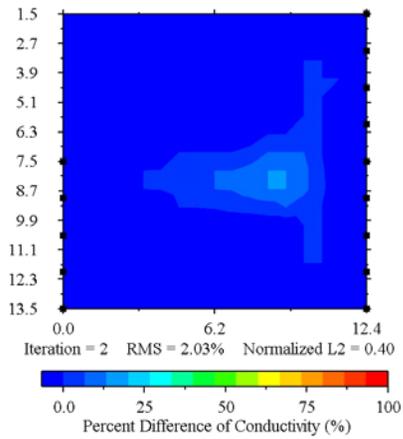
11/11



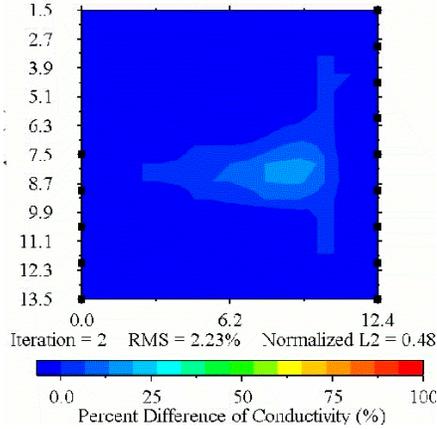
11/12



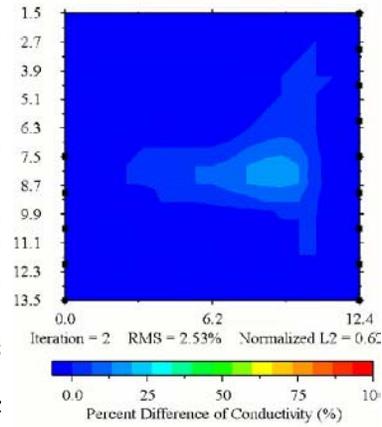
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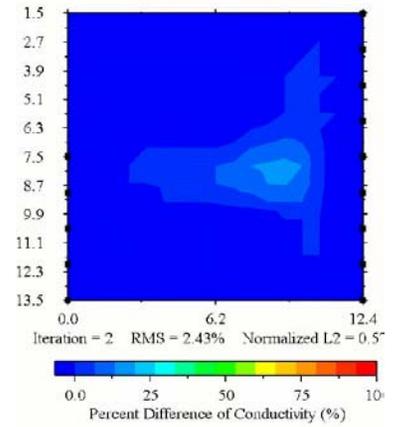
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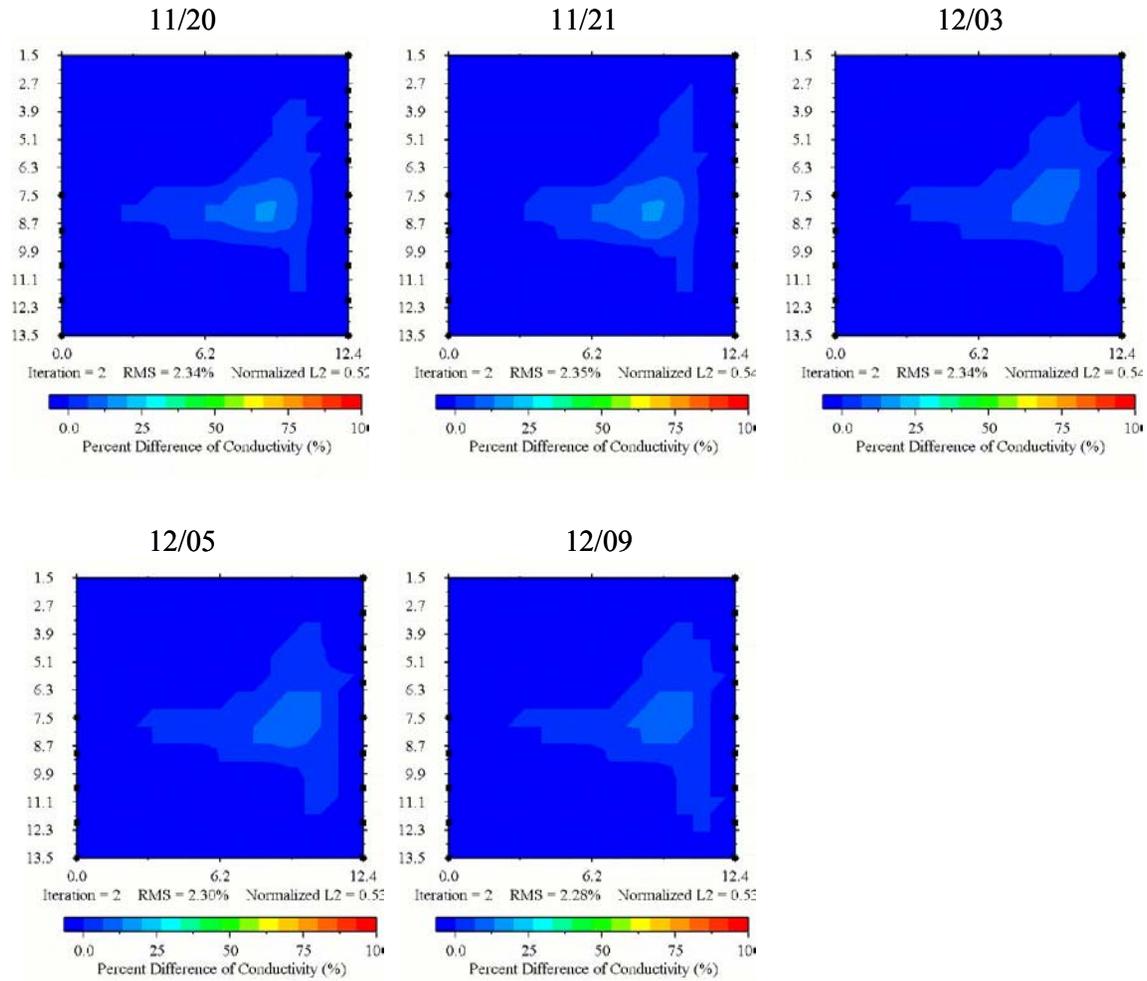
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11/19

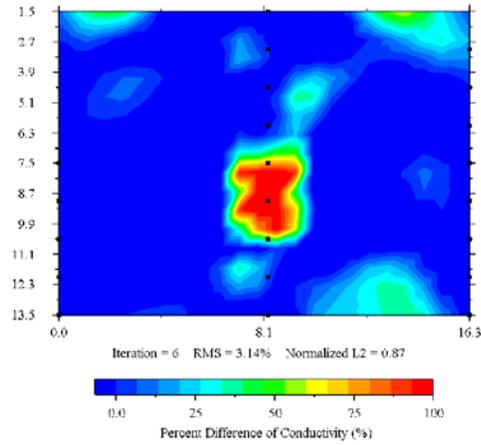


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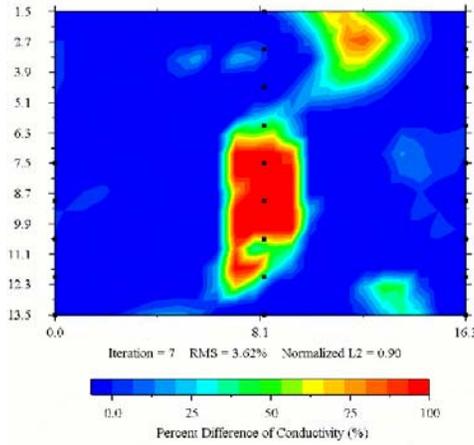


VEA 2 – VEA 5 – VEA 4

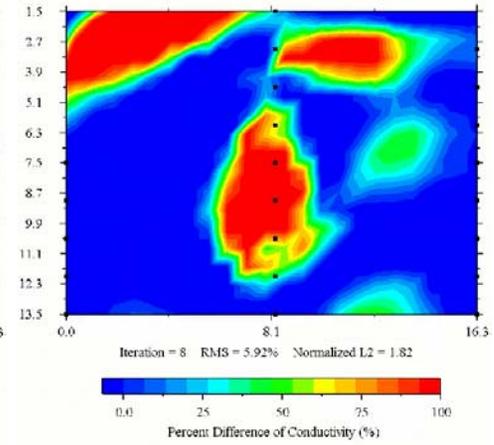
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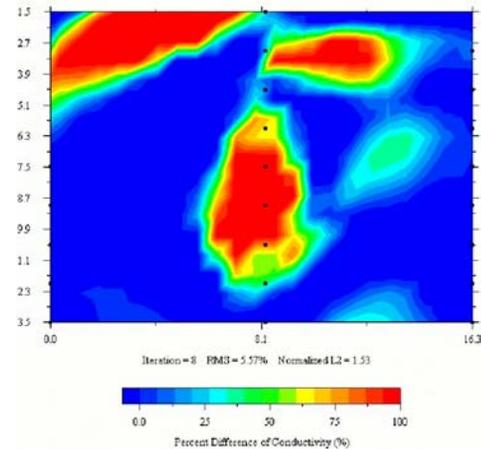
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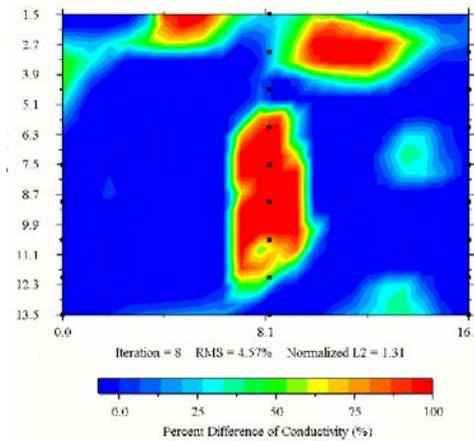
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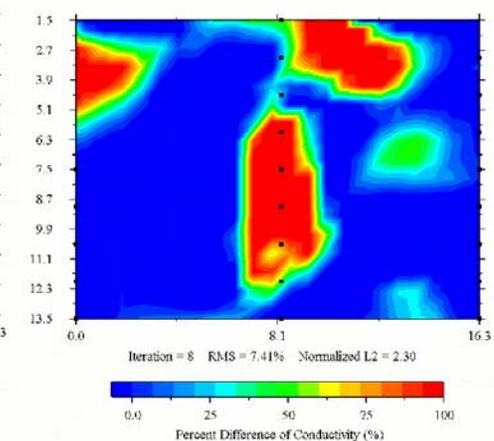
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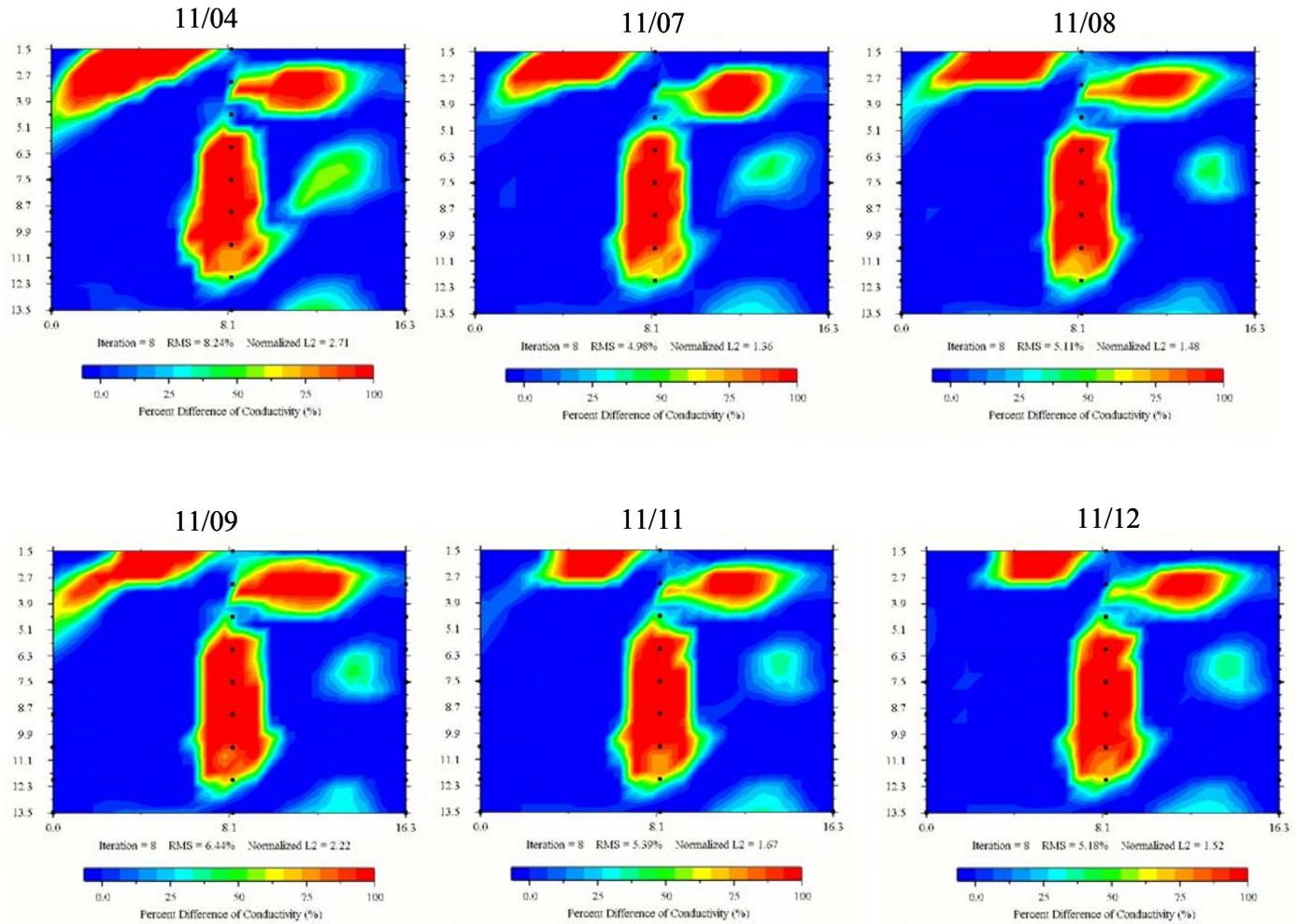
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11/01

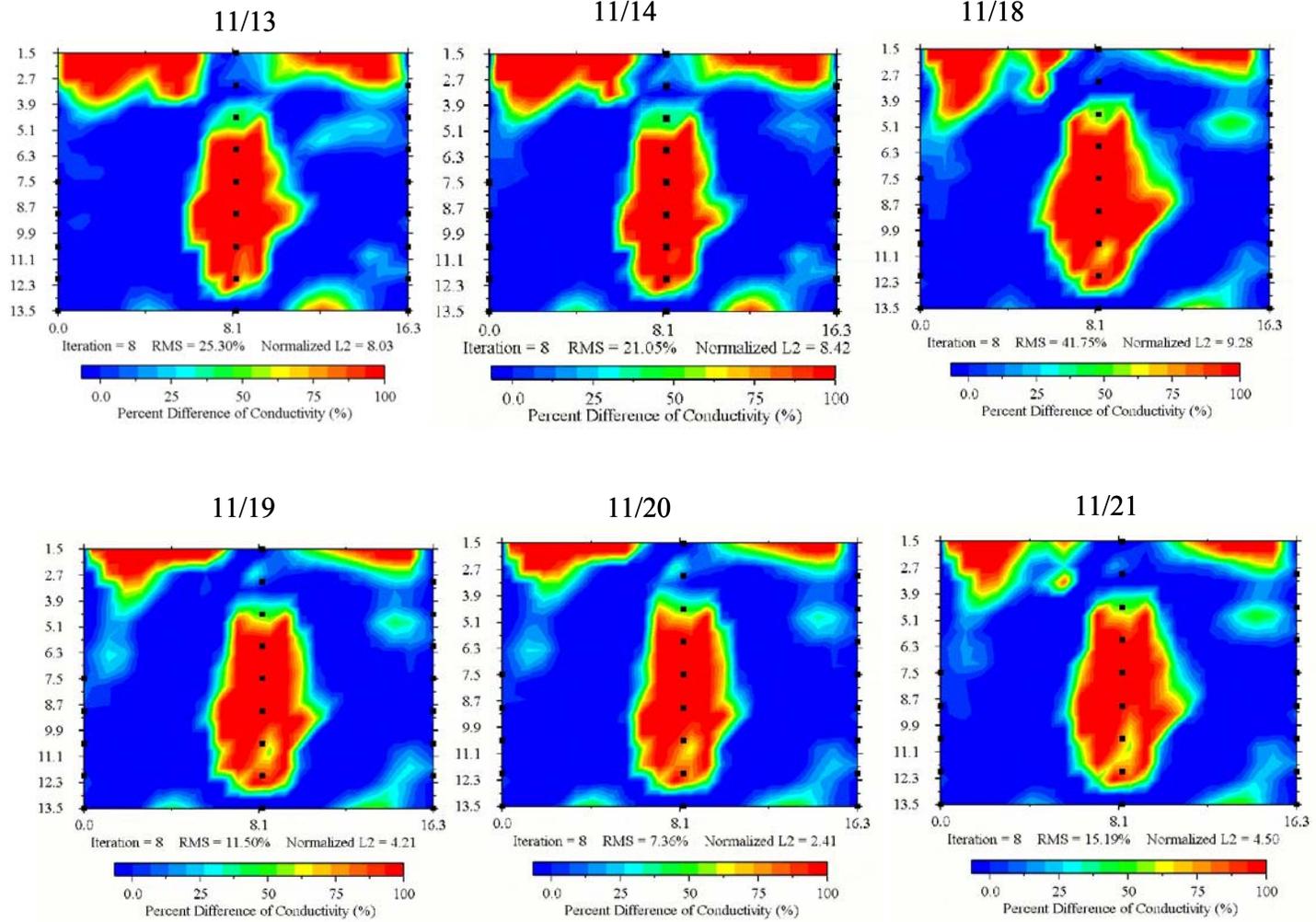


VEA 2 – VEA 5 – VEA 4



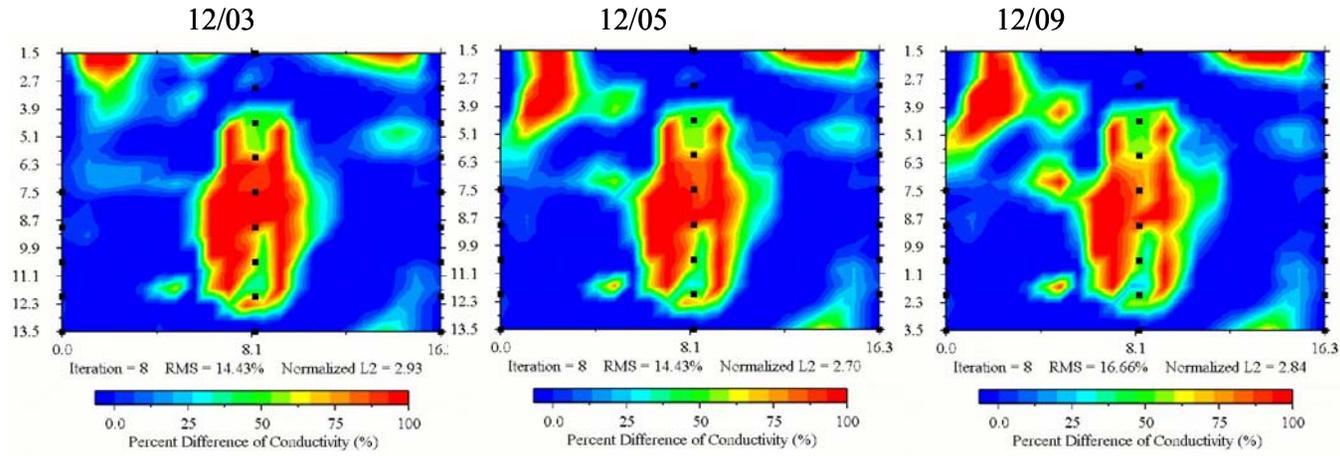
VEA-2, VEA-5, and VEA-4 (Page 2 of 4)

VEA 2 – VEA 5 – VEA 4



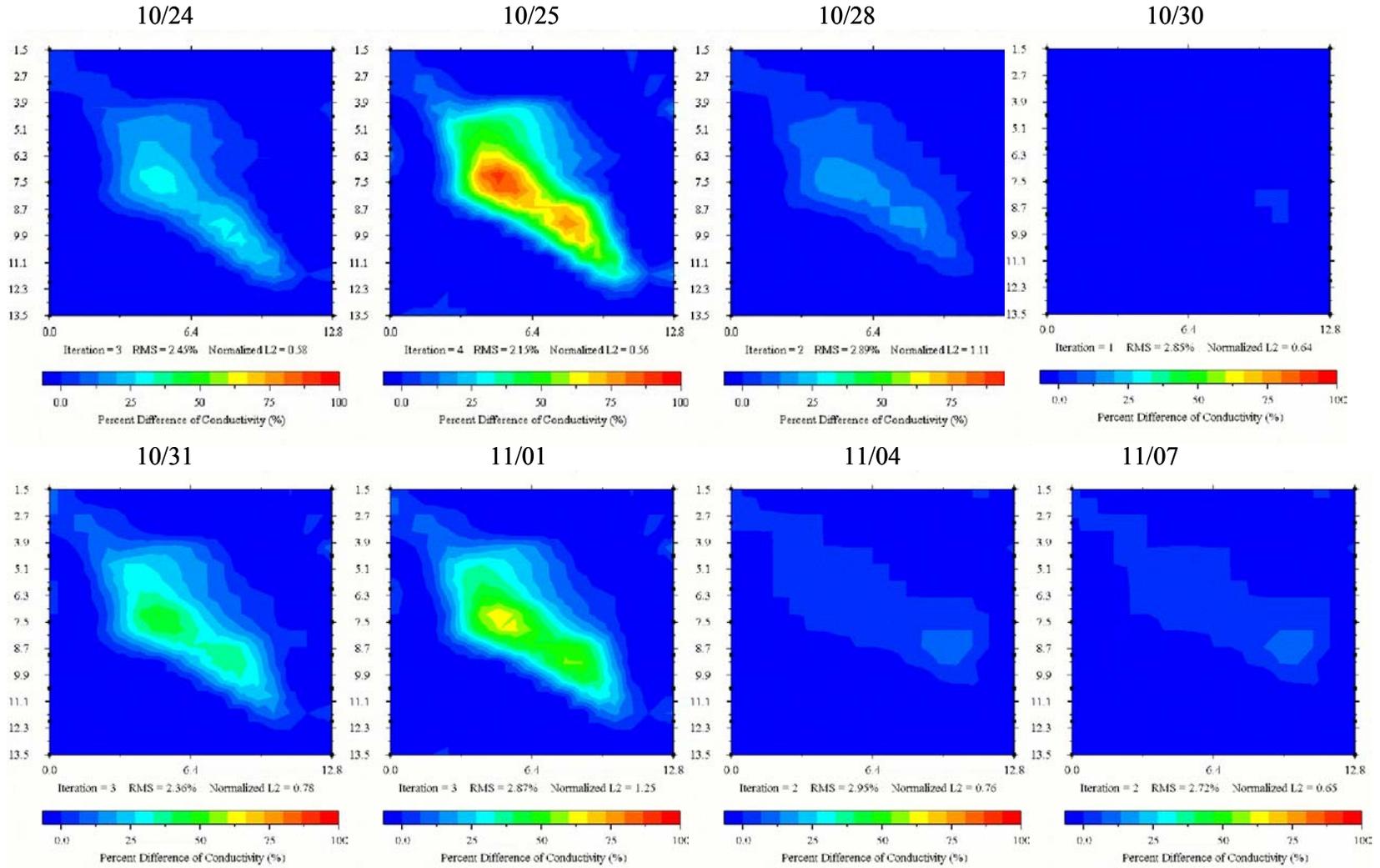
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VEA 2 – VEA 5 – VEA 4

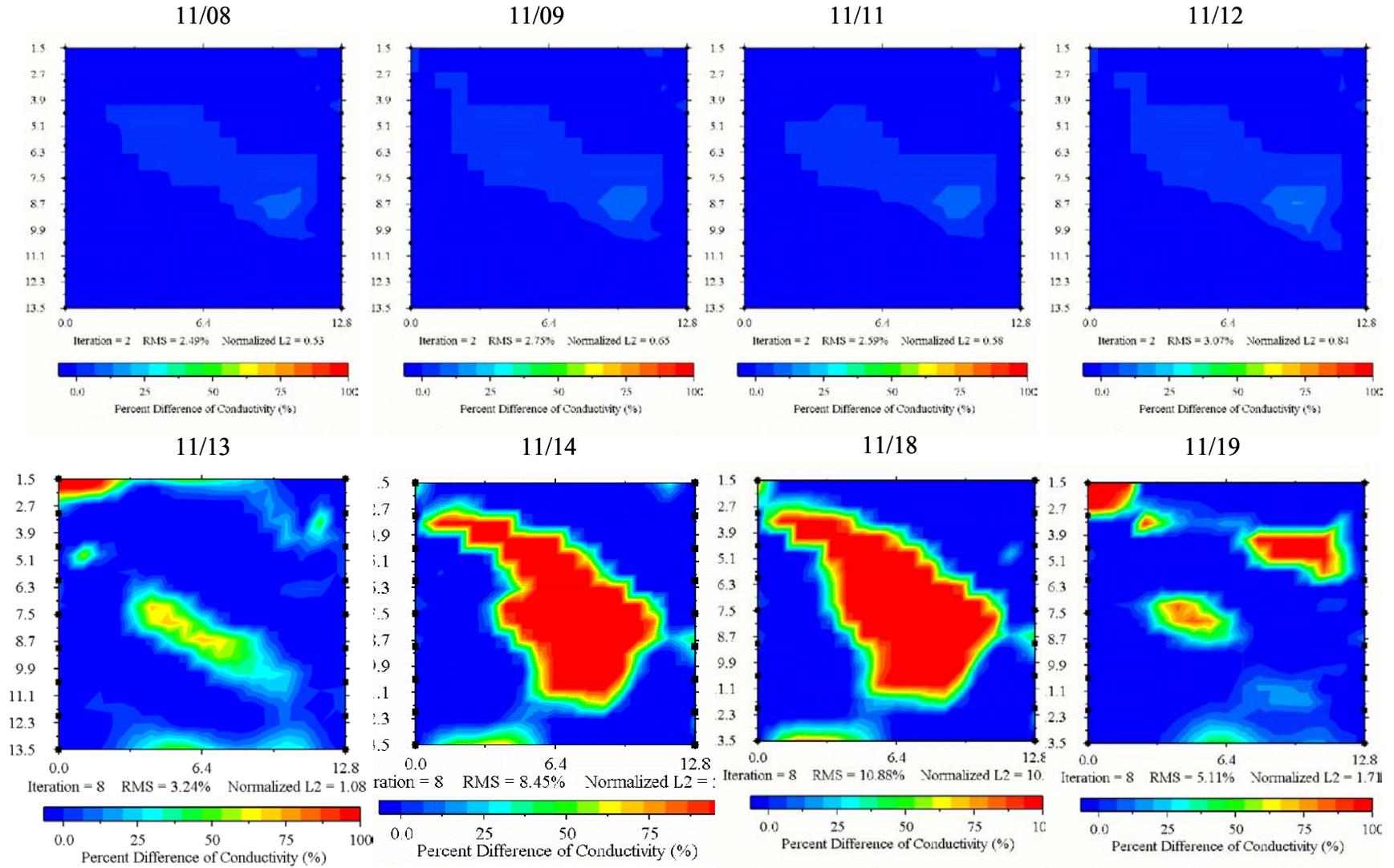


VEA-2, VEA-5, and VEA-4 (Page 4 of 4)

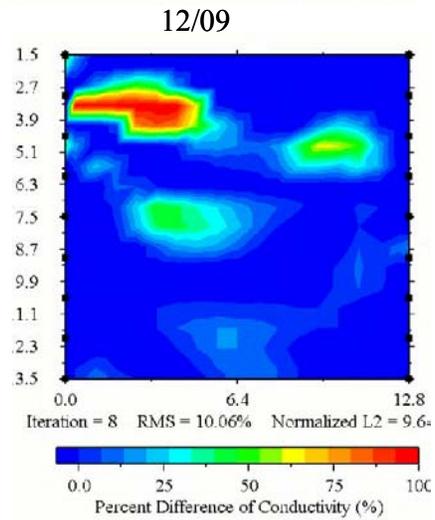
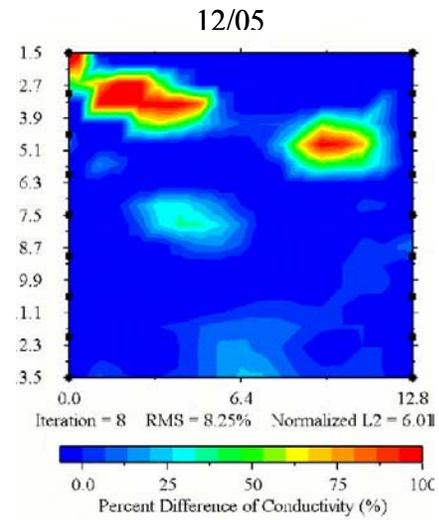
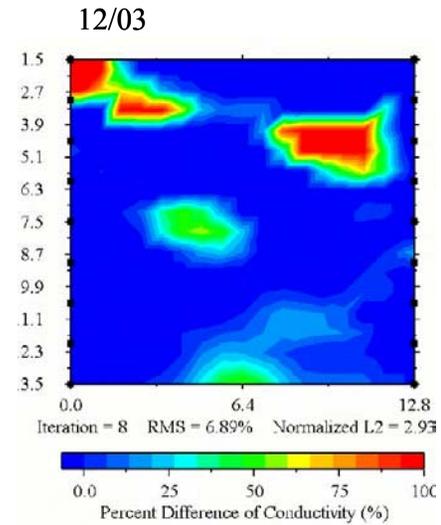
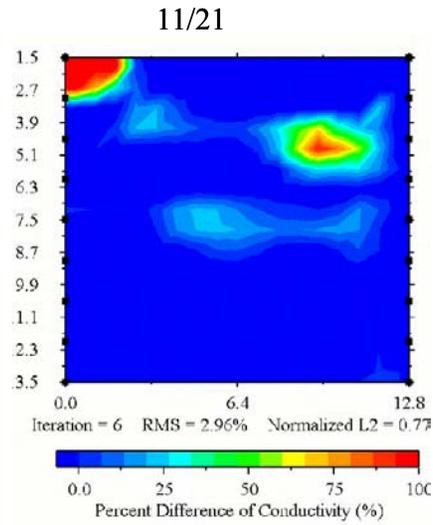
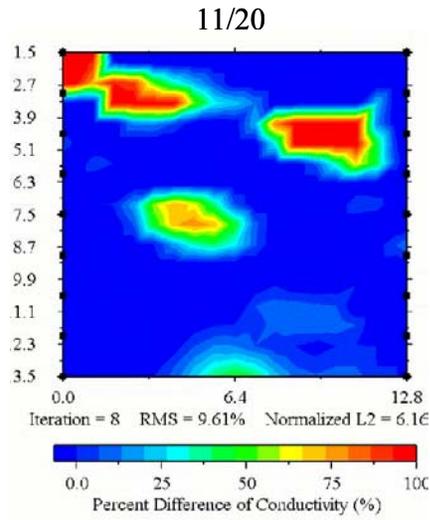
VEA 4 – VEA 3



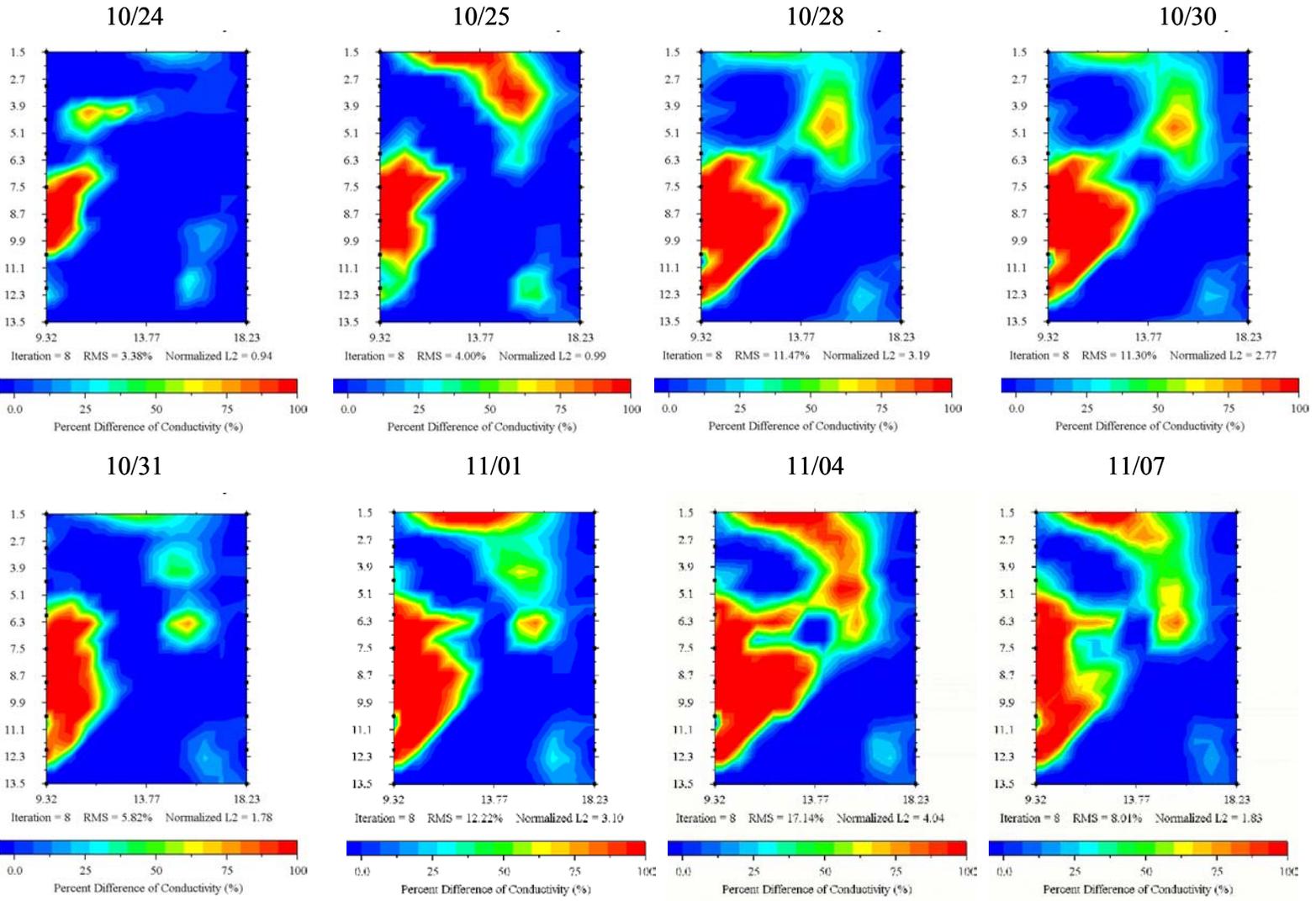
VEA 4 – VEA 3



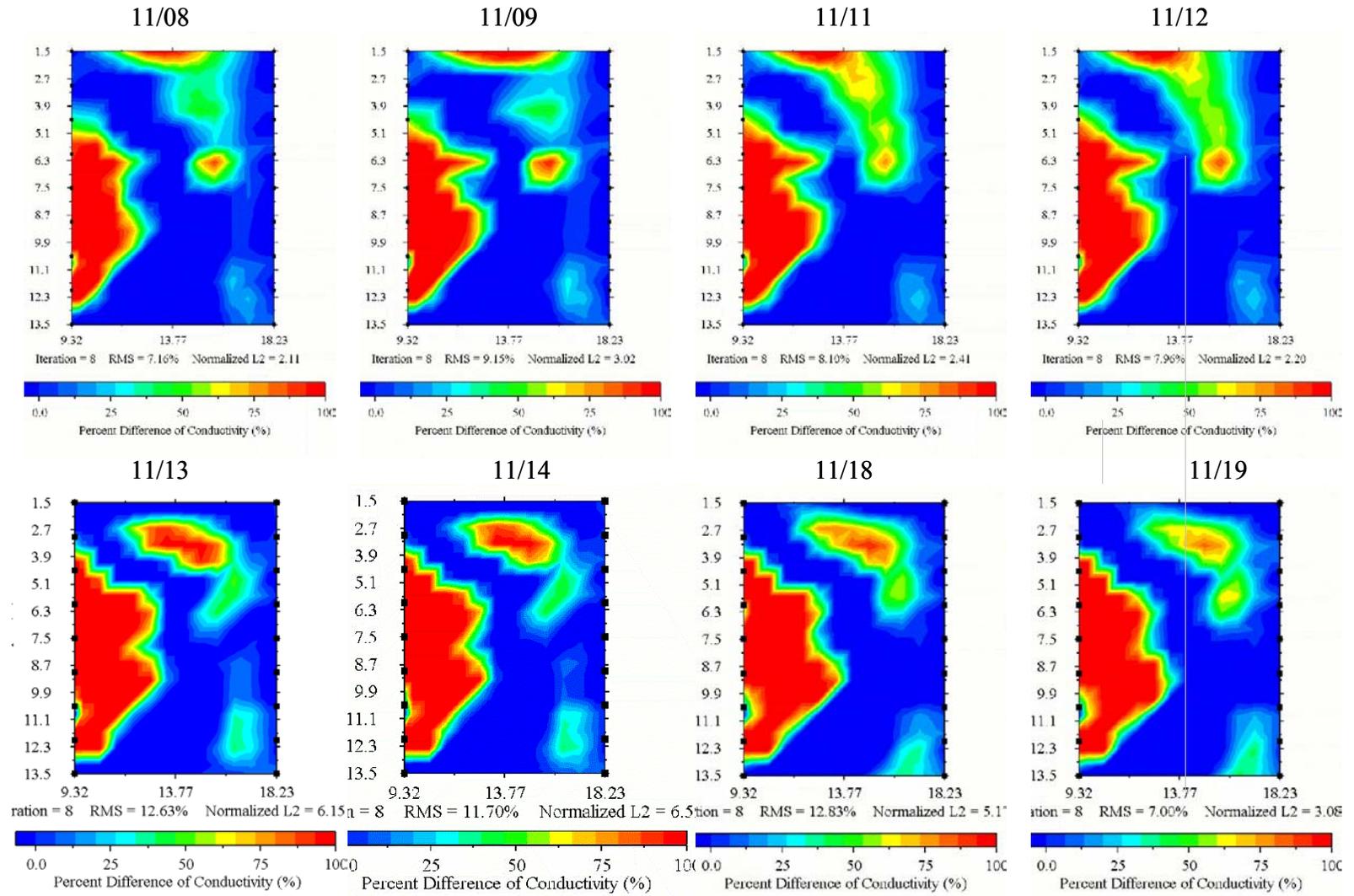
VEA 4 – VEA 3



VEA 5 – VEA 3



VEA 5 – VEA 3



VEA 5 – VEA 3

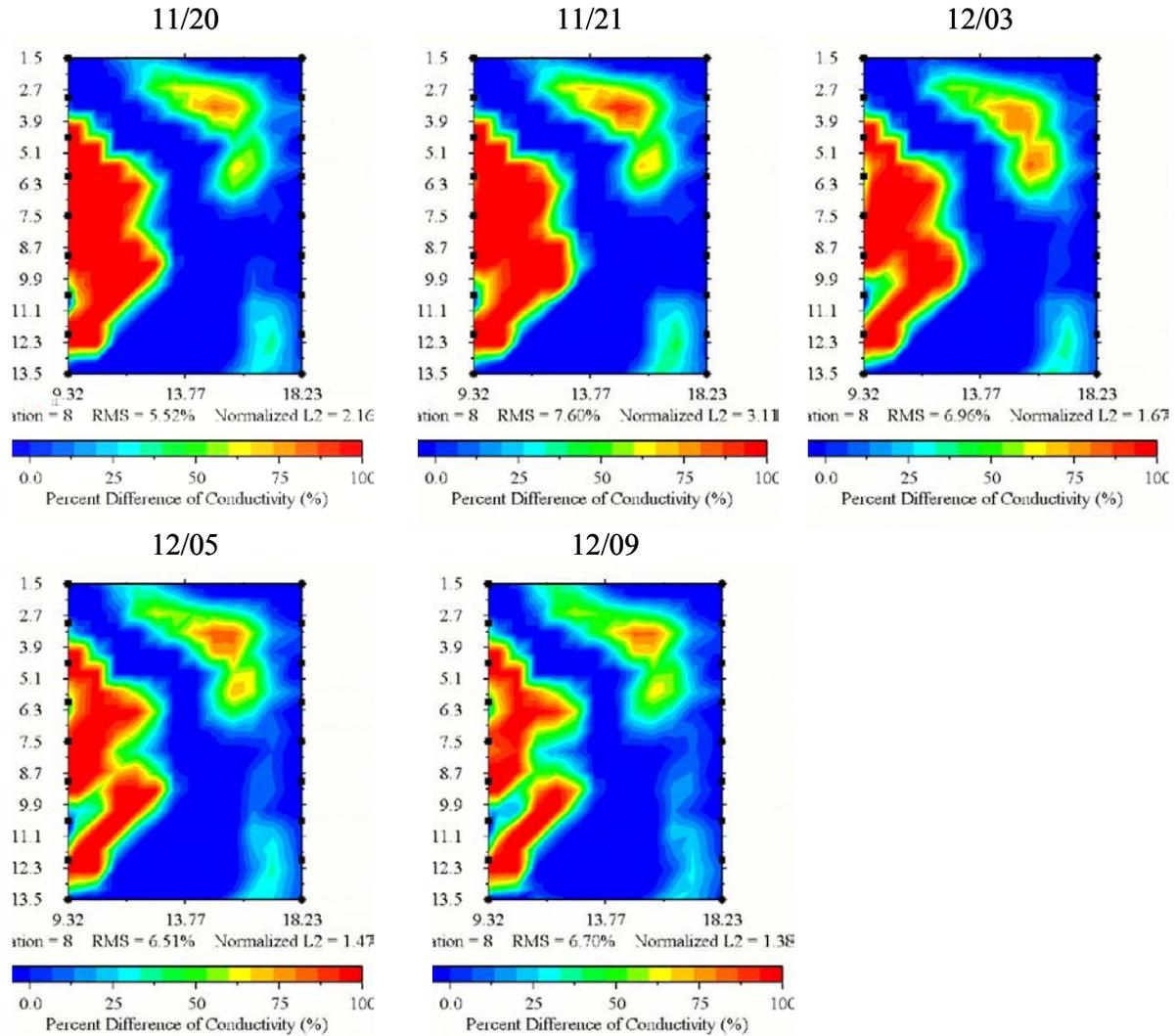


Table F-1. Steam Injection Phase: Process Data

Sheet 1: Steam Injection Phase: Process Data												
Start Cycle 1A										Between Cycles		
Date/time		10/23/2002 15:40	10/23/2002 16:40	10/23/2002 20:00	10/24/2002 0:00	10/24/2002 4:00	10/24/2002 9:15	10/24/2002 16:20	10/25/2002 0:00	10/25/2002 8:00	10/25/2002 16:00	10/30/2002 15:20
time elapsed	hrs	0	1.00	3.33	4.00	4.00	5.25	7.08	7.67	8.00	8.00	119.33
Cycle cumulative time		0	1.00	4.33	8.33	12.33	17.58	24.67	32.33	40.33	48.33	119.33
Total cumulative time		0	1.00	4.33	8.33	12.33	17.58	24.67	32.33	40.33	48.33	167.67
operator		SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	JE
Steam Generator												
Supply water total in reading	gal	499.2	509.7	557.6	610.6	690.3	859.4	1270	1650.1	2062.8	2443.1	2443.1
Supply water total in (actual)	gal	0	10.5	58.4	111.4	191.1	360.2	770.8	1150.9	1563.6	1943.9	1943.9
Condensate total out reading	gal	212.5	212.5	212.5	212.5	212.5	212.5	367.43	367.43	379.59	403.05	403.05
Condensate total out (actual)	gal	0	0	0	0	0	0	154.93	154.93	167.09	190.55	190.55
Steam injection pressure	Steam pressure (psig)	6	5	11	15	20	20	25	24	24	24	0
Steam temperature	Steam temp (°F)	230	226	241	246	258	258	268	266	268	268	50
Steam injection rate (lbs/hr)	lbs/hr	0	87.50	119.75	110.42	166.04	268.41	300.79	413.15	417.23	371.71	0.00
O ₂ injection rate	Oxygen injection rate (scfh)	0	0	0	0	0	0	0	0	0	0	0
O ₂ pressure	psig	0	0	0	0	0	0	0	0	0	0	0
Fuel Tank												
Date/time		10/23/2002 15:30	10/24/2002 8:00	10/24/2002 13:30	10/24/2002 14:30							10/29/2002 14:30
operator		DC	DC	DC	DC							JE
Propane level	%	14	12%	8%	50%							45
Propane pressure	psig	145	145	145	110							

2014 gal. Delivered at 14:00

Table F-1. Steam Injection Phase: Process Data (Continued)

Sheet 1: Steam Injection Ph													
	Start Cycle 1B												
Date/time	10/30/2002	10/30/2002	10/30/2002	10/30/2002	10/30/2002	10/30/2002	10/30/2002	10/30/2002	10/31/2002	10/31/2002	10/31/2002	10/31/2002	10/31/2002
	15:20	17:30	19:30	20:30	20:45	22:00	22:45	8:20	10:30	11:00	11:30	15:10	
time elapsed	0.00	2.17	2.00	1.00	0.25	1.25	0.75	9.58	2.17	0.50	0.50	3.67	
Cycle cumulative time	0.00	2.17	4.17	5.17	5.42	6.67	7.42	17.00	19.17	19.67	20.17	23.83	
Total cumulative time	167.67	169.83	174.00	179.17	184.58	191.25	198.67	215.67	234.83	254.50	274.67	298.50	
operator	JE	JE	JE	JE	JE	JE	JE	JE	JE	JE	JE	JE	
Steam Generator	O2 ON			O2 OFF				ELEC/STEAM OFF		STEAM ON			
Supply water total in reading	2443.1	2558.3	2595	2614	2631.5	2649	2670	2976	3058	3097	3107	3107	
Supply water total in (actual)	1943.9	2059.1	2095.8	2114.8	2132.3	2149.8	2170.8	2476.8	2558.8	2597.8	2607.8	2607.8	
Condensate total out reading	403.05	473.2	473.2	473.2	473.2	473.2	473.2	473.2	481	499	499	499	
Condensate total out (actual)	190.55	260.7	260.7	260.7	260.7	260.7	260.7	260.7	268.5	286.5	286.5	286.5	
Steam injection pressure	0	16	16	16	20	20	20.5	20.5	23	23.5	0	10	
Steam temperature	50	250	251	251	260	260	260	260	264	265	0	240	
Steam injection rate (lbs/hr)	0.00	173.27	152.92	158.33	583.33	116.67	233.33	266.09	285.38	350.00	166.67	0.00	
O ₂ injection rate	0	32	55	70	0	0	0	0	0	0	0	0	
O ₂ pressure	0	16.5	17	17	26	0	0	0	0	0	0	0	
Fuel Tank													
Date/time											10/31/2002		
operator											13:55		
Propane level												38	
Propane pressure												125	

Table F-1. Steam Injection Phase: Process Data (Continued)

Sheet 1: Steam Injection Phase											End Cycle 1B
Date/time	10/31/2002 16:05	10/31/2002 16:35	10/31/2002 16:50	10/31/2002 17:00	10/31/2002 18:40	10/31/2002 22:00	11/1/2002 8:10	11/1/2002 9:30	11/1/2002 10:30	11/1/2002 12:20	11/1/2002 17:45
time elapsed	0.92	0.50	0.25	0.17	1.67	3.33	10.17	1.33	1.00	1.83	5.42
Cycle cumulative time	24.75	25.25	25.50	25.67	27.33	30.67	40.83	42.17	43.17	45.00	50.42
Total cumulative time	323.25	348.50	374.00	399.67	427.00	457.67	498.50	540.67	583.83	628.83	679.25
operator	JE	JE	JE	JE	JE	JE	JE	JE	JE	JE	JE
Steam Generator	O2 ON		O2 OFF			O2 ON		O2 OFF STEAM OFF			
Supply water total in reading	3160	3174	3188	3218	3248	3347	3698	3749	3785	3858	4047
Supply water total in (actual)	2660.8	2674.8	2688.8	2718.8	2748.8	2847.8	3198.8	3249.8	3285.8	3358.8	3547.8
Condensate total out reading	520	520	520	520	520	520	594	598	602	614	627
Condensate total out (actual)	307.5	307.5	307.5	307.5	307.5	307.5	381.5	385.5	389.5	401.5	414.5
Steam injection pressure	16	22	20.5	20.5	21	21	21	21	20.5	20.5	0
Steam temperature	251	262	260	259	260	262	260	261	259	260	0
Steam injection rate (lbs/hr)	290.91	233.33	466.67	#N/A	150.00	247.50	227.05	293.75	266.67	277.27	270.77
O ₂ injection rate	0	0	50	20	18	0	0	0	22	20	0
O ₂ pressure	0	25	21	22	21	0	0	0	20.5	20.5	0
Fuel Tank											
Date/time											
operator											
Propane level											
Propane pressure											

Table F-1. Steam Injection Phase: Process Data (Continued)

Sheet 1: Steam Injection Phase				CYCLE 2 Time Elapsed Boiler Total		Between Cycles	Start Cycle 3					
	11/8/2002	11/9/2002	11/9/2002	TOTAL	TOTAL	11/12/2002	11/12/2002	11/12/2002	11/12/2002	11/12/2002	11/12/2002	11/13/2002
Date/time	23:00	9:00	11:15			15:55	15:55	16:23	16:42	18:32	23:40	8:00
time elapsed	6.00	10.00	2.25	41.17	31.22	76.67	0.00	0.47	0.32	1.83	5.13	8.33
Cycle cumulative time	18.97	28.97	31.22			76.67	0.00	0.47	0.78	2.62	7.75	16.08
Total cumulative time	896.55	925.52	956.73			1033.40	1033.40	1033.87	1034.65	1037.27	1045.02	1061.10
operator	JE	JE	JE	JE	JE	JE	JE	JE	JE	JE	JE	JE
Steam Generator								O2 On	O2 off			
Supply water total in reading	4644	5011	5117			5117	5117	5149	5149	5202	5360	5645
Supply water total in (actual)	4144.8	4511.8	4617.8	1070	1070	4617.8	4617.8	4649.8	4649.8	4702.8	4860.8	5145.8
Condensate total out reading	768	768	806			806	806	845	845	845	845	845
Condensate total out (actual)	555.5	555.5	593.5	179	179	593.5	593.5	632.5	632.5	632.5	632.5	632.5
Steam injection pressure	27	26	26	0	0	0	0	11	24	24	25	26
Steam temperature	268	268	268	0	0	0	0	240	264	264	265	268
Steam injection rate (lbs/hr)	252.78	305.83	251.85	180.36	237.85	0.00	0.00	-125.00	0.00	240.91	256.49	285.00
O ₂ injection rate	0	0	0	0	0	0	0	0	15	15	0	0
O ₂ pressure	0	0	0	0	0	0	0	0	23.5	24	0	0
Fuel Tank												
Date/time						11/12/2002	15:45					
operator						JE						
Propane level						32						
Propane pressure						130						

Table F-1. Steam Injection Phase: Process Data (Continued)

Sheet 1: Steam Injection Phase		CYCLE 3 Time Elapsed	CYCLE 3 Boiler Total
		TOTAL	TOTAL
Date/time	11/14/2002 14:45		
time elapsed	0.58	46.83	46.33
Cycle cumulative time	46.83		
Total cumulative time	1476.67		
operator	JE	JE	JE
Steam Generator	Blowdown Complete		
Supply water total in reading	6760		
Supply water total in (actual)	6260.8	1643	1643
Condensate total out reading	895		
Condensate total out (actual)	682.5	89	89
Steam injection pressure	11	0	0
Steam temperature	239	0	0
Steam injection rate (lbs/hr)	214.29	276.51	279.50
O ₂ injection rate	0	0	0
O ₂ pressure	0	0	0
Fuel Tank			
Date/time			
operator			
Propane level			
Propane pressure			

Table F-2. Summary of Steam Injection Phases

		CYCLE 1A TOTAL	CYCLE 1B Boiler Total TOTAL	CYCLE 2 Boiler Total TOTAL	CYCLE 3 Boiler Total TOTAL
Date/time		10/25/2002 16:00			
time elapsed	hrs	48.33	46.75	31.22	46.33
Cycle cumulative time					
Total cumulative time					
operator		SC	JE	JE	JE
Steam Generator					
Supply water total in reading	gal				
Supply water total in (actual)	gal	1943.9	1603.9	1070	1643
Condensate total out reading	gal				
Condensate total out (actual)	gal	190.55	223.95	179	89
Total water in	gal	1753.35	1379.95	891	1554
120% of water in	gal	2104.02	1655.94	1069.2	1864.8
Steam injection pressure	Steam pressure (psig)				
Steam temperature	Steam temperature (deg F)				
Steam injection rate (lbs/hr)	lbs/hr	302.32	245.98	237.83	279.52
O ₂ injection rate	Oxygen injection rate (scfh)				
O ₂ pressure	psig at wellhead				
Fuel Tank					
Date/time		10/23/2002	10/29/2002	11/5/2002	11/20/2002
operator		SC	JE	JE	JE
Propane level	%	50	45	38	30
Propane pressure	psig	145		120	135

Table F-3. Extraction Phase: Process Data (Continued)

	Ext. off at 2110					
Date/time	11/20/2002 10:30	11/20/2002 12:00	11/20/2002 15:15	11/20/2002 18:00	11/20/2002 20:40	11/20/2002 21:25
time elapsed (min)	90	90	195	165	160	45
cumulative time	22290	22380	22575	22740	22900	22945
operator	JE	JE	JE	JE	JE	JE
Vapor Treatment System						
HE-1 INLET Temp	130	135	132	120	130	72
HE-1 OUTLET Temp	125	128	126	110	106	95
KO-2 LIQUID LEVEL	50	60	60	50	50	40
KO-2 Pressure	-22	-24	-23	-21	-18	-4
KO-2 OUTLET Temp	126	130	136	110	102	96
HE-2 INLET Temp	105	104	111	96	84	81
HE-2 Pressure	16	16	16	16	16	18
HE-2 OUTLET Temp	91	92	98	83	84	83
M-04 Cumulative Flow	71953	72649	74263	75532	76862	77176
M-04 Flow rate (seal water)	8.2	8.2	8	7.1	8.1	7.7
KO-3 INLET Temp	102	102	11	96		81
KO-3 Pressure	0	0	0	0	0	0
KO-3 OUTLET Temp	90	90	96	90	80	76
HE-4 INLET Temp	72	80	74	69	68	60
HE-4 OUTLET Temp	76	82	76	84	78	80
Seal Water Cumulative Inflow	82	84	93	95	98	98
Liquid Cumulative to Tank	3248	3368	3595	3774	3931	3973
V-2 FLOW RATE	0.01	0.01	0.02	0.15	0.01	0.01
Flow to tank from formation	133	118	218	177	154	42
Cum. flow to tank from fm. this cycle	1201	1319	1537	1714	1868	1910
Cum. flow to tank from fm.	3770	3888	4106	4283	4437	4479
S-1						
Well-head temperature						
Well-head pressure						
Bubbler delta-P						
Liquid line temperature						
Liquid line pressure						
Pump motor setting						
Liquid line cumulative flow						
flow rate						
Holding tank level						

Table F-3. Extraction Phase: Process Data (Continued)

	Ext. off at 2110					
Date/time	11/20/2002 10:30	11/20/2002 12:00	11/20/2002 15:15	11/20/2002 18:00	11/20/2002 20:40	11/20/2002 21:25
time elapsed (min)	90	90	195	165	160	45
cumulative time	22290	22380	22575	22740	22900	22945
operator	JE	JE	JE	JE	JE	JE
Vapor Treatment System						
HE-1 INLET Temp	130	135	132	120	130	72
HE-1 OUTLET Temp	125	128	126	110	106	95
KO-2 LIQUID LEVEL	50	60	60	50	50	40
KO-2 Pressure	-22	-24	-23	-21	-18	-4
KO-2 OUTLET Temp	126	130	136	110	102	96
HE-2 INLET Temp	105	104	111	96	84	81
HE-2 Pressure	16	16	16	16	16	18
HE-2 OUTLET Temp	91	92	98	83	84	83
M-04 Cumulative Flow	71953	72649	74263	75532	76862	77176
M-04 Flow rate (seal water)	8.2	8.2	8	7.1	8.1	7.7
KO-3 INLET Temp	102	102	11	96		81
KO-3 Pressure	0	0	0	0	0	0
KO-3 OUTLET Temp	90	90	96	90	80	76
HE-4 INLET Temp	72	80	74	69	68	60
HE-4 OUTLET Temp	76	82	76	84	78	80
Seal Water Cumulative Inflow	82	84	93	95	98	98
Liquid Cumulative to Tank	3248	3368	3595	3774	3931	3973
V-2 FLOW RATE	0.01	0.01	0.02	0.15	0.01	0.01
Flow to tank from formation	133	118	218	177	154	42
Cum. flow to tank from fm. this cycle	1201	1319	1537	1714	1868	1910
Cum. flow to tank from fm.	3770	3888	4106	4283	4437	4479
S-1						
Well-head temperature						
Well-head pressure						
Bubbler delta-P						
Liquid line temperature						
Liquid line pressure						
Pump motor setting						
Liquid line cumulative flow						
flow rate						
Holding tank level						

Table F-4. Boiler and SVE Operating Log

Boiler operating hours

	from	to	Hrs	Min	Subtotal Time (hrs)	Running Cycle Total	Running Cumulative Total	CYCLE
10/23/02	1540	2400	8	20	8.33	8.33	8.33	1A
10/24/02	0	2400	24	0	24.00	32.33	32.33	
10/25/02	0	1540	15	40	15.67	48.00	48.00	
10/30/02	1520	2400	8	40	8.67	8.67	56.67	1B
10/31/02	0	1130	11	30	11.50	20.17	68.17	
10/31/02	1510	2400	8	50	8.83	29.00	77.00	
11/01/02	0	1745	17	45	17.75	46.75	94.75	
11/07/02	1805	2210	4	5	4.08	4.08	98.83	2
11/08/02	807	2400	15	53	15.88	19.97	114.72	
11/09/02	0	1115	11	15	11.25	31.22	125.97	
11/12/02	1555	2400	8	5	8.08	8.08	134.05	3
11/13/02	0	1750	17	50	17.83	25.92	151.88	
11/13/02	1820	2400	5	40	5.67	31.58	157.55	
11/14/02	0	1355	13	55	13.92	45.50	171.47	

SVE operating hours

	from	to	Comments
10/29/2002	16:00	18:00	Shake-down test. No soil vapor extracted
10/30/2002	9:20		Shake-down test. No soil vapor extracted

	from	to	Hrs	Min	Subtotal Time (hrs)	Running Cycle Total	Running Cumulative Total
11/04/02	2300	2315	0	15	0.25	0.25	0.25
11/05/02	900	1010	1	10	1.17	1.42	1.42
11/05/02	1140	1230	0	50	0.83	2.25	2.25
11/05/02	1745	2400	6	15	6.25	8.50	8.50
11/06/02	0	1437	14	37	14.62	23.12	23.12
11/06/02	1500	1520	0	20	0.33	23.45	23.45
11/06/02	1610	2400	7	50	7.83	31.28	31.28
11/07/02	0	600	6	0	6.00	37.28	37.28
11/07/02	845	1320	4	35	4.58	41.87	41.87
11/08/02	1130	1200	0	30	0.50	42.37	42.37
11/11/02	1530	2330	8	0	8.00	8.00	50.37
11/12/02	940	1050	1	10	1.17	9.17	51.53
11/18/02	1600	2030	4	30	4.50	4.50	56.03
11/19/02	1000	2100	11	0	11.00	15.50	67.03
11/20/02	830	2110	12	40	12.67	28.17	79.70

Table F-5. Summary of Oxygen Injection During Steam Injection Phases (Continued)

O2 Injection Log

	from	to	Hrs	Min	Subtotal Time (hrs)	Running Cycle Total	Running Cum. Total	Estimated Avg rate (scf)	Total for Interval (scf)	Running Cycle Total (scf)	Running Cum. Total (scf)	CYCLE
10/23/02	0	0	0	0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1A
10/24/02	0	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0		
10/25/02	0	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0		
10/30/02	1700	1730	0	30	0.50	0.50	0.50	32.0	16.0	16.0	16.0	1B
10/30/02	1730	1930	2	0	2.00	2.50	2.50	43.5	87.0	103.0	103.0	
10/30/02	1930	2030	1	0	1.00	3.50	3.50	62.5	62.5	165.5	165.5	
10/30/02	2030	2045	0	15	0.25	3.75	3.75	70.0	17.5	183.0	183.0	
10/31/02	1635	1651	0	16	0.27	4.02	4.02	54.0	14.4	197.4	197.4	
10/31/02	1651	1715	0	24	0.40	4.42	4.42	20.0	8.0	205.4	205.4	
10/31/02	1715	1845	1	30	1.50	5.92	5.92	18.0	27.0	232.4	232.4	
11/01/02	935	1225	2	50	2.83	8.75	8.75	21.0	59.5	291.9	291.9	
11/08/02	950	1000	0	10	0.17	8.92	8.92	25.0	4.2	4.2	296.1	2
11/08/02	1000	1050	0	50	0.83	9.75	9.75	17.5	14.6	18.8	310.7	
11/08/02	1050	1140	0	50	0.83	10.58	10.58	25.0	20.8	39.6	331.5	
11/08/02	1140	1315	1	35	1.58	12.17	12.17	24.0	38.0	77.6	369.5	
11/08/02	1315	1430	1	15	1.25	13.42	13.42	24.0	30.0	107.6	399.5	
11/08/02	1430	1555	1	25	1.42	14.83	14.83	20.0	28.3	135.9	427.8	
11/12/02	1640	1832	1	52	1.87	16.70	16.70	15.0	28.0	163.9	455.8	3
11/13/02	835	1235	4	0	4.00	20.70	20.70	11.0	44.0	207.9	499.8	
11/13/02	1405	1712	3	7	3.12	23.82	23.82	10.0	31.2	239.1	531.0	

Table F-5. Summary of Oxygen Injection During Steam Injection Phases (Continued)

O2 Injection Log

	from	to	Hrs	Min	Subtotal Time (hrs)	Running Cycle Total	Running Cum. Total	Estimated Avg rate (scf)	Total for Interval (scf)	Running Cycle Total (scf)	Running Cum. Total (scf)	CYCLE
10/23/02	0	0	0	0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	1A
10/24/02	0	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0		
10/25/02	0	0	0	0	0.00	0.00	0.0	0.0	0.0	0.0		
10/30/02	1700	1730	0	30	0.50	0.50	0.50	32.0	16.0	16.0	16.0	1B
10/30/02	1730	1930	2	0	2.00	2.50	2.50	43.5	87.0	103.0	103.0	
10/30/02	1930	2030	1	0	1.00	3.50	3.50	62.5	62.5	165.5	165.5	
10/30/02	2030	2045	0	15	0.25	3.75	3.75	70.0	17.5	183.0	183.0	
10/31/02	1635	1651	0	16	0.27	4.02	4.02	54.0	14.4	197.4	197.4	
10/31/02	1651	1715	0	24	0.40	4.42	4.42	20.0	8.0	205.4	205.4	
10/31/02	1715	1845	1	30	1.50	5.92	5.92	18.0	27.0	232.4	232.4	
11/01/02	935	1225	2	50	2.83	8.75	8.75	21.0	59.5	291.9	291.9	2
11/08/02	950	1000	0	10	0.17	8.92	8.92	25.0	4.2	4.2	296.1	
11/08/02	1000	1050	0	50	0.83	9.75	9.75	17.5	14.6	18.8	310.7	
11/08/02	1050	1140	0	50	0.83	10.58	10.58	25.0	20.8	39.6	331.5	
11/08/02	1140	1315	1	35	1.58	12.17	12.17	24.0	38.0	77.6	369.5	
11/08/02	1315	1430	1	15	1.25	13.42	13.42	24.0	30.0	107.6	399.5	
11/08/02	1430	1555	1	25	1.42	14.83	14.83	20.0	28.3	135.9	427.8	
11/12/02	1640	1832	1	52	1.87	16.70	16.70	15.0	28.0	163.9	455.8	3
11/13/02	835	1235	4	0	4.00	20.70	20.70	11.0	44.0	207.9	499.8	
11/13/02	1405	1712	3	7	3.12	23.82	23.82	10.0	31.2	239.1	531.0	

Table F-6. Summary of Wasterwater Sample Profiles at L-2 (µg/L)

Parameter	Target Limit	L-2 120502 13:00	L-2 120502 13:45
	µg/L	µg/L	µg/L
Ammonia (as N)	1,500	<500	<500
Barium	1,000	79	50
Boron	1,000	280	260
Copper	13	<5	9.2
Cyanide	5.2	<3	<3
Mercury	0.012	0.066	0.0797
Cadmium	1.2	<1	<1
Methylene blue active substances (MBAS)	500	<50	<50
Oil and grease	10,000	<5,000	<5,000
TPH-GRO	50	<50	<50
TPH-MO	100	<100	<100
TPH-DRO	100	<50	<50
<i>bis</i> (2-ethylhexyl)phthalate	1.8	<1	<1
Chloroform	0.5	<0.5	<0.5
1,1,2-trichloroethane	0.5	<0.5	<0.5
<i>trans</i> -1,2-DCE	0.5	<0.5	<0.5
<i>cis</i> -1,2-DCE	0.5	<0.5	<0.5
TCE	0.5	<0.5	<0.5
PCE	0.5	<0.5	<0.5
VC	0.5	<0.5	<0.5

Shading denotes any detection above reporting limits, but not necessarily exceeds the listed target limits. Bold face indicates that the analysis results exceed the target limit.

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

Item	Value	Units	Item	Value	Units
Width of DNAPL zone, w	100	ft	Hyd. conductivity, K	1	ft/d
Depth of DNAPL zone, d	30	ft	Hyd. gradient, I	0.0007	ft/ft
Cross-sectional area of DNAPL zone, a	3000	sq ft	Porosity, n	0.3	
Capture zone required	7	cu ft/d	Gw velocity, v	0.002333	ft/d
Safety factor, 100%	2				
Required capture zone	14	cu ft/d	GPM =	0.1	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 G-2. Capital Investment for a P&T System

Item	# units		Unit Price	Cost	Basis
Design/Procurement					
Engineer	200	hrs	\$85	\$17,000	
Drafter	160	hrs	\$40	\$6,400	
Hydrologist	200	hrs	\$85	\$17,000	
Contingency	1	ea	\$30,000	\$30,000	10% of total capital
TOTAL				\$70,400	
Pumping system					
Extraction wells	6	ea	\$5,000	\$30,000	2-inch, 40 ft deep, 30-foot SS screen; PVC; includes installation
Pulse pumps	6	ea	\$595	\$3,570	2.1 gpm max., 1.66"OD for 2-inch wells; handles solvent contact; pneumatic; with check valves
Controllers	6	ea	\$1,115	\$6,690	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	6	ea	\$5,000	\$30,000	Estimate
Tubing	900	ft	\$3	\$3,051	1/2-inch OD, chemical resistant; well to surface manifold
TOTAL				\$73,956	
Treatment System					
Piping	900	ft	\$3	\$3,051	chemical resistant
Trench	3	day	\$320	\$960	ground surface
DNAPL separator 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				\$88,346	
Site Preparation					
Concrete 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	15	wells	\$2,149	\$32,235	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				\$47,344	
Installation/Start Up of Treatment System					
Engineer	80	hrs	\$85	\$6,800	Labor
Technician	200	hrs	\$40	\$8,000	Labor
TOTAL				\$14,800	
TOTAL CAPITAL INVESTMENT				\$294,846	

Table G-2. Capital Investment for a P&T System (continued)

O&M Cost for P&T System					
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	72	smpls	\$120	\$8,640	15 wells; quarterly; MS, MSC
Sampling materials	1	ea	\$500	\$500	Miscellaneous
Technician	80	hrs	40	\$3,200	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				\$11,760	
TOTAL ANNUAL COST				\$62,015	
Periodic Maintenance, Every 5 years					
Pulse pumps	6	ea	\$595	\$3,570	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				\$14,055	
				\$76,070	
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				\$104,405	

Table G-3. Present Value of P&T System Costs for 30 years of operation

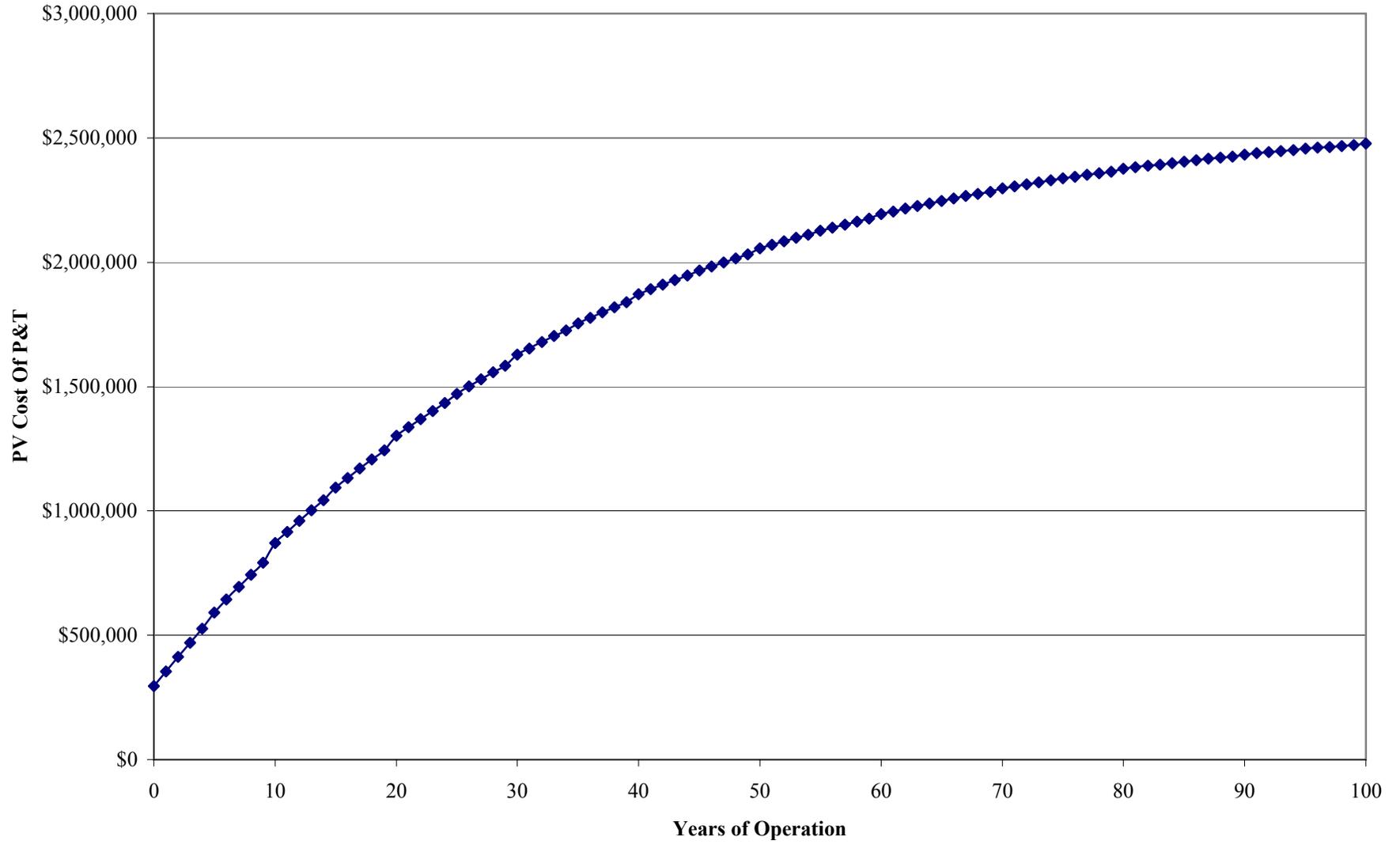
Year	P&T		
	Annual Cost *	PV of Annual Cost	Cumulative PV of Annual Cost
0	\$294,846	\$294,846	\$294,846
1	\$62,015	\$60,267	\$355,113
2	\$62,015	\$58,569	\$413,682
3	\$62,015	\$56,918	\$470,600
4	\$62,015	\$55,314	\$525,914
5	\$76,070	\$65,938	\$591,852
6	\$62,015	\$52,240	\$644,092
7	\$62,015	\$50,768	\$694,859
8	\$62,015	\$49,337	\$744,197
9	\$62,015	\$47,947	\$792,143
10	\$104,405	\$78,445	\$870,588
11	\$62,015	\$45,282	\$915,871
12	\$62,015	\$44,006	\$959,877
13	\$62,015	\$42,766	\$1,002,642
14	\$62,015	\$41,561	\$1,044,203
15	\$76,070	\$49,543	\$1,093,746
16	\$62,015	\$39,251	\$1,132,997
17	\$62,015	\$38,145	\$1,171,142
18	\$62,015	\$37,070	\$1,208,211
19	\$62,015	\$36,025	\$1,244,236
20	\$104,405	\$58,940	\$1,303,177
21	\$62,015	\$34,023	\$1,337,200
22	\$62,015	\$33,064	\$1,370,264
23	\$62,015	\$32,132	\$1,402,396
24	\$62,015	\$31,227	\$1,433,623
25	\$76,070	\$37,224	\$1,470,848
26	\$62,015	\$29,491	\$1,500,339
27	\$62,015	\$28,660	\$1,528,999
28	\$62,015	\$27,853	\$1,556,852
29	\$62,015	\$27,068	\$1,583,920
30	\$104,405	\$44,285	\$1,628,205

* 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

Table G-4. Present Value of P&T System Costs for 100 years of operation

Year	P&T PV of			Year	P&T PV of		
	Annual Cost *	Annual Cost	Cumulative PV of Annual Cost		Annual Cost *	Annual Cost	Cumulative PV of Annual Cost
0	\$294,846	\$294,846	\$294,846	51	\$62,015	\$14,432	\$2,070,339
1	\$62,015	\$60,267	\$355,113	52	\$62,015	\$14,025	\$2,084,364
2	\$62,015	\$58,569	\$413,682	53	\$62,015	\$13,630	\$2,097,993
3	\$62,015	\$56,918	\$470,600	54	\$62,015	\$13,245	\$2,111,239
4	\$62,015	\$55,314	\$525,914	55	\$76,070	\$15,789	\$2,127,028
5	\$76,070	\$65,938	\$591,852	56	\$62,015	\$12,509	\$2,139,538
6	\$62,015	\$52,240	\$644,092	57	\$62,015	\$12,157	\$2,151,694
7	\$62,015	\$50,768	\$694,859	58	\$62,015	\$11,814	\$2,163,509
8	\$62,015	\$49,337	\$744,197	59	\$62,015	\$11,481	\$2,174,990
9	\$62,015	\$47,947	\$792,143	60	\$104,405	\$18,784	\$2,193,774
10	\$104,405	\$78,445	\$870,588	61	\$62,015	\$10,843	\$2,204,618
11	\$62,015	\$45,282	\$915,871	62	\$62,015	\$10,538	\$2,215,155
12	\$62,015	\$44,006	\$959,877	63	\$62,015	\$10,241	\$2,225,396
13	\$62,015	\$42,766	\$1,002,642	64	\$62,015	\$9,952	\$2,235,348
14	\$62,015	\$41,561	\$1,044,203	65	\$76,070	\$11,864	\$2,247,211
15	\$76,070	\$49,543	\$1,093,746	66	\$62,015	\$9,399	\$2,256,610
16	\$62,015	\$39,251	\$1,132,997	67	\$62,015	\$9,134	\$2,265,744
17	\$62,015	\$38,145	\$1,171,142	68	\$62,015	\$8,877	\$2,274,621
18	\$62,015	\$37,070	\$1,208,211	69	\$62,015	\$8,627	\$2,283,248
19	\$62,015	\$36,025	\$1,244,236	70	\$104,405	\$14,114	\$2,297,361
20	\$104,405	\$58,940	\$1,303,177	71	\$62,015	\$8,147	\$2,305,509
21	\$62,015	\$34,023	\$1,337,200	72	\$62,015	\$7,918	\$2,313,426
22	\$62,015	\$33,064	\$1,370,264	73	\$62,015	\$7,694	\$2,321,121
23	\$62,015	\$32,132	\$1,402,396	74	\$62,015	\$7,478	\$2,328,598
24	\$62,015	\$31,227	\$1,433,623	75	\$76,070	\$8,914	\$2,337,512
25	\$76,070	\$37,224	\$1,470,848	76	\$62,015	\$7,062	\$2,344,574
26	\$62,015	\$29,491	\$1,500,339	77	\$62,015	\$6,863	\$2,351,437
27	\$62,015	\$28,660	\$1,528,999	78	\$62,015	\$6,670	\$2,358,106
28	\$62,015	\$27,853	\$1,556,852	79	\$62,015	\$6,482	\$2,364,588
29	\$62,015	\$27,068	\$1,583,920	80	\$104,405	\$10,605	\$2,375,192
30	\$104,405	\$44,285	\$1,628,205	81	\$62,015	\$6,121	\$2,381,314
31	\$62,015	\$25,563	\$1,653,768	82	\$62,015	\$5,949	\$2,387,263
32	\$62,015	\$24,843	\$1,678,611	83	\$62,015	\$5,781	\$2,393,044
33	\$62,015	\$24,143	\$1,702,754	84	\$62,015	\$5,618	\$2,398,662
34	\$62,015	\$23,462	\$1,726,217	85	\$76,070	\$6,697	\$2,405,360
35	\$76,070	\$27,969	\$1,754,186	86	\$62,015	\$5,306	\$2,410,666
36	\$62,015	\$22,159	\$1,776,344	87	\$62,015	\$5,157	\$2,415,822
37	\$62,015	\$21,534	\$1,797,878	88	\$62,015	\$5,011	\$2,420,833
38	\$62,015	\$20,927	\$1,818,806	89	\$62,015	\$4,870	\$2,425,703
39	\$62,015	\$20,337	\$1,839,143	90	\$104,405	\$7,968	\$2,433,671
40	\$104,405	\$33,274	\$1,872,417	91	\$62,015	\$4,599	\$2,438,271
41	\$62,015	\$19,207	\$1,891,624	92	\$62,015	\$4,470	\$2,442,740
42	\$62,015	\$18,666	\$1,910,290	93	\$62,015	\$4,344	\$2,447,084
43	\$62,015	\$18,140	\$1,928,430	94	\$62,015	\$4,221	\$2,451,305
44	\$62,015	\$17,629	\$1,946,059	95	\$76,070	\$5,032	\$2,456,338
45	\$76,070	\$21,015	\$1,967,073	96	\$62,015	\$3,987	\$2,460,324
46	\$62,015	\$16,649	\$1,983,722	97	\$62,015	\$3,874	\$2,464,199
47	\$62,015	\$16,180	\$1,999,902	98	\$62,015	\$3,765	\$2,467,964
48	\$62,015	\$15,724	\$2,015,626	99	\$62,015	\$3,659	\$2,471,623
49	\$62,015	\$15,281	\$2,030,907	100	\$104,405	\$5,987	\$2,477,610
50	\$104,405	\$25,001	\$2,055,907				

Figure G-1. P&T System Costs - 100 years



**Final
Demonstration Work Plan:
Dynamic Underground Stripping with Hydrous Pyrolysis
Oxidation (DUS/HPO) Technology at Beale Air Force Base**

Prepared for:

**Naval Facilities Engineering Service Center
Port Hueneme, CA**

Technology provided by:

Lawrence Livermore National Laboratory, CA

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Beale Air Force Base, CA

Prepared by:

**Battelle
Columbus, OH**

and

**SteamTech Environmental Services
Bakersfield, CA**

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Washington, DC**

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Contents

Appendices.....	v
Figures.....	vi
Tables.....	vi
Acronyms and Abbreviations	vii
1.0 Introduction.....	1
1.1 Background.....	1
1.2 Objectives of the Demonstration	1
1.3 Regulatory Drivers.....	2
1.4 Stakeholder/End-User Issues	2
2.0 Technology Description.....	3
2.1 Technology Development and Application	3
2.2 Previous Testing of the Technology	3
2.3 Factors Affecting Cost and Performance.....	4
2.4 Advantages and Limitations of the Technology	5
3.0 Demonstration Design	6
3.1 Performance Objectives	6
3.2 Selecting the Demonstration Site.....	8
3.3 Demonstration Site History/Characteristics.....	8
3.3.1 Geology and Hydrogeology	10
3.3.2 Nature and Extent of Contamination.....	12
3.3.3 Groundwater Geochemistry	16
3.4 Present Operations	16
3.5 Operation and Evaluation Plan	17
3.5.1 Demonstration Setup and Startup.....	17
3.5.2 Period of Operation	26
3.5.3 Amount/Treatment Rate of Material	28
3.5.4 Residuals Handling.....	28
3.5.5 Operating Parameters for the Technology.....	29
3.5.6 Demonstration System	29
3.5.6.1 Feed-Water and Steam Injection Stream	30
3.5.6.2 Extraction and Effluent Treatment System.....	30
3.5.6.3 First Steam Injection Phase.....	32
3.5.6.4 Soaking and HPO Destruction Period.....	32
3.5.6.5 Extraction and Control Phase.....	32
3.5.6.6 Subsequent Cycles (Steam Injection/Soak/Extraction Phases).....	34
3.5.6.7 Cessation of Operations	34
3.5.7 Sampling Plan.....	34
3.5.7.1 Data Quality Objectives.....	34
3.5.7.2 COCs and Analytical Parameters.....	35

3.5.7.3	Sampling Methods	35
3.5.7.4	Analytical Methods, Calibration, Detection Limits, and Accuracy	37
3.5.7.5	Sampling Locations and Frequencies	37
3.5.7.6	Quality Assurance/Quality Control (QA/QC)	41
3.5.8	Demobilization	41
3.5.9	Health and Safety Plan	42
3.6	Selection of Analytical/Testing Methods.....	42
3.7	Selection of Analytical/Testing Laboratory.....	44
3.8	Management and Staffing.....	44
3.9	Demonstration Schedule	44
4.0	Performance Assessment	47
4.1	Performance Objectives	47
4.1.1	In Situ Destruction of COCs by Means of HPO	47
4.1.2	Heat the Soil Around the Injection Well by Means of Steam Injection.....	49
4.1.3	Maintain Hydraulic Control and Prevent Significant Migration of COCs.....	50
4.2	Performance Confirmation Methods.....	50
4.2.1	Sampling During Drilling and Installation.....	51
4.2.2	Aquifer Testing.....	52
4.2.3	Operational Monitoring.....	52
4.2.3.1	Subsurface Temperature and ERT Monitoring.....	52
4.2.3.2	Process Monitoring.....	52
4.2.4	Poststeam Monitoring.....	54
4.2.4.1	Poststeam Strategy.....	54
4.2.4.1	Subsurface Monitoring.....	55
4.2.4.2	Drilling and Characterization.....	55
4.3	Data Analysis, Interpretation and Evaluation	55
4.3.1	Presteam Temperature and ERT Data	55
4.3.2	Temperature Monitoring	55
4.3.3	Steam Injection Volumes and Rates.....	56
4.3.4	Groundwater Quality.....	56
4.3.5	Soil-Gas COC Concentrations.....	56
4.3.6	Effluent Treatment System Performance	57
4.3.7	TCE Removal Calculations.....	57
5.0	Cost Assessment	58
5.1	Cost Reporting.....	58
5.2	Cost Analysis	58
6.0	Implementation Issues	59
6.1	Environmental Checklist.....	59
6.1.1	Resource Conservation and Recovery Act (RCRA) and Title 22, Division 4.5 of the California Code of Regulations.....	59
6.1.2	Clean Water Act.....	60

6.1.3	Safe Drinking Water Act and the California Safe Drinking Water Act.....	60
6.1.4	Clean Air Act.....	61
6.1.5	Occupational Safety and Health Administration Rules.....	61
6.1.6	Other Selected Federal Regulations	61
6.1.7	Other Selected State Regulations	62
6.1.8	Other Selected Local Regulations	62
6.2	Permitting and Waste Disposal Issues	62
6.3	Other Regulatory and End-User Issues.....	65
7.0	References.....	66

Appendices

Appendix A.	Points of Contact
Appendix B.	Slug Test Results and Boring Logs
	B-1. Slug Test Results
	B-2. Soil Borings and Well Logs
	B-3. Well Completion Diagram
	B-4. Site Characterization and Analysis Penetrometer System Results
Appendix C.	Health and Safety Plan

Figures

Figure 3-1.	Map of Historic and Phase 1, 2, and 3 Site Characterization Locations.....	9
Figure 3-2.	Geologic Cross Section A-A' at SWMU 23	11
Figure 3-3.	Groundwater Levels Based on August 2001 Survey	13
Figure 3-4.	Well Layout at Demonstration Site, Showing Location of Existing Wells and Footprint of SES Equipment	19
Figure 3-5.	Cross-Section Extending from SW (left) to NE (right) of Demonstration Site	20
Figure 3-6.	Summary of Well Design Features: a) Well Design, b) Detail of Wellhead.....	21
Figure 3-7.	Groundwater Monitoring Well and VEA Borehole Design	22
Figure 3-8.	Construction Diagram for Soil-Gas Monitoring Points	23
Figure 3-9.	Steam Generation and Injection Schematic Diagram	31
Figure 3-10.	Simplified Effluent Treatment System Flow Diagram	33
Figure 3-11.	Vertical Electrode Array Design Detail	43
Figure 3-12.	Project Organization Chart	45
Figure 3-13.	Preliminary Demonstration Schedule	46

Tables

Table 3-1.	Objectives of Demonstration Project	6
Table 3-2.	Summary of Slug Test Results at Beale AFB, CA.....	12
Table 3-3.	Summary of VOC Results in Phase 1 Monitoring Wells.....	14
Table 3-4.	Summary of Highest TCE levels in µg/L at Each Phase 2 MIP Location	15
Table 3-5.	Summary of VOC Results in Phase 3 Monitoring Wells.....	16
Table 3-6.	Field Parameters and Inorganic Sampling Results in Phase 1 Monitoring Wells.....	17
Table 3-7.	Field Parameters in Phase 3 Monitoring Wells.....	17
Table 3-8.	Major Design Parameters and Tentative Specifications for the Equipment Used for the HPO Demonstration	27
Table 3-9.	Contaminants of Concern for the Beale DUS/HPO Demonstration	36
Table 3-10.	Analysis Method for Sampling of Groundwater, Vapor and Soil.....	36
Table 3-11.	Overview of Sampling, Analyses, and Monitoring Frequencies.....	39
Table 3-12.	Emitted Vapor Criteria	40
Table 3-13.	Liquid Effluent Limitations for Parameters Specified by CRWQCB ^(a)	40
Table 3-14.	Summary of QA/QC Samples	42
Table 4-1.	Summary of Performance Criteria	47
Table 4-2.	Overview of Expected Performance and Performance Confirmation Methods.....	51
Table 4-3.	Process Monitoring During Operations.....	53
Table 6-1.	Permit Requirements	63
Table 6-2.	Estimated Waste Generation	64

Acronyms and Abbreviations

3-D	three-dimensional
AFB	Air Force Base
AQMD	Air Quality Management District
ASME	American Society of Mechanical Engineers
BAAQMD	Bay Area Air Quality Management District
BACT	Best Available Control Technology
BERC	Berkley Environmental Restoration Center
bgs	below ground surface
BTU/hr	British thermal units per hour
CAA	Clean Air Act
CCR	California Code of Regulations
CFR	Code of Federal Regulations
CO ₂	carbon dioxide
COC	contaminant of concern
COD	chemical oxygen demand
CPT	cone penetrometer test
CRWQCB	California Regional Water Quality Control Board
CVOC	chlorinated volatile organic compound
CWA	Clean Water Act
DCE	dichloroethene
DNAPL	dense, nonaqueous-phase liquid
DO	dissolved oxygen
DoD	United States Department of Defense
DOE	United States Department of Energy
DSITMS	direct-sampling ion-trap mass spectrometer
DUS	dynamic underground stripping
ERT	electrical resistivity tomography
ESA	Endangered Species Act
ESTCP	Environmental Security Technology Certification Program
EVS	Environmental Visualization System
GAC	granular activated carbon
gpd	gallons per day
gpm	gallons per minute
HAP	hazardous air pollutant
HASP	Health and Safety Plan

HPO	hydrous pyrolysis oxidation
HSA	hollow-stem auger
KO-1	knockout vessel 1 (liquid-vapor separator)
KO-2	knockout vessel 2 (liquid-vapor separator)
LLNL	Lawrence Livermore National Laboratory
LNAPL	light, nonaqueous-phase liquid
MACT	Maximum Achievable Control Technology
MBAS	methylene blue active substances
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MIP	membrane interface probe
mS/cm	millisiemens per centimeter
MW	monitoring well
NA	not available
N/A	not applicable
NAAQS	National Ambient Air Quality Standards
NAPL	nonaqueous-phase liquid
NFESC	Naval Facilities Engineering Service Center
NHPA	National Historical Preservation Act
O&M	operation and management
ORP	oxidation/reduction potential
OSHA	Occupational Safety and Health Administration
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PID	photoionization detector
ppb	parts per billion (microgram per liter)
PPE	personal protective equipment
ppm	parts per million (milligram per liter)
ppmv	parts per million by volume
psi	pounds per square inch
psia	pounds per square inch/area
psig	pounds per square inch gauge
PV	present value
PVC	polyvinyl chloride

QA	quality assurance
QA/QC	quality assurance/quality control
QC	quality control
RCRA	Resource Conservation and Recovery Act
RWQCB	(California) Regional Water Quality Control Board, Central Valley Region
SCADA	Supervisory Control and Data Acquisition
SCAPS	Site Characterization and Analysis Penetrometer System
S/D	shallow/deep
SDWA	Safe Drinking Water Act
SES	SteamTech Environmental Services
SIP	State Implementation Plan
STLC	soluble threshold limit concentration
SWMU	Solid Waste Management Unit
SWRCB	State Water Resources Control Board
TCA	trichloroethane
TCE	trichloroethylene
TDS	total dissolved solids
TOC	total organic carbon
TPH-DRO	total petroleum hydrocarbons–diesel-range organics
TPH-GRO	total petroleum hydrocarbons–gasoline-range organics
TPH-MO	total petroleum hydrocarbons–motor oil
TTLC	total threshold limit concentration
U.S. EPA	United States Environmental Protection Agency
VC	vinyl chloride
VEA	vertical electrode array
VOA	volatile organic analysis
VOC	volatile organic compound
WET	(California) Waste Extraction Test
µg/L	micrograms per liter

1.0 Introduction

1.1 Background

Because of the limited success with conventional technologies in achieving cost-effective and timely cleanup of groundwater contaminated with chlorinated solvents such as trichloroethylene (TCE), there has been a strong demand for the development and testing of remediation technologies that rely on physical, chemical, thermal, or biological mechanisms to enhance the removal and/or destruction of these compounds. As part of research efforts to address this demand, the U.S. Department of Energy's (DOE's) Lawrence Livermore National Laboratory (LLNL) has developed and patented an innovative technology called dynamic underground stripping (DUS) with hydrous pyrolysis oxidation (HPO). The DUS/HPO technique relies on both thermal and chemical mechanisms to enhance the remediation and destruction of chlorinated solvents in the subsurface. DUS involves the injection/extraction of steam combined with electrical heating. DUS/HPO involves the injection of air along with the steam. This combination promotes the in situ oxidation of chlorinated solvents to carbon dioxide (CO₂), chloride ions, and water in the presence of sufficient dissolved oxygen (DO) and under high temperatures, which brings about more rapid chemical reactions and higher mass transfer rates.

1.2 Objectives of the Demonstration

The United States Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP) has recognized the potential benefit in applying the DUS/HPO technology at many DoD environmental restoration sites, and is supporting this demonstration and validation effort at Beale Air Force Base (AFB) in Marysville, CA.

Previous applications of this technology have focused primarily on contaminant removal through steam injection and extraction, along with extensive aboveground treatment of the extracted fluids. This demonstration will be conducted at a site without a significant dense, nonaqueous-phase liquid (DNAPL) source zone present and will be concerned primarily with the in situ destruction of TCE in the dissolved-phase plume at Solid Waste Management Unit (SWMU) 23. The DUS/HPO technique also could be employed as a "polishing" step (after source zone removal has been implemented) to reduce elevated groundwater contaminant levels by several orders of magnitude in order to meet acceptable cleanup criteria (e.g., maximum contaminant levels [MCLs]). Compared to DUS/HPO, other competing chemical oxidation methods (e.g., potassium permanganate injection) may be limited by higher mass transfer limitations and/or poor contact due to displacement of the contaminant during reagent injection.

This demonstration employs a novel mode of DUS/HPO application using a cycled steam injection and extraction process from a single well, termed the "huff-and-puff" technique. The method involves intermittent operation of the system consisting of active steam/air injection into the subsurface, a passive "soaking" period, which allows the oxygen (O₂)-laden steam to condense and mix with contaminated groundwater in a heated zone, and then active extraction to recover displaced contaminants and to minimize their migration outside of the target treatment area. The majority of the contaminant is oxidized during the passive "soaking" period. This

novel method represents a significant advance over the application of DUS alone, primarily because in situ treatment of the chlorinated solvents results in a reduction in aboveground treatment requirements and costs as follows: (1) contaminants are significantly degraded in situ, which decreases the contaminant levels in the extracted fluids; (2) cyclic steam injection and extraction reduces the volume of extracted fluids; and (3) cyclic operation requires less intensive operation and maintenance of the system. Another potential enhancement to the application of DUS/HPO considered in this demonstration is to increase the O₂ delivery rate through the injection of pure O₂ with the steam.

1.3 Regulatory Drivers

The application of DUS/HPO should result in the rapid in situ destruction of chlorinated solvents in groundwater and should diminish the hazard posed by the contamination and accelerate site closure. Thus, in an overall site remediation scheme, DUS/HPO could follow source zone removal and be used to treat residual contamination in the dissolved-phase plume to meet federal or state MCLs or other risk-based cleanup levels.

1.4 Stakeholder/End-User Issues

This project will address stakeholder and end-user issues through demonstration and optimization of the proposed cycled, single-well DUS/HPO process. This effort and the resulting technical reports will serve as a means of technology transfer to other end-users who could benefit from the use of this remediation technology at their site.

2.0 Technology Description

2.1 Technology Development and Application

Steam-enhanced remediation is a technology in which steam is injected into the subsurface through wells, and contaminated fluids are extracted for on-site treatment. The fundamentals of steam injection and extraction technology were developed for enhanced oil recovery within the oil industry during the 1960s and 1970s. Several demonstrations of steam injection for contaminant recovery were conducted in the Netherlands in the early 1980s, and in the late 1980s at University of California, Berkeley (Udell and Stewart, 1989). Later, a process called steam-enhanced extraction, involving steam injection and dual-phase extraction deployed in a specific manner, was patented (Udell et al., 1991). The patented approach involves cessation of steam injection while continuing liquid and vapor extraction. Steam injection was later combined with electrical heating by Lawrence Livermore National Laboratory and University of California to form the DUS process, which then was patented (Newmark et al., 1994; Newmark and Aines, 1997; Daily et al., 1995). This process was successfully demonstrated at the Livermore Gasoline Pad Site for removal of a light, nonaqueous-phase liquid (LNAPL) source trapped below the water table (Newmark et al., 1994).

HPO is a rapid, in situ remediation technique that destroys subsurface contaminants, such as TCE and other dissolved organic components, with a minimal need for extraction. Steam and air is injected into the target zone, building a heated, oxygenated zone in the subsurface, where TCE is oxidized and degraded chemically. When the injection of steam and air is stopped, the steam condenses and contaminated groundwater returns to the heated zone, mixing with the air and condensate. Then, in the presence of heat, TCE is oxidized into CO₂ and chloride. This method takes advantage of the much more rapid reactions that take place at steam temperature, as well as the large increases in mass transfer rates (dissolution of nonaqueous-phase liquid [NAPL] into the water), which makes contaminants more available for destruction.

The workers at LLNL have shown complete mineralization of common contaminants such as polycyclic aromatic hydrocarbons (PAHs) (coal tar and creosote components), and chlorinated solvents and oil and gasoline components (Knauss et al., 1997). A detailed study on the kinetics of TCE destruction also was completed (Knauss et al., 1998).

2.2 Previous Testing of the Technology

The most noteworthy test of HPO processes in a hydrogeological setting comparable to the setting at the Beale AFB demonstration site is a test conducted by LLNL at the Visalia Pole Yard site in the San Joaquin Valley of California (Newmark et al., 1998). This study was conducted as part of a successful application of steam stripping (i.e., DUS) by Southern California Edison, the site owner. The disappearance of DO in groundwater, appearance of oxidized intermediate products of the contaminants, and production of CO₂ bearing a stable carbon isotope signature more similar to that of the contaminants than of air and soil gases all provided evidence to support the in situ destruction of hydrocarbons by HPO.

SteamTech Environmental Services (SES) is the first commercial licensee of the patented steam and HPO technologies, bringing the technologies to bear on environmental cleanup sites. SES has applied the technology at the Visalia Pole Yard (as a subcontractor to Southern California Edison), at Portsmouth Gaseous Diffusion Plant (as the prime contractor), and at Alameda Point as a subcontractor to Berkeley Environmental Restoration Center (BERC, 2000).

The only completed field study of HPO destruction of TCE to date was performed by SES at Portsmouth, OH. Results were encouraging, and elevated CO₂ levels in the extracted vapors indicated that HPO reactions probably were important for removing TCE at the site. A total of approximately 1,000 lb of TCE was removed from a small pilot demonstration area through a combination of DUS and HPO (SES, 1999; Heron et al., 2000).

At an ongoing demonstration of steam injection at Savannah River Site in Aiken, SC, preliminary data on effluent vapor CO₂ levels indicate that a substantial amount of TCE and/or tetrachloroethene (PCE) is being degraded in situ (Integrated Water Resources, Inc., 2001). This field demonstration involves steam and air injection into multiple screens at three well locations, and liquid and vapor extraction at a central location.

To date, no demonstration of the single-well HPO technology has been conducted. All previous work has involved multiple wells where dedicated wells were used for either steam injection or extraction. Also, the injection of pure O₂ with the steam for the purpose of increasing the O₂ delivery rate and eliminating volatile organic compound (VOC) migration in the injected noncondensable air has not previously been attempted.

In summary, the steam and co-air injection technology has shown promise at previous demonstrations, with the data indicating that HPO reactions played a major role in the remedial processes at sites where VOC removal by DUS was the main focus. Therefore, it is anticipated that HPO reactions may be further optimized by using the proposed single well injection-soaking-extraction cycles to minimize VOC migration away from the well, and pure O₂ injection to optimize the reaction rates in the groundwater upon mixing of the steam condensate with the native contaminant of concern (COC)-laden groundwater.

2.3 Factors Affecting Cost and Performance

The principal factor affecting performance in the application of this DUS/HPO technology is the distribution of permeability. The radius of influence of steam injected over a screened interval in a well is governed by permeability. Modeling of steam migration using data collected during initial characterization suggests that the permeability of the soil in the vicinity of the demonstration site is sufficiently high enough that the indicated treatment zone can be heated to its target temperature and for steam, with co-injected air, to impact contaminant-filled pores within that volume, in the time available for the demonstration. If permeability proves to be rather lower within the target volume, the radius of influence of injected steam may be significantly smaller than predicted and consequently the contaminant mass impacted would be smaller.

Redox conditions in the saturated zone at the demonstration site also could affect performance. Chlorinated solvents such as TCE commonly are degraded more easily under reducing conditions. In addition, if significant quantities of reduced minerals are present in soils within the target volume, these minerals will tend to take up O₂ coinjected to encourage HPO, with a consequent loss of available O₂ for destruction of contaminants. Redox conditions will be assessed by measuring DO concentrations in groundwater within the target volume. This process is discussed further in Section 3.5.7 (the Sampling Plan).

These factors would have the effect of reducing the overall effectiveness of the process, by limiting the extent of heating or of O₂ addition. In a full-scale cleanup, these limitations would increase the length of time required for cleanup, with consequent increases in costs of fuel used, labor, sampling and analyses.

2.4 Advantages and Limitations of the Technology

Advantages:

1. Low installation cost due to few wells or single injection/extraction well used for operation.
2. Low treatment cost due to minimizing need for extraction and treatment of extracted fluids.
3. Technology monitoring at an advanced stage may be reduced to temperature and flowrate monitoring along with confirmatory groundwater and soil samples.
4. By using fluid injection, the technology preferentially treats the permeable zones in contact with the well, which also are the zones that govern groundwater flowrates and downgradient groundwater quality.
5. The industry is looking for a less aggressive technology for use after source zone removal, where the groundwater COC levels (parts per million [ppm] range) may be several orders of magnitude higher than acceptable levels (parts per billion [ppb] range). The HPO technology may be used and optimized using the same wells as used for source zone removal.

Limitations:

1. Low radius of influence in tight formations where permeability limits the injection rate for steam and O₂.
2. Need to demonstrate that volatilization does not lead to migration of the COCs to the vadose zone or into other regions where the COCs are not extracted in the following extraction phase.
3. The HPO technology is limited to COCs that are degradable in heated, oxygenated water under actual field conditions in a time period of less than a few years.
4. The creation of an oxygenated, heated zone where the COCs are present in the groundwater may be complicated for volatile COCs that tend to vaporize when heated.
5. Formations with reducing conditions may have large chemical oxygen demand (COD), and reduced minerals such as iron sulfide, iron carbonate, or methane may consume the injected O₂ until the COD is overcome. This effect may dramatically increase the O₂ injection demand.

3.0 Demonstration Design

3.1 Performance Objectives

The performance objectives of the DUS/HPO demonstration and methods for evaluating performance are listed in Table 3-1; rationales for these objectives are discussed in detail in Section 4.1.

Table 3-1. Objectives of Demonstration Project^(a)

Performance Objectives	Expected Performance (Metric)	Method for Evaluating Performance
Primary Objective		
(1) Destroy COCs in situ by HPO	Statistically significant difference (reduction) between pre-and postdemonstration TCE concentrations in the monitoring wells in the target treatment zone.	<ul style="list-style-type: none"> a) Comparison of post-steam groundwater COC concentrations within the treatment zone against pre-steam baseline sampling concentrations. b) Monitoring of alkalinity (resulting from increased CO₂ production), CO₂ and chloride concentrations, methane levels (as an indicator of enhanced biological activity) and of the presence of COC degradation products (<i>cis</i>-1,2-DCE, and vinyl chloride) in effluent streams and groundwater in treatment zone.
Secondary Objectives		
(2) Heat the soil around the injection well by steam injection.	Heating of soil surrounding injection well to a temperature sufficient for HPO processes to operate (>80°C)	<ul style="list-style-type: none"> a) Direct measurement of temperature by thermocouples in monitoring boreholes and wells. b) Indirect measurement of soil temperature by ERT.
(3) Maintain hydraulic control of the site and prevent significant migration of COCs beyond the zone of effective HPO.	<ul style="list-style-type: none"> a) Recovery of groundwater volume in excess of original volume. b) Recovery of bromide-tagged water injected as steam. c) No evidence of significantly increased COC concentrations in groundwater monitoring wells lying outside the treatment zone (greater than 30 ft radius) over the course of the demonstration. d) No evidence of increased COC concentrations in soil gas above treatment zone. 	<ul style="list-style-type: none"> a) Water balance. b) Measurement of mass of bromide-tagged water recovered. c) Groundwater sampling of surrounding wells after completion of the demonstration and postdemonstration COC groundwater depth profiling of the site compared to a pre-steam baseline profile. d) Soil-gas monitoring for COCs during and after the demonstration compared to baseline sampling.

(a) Statistical significance to be defined jointly by SES, Battelle, and LLNL.
ERT = electrical resistivity tomography.

The first objective in Table 3-1 is the primary objective. For the first performance objective (evaluating TCE reduction in the treatment zone), groundwater sampling, rather than soil

sampling will be used to evaluate degree of treatment. Soil sampling would be useful if there were true free-phase DNAPL. Because this site contains relatively low concentrations of TCE, the treatment effectiveness will be measured by comparing pre- and postdemonstration groundwater water samples. Predemonstration water samples will be collected from all monitoring wells in the test area during three sampling events spaced at about one week each. Postdemonstration water samples will be collected during the first, second and third weeks after the steam injection system is turned off. Postdemonstration water samples (as well as the intermediate samples collected at the end of the first, third, and fifth cycles) are expected to be at elevated temperatures. It is to run the water withdrawn from the well through a cooling loop before collection. The cooling loop is an extra length of tubing that is immersed in an ice bath. The water comes out of the well, passes through the cooling loop and then goes to the flow-through cell for verification of stable field parameters. Then the flow-through cell is detached and the sample is collected from the water exiting the cooling loop. Our past experience is that it may take as much as a year before the water temperature subsides to ambient. A statistical comparison of the pre- and post treatment water concentrations will be conducted to evaluate effectiveness of steam treatment. The determination of how successful HPO has been will be made by looking at the following indicators:

- Statistically significant difference (reduction) between pre- and postdemonstration TCE concentrations in the monitoring wells in the target treatment zone.
- Increase between pre- and postdemonstration *cis*-1,2 DCE and vinyl chloride (TCE degradation byproducts) levels. This is not likely if degradation route is oxidative; however, in some fringe areas, there may be some reductive dehalogenation at higher temperatures.
- Elevated carbon dioxide measurements in the extracted vapor stream during each cycle (this is the more probable byproduct of TCE under oxidative conditions induced by the injected oxygen).
- No major elevation of TCE levels in surrounding wells and soil-gas monitoring points (that would indicate any spreading or any noticeable volatilization loss of TCE to the surroundings).
- Noticeable increase in chloride and alkalinity levels in the groundwater in the target zone (this will be difficult to evaluate, as chloride levels are naturally high and TCE levels are relatively low in the treatment zone).

The contaminant mass balance and recovery calculation are beyond the scope of this demonstration due to the heterogeneous nature of the aquifer. This application of the DUS/HPO technology at Beale AFB is solely aimed to treat the dissolved TCE plume; however, application of this technology should include a mass balance calculation in other sites where DNAPL is present.

3.2 Selecting the Demonstration Site

The demonstration site selected for this study is Beale AFB. LLNL conducted a search of several DoD sites and selected Beale AFB because it exhibited a number of characteristics suitable for the demonstration. It had a small suspected TCE source area with a relatively small plume, where the demonstration could be conducted with a single steam injection-extraction well. The affected aquifer is not very deep. Although the soil is mostly silts and clays, sand and gravel zones are present that could facilitate steam transport. Also, the site personnel and state regulators involved with this site showed good interest in pursuing the demonstration.

3.3 Demonstration Site History/Characteristics

The proposed location of the DUS/HPO demonstration project at SWMU 23 is shown in Figure 3-1. Historic waste management practices related to the storage of electrical equipment and transportation/vehicle maintenance at SWMU 23 resulted in an impact to both soil and groundwater at this site. The results of several site investigation efforts have been compiled in order to develop a conceptual site model for the geology and hydrogeology of the SWMU 23 area, as well as an understanding of the nature and extent of the groundwater contamination. These site investigation activities are summarized briefly as follows:

- During historic site investigation activities (1997-1999), approximately 41 soil samples, 14 groundwater samples, and three soil-gas samples were collected in the vicinity of SWMU 23. Several Hydropunches™ were advanced and one monitoring well (MW-1) was installed as shown in Figure 3-1.
- In April 2001 (Phase 1), Battelle installed three groundwater monitoring wells (BAT-1, BAT-2, and BAT-3, as shown in Figure 3-1) using a hollow-stem auger (HSA) rig. A split-spoon sampler was used to collect soil samples during the well installations. Groundwater monitoring and aquifer slug tests subsequently were performed at these three locations.
- In May 2001 (Phase 2), Battelle conducted a site survey with the Navy's Site Characterization and Analysis Penetrometer System (SCAPS) rig with a membrane interface probe (MIP) coupled with a direct-sampling ion-trap mass spectrometer (DSITMS). The MIP/DSITMS was used to determine chlorinated volatile organic compound (CVOC) levels in groundwater at 13 separate locations, as shown in Figure 3-1. Pushes were run to refusal at approximately 39-40 ft below ground surface (bgs) and then discrete MIP tests were performed at intervals where contamination was detected. Data on tip resistance, local friction, pore pressure, and friction ratio were not available due to a damaged data cable.
- In August 2001 (Phase 3), Battelle installed two additional clustered monitoring wells (BAT-4 shallow/deep [S/D] and BAT-5 S/D, as shown in Figure 3-1). These wells were installed in the area with elevated TCE levels as indicated by the MIP survey. Groundwater monitoring and aquifer slug tests subsequently were performed at these locations.

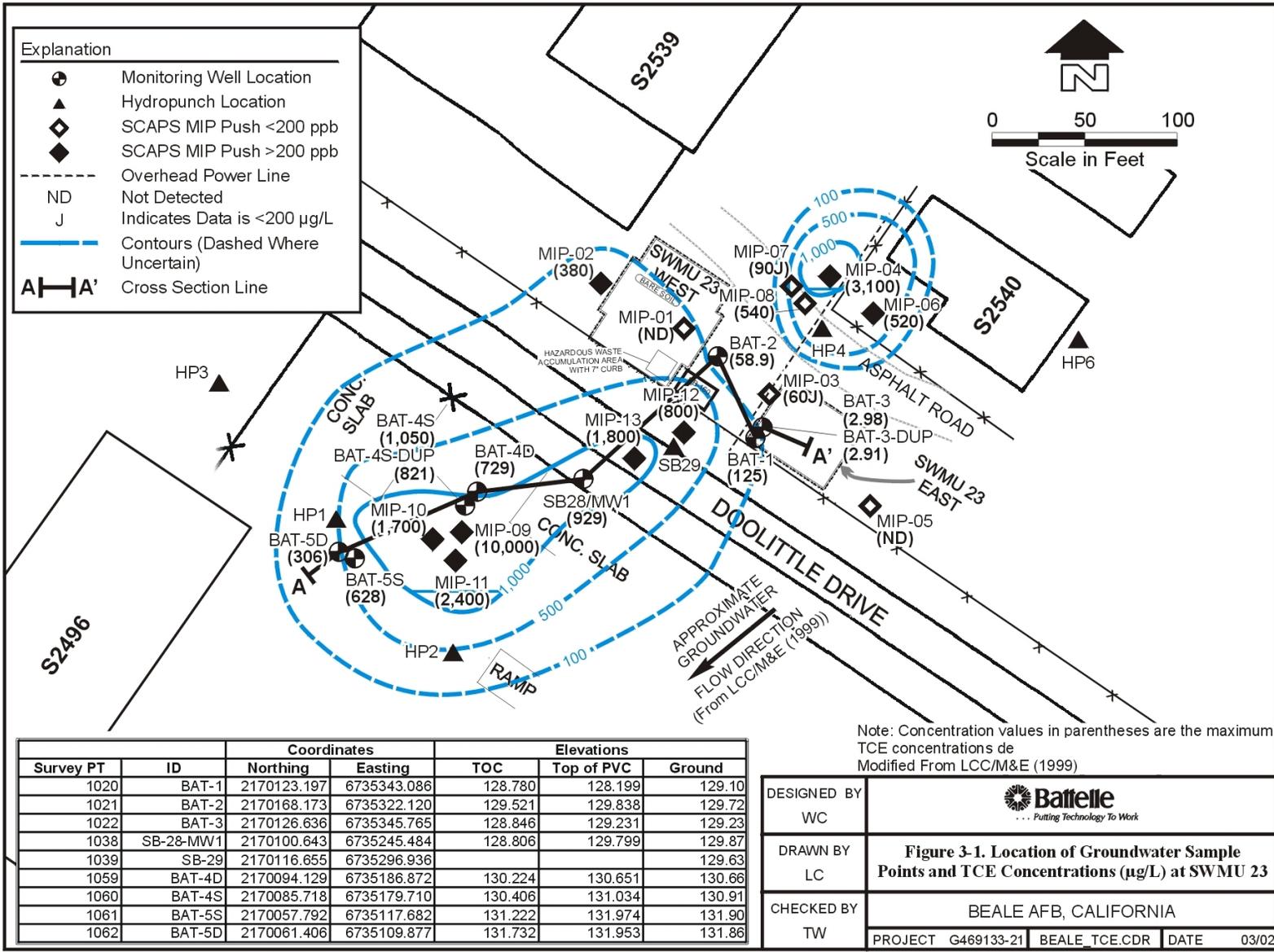


Figure 3-1. Map of Historic and Phase 1, 2, and 3 Site Characterization Locations

The results of these site investigation activities are discussed in the following sections.

3.3.1 Geology and Hydrogeology

Figure 3-2 shows a geological cross section through the wells at SWMU 23. The site soils can be categorized into approximately five hydrostratigraphic units. The first unit from 0 to 24 ft bgs consists of a hard, reddish, light brown sandy/silty clay. The second unit from 24 to 29 ft bgs

consists of a reddish, light brown clay to silty sand and gravel. The third unit from 29 to 35 ft bgs is a reddish, light brown sandy/silty clay to clayey sand. The fourth unit is the main water-bearing zone in the area of SWMU 23 and it consists of grayish, light brown gravel with silt, sand, and clay from 35 to 45 ft bgs. The bedrock is encountered at approximately 45 ft bgs and consists of a weathered siltstone, which may contain brackish water. Soil boring logs for SWMU 23 are included in Appendix B.

Based on the most recent groundwater surveys (April 24, 2001, and August 20, 2001), the depth to groundwater at the site ranges from approximately 13 to 21 ft bgs. It appears that the aquifer is confined, as the water levels in the wells are higher than the depth of the hard clay layer, which was found at 24 ft bgs. Although indications are that the aquifer is confined, this would have to be confirmed through slug tests in wells screened in the upper clay layer, or through pump tests in the aquifer. As there are no existing wells screened solely in this clay zone, and no new wells in this zone are planned to conserve resources for the treatment, the exact nature of the aquifer cannot be confirmed at this time. Because the contamination is relatively sparse, we have been reluctant to conduct pump tests due to concern over extraction of existing contamination in the treatment zone. Water levels measured in the six groundwater monitoring wells are noted in Figure 3-2. Based on historic potentiometric maps and the groundwater survey on August 20, 2001 (see Figure 3-3), it appears that the overall gradient at the site is towards the southwest.

Battelle conducted slug tests in April 2001 on wells BAT-1, BAT-2, and BAT-3 and in August 2001 on BAT-4 S/D and BAT-5 S/D. The tests consisted of placing a TROLL™ pressure transducer/data logger and 1.0-inch-diameter by 5-ft-long polyvinyl chloride (PVC) slug within the well. After the water level reached an equilibrium, the slug was removed rapidly. Removal of the slug created approximately 0.45 ft of change in water level within the well. Water level recovery then was monitored for 10 minutes using the TROLL™ pressure transducer/data logger. The data was downloaded to a notebook computer for analysis. The recovery rates of the water levels were analyzed with the Bouwer (1989), Bouwer and Rice (1976), and Hvorslev (1951) methods for slug tests. Although the Bouwer and Rice method is sometimes used in confined aquifers where the top of the screen is well below the bottom of the confining layer, this method is more suitable for unconfined aquifers. The Hvorslev method is more applicable in confined aquifers, but may fail to account for the effects of a sand pack. Therefore, data interpretation was conducted by both methods. Table 3-2 summarizes the slug test results; 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. Water level response showed a good correlation to curve fits. Some early “two-line” responses were evident in the wells, indicating early response from the sand pack followed by response from the

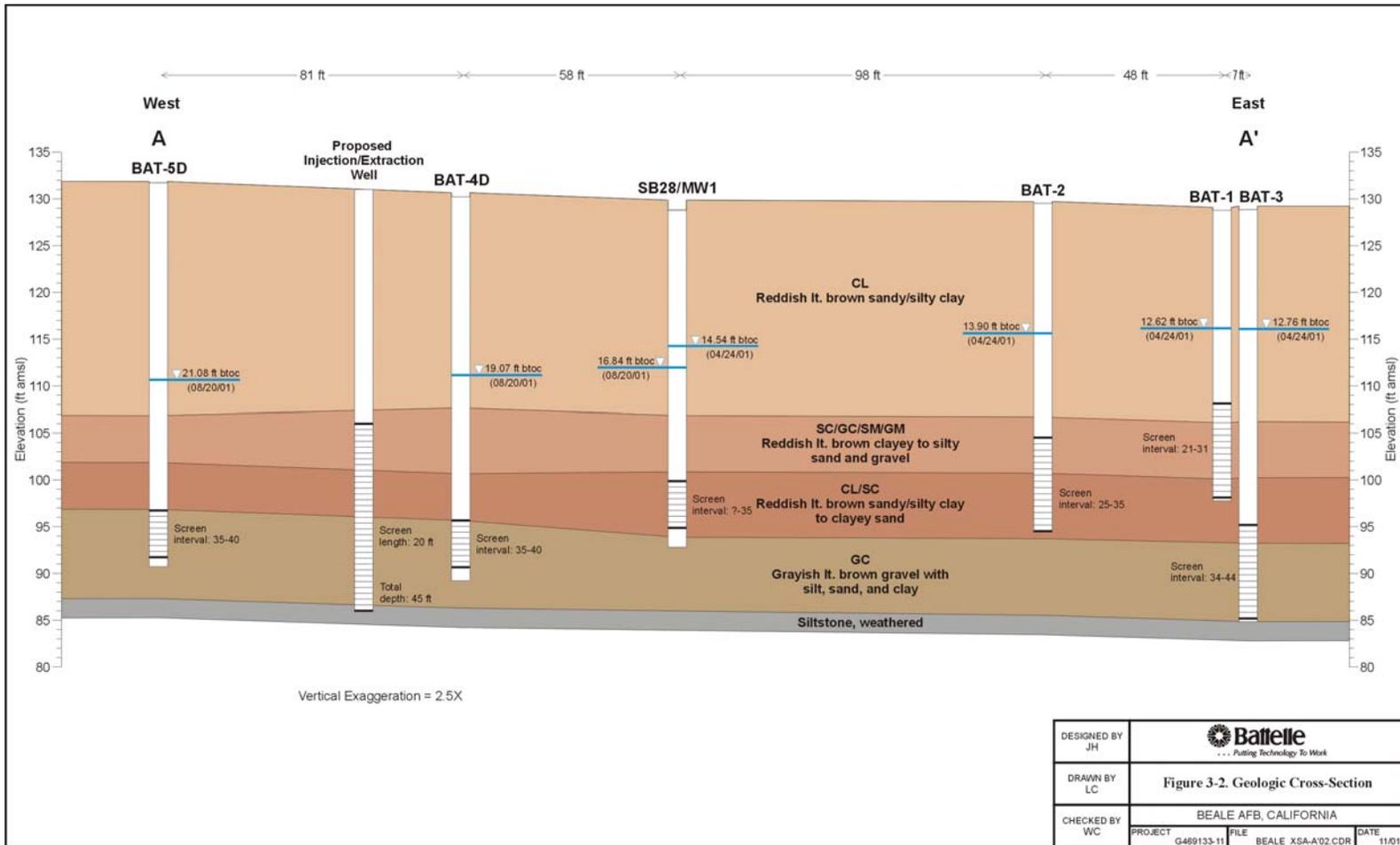


Figure 3-2. Geologic Cross Section A-A' at SWMU 23

Table 3-2. Summary of Slug Test Results at Beale AFB, CA

Well	Well Depth (ft)	Screened Interval		Saturation Thickness (ft)	Well Radius (ft)	Borehole Radius (ft)	Hydraulic Conductivity (ft/day)	
		Top (ft bgs)	Bottom (ft bgs)				Hvorslev	Bouwer and Rice
BAT-1	32	21	31	32	0.0833	0.333	6.4	4.2
BAT-2	35	25	35	32	0.0833	0.333	14.3	6.6
BAT-3	45	35	45	32	0.0833	0.333	3.8	1.4
BAT-4S	30	25	30	30	0.0833	0.333	NA ^(a)	NA ^(a)
BAT-4D	40	35	40	30	0.0833	0.333	1.2	0.75
BAT-5S	30	25	30	30	0.0833	0.333	4.5	1.8
BAT-5D	40	35	40	30	0.0833	0.333	1.3	0.78

(a) Results from well BAT-4S were not recorded due to a malfunction of the TROLL™ data recorder. NA= not available.

aquifer. These data from the slug tests can be found in Appendix B. Overall, the hydraulic conductivity estimates ranged from 0.75 to 14.3 ft/day.

Results generated using the Hvorslev method are about 1.3 to 4 times higher than estimates calculated using the Bouwer and Rice method, as might be expected for a confined aquifer. The permeabilities are generally in the range expected from silty sand sediments as seen during drilling. Recovery rates observed during sampling well development also suggest that the aquifer is reasonably productive. No pump test was conducted so that the disturbance to the plume was minimized.

Estimates from wells BAT-1 and BAT-2 are similar, because the wells are screened at the same depths. The hydraulic conductivity at BAT-3 is somewhat lower than the other two nearby wells, suggesting the aquifer sediments differ at the greater depth. At BAT-4 and BAT-5, the hydrostratigraphic layer corresponding to the shallow well BAT-5S had a hydraulic conductivity that was almost twice the deeper nested wells BAT-4D and BAT-5D. The estimated hydraulic conductivities are generally in the range reported in the literature for silty sands.

3.3.2 Nature and Extent of Contamination

The primary objectives of the site investigation program were to locate the DNAPL source zone (if present) and to determine the optimal location for the HPO demonstration based on the location with the highest TCE/PCE concentrations in groundwater. Site investigation efforts to date have not identified DNAPL at SWMU 23. In general, the levels of TCE in the dissolved-phase plume are relatively low (i.e., generally below 1% of the compound's water solubility), which suggest that a DNAPL source is either absent or minimal.

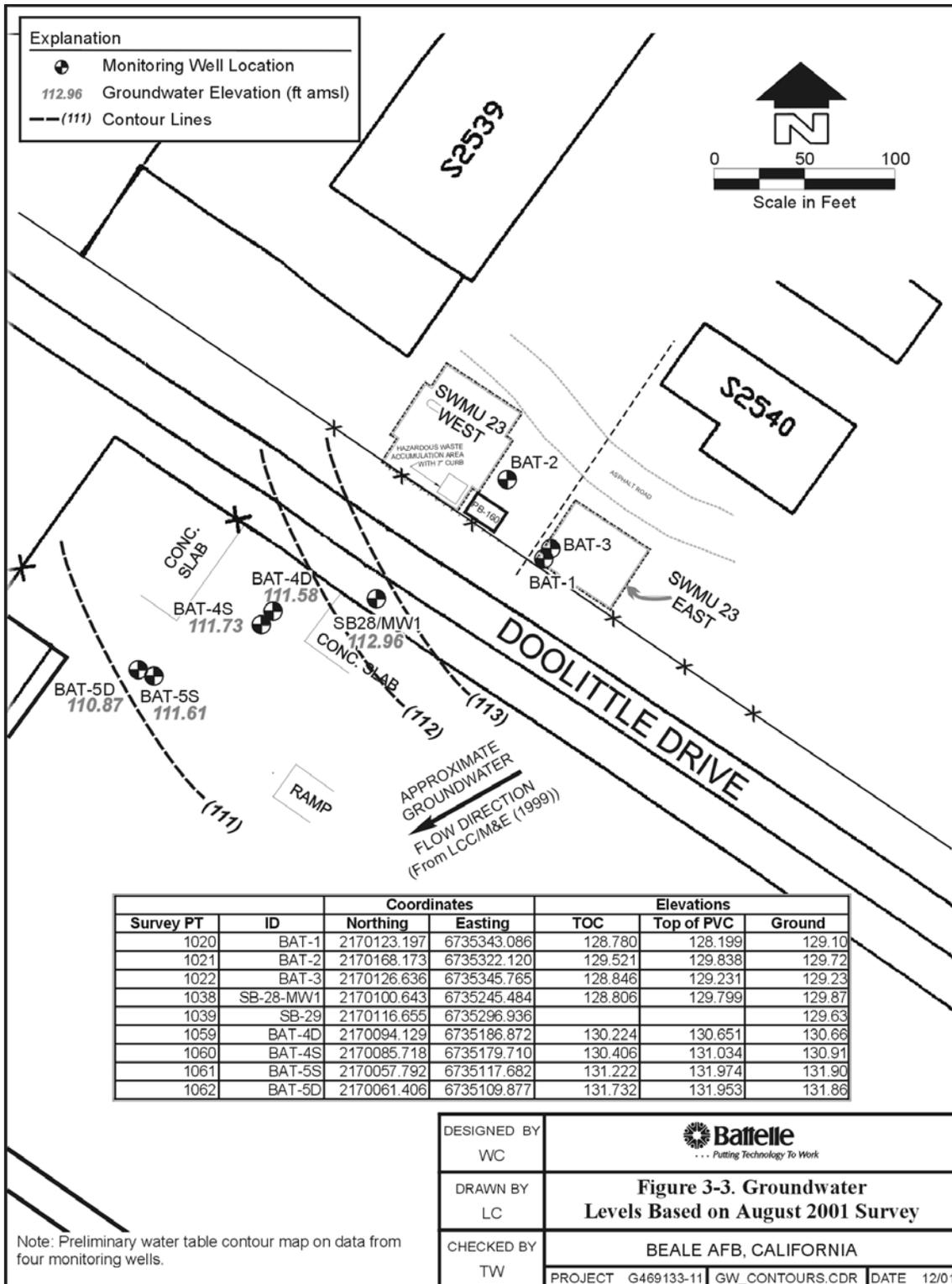


Figure 3-3. Groundwater Levels Based on August 2001 Survey

Based on historical data from the Hydropunches™ conducted in 1998, the highest TCE level detected at the site was 1,600 micrograms per liter (µg/L) at SB-29 at 25 ft bgs. In general, the concentrations measured in these historic Hydropunch™ locations have not been confirmed with conventional wells. During Phase 1 (April 2001), Battelle collected groundwater samples from MW-1, BAT-1, BAT-2, and BAT-3. Table 3-3 summarizes VOC results from Phase 1 sampling and analysis. The highest TCE level was found in MW-1 at 929 µg/L. The highest PCE level was found in BAT-3 at 136 µg/L.

Table 3-3. Summary of VOC Results in Phase 1 Monitoring Wells

	PCE (µg/L)	TCE (µg/L)	<i>cis</i> -1,2-DCE (µg/L)	<i>trans</i> -1,2-DCE (µg/L)	1,1,1-TCA (µg/L)	VC (µg/L)
BAT-1	105	125	2.63	0.33 J	<1	<1
BAT-2	6.69	58.9	0.52 J	0.2 J	<1	<1
BAT-3	135	2.98	0.19 J	<0.1	<1	<1
BAT-3-DUP	136	2.91	0.20 J	<0.1	<1	<1
MW-1/SB-28	60.7	929	2.01	0.29 J	<1	<1
EB-1	<1	<1	<1	<1	<1	<1
Trip Blank	<1	<1	<1	<1	<1	<1

DCE = dichloroethene.

MW-1 = an existing well south of Doolittle Drive.

TCA = trichloroethane.

VC = vinyl chloride.

EB = QA for equipment rinsate blank.

To gain a better understanding of the nature and extent of the CVOC contamination in groundwater at SWMU 23, additional site characterization was carried out which was focused on the areas of historically high contamination including the area south of Doolittle Drive and near SB-29 in Doolittle Drive (Figure 3-1). The Navy SCAPS rig was used to complete a near real-time, in situ survey to screen for VOCs. The SCAPS rig can be deployed with a standard cone penetrometer test (CPT) platform and consists of an in situ helium gas sparge module interfaced with an ion-trap mass spectrometer. The system has been certified for analysis of TCE, PCE, carbon tetrachloride, and several other VOCs.

Thirteen CPT pushes were performed during the Phase 2 event in June 2001 in the area of interest. The push locations were selected based on likely source areas and migration directions of DNAPL. Sampling began near building PB-160 and continued along a northwest-southeast transect across the SWMU 23 area. These locations were generally low in concentrations (MIP-1 to MIP-3). Sampling then was focused on a potential source near building S2540. TCE concentrations up to 3,100 µg/L were detected at 31.2 ft bgs in MIP-04. TCE concentrations found in MIP-05, MIP-06, MIP-07, and MIP-08 were relatively low, ranging from nondetect to 540 µg/L. Sampling was then aimed at the area south of Doolittle Drive. The results of the MIP survey indicate that the highest confirmed concentrations are located near MIP-09, MIP-10, and MIP-11 south of Doolittle Drive. TCE concentrations were measured at levels up to 10,000 µg/L.

in this area. Generally, TCE concentrations were greater than 200 µg/L from 23 to 37 ft bgs in the area. PCE also was detected in this zone.

These findings indicate the plume is migrating from the SWMU 23 area, where the source zone was originally suspected two years ago, along the direction of groundwater flow toward the southwest. Although some contamination was detected near building S2540, it was difficult to confirm this result and it may be more indicative of a depleted source zone. Overall, it appears that the area south of Doolittle Drive (near MIP-09, MIP-10, and MIP-11) is the best location for the DUS/HPO demonstration. Table 3-4 summarizes the highest TCE hit with depth at each MIP location and the complete results from the MIP survey locations are provided in Appendix C.

Table 3-4. Summary of Highest TCE levels in µg/L at Each Phase 2 MIP Location

Sample ID	Test Type ^(a)	Depth (ft bgs) ^(b)	TCE (µg/L)	PCE (µg/L)	DCE (µg/L)	CHC13 (µg/L)	VC (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Hydrocarbons (µg/L)	M/Z 151+153 ^(c) (µg/L)	M/Z 197+199 (µg/L)
MIP-01	DR	2.4-35.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MIP-02	D	37.5	380	ND	ND	ND	ND	ND	ND	Yes	ND	ND
MIP-03	D	23	60 J	ND	ND	ND	ND	ND	ND	Yes	ND	ND
MIP-04	DR	31.2	3,100	220	ND	ND	ND	ND	ND	Yes	2,400	370
MIP-05	C	0-36.9	ND	240	ND	ND	ND	ND	ND	ND	280	ND
MIP-06	C	0-37.4	520	ND	ND	ND	ND	ND	ND	ND	ND	ND
MIP-07	C	0-40.1	90 J	ND	ND	ND	ND	ND	ND	Yes	ND	ND
MIP-08A	C	0-37.8	540	ND	ND	ND	ND	ND	ND	ND	ND	ND
MIP-09	H	26.3-29.6	10,000	700	ND	ND	ND	ND	ND	ND	ND	ND
MIP-10	H	30.4-33.8	1,700	110 J	ND	ND	ND	ND	ND	ND	ND	ND
MIP-11	H	36.7-40.2	2,400	350	ND	ND	ND	ND	ND	ND	ND	ND
MIP-12	H	26.5-29.9	800	130 J	ND	ND	ND	ND	ND	ND	ND	ND
MIP-13	H	26.8-30.1	1,800	220	ND	ND	ND	ND	ND	ND	ND	ND

Note: Data flagged “J” indicates <200 µg/L, but compound identified present by mass spectrum. ND indicates not detected above 200 µg/L.

CHC = chlorinated hydrocarbon.

(a) Test types:

D = Discrete static measurement

R = Measured during retraction

C = Continuous measurement

H = Hybrid measurement.

(b) Depth intervals are shown for continuous and hybrid measurements. Contamination within the interval may be variable. The reported concentration is the maximum within the interval.

(c) M/Z 151+153 is likely Freon[®] 113.

During Phase 3 (August 2001), two additional clustered groundwater monitoring wells were installed and sampled to further corroborate the results of the MIP survey and to obtain more data from the target demonstration area. Another reason Phase 3 activities were conducted was that soil samples collected using the SCAPS rig could not corroborate high VOC concentration

identified by the MIP. Table 3-5 summarizes VOC results from Phase 3 sampling and analysis. During Phase 3, the highest TCE level (1,050 µg/L) was detected in BAT-4S at a depth of 30 ft bgs. From 30 to 40 ft bgs, TCE concentrations ranged from 306 to 1,050 µg/L, which is approximately 60 to 200 times greater than the federal and California MCL of 5 µg/L. The high TCE hit of 10,000 µg/L at MIP-09 based on the SCAPS survey was not corroborated with the sampling results from the nearby conventional monitoring wells. This may be due to the fact that the wells have wider sampling intervals than the MIP probe.

Table 3-5. Summary of VOC Results in Phase 3 Monitoring Wells

Well ID	PCE (µg/L)	TCE (µg/L)	<i>cis</i> -1,2-DCE (µg/L)	<i>trans</i> -1,2-DCE (µg/L)	1,1,1-TCA (µg/L)	Vinyl Chloride (µg/L)
BAT-4S	76.3	1,050	2.31	0.25 J	<1.0	<1.0
BAT-4S-DUP	76.7	821	2.19	0.26 J	<1.0	<1.0
BAT-4D	65.6	729	2.2	0.19 J	<1.0	<1.0
BAT-5S	61.6	628	1.36	0.14 J	<1.0	<1.0
BAT-5D	45.1	306	0.55	<1.0	<1.0	<1.0
RB-1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Trip Blank	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

RB: Rinsate blank for QA.

EB: QA for rinsate blank.

3.3.3 Groundwater Geochemistry

The results of the CVOC sampling and analysis are described above in Section 3.3.2. The Phase 1 results of water quality tests (e.g., total dissolved solids) and field parameter measurements (e.g., pH, DO, oxidation-reduction potential [ORP]) are provided in Tables 3-6 and 3-7.

Total dissolved solids (TDS) in groundwater are relatively low and ranged from 234 to 329 mg/L. Total organic carbon (TOC) was also low at non-detect levels.

Based on Phase 3 of groundwater sampling, the DO levels at the site range from 2.1 to 3.3 mg/L, which suggest that groundwater is relatively aerobic in the demonstration area from wells BAT-4 and BAT-5 (i.e., greater than 2 mg/L based on Leeson et al., 2001). The pH of the groundwater ranges from approximately 6.9 to 7.2, and the conductivity ranges from 0.49 to 0.57 milli-Siemens per centimeter (mS/cm).

3.4 Present Operations

There are no ongoing groundwater remediation activities at SWMU 23. In August of 2000, surface soil contaminated with polychlorinated biphenyls (PCBs) was removed for off-site treatment and disposal. The site was refilled and repaved following the excavation.

Table 3-6. Field Parameters and Inorganic Sampling Results in Phase 1 Monitoring Wells

Well ID	Temperature (°C)	pH	ORP (mV)	Conductivity (mS/cm)	DO (mg/L)
BAT-1	20.98	6.34	211.9	0.763	2.44
BAT-2	21.66	6.33	312.6	0.835	1.50
BAT-3	20.68	6.77	107.1	0.489	3.62
MW-1	22.35	6.21	130	0.689	2.32

Well ID	Ca (mg/L)	Fe (mg/L)	Mg (mg/L)	Mn (mg/L)	K (mg/L)	Na (mg/L)	Alk (mg/L)
BAT-1	40.6	<0.1	29.9	0.0398	2.31	22.3	181
BAT-2	40.6	<0.1	29.9	0.0862	2.88	27.2	190
BAT-3	27.6	<0.1	14.9	0.133	2.49	20.0	115

Well ID	Br (mg/L)	Cl (mg/L)	NO ₃ /NO ₂ -N (mg/L)	SO ₄ (mg/L)	TDS (mg/L)	COD (mg/L)	TOC (mg/L)
BAT-1	<2	20.0	7.42	17.5	329	<10	<5
BAT-2	<2	33.1	4.98	22.8	362	<10	<5
BAT-3	<2	13.5	3.35	15.3	234	<10	<5

Table 3-7. Field Parameters in Phase 3 Monitoring Wells

Well ID	Temperature (°C)	pH	ORP (mV)	Conductivity (mS/cm)	DO (mg/L)
BAT-4S	21.8	7.16	41	0.52	2.60
BAT-4D	20.9	6.86	14	0.49	3.33
BAT-5S	22.7	7.2	34	0.57	2.10
BAT-5D	22.7	7.02	51	0.54	3.30

3.5 Operation and Evaluation Plan

3.5.1 Demonstration Setup and Startup

This section describes premobilization, mobilization, and immediately preoperational tasks of the steam and treatment systems.

The major components required for the demonstration are a steam generator and associated freshwater treatment system, and a contaminant treatment system, including facilities for liquid/vapor separation, carbon filtration, and vacuum extraction systems.

Procurement of necessary items not currently in the SES inventory will begin once the contract allows for funds for such purchases. Equipment available from the SES inventory will be inspected at the SES facility in Bakersfield, CA. Prior to shipping to the demonstration site, SES

will construct and predemonstrate, under simulated operating conditions, as many items and systems as is practical at its Bakersfield facility. An additional sequence of tests will be conducted at the demonstration site prior to onset of operations. The bulk of the purchased items will be delivered to the SES Bakersfield facility, in order to ensure better inventory and quality control during initial assembly.

Well drilling, installation and characterization will be conducted simultaneously with procurement and testing of equipment in SES facilities. Wells will be drilled using a single HSA rig, at locations in Figure 3-4. Drilling operations are expected to require 11 working days to complete. A total of 11 holes will be drilled to a depth of 45 ft, allowing construction of a short sump and ensuring that injection, extraction, and process monitoring is extended close to the base of the principal aquifer. The central injection/extraction hole will be drilled at 10-inches diameter, and the surrounding groundwater and geophysical monitoring holes will be drilled at 6-inches diameter. Holes for soil-gas monitoring points will be drilled to a depth of 6 ft, at 6-inches diameter at distances of 5 ft from the closest monitoring well. Borehole locations and completion depths are shown in Figures 3-4, 3-5, 3-6, 3-7, and 3-8. Details of well completion are illustrated in Figures 3-6 and 3-7.

All drilling equipment that comes in contact with groundwater will be steam-cleaned between each well location. Cuttings and wastewater generated during drilling will be stored in 55-gal drums and disposed of using established methods at Beale AFB. Upon completion, the injection/extraction well will be developed by means of bailing until turbidity is not apparent on visual inspection. Wastewater purged from the wells will be stored in a tank on site, for testing and treatment to meet Beale AFB discharge limits. A purged water volume equivalent to six well volumes has been assumed for estimation purposes.

The general lithology and vertical contaminant distribution at the demonstration area is considered to have been adequately characterized; hence it is proposed that all holes be driven to a depth of 20 ft bgs without sampling, other than noting of the cuttings lithology. In order to establish a contaminant distribution baseline, continuous coring will be conducted from 20 ft bgs to the total depth of each hole, using a standard split-spoon sample barrel. An SES geologist will note lithology and any other notable features, and will photograph the core sample. A handheld photoionization detector (PID) will be used to screen the core in the field as a semiquantitative profile of VOC distribution. A single sample will be collected from the center of each core length for headspace analysis on site using a handheld PID. Any "hot-spots" removed from the center sample based on PID screening also will be sampled for headspace analysis. No soil will be screened with a PID from ground surface to 20 ft bgs because previous screens conducted in the two deep wells in the area (BAT-4D and BAT-5D) have not shown any contamination at these shallow depths (see Appendix B for soil logs with PID readings). Additional samples will be collected for TOC analysis. These samples will be collected from the central injection/extraction well and from one of the groundwater monitoring wells, from the PID screened interval of cores recovered from each of the three sandy or gravelly layers at 25-45 ft bgs (see Figures 3-2 and 3-5).

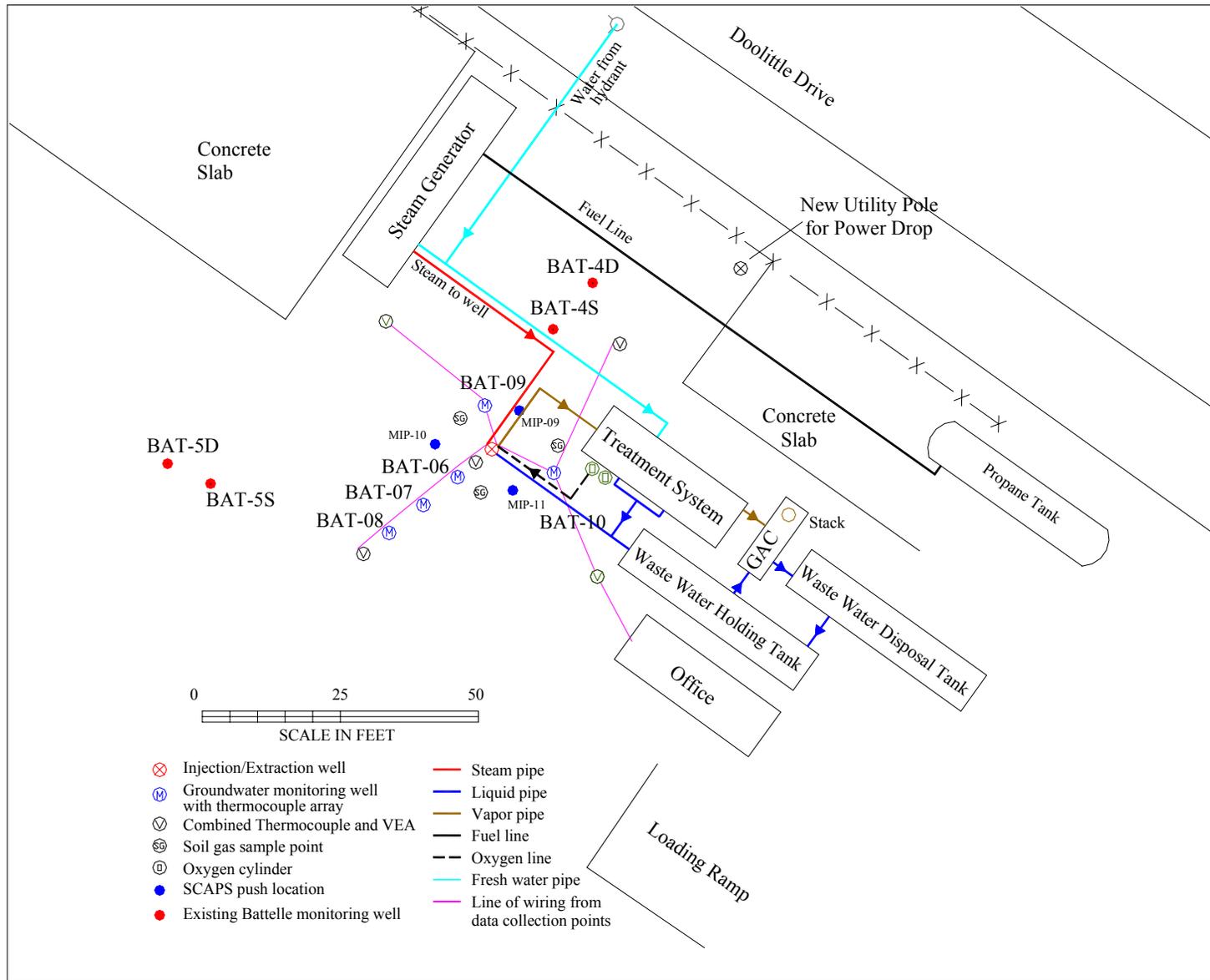


Figure 3-4. Well Layout at Demonstration Site, Showing Location of Existing Wells and Footprint of SES Equipment

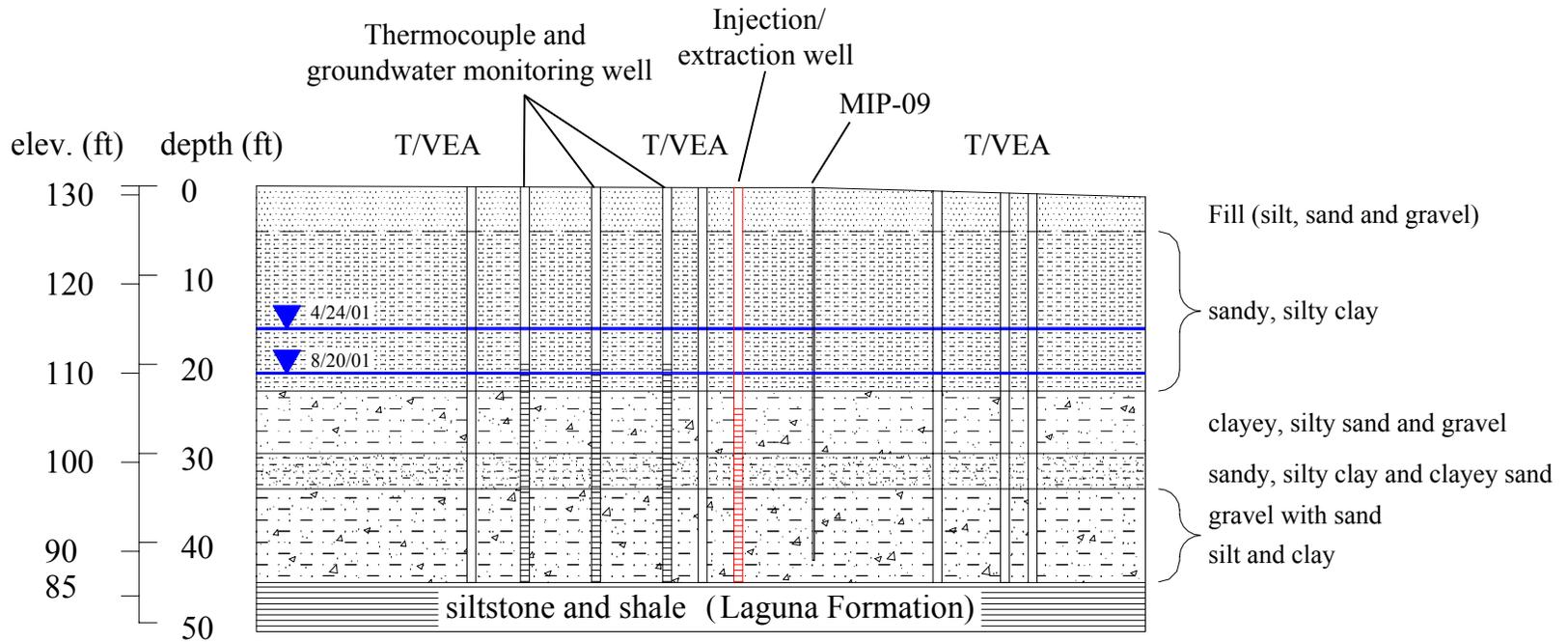


Figure 3-5. Cross-Section Extending from SW (left) to NE (right) of Demonstration Site

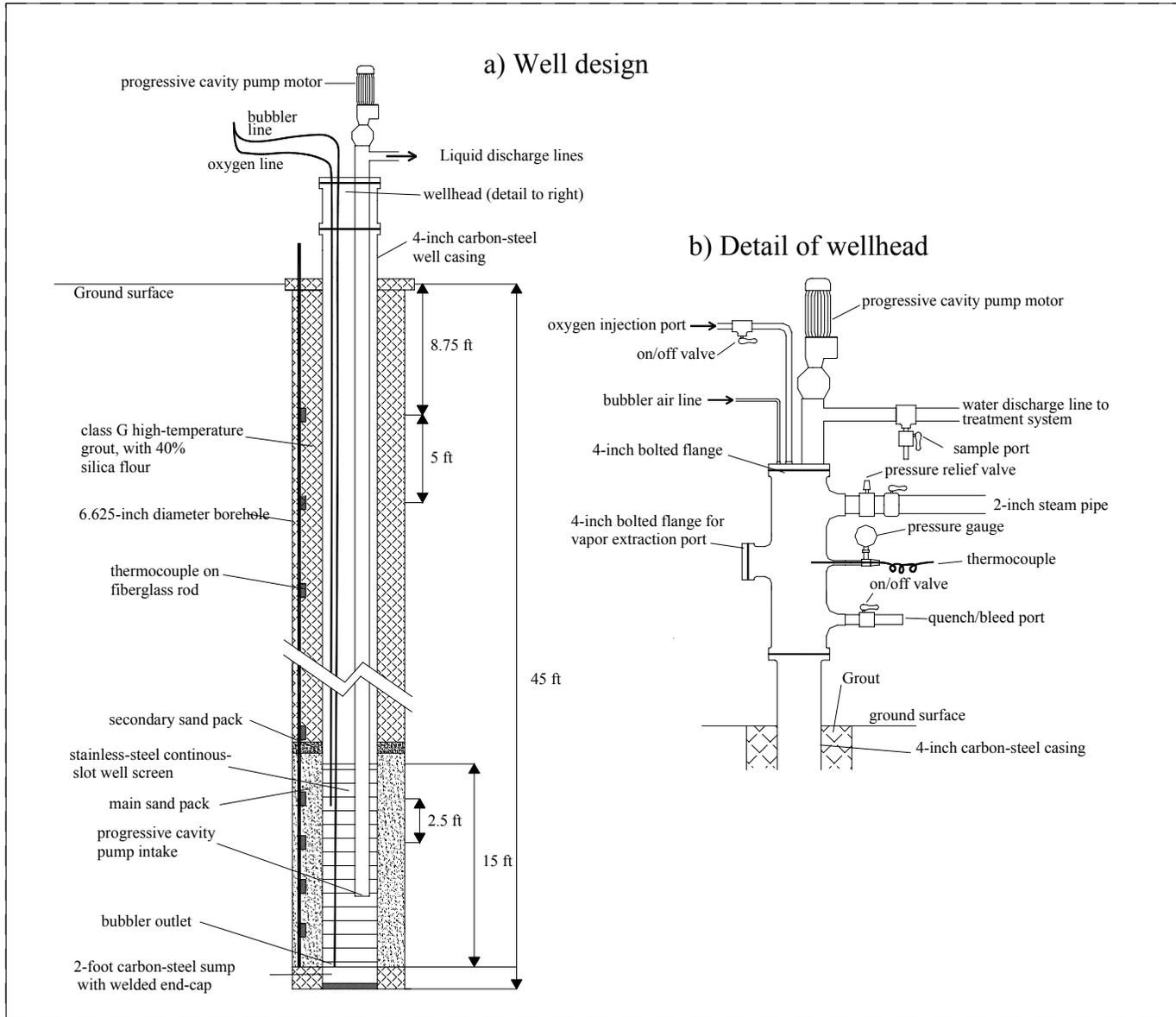


Figure 3-6. Summary of Well Design Features: a) Well Design, b) Detail of Wellhead

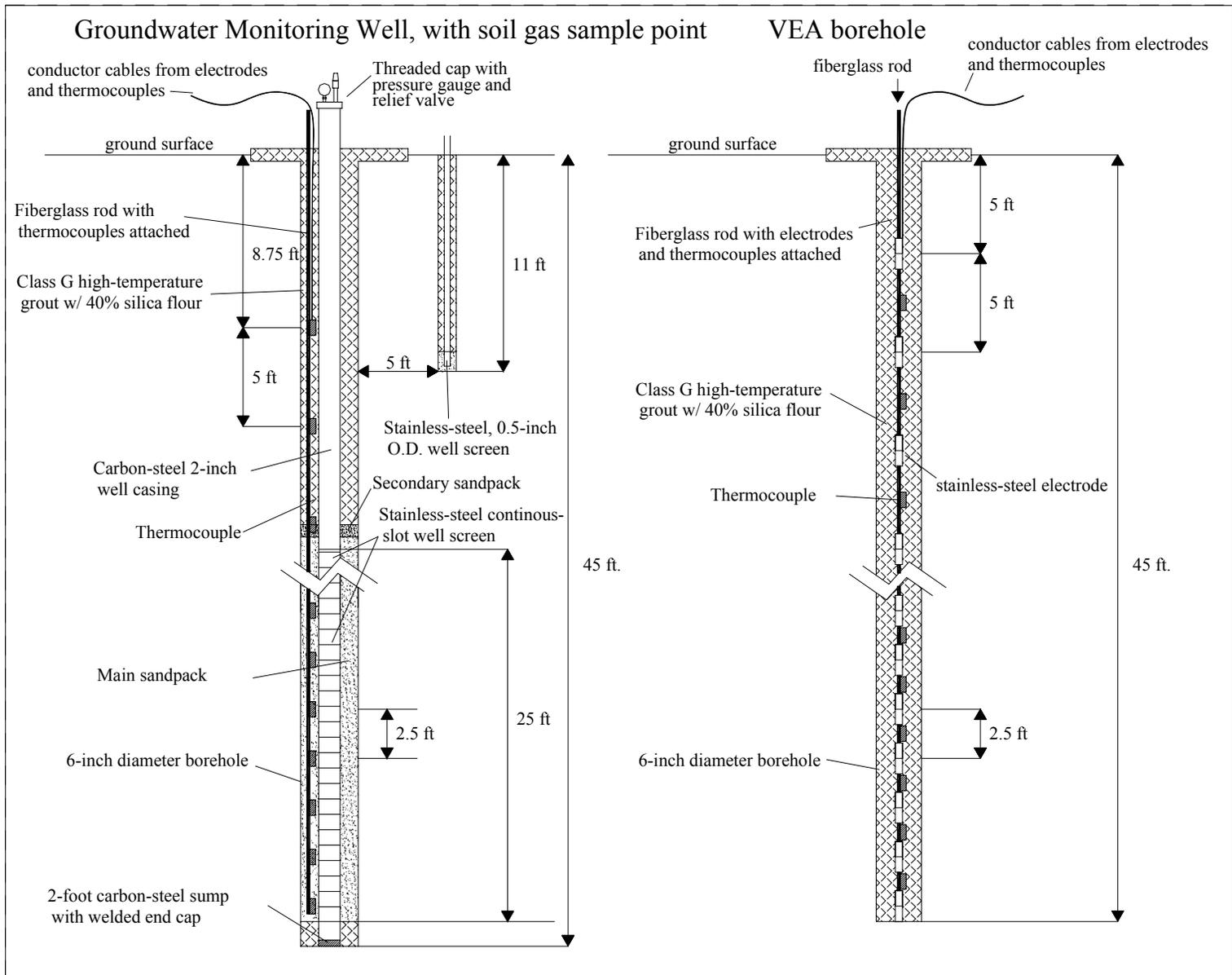


Figure 3-7. Groundwater Monitoring Well and VEA Borehole Design

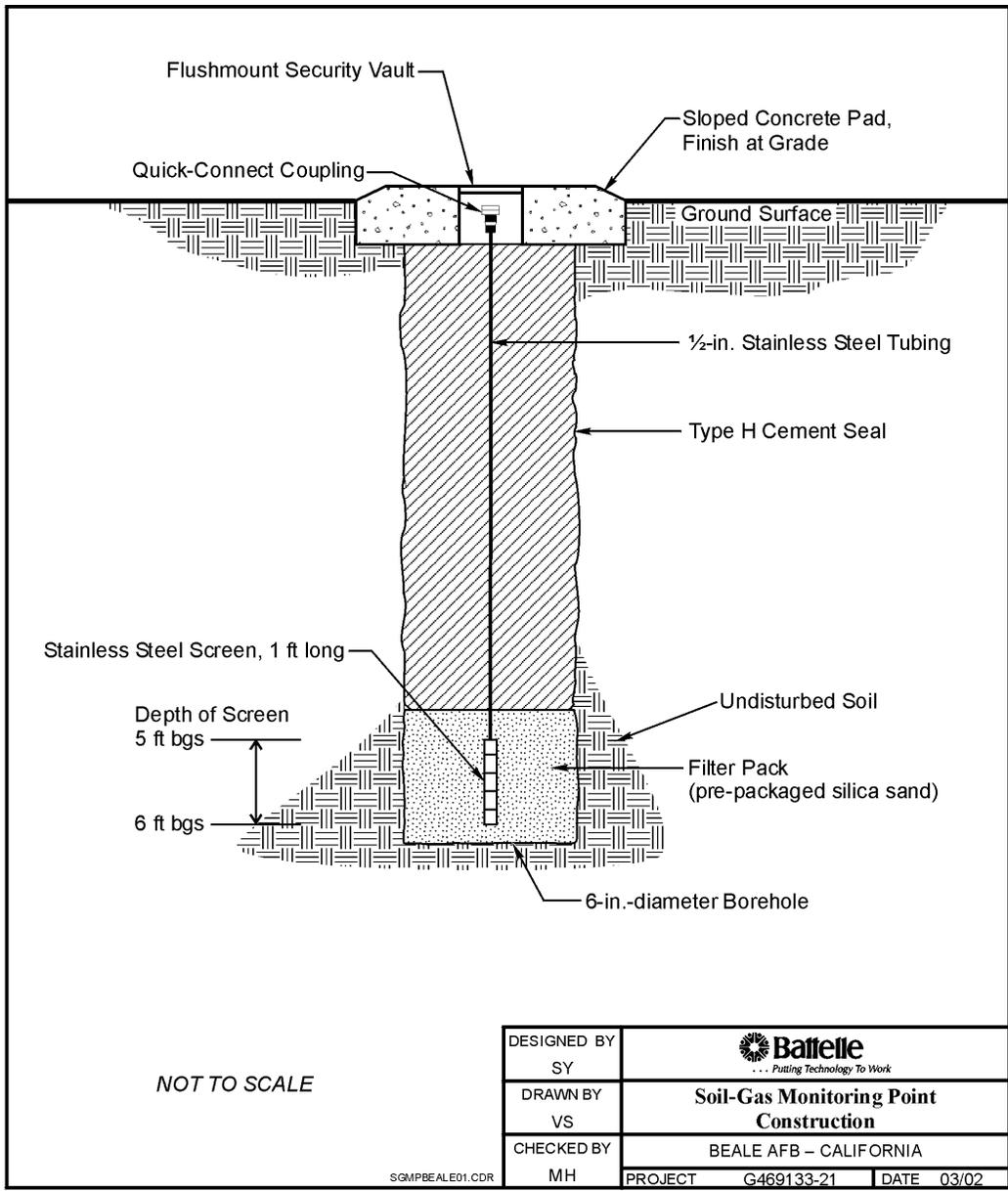


Figure 3-8. Construction Diagram for Soil-Gas Monitoring Points

Groundwater characterization during the setup phase will be limited to the collection of three rounds of grab samples from developed and equilibrated screened intervals in each of the groundwater monitoring wells and from the injection/extraction well. Subject to availability of funding, additional depth profiling during Hydropunch™ drilling at the locations of the proposed groundwater monitoring wells may also be conducted. Upon completion of Hydropunch™ profiling, the final groundwater monitoring wells will be drilled at the same location by the auger rig.

Upon completion and development of the central injection/extraction well, a falling head slug test will be conducted in order to establish hydraulic conductivity immediately adjacent to the well. Water level changes will be logged by means of a pressure transducer. Raw data will be interpreted using standard hydrogeological solutions. Any groundwater displaced during aquifer testing will be stored on site until such times as it can be treated and disposed of.

SES will coordinate the shipping of all steam injection plant material to the demonstration site. Transportation of material will be handled using a common carrier trucking company. All items will be insured for their appropriate value. Shipping activities will be consolidated so as to minimize crate expenses. Receipt of shipped steam injection plant items at the base will be the responsibility of SES. SES personnel or SES designated personnel will be present at Beale AFB for off-loading activities. All equipment is trailer-mounted and it is understood that tractor-trailer access to the demonstration site is practical and that there is sufficient hard standing for safe and secure final location of equipment, without the need for ground preparation.

The steam injection equipment will be placed in its permanent position at the demonstration site within specified footprints (Figure 3-4). A temporary staging area for the pickup and delivery of piping and miscellaneous pieces of equipment will be established adjacent to the demonstration site, for use during the assembly phase. On-site function testing of individual plant components will be conducted. Any units failing to meet their design criteria will be repaired or replaced.

Complete wellhead assemblies consisting of the injection/extraction wells and all groundwater monitoring wells and temperature/ERT holes with appropriate connections, gauges, meters and pipe or hose connections will be assembled in the SES Bakersfield facility prior to shipment to Beale AFB. Attachment of the injection/extraction wellhead to the well casing will occur at the demonstration site during the first phase of construction.

SES personnel will assemble the well-field infrastructure at the demonstration site, with the assistance of local labor and professional trades, if required. SES will provide appropriate supervision, safety personnel and project management to efficiently coordinate on-site assembly. SES will lay the necessary cable and piping throughout the wellfield upon completion of the wellheads. The surface piping extending from the combined injection/extraction well will be connected to the effluent treatment system and steam generator by way of manifolds equipped with appropriate valves, gauges, and meters. Any piping will be assembled to American Society of Mechanical Engineers (ASME) standards. SES will inspect and test all piping with fresh water or air before any steam or process water is introduced.

A total of 11 wells or boreholes will have temperature or geophysical monitoring equipment installed. Each of the groundwater monitoring wells will have a thermocouple array strapped to the casing and screen using polyethylene ties prior to installation. In addition, five dedicated geophysical monitoring holes will have a combined thermocouple and vertical electrode array (VEA) installed in open holes prior to removal of the auger. These holes will be grouted to the surface using class H cement mixed with silica flour.

After installation of VEAs and curing of grout in VEA holes, two complete ERT data sets will be collected by SES's contractor, in order to assess hardware performance and to troubleshoot any problems that may have arisen during installation. Upon satisfactory completion of field testing, at least two complete background ERT data sets will be collected in order to provide a reference for the subsequent monitoring of heat-up and steam migration.

ERT and temperature data will be collected on a daily basis during steaming phases, and upon completion of soaking and extraction phases. Data processing, inversion, and initial presentation to SES will be conducted by SES's geophysical contractor. Final interpretation and presentation of data to Battelle will be the responsibility of SES.

After installation of all wells and boreholes at the demonstration site, process equipment will be delivered by truck from the SES facility in Bakersfield, CA. The major process equipment items to be installed are:

- Power distribution panel with circuit breakers
- Water treatment unit for boiler feed-water
- Steam generation system including water softeners and stack-gas treatment units
- Vapor cooling system
- Effluent liquid cooling, separation, and treatment system
- Storage tank and roll-off bins for minor waste
- General equipment for all processes, including air compressor and drying units, as may be required
- All interconnecting pipes, valves, regulators, meters, and sampling ports
- Downhole pumps in all extraction and monitoring wells, and provision of needed power and other utilities at the active wellheads
- Automation and data collection system: Supervisory Control and Data Acquisition (SCADA) system.

Utility requirements for on-site equipment are summarized in Table 3-8.

Installation work on interconnecting piping will be carried out by local trades acting under SES supervision. SES personnel will conduct all electrical installation work upon completion of piping work. Automation and setup of the SCADA system will begin upon completion of the piping and electrical tasks. Automatic monitoring instruments will be mounted on posts or attached directly to the equipment being monitored. Low-voltage power supply and communication cable will be run to each device from a central power distribution panel. Connections will be rechecked before a full-system test is begun.

Piping systems will be tested for leaks by charging with air pressure or fresh water. During testing of the process system under full weighted load conditions, adjustments will be made to support systems, as may be required. At this time, all high-power AC electrical systems will be tested and all electrical motors will be checked for rotation and full amperage load.

Calibration of the automation and SCADA systems will be conducted for monitored liquid levels, flowrates, temperature and pressure. Prestartup checks, including documentation of condition and calibration, will be performed by the quality control (QC) officer assisted by operators, technicians and any other appropriate staff involved in the setup process.

As part of the preparation for on-site analytical work, the PID, and CO₂ analyzers will be installed and calibrated, and the in-line instruments (GashoundTM) will be automated. Ambient air will be used for calibration of the infrared sensor for CO₂ monitoring. All chloride analyses will be performed at an off-site analytical laboratory. A small on-site laboratory for calibration of equipment will be established, probably in a well-ventilated section of the office space. Before the onset of operations, several groundwater and vapor samples will be analyzed to verify the analytical range and functions of the equipment. Details of this sampling are provided in Section 3.5.7.

The on-site facilities will contain storage space, sample containers for water and vapor sampling, refrigerators for storage of samples, a small decontamination station, and a fume hood.

The proposed application of steam remediation and HPO at the demonstration site is a dynamic process, involving several cycles during which a range of parameters will be varied. Accordingly, the details of startup are described in Sections 3.5.5 and 3.5.6.

3.5.2 Period of Operation

Process modeling conducted by LLNL and supplied to SES indicates that optimum efficiency can be expected from the HPO process if shorter injection and extraction cycles are used than had been envisaged in the original scope of work. Accordingly, SES intends to operate for a total of 5 cycles in an overall work period of 35 calendar days (25 work days). Each cycle will consist of an initial steam injection phase followed by a steam-soaking phase, which is in turn followed by a liquid and vapor extraction phase. These phases will each last for 2, 2, and 3 days, respectively. Steam injection will occur on Thursdays and Fridays, allowing the soaking phase

Table 3-8. Major Design Parameters and Tentative Specifications for the Equipment Used for the HPO Demonstration

Equipment Description	Function	Design Rating and Specifications	Comments
Power supply	Power to equipment	150 A, 480 V, 3-phase	Average load 50-100 A
Power panel	Breakers, meter, and distribution	150 A, 480 V in, 480 V/240 V/110 V out	No backup power planned.
Water supply	Water to steam and treatment system	Max 50 gpm briefly, 5 gpm continuous at 60 pounds per square inch gauge (psig)	Average water usage will be below 5 gpm.
Water predemonstration unit	Supply soft, low O ₂ water to steam generator	10 gpm, TDS < 250 mg/L, DO < 0.5 mg/L	Sulfite added to reduce DO levels, pH and TDS adjusted to prevent scale buildup.
Fuel supply	Fuel for steam generator	Natural gas line	Capacity and availability to be determined.
Steam generator	Supply steam to injection well system	2.5×10^6 (2.5 million) BTU/hr, ~2,500 lb/hr, 135°C, 30 psig	Steam quality at injection points should be >80%.
Steam pressure regulator and manifold	Reduce pressure to injection pressure	Air-operated pressure regulator valve, condensate spitter, 2-inch steam pipe with orifice plates for steam flow measurement	Orifice plates to be sized during procurement and construction phase.
Liquid-vapor separator, KO-1	Knockout liquid component and fines before cooling	Maximum 2 gpm liquid, 1,000 cfm vapor including steam component	Vessel on the ground to allow for pipe drainage into it.
Vapor line condenser/heat exchanger	Cool vapors to 30-40°C and condense out condensable gases	Maximum cooling capacity 1×10^6 (1 million) BTU/hr = 300 kW, maximum condensate flow 2 gpm, effluent temperature <40°C (vapors and liquids)	Will be running at much less than full capacity most of the time. Designed for peak performance at time of maximum steam extraction.
Liquid-vapor separator, KO-2	Knockout liquid component and condensate after cooling	2 gpm liquid, 50 scfm noncondensable vapor	Aerosols in vapor stream should be minimized.
Vacuum pump, liquid ring with associated cooling system	Apply vacuum to vapor extraction line, deliver vapor to vapor treatment system at positive pressure	50 scfm, inlet side vacuum 0.5 atm = 7.4 pounds per square inch/area (psia). Outlet side pressure between 1.0 and 1.5 atm absolute. Adjustable.	Final specifications to be determined later.
Vapor-phase carbon canister system	Adsorb organics from vapor stream	Inlet 50 scfm, 1.0-1.5 atm absolute pressure (14.7-22 pounds per square inch [psi]), <50°C. 200 lb of activated charcoal in 55-gal drum.	Not applicable.
Water holding tank	Store water for cleaning and discharge	Minimum 20,000 gal	Sufficient to contain the wastewater of a single cycle.
Water carbon canister system	Remove dissolved organics from liquid effluent stream	10 gpm, 200-lb drum	Not applicable.

to occur on Saturday and Sunday, during which time the site and process equipment can be left unattended. Liquid and vapor extraction will begin on Monday mornings and continue until Thursday morning, when the succeeding steam injection phase can begin. A projected start date for first cycle steam injection is early May 2002, and the end of the fifth cycle of liquid and vapor extraction is projected to occur on June 13, 2002. It should be noted that conditions encountered during the first cycle in field operations may compel the adoption of later cycles and/or phases of different length to those described in this work plan.

3.5.3 Amount/Treatment Rate of Material

One of the primary objectives of the demonstration is to heat the soil surrounding the screened interval of the injection/extraction well to a target temperature. The actual radius of influence of injected steam is governed primarily by soil permeability, a parameter which is currently unknown for this location. Order-of-magnitude determinations of permeability derived for the nearby SWMU 23 area suggest that a reasonable expectation of radius of influence may be about 30 ft. This potential radius of influence extending over the 15-ft screened interval in the injection/extraction well yields a volume of soil of about 42,000 ft³ (1,570 yd³). The actual volume is expected to be larger due to upward steam migration and treatment of groundwater at depths above the screened interval. It must be stressed that a reasonable target volume cannot be calculated with any greater accuracy from data presently available. Considerable uncertainty exists as to the total volume of TCE that might be present within the target volume of soil, as there is no unequivocal method of converting MIP-DSTMS data into actual soil concentrations, coupled with the strong probability that any free product present is concentrated in thin layers. In consequence, no generally accepted volume of product is available to use as a measure of remediation success.

The anticipated wastewater treatment rate will typically not exceed 1.5 gpm over the course of each extraction phase. This rate will yield about 7,000 gallons during any extraction phase. This extracted volume represents about 120% of the volume of water injected as steam during the immediately preceding injection phase, which may provide the best indicator of treatment rates and volumes. The volume actually treated will be determined during the course of the demonstration, based on direct temperature measurement and ERT data. The final report will contain details on both areal-extent, depth intervals treated, and total volume within the treatment zone.

3.5.4 Residuals Handling

Soil and water generated during drilling operations, well development, and aquifer testing will be stored on site in drums or rented storage tanks (in case of water) for subsequent disposal in accordance with existing practices at Beale AFB.

Groundwater extracted during operations is not expected to contain significant quantities of TCE; however, all groundwater recovered during the first extraction phase will initially be stored in a tank on site. Analyses of water samples collected during the first cycle extraction phase will become available during the second steam injection phase. Subject to stored water meeting discharge standards for the Beale AFB sewer system, the first cycle wastewater then will be dis-

charged to the base sewer system. If stored water quality fails to meet discharge standards, the wastewater will be treated using activated carbon prior to final discharge. Wastewater will be regularly sampled for analysis at the point of discharge to the base sewer system. Groundwater extracted during the extraction phase of subsequent cycles will be handled in the same way.

Minor volumes of residuals, such as used personal protective equipment (PPE), sample vessels and spent carbon, will be stored temporarily in drums or bins and disposed of in line with existing practices at Beale AFB.

3.5.5 Operating Parameters for the Technology

Mobilization, setup, and demobilization at the demonstration site will require the presence of 3 to 4 SES personnel, in addition to a small number of laborers and trades hired locally. Under normal operations, the HPO demonstration equipment will require the presence of an SES boiler operator whom also will function as an on-site sampling technician. Liquid and vapor samples for off-site analysis will be collected from the SES process equipment during extraction phases by a dedicated SES sample technician. Subsurface samples of groundwater and soil gas will be collected by a Battelle sample technician. During steam injection phases, the steam generator will operate continuously. Automation of safety systems and alarms on the steam generator are such that the continuous presence of the boiler operator is not required outside normal (8 hour) working hours. However, the operator will be based locally during operations and will be automatically notified of problems in the running of the boiler. Ready access to the demonstration site from the main gate at Beale AFB must be available at all times, in order to permit a timely response to alarms. The steam generator will not operate during the steam soaking and liquid extraction phases of each operational cycle and the site will be unattended during soaking phases. An SES technician will be on site to collect samples during liquid extraction phases. Process parameters including flowrates, temperatures, and pressure will be recorded continuously and automatically using a SCADA system. Data collated by the SCADA system will be transmitted to the SES facility in Bakersfield at regular intervals.

Liquid and vapor samples from the process stream will be collected manually by the boiler operator/sample technician according to the procedures described below in the sampling plan.

Geophysical monitoring equipment will be operated by SES's contractor. Field data will be collected and transmitted for processing automatically. Minor maintenance of geophysical equipment located at the ground surface may be necessary, but will not require the continuous presence of a geophysical technician.

3.5.6 Demonstration System

The demonstration system design presented in this section is intended to meet the requirements for the HPO demonstration outlined in the scope of work presented to SES, incorporating minor modifications regarding location, target treatment volumes, and cycle length. In general, Battelle will collect all subsurface measurements and samples during the demonstration, including the groundwater and soil-gas samples, for performance assessment of the technology. SES will

collect all aboveground samples and measurements, including samples of the extracted vapor and liquid streams, to verify operational progress and assist in performance assessment.

3.5.6.1 Feed-Water and Steam Injection Stream

This section describes the water supply, injected water treatment, and steam generation equipment. This process is shown in Figure 3-9.

Steam will be generated on site using a gas-fired steam generator rated at a maximum of 2,500 lb/hr, equal to an energy input of 2.5 million BTU/hr. The maximum continuous water supply of 5 gpm will be from the closest convenient fire hydrant. The water will be softened using an ion-exchange resin. The steam injection pressure will be controlled to within a range of 1 psi using an air-powered oilfield-type pressure regulator. Metal pipe will be used to deliver the steam to the injection wellhead. Steam injection rates will be measured using a steam orifice plate with differential pressure measurement on the injection line. Steam pressure, temperature, and quality will be measured and calculated using standard instruments and calculation routines.

Steam and O₂ will be injected at the wellhead through separate side ports (Figure 3-6). The O₂ flowrate will be adjusted to match the steam injection rate, so that a concentration of 100 ± 50 ppm of O₂ is achieved. The O₂ flow will be metered using a rotameter or equivalent measuring device.

Bromide-tagged fresh water will be introduced to the casing of the injection well, as a 10-gallon slug, a short time before steam injection begins.

3.5.6.2 Extraction and Effluent Treatment System

Liquids are extracted using a dedicated pneumatic positive displacement pump (Figure 3-6). The pump is powered by an air compressor. Vapors are extracted through a side-port in the wellhead (Figure 3-6). The vacuum is supplied by a vacuum pump, which is an integral part of the effluent treatment system.

Vapor and liquid effluents will be treated using the process shown in Figure 3-10. The effluents requiring treatment are: (1) vapors extracted from the subsurface by the vacuum extraction system, and (2) all liquids extracted from the subsurface by the liquid recovery system. In addition, a small quantity of boiler blow-down water will be added to the waste stream. The blow-down water will amount to less than 500 gallons per day (gpd) of steam injection.

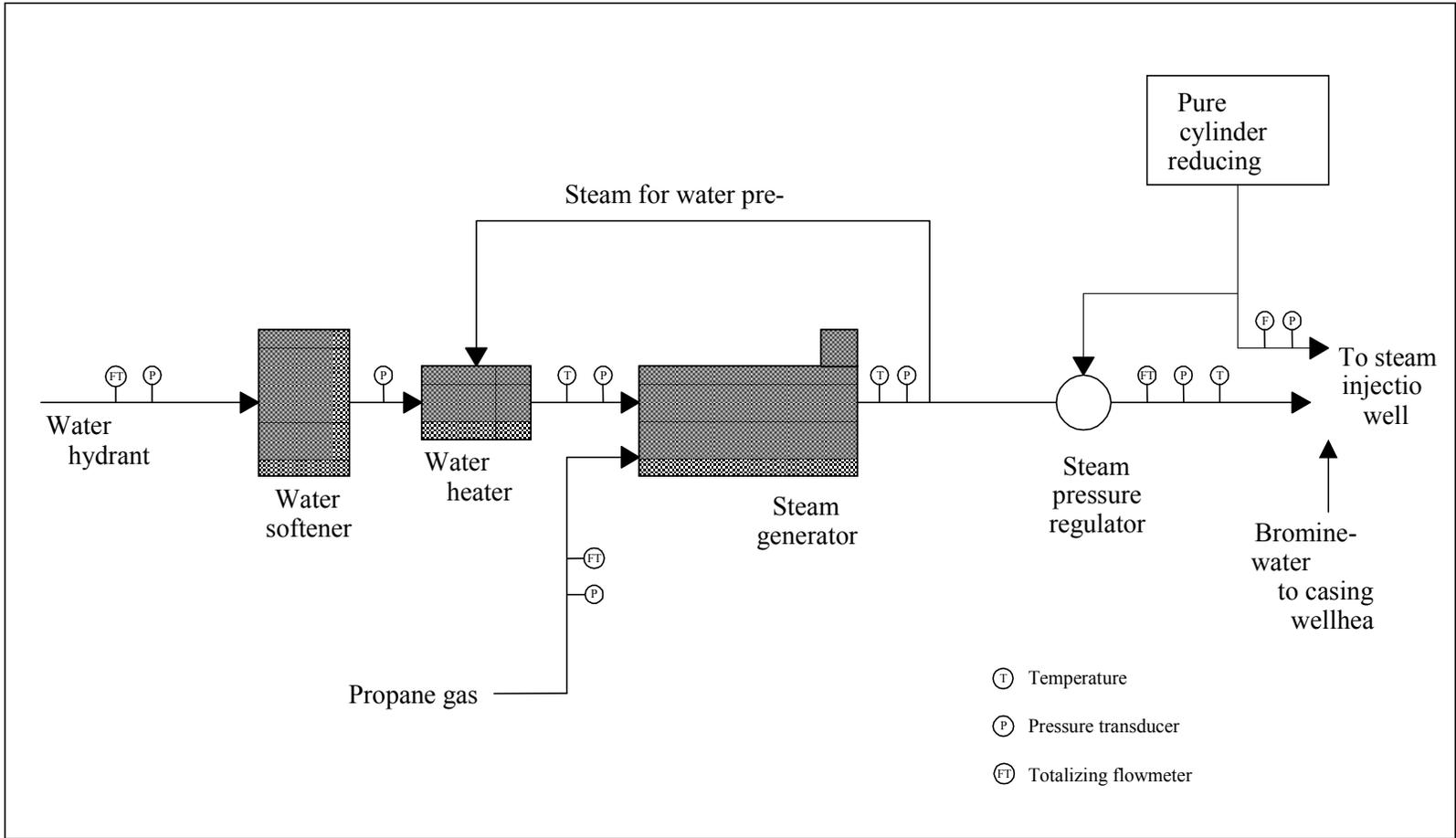


Figure 3-9. Steam Generation and Injection Schematic Diagram

The extracted vapors are carried to the treatment system through surface piping. The vapors first enter a liquid-vapor separator, also named a knock-out vessel (KO-1), in which water and fines carried with the vapor are removed from the vapor stream. Next, the vapors pass through a heat exchanger/condenser, in which their temperature is reduced to below 50°C (120°F). This leads to condensation of water vapors and contaminants (the condensable gases). The condensate is removed from the vapor stream in a second liquid-vapor separator (KO-2), and the noncondensable gases are carried to the vacuum pump. The effluent vapors from the vacuum pump are treated by carbon adsorption before being vented to the atmosphere (Figure 3-10).

The liquids removed from the extraction well will be stored temporarily in a large capacity holding tank such as a 21,000-gal Baker tank. This tank will be epoxy-coated and have vapor-tight top hatches in order to minimize contaminant loss prior to sampling of the tanks. No provisions for cooling are necessary, as the succeeding step in the treatment process is to remove volatile organics from the water. Before the water is passed via a mobile tank on to Beale AFB for use, it will be cleaned of organic contaminants by simple carbon adsorption using a 200-lb carbon canister (Figure 3-10).

Specific discharge and emissions criteria for individual COCs and other parameters specified by the California RWQCB, Central Valley Region, and the Bay Area Air Quality Management District (BAAQMD) are presented in Section 3.5.7.5.

3.5.6.3 First Steam Injection Phase

Steam and O₂ will be injected continuously into the well at a pressure giving the desired steam front velocity. The velocity is calculated using a simulator developed by SES. Subsurface monitoring of temperature (both directly using thermocouples and indirectly using ERT) will be used to follow the steam zone growth around the well. When the steam zone is judged to have reached the desired size, the steam injection rate will be lowered considerably over a period of hours, and finally ceased completely. The first injection phase is planned to last for two days.

3.5.6.4 Soaking and HPO Destruction Period

Upon completion of the steam and air injection phase, the site will be allowed to “soak,” a process in which the steam zone is allowed to slowly collapse back in on itself. During this time, the O₂ injected with the steam in the first phase will mix with the condensed water, and HPO reactions will occur, encouraged by the elevated soil temperatures. This phase is planned to last for two days, and resulting soaking temperatures are expected to be in the 80-100°C range.

3.5.6.5 Extraction and Control Phase

After the soaking/destruction period is complete, the extraction system will be started, and vapors and water extracted until a volume of liquid equivalent to at least 120% of the injected volume has been extracted. This will allow for capture of any remaining dissolved COCs that may have escaped destruction by HPO. Measurement of COC concentrations in the wastewater stream will provide an indication of the mass of contaminants removed from the subsurface with the extracted fluids. DO concentrations in the wastewater stream also will provide an indication

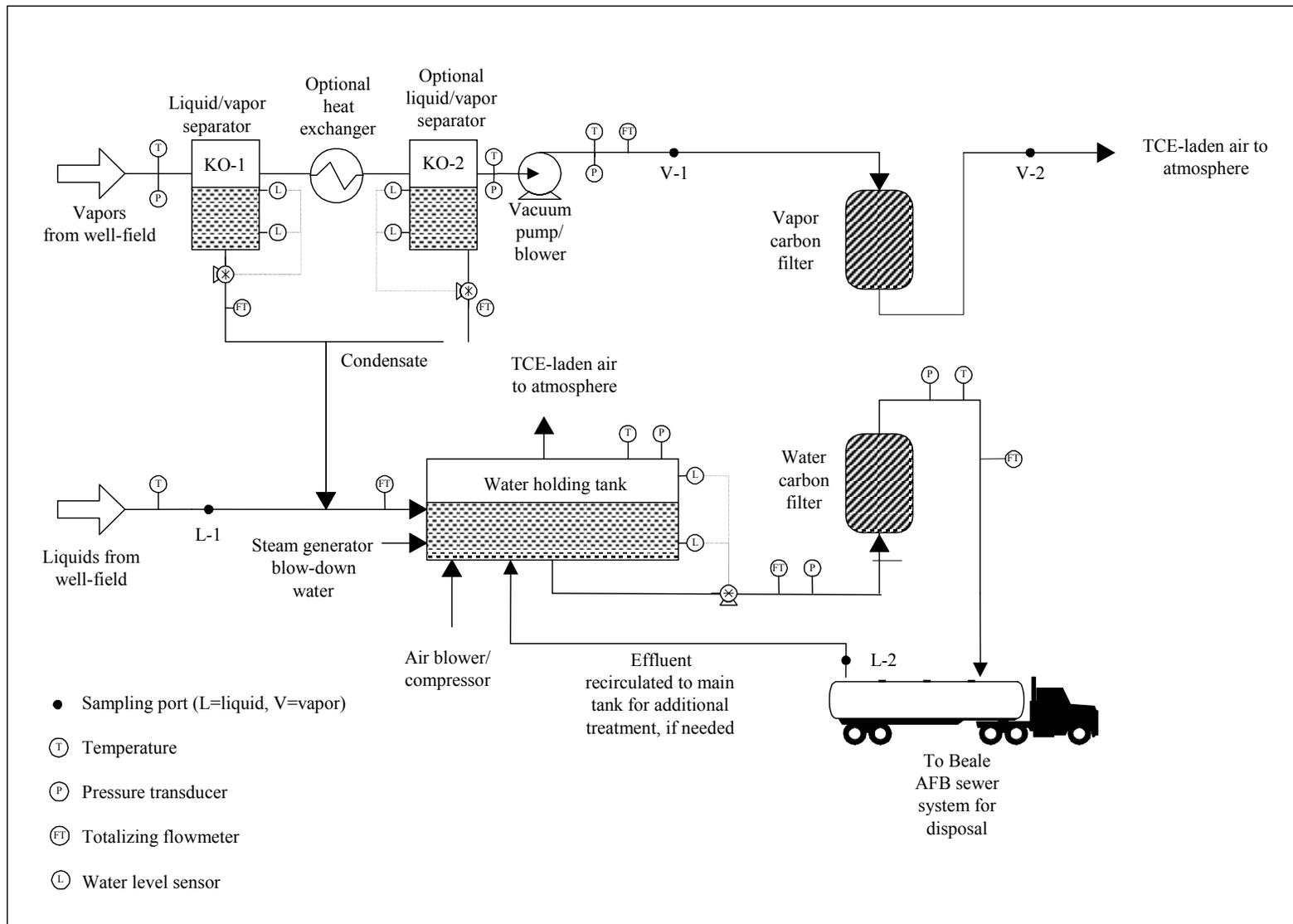


Figure 3-10. Simplified Effluent Treatment System Flow Diagram

of whether sufficient O₂ was coinjected during the steam injection phase to allow for aerobic conditions around the well. This period is planned to last for three days.

3.5.6.6 Subsequent Cycles (Steam Injection/Soak/Extraction Phases)

A second cycle of steam and co-air injection will follow the completion of the first operational cycle. Battelle and SES anticipate conducting up to five such cycles in the 35 days of field operation planned for this demonstration. Steam migration is expected to be more rapid in the second cycle, as the treatment zone will have been preheated. The desired injection pressures and rates may be calculated using the same simulator as was used for designing the initial steam injection period. The steam zone during the second cycle will probably be larger than the first, as it is anticipated that the majority of the COCs near the well have been destroyed or extracted during the first cycle. Following the injection, another soaking period will be initiated, followed by another extraction period. Again, measurement of COC concentrations in monitoring wells as well as the extraction well will be used to estimate remedial progress. Additional cycles of steam injection-soak-extraction will follow.

3.5.6.7 Cessation of Operations

The final action may be either injection or extraction, depending on the effectiveness of HPO during up to 5 cycles planned, and the demands of site-specific objectives such as final soil volume temperature requirements. If traces of COCs are still apparent within the treatment volume at the conclusion of operations, it may be desirable to leave the site as hot as possible, so that HPO processes can continue after the completion of the field operations part of the demonstration. This strategy would be achieved by following the fifth cycle extraction phase by a short period of steam and O₂ coinjection. However, if Battelle, Beale AFB, or ESTCP require that the site must be cooled to ambient temperatures, a longer final extraction period may be necessary. In general, the ending phase will be determined by the COC levels residual in the groundwater and the regulatory expectations on subsequent volatilization of COCs.

3.5.7 Sampling Plan

3.5.7.1 Data Quality Objectives

The chemical sampling and analysis will be focused on collecting data sufficient to meet the objectives listed in Section 3.1. The main objectives of the analyses are as follows:

- COC analyses: Determine the presence or absence of all COCs in each sample and quantify the concentration levels at the 80% confidence level. For water analyses, the reporting limits should be significantly lower than the MCL. This standard can readily be achieved using EPA Method 8260A.
- PID screening: These analyses are carried out with the sole purpose of getting an indication of the contaminant level in the vapor streams. The levels will be used in conjunction with the COC data gathered using EPA Method TO-14 to predict the amount of COCs extracted in the vapor phase. The inlet to the vapor-phase granular activated carbon (GAC) vessel will provide an indication of the VOC level being extracted by the vacuum

system, and will show temporal trends in the levels. No quantification of the concentration of individual compounds will be attempted using the PID data.

- Redox-sensitive groundwater parameters: These data are collected in order to assess the redox conditions in the subsurface. The principal objective of the demonstration is to create aerobic conditions that favor destruction of the COCs by oxidation, using DO as the oxidant. Therefore, the objectives of the groundwater redox parameter monitoring are simple: Document that the DO levels are above 1 mg/L, and that the concentrations of reduced species such as methane, ferrous iron, and manganese are negligible. Measurements of ORP will be conducted to support the overall redox condition assessment. It should be noted that standard methods do not exist for hot water samples. The samples will be cooled to ambient temperatures before measurement of DO, ORP, and other inorganic water parameters.
- Bromide tracer analysis: These analyses will be conducted in an attempt to document recovery of the injected steam. An accuracy of $\pm 5\%$ on the analyses will be acceptable.
- HPO-related groundwater parameters (Cl^- , CO_2 , O_2 , DO): The accuracy of these measurements will be optimized, as it is likely that the changes in chloride and alkalinity will be small compared to the background levels.
- Effluent stream vapor analyses: VOC by EPA Method TO-14 with detection or quantification limit better than the criteria defined in the permit or permit application. CO_2 , methane, and O_2 will be measured using real-time instruments with an accuracy of $\pm 5\%$ or better. The CO_2 accuracy will be optimized, because the expected changes will be small compared to the background levels.
- Effluent stream water analyses: Determine the presence of all COCs in each sample and quantify the concentration levels with $\pm 10\%$ accuracy or better. The reporting limits should be significantly lower than the discharge criteria (using EPA Method 8260A).

3.5.7.2 COCs and Analytical Parameters

Table 3-9 lists the COCs for the DUS/HPO demonstration. This list was developed on the basis of the extensive site characterization work performed by Battelle. All of the COCs can be quantified using EPA Methods 8260 (water) and TO-14 (vapor). The analytical methods are provided in Table 3-10.

3.5.7.3 Sampling Methods

In summary, the following sample matrices will be analyzed:

- Soil samples collected prior to the demonstration for PID scanning.
- Water samples (groundwater and process) collected prior to, during, or after operations.
- Vapor samples (soil gas and process) collected prior to, during the first of two cycles of operations.

Table 3-9. Contaminants of Concern for the Beale DUS/HPO Demonstration

Chemical	Maximum Concentration in Groundwater (µg/L)	MCL (µg/L)
PCE	76.7	5
TCE	1,050.0	5
<i>cis</i> -1,2-DCE	2.31	6
VC	<1.0	2

Table 3-10 summarizes the analytical parameters, sampling containers, preservation, and holding times. Soil samples will be collected during drilling by the best available techniques, based on an evaluation during drilling. All containers will be glass with Teflon[®]-lined septa. Care will be taken to avoid losses by evaporation.

Table 3-10. Analysis Method for Sampling of Groundwater, Vapor and Soil

Measurements	Matrix	Task/ Analysis Method	Holding Time	Comments
Temperature	Soil and groundwater	N/A	N/A	Thermocouple
Primary Measurements				
CVOC	Groundwater	SW8260A	14 days	3 × 40 mL VOA vials
CVOC	Soil screening	PID reading	N/A	Soil screening as soil samples are retrieved during well installation.
CVOC	Organic vapor	EPA TO-14	14 days	Summa canister will collect a 12-hr cumulated air sample.
Secondary Measurements				
Groundwater				
Chloride	Groundwater	EPA300.0	28 days	250-mL plastic without preservative
Bromide	Groundwater	EPA9056	28 days	3 × 40-mL VOA vials without preservative
Alkalinity	Groundwater	EPA310.1	28 days	250-mL plastic bottle without preservative
Fe, Mn	Groundwater	SW6010	28 days	250-mL plastic bottle without HNO ₃
Methane	Groundwater	EPA 3810 Modified (RS Kerr procedure)	7 days	3 × 40-mL VOA vials with HCl.
Field Parameters ^(a)	Groundwater	N/A	N/A	Horiba U-22
Soil Gas				
CO ₂	Ambient air	Infrared sensor	N/A	N/A
Methane	Ambient air	N/A	N/A	N/A
O ₂	Ambient air	N/A	N/A	N/A

(a) Field parameters: pH, ORP, DO, temperature, and conductivity.

N/A = not applicable.

VOA = volatile organic analysis.

Water samples will be collected through side ports of pipes carrying water, and through tubing connected to sampling pumps. Low flow groundwater will be purged through a flow-through cell in a closed system, which follows United States Environmental Protection Agency (U.S. EPA) micropurge sampling guideline (Puls and Barcelona, 1996). All samples will be collected in triplicate in 40 mL VOA vials with Teflon[®]-lined septa after the field parameters, such as pH, DO, conductivity, temperature, and ORP, stabilize. The field parameters will be measured after the water comes out of the cooling loop. Each vial will be flushed with at least one volume of water prior to collection of the sample. Care will be taken to prevent gas bubbles in the vials, and the vials will therefore be filled to capacity. Samples of hot water will be cooled before sampling using a cooling coil suspended in cool water. Sampling temperatures will be below 30°C. Samples requiring refrigeration will be stored in ice chests at between 0 and 4°C and analyzed within the holding times specified in those methods listed in Table 3-10.

Vapor samples will be collected in new 1-L Tedlar[™] bags for PID screening, or Summa canisters for TO-14 VOC analysis. Grab samples will be collected from vapor lines at positive pressure, so passive fill of the bags is used. If streams under negative pressure need to be sampled, a vacuum chamber will be used to sample directly into Tedlar[™] bags without any contact of the vapor with the vacuum pump.

Soil cuttings will be collected carefully in jars and analyzed for waste disposal.

3.5.7.4 Analytical Methods, Calibration, Detection Limits, and Accuracy

Table 3-10 lists the analytical methods used for analysis of the samples collected by SES. The laboratory selected will follow standard procedures for instrument calibration. Detection limits and accuracy are determined by the standard methods/analytical procedures.

Samples of soil and water will be analyzed for VOCs using EPA Method 8260A.

Vapor samples will be analyzed for VOCs using EPA Method TO-14.

In addition, grab vapor and water samples will be screened for VOC components using a PID. This data represents the organic load on the vapor treatment unit (V-1) and in the emitted vapor (V-2), and will reflect temporal changes in contaminant concentrations. The PID will be calibrated to a 100-parts-per-million-by-volume (ppmv) isobutylene standard gas.

Chemical parameters such as pH, DO, and ORP will be measured on site using a field instrument such as Horiba[®] U-22. Methods for all other analyses are provided in Table 3-10.

3.5.7.5 Sampling Locations and Frequencies

A simplified effluent treatment system diagram identifying sampling ports is shown in Figure 3-10. These consist of liquid sample ports at the extraction wellhead (L-1), and at the final discharge point from the treatment system (L-2). Vapor sample ports are located before (V-1)

and after (V-2) the carbon canister. Solid wastes generated during operations are spent GAC and solids from filters and strainers.

Table 3-11 lists the sampling and analyses performed during operations. Sampling points V-1 and V-2 are vapor sampling points consisting of a ¼-inch stainless-steel tube connected to the main vapor line through a ball valve. Note that sampling point V-2 is the vapor emissions point at which performance samples are to be collected according to the air emission permit. Criteria for COCs in vapor emissions are listed in Table 3-12. Vapor samples for VOC analysis will be collected at V-1 during the extraction phase of each cycle, at 1, 24, 48 and 72 hours (at the beginning of each day of extraction and immediately before the following steam phase) after the beginning of extraction, respectively. Vapor grab samples for screening using PID will be collected seven times during the extraction phase of each cycle, at 1, 8, 24, 32, 48, 56, and 72 hours after the onset of extraction (at the beginning and end of each 8-hour day). Grab samples for O₂ analysis will be collected at sample point V-1 at the same times. CO₂ will be monitored continuously, using an in-line analyzer during the operation. Grab samples also will be collected from the postdemonstration vapor stream at the same times as the predemonstration samples. SES personnel will collect all process vapor samples.

Sampling points L-1 and L-2 are both liquid sampling points, consisting of a ¼-inch stainless-steel tube connected to the liquid pipe through a ball valve. Note that sampling point L-2 is the water discharge point at which performance samples are to be collected according to the liquid discharge permit. Criteria for water discharge are listed in Table 3-13. Water samples will be collected at point L-1 (at the extraction well) for VOC analysis and again for a range of redox and HPO parameters three separate times prior to the beginning of the demonstration, in order to provide a baseline characterization of groundwater chemistry. During operations, L-1 will be sampled during the extraction phase only. VOC samples will be collected four times (at 1, 24, 48, and 72 hours after onset of pumping) at the same time as predemonstration (V-1) VOC vapor samples. Redox and HPO parameters will be analyzed in samples collected at the beginning and end of the extraction phase in the first, third, and fifth cycles only, in order to assess temporal trends in the effectiveness of HPO between steam phases. In addition to this program of sampling for inorganic parameters, the presence of bromide-tagged water also will be analyzed for in samples collected at four intervals (in L-1 sampling port) during the extraction phase (i.e., 1, 24, 48 and 72 hours after onset of pumping) in the first, third and fifth cycles. In the second and fourth cycles, only one sample will be collected at the end of extraction phase from the L-1 sampling port. A final three rounds of sampling for all organic, inorganic and redox parameters will be taken at point L-1 at intervals 1, 2, and 4 weeks after the end of the last cycle, as part of the poststeam characterization. SES personnel will collect all samples from point L-1. Sample point L-2 (postdemonstration) in the extracted liquid stream will be sampled once for analysis of VOCs and other parameters listed in Table 3-13 during each extraction phase, at a time to be determined during the demonstration. A single sample will be collected from L-2 during the first extraction phase, for analysis for a range of substances, in line with liquid discharge regulations at the site. SES personnel will collect samples from this point.

Table 3-11. Overview of Sampling, Analyses, and Monitoring Frequencies

Sampling Location	Matrix	Duration (days) Analysis	Pre-Demo			1st Cycle			2nd Cycle			3rd Cycle			4th Cycle			5th Cycle			Post-Demo			Total No. of Samples
			Round 1	Round 2	Round 3	Inject	Soak	Extract	Inject	Soak	Extract	Inject	Soak	Extract	Inject	Soak	Extract	Inject	Soak	Extract	Round 1	Round 2	Round 4	
			1	1	1	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3	1	1	1	
Operational Monitoring																								
L-1: Injection/Extraction Well (SI-1)	Water	VOC	1	1	1	0	0	4	0	0	4	0	0	4	0	0	4	0	0	4	1	1	1	26
	Water	Cl-, Alkalinity, DO, ORP, Fe, Mn, CH ₄ , pH	1	1	1	0	0	2	0	0	0	0	0	2	0	0	0	0	0	2	1	1	1	12
	Water	Br	1	1	1	0	0	4	0	0	1	0	0	4	0	0	1	0	0	4	1	1	1	20
V-1: Pre-Vapor Treatment	Vapor	VOC	0	0	0	0	0	4	0	0	4	0	0	4	0	0	4	0	0	4	0	0	0	20
	Vapor	PID grab	0	0	0	0	0	7	0	0	7	0	0	7	0	0	7	0	0	7	0	0	0	35
	Vapor	PID CO ₂ , O ₂ grab	0	0	0	0	0	7	0	0	7	0	0	7	0	0	7	0	0	7	0	0	0	35
V-2: Emitted Vapor	Vapor	VOC (and BAAQMD specs.)	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	5
	Vapor	PID grab	0	0	0	0	0	7	0	0	7	0	0	7	0	0	7	0	0	7	0	0	0	35
L-2: GAC Outlet	Water	VOC	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	5
	Water	RWQCB sample	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
Quality Assurance (QA) Samples	Vapor	VOC	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	
Soil Sampling	Soil	PID	102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102
	Soil	TOC	6																				6	
Subsurface Monitoring																								
Temperature (field)			0	1	1	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3	1	1	1	40 (rounds)
ERT (field)			0	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	1	1	1	25 (rounds)
Treatment Zone Monitoring Wells (5 Wells; BAT-6 to -10)	Water	VOC	5	5	5	0	5	5	0	0	0	0	5	5	0	0	0	0	5	5	5	5	5	60
	Water	Br	5	0	0	0	5	5	0	0	0	0	0	5	0	0	0	0	0	5	0	0	0	25
	Water	Cl-, Alkalinity, DO, ORP, Fe, Mn, CH ₄ , pH	5	5	5	0	5	5	0	(DO only)	0	0	5	0	0	(DO only)	0	0	5	0	5	5	5	50
Perimeter Wells (4 Wells; BAT-4S/D and -5S/D)	Water	VOC	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	24
	Water	Br	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	8
	Water	Cl-, Alkalinity, DO, ORP, Fe, Mn, CH ₄ , pH	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	8
Soil-Gas Points (SG-1 to 3)	Vapor	VOC	3	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
QA Samples	Water	VOC	4	0	0	0	0	4	0	0	0	0	0	4	0	0	0	0	0	4	4	0	0	20
	Vapor	VOC	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

Table 3-12. Emitted Vapor Criteria

Parameter	Trigger Level	Sample Location
TCE	97 lb/year	V-2: Emitted vapor
PCE	33 lb/year	V-2: Emitted vapor
VC	2.5 lb/year	V-2: Emitted vapor

Table 3-13. Liquid Effluent Limitations for Parameters Specified by CRWQCB^(a)

Parameter	Target (µg/L)	Sample Point	Comments
Ammonia (as N)	1,500	L-2: Liquid discharge point	
Barium	1,000	L-2: Liquid discharge point	Monthly mean
Boron	1,000	L-2: Liquid discharge point	Monthly mean
Copper	13	L-2: Liquid discharge point	Monthly mean
Cyanide	5.2	L-2: Liquid discharge point	Monthly mean
Mercury	0.012	L-2: Liquid discharge point	Monthly mean
Cadmium	1.2	L-2: Liquid discharge point	Monthly mean
Methylene blue active substances (MBAS)	500	L-2: Liquid discharge point	Monthly mean
Oil and grease	10,000	L-2: Liquid discharge point	Monthly mean
TPH-GRO	50	L-2: Liquid discharge point	
TPH-MO	100	L-2: Liquid discharge point	
TPH-DRO	100	L-2: Liquid discharge point	Monthly mean
<i>bis</i> (2-ethylhexyl)phthalate	1.8	L-2: Liquid discharge point	
Chloroform	0.5	L-2: Liquid discharge point	Monthly mean
1,1,2-trichloroethane	0.5	L-2: Liquid discharge point	
<i>trans</i> -1,2-DCE	0.5	L-2: Liquid discharge point	
<i>cis</i> -1,2-DCE	0.5	L-2: Liquid discharge point	COC in demonstration
TCE	0.5	L-2: Liquid discharge point	COC in demonstration
PCE	0.5	L-2: Liquid discharge point	COC in demonstration
VC	0.5	L-2: Liquid discharge point	COC in demonstration

(a) Discharged liquids should not exceed stated target levels.

Groundwater in the treatment zone monitoring wells (BAT-6 to BAT-10) will be sampled for VOC and redox/HPO parameter analysis three times prior to the beginning of operations. During operations, these wells also will be sampled for VOCs and inorganic parameters immediately after the soaking phase in the first, third, and fifth cycles, subject to indication of safe pressure and temperature readings at the wellheads. An additional round of samples for VOC and redox/HPO parameter analysis will be collected from each of the monitoring wells at the end of the extraction phase in the first cycle. In subsequent cycles, samples will be collected at the end of the extraction phase for VOC analysis only in the third and fifth cycles. No samples will be collected from the treatment zone monitoring wells during the second and fourth cycles, except for dissolved oxygen, which will be measured after every cycle in BAT-6 to BAT-10. A final three rounds of sampling for VOCs and inorganic parameters will be conducted at all of the monitoring wells as part of the poststeam demonstration. All groundwater monitoring wells (BAT-6 to BAT-10) in the treatment zone will be conducted by Battelle personnel.

Groundwater in perimeter wells (BAT-4S/D and BAT-5S/D) also will be sampled for VOCs and inorganics three rounds before and after the demonstration, but not during the operations. Battelle personnel will collect all monitoring (treatment zone and perimeter) wells samples.

Given sufficient time after the demonstration, it would be desirable to continue monitoring groundwater concentrations of TCE and byproducts until the aquifer has finally cooled to ambient temperature. However, based on past experience with in situ thermal technologies, it may take as much as one year or more for the aquifer to cool down to ambient conditions. During this time, the upgradient plume may migrate into the treatment zone making the evaluation more difficult. Given the technical and resource limitations, postdemonstration sampling is currently limited to the four weeks after the fifth and final steam injection/extraction cycle.

Soil-gas sample points are located in dedicated boreholes, within 5 ft of three treatment monitoring wells (BAT-6, 7, and 8). Soil gas at these points will be sampled for VOC analysis: once during the predemonstration and twice (injection phase of first and second cycles) during the operation. Battelle personnel will collect all soil-gas samples.

Grab samples for PID analysis will be collected from the center of each soil core retrieved during drilling for installation of the injection/extraction and monitoring wells. SES will assume the responsibility for collecting and screening these samples. Any requirement for soil sampling, as part of the postoperational characterization program, will be determined by Battelle and SES.

In situ monitoring of temperature and resistivity (ERT) will consist of collecting two complete data sets prior to the beginning of steam injection and a final three complete data sets at intervals of 1 week, 2 weeks, and 4 weeks after completion of the final extraction phase, as part of the poststeam characterization effort. During operations, temperature will be recorded at all thermocouples in the monitoring network once during each day of operation. ERT data will be collected at the end of each day during the steam phase and at the end of the steam soak and extraction phases. SES or its geophysical contractor will be responsible for collection of all temperature and ERT data.

3.5.7.6 Quality Assurance/Quality Control (QA/QC)

The QA/QC procedures are listed in Table 3-14. In general, duplicate samples will be collected for 5% of the total number of samples and submitted for analysis. In addition, 5% of laboratory samples analyzed will be duplicates. Trip blanks will be included at frequent intervals.

3.5.8 Demobilization

Because all major equipment is trailer-mounted, demobilization is anticipated to require only three to five days. Surface piping and wiring will be dismantled by SES personnel and removed from the site for recovery or final disposal, as appropriate. The central injection/extraction wellhead assembly will be removed and the casing will be cut flush with the ground surface. The central well and adjacent groundwater monitoring wells will be used for postoperational

Table 3-14. Summary of QA/QC Samples

Phase of Work		Matrix	Frequency	Analytes
Field Collected Replicas	Well Field	Soil	5 % (1 in 20)	All
		Water	5 % (1 in 20)	All
		Vapor	5 % (1 in 20)	All
	Effluent Treatment System	Water	5 % (1 in 20)	All
		Vapor	5 % (1 in 20)	All
		Wastes	5 % (1 in 20)	All
Lab Duplicates		Soil	5 % (1 in 20)	All
		Water	5 % (1 in 20)	All
		Vapor	5 % (1 in 20)	All

sampling for at least four weeks after the end of the final extraction phase. After this time, the wells may be retained at the request of Battelle, Beale AFB, or ESTCP for long-term monitoring purposes. As part of the scheduled postoperational monitoring process, SES is prepared to leave the process equipment on site until the last groundwater and soil concentration data arrive, and the final decision is made that no more activities are needed. Alternatively, if no postdemonstration use for the wells is anticipated, SES will grout up the wells for final abandonment, as directed by Battelle, Beale AFB, or ESTCP.

3.5.9 Health and Safety Plan

A detailed Health and Safety Plan (HASP) is attached as Appendix C.

3.6 Selection of Analytical/Testing Methods

ERT will be used as one of the principal methods for monitoring subsurface processes during the demonstration. ERT is an adaptation of the established surface-based resistivity method that measures the electrical resistivity of the subsurface. Electrical methods are the geophysical imaging techniques best suited to providing detailed images of hydrological flow and transport processes, because electrical properties are primarily sensitive to various hydrologic properties of soil and rock (Archie, 1942; Keller, 1988). For example, the electrical resistivity (or its inverse, the electrical conductivity) primarily depends on the formation porosity, the saturation, the electrical conductivity of the pore fluid (which in turn depends on temperature), and to a lesser degree the amount of clay that is present. By making measurements of the electrical fields at discrete locations on the surface and in the subsurface, three-dimensional (3-D) estimates of the electrical properties can be constructed, which then can be related to the hydrologic properties of interest.

To provide 3-D images of the subsurface, ERT uses electrodes placed in boreholes or wells and on the surface. These electrodes typically consist of short pieces of stainless steel tubing fixed to a temperature-resistant fiberglass rod or similar nonconductive material. Each electrode is connected to the surface by a Teflon[®]-coated wire (Figure 3-11). A VEA is placed either in a small-diameter open borehole or in a fiberglass-cased injection/extraction well and grouted

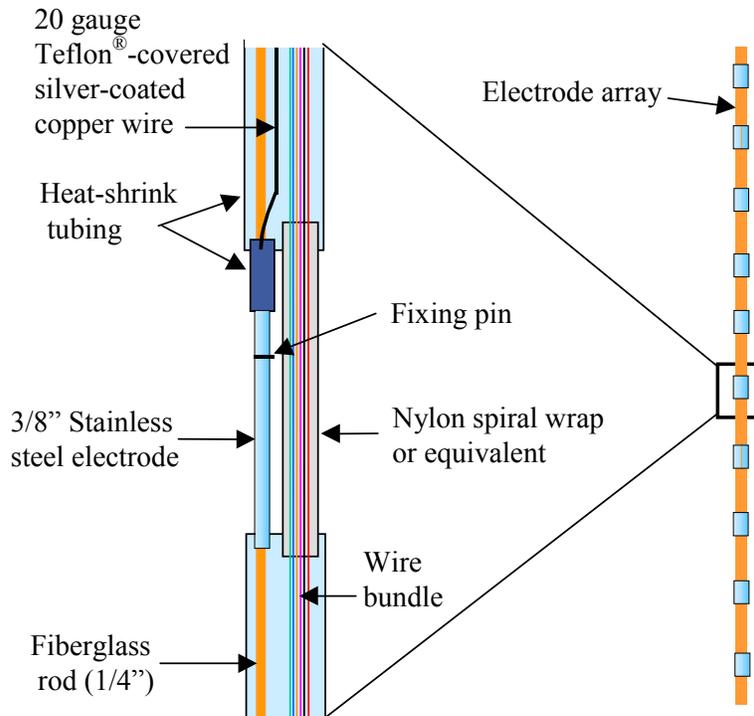


Figure 3-11. Vertical Electrode Array Design Detail

permanently in place. An ERT data point is measured by injecting electric current into the ground through a pair of electrodes and measuring voltage across another pair of electrodes. For a site with five monitoring wells and about 150 electrodes, a complete data set with reciprocals consists of 22,000 independent data points. These data can be collected in 9 to 10 hours using a single channel data acquisition system developed by SES that automatically makes measurements using many different pairs of electrodes.

A sophisticated inverse modeling algorithm is then used to create a 3-D image of electrical properties from the ERT data set. The algorithm used for this project was developed by SES and is described in LaBrecque and Yang (2000). It uses a finite-difference method to calculate the response of an earth with a 3-D distribution and a robust, Occam's-type inversion (LaBrecque et al., 1995; Morelli and LaBrecque, 1996; LaBrecque and Yang, 2000) to determine the resistivity distribution response which best fits the observed data. The in situ temperature and steam distribution can be inferred from the 3-D images.

ERT monitoring will be supplemented by direct temperature monitoring in the same boreholes by the use of thermocouples attached to the central rod between electrodes. Thermocouples also will be present in the annulus of the injection/extraction well. The thermocouples themselves and the use of downhole thermocouples to monitor temperature in the subsurface is a well-established technology.

3.7 Selection of Analytical/Testing Laboratory

Groundwater samples for VOCs, inorganics (iron, manganese, chloride, bromide, and alkalinity), and methane will be sent to a State of California-certified laboratory (DHL Analytical, Round Rock, TX). Waste analysis for liquid and solid (soil cuttings) will also be analyzed at a State of California-certified laboratory (Alpha Analytical, Utica, CA). For air and soil-gas samples, a State of California-certified laboratory (Air Toxics, Folsom, CA) will be used.

3.8 Management and Staffing

Figure 3-12 shows the project organization for the demonstration. NFESC, which reports to ESTCP, has the overall project lead role. LLNL provides the licensed technology and technical support and review. Battelle, under contract to NFESC, oversees the preparation of the demonstration plan, its implementation, data collection and analysis, and preparation of the final technology evaluation report and cost and performance report. Battelle will collect all groundwater and soil-gas samples required before, during, and after the demonstration for performance assessment of the technology. Battelle is supported by the following organizations:

- **SES.** SES is the primary steam injection technology licensed vendor responsible for designing and implementing the steam injection application, given the overall objectives of the demonstration. SES will collect all aboveground samples during the demonstration to determine operational competence and assist in performance assessment. SES (and its representatives) will be responsible for conducting the ERT assessment during the demonstration. SES will provide technical support for the demonstration plan and final reports.
- **Drilling Subcontractor.** A drilling subcontractor will be subcontracted by SES to install the steam injection and monitoring wells.
- **Analytical Laboratory.** The primary laboratory subcontracted by Battelle is DHL Analytical, a State of California-certified laboratory to conduct off-site analysis of the samples collected during the demonstration.

3.9 Demonstration Schedule

A preliminary schedule is shown in Figure 3-13.

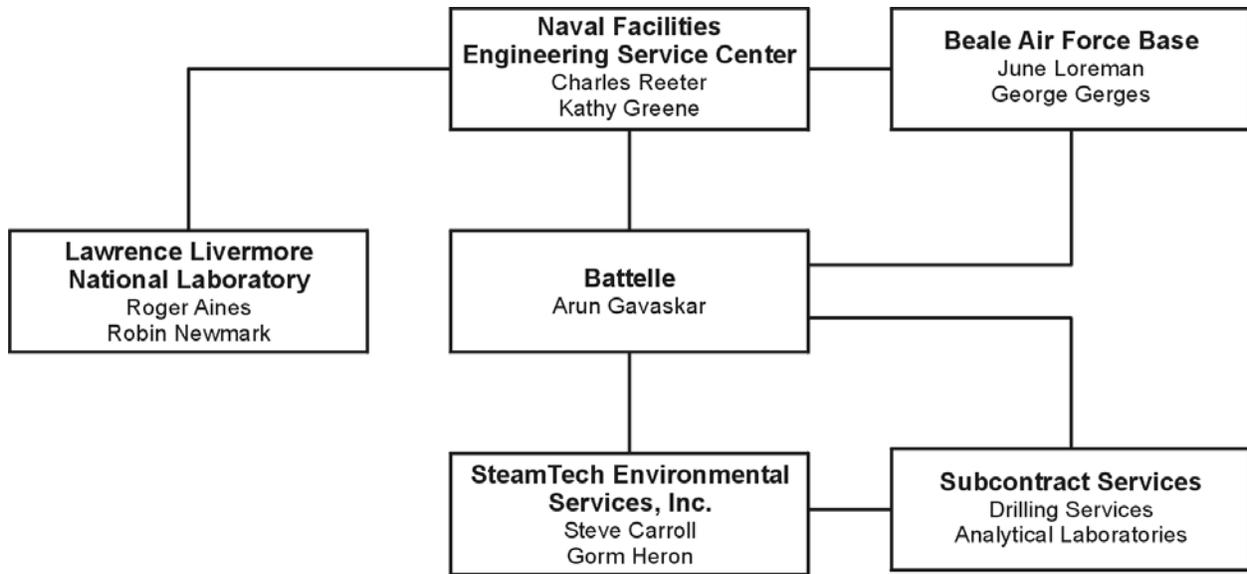


Figure 3-12. Project Organization Chart

4.0 Performance Assessment

4.1 Performance Objectives

Performance objectives of the DUS/HPO demonstration are listed in Table 4-1. Details and discussion of each objective and its associated data are listed below.

Table 4-1. Summary of Performance Criteria

Performance Objectives	Description	Primary or Secondary
Destroy COCs in situ by HPO.	The technology will destroy COCs (TCE, PCE, <i>cis</i> -1,2-DCE, vinyl chloride) in situ.	Primary
Heat the soil around the injection well by steam injection.	The technology will heat the soil in the treatment zone to a temperature sufficient for HPO to occur, using steam injected at a single well as the heat source.	Secondary
Maintain hydraulic control of the site and prevent significant migration of COCs beyond the zone of effective HPO.	The technology will extract liquid and vapor from the subsurface at a rate and volume sufficient to ensure that any COCs not destroyed by HPO will be recovered.	Secondary

4.1.1 In Situ Destruction of COCs by Means of HPO

The objectives of this demonstration are to reduce the groundwater concentrations for COCs within the target volume, to prevent statistically significant COC concentration increases at the end of the demonstration in those monitoring wells located outside the target volume, and to show that vadose zone soil-gas COC concentrations are not increased substantially by the remedial action. Data collection involves documentation of groundwater concentrations for COCs both in the operational wells and the monitoring wells, and COC concentrations in the soil-gas monitoring locations.

A goal of this HPO demonstration is to destroy COCs in groundwater inside the demonstration area, thereby resulting in a statistically significant reduction in the dissolved TCE concentration levels. Wells used for the statistical analysis are those located within the treatment volume, including the injection/extraction well. Note that the treatment volume will be defined during operations once the radius of influence of the steam zone has been determined. A level of confidence of 80% will be used in the statistical evaluation. Given the natural heterogeneity and variability of the TCE data and the limited sampling being performed, this level of confidence is expected to be more achievable than, for example, a stricter 90% confidence level. A paired t-test will be conducted between pre- and postdemonstration concentrations in wells BAT-6 to BAT-10 to statistically evaluate the effectiveness of the treatment. Reduction of TCE level in the groundwater to its MCL (5 µg/L) is desirable, but is not a direct goal of the demonstration.

In order to provide a comparison of pre- and postoperation COC levels, data will be collected to evaluate COC groundwater concentrations in the vicinity of the target zone. All groundwater

COC data will be analyzed statistically, and the target is to document that the COC concentrations do not increase significantly on an 80% confidence level. A minimum of three sampling rounds will be used, and the 80% confidence level test will be performed for each COC individually. Wells used for the statistical analysis are within a radius of 50 ft from the injection/extraction well.

Data will be collected to evaluate COC concentrations in soil gas above and inside the treatment zone only for predemonstration, and during the first and second injection cycles. The possibility of any considerable TCE vapors being generated is highest during the two cycles of operations. As the level of contamination in the treated zone goes down, there will not be much contamination in the treatment zone to volatilize.

Soil-gas sampling locations are those installed in the upper portion of each monitoring well.

During operations, the COC concentrations in groundwater will be monitored at the beginning of each soaking phase and at the beginning of each extraction phase. During the first, third and fifth cycles this approach will provide data for the temporal changes in the COC distribution in groundwater including the maximum concentrations induced in the subsurface as a consequence of steam injection.

Knauss et al. (1997) investigated the kinetics of TCE oxidation by HPO and concluded that TCE is readily mineralized into water, chloride, and CO₂. For TCE oxidized by O₂, the overall reaction is:



For a field demonstration, it is desirable to quantify the importance of HPO at the field scale. The most useful parameters to analyze are CO₂, alkalinity, and chloride.

For CO₂, assuming the same amount of TCE is oxidized, and the produced CO₂ is diluted into the extracted air, the potential increase of the CO₂ in vapor phase concentration in ppmv should be measured. Therefore, a CO₂ analyzer will be placed in the air stream of the treatment system.

Alkalinity will be measured in the extracted water. If a substantial amount of COC is degraded, the evolved CO₂ may lead to carbonate buffering reactions that affect the alkalinity of the groundwater. Although measurable changes are not expected, these data will be collected to contribute to the overall understanding of the subsurface processes. The background alkalinity is 115-190 mg/L, two orders of magnitude higher than the expected change due to TCE oxidation to CO₂.

Simple calculations show that chloride concentrations are unlikely to be significantly affected by oxidation of TCE. Background Cl⁻ concentrations vary from 13 to 33 mg/L in just three BAT wells, and approximately 1 mg/L will be produced if all TCE is oxidized at once. However, chloride data will be collected in order to test this hypothesis.

In summary, this demonstration objective can be met by the successful collection of the data on the HPO-related parameters. No specific claims are made regarding the achievement of statistically significant changes in any of the parameters, because the background parameter values are large compared to the suspected changes.

4.1.2 Heat the Soil Around the Injection Well by Means of Steam Injection

This objective involves heating of the target zone by the injection of steam, creation of oxidizing conditions in the groundwater by the injection of O₂ and steam zone collapsing, and documentation of the volumetric extent of the heated zone.

The amount of steam (and the associated enthalpy) will be monitored by the amount of water injected as steam times the specific enthalpy at the actual injection temperature and pressure. For each injection cycle the injected amount of energy/enthalpy will be sufficient to heat a soil volume of at least 100 yd³ from ambient temperature to steam temperature. The actual heated volume will be larger.

Achievement of oxidizing conditions in the groundwater will be documented by sampling for DO in the monitoring wells at the onset of the soaking and extraction phases, and in the extracted liquid during the extraction phase (see Section 3.5.7.5 and Table 3-11). A minimum of 1 mg/L of DO is considered to indicate aerobic/oxidizing conditions in the groundwater. Where the groundwater temperature is above ambient, a cooling coil will be used to reduce the sample temperature to below 30°C before the DO analysis. Other groundwater indicator parameters will include:

- ORP (expected to increase to above +100 mV)
- Dissolved iron (expected to decrease to below 0.1 mg/L)
- Methane (expected to decrease to below 0.5 mg/L).

Due to difficulties in measuring the inorganic redox indicator parameters in hot water samples, and because standard procedures for cooling and analyses have not been established, no specific claims are made for the values actually measured for any parameter.

The target temperatures for the oxidized groundwater zone is 80-100°C, which is sufficient to achieve a short half-life for TCE according to laboratory studies (Knauss et al., 1997), and which is achievable upon collapse of a steam zone with a steam temperature in the 100-120°C range. Achievement of this temperature will be documented by the use of dedicated thermocouples installed in the operational well, all monitoring wells, and in dedicated temperature monitoring points on the VEAs. The hard temperature data will be supported by ERT data, which provide interpreted temperature data with greater spatial coverage between boreholes. ERT data will be collected four (4) times per cycle, and temperature data will be collected more frequently.

4.1.3 Maintain Hydraulic Control and Prevent Significant Migration of COCs

This demonstration objective involves both achieving a net extraction of liquids from the site, and collecting data that allows for an evaluation of whether the injected bromide tracer is recovered.

The first interim (net extraction) will be documented by comparing the cumulative amount of steam injected for each cycle with the cumulative amount of liquids extracted in the subsequent extraction phase. A minimum of 120% more extraction than injection will be documented for each cycle. The cumulative amount of steam injected is determined based on both water usage for steam generation and direct measurement of steam flowrates at the injection wellhead. The cumulative amount of water extracted will be determined based on flowrates and totalized readings at the extraction well and at the sampling point L-2 of the effluent treatment system. Both quantities are calculated as:

$$\text{mass} = \text{sum} (\text{flowrate} \times \text{period of operation})$$

where the flowrates are instantaneous measurements and the periods are measured between flowrate measuring events. Where a totalizing flowmeter is used, the cumulative flow volumes/masses will be read periodically and added to a database.

The second criterion (bromide tracer evaluation) will be documented by collecting bromide concentrations in the extracted water, and documenting of the approximate recovery of the tracer. No specific claims are made regarding complete recovery of the tracer, since the steam migration pathways cannot be guaranteed to be identical to those of the extraction pathways. However, these data will be used to determine the duration of the extraction phases, as greater than 90% recovery of the tracer will be targeted.

4.2 Performance Confirmation Methods

Section 3.5 contains the detailed experimental design and sampling strategy to achieve the performance objectives of the demonstration. The sampling and analysis methods for chemical analyses are listed in Section 3.5.7. Subsurface temperature and ERT monitoring methods are described in Section 3.6. Process data measurement methods are described in this section.

An overview of the process monitoring parameters is given in Table 4-2. The monitoring consists of flowrate and cumulative flow measurements (using in-line flowmeters and counters), temperature measurements (using thermocouples and manually read gauges), pressure measurements (using pressure transducers and manually read gauges), and liquid level measurements (using level probes, side glasses, and manually read gauges).

Table 4-2. Overview of Expected Performance and Performance Confirmation Methods

Performance Criteria	Expected Performance (Predemonstration)	Performance Confirmation Method
<i>Primary Criterion</i>		
(1) In situ destruction of COCs by HPO	Statistically significant decrease in COC concentrations in wells within the treatment zone, allied to performance indicators in criterion (3).	Sampling of groundwater before and after demonstration.
<i>Secondary Criteria</i>		
(2) Heat the soil around the injection well by means of steam injection.	Heating of soil surrounding injection well to a temperature sufficient for HPO processes to operate (>80°C)	Temperature monitoring of treatment zone using ERT grid and thermocouples in monitoring wells.
(3) Maintain hydraulic control of the site and prevent significant migration of COCs beyond the zone of effective HPO.	<ul style="list-style-type: none"> a) Recovery of groundwater volume in excess of original volume. b) Recovery of bromide-tagged water injected as steam. c) No evidence of significantly increased COC concentrations in groundwater monitoring wells lying outside the treatment zone (greater than 30-ft radius) over the course of the demonstration. d) No evidence of increased COC concentrations in soil gas above treatment zone. 	<ul style="list-style-type: none"> a) Water balance. b) Measurement of mass of bromide-tagged water recovered. c) Groundwater sampling of surrounding wells after completion of the demonstration and postdemonstration COC groundwater profiling of the site compared to a presteam baseline profile. d) Soil-gas monitoring for COCs during and after the demonstration compared to baseline sampling.

The main purpose of the process monitoring is to establish a mass balance for all the fluids moving through both the steam generation and distribution system (Figure 3-9) and the effluent treatment system (Figure 3-10). Once the fluid flows have been well described, they can be coupled with the chemical concentration measurements described below to estimate mass removal rates for each COC, as well as estimates of the in-ground HPO destruction rates and O₂ consumption.

The frequency of the monitoring is as follows: All continuous monitoring will be automatically data based using a SCADA system. Manual readings will be performed three times per day.

4.2.1 Sampling During Drilling and Installation

During installation, soil cores will be collected from between 20 ft bgs and 45 ft bgs in the injection/extraction well and in all monitoring wells. An SES geologist will record lithology and visual and/or olfactory evidence of VOC presence in soil cores. Soil core samples will be subjected to field screening for VOCs using handheld PID analysis, and any “hot spots” also will be sampled for laboratory analysis. Additional soil samples will be collected for TOC analysis from the central injection/extraction well soil recovered from each of the three sandy or gravelly layers identified at 25-45 ft bgs in characterization holes drilled by SES.

Presteam groundwater grab samples will be collected from the injection/extraction (SI-1) well, the five monitoring wells (BAT-6 to BAT-10), and the perimeter (BAT-4 S/D and BAT-5 S/D) wells upon completion of well development. A minimum of three sampling rounds will be completed before onset of operation, in order to establish a statistical background level for each sampling point. Subject to approval, groundwater profiling comprising sampling of discrete depth intervals by Hydropunch™ also may be conducted.

4.2.2 Aquifer Testing

Upon completion of well development, a slug test will be performed in the operational well in order to confirm that the permeability is sufficient for the desired steam injection and heating rate.

4.2.3 Operational Monitoring

4.2.3.1 Subsurface Temperature and ERT Monitoring

During the demonstration operations, both ERT and temperature data will be collected daily during the injection cycles. Temperature data also will be collected daily during the steam soak and extraction phases. ERT data will be collected at the end of each steam soak and extraction phase. This will provide information on the progression of heated zones, the migration of steam in the subsurface, and creation of conditions where HPO reactions are favored.

Temperature versus depth profiles will be available within 24 hours of completion of temperature measurements. Temperature data collection will be manual. SES will have a technician on site to take scheduled temperature measurements. Drawings and summary of results will be available within 24 hours of completion of data collection.

To monitor the expected initial changes in the subsurface, ERT data will be collected daily during the injection periods, and at the end of phases thereafter. A total of 25 ERT data sets will be collected during the demonstration (two preoperational sets, three postoperational sets, and 20 sets during the remediation cycles).

ERT data from the eight vertical planes connecting each of the five VEAs to the VEAs immediately adjacent will be combined together for a single 3-D inversion. It is assumed that phone connections will be available on site for ERT data transfer. Drawings and summary of results will be available within 24 hours of complete data collection.

4.2.3.2 Process Monitoring

The surface equipment is presented on Figures 3-9 and 3-10, and in Table 3-8. This section describes the monitoring performed during operation of those systems.

Flow and Volume

Steam injection rates will be measured using a steam orifice plate with differential pressure measurement. Total steam flow, steam pressure, temperature, and quality will be measured at the steam generator and calculated using standard instruments and calculation routines.

The total steam injection rate will be checked against the total water flow into the steam generator. A totalizing flowmeter on the steam generator will be read at least three times daily.

Liquid extraction rates for the downhole pump will be recorded as the number of pump strokes per minute, with calibration of the pump stroke volumes at the end of each extraction phase. In addition, total stroke counters will be mounted on the downhole pump control station, allowing for calculation of the total extraction volume for the pump (Figure 3-6). Liquid flowrates and total flow will be monitored at several locations within the treatment system (see Figure 3-10 and Table 4-3). Condensate flowrate and volume will be monitored

Table 4-3. Process Monitoring During Operations

Monitoring Process or Location ^(a)	Description	Parameter				
		Flow	Temperature	Pressure	Liquid Level	Sample
Water supply	Intake line	NA	NA	P	NA	NA
	Water softener output	NA	NA	P	NA	NA
	Deaerator output	NA	T	P	NA	NA
Steam generator	Gas intake	FR	NA	P	NA	NA
	Clean water intake	FT	T	NA	NA	NA
	Steam output	NA	T	P	NA	NA
Steam manifold	Primary side	NA	NA	P	NA	NA
	Secondary side	FR	NA	P	NA	NA
Steam injection well	Wellhead measurements	NA	T	P	NA	NA
Vapor extraction line	Vapor extraction header	NA	T	P	NA	NA
Liquid extraction line	Downhole pump discharge line	FT	T	NA	NA	NA
Liquid line, treatment system	L-1: extraction well	FT	T	NA	NA	LS
	Water holding tank	NA	T	NA	L	NA
	L-2: GAC outlet (discharge point)	FRT	T	P	NA	LS
Vapor line, treatment system	KO-1 inlet	NA	T	P	NA	NA
	KO-1 liquid outlet	FT	NA	NA	NA	NA
	KO-2 vapor outlet	NA	T	P	NA	NA
	KO-2 liquid outlet	FT	NA	NA	NA	NA
	Vacuum pump output	NA	T	P	NA	NA
	V-1: air drier outlet	FRT	T	P	NA	VS
	V-2: vapor GAC outlet, emission point	NA	NA	NA	NA	VS

(a) Every point is monitored at least twice daily.

FR = flowrate monitoring.

FT = cumulative flow monitoring.

FRT = flowrate and cumulative flow monitoring.

LS = liquid sample.

NA = not available.

VS = vapor sample.

using a totalizing flowmeter on the liquid effluent lines from KO-1 and KO-2. The total water flowrate to the water carbon filters will be monitored using a totalizing flowmeter. Finally, the water discharge volume will be recorded using a totalizing flowmeter at sampling point L-2, the water discharge point.

Vapor flowrates will be measured after the vacuum pump using a totalizing flowmeter. This vapor flow represents the vapor flowrate into the carbon vessels as well as to the atmosphere.

Pressure and Temperature

Steam injection pressure and temperature will be measured at the steam generator and at the injection wellhead, and recorded at least three times daily.

Pressures and temperatures are measured three times daily at numerous locations in the effluent treatment system as given on Figure 3-10 and Table 4-3. Both will be read manually at gauges.

Contaminant Concentrations

The contaminant concentration monitoring is described in Section 3.5.7. Liquid- and vapor-phase concentrations will be converted into mass fluxes, and then used to establish a total mass balance for the COCs. In general, the recovered mass of COCs is derived from sampling at points V-1 and L-1, and the combined water streams.

4.2.4 Poststeam Monitoring

4.2.4.1 Poststeam Strategy

The overall demonstration strategy, as described by the inventors (LLNL), is based on using the single-well push-pull steam injection to remediate smaller or weaker sources or as a polishing step for residuals after primary source treatment with conventional steam application has been completed. The effectiveness of the single well application will be judged on the basis of observing a statistically significant reduction in TCE concentrations in treatment zone wells, immediately following treatment. This observation will be supplemented by an effort to identify the generation of potential byproducts of TCE degradation, namely, ethene, ethane, CO₂, and chloride. Although it would be desirable to monitor the treatment zone for the several months (or a year) that it would take to determine the level of risk reduction and potential for rebound, there are several factors that would make this determination difficult. One of the reasons is that we are not in a true source zone, in which an advantage would have been absence of upgradient contamination after treatment. Over the time that it takes the treatment zone to cool, several pore volumes of groundwater from the upgradient portion of the plume is likely to have flowed through the treatment zone. It would be difficult to trace the origin of any observed rebound in TCE concentrations to either migration from the upgradient plume or from release of TCE from any adsorbed residuals persistent in the treatment zone. This is an acknowledged limitation of the demonstration at this site. Therefore, the investigators are limiting the postdemonstration risk-reduction evaluation to the short-term effectiveness of the technology, as measured by the drop in TCE levels immediately after treatment.

4.2.4.1 Subsurface Monitoring

During the postdemonstration, ERT and temperature data will be collected at the end of the first, second and fourth week after the end of the fifth cycle. At the end of postdemonstration monitoring, animated ERT and temperature images will be created in Environmental Visualization System (EVS) or similar software to show spatial and temporal changes of subsurface.

4.2.4.2 Drilling and Characterization

A minimum level of poststeam site characterization will entail collection of groundwater samples from the operational and monitoring wells during the cooling period. SES recommends that three sampling rounds be conducted, at the end of the first, second, and fourth week after the end of the fifth cycle, in order to establish data for a statistical analysis and comparison to pre-demonstration COC concentrations.

4.3 Data Analysis, Interpretation and Evaluation

Data analysis, interpretation, and evaluation will follow the principles presented in Section 4.1. More detail is provided in the following sections.

4.3.1 Presteam Temperature and ERT Data

Background ERT images will be prepared, showing both vertical transects between all of the vertical VEAs, and horizontal slices of the target zone. These maps will display the formation resistivity (typically in Ohm-meters) and will be either color-scale or gray-scale plots with contour lines overlain, or contoured plots only. Temperature data will be presented as depth profiles. A minimum of two complete datasets will be collected prior to operation.

4.3.2 Temperature Monitoring

The subsurface monitoring of temperature (using thermocouples) and electrical resistivity (using ERT) will be documented in a series of vertical cross sections and a number of horizontal planes at selected depths. The vertical planes include all eight planes between the VEAs.

The number of plots and cross sections generated will be selected based on the actual steam migration observed in the demonstration. A large quantity of data will be archived without further preparation for presentation in the final report.

The criteria used to determine that the temperature achieved in the subsurface is sufficient will be a minimum temperature of 80°C as determined by direct thermocouple readings. SES will use the collected temperature data and the supporting ERT data to generate drawings and sketches to define the 3-D volume of subsurface material for which the desired temperature condition is achieved. In addition, the subsurface volume will be estimated with an accuracy of no less than 25% based on interpretation of the data.

The combined temperature and ERT data will be used to indicate where steam zones are present in the subsurface at a minimum of 15 times during operations (at the end of each phase in each

cycle; for instance, after the first steam injection phase, after the first steam soak phase, and after the first extraction phase).

4.3.3 Steam Injection Volumes and Rates

Plots of total steam injection rate, cumulative steam injected, and rates will be prepared in the progress reports. A steam balance will be presented in the report based on all steam rate measurements and the total water consumption rate of the steam generator. Steam injection rates and cumulative amounts will be used to determine within an accuracy of no more than 100 water gallon equivalents (equal to about 800 lb of steam injected) for each injection phase.

The injected steam volumes will be used to calculate a heated volume of rock within the target depth interval. This volume will be compared to the volume heated as defined by the subsurface monitoring described in Section 4.3.2.

4.3.4 Groundwater Quality

Groundwater samples will be collected from the operational well (SI-1), the treatment zone monitoring wells (BAT-6 to BAT-10) and the perimeter wells (BAT-4 S/D and BAT-5 S/D). Each well will be purged with a minimum of three casing volumes, and the water will be free of turbidity prior to sampling. Hot water will be cooled via a cooling loop in an ice bath before sampling for COCs and inorganic parameters.

Three sampling rounds will be collected before and after the DUS/HPO operations, at the end of the first, second, and fourth week after the end of the fifth cycle. In addition, the seven monitoring wells (demonstration wells plus BAT-4 and BAT-5) will be sampled at the beginning of the soaking and extraction phases of each of the cycles (Table 3-11). Data quality objectives are listed in Section 3.5.7.

4.3.5 Soil-Gas COC Concentrations

Soil gas will be collected from sampling points SG-1 through SG-5. The soil-gas monitoring points will be close to monitoring wells and the exact location will be determined later. For COCs, a single sampling round will be collected before the demonstration. In addition, the five soil-gas sampling locations will be sampled during the steaming phase of the first and second cycle. Data quality objectives are listed in Section 3.5.7.

The soil-gas monitoring points will be completed as follows:

- a. An HSA rig will be used to advance the boring to approximately 7 ft bgs. A 6-inch borehole will be prepared for each point.
- b. The monitoring points will be constructed of small-diameter stainless steel tubing (e.g., ½-inch), with a 1-ft fine mesh stainless steel attached at the bottom that extends 1 ft above land surface.

- c. A filter sand pack will be installed surrounding the 1-ft well screen, and Type H cement will be emplaced above the sand pack to the ground surface.
- d. Surface completion will include a concrete pad and a protective PVC casing surrounding the stainless steel soil-gas tubing that extends above land surface.
- e. Each monitoring point will have a sampling port that allows for the collection of a grab sample with a Summa canister or similar device.
- f. Each well will be clearly identified by a permanent marker (i.e., metal tag set in the concrete).

4.3.6 Effluent Treatment System Performance

The function and environmental compliance of the treatment system will be documented in data tables listing the results for sampling points L-2 and V-2 for water discharge and vapor emissions, respectively. In addition to process monitoring samples, analyses will be conducted for the range of parameters specified by the BAAQMD and California RWQCB for air emissions and liquid discharge. The appropriate authorities at Beale AFB will be notified of analytical results for air emissions on a weekly basis and for liquid discharge on a monthly basis (i.e., prior to the first and last discharges to the base sewer system).

The concentrations of COCs removed by the treatment system will be shown as concentration curves for the COCs on a time scale defined by the operations period. The data will be from sampling points L-1 and V-1 for water and vapor, respectively. Data quality objectives are listed in Section 3.5.7.

4.3.7 TCE Removal Calculations

A water balance for the site will be prepared, using total steam injection volumes and total liquid and condensate extraction volumes. The net extraction rates and cumulative volumes will be presented in figures.

The COC concentration at sampling points L-1 and V-1 will be used to estimate total masses for each COC by using the flowrate and cumulative flow data obtained from the totalizing flowmeters. Curves will be prepared, showing the masses of selected COCs extracted and recovered in water and vapor phases. Data quality objectives are listed in Section 3.5.7.

TCE mass recovered estimates will be conducted only for the fluid streams recovered aboveground. For all subsurface TCE measurements, a statistical analysis of the TCE concentrations will be the main method for evaluating treatment effectiveness, as described in Section 4.1.1.

5.0 Cost Assessment

5.1 Cost Reporting

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

- Application cost of steam injection at the demonstration site. This cost includes costs incurred during the Operation & Management (O&M) of the technology. Costs of the technology application at Beale AFB will be tracked by the vendor (SES) and Battelle. The O&M costs will include labor, fuel, utilities, and waste disposal.
- Site preparation costs incurred by the owner. Beale AFB and Battelle will track the site preparation costs; that is, the costs incurred by the site owner.
- Site characterization and performance assessment costs. Battelle will estimate these costs based on the site characterization and performance assessment conducted during the demonstration.

5.2 Cost Analysis

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 steam injection cost with the cost of a conventional pump-and-treat system.

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 must be calculated and compared with the cost of steam injection, a short-term treatment. The present value (PV) of a long-term pump-and-treat application will be calculated. The PV analysis will be conducted over a 30-year period, as is typical for long-term remediation programs at Superfund sites.

For the purpose of comparison, it is assumed that a pump-and-treat system would have to treat the same portion of the plume that the steam injection treats. Recent research (Pankow and Cherry, 1996) indicates that the most efficient pump-and-treat system for source containment would extract water at the minimum rate required to capture all the groundwater flowing through the targeted portion of the aquifer. This type of minimal containment pumping ensures that the source/plume is contained without having to extract and treat groundwater from cleaner surrounding regions, as would be the case in more aggressive conventional pump-and-treat systems. The extracted groundwater would be treated with an air stripper and polishing carbon.

6.0 Implementation Issues

6.1 Environmental Checklist

This section provides a brief description of the federal regulations that are potentially applicable to the implementation of the DUS/HPO demonstration project at Beale, AFB. The state of California regulations and local permitting requirements for the DUS/HPO system also are discussed.

6.1.1 Resource Conservation and Recovery Act (RCRA) and Title 22, Division 4.5 of the California Code of Regulations

The goal of RCRA is to regulate hazardous waste management activities. Solid wastes generated during the DUS/HPO project may be hazardous and therefore managed under the RCRA or state of California RCRA program. Solid wastes that may be generated include soil cuttings, spent GAC, and other solid wastes associated with monitoring (e.g., tubing, paper towels, etc.). Hazardous waste is defined as materials that contain those constituents listed in RCRA Subtitle C or materials that exhibit hazardous characteristics, including ignitability, corrosivity, reactivity, and toxicity. In addition to these rules, certain RCRA provisions will require corrective action when point-of-compliance wells at SWMUs are above the permitted groundwater protection standards. The corrective action requirements of RCRA are extensive and a complete discussion of the regulatory implications is beyond the scope of this work plan. The RCRA regulations are included in 40 Code of Federal Regulations (CFR) Parts 240-282.

The following is a list of potential responsibilities generated by RCRA requirements:

- Perform corrective action at out-of-compliance solid waste management units.
- Identify, characterize, and label hazardous waste.
- Manifest hazardous waste for off-site disposal.
- Maintain required records and documentation.
- Ensure that land disposal restrictions are followed.
- Ship wastes within mandated time limits.

The state of California “Environmental Health Standards for the Management of Hazardous Waste,” set forth in Title 22 California Code of Regulations [CCR], Division 4.5 (CCR Title 22, Division 4.5), were approved by the U.S. EPA as a component of the federally authorized state of California RCRA program. Therefore, the regulations of CCR Title 22, Division 4.5 are the source of RCRA-related federal regulations. A waste determined not to be a RCRA hazardous waste may still be considered a state-regulated, non-RCRA hazardous waste because the state is more stringent in determining its hazardous waste classifications. CCR Title 22, §66261.24(a)(2) lists the total threshold limit concentrations (TTLCs) and the soluble threshold limit concentrations (STLCs) for non-RCRA hazardous waste. The state applies its own leaching procedure, the California Waste Extraction Test (WET), which uses a different acid reagent and has a different dilution factor (tenfold). In addition, other state requirements that may be broader in scope than the federal RCRA program and should be consulted include the solid waste classifications at CCR Title 27, §§ 20210, 20220, and 20230.

6.1.2 Clean Water Act

The Clean Water Act (CWA) sets surface water quality standards and permit requirements for the treatment and discharge of wastewater and stormwater. The CWA is applicable to this DUS/HPO remediation project because liquid wastes will be treated and disposed of via a sewer hookup or other method to the Beale AFB wastewater treatment facility. The base will treat the combined water from surface water and general sewer water generated from normal activities.

The groundwater extracted during the DUS/HPO project does not require a permit to discharge into the base sewer line; however, it must meet the appropriate standards (Table 3-13) set by the CRWQCB Central Valley Region before discharge. Before sewer discharge, the analytical results from the treated water must be submitted (e.g., ammonia, MBAS, oil and grease, total petroleum hydrocarbons-gasoline-range organics [TPH-GRO], total petroleum hydrocarbons-motor oil [TPH-MO], total petroleum hydrocarbons-diesel range organics [TPH-DRO]; barium, boron, copper [dissolved], cyanide, mercury, cadmium; *bis*(2-ethylhexyl)phthalate, *cis*-1-2-DCE, *trans*-1,2-DCE, TCE, chloroform, and other constituents) and the discharge should be approved by the appropriate base authority.

Liquid wastes generated at DUS/HPO sites may include recovered groundwater, monitoring well purge water, decontamination water, and knock-out tank condensate from the vapor extraction system. The CWA regulations are included in 40 CFR Parts 100-136, 140, 230-233, 401-471, and 501-503. All federal, state, and local predemonstration standards will be followed for discharges.

6.1.3 Safe Drinking Water Act and the California Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) sets standards for the permissible level of contaminants in drinking water and establishes treatment standards for drinking water supply systems. If the affected groundwater at a site is a current or potential drinking water source, then the full-scale corrective action may have to meet MCLs or maximum contaminant level goals (MCLGs) for protection of the groundwater source. The SDWA regulations are included in 40 CFR Parts 141-149. However, because this project is a demonstration project, cleanup levels have not been defined and MCLs are more applicable to the full-scale corrective action.

The following is a list of potential responsibilities generated by SDWA requirements:

- Meet MCLs or MCLGs to protect groundwater source and achieve site closure.

In addition to the SDWA, the California Safe Drinking Water Act (California Health and Safety Code, Division 5, Part 1, Chapter 7) sets MCLs for drinking water. State MCLs can be more stringent than corresponding federal MCLs. The federal and state MCLs for TCE are both set at 5 µg/L.

6.1.4 Clean Air Act

The Clean Air Act (CAA) regulates point source and mobile source emissions and sets ambient air quality standards. For this DUS/HPO demonstration project, off-gas treatment will be required and will involve the control of VOC emissions via GAC adsorption from two process streams: (1) the vapor extraction system and (2) the water-holding tank. Several CAA requirements will be relevant to the operation of the GAC unit(s) and any discharges of regulated pollutants from these two points. If VOC emissions from the water-holding tank are below certain allowable limits, a certificate of exemption may be appropriate and the VOC off-gas from the tank may be directly discharged to the atmosphere. In addition, the boiler used to generate the steam for injection is fueled by natural gas and will therefore have emission limits for combustion-related pollutants (e.g., particulate matter, SO₂, NO_x, and carbon monoxide).

The permit to construct and operate the DUS/HPO system will be issued by the Feather River Air Quality Management District (AQMD). The Feather River AQMD is authorized to issue these permits and in doing so must make sure that the emission limits set by the permit comply with all local and state regulations, along with certain CAA provisions. Only Title I and Title III of CAA are likely to directly impact the DUS/HPO demonstration project. Title I of the Act requires states to identify areas that have not achieved National Ambient Air Quality Standards (NAAQS) for certain critical air pollutants. If the project is in a nonattainment area, it may be subject to additional emission control standards as outlined in the State Implementation Plan (SIP). Title III of the act specifies point source standards for hazardous air pollutants (HAPs). For all sources that emit HAPs, the U.S. EPA sets Maximum Achievable Control Technology (MACT) standards. The CAA regulations are included in 40 CFR Parts 50-99.

The following is a list of potential responsibilities generated by CAA requirements:

- Obtain the necessary permits for construction and operation of the remediation system (or the appropriate certificate of exemption).
- Maintain emissions of all regulated pollutants within permitted levels.
- Comply with State Implementation Plan requirements.
- Maintain all required records and documentation.

6.1.5 Occupational Safety and Health Administration Rules

The Occupational Safety and Health Administration (OSHA) requires that all work performed on a hazardous waste site be in compliance with a site-specific HASP as described in 29 CFR 1910.120. A site-specific HASP (Appendix C) should be prepared and should address all hazards associated with the site and remediation activities.

6.1.6 Other Selected Federal Regulations

Other federal regulations and executive orders that could apply to remediation projects under certain limited conditions include the Endangered Species Act (ESA), Executive Order Number

11988, Floodplain Management, Executive Order Number 11990, Protection of Wetlands, and the National Historical Preservation Act (NHPA). However, because the demonstration area identified for the DUS/HPO component installation is located on a previously disturbed and developed area of the Beale AFB campus, it is unlikely that any of the above federal laws or executive orders apply.

6.1.7 Other Selected State Regulations

Several other state regulations may apply to the administration of the DUS/HPO project, including the following:

- State Water Resources Control Board (SWRCB) Resolution 68-16, Policy with respect to maintaining high quality of waters in California. [Water Code Section 13140] which requires that water quality remain protective of all beneficial uses and requires cleanup to background water quality or to lowest technically and economically feasible concentrations.
- California Title 23 [CCR, Division 3, Chapter 15, Article 5, Section 2550], which sets standards for corrective action of waste management units and establishes water quality protection standards and requires cleanup levels greater than background to be the lowest economically and technologically achievable.
- SWRCB Resolution 92-49, Policies and procedures for investigation and cleanup and abatement of discharges under Water Code Section 13304 [Water Code Section 13307], which establishes policies and procedures for the oversight of investigations and cleanup and abatement activities resulting from discharges of waste that affect or threaten water quality.

Because the DUS/HPO project is a demonstration project and not a full-scale corrective action, it is unlikely that the above regulations are directly applicable to project implementation. However, they could be considered relevant and appropriate.

6.1.8 Other Selected Local Regulations

Other local regulations that apply to the administration of the DUS/HPO project include soil boring/well installation permits. Beale AFB is located in Yuba County, which requires permits for all subsurface installations. All steam injection/extraction wells and groundwater monitoring wells will require a boring/well permit. In addition, the proper base authority should be notified prior to installation activities and base personnel should mark the location of all subsurface utilities prior to installation of the remediation system.

6.2 Permitting and Waste Disposal Issues

As discussed above, several permits will be needed for proper implementation of the DUS/HPO demonstration project. The permit requirements and corresponding issuing agency are summarized below in Table 6-1.

Table 6-1. Permit Requirements

Type	Permits Required	Permit Agency	Comments
<i>Before Treatment</i>			
Well Permits/Dig Permit/ Utility Clearance	Yes	Yuba County/Beale AFB.	Not applicable
Fuel Supply/ hookup	No	Approved by Beale AFB.	Will be provided by Beale AFB
Water Supply	No	Approved by Beale AFB.	Will be provided by Beale AFB; maximum 50 gpm briefly, 5 gpm continuous at 60 psig
Power Supply	No	Approved by Beale AFB.	Will be provided by Beale AFB; 110V and 150 A, 3-phase 480 V
Gas Boiler	Yes	Submit a boiler application to Feather River AQMD (controlled by AP-42); (1) NO _x emission test, (2) test of Best Available Control Technology (BACT), which is available from manufacturer	For boiler: 2.5×10^6 BTU/hr, ~2,500 lb/hr, 135°C, 30 psig For NO _x test: NO _x <25 lb/day at startup
Pure O ₂ Tank	No	No approval required.	5 cylinders (1,250 ft ³)
<i>During Treatment (Extracted Water)</i>			
Treated Water Discharge	No	Approved by Beale AFB upon results of water analysis of RCRA before discharge. Monthly progress report to Environmental Office at Beale AFB.	Up to 14,000 gal in a 3-day period.
Residual Liquid (well development and aquifer testing)	No	Approved by Beale AFB upon results of water analysis of RCRA before discharge. Monthly progress report to Environmental Office at Beale AFB.	505 ft ³ (3,763 gal)
Air Discharge from Boiler	Yes	Feather River AQMD; required for analysis of CO ₂ and NO _x .	NO _x <25 lb/day
Extracted Vapor Discharge	Yes	Feather River AQMD; daily for 3 weeks and weekly thereafter by a handheld monitoring unit.	216,000 scfm (maximum)
Water Holding Tank Air Discharge	Yes	Feather River AQMD.	To be determined. May be eligible for certificate of exemption.
<i>After Treatment</i>			
Extracted Groundwater	No	Approved by Beale AFB upon results of water analysis of RCRA before discharge. Monthly progress report to Environmental office at Beale AFB.	7,000 gal
Residual Liquid	No	Approved by Beale AFB upon results of water analysis of RCRA before discharge. Monthly progress report to Environmental Office at Beale AFB.	Not available.

Waste generated during the DUS/HPO project will have to be handled in compliance with all appropriate federal, state, and local regulations. Table 6-2 summarizes the estimated type and volume of waste to be generated during this project.

Table 6-2. Estimated Waste Generation

Waste Type	Estimated Volume	Expected Concentration in the Waste	Comments
Before Treatment			
Soil Cuttings (generated during well and VEA installation)	353 ft ³ (14 drums)	<500 mg/kg for any of the COCs	Submit solid RCRA waste analysis results to Beale AFB.
Liquid (from well development and decontamination)	505 ft ³ (6 well volumes)	<150 µg/L	Liquid will be contained in a Baker tank until disposal. Disposal will be determined based on results of RCRA waste analysis results submitted to Beale AFB.
Other Solids (generated from predemonstration monitoring [tubing, paper towels, etc.]	4 drums	N/A	Will be stored in a 55-gal drum for disposal.
During System Operation/Treatment			
Liquid			
Water in the Holding Tank (Cycle 1)	7,000 gal	100 µg/L	Water will be stored in a 25,000-gal Baker tank, treated with carbon, and discharged into a sewer line, if it meets discharge limits of 0.5 µg/L for each target VOC and chloroform and 1,1,2,2-tetrachloroethane.
Water in the Holding Tank (Cycle 2)	7,000 gal	80 µg/L	Same as above.
Water in the Holding Tank (Cycle 3)	7,000 gal	60 µg/L	Same as above.
Water in the Holding Tank (Cycle 4)	7,000 gal	40 µg/L	Same as above.
Water in the Holding Tank (Cycle 5)	7,000 gal	20 µg/L	Same as above.
Solids			
Other Solids (generated during monitoring and system operation)	1,200 lb spent carbon	80 mg/kg (10-200 mg/kg range)	Required for analyzing lead and SW8260 TCLP (vendor needs to dispose spent carbon).
Vapor			
Vapor from Carbon Filter		Below target level	Required for EPA 8260 TCLP.
TCE-Laden Air to Atmosphere from Water Holding Tank	35,000 gal (4,679 ft ³)	6.8 ppmv	Pending depending on monitoring results.
After Treatment			
Purged Water (from postmonitoring)	Battelle to supply	Below target level	Not available.
Soil Cuttings (from soil sampling)	Battelle to supply	Below target level	Not available.
Other Solids (generated from postdemo monitoring [tubing, paper towels, etc.]	Battelle to supply	N/A	Not available.

6.3 Other Regulatory and End-User Issues

No other outstanding regulatory issues have been identified at this time. Base personnel and the appropriate regulatory authorities will be kept apprised of the progress of the demonstration project as needed. There are currently no plans to hold a public meeting or to conduct other public participation efforts. However, the technology transfer tools available through the Naval Facilities Engineering Service Center (NFESC) will be used to the full extent to promote a better understanding of the advantages and limitations associated with the implementation of DUS/HPO. The tools available for technology transfer include the NFESC Web page, technical abstracts and journal articles, and technology transfer newsletters and fact sheets.

7.0 References

- Archie, G.E. 1942. "Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics." *Am. Inst. Mining and Metal. (Engr. Transl.)*, 146: 54-62.
- BERC. 2000. *Steam Enhanced Extraction Demonstration at Site 5, Alameda Point. Field Feasibility Demonstration for the U.S. Navy, DO-9*. Berkeley Environmental Restoration Center, University of California at Berkeley. Berkeley, CA. Final report in preparation.
- 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*, 12(3): 423-428.
- Bouwer, H. 1989. "The Bouwer and Rice Slug Test – An Update." *Ground Water*, 27(3): 304-309.
- Daily, W.D., A.L. Ramirez, R.L. Newmark, K.S. Udell, H.M. Buettner, R.D. Aines. 1995. *Dynamic Underground Stripping: Steam and Electric Heating for In Situ Decontamination of Soils and Groundwater*. U.S. Patent # 5,449,251.
- Heron, G., D. LaBrecque, D. Beadle, and H.J. Sowers. 2000. "Steam Stripping/Hydrous Pyrolysis Oxidation for In-Situ Remediation of a TCE DNAPL Spill." In: G.B. Wickramanayake and A.R. Gavaskar (eds.), *Remediation of Chlorinated and Recalcitrant Compounds: Physical and Thermal Technologies*. Vol. C2-5 of the Proceedings of the Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, CA, May 22-25. pp 149-156.
- Hvorslev, M.J. 1951. *Time Lag and Soil Permeability in Groundwater Observations*. U.S. Army Corps of Engineers, Waterways Experiment Station Bulletin 36. Vicksburg, MI.
- Integrated Water Resources, Inc. 2001. "Field Demonstration of Steam Injection and Hydrous Pyrolysis Oxidation at the Savannah River Site, Aiken, South Carolina." Presentation at 2001 International Containment and Remediation Technology Conference and Exhibition, Orlando, FL, June 10-13.
- Keller, G.V. 1988. "Rock and Mineral Properties." In: M.N. Nabighain (ed.), *Electromagnetic Methods in Applied Geophysics, Vol. 1*. Society of Exploration Geophysicists, Tulsa, OK.
- Knauss, K., R.D. Aines, M.J. Dibley, R.N. Leif, and D.A. Mew. 1997. *Hydrous Pyrolysis/Oxidation: In-Ground Thermal Destruction of Organic Contaminants*. UCRL-JC-126636, Lawrence Livermore National Laboratory, CA.

- Knauss, K., M. Dibley, R. Leif, D. Mew, and R. Aines. 1998. "Aqueous Oxidation of Trichloroethene (TCE): A Kinetic and Thermodynamic Analysis." In: G.B. Wickramanayake and R.E. Hinchee (eds.), *Remediation of Chlorinated and Recalcitrant Compounds: Physical, Chemical, and Thermal Technologies*. Vol. C1-5 of the Proceedings of the First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, CA, May 18-21. pp 359-364.
- LaBrecque, D.J., G. Morelli, W.D. Daily, A. Ramirez, and P. Lundegard. 1995. "Occam's Inversion of 3-D ERT Data." Proceedings of the First International Symposium on 3-D Electromagnetics, Schlumberger, Doll Research Center, Ridgefield, CT. pp. 471-482.
- LaBrecque, D., and X. Yang. 2000. "Difference Inversion of ERT Data – A Fast Inversion Method for 3-D In-Situ Monitoring." Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), pp. Arlington, VA, Feb. 20-24.
- Leeson, A., P.C. Johnson, R.L. Johnson, R.E. Hinchee, and D.B. McWhorter. 2001. *DUS/HPO Design Paradigm*. Prepared for Battelle, Columbus, OH.
- Morelli, G., and D.J. LaBrecque. 1996. "Advances in ERT Interpretation." First European Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), Torino, Italy.
- Newmark, R.L. et al. 1994. Final report: *Demonstration of Dynamic Underground Stripping at the LLNL Gasoline Spill Site*. UCRL-ID-116964, Vol. 1-4. Lawrence Livermore National Laboratory, Livermore, CA.
- Newmark, R.L., and R.D. Aines. 1997. *Dumping Pump and Treat: Rapid Cleanups Using Thermal Technology*. UCRL-JC-126637. Lawrence Livermore National Laboratory, Livermore, CA.
- Newmark, R.L., R.D. Aines, K. Knauss, R. Leif, M. Chiarappa, B. Hudson, C. Carrigan, A. Tompson, J. Richards, C. Eaker, R. Wiedner, T. Sciarotta. 1998. *In Situ Destruction of Contaminants via Hydrous Pyrolysis/Oxidation: Visalia Field Test*. Lawrence Livermore National Laboratory, CA. Public No. LNL UCRL-JC-132671
- Pankow, J., and J.Cherry. 1996. *Dense Chlorinated Solvents and Other DNAPLs in Groundwater: History, Behavior, and Remediation*. Waterloo Press, Portland, OR.
- Puls, R.W. and Barcelona, M.J. (1996), *Low-Flow (Minimal Drawdown) Groundwater Sampling Procedures*, EPA/540/S-95/504, OSWER/ORD, US Environment Protection Agency, Washington, DC.

SES, see SteamTech Environmental Services.

SteamTech Environmental Services. 1999. Final report: *Steam Stripping and Hydrous Pyrolysis Pilot Project for the Portsmouth Gaseous Diffusion Plant, Portsmouth, Ohio*. Prepared for U.S. Department of Energy. DOE #DOE/OR/11-3032&D1.

Udell, K.S., and L. Stewart. 1989. *Field Study of In Situ Steam Injection and Vacuum Extraction for Recovery of Volatile Organic Solvents*. UCB-SEEHRL Report No. 89-2, University of California, Berkeley.

Udell, K.S., et al. 1991. U.S. Patent #5,018,576 for steam-enhanced extraction with steam injection and dual-phase extraction technology.

Appendix A
Points of Contact

Appendix A

Points of Contact

DoD Contacts

Charles Reeter
Naval Facilities Engineering Service Center
1100 23rd Avenue
Port Hueneme, CA 93043
Tel: (805) 982-4991
Fax: (805) 982-4304
E-Mail: reetercv@nfesc.navy.mil

Kathy Greene
Naval Facilities Engineering Service Center
1100 23rd Avenue
Port Hueneme, CA 93043
Tel: (805) 982-5284
Fax: (805) 982-4304
E-Mail: Greeneka@nfesc.navy.mil

June Loreman/George Gerges
9 CES/CEV
6601 B Street
Beale AFB, CA 95903-1708
Tel: (530) 634-2593
Fax: (530) 634-2845
E-Mail: June.Loreman@beale.af.mil
George.Gerges@beale.af.mil

Lawrence Livermore National Laboratory

Roger Aines
Earth and Environmental Sciences L-219
Lawrence Livermore National Laboratory
Livermore, CA 94550
Tel: (925) 423-7184
Fax: (925) 422-0208
E-Mail: aines@llnl.gov

Robin Newmark
Earth and Environmental Sciences L-208
Lawrence Livermore National Laboratory
Livermore, CA 94550
Tel: (925) 423-3644
Fax: (925) 422-3925
E-Mail: newmark@llnl.gov

Battelle

Arun R. Gavaskar
Battelle
505 King Avenue, 10-153
Columbus, OH 43201
Tel: (614) 424-3403
Fax: (614) 424-3667
E-Mail: gavaskar@battelle.org

SteamTech Environmental Services, Inc.

Steve Carroll
SteamTech
4750 Burr Street
Bakersfield, CA 93308
Tel: (775) 826-5057
Fax: (661) 322-6552
E-Mail: carroll@steamtech.com

Gorm Heron
SteamTech
4750 Burr Street
Bakersfield, CA 93308
Tel: (661) 322-6478
Fax: (661) 322-6552
E-Mail: heron@steamtech.com

ESTCP Contact

Andrea Leeson
ESTCP Program Office
901 North Stuart Street, Suite 303
Arlington, VA 22203
Tel: (703) 696-2118
Fax: (703) 696-2114
E-Mail: andrea.leeson@osd.mil

Appendix B

Slug Test Results and Boring Logs

Appendix B-1. Slug Test Results

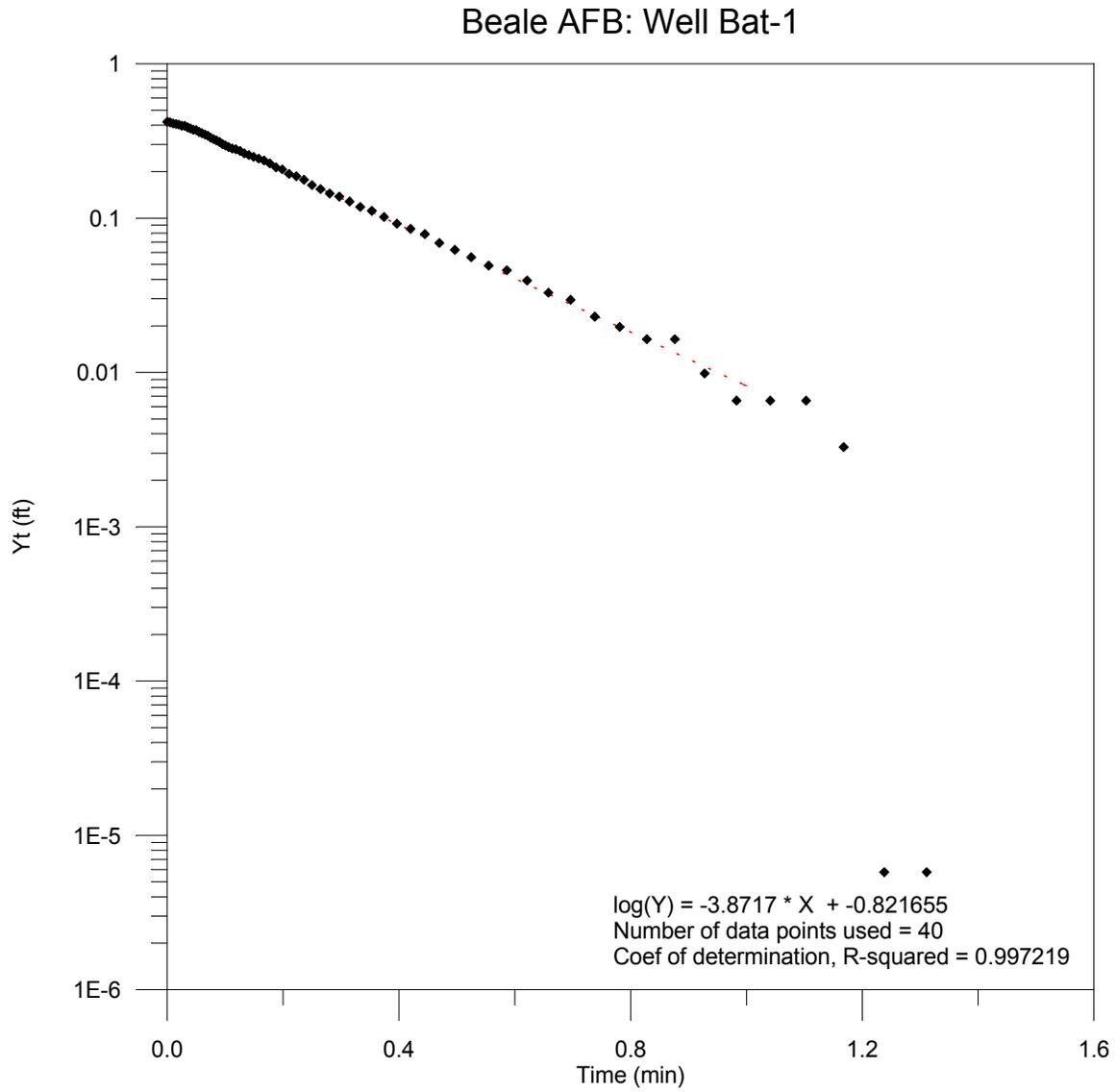


Figure B-1. Response from BAT-1

Beale AFB: Well Bat-2

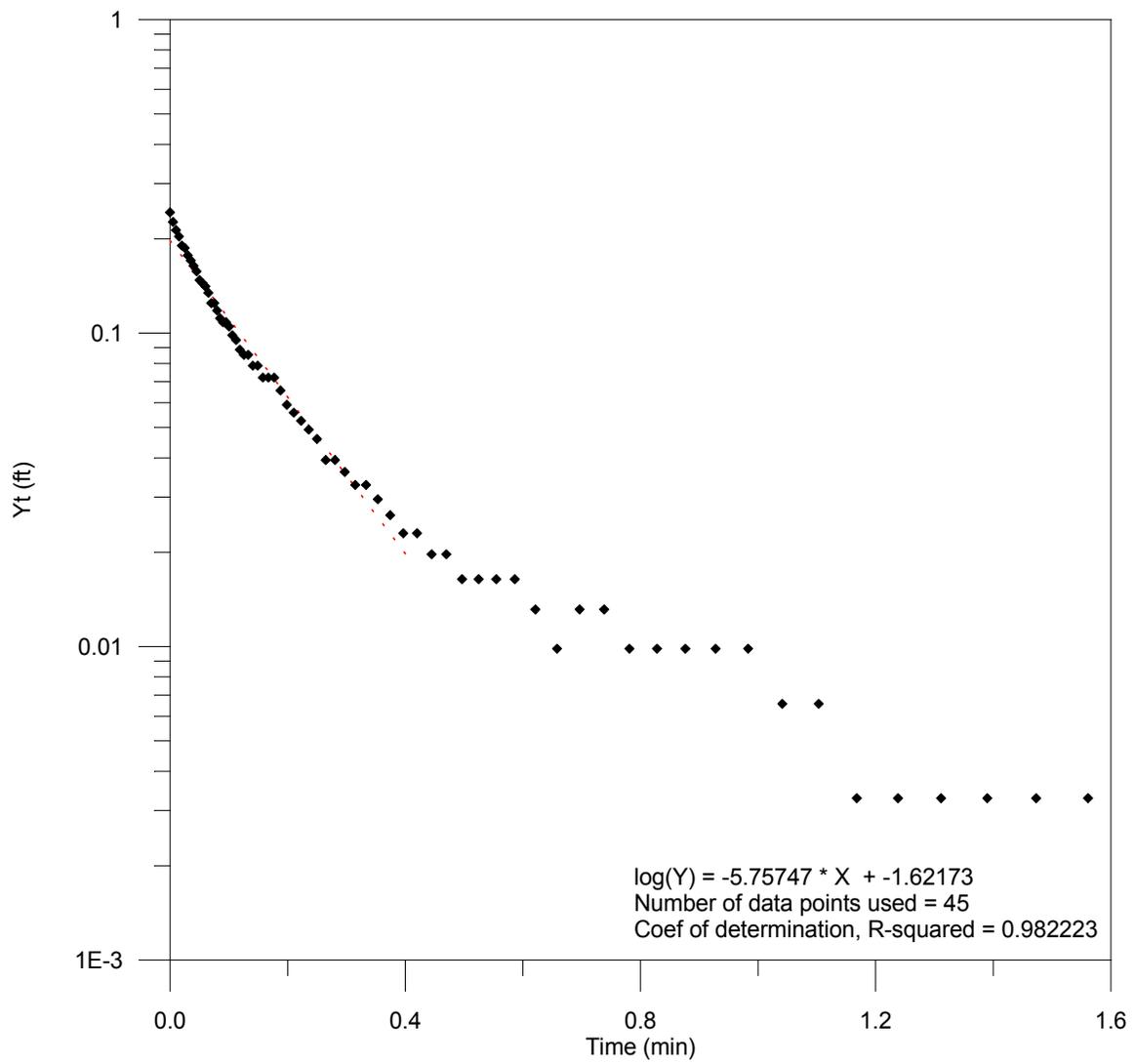


Figure B-2. Response from BAT-2

Beale AFB: Well Bat-3

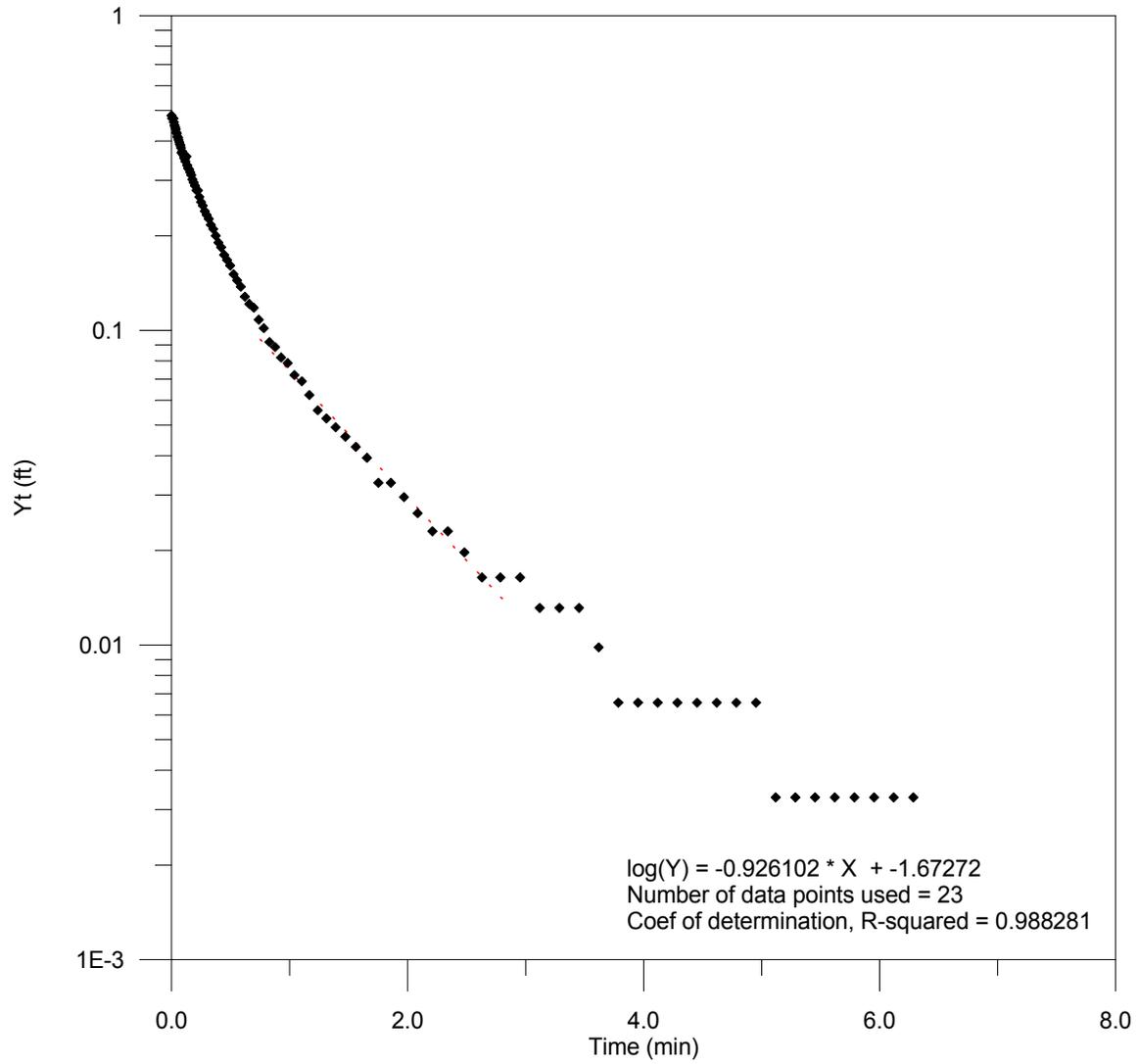


Figure B-3. Response from BAT-3

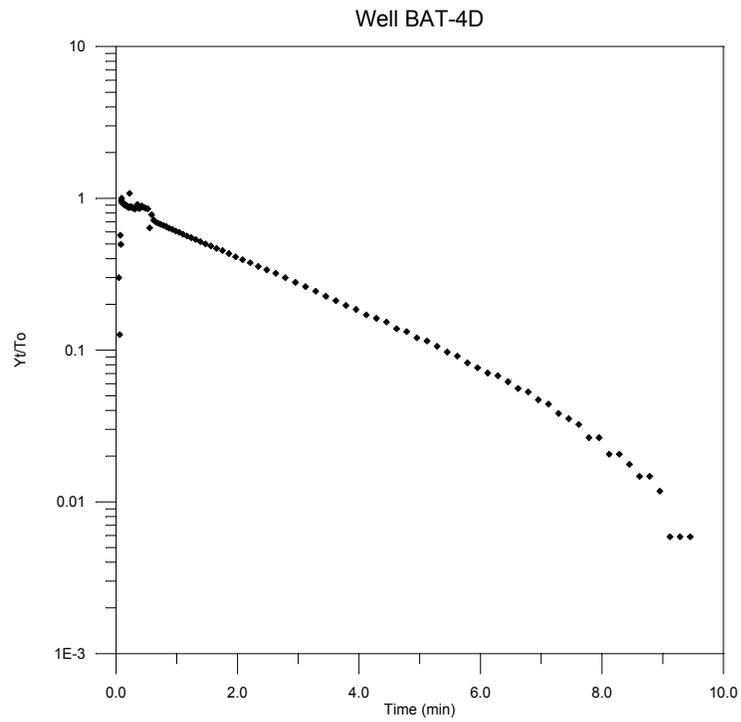
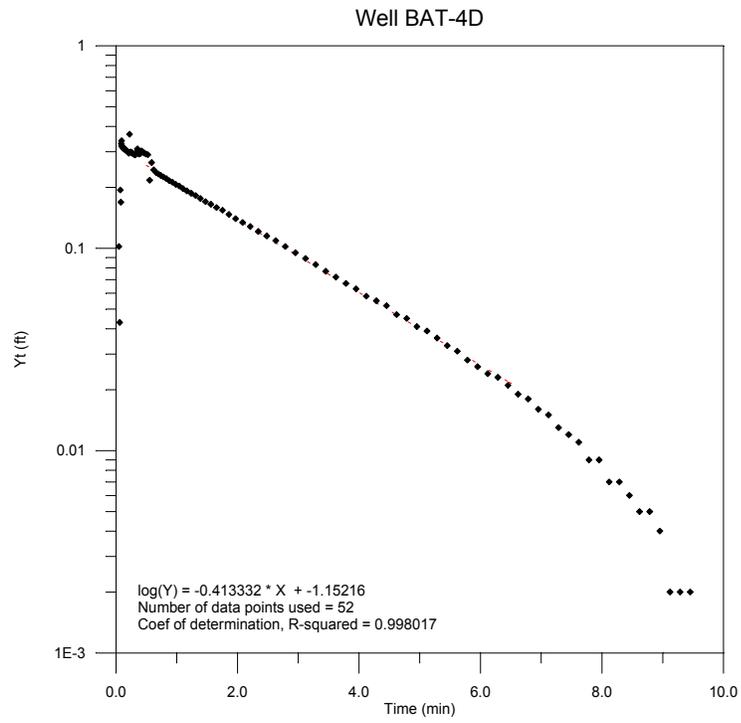


Figure B-4. Response from BAT-4D

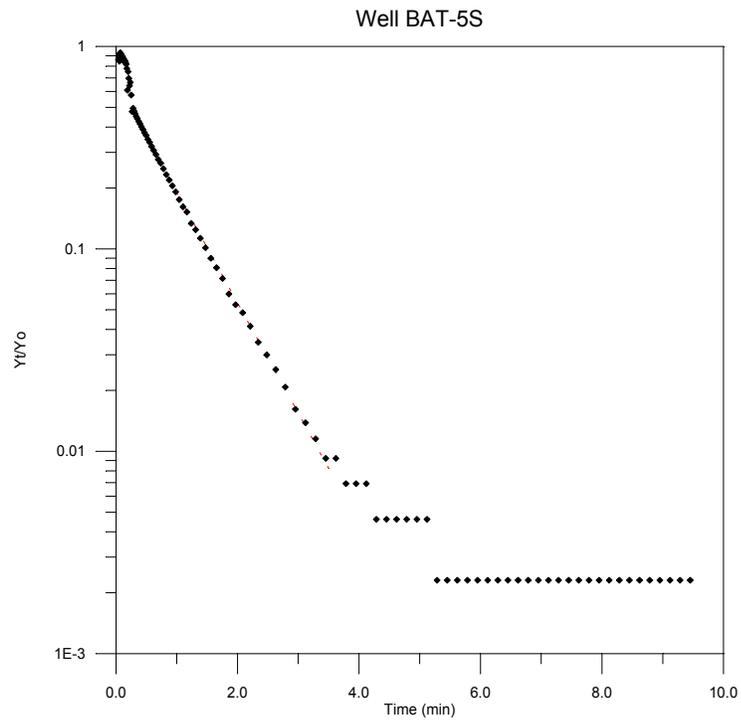
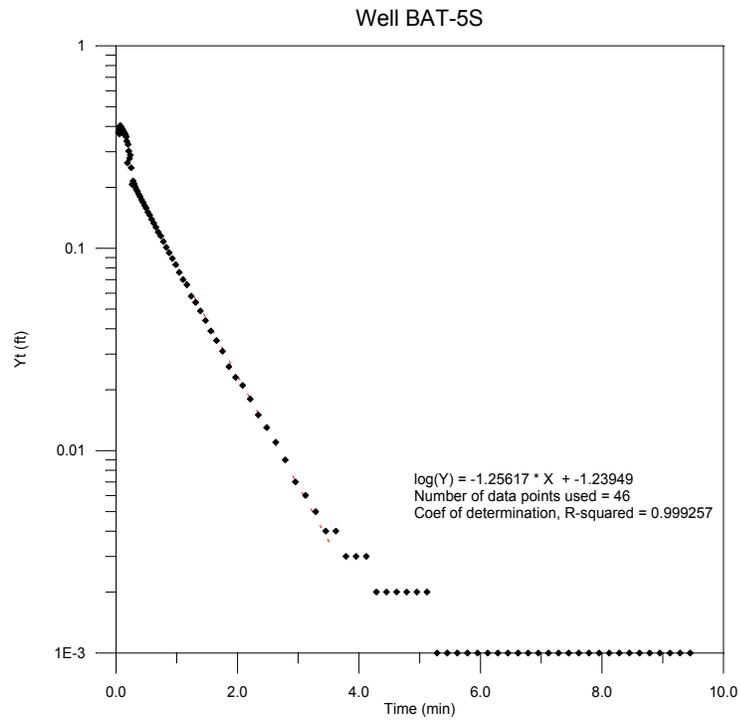


Figure B-5. Response from BAT-5S

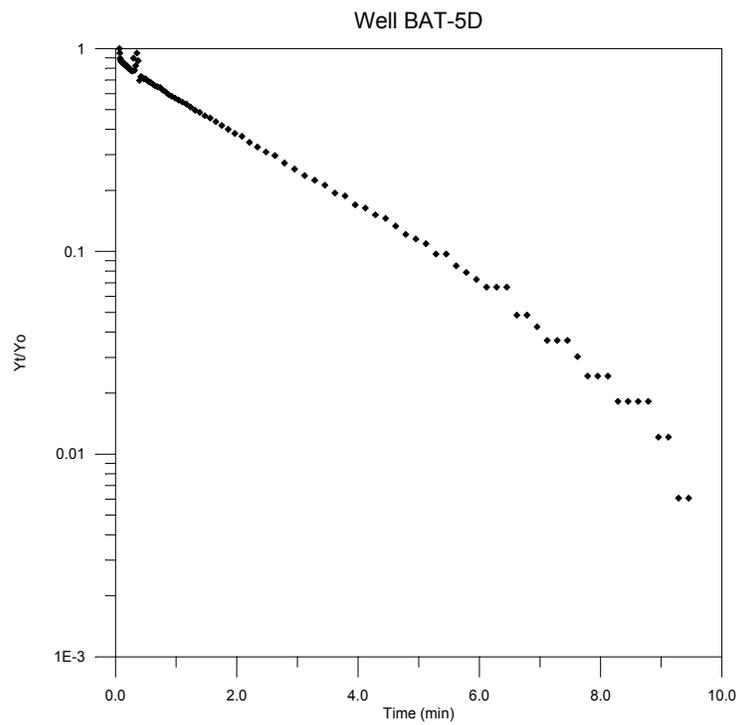
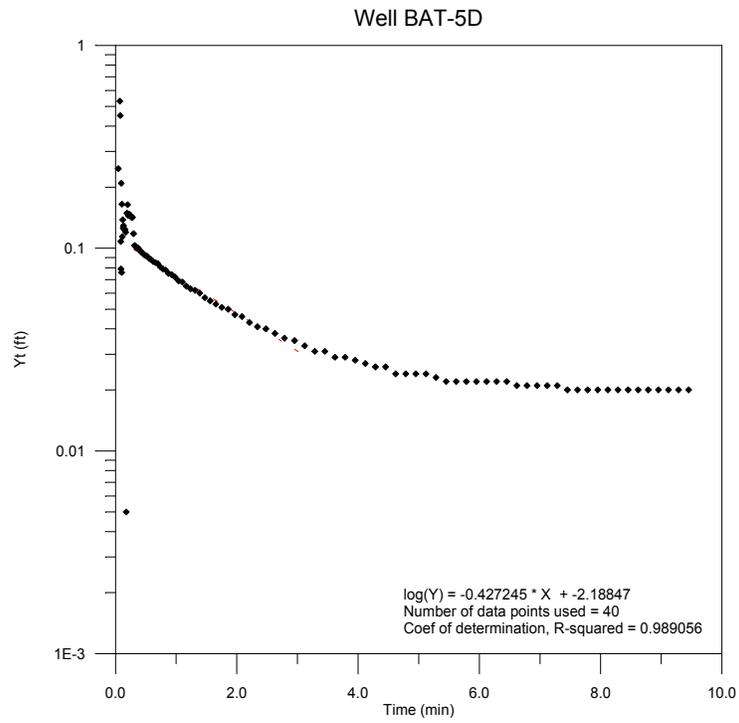


Figure B-6. Response from BAT-5D

Appendix B-2. Soil Borings and Well Logs

Coring Logsheet		Boring ID <u>BAT-1</u>	 Battelle ... Putting Technology To Work		
Date <u>4/18/01</u>		Location <u>Beale AFB, CA</u>			
Boring Diameter	<u>8</u> in	Total Depth	<u>32</u> ft		
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u>RMC 2/12</u>		
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>18</u> to <u>32</u> ft		
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>		
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>3</u> to <u>15</u> ft		
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>		
Screen Length	<u>10</u> ft	Drilling Method	<u>HSA</u>		
Screen Depth	from <u>21</u> to <u>31</u> ft	Driller	<u>Precision Sampling</u>		
Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Post hole dig- Red sandy clay, little gravel, fine (see photo)	0-5	NA	NA	-	-
No cores collected from 5-20. Wet at 8 ft	5-20	NA	NA	-	-
Lt brown silty clay, little sand, mottled, black organic specs, hard, med. plasticity 12-16-22	20-21.5	NS	CL	100	0
As above to soft clay, wet, to lt brown silty clay, mottled, black org. specs, hard 11-18-32	21.5-23	NS	CL	80	0
Silty clay with sand, soft, wet, to clayey med. sand, little gravel. loose to dense 8-12-26	23-24.5	NS	SC	100	0
Clayey coarse sand and fine gravel, trace gravel, subrounded, to sandy clay, mottled, stiff, to clayey sand, loose-dense to sandy clay, mottled, stiff 12-17-22	24.5-26	BAT-1 24.5-26	GC/ SC/CL	100	0
No recovery 10-14-17	26-27.5	NS	NA	-	-
Lt brown, clayey med. sand, trace fine gravel, subrounded, at bottom, wet 4-8-14	27.5-29	NS	SC	100	0
As above at top 3 inches to silty/sandy clay, mottled, black org. specs, hard, med plastic 8-9-14	29-31.5	NS	SC/ CL	100	0
Silty/sandy clay (less sand than above), mottled, black org. specs, hard, med. plasticity 4-8-12	30.5-32	NS	CL	25	0
End Coring					

Logged by: L. Cumming

Construction Notes: 18 inch sampler

Coring Logsheet		Boring ID <u>BAT-2</u>	 Battelle ... Putting Technology To Work
Date <u>4/17/01</u>		Location <u>Beale AFB, CA</u>	
Boring Diameter	<u>8</u> in	Total Depth	<u>35</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u>RMC 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>22</u> to <u>36</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>3</u> to <u>18.8</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>10</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>25</u> to <u>35</u> ft	Driller	<u>Precision Sampling</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Push augers to 20 ft prior to collecting cores. Caliche/hard pan layer observed @10-11 ft. Cuttings- red brown clay, silt, sand, gravel	0-10	NA	NA	-	-
Hit water ~ 10 ft	10-20	NA	NA	-	-
Lt brown sandy/silty clay, mottled, hard. Moist 38-50 for 5"	20-21.5	NS	CL	90	0
Lt brown sandy/silty clay, mottled, hard, black organic specs, moist (see photo) 24-74 for 5"	21.5-23	NS	CL	100	0
As above to m-c sand with silt and clay, loose, wet. 22-44-48	23-24.5	BAT-2-23-24.5	CL/SM	100	0.2
Lt. brown m-c sand, little silt and clay, little fine gravel, subangular to subrounded, loose, wet. 12-13-15	24.5-26	BAT-1 24.5-26	SP	50	0.1
As above to lt. brown fine gravel, subangular-subrounded, with sand and clay, wet, to silty/sandy clay, mottled.	26-27.5	NS	GM/SC	75	0
Lt brown, clayey gravel to sandy clay, mottled, trace fine gravel, to clayey fine gravel to silty/sandy clay, mottled	27.5-29	NS	GM/CL GC/CL	100	0
Lt. brown silty clay with medium to coarse sand to lt. brown silty clay, little med-coarse sand, hard, med plasticity 11-22-48	29-31.5	NS	CL	100	0
Lt. brown sandy clay, soft, wet, with lt. brown silty clay, little med-coarse sand to lt. brown clayey fine-med. sand 24-54-53	30.5-32	NS	CL/SC	100	0
Lt. brown clayey fine-med. sand to lt. brown silty clay with fine-med sand, hard, med. plasticity 7-28-39	32-33.5	NS	CL/SC	100	0

Logged by: L. Cumming

Construction Notes: 18" split spoon

Coring Logsheet

Boring ID BAT-3



Date 4/16/01

Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>45.5</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u>RMC 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>31</u> to <u>44.5</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>3</u> to <u>29</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>10</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>34</u> to <u>44</u> ft	Driller	<u>Precision Sampling</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Hand augered with post hole digger 0-5 ft, gravel at surface, red sandy clay, little fine gravel	0-5	NA	NA	-	-
Red brown to red lt. brown clay and gravel with sand, stiff, dry 8-29->50	5-6.5	BAT-3-5-6.5	CL-GC	100	NA
Red to lt. brown clay with silt/sand, stiff, hard, dry 18-50	6.5-8	BAT-3-6.5-8	CL	80	0
Lt. brown sandy clay, hard, dry	8-9.5	BAT-3-8-9.5	CL	50	0.1
Lt. brown silty clay, little coarse sand, v stiff - hard, dry. Advance augers to 15 ft. 80 for 4 inches	9.5-11	BAT-3-9.5-11	CL	25	0.0
Lt. brown silty clay, mottled, little coarse sand, stiff, hard, dry to moist, black organic specs. 10-18-21	15-16.5	BAT-3-15-16.5	CL	75	0
As above 15-65 for 5"	16.5-18	BAT-3-16.5-18	CL	75	0
As above 13-21-48	18-19.5	BAT-3-18-19.5	CL	100	0
As above	19.5-21	BAT-3-19.5-21	CL	100	0
As above	21-22.5	BAT-3-21-22.5	CL	100	0
Lt. brown silty clay with fine sand, mottled, med. stiff to stiff, very moist 10-12-14	22.5-24	BAT-3-22.5-24	CL/SC	100	0

Logged by: L. Cumming

Construction Notes: 18" split spoon

Coring Logsheet

Boring ID BAT-4S



Date 8/14/01

Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>31</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u># 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>23</u> to <u>31</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>2</u> to <u>23</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>5</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>25</u> to <u>30</u> ft	Driller	<u>West Hazmat</u>

Lithologic Description	Depth	Sample	USCS	Ret. %	PID
Rocky dark brown silty clay	0-5	---	CL	ctg	0
Red-brown silty clay	5-10	---	CL	ctg	0
Red-brown to tan silty clay and sand.	10-15	---	CL	ctg	0
Red-brown silty clay, moist	15-20	---	CL	ctg	0
Red-brown silty clay, moist, stiff	20-25	---	CL	ctg	0
Red-brown clay to red-brown silty coarse sand, wet (8-13-35)	25-26.5	BAT-4S-26.5	CL-SM	100	0
Stiff, mottled gray-red clay to silty-clayey medium sand, wet (12-8-41)	28-5-30	BAT-4S-30	CL-SM	100	0

Logged by: J. Sminchak

Completion Date: 8/14/01

Construction Notes:

1 ft sand sump, 2 ft of bentonite pellets between sand pack and grout, ~25 gallons of grout

Coring Logsheet

Boring ID BAT-4D



Date 8/14/01

Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>41</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u># 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>33</u> to <u>41</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>2</u> to <u>33</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>5</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>35</u> to <u>40</u> ft	Driller	<u>West Hazmat</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Silty red-brown clay to tan sand, silt, and gravel (moist)	0-5	(SS)	CL-GC	100	0
Tan to red clayey silt (42/1.5')	5-10	(SS)	SM	100	0
Mottled tan to red-brown silty clay, moist (31/1.5')	10-15	(SS)	CL	100	0
Mottled tan to red-brown silty clay, stiff, moist (50/1.5')	15-20	(SS)	CL	100	0
Silty clayey coarse sand to clay, wet (29/1.5')	20-25	(SS)	SM-CL	100	0
Mottled silty clay and sand, tan to gray (41/1.5')	25-30	(SS)	SC	100	0
Silty red-brown sand to silty clay, wet, stiff (35/1.5)	30-35	(SS)	SC-CL	100	0
Silty red-brown sand and clay, wet (41/1.5')	35-36.5	BAT-5D-36.5	SC	100	0
Gravelly, silty sand, very wet, loose, poor recovery (38/1.5')	38.5-40	BAT-5D-40	SM-GM	5	0

Logged by: J. Sminchak

Construction Notes:

Completion Date: 8/14/01

1 ft sand sump, 2 ft of bentonite pellets between sand pack and grout, ~40 gallons of grout

Coring Logsheet

Boring ID BAT-5S



Date 8/13/01

Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>31</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u># 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>23</u> to <u>31</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>2</u> to <u>23</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>5</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>25</u> to <u>30</u> ft	Driller	<u>West Hazmat</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Red-brown clayey silt, sand, and stones	0-5	---	SC-CL	ctg	0
Red-brown silty clay, dry.	5-10	---	CL	ctg	0
Red-brown silty clay, moist.	10-15	---	CL	ctg	0
Red-brown silty clay, moist	15-20	---	CL	ctg	0
Red-brown silty clay, some sand, moist, stiff	20-25	---	CL	ctg	0
Red-brown silty clay moist (10-20-30)	25-26.5	BAT-5S-26.5	CL	100	0
Mottled red black silty sand, moist (13-20-25)	28-5-30	BAT-5S-30	SM	100	0
Red-brown silty-clayey sand, moist to wet	30-31	---	SM	ctg	0
(water at 25'? slowly seeps in a depth)					

Logged by: J. Sminchak

Completion Date: 8/13/01

Construction Notes:

1 ft sand sump, 2 ft of bentonite pellets between sand pack and grout, ~25 gallons of grout

Coring Logsheet

Boring ID BAT-5D



Date 8/13/01

Location Beale AFB, CA

Boring Diameter	<u>8</u> in	Total Depth	<u>41</u> ft
Casing Outer Diameter	<u>2 3/8</u> in	Sand Pack	<u># 2/12</u>
Casing Inner Diameter	<u>2</u> in	Sand Pack Depth	from <u>32</u> to <u>41</u> ft
Casing Material	<u>304 SS SCH5</u>	Grout Material	<u>TYPE H Cement, 30% Silica Flour</u>
Screen Type	<u>304 SS SCH5</u>	Grout Depth	from <u>2</u> to <u>32</u> ft
Screen Slot	<u>0.01</u>	Surface Completion	<u>Flush Mount</u>
Screen Length	<u>5</u> ft	Drilling Method	<u>HSA</u>
Screen Depth	from <u>35</u> to <u>40</u> ft	Driller	<u>West Hazmat</u>

Lithologic Description	Depth	Sample	USCS	Rec. %	PID
Rocky red-brown clayey silt, dry	0-5	---	SC	ctg	0
Red-brown silty clay, some sand/gravel, dry.	5-10	---	SC	ctg	0
Brown to red-brown sandy silt and clay, dry.	10-15	---	SM-CL	ctg	0
Red-brown silty clay, some sand, moist	15-20	---	CL	ctg	0
Red-brown silty clay, some sand, moist, stiff	20-25	---	CL	ctg	0
Red-brown silty clay to sandy silt, moist	25-30	---	SC-SM	ctg	0
Red-brown silty clay, some sand, mottled, moist-wet.	30-35	---	CL	ctg	0
Brown-tan silty, clayey fine sand, wet (12-20-30).	35-36.5	BAT-5D-36.5	SM	100	0
Brown tan silty fine sand, wet, some gravel (10-22-23).	38.5-40	BAT-5D-40	SC-GC	100	0
Brown-tan silty fine sand with some gravel.	40-41	---	SM-GC	ctg	0

Logged by: J. Sminchak

Construction Notes:

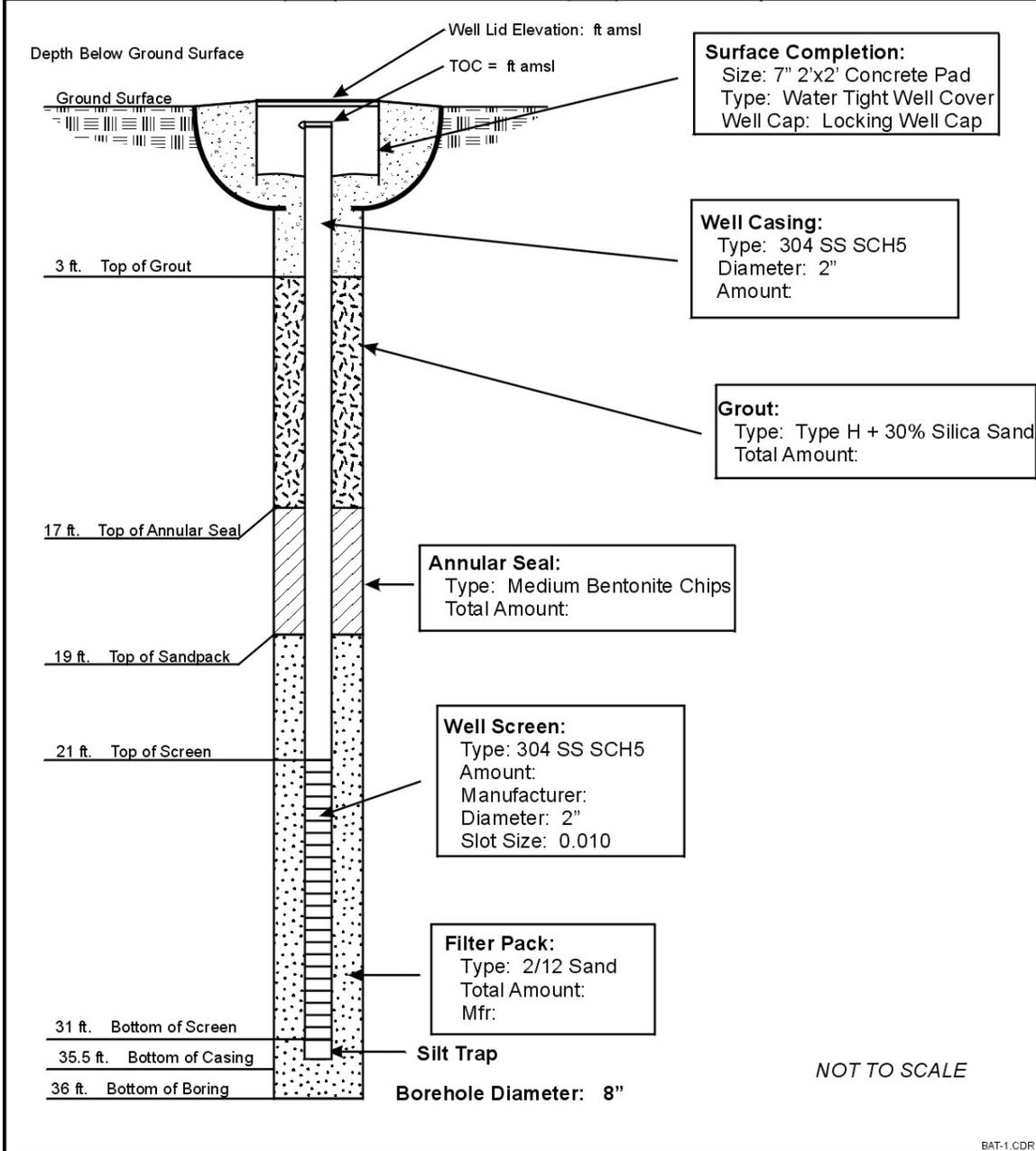
Completion Date: 8/13/01

1 ft sand sump, 2 ft of bentonite pellets between sand pack and grout, ~25 gallons of grout

Appendix B-3. Well Completion Diagrams

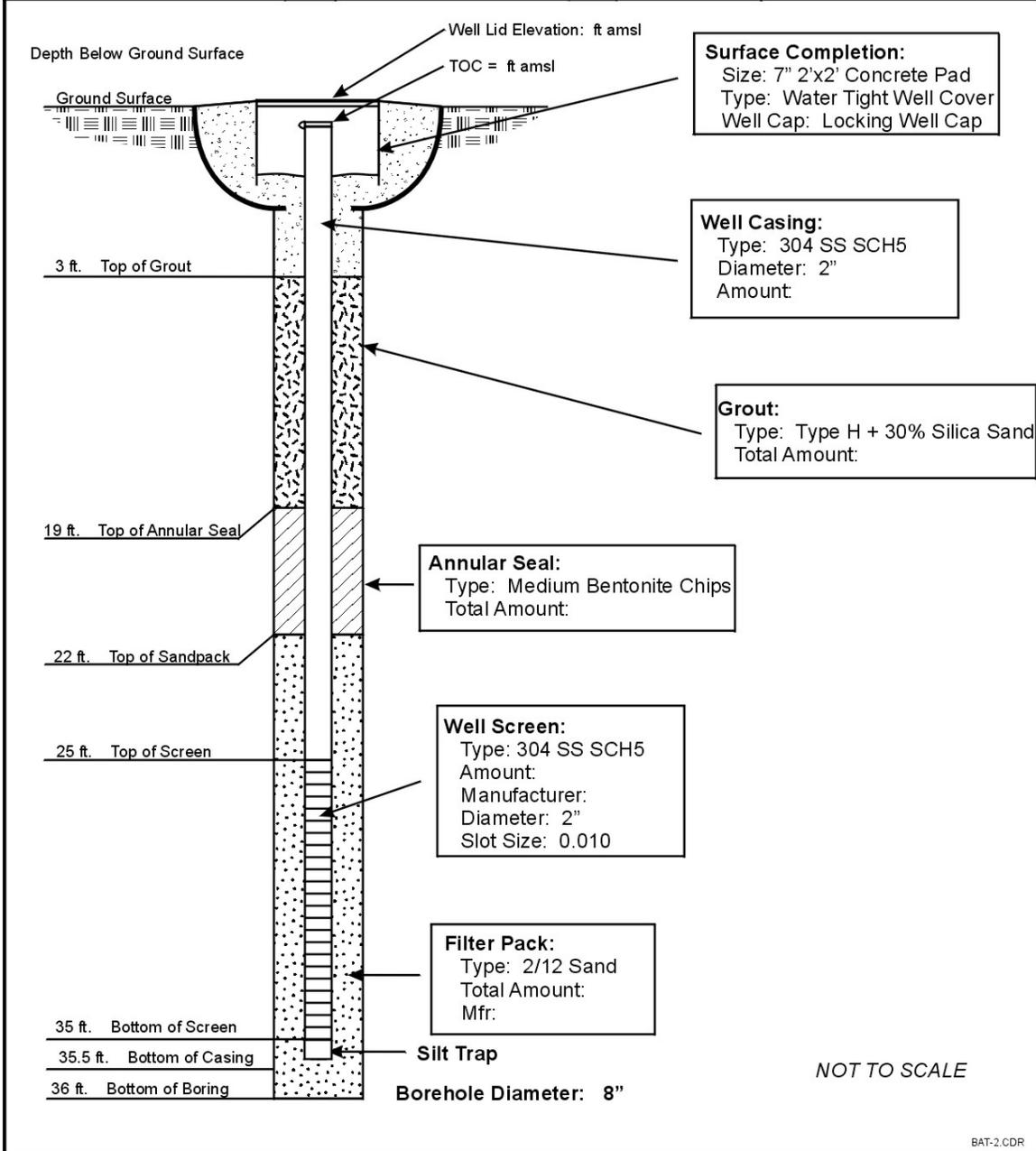
WELL COMPLETION DIAGRAM

Project #: G469133-11	Site: Beale AFB SWMU 23	Well #: BAT-1	Northing (NAD 83): 2170123.197
Drilling Contractor: Precision Sampling, Inc.	Rig Type and Drilling Method: HSA	Date: Mar 2001	Easting (NAD 83): 6735343.086
Reviewed by: Sam Yoon	Driller: Precision Sampling, Inc.	Hydrogeologist: Lydia Cumming	Surface Elevation (ft msl): 129.10



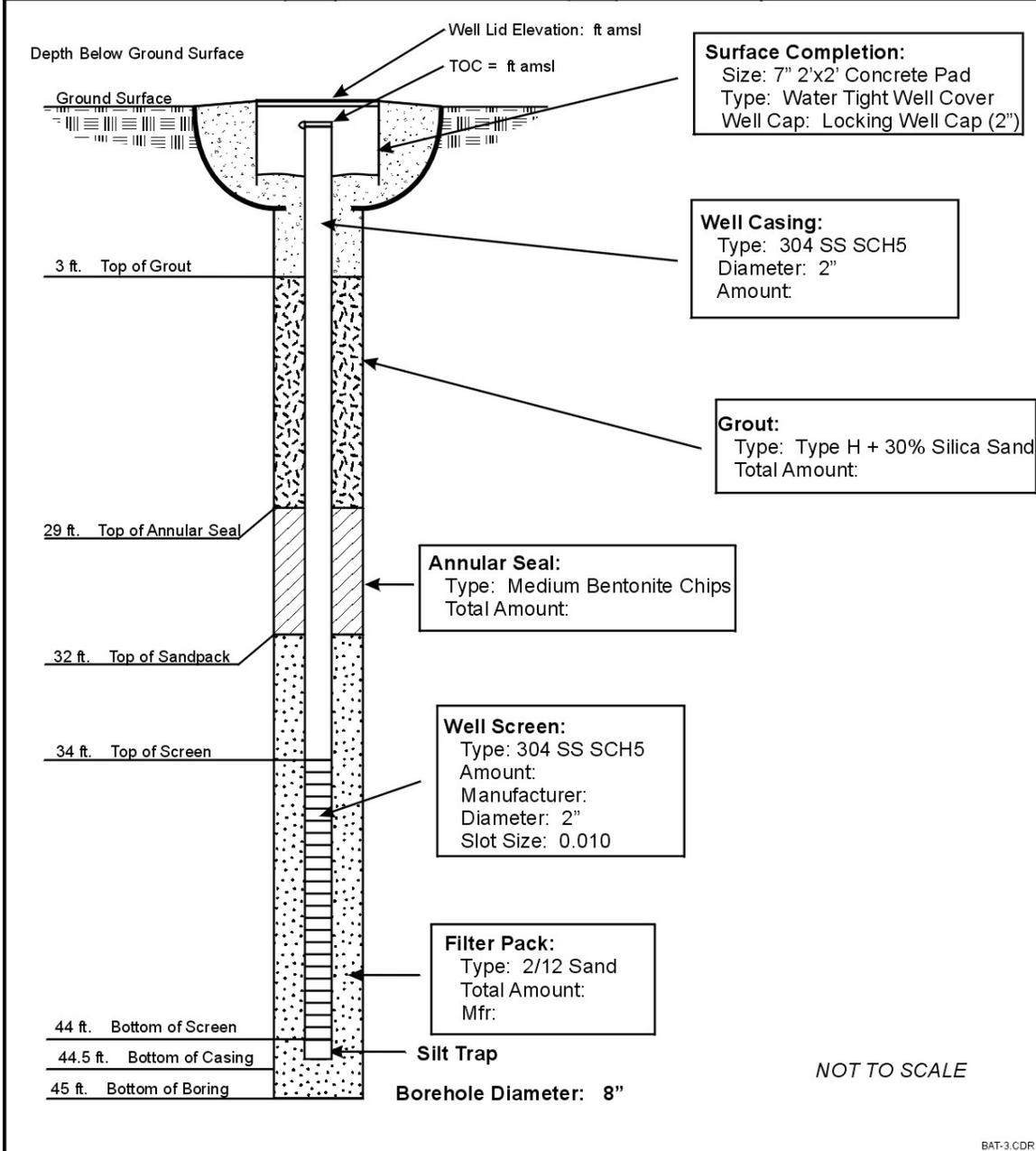
WELL COMPLETION DIAGRAM

Project #: G469133-11	Site: Beale AFB SWMU 23	Well #: BAT-2	Northing (NAD 83): 2170168.173
Drilling Contractor: Precision Sampling, Inc.	Rig Type and Drilling Method: HSA	Date: Mar 2001	Easting (NAD 83): 6735322.120
Reviewed by: Sam Yoon	Driller: Precision Sampling, Inc.	Hydrogeologist: Lydia Cumming	Surface Elevation (ft msl): 129.72



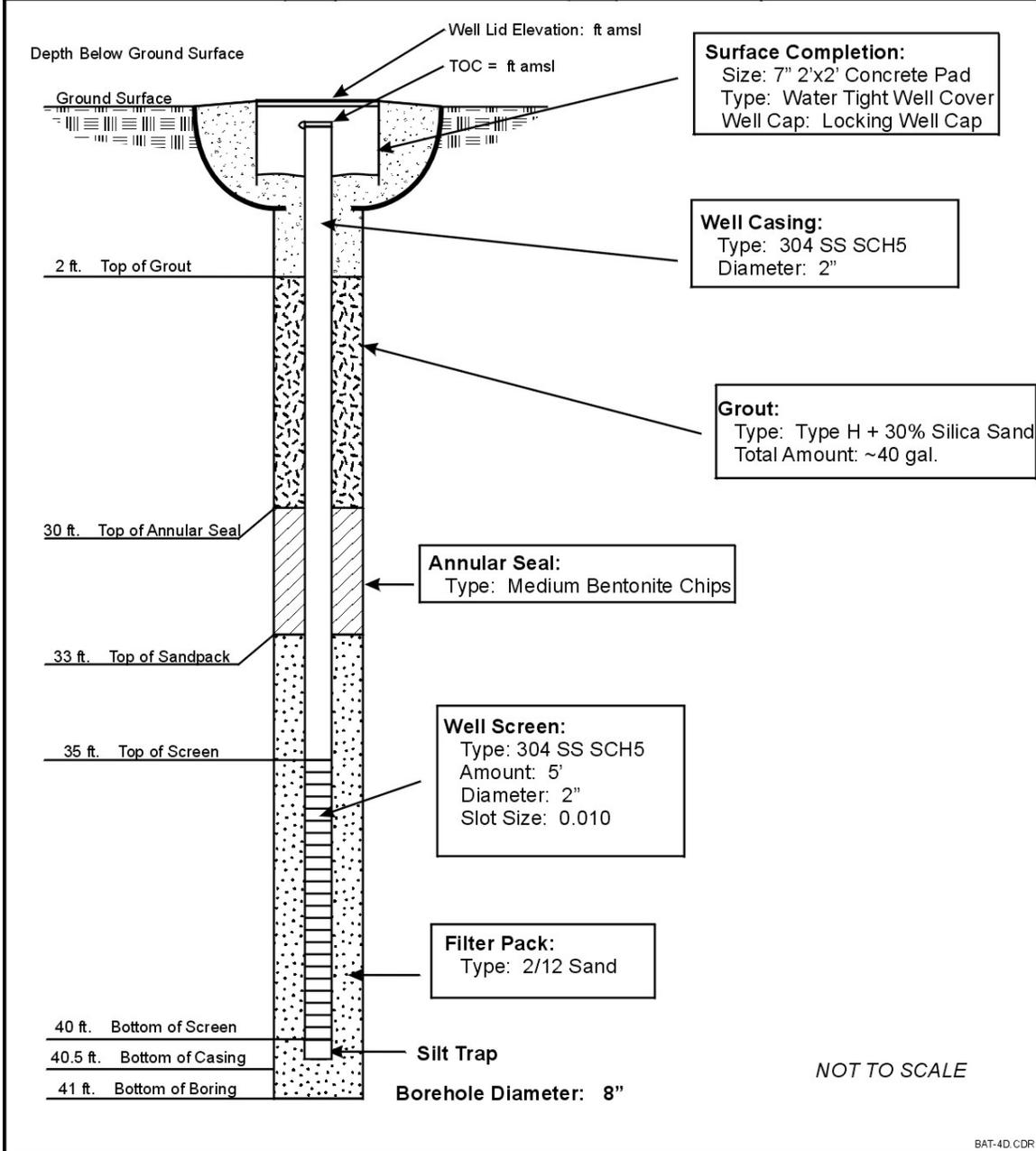
WELL COMPLETION DIAGRAM

Project #: G469133-11	Site: Beale AFB, SWMU 23	Well #: BAT-3	Northing (NAD 83): 2170126.636
Drilling Contractor: Precision Sampling, Inc.	Rig Type and Drilling Method: HSA	Date: Mar 2001	Easting (NAD 83): 6735345.765
Reviewed by: Sam Yoon	Driller: Precision Sampling, Inc.	Hydrogeologist: Lydia Cumming	Surface Elevation (ft msl): 129.23



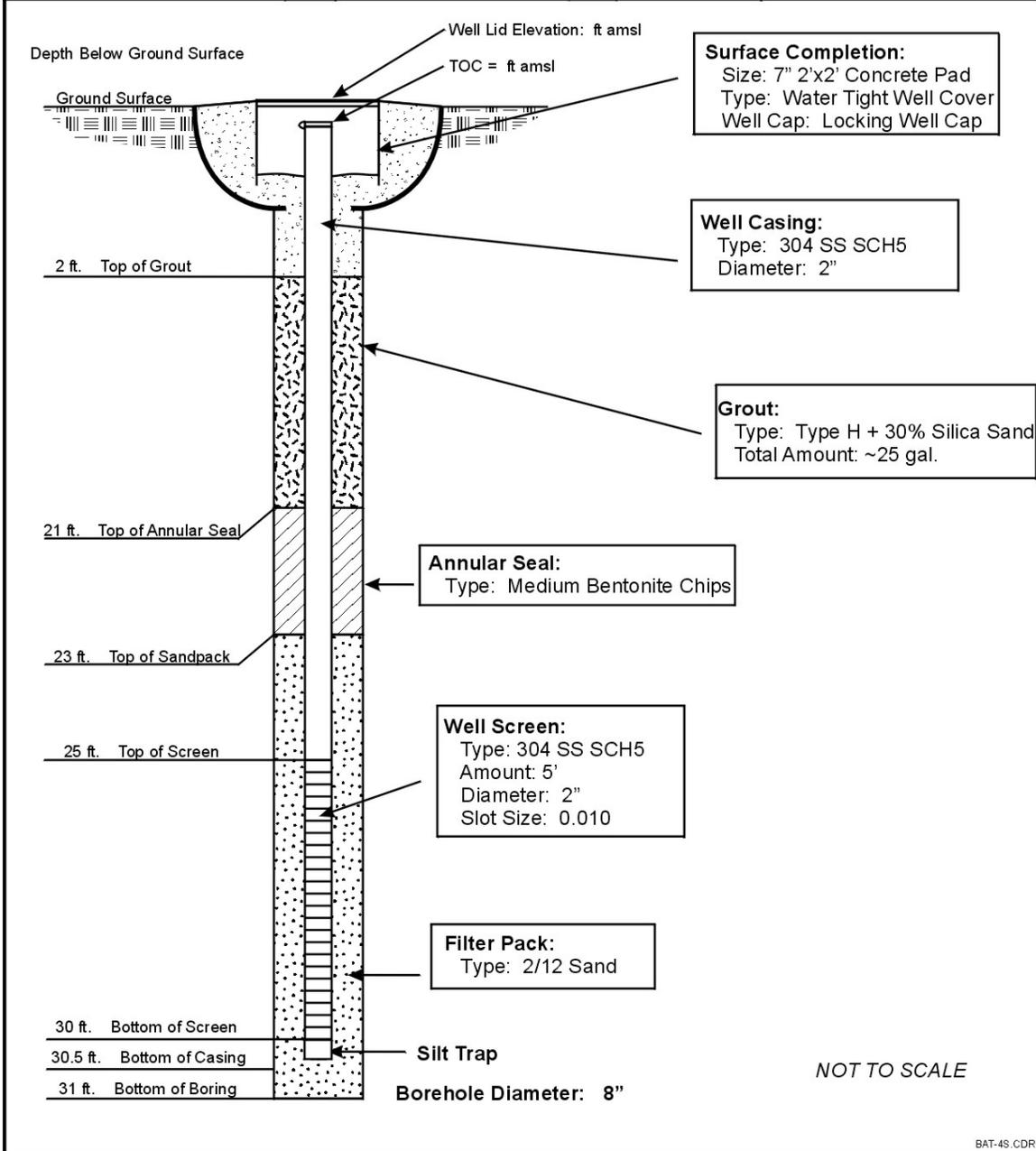
WELL COMPLETION DIAGRAM

Project #: G469133-11	Site: Beale AFB SWMU 23	Well #: BAT-4D	Northing (NAD 83): 2170094.129
Drilling Contractor: West HAZMAT	Rig Type and Drilling Method: HSA	Date: Aug. 13, 2001	Easting (NAD 83): 6735186.872
Reviewed by: Sam Yoon	Driller: West HAZMAT	Hydrogeologist: Joel Sminchak	Surface Elevation (ft msl): 130.66



WELL COMPLETION DIAGRAM

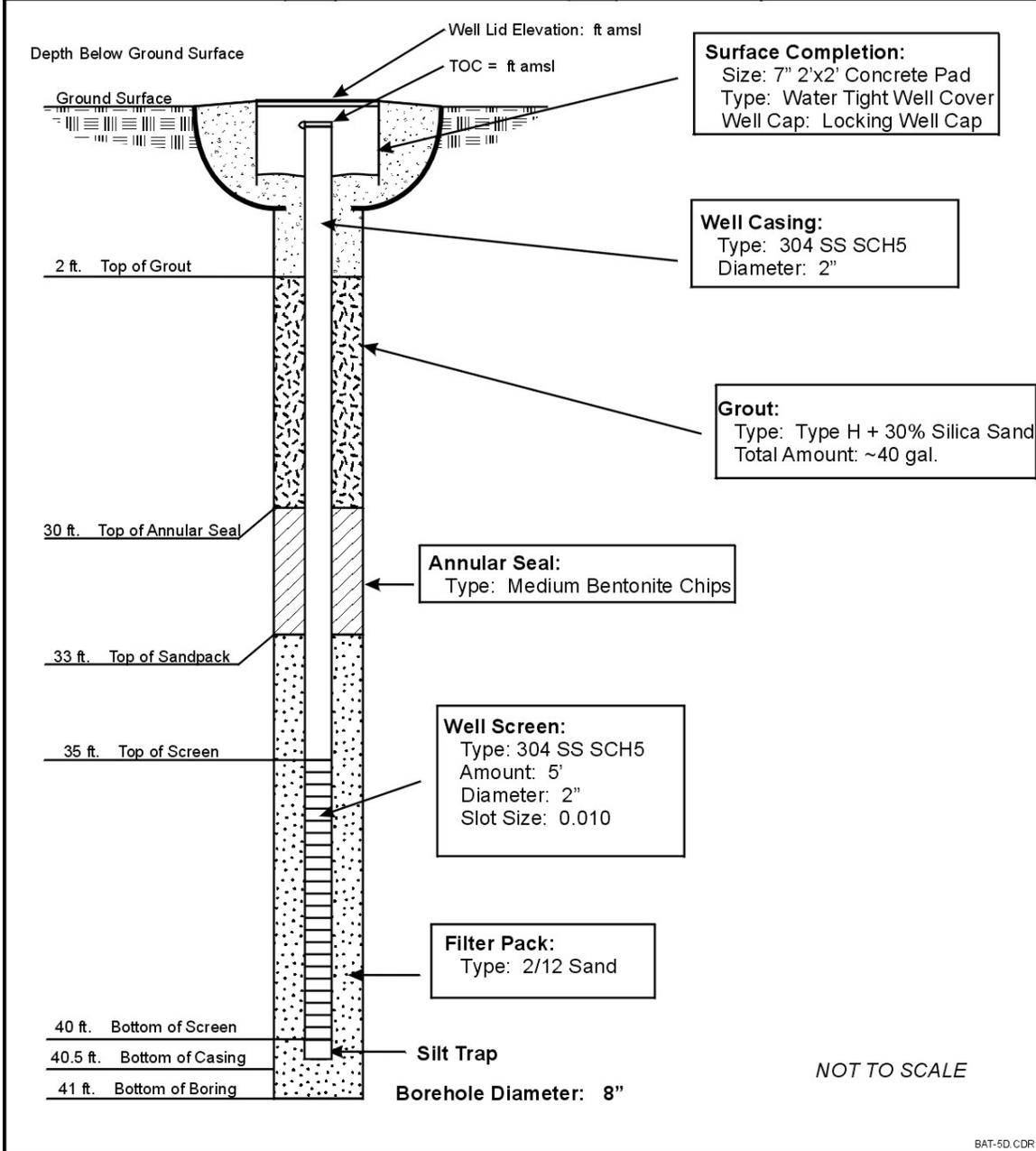
Project #: G469133-11	Site: Beale AFB SWMU 23	Well #: BAT-4S	Northing (NAD 83): 2170085.718
Drilling Contractor: West HAZMAT	Rig Type and Drilling Method: HSA	Date: Aug. 13, 2001	Easting (NAD 83): 6735179.710
Reviewed by: Sam Yoon	Driller: Brett Arenas	Hydrogeologist: Joel Sminchak	Surface Elevation (ft msl): 130.91



BAT-4S.CDR

WELL COMPLETION DIAGRAM

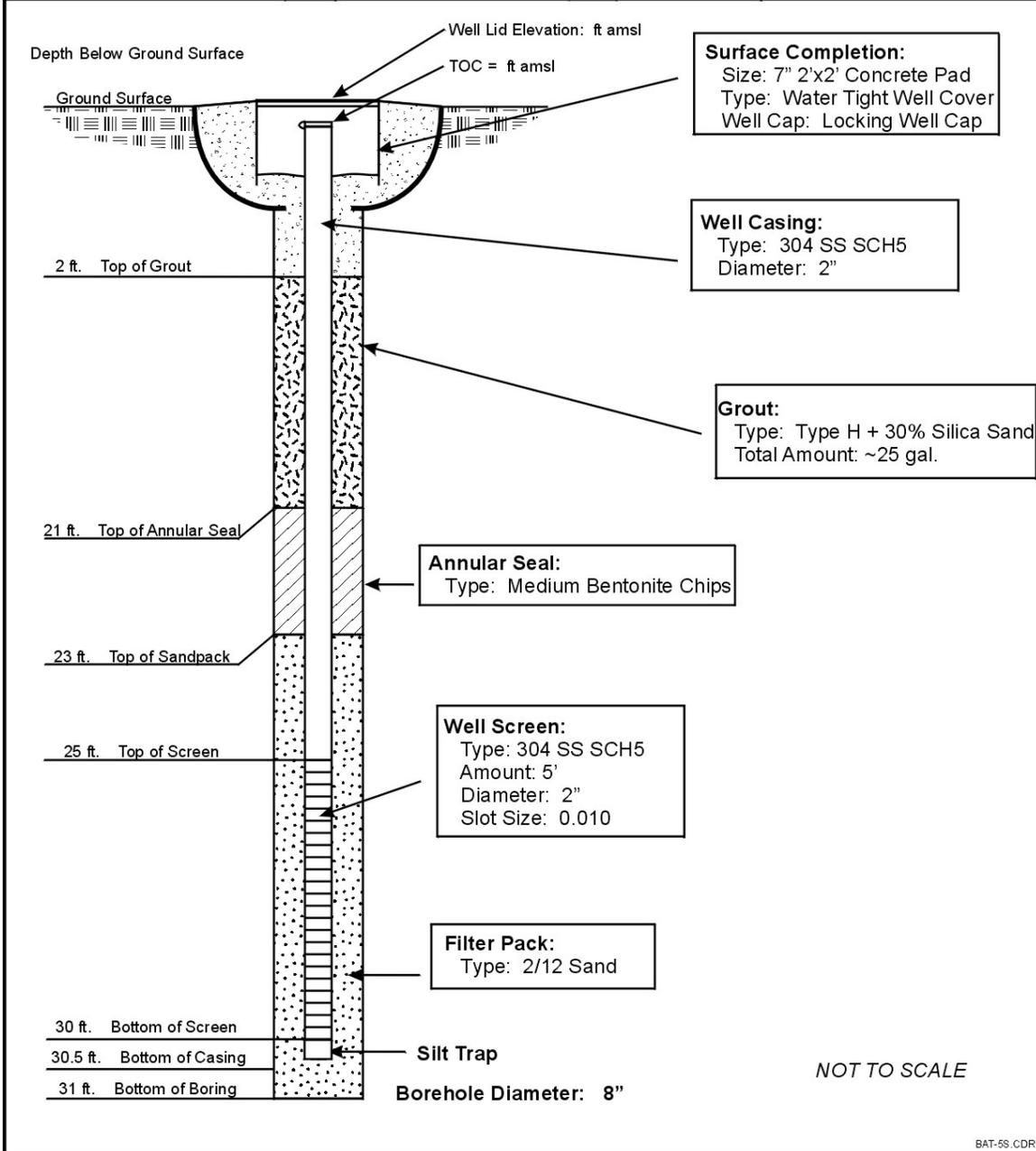
Project #: G469133-11	Site: Beale AFB SWMU 23	Well #: BAT-5D	Northing (NAD 83): 2170061.406
Drilling Contractor: West HAZMAT	Rig Type and Drilling Method: HSA	Date: Aug. 13, 2001	Easting (NAD 83): 6735109.877
Reviewed by: Sam Yoon	Driller: West HAZMAT	Hydrogeologist: Joel Sminchak	Surface Elevation (ft msl): 131.86



BAT-5D.CDR

WELL COMPLETION DIAGRAM

Project #: G469133-11	Site: Beale AFB SWMU 23	Well #: BAT-5S	Northing (NAD 83): 2170057.792
Drilling Contractor: West HAZMAT	Rig Type and Drilling Method: HSA	Date: Aug. 13, 2001	Easting (NAD 83): 6735117.682
Reviewed by: Sam Yoon	Driller: Brett Arenas	Hydrogeologist: Joel Sminchak	Surface Elevation (ft msl): 131.90

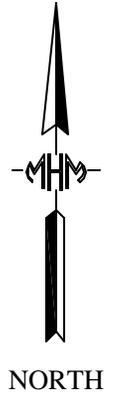


Appendix B-4. Site Characterization and Analysis Penetrometer System Results

S2539

LEGEND

-  MONITORING WELL
-  SOIL BORING
-  FENCE
-  SCAPS MIP Push <200 ppb (nondetect)
-  SCAPS MIP Push >200 ppb
-  Refusal above target depth



DOOLITTLE DRIVE

S2540

MIP-02
Estimated
200-500 ppb
TCE @ 37'

SWMU 23
WEST
(APPROX.)

MIP-04
Estimated
3000 ppb
TCE @ 31'

MIP-07
MIP-08

MIP-06

MIP-01

CONC.

MIP-03

SWMU 23
EAST
(APPROX.)

BAT-3
BAT-1

MIP-13

MIP-12

SB-29

LIF-01

SB28-MW1

MIP-05

MIP-09

MIP-10

MIP-11

SCAPS PRELIMINARY SUMMARY 7/3/01
 JUNE 20-24, 2001
 TRI-CORDERS ENVIROMENTAL, INC and
 NAVY PWC SAN DIEGO CODE 980

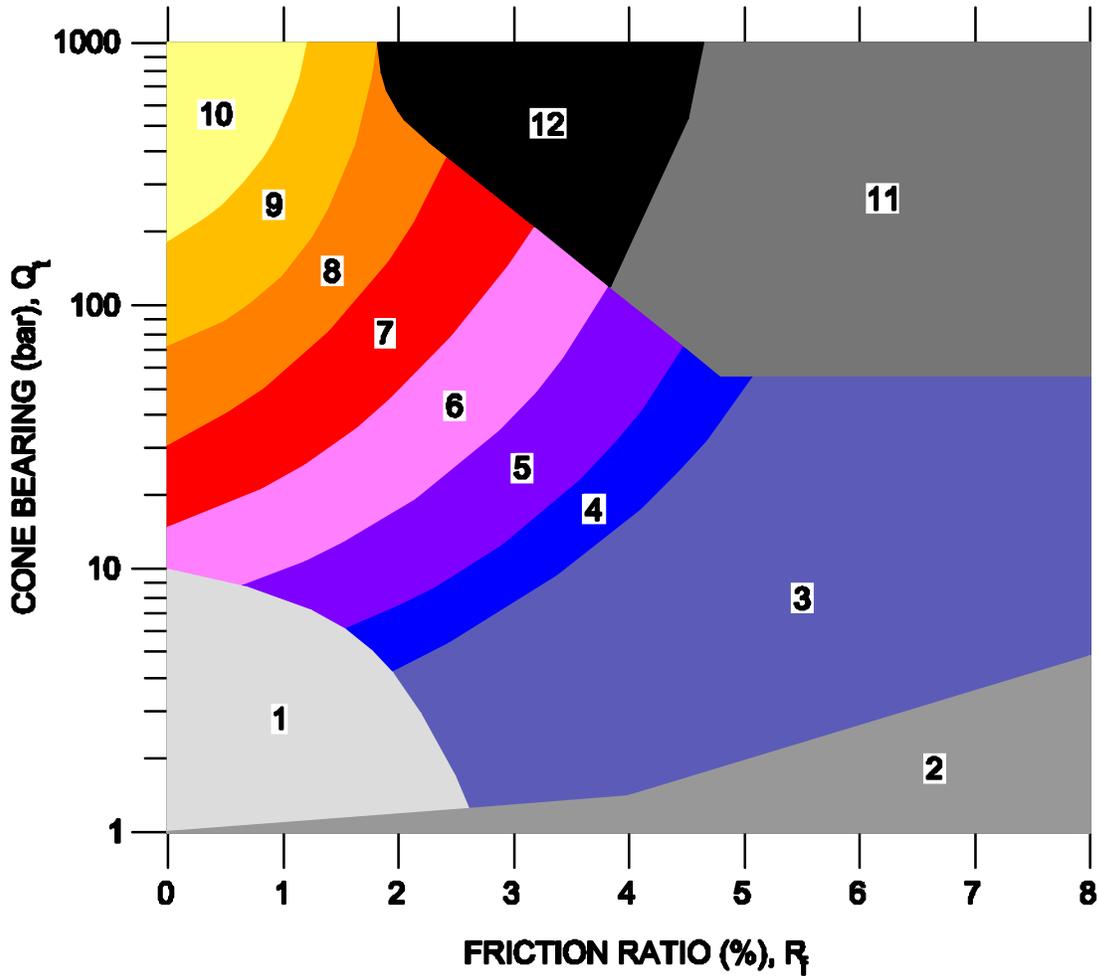
BATTELLE
 ENVIRONMENTAL
 RESTORATION
 SITE MAP
 BEALE AIR FORCE BASE CA



SCALE IN FEET

Modified From MHM Inc.

CPT CLASSIFICATION CHART
(after Robertson and Campanella, 1988)

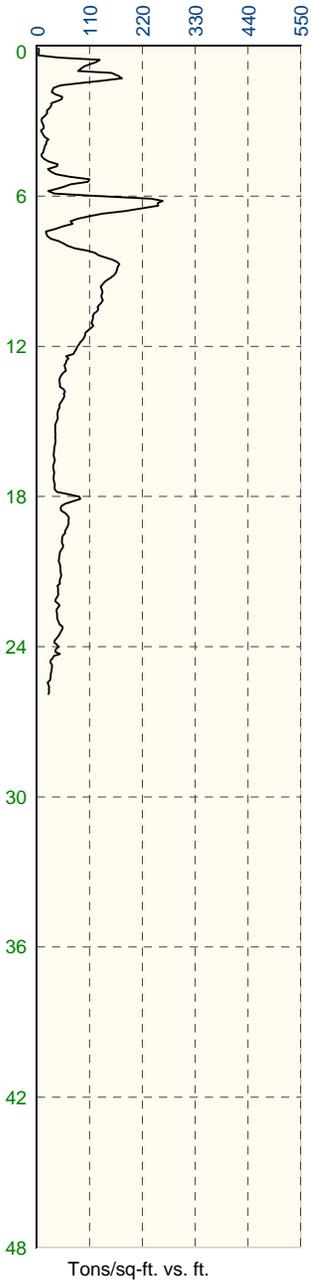


Friction Ratio (R_f) = Sleeve Friction (F_s)/Cone Pressure (Q_c) x 100%
 1 bar \approx 0.9576 tons per square foot (tsf)
 N = Standard penetration value, blows/foot

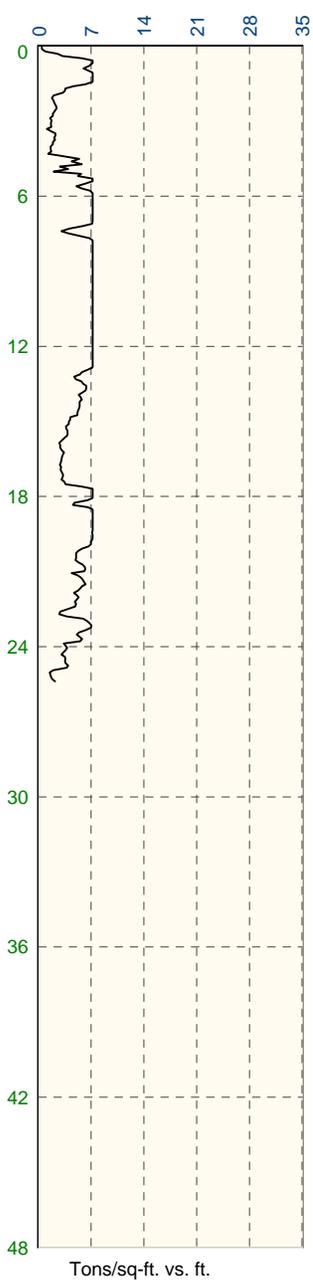
Zone	Q_t / N	Soil Behavior Type
1	2	sensitive fine grained
2	1	organic material
3	1	clay
4	1.5	silty clay to clay
5	2	clayey silt to silty clay
6	2.5	sandy silt to clayey silt
7	3	silty sand to sandy silt
8	4	sand to silty sand
9	5	sand
10	6	gravelly sand to sand
11	1	very stiff fine grained*
12	2	sand to clayey sand*

* overconsolidated or cemented

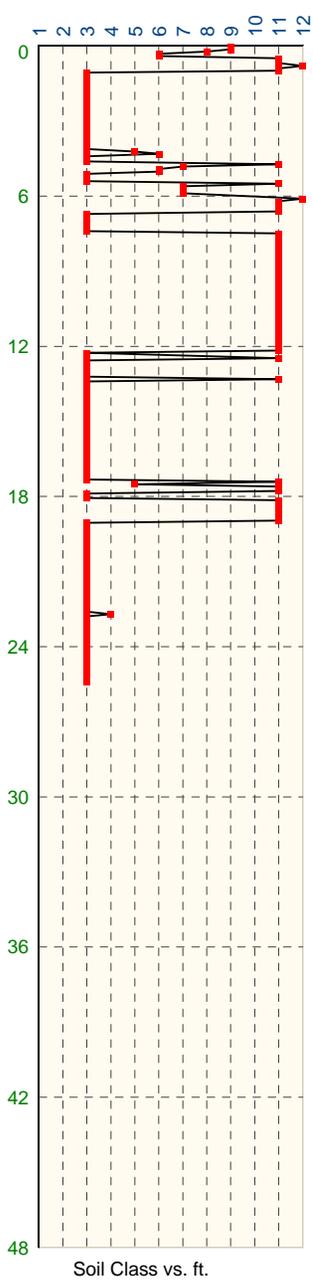
beale swmu 23 lif 01
Qc



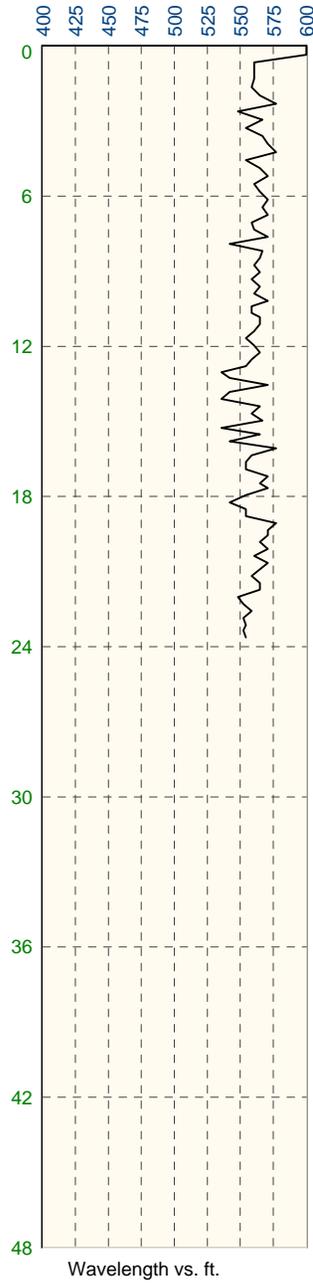
beale swmu 23 lif 01
Qs



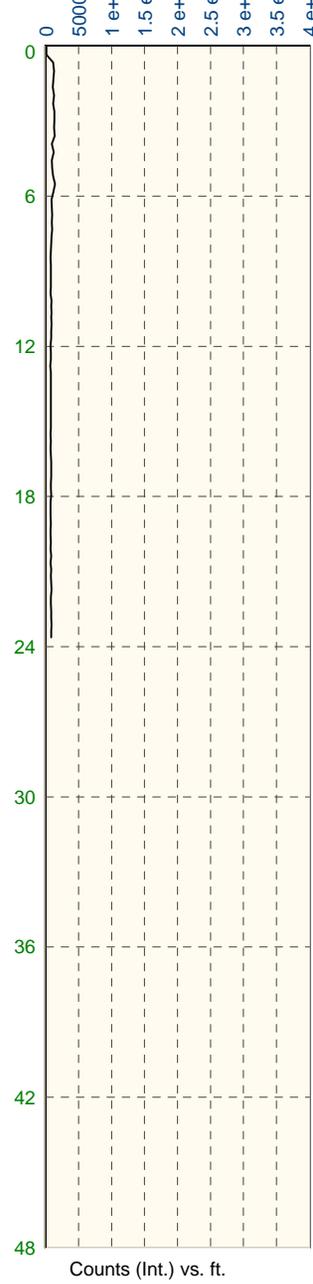
beale swmu 23 lif 01
Soil Class



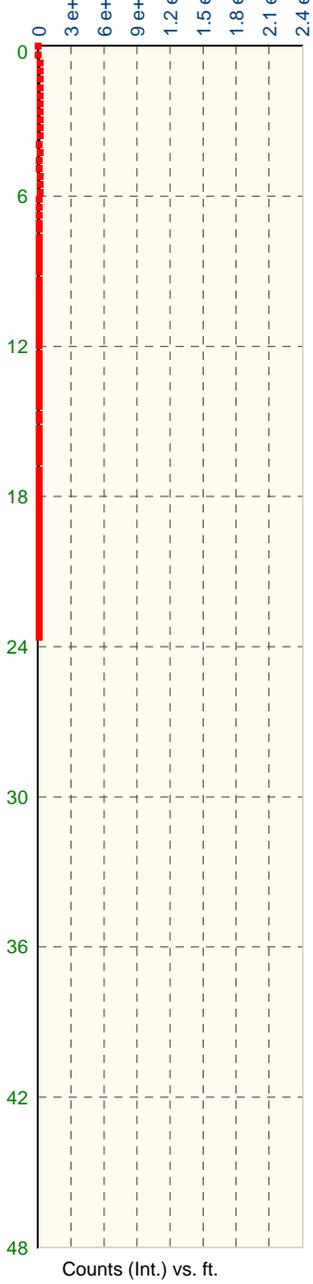
beale swmu 23 lif 01: LIF
Wavelength @ Peak

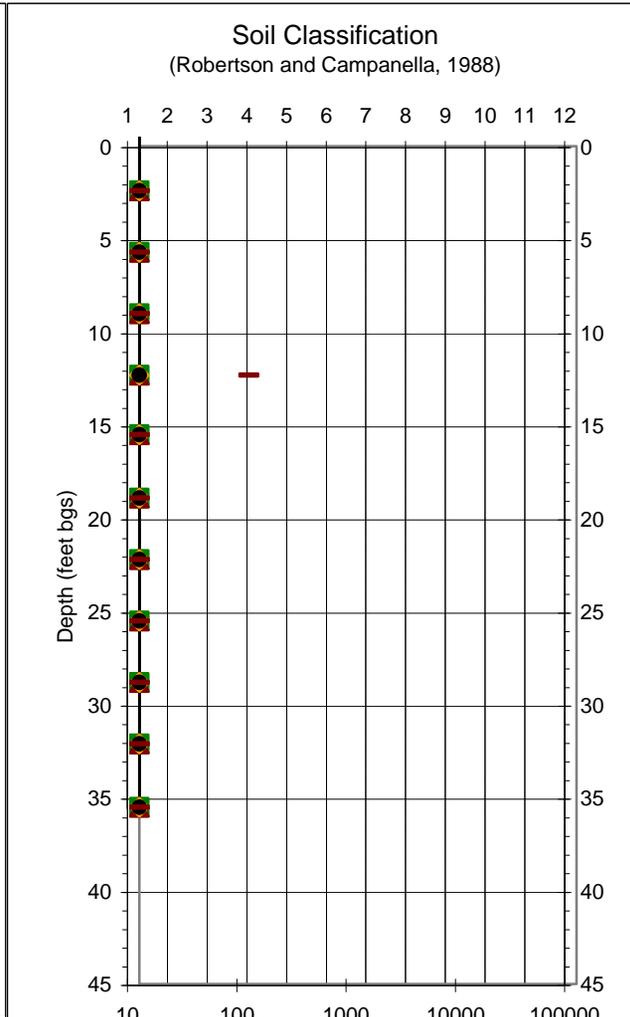
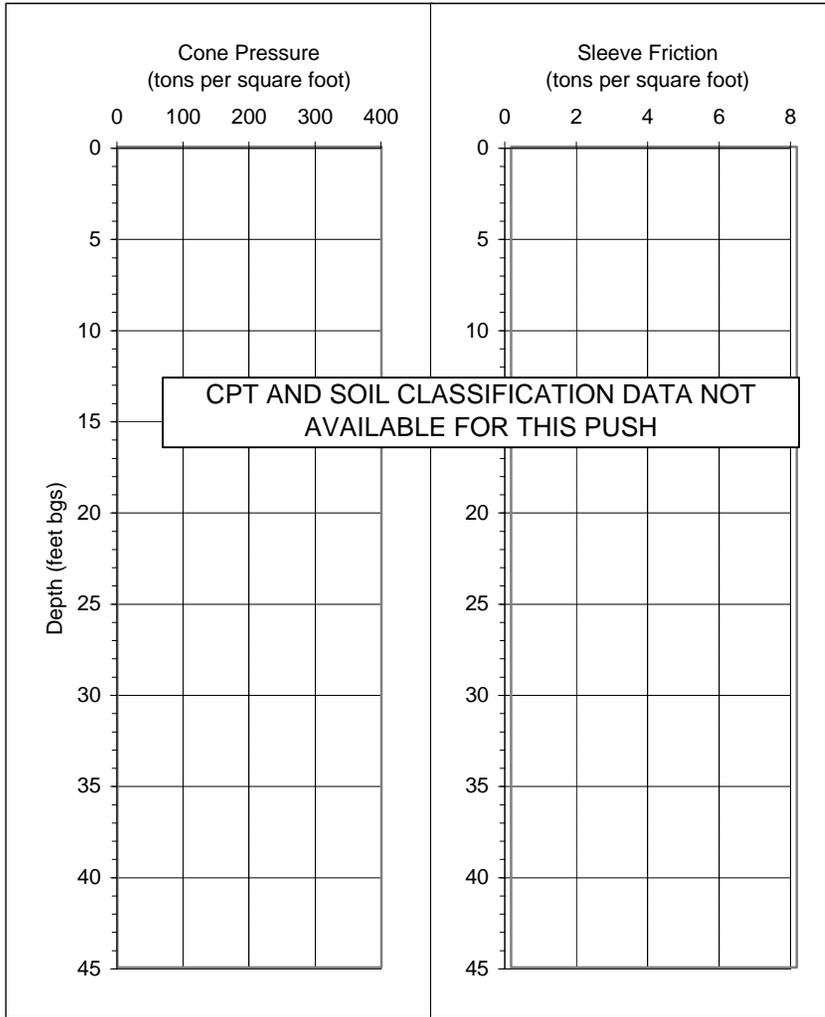


beale swmu 23 lif 01: LIF
Peak Intensity



beale swmu 23 lif 01: LIF
Peak Intensity





PUSH ID:
BEALE SWMU 23 MIP 01
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595599
 Easting: 6309669

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113.
 Concentration is estimated.

m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

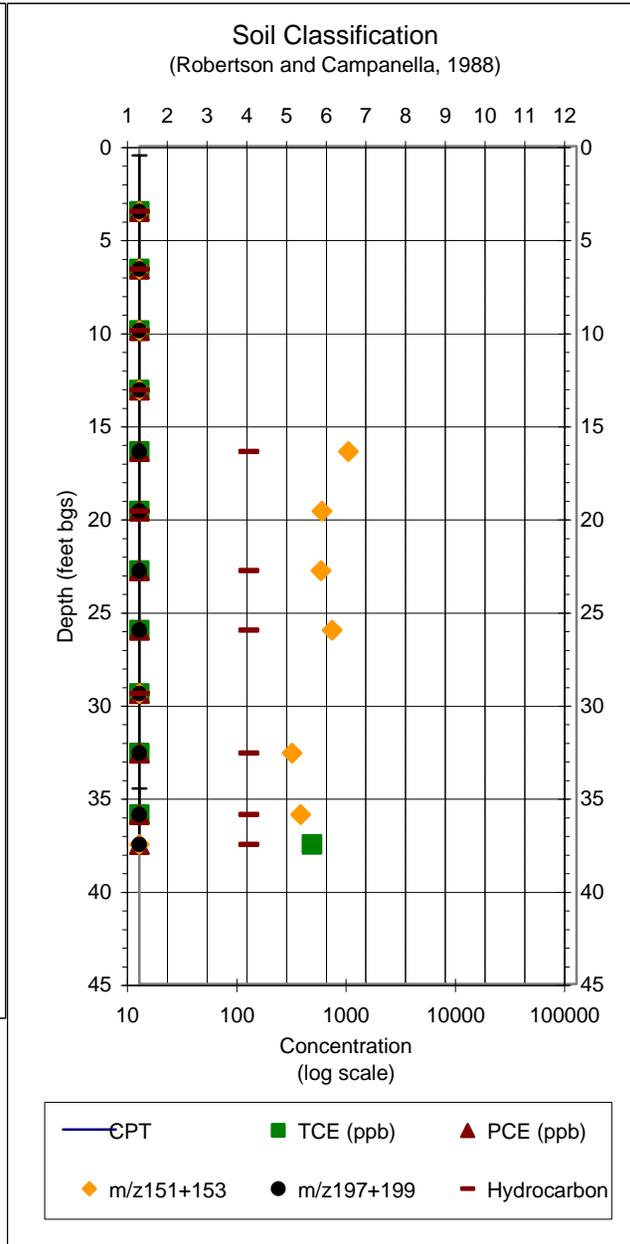
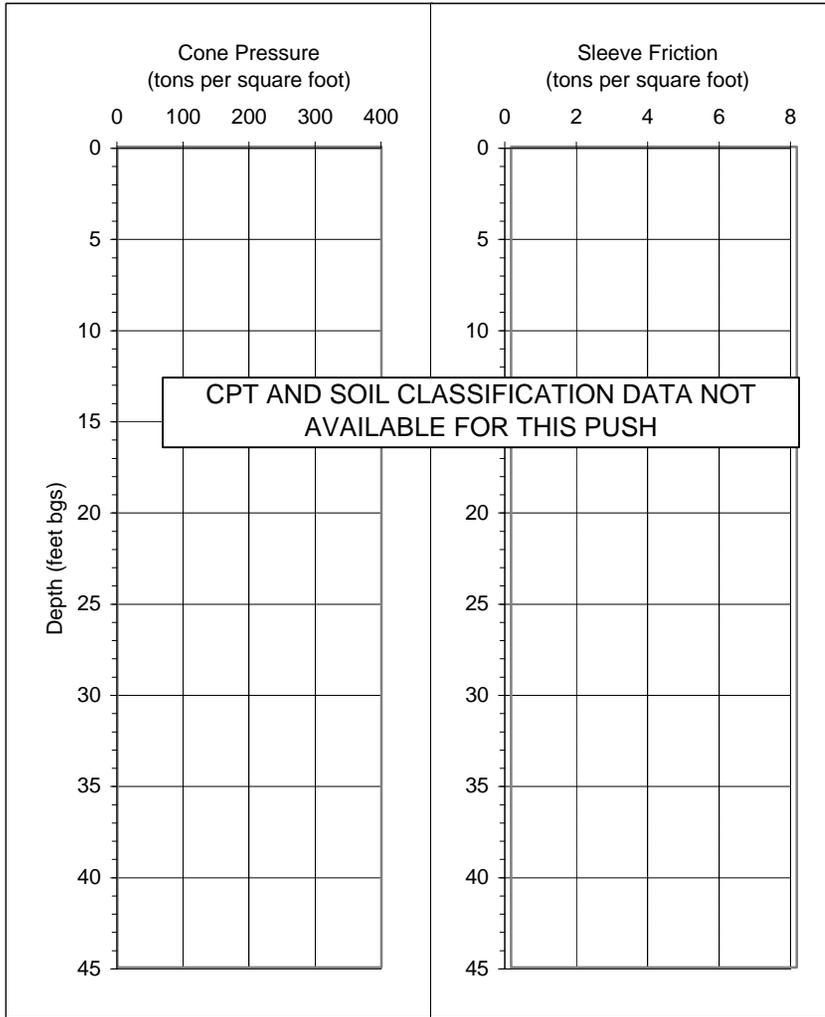
Hydrocarbons are detect/nondetect only; they are not quantitated.

nd - not detected above 200 ng/ml.
 Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
18.9	ND	ND	ND	ND	ND
22.2	ND	ND	ND	ND	ND
25.5	ND	ND	ND	ND	ND
28.8	ND	ND	ND	ND	ND
32.1	ND	ND	ND	ND	ND
35.5	ND	ND	ND	ND	ND

NOTES: Contaminants were analyzed using continuous data observation during penetration and discrete measurements recorded during retraction.



PUSH ID:
BEALE SWMU 23 MIP 02
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595627
 Easting: 6309623

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113.
 Concentration is estimated.

m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

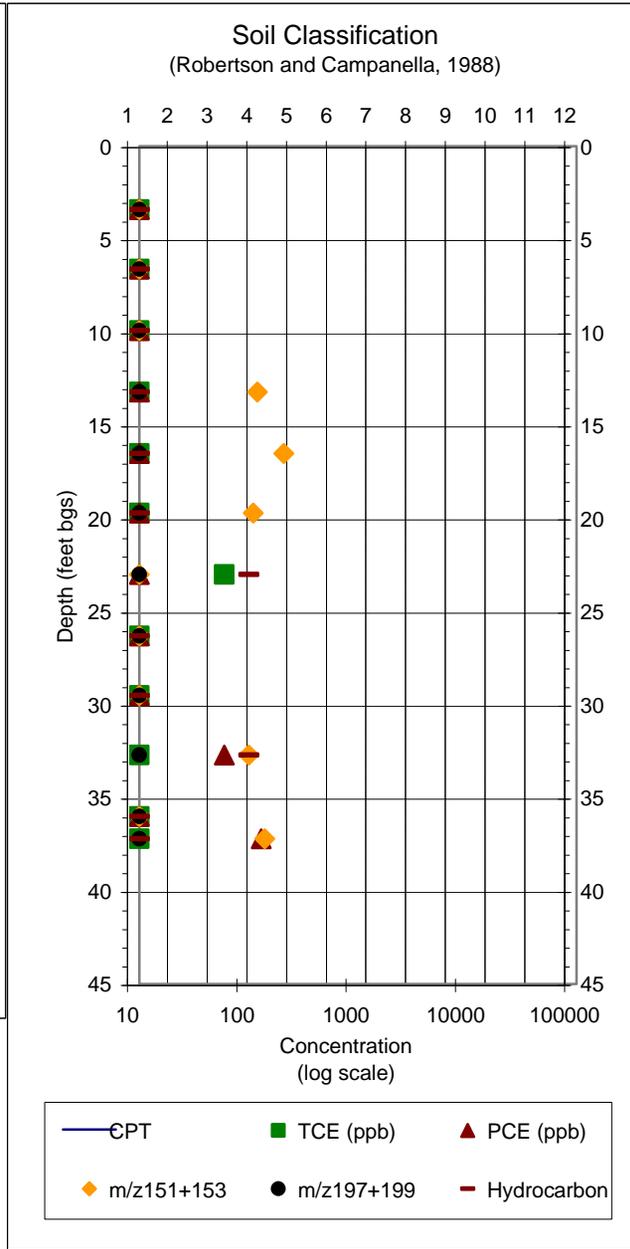
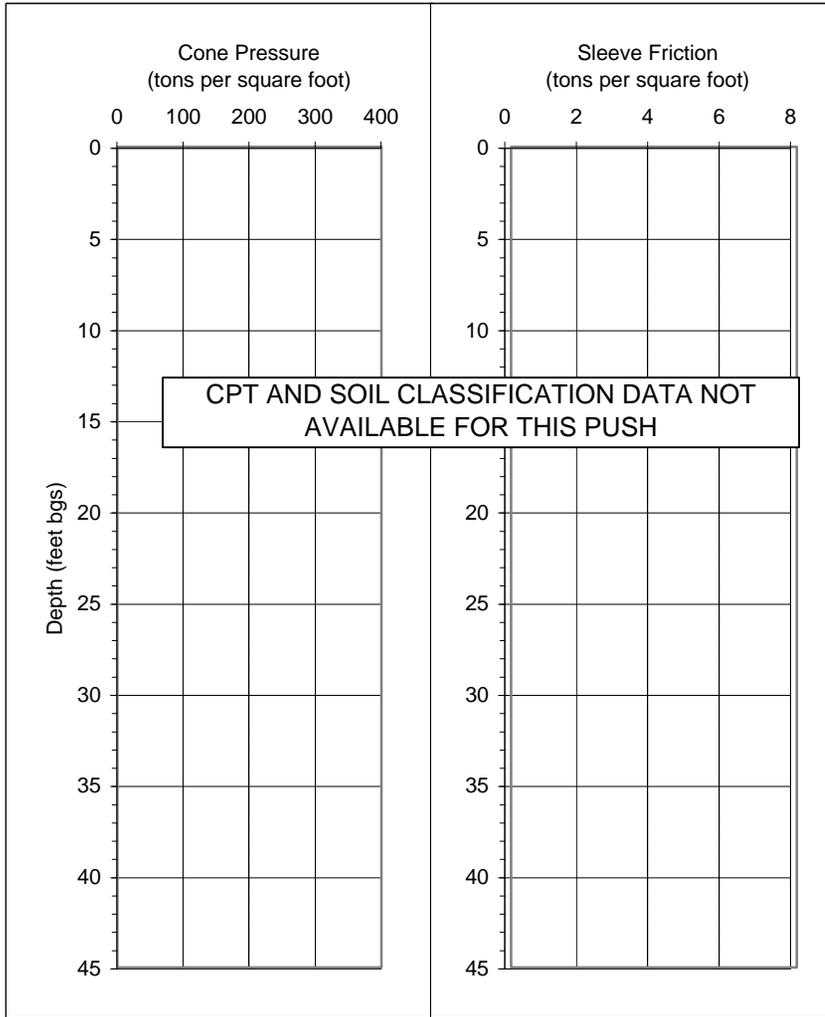
Hydrocarbons are detect/nondetect only; they are not quantitated.

nd - not detected above 200 ng/ml.
 Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
22.8	ND	ND	460	ND	yes
26	ND	ND	580	ND	yes
29.4	ND	ND	ND	ND	ND
32.6	ND	ND	250	ND	yes
35.9	ND	ND	300	ND	yes
37.5	380	ND	ND	ND	yes

NOTES: Contaminants were analyzed by recording discrete measurements during penetration.



PUSH ID:
BEALE SWMU 23 MIP 03
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595556
 Easting: 6309726

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113.
 Concentration is estimated.

m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

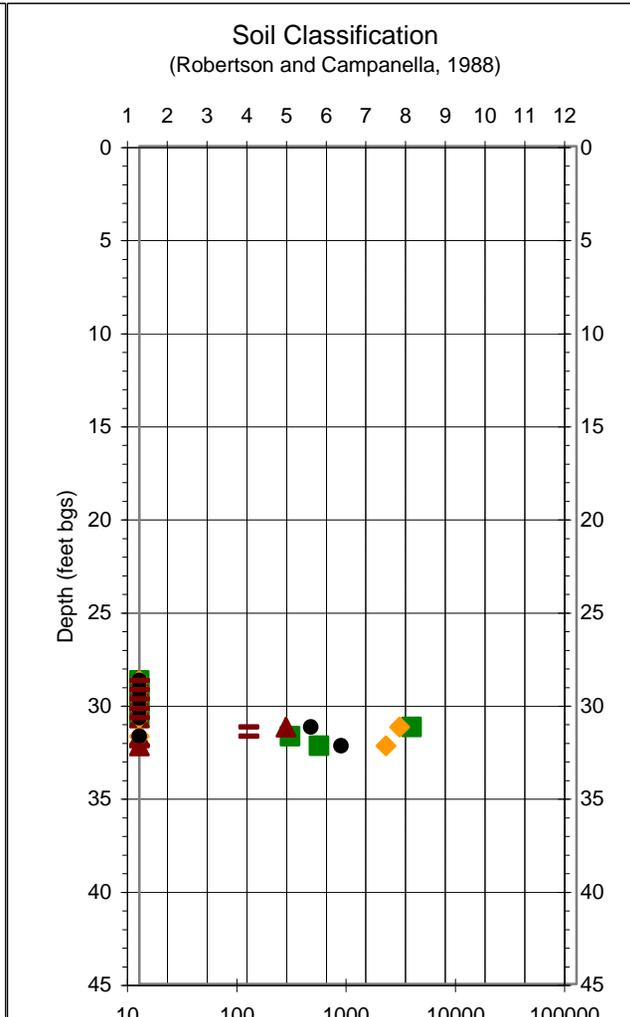
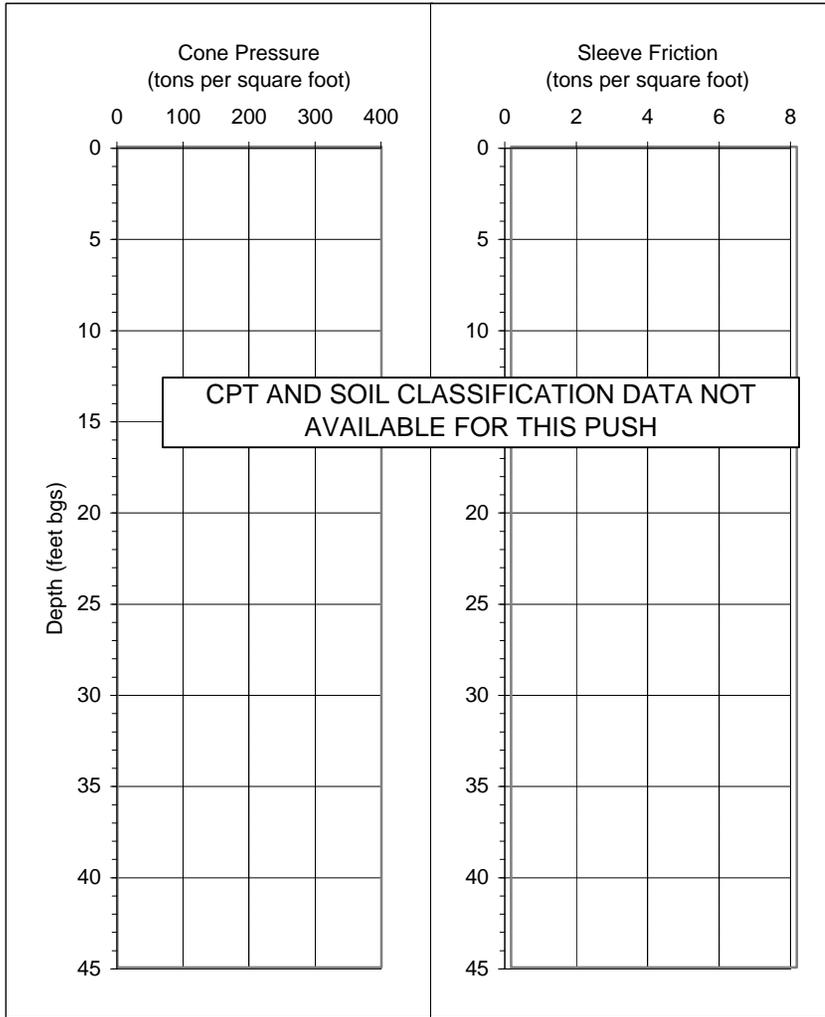
Hydrocarbons are detect/nondetect only; they are not quantitated.

nd - not detected above 200 ng/ml.
 Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

NOTES: Contaminants were analyzed by recording discrete measurements during penetration.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
23	60 J	ND	ND	ND	yes
26.3	ND	ND	ND	ND	ND
29.5	ND	ND	ND	ND	ND
32.7	ND	60 J	100 J	ND	yes
36	ND	ND	ND	ND	ND
37.2	ND	130 J	140 J	ND	ND



PUSH ID:
BEALE SWMU 23 MIP 04
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595619
 Easting: 6309766

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113. Concentration is estimated.

m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

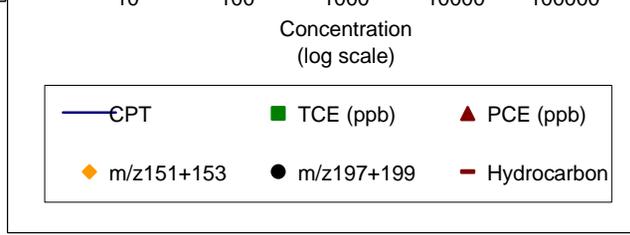
Hydrocarbons are detect/nondetect only; they are not quantitated.

nd - not detected above 200 ng/ml. Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

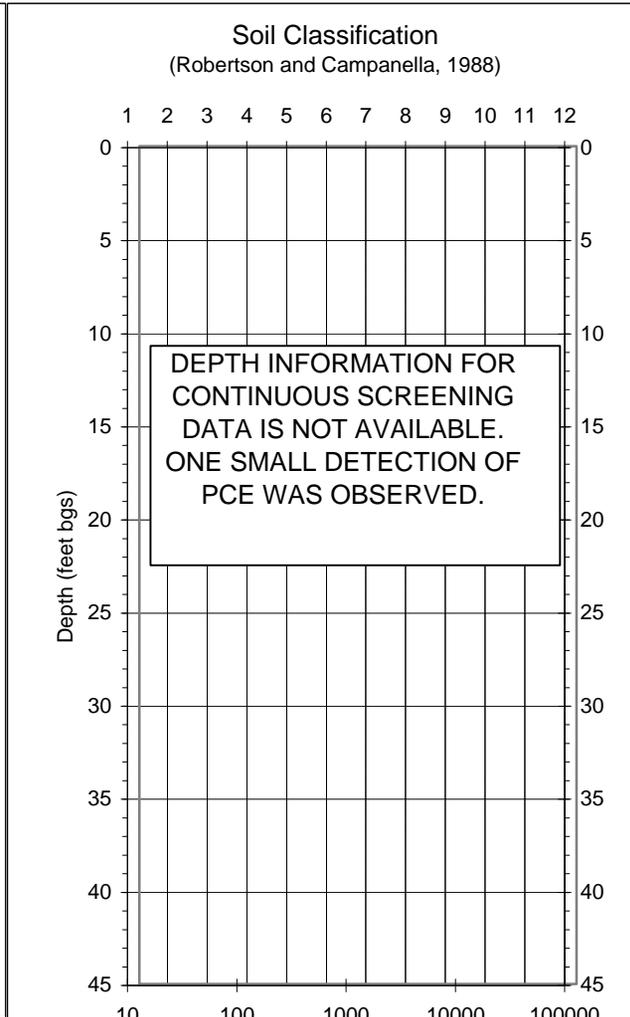
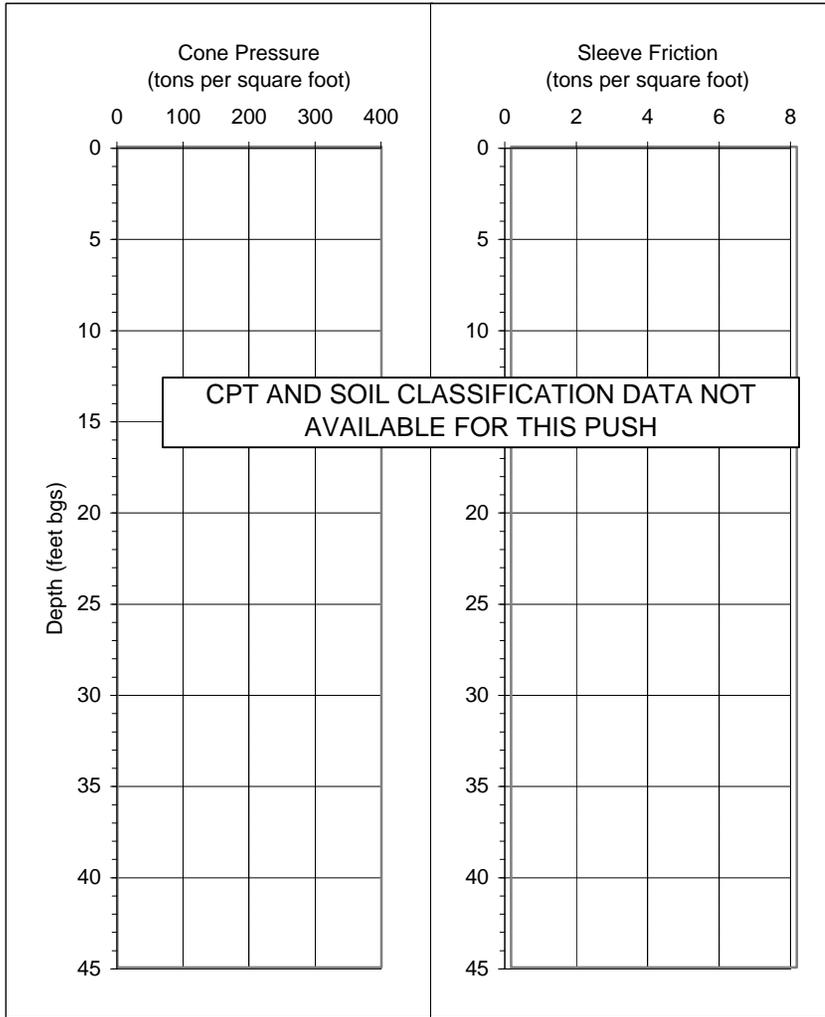
DCE, Vinyl Chloride, CHC13, and Benzene were not detected.

Toluene was detected at 32.2 feet bgs at a concentration of 380 ng/ml.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
29.7	10	10	10	10	10
30.2	10	10	10	10	10
30.7	10	10	10	10	10
31.2	3,100	220	2,400	370	100
31.7	240	10	10	10	100
32.2	440	10	1,800	700	10



NOTES: Contaminants were analyzed using continuous data screening during penetration and discrete measurements recorded during retraction.



PUSH ID:
BEALE SWMU 23 MIP 05
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595491
 Easting: 6309794

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113.
 Concentration is estimated.

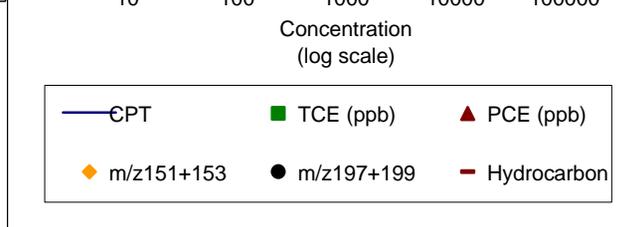
m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

Hydrocarbons are detect/nondetect only; they are not quantitated.

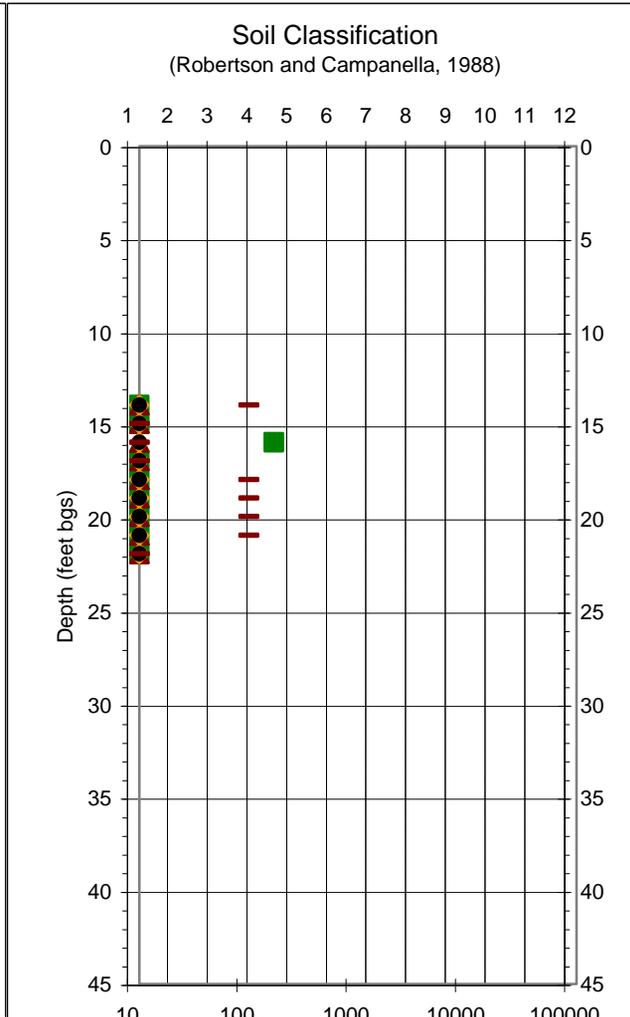
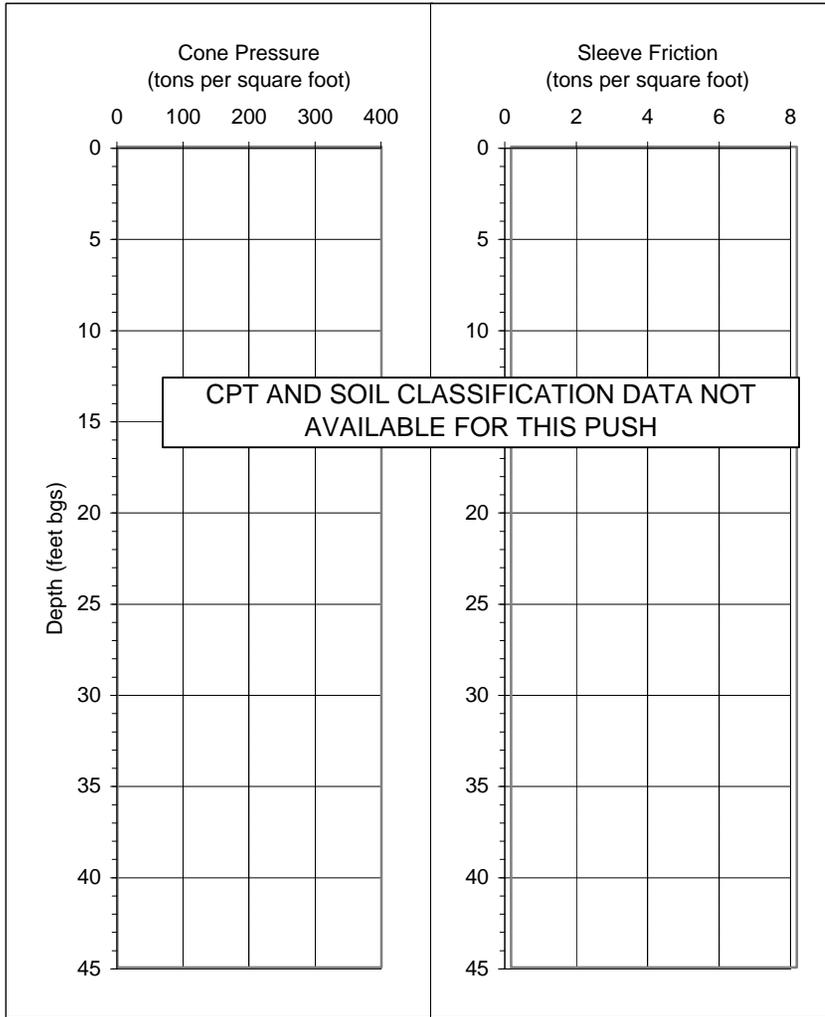
nd - not detected above 200 ng/ml. Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
0.0 - 36.9	ND	240	280	ND	ND



NOTES: Contaminants were analyzed using continuous data screening during penetration



PUSH ID:
BEALE SWMU 23 MIP 06
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595598
 Easting: 6309792

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113.
 Concentration is estimated.

m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

Hydrocarbons are detect/nondetect only; they are not quantitated.

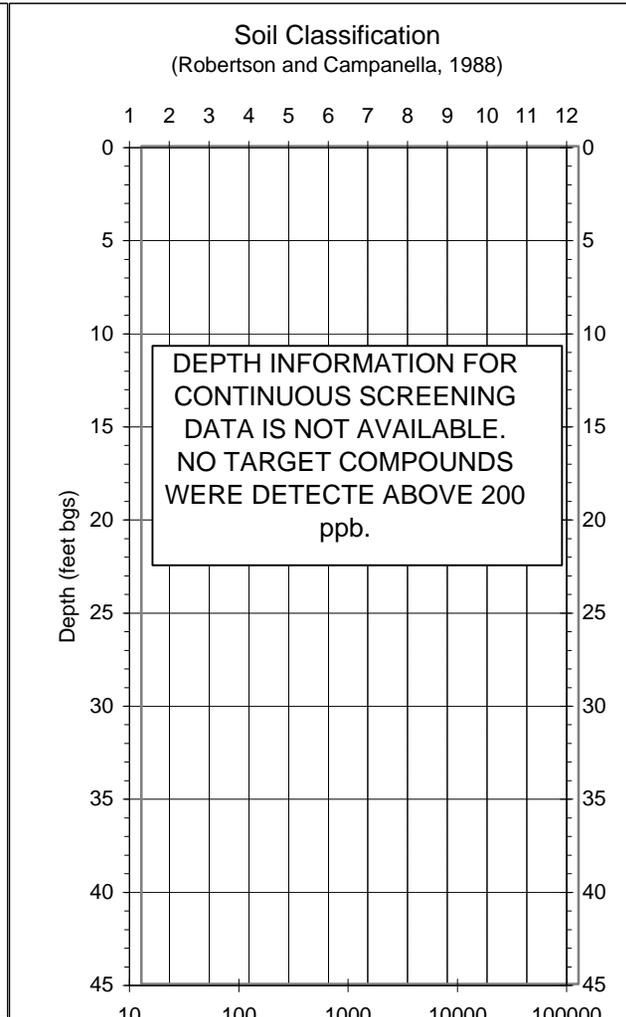
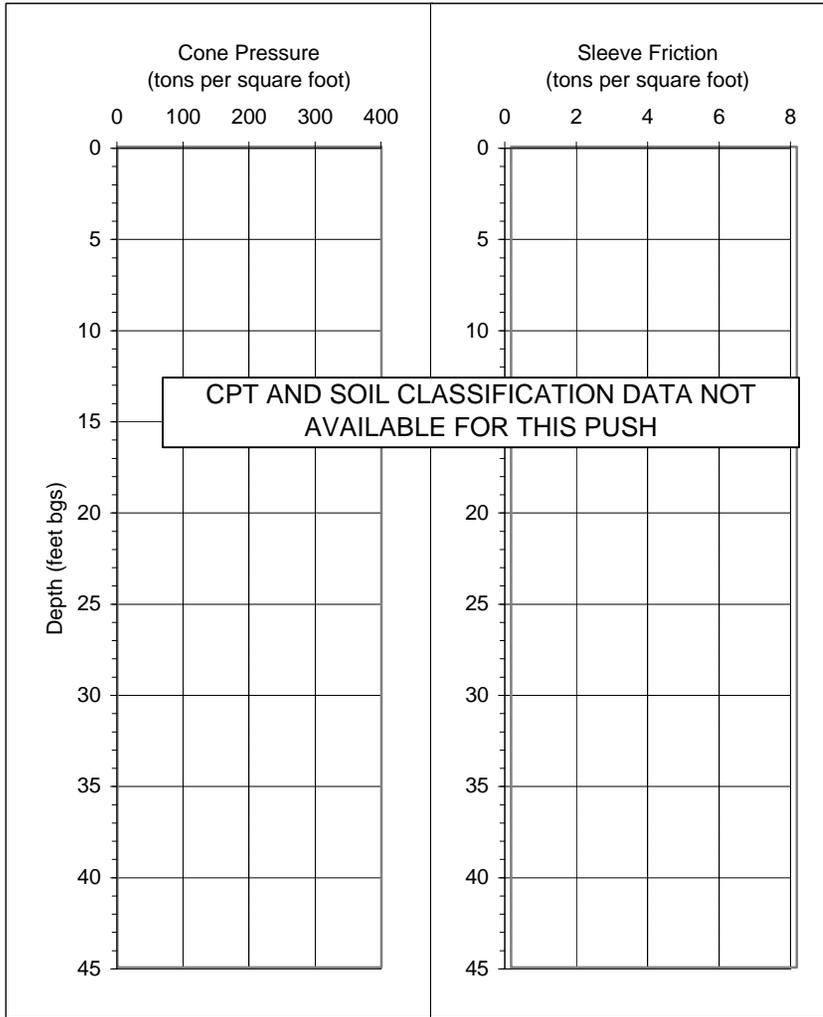
nd - not detected above 200 ng/ml.
 Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
13.9	ND	ND	ND	ND	yes
14.9	ND	ND	ND	ND	ND
15.9	170 J	ND	ND	ND	ND
16.9	ND	ND	ND	ND	ND
17.9	ND	ND	ND	ND	yes
18.9	ND	ND	ND	ND	yes

— CPT ■ TCE (ppb) ▲ PCE (ppb)
 ◆ m/z151+153 ● m/z197+199 - Hydrocarbon

NOTES: Contaminants were analyzed using continuous data screening during penetration and discrete measurements recorded during retraction.



PUSH ID:
BEALE SWMU 23 MIP 07
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595612
 Easting: 6309747

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113. Concentration is estimated.

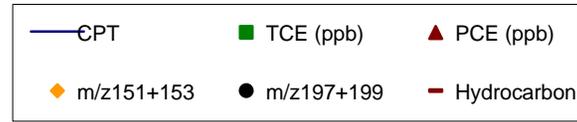
m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

Hydrocarbons are detect/nondetect only; they are not quantitated.

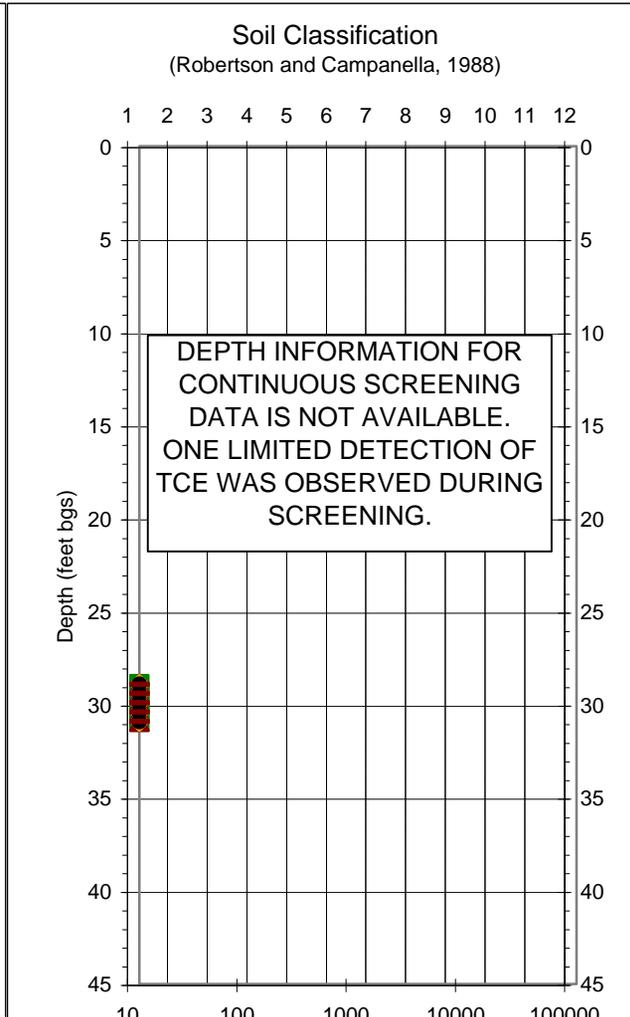
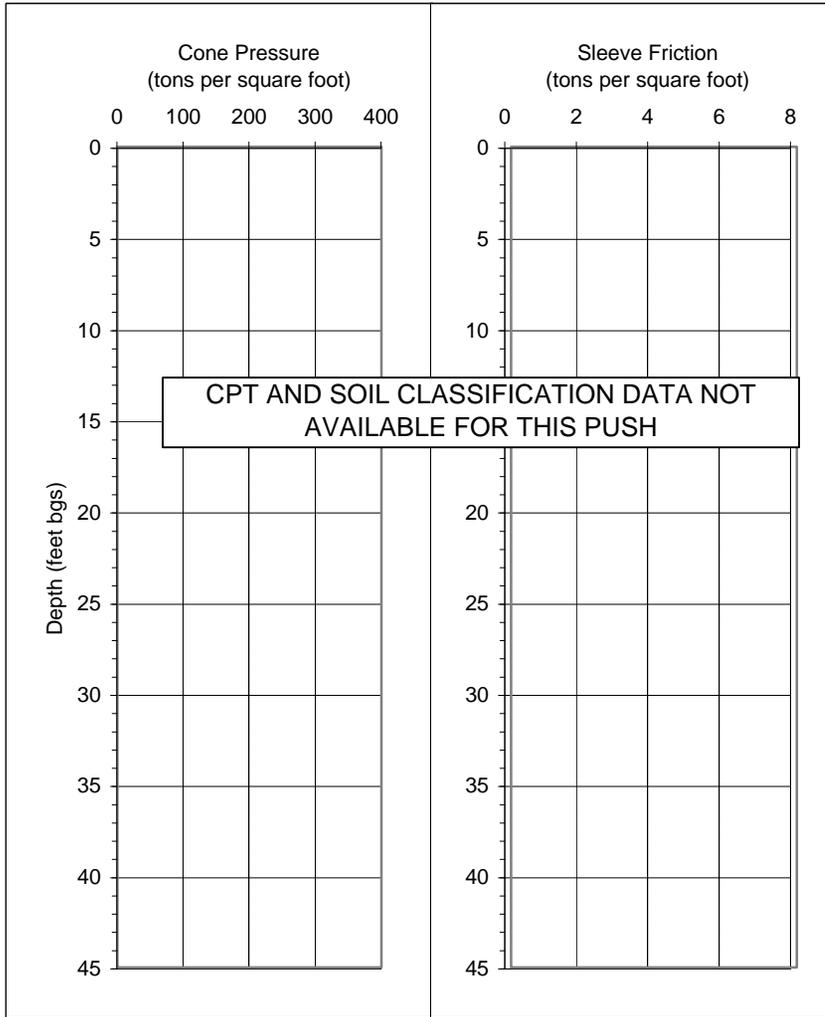
nd - not detected above 200 ng/ml. Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
0.0 - 40.1	90 J	ND	ND	ND	yes



NOTES: Contaminants were analyzed using continuous data screening during penetration



PUSH ID:
BEALE SWMU 23 MIP 08a
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595606
 Easting: 6309753

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113. Concentration is estimated.

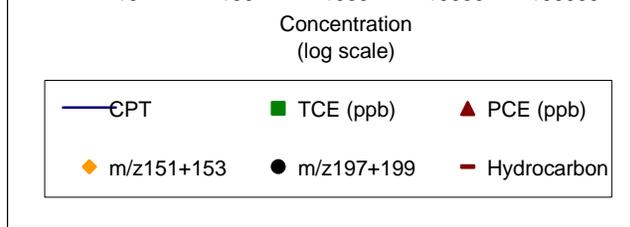
m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

Hydrocarbons are detect/nondetect only; they are not quantitated.

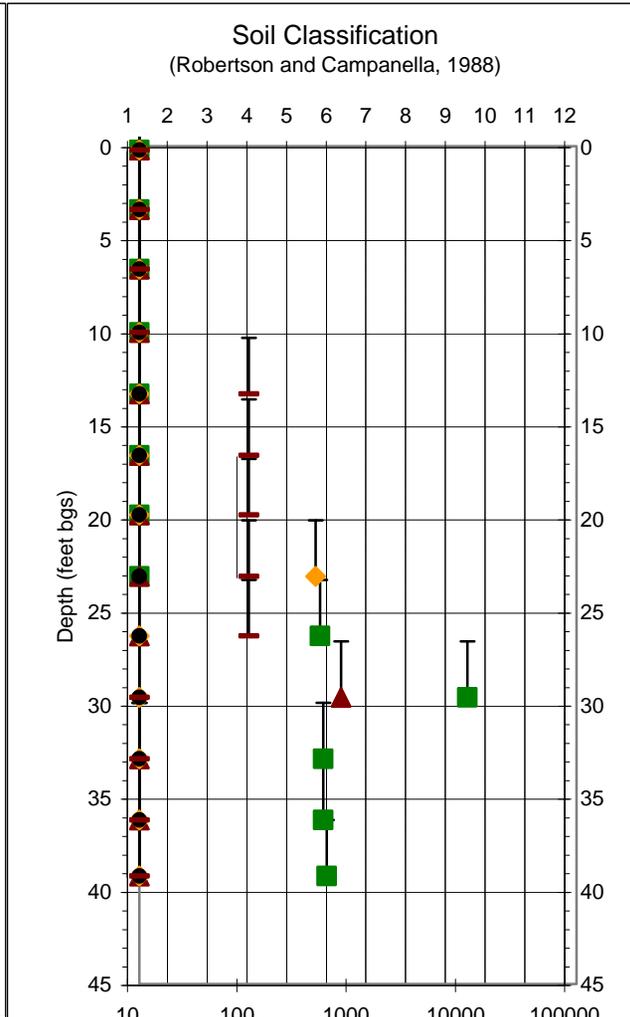
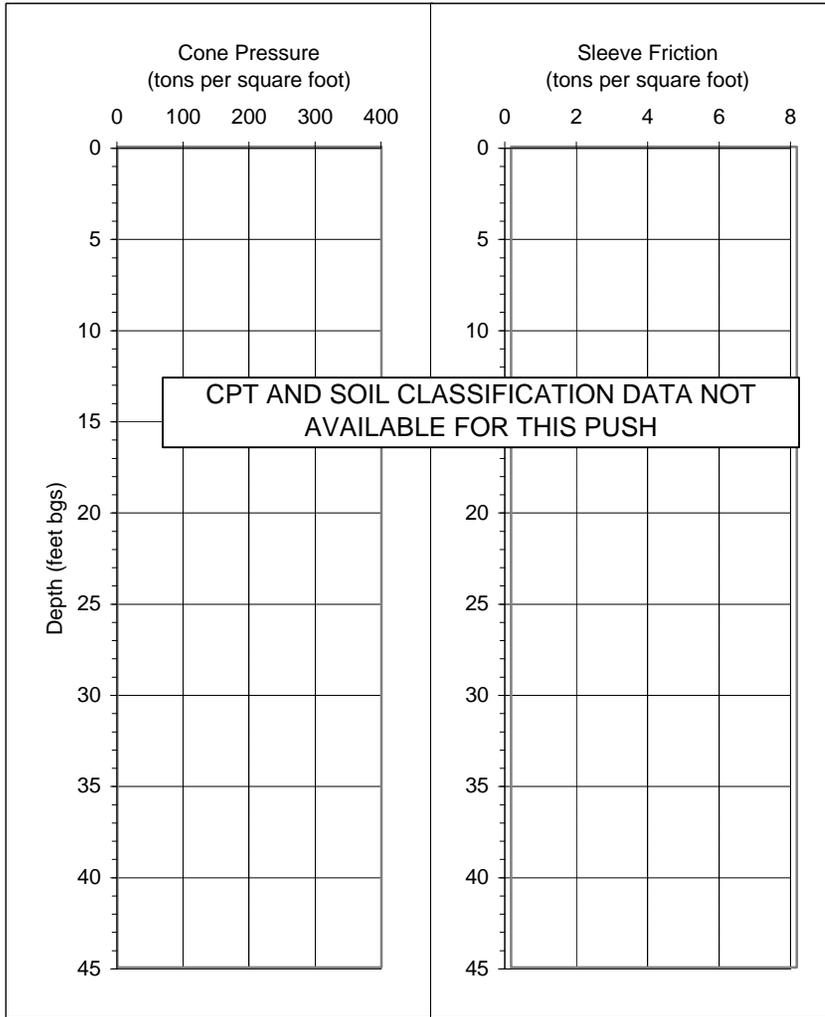
nd - not detected above 200 ng/ml. Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
0.0 - 37.8	540	ND	ND	ND	ND
28.9	ND	ND	ND	ND	ND
29.4	ND	ND	ND	ND	ND
29.9	ND	ND	ND	ND	ND
30.4	ND	ND	ND	ND	ND
30.9	ND	ND	ND	ND	ND



NOTES: Contaminants were analyzed using continuous data screening during penetration and discrete measurements recorded during retraction.



PUSH ID:
BEALE SWMU 23 MIP 09
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595482
 Easting: 6309548

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113.
 Concentration is estimated.

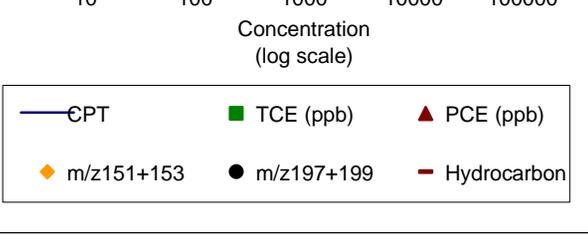
m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

Hydrocarbons are detect/nondetect only; they are not quantitated.

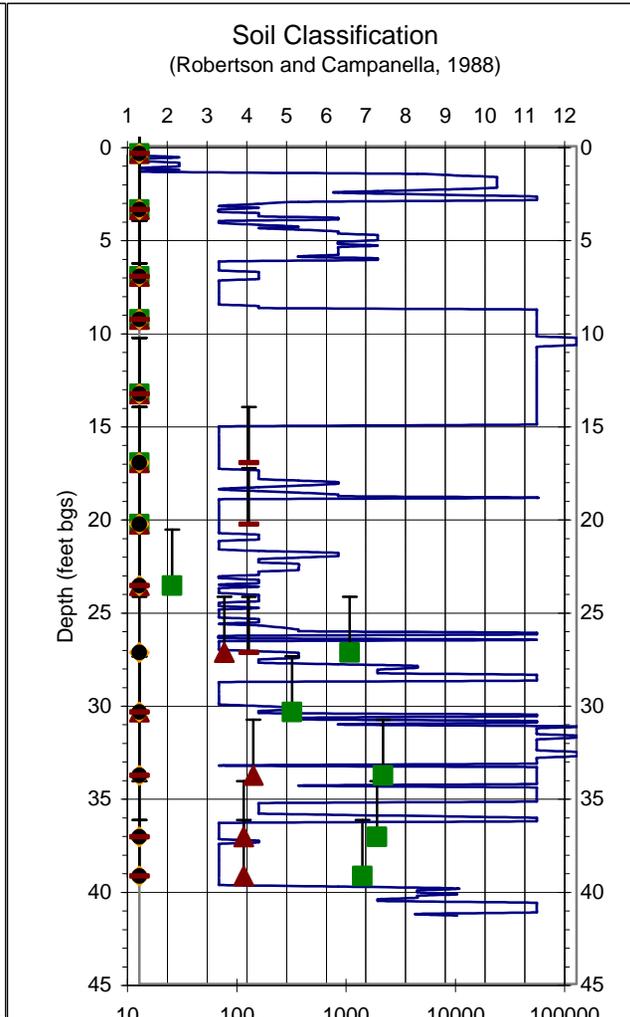
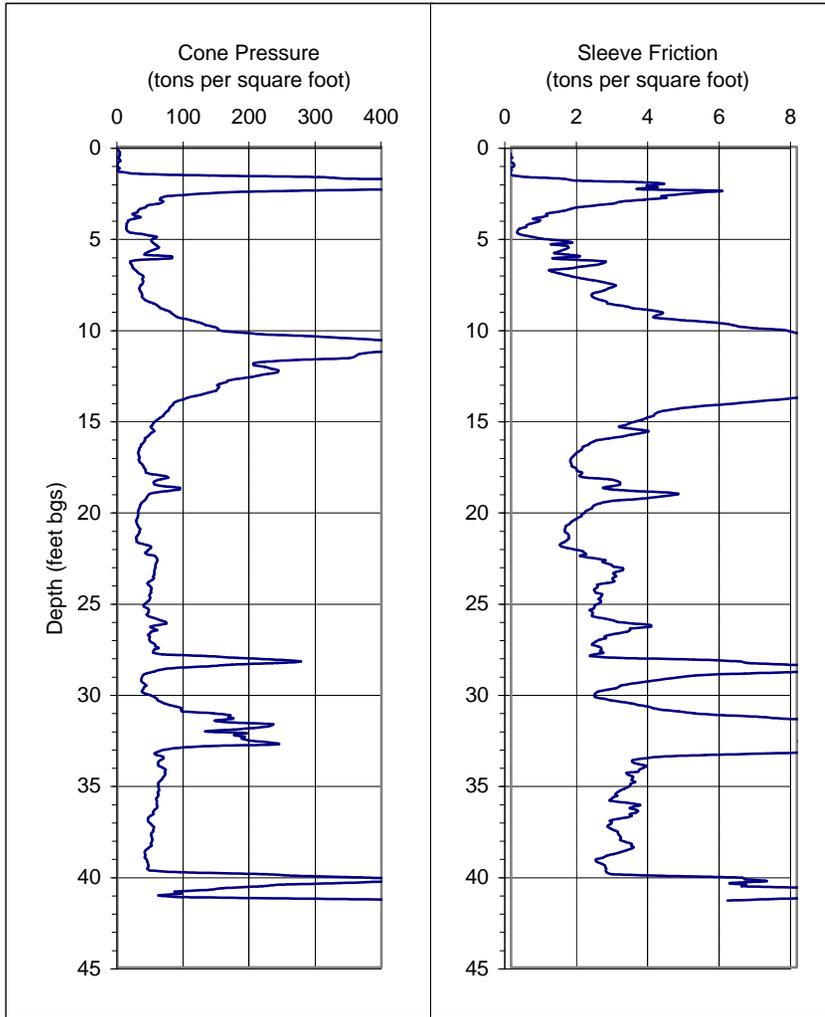
nd - not detected above 200 ng/ml.
 Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
19.8 – 23.1	ND	ND	410	ND	yes
23.1 – 26.3	450	ND	ND	ND	yes
26.3 – 29.6	10,000	700	ND	ND	ND
29.6 – 32.9	480	ND	ND	ND	ND
32.9 – 36.2	480	ND	ND	ND	ND
36.2 – 39.2	520	ND	ND	ND	ND



NOTES: Contaminants were analyzed using a "hybrid" method consisting of continuous data collected during a single rod penetration with a discrete measurement collected at the terminal depth of each rod.



PUSH ID:
BEALE SWMU 23 MIP 10
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595476
 Easting: 6309532

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113.
 Concentration is estimated.

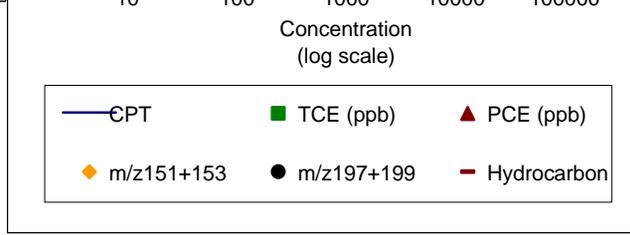
m/z197+199 is an unidentified
 compound with a tentative estimated
 relative concentration.

Hydrocarbons are detect/nondetect
 only; they are not quantitated.

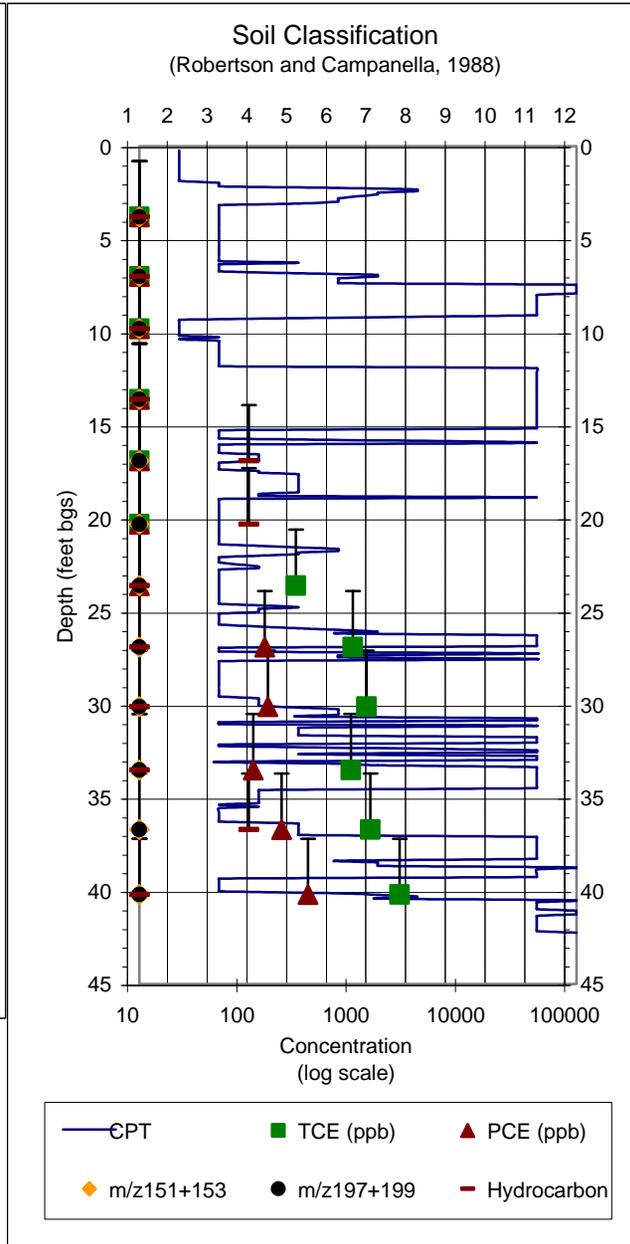
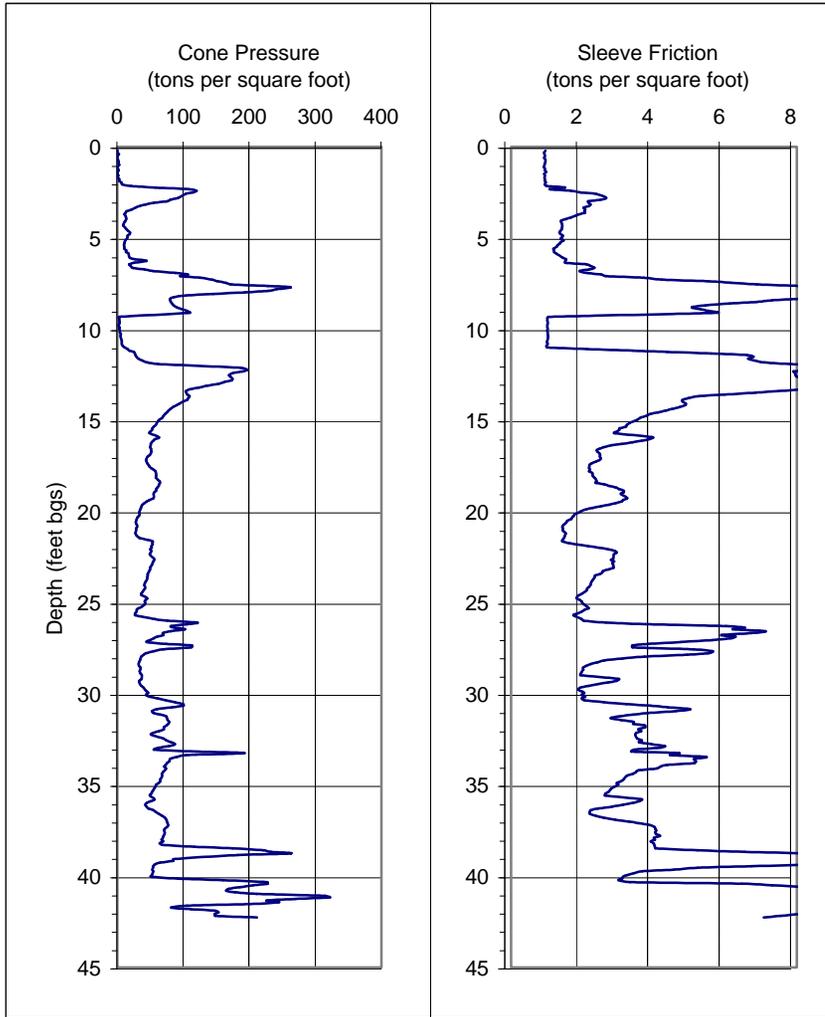
nd - not detected above 200 ng/ml.
 Concentrations reported <200 ng/ml
 are flagged "J" and estimated, but
 the compounds were identified
 present by mass spectrum.

DCE, Vinyl Chloride, CHC13,
 Benzene, and Toluene were not
 detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
20.3 – 23.6	20 J	ND	ND	ND	ND
23.6 – 27.2	840	60 J	ND	ND	yes
27.2 – 30.4	250	ND	ND	ND	ND
30.4 – 33.8	1,700	110 J	ND	ND	ND
33.8 – 37.1	1,500	90 J	ND	ND	ND
37.1 – 39.2	1,100	90 J	ND	ND	ND



NOTES: Contaminants were analyzed using a "hybrid" method consisting of continuous data collected during a single rod penetration with a discrete measurement collected at the terminal depth of each rod.



PUSH ID:
BEALE SWMU 23 MIP 11
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595468
 Easting: 6309546

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113.
 Concentration is estimated.

m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

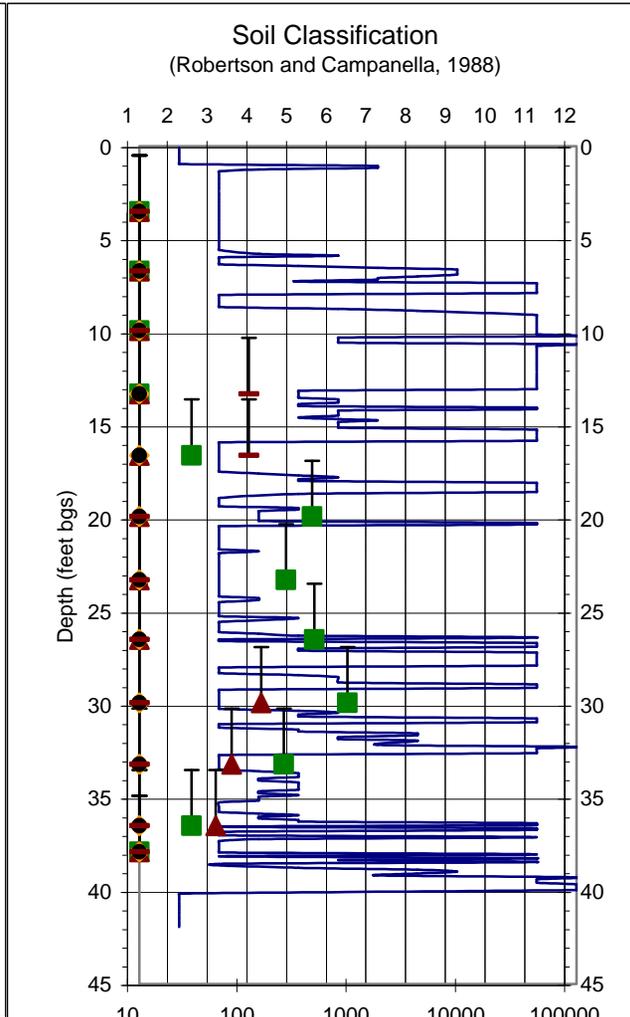
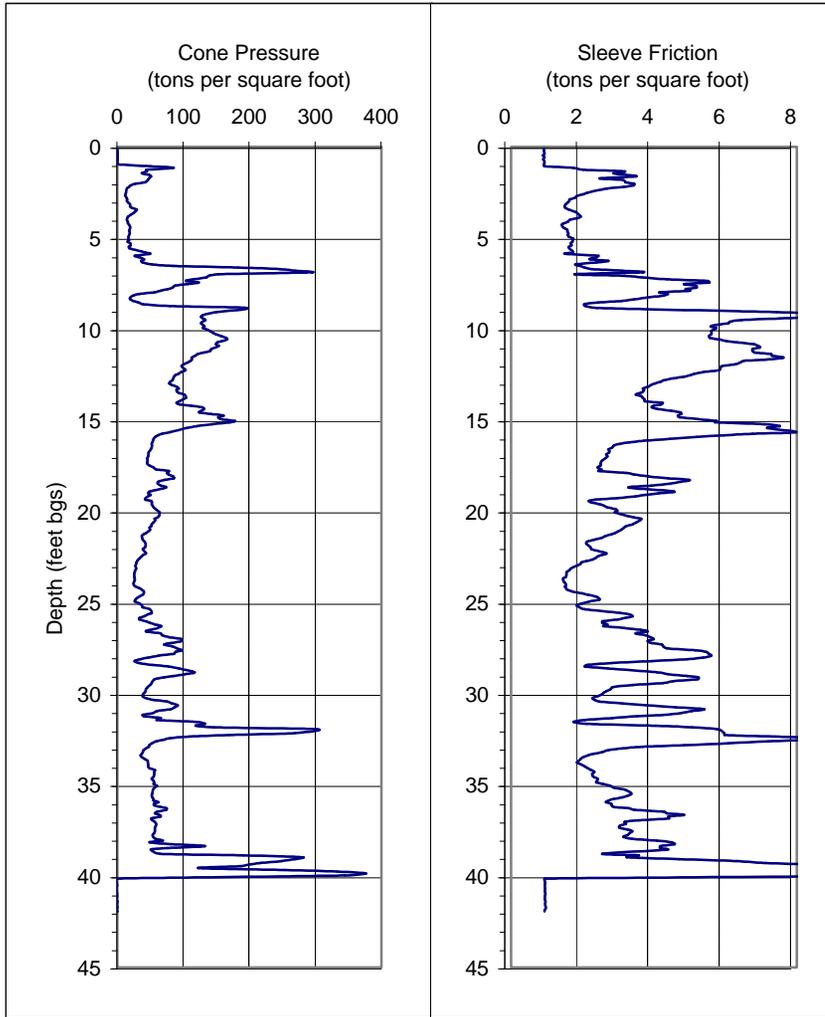
Hydrocarbons are detect/nondetect only; they are not quantitated.

nd - not detected above 200 ng/ml.
 Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
20.3 – 23.6	270	ND	ND	ND	ND
23.6 – 26.9	900	140 J	ND	ND	ND
26.9 – 30.1	1,200	150 J	ND	ND	ND
30.1 – 33.5	860	110 J	ND	ND	ND
33.5 – 36.7	1,300	200	ND	ND	yes
36.7 – 40.2	2,400	350	ND	ND	ND

NOTES: Contaminants were analyzed using a "hybrid" method consisting of continuous data collected during a single rod penetration with a discrete measurement collected at the terminal depth of each rod.



PUSH ID:
BEALE SWMU 23 MIP 12
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595529
 Easting: 6309665

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113.
 Concentration is estimated.

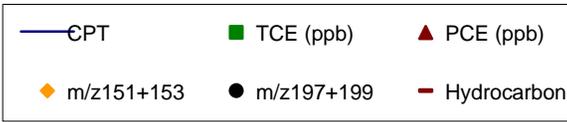
m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

Hydrocarbons are detect/nondetect only; they are not quantitated.

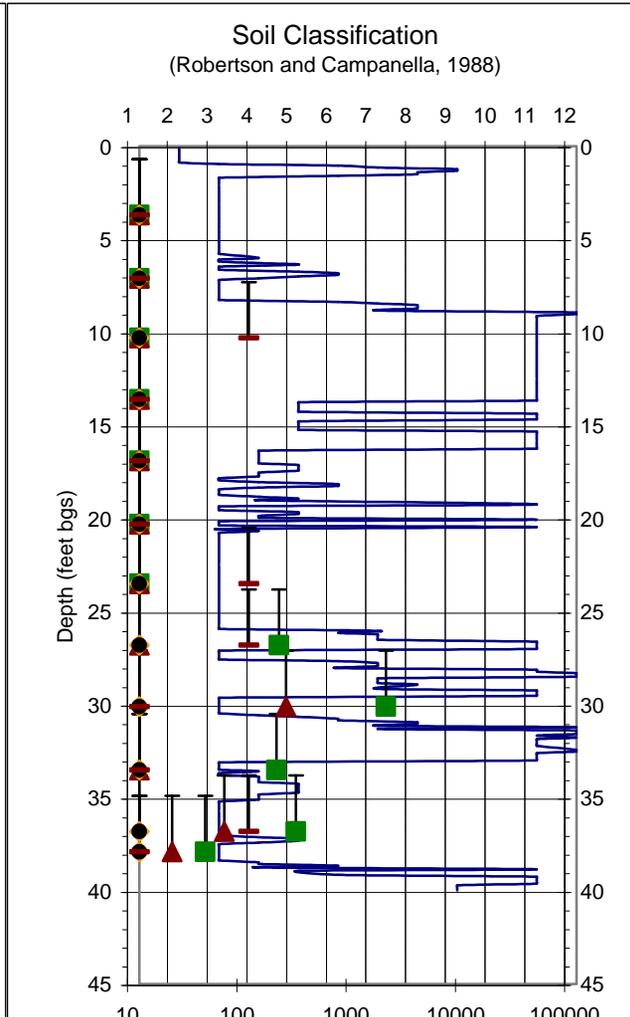
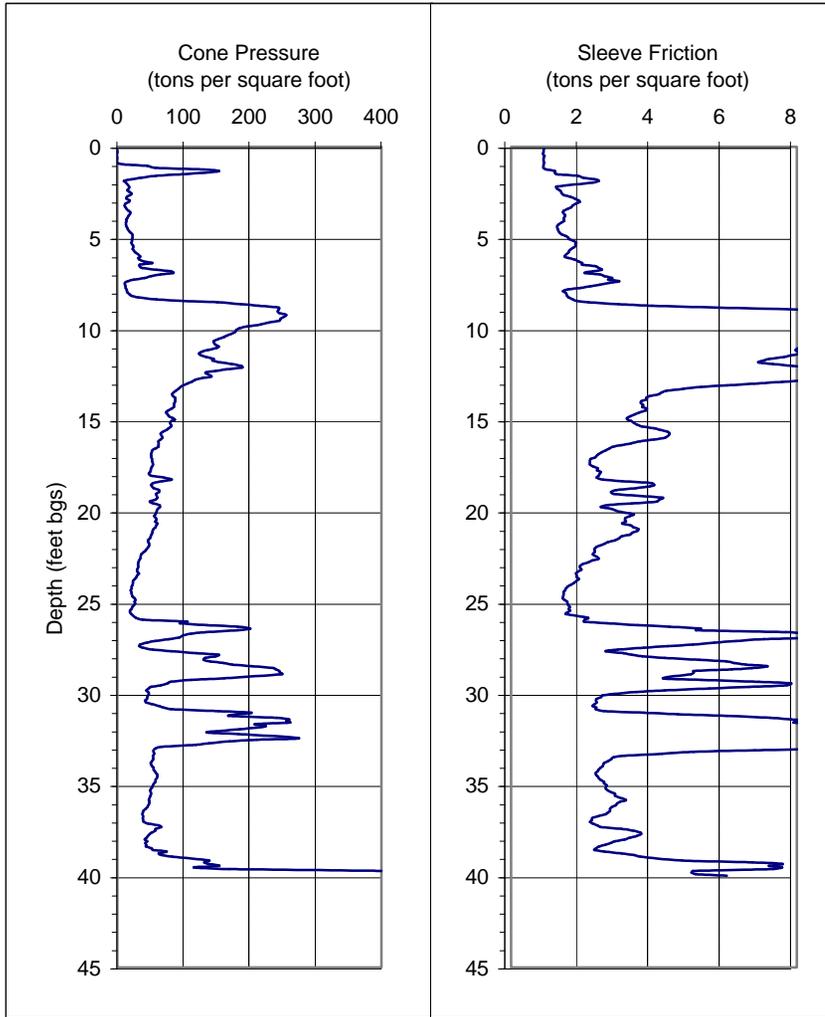
nd - not detected above 200 ng/ml.
 Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
16.6 – 19.9	380	ND	ND	ND	ND
19.9 – 23.3	220	ND	ND	ND	ND
23.3 – 26.5	400	ND	ND	ND	ND
26.5 – 29.9	800	130 J	ND	ND	ND
29.9 – 33.2	210	70 J	ND	ND	ND
33.2 – 36.5	30 J	50 J	ND	ND	ND



NOTES: Contaminants were analyzed using a "hybrid" method consisting of continuous data collected during a single rod penetration with a discrete measurement collected at the terminal depth of each rod.



PUSH ID:
BEALE SWMU 23 MIP 13
 State Plane NAD 83
 Zone 3 Coordinates
 Northing: 2595520
 Easting: 6309638

TCE - trichloroethylene
 PCE - tetrachloroethylene

m/z 151+153 is likely Freon 113.
 Concentration is estimated.

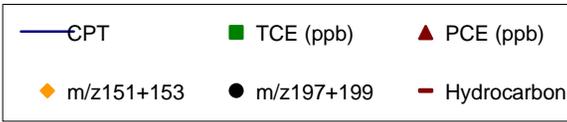
m/z197+199 is an unidentified compound with a tentative estimated relative concentration.

Hydrocarbons are detect/nondetect only; they are not quantitated.

nd - not detected above 200 ng/ml.
 Concentrations reported <200 ng/ml are flagged "J" and estimated, but the compounds were identified present by mass spectrum.

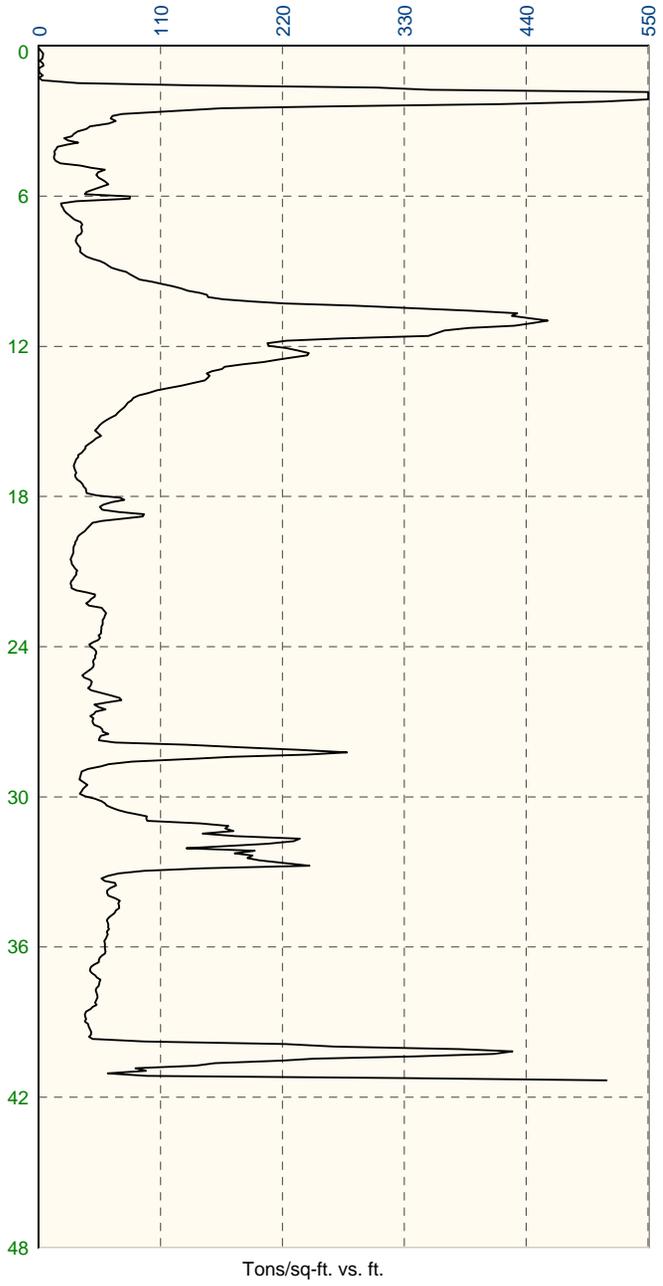
DCE, Vinyl Chloride, CHC13, Benzene, and Toluene were not detected.

Depth	TCE (ppb)	PCE (ppb)	m/z151+153	m/z197+199	Hydrocarbon
20.3 – 23.5	ND	ND	ND	ND	yes
23.5 – 26.8	190 J	ND	ND	ND	yes
26.8 – 30.1	1,800	220	ND	ND	ND
30.1 – 33.5	180 J	ND	ND	ND	ND
33.5 – 36.8	270	60 J	ND	ND	yes
36.8 – 37.9	40 J	20 J	ND	ND	ND

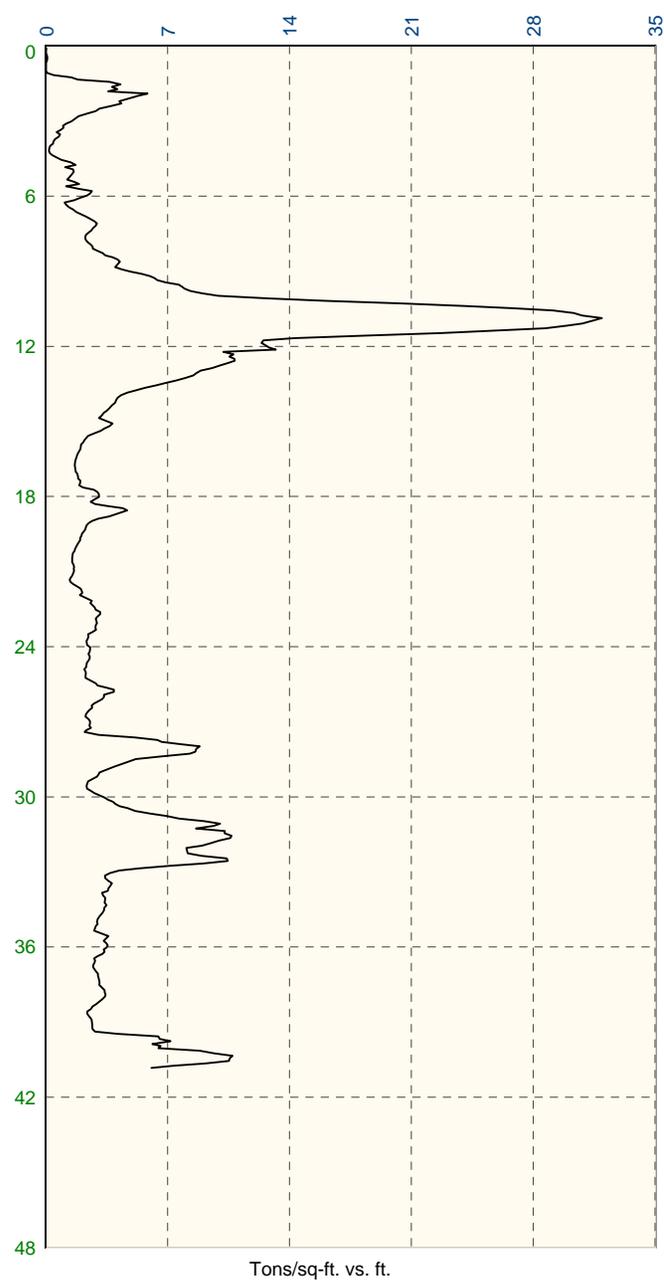


NOTES: Contaminants were analyzed using a "hybrid" method consisting of continuous data collected during a single rod penetration with a discrete measurement collected at the terminal depth of each rod.

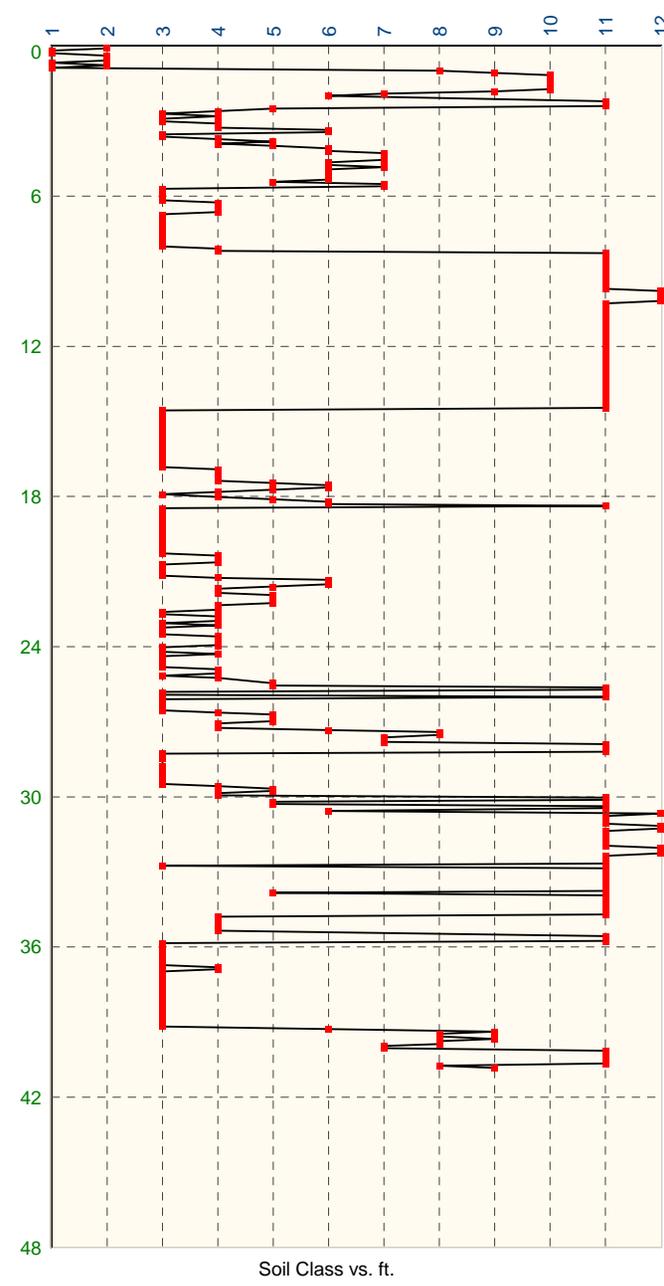
beale swmu 23 mip 10
Qc



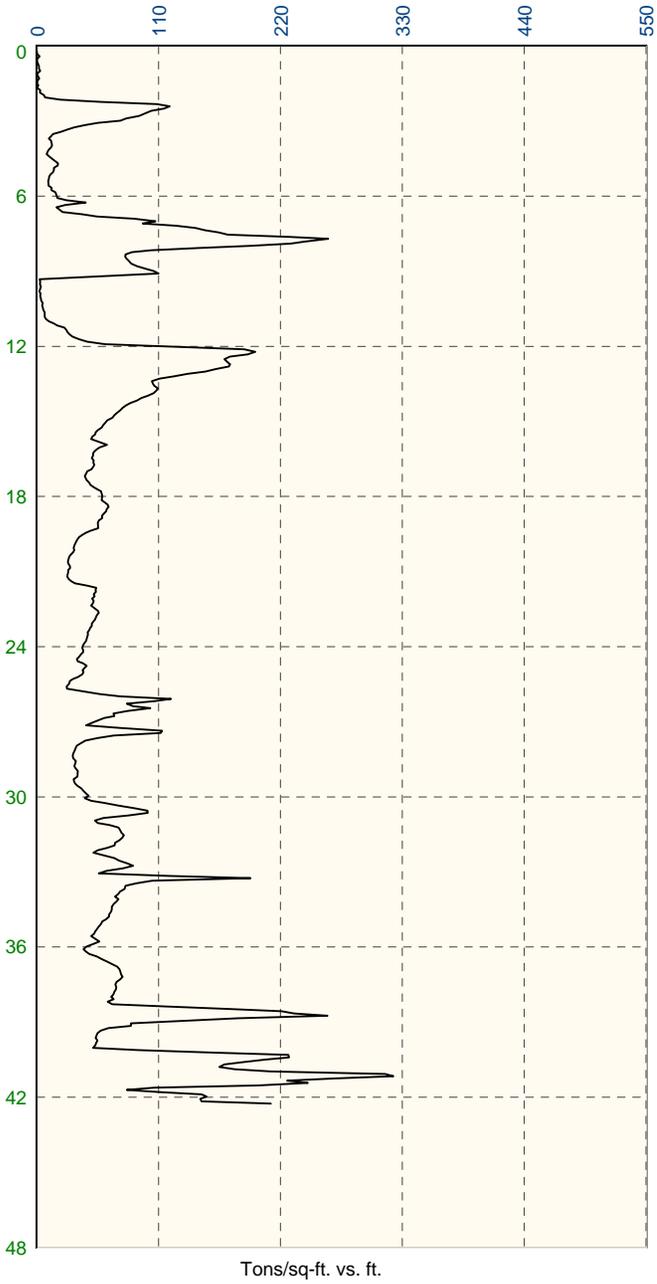
beale swmu 23 mip 10
Qs



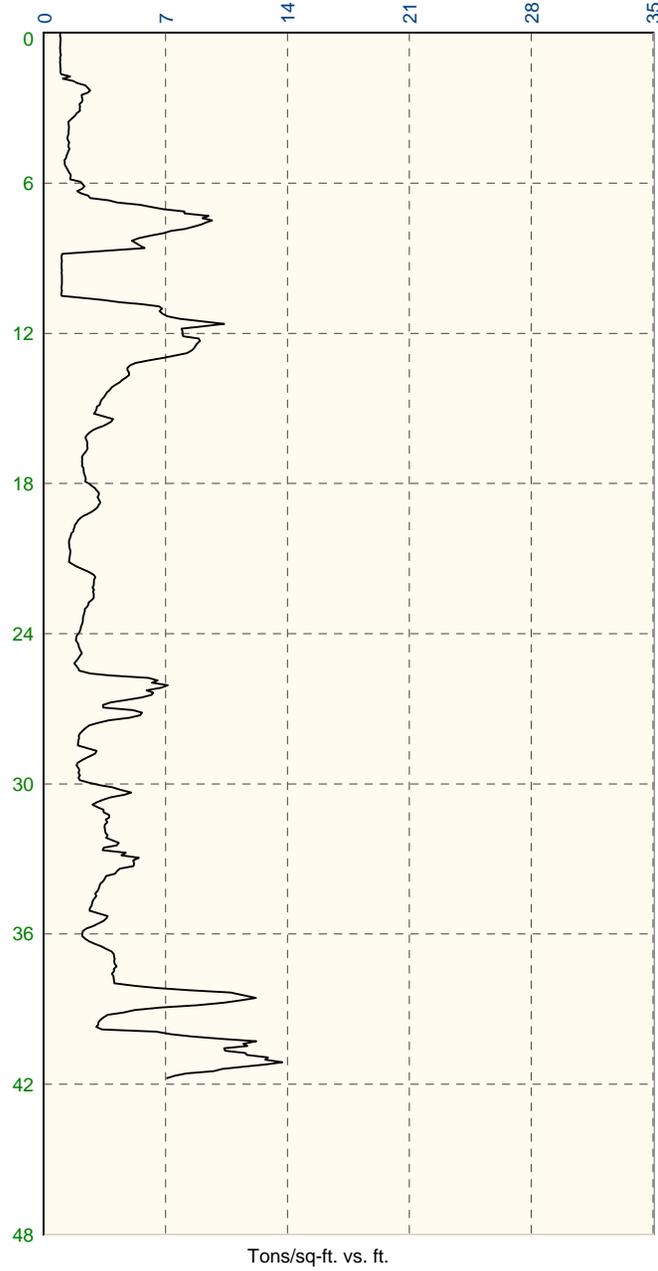
beale swmu 23 mip 10
Soil Class



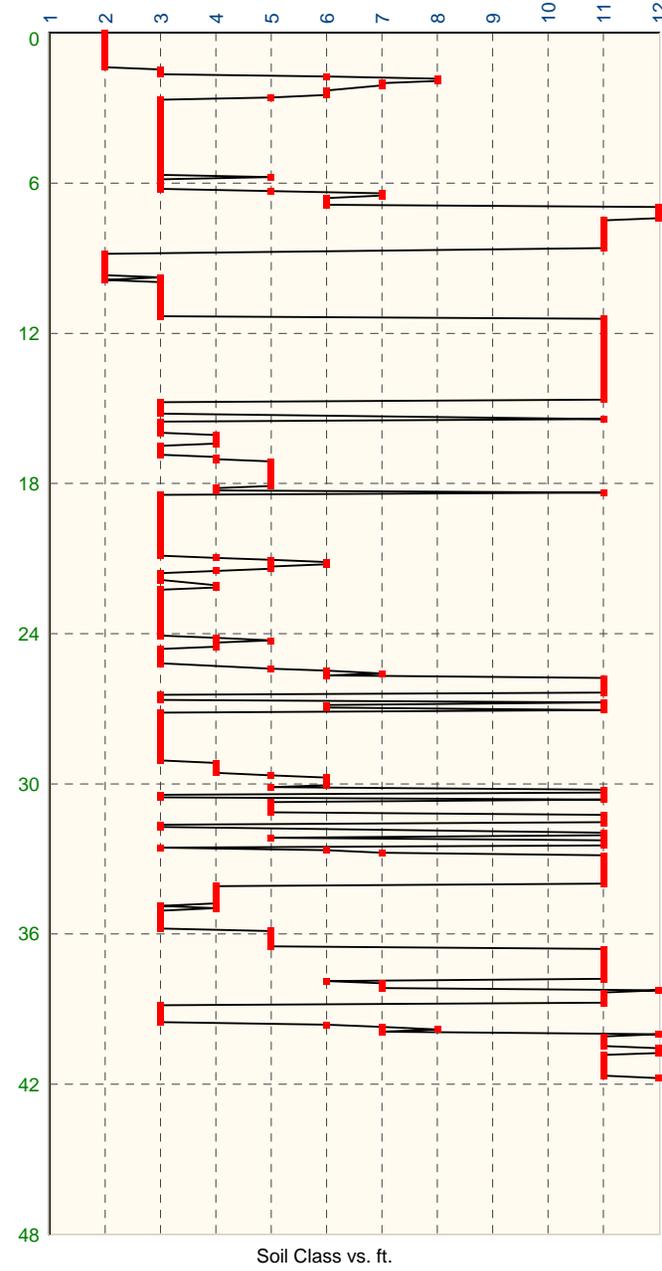
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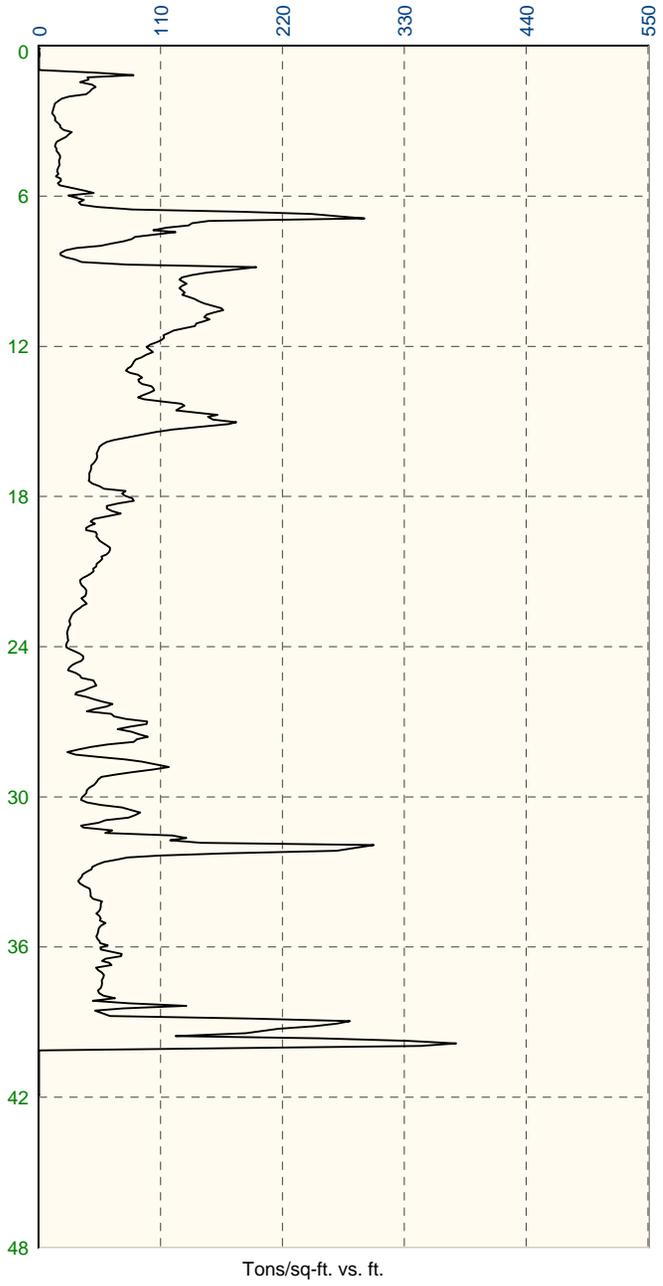
beale swmu 23 mip 11
Qs



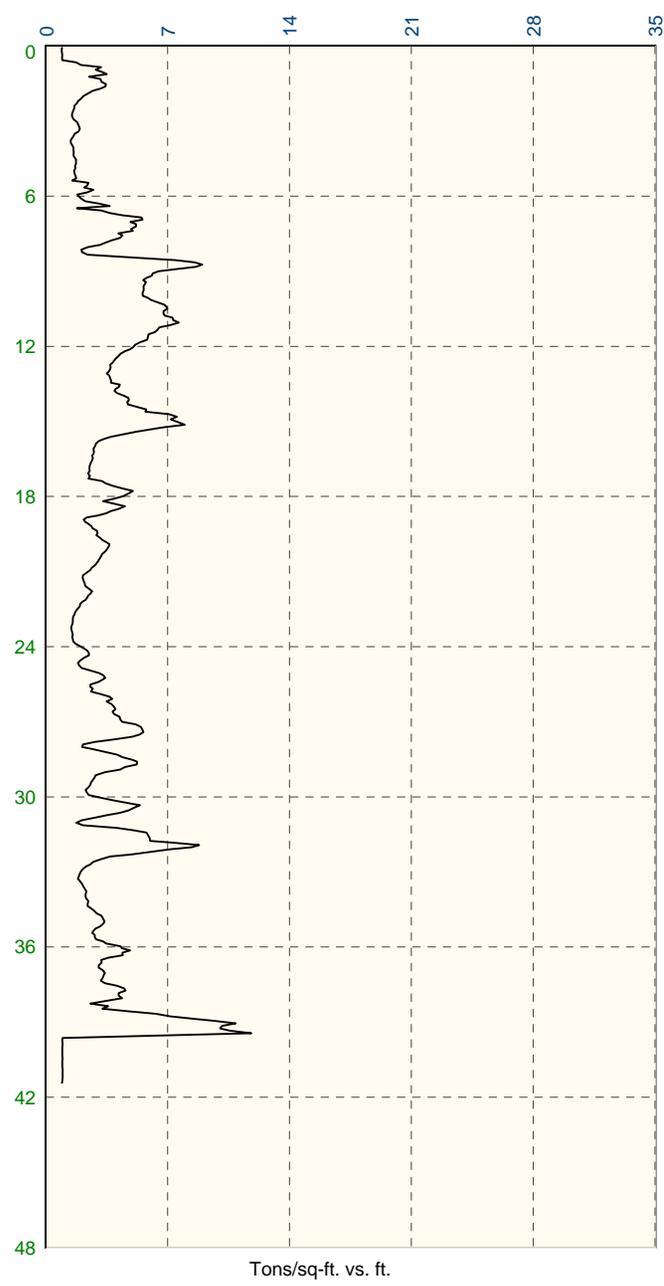
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Soil Class



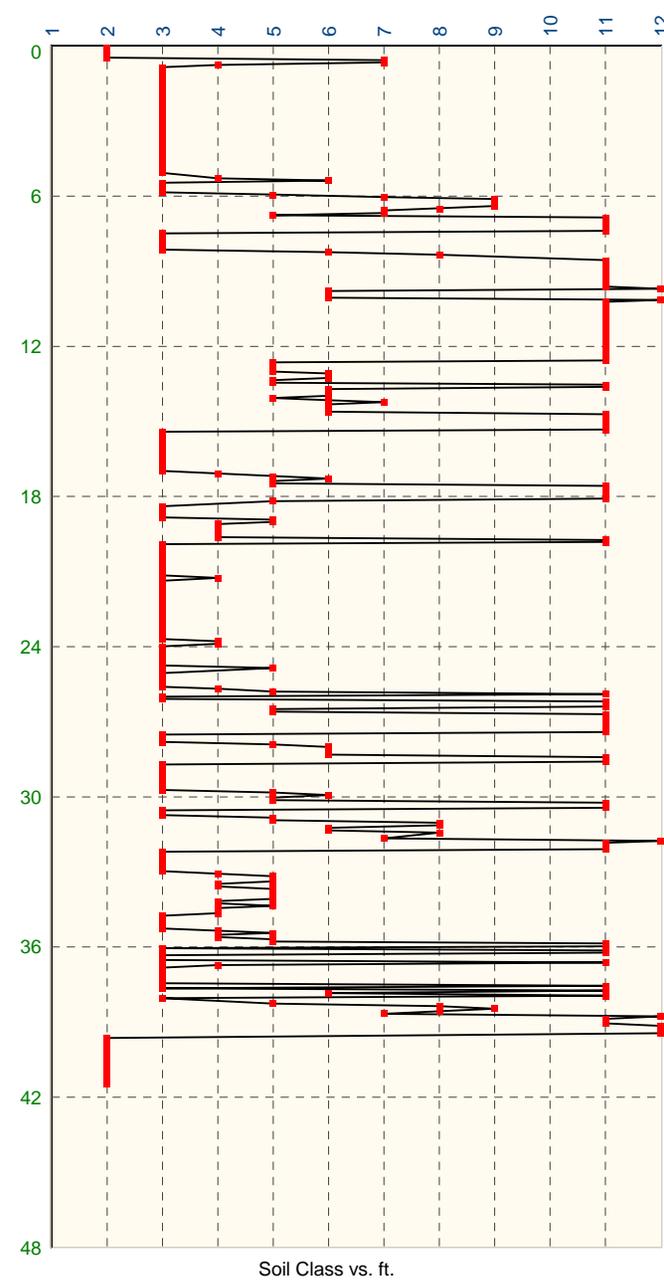
beale swmu 23 mip 12
Qc



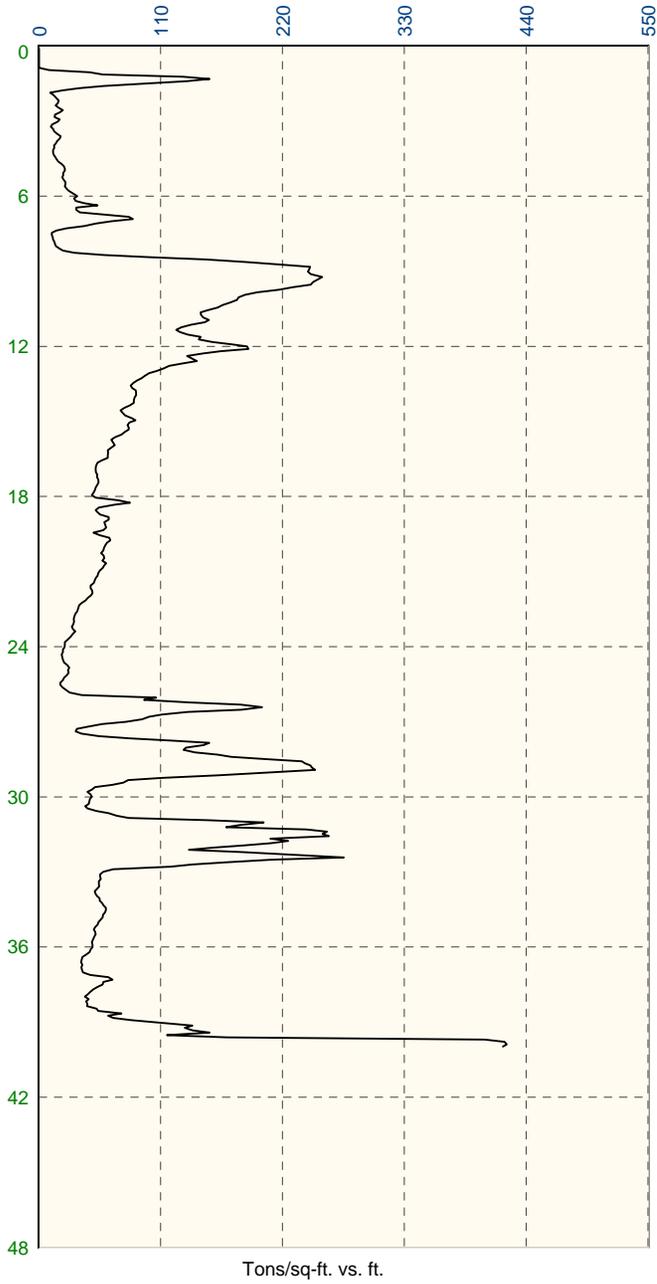
beale swmu 23 mip 12
Qs



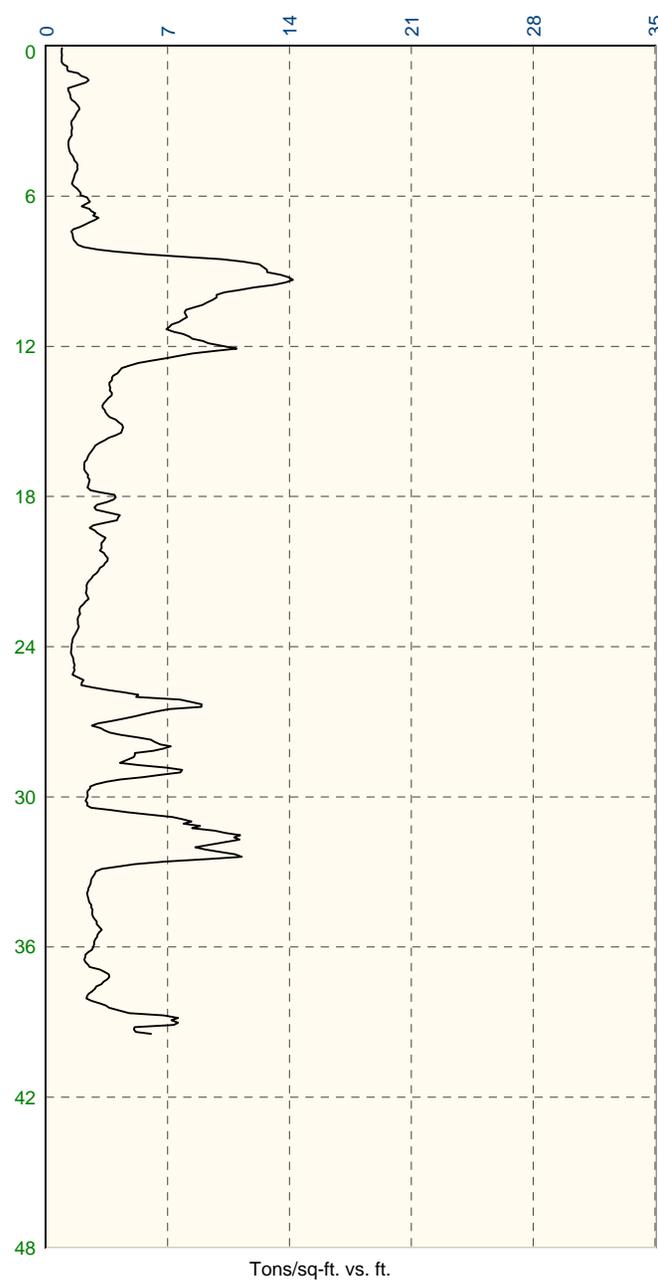
beale swmu 23 mip 12
Soil Class



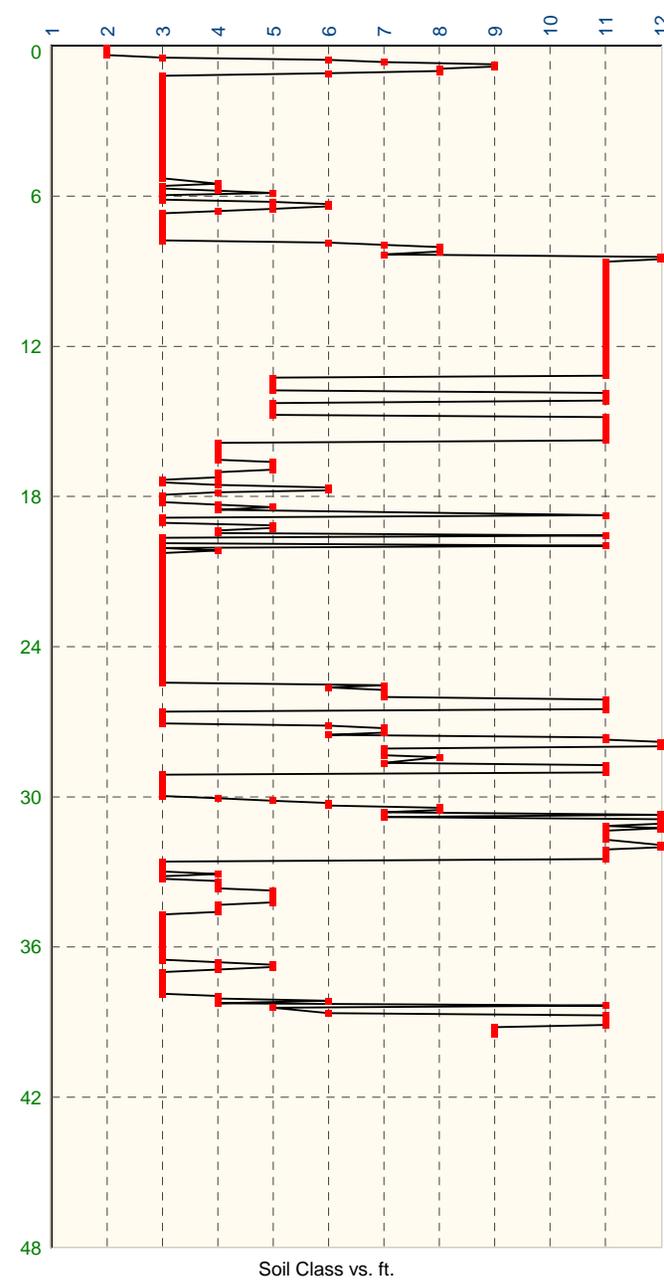
beale swmu 23 mip 13
Qc



beale swmu 23 mip 13
Qs



beale swmu 23 mip 13
Soil Class



Sample MIP 11 VAL 01

Push Location: Beale SWMU 23 MIP 11
Depth: 17 – 18 feet below ground surface

Mottled, mostly strong brown (7.5YR 5/6) with some pale yellow (5Y 7/3) very fine to medium sandy CLAY (CL) with some black organic (?) inclusions, damp to slightly moist, stiff.



Sample MIP 11 VAL 02

Push Location: Beale SWMU 23 MIP 11

Depth: 26.5 – 27.5 feet below ground surface

Mottled, mostly strong brown (7.5YR 4/6) with some pale yellow (5Y 7/3) very fine to medium sandy CLAY (CL) with some black organic (?) inclusions and a few subangular to subrounded pebbles up to approximately ½ inch, moist to wet, stiff.



Sample MIP 11 VAL 03

Push Location: Beale SWMU 23 MIP 11

Depth: 39 – 40.75 feet below ground surface

Light yellowish brown (2.5Y 6/3) slightly silty CLAY (CL) with subrounded to rounded pebbles up to approximately 1 inch, and some black organic (?) inclusions, wet to saturated, stiff to very stiff.



Appendix C
Health and Safety Plan

**Final
Health and Safety Plan
for the Steam Injection Demonstration
at Beale Air Force Base**

Prepared for:

**Naval Facilities Engineering Service Center
Port Hueneme, CA**

Technology provided by:

Lawrence Livermore National Laboratory, CA

Site provided by:

Beale Air Force Base, CA

Prepared by:

**Battelle
Columbus, OH**

and

**SteamTech Environmental Services
Bakersfield, CA**

March 22, 2002

Project funded by:



**Environmental Security Technology Certification Program (ESTCP)
Washington, DC**

The vendors and products, including the equipment, system components, and other materials identified in this report, are primarily for information purposes only. Although Battelle may have used some of these vendors and products in the past, mention in this report does not constitute Battelle's recommendation for using these vendors or products.

Contents

Figures.....	C-v
Tables.....	C-v
Acronyms and Abbreviations	C-vi
1. Introduction.....	C-1
1.1 Integrated Safety Management	C-1
1.2 Zero Accident Performance	C-2
2. Health and Safety Organization.....	C-4
2.1 Health and Safety Manager.....	C-4
2.2 Project Manager.....	C-5
2.3 SES Site Environmental, Safety, and Health Representative	C-5
2.4 Site Personnel.....	C-5
3. Hazard Assessment.....	C-6
3.1 Task-Specific Hazard Analysis.....	C-9
3.2 Chemical Exposure	C-10
3.3 Physical Hazards.....	C-10
3.4 Hazards Associated with Pure Oxygen Use.....	C-10
4. Hazard Communication, Training, and Medical Surveillance Requirements	C-12
4.1 Hazard Communication	C-12
4.2 Training.....	C-12
4.3 Medical Surveillance	C-14
4.4 Records	C-14
5. Site Control and Personal Protective Equipment.....	C-16
5.1 Site Control.....	C-16
5.1.1 Exclusion Zone.....	C-16
5.1.2 Contamination Reduction Zone.....	C-17
5.1.3 Support Zone.....	C-17
5.2 Personal Protective Equipment.....	C-17
5.2.1 Types of Equipment	C-18
5.2.2 Cleaning, Storage, and Program Verification	C-18
6. Monitoring.....	C-19
7. Safe Work Practices.....	C-20
7.1 General Safety Requirements	C-20
7.2 Ergonomics–Lifting and Carrying Heavy Objects	C-20

Contents (Continued)

7.3	Walking/Working Surfaces–Trip and Fall Hazards.....	C-21
7.4	Underground Hazards	C-21
7.5	Drum/Container Handling	C-21
7.6	Electrical Safety	C-21
7.7	Lockout/Tagout.....	C-22
7.8	Illumination.....	C-22
7.9	Sanitation	C-22
7.10	Cold Stress	C-22
7.11	Heat Stress	C-23
7.12	Soil Sampling Equipment	C-23
7.13	Noise	C-23
7.14	Forklift Operations.....	C-24
7.15	Biological Hazards.....	C-24
7.16	Equipment Handling and Mobilization.....	C-24
7.17	Nuisance Dust.....	C-25
7.18	Pressure Systems.....	C-25
8.	Decontamination Procedures	C-26
8.1	Chemical Contamination Avoidance	C-26
8.2	Equipment Decontamination	C-26
8.3	Personnel Decontamination	C-26
8.3.1	Level D Protection Decontamination	C-27
8.3.2	Level D+ Protection Decontamination.....	C-27
8.3.3	Level C Protection Decontamination	C-27
8.4	Emergency Decontamination.....	C-28
8.5	Disposal Procedures.....	C-28
9.	Emergency Plan	C-29
9.1	Emergency Contacts	C-29
9.2	Evacuation.....	C-29
9.3	Potential or Actual Fire.....	C-30
9.4	Personnel Injury	C-30
9.5	Overt Personnel Chemical Exposure or Decontamination and First Aid	C-30
9.6	Alarm Signals.....	C-32
9.7	Adverse Weather Conditions	C-32
9.8	Accident/Incident Reporting.....	C-32
9.9	Spill Release Control Measures and Reporting	C-33
9.9.1	Communication System for Reporting Spills.....	C-33
9.9.2	Immediate Local Action Required	C-33
9.9.3	Site Emergency Direction	C-33

**Contents
(Continued)**

9.9.4 Spill Control Measures	C-34
9.9.5 Spill Response Training	C-36
9.9.6 Site Contingency Plan Overview	C-37
10. Environmental Compliance Plan	C-40

Figure

Figure C-1. Directions to Local Hospital for Emergency	C-31
--------------------------------------------------------------	------

Tables

Table C-1. Hazards Inventory and Hazards Analysis and Control	C-6
Table C-2. Chemical Exposure	C-10
Table C-3. Training Requirements	C-12
Table C-4. Monitoring Requirements and Action Limits	C-19
Table C-5. Alarm Signals and Responses at Beale AFB	C-32

Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
AFB	Air Force Base
CCR	California Code of Regulations
CFR	Code of Federal Regulations
CNS	central nervous system
COC	contaminant of concern
CPR	cardiopulmonary resuscitation
DCE	dichloroethylene
DOT	U.S. Department of Transportation
EM	Environmental Management
EC&HS	Environmental Compliance and Health and Safety
EFC	Environmental Flight Center
EHS	Environmental Health and Safety Handbook
ES&H	Environmental Safety and Health
FCO	Field Change Order
GET	General Employee Training
HASP	(Site Environmental) Health and Safety Plan
HAZWOPER	hazardous waste operations and emergency response
HPO	hydrous pyrolysis/oxidation
HSA	hollow-stem auger
HSM	Health and Safety Manager
IC	Incident Commander
ISMS	Integrated Safety Management System
LED	Local Emergency Director
MSDS	Material Safety Data Sheet
OJT	on-the-job training
OSHA	Occupational Safety and Health Administration
PCE	tetrachloroethylene
PEL	permissible exposure limit
PID	photoionization detector
PPE	personal protective equipment

ppm	parts per million
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
SAA	Satellite Accumulation Area
SES	SteamTech Environmental Services
SOP	Standard Operating Procedure
STEL	short-term exposure limit
STR	Site Technical Representative
TCE	trichloroethylene
TLV	threshold limit value
U.S. EPA	United States Environmental Protection Agency

1. Introduction

SteamTech Environmental Services (SES) formal policy is to take every reasonable precaution to protect the health and safety of employees, the public, and the environment. To this end, this Site Environmental Health and Safety Plan (HASP) sets forth the basic procedures required to protect field personnel involved in field activities during the hydrous pyrolysis/oxidation (HPO) demonstration at Beale Air Force Base (AFB).

This plan has been prepared in accordance with the SES Environmental Health and Safety Handbook (EHSB), the requirements of Occupational Safety and Health Administration (OSHA) 29 CFR 1910.120, and 29 CFR 1926.65. It contains information about the site, potential contaminants and hazards that may be encountered, and hazards inherent to routine site characterization procedures. This HASP describes:

- General descriptions of the site and work tasks;
- Primary and contingency personal protection;
- Monitoring equipment and action levels;
- Personnel and equipment decontamination; and
- Emergency contacts.

This HASP is designed to accommodate all anticipated contingencies and should not need revision. If unexpected conditions are encountered, this HASP will be modified to address such conditions to ensure the health and safety of all field personnel, subcontractors, and other persons conducting field activities. This modification will be documented on a Field Change Order (FCO) approved by the Health and Safety Manager (HSM).

1.1 Integrated Safety Management

SES is committed to the implementation of an Integrated Safety Management System (ISMS) that promotes the company's core values and principles. The objective of the ISMS is to systematically integrate safety and environmental protection in management and work practices at all levels so that workers, the public, and the environment are protected while assigned missions are accomplished.

ISMS elements that SES includes in the corporate EHSB are:

- Line management responsibility for environmental safety and health (ES&H)
- Clear assignment of roles and responsibilities
- Competence commensurate with responsibilities
- Balanced priorities
- Clear identification of appropriate ES&H standards and requirements
- Hazard controls tailored to the work being performed
- Assurance that all work has been reviewed and is authorized.

SES will demonstrate that the following functions are completed for all work performed under this contract:

- The scope of all work will be clearly understood before it is begun;
- The hazards associated with that work will be analyzed and clearly understood;
- Appropriate standards and requirements will be applied to control the hazards associated with the work to be performed;
- The work will be performed in accordance with the standards and requirements identified, and
- A process for worker feed back and continuous improvement will be in place and utilized.

SES has empowered its employees to adhere to all ES&H requirements. SES employees have the right and obligation to report unsafe conditions and to interrupt or stop work without fear of reprisal.

1.2 Zero Accident Performance

SES has adopted a “Zero Accident” policy, and is committed to zero accidents as a goal. Toward that end, SES will incorporate the guiding principles and core functions of the ISMS and will include the following:

- The safety and health of employees, site visitors, and the public, and the protection of the environment are the first priority.
- All accidents are preventable.
- Line management is directly responsible for the protection of the public, the workers, and the environment.
- No unsafe act is tolerated or accepted.
- Clear and unambiguous lines of authority and responsibility for ensuring safety are established at all organizational levels.
- ES&H controls tailored for the work being performed, while maintaining strict compliance with requirements established in the subcontract.
- Managers and supervisors are proactive in field implementation of ES&H policies and programs.

- The work to be performed is clearly defined and understood by all personnel involved.
- ES&H considerations are planned into all activities before work begins.
- Employees are trained and qualified commensurate with their responsibilities.
- Accidents and incidents are immediately reported, investigated, and followed by timely corrective actions.

The purpose for the HASP is to identify potential health and safety concerns that may be encountered by the hazard controls required for each site task.

2. Health and Safety Organization

2.1 Health and Safety Manager

The HSM will be responsible for directing and coordinating all health and safety monitoring activities and ensuring that proper personal protective equipment (PPE) is used by all field team members. The HSM will be hazardous waste operations and emergency response (HAZWOPER) trained per the scope of work. The HSM and/or the Project Manager will conduct safety briefings, as appropriate, and ensure that the field team members comply with the requirements of the HASP. The HSM has the authority to stop work if he or she should determine that an imminent safety hazard, emergency situation, or other potentially dangerous situation is present at the site, and will report directly to the Project Manager. The HSM is responsible for imparting ES&H requirements to SES employees and lower tier subcontractors. Other responsibilities of the health and safety manager include the following:

- Maintenance of OSHA 200 Log.
- Interface with the Site Technical Representative (STR), and other ES&H personnel.
- Conduct regular safety briefings and regular safety meetings for all SES and SES subcontractor employees.
- Provide site-specific training for new employees and visitors.
- Establish and implement routine ES&H procedures.
- Establish and maintain emergency warning systems for the site (including evacuation alarms, accountability rosters, and assembly points).
- Participate in all applicable on-site job-planning meetings.
- Maintain and post emergency response phone numbers for the site near all phones.
- Ensure that the site map includes safety information such as locations of fire extinguishers and eye wash stations, and ensure that first-aid kits are kept current.
- Ensure that proper chemical and safety postings are in place and legible.
- Post and keep current all employee right-to-know information.
- Establish and maintain the hazard communications program (including Material Safety Data Sheets [MSDSs] and training).
- Evaluate the site for any hazards not identified in the activity hazard assessment, initiate safety measures required to protect personnel, and revise documentation accordingly.

- Establish and maintain programs required to mitigate hazards identified in the activity hazard analysis (including confined space entry, respiratory protection, blood borne pathogens, and hearing conservation).
- Monitor implementation of the HASP, including incorporation of safety and health requirements into site activities.
- Maintain first aid logs, and relay accidents and injuries through the appropriate channels.
- Coordinate with the off-site emergency responders to ensure off-site emergency preparedness and verify that phone number, addresses, and contacts are current and accurate.
- Conduct accident/incident investigations as directed, including completion of appropriate forms.

2.2 Project Manager

The Project Manager has overall responsibility for the health and safety of all site personnel, and will ensure that adequate resources are provided to field crews to carry out all health and safety procedures specified in this project-specific HASP. The Project Manager has the ultimate responsibility for implementing this HASP and ensuring compliance by field staff, visitors, subcontractors, and Beale AFB representatives.

2.3 SES Site Environmental, Safety, and Health Representative

The boiler operator/sampling technician will be the sole SES representative on site throughout much of the demonstration. That individual shall be responsible for implementation of SES health and safety policies at the site on a day-to-day basis.

2.4 Site Personnel

It is the responsibility of all site personnel, including subcontractors and visitors, to report any unsafe or potentially hazardous conditions to the HSM. They should maintain knowledge of the information, instructions, and emergency response actions contained in this HASP. Additionally, they must comply with the rules, regulations, and procedures as set forth in this HASP and any revisions that are instituted, and prevent admittance of unauthorized personnel to the work site. All site personnel have the authority to stop work when conditions at the site present an unsafe or potentially dangerous situation to personnel, the public, or the environment.

3. Hazard Assessment

The purpose of the hazard assessment is to identify and assess potential hazards that may be encountered by personnel and to prescribe required controls. Table C-1 is a combination of the general checklist of common hazards that may be absent or present during project activities and the list of site-specific hazards analysis and control. Specific site tasks include operating geophysical equipment, well installation, and sampling subsurface soil and groundwater.

Table C-1. Hazards Inventory and Hazards Analysis and Control

Safety and Health Hazards	Controls	Monitoring
<i>General Site Hazards</i>		
Equipment mobilization General safety hazards (machinery, suspended loads, moving equipment, lifting, slips, falls)	<ul style="list-style-type: none"> Level D or D+ PPE (see Section 8) plus hard hat, buddy system. No employees under lifted loads. Only necessary and experienced personnel, two functional kill switches, functional back-up alarm, drill rig operating manual on site, lifts of >75 lb will be performed by two or more personnel or using mechanical assistance, extensive heavy lifting will require additional lifting training. HAZWOPER 40-hour training, standard procedures. 	<ul style="list-style-type: none"> Daily site safety inspections Daily equipment inspections
Weather	<ul style="list-style-type: none"> Administrative controls (see Section 7). 	<ul style="list-style-type: none"> Daily visual inspections, temperature measurements as appropriate
Trips, slips, and falls	<ul style="list-style-type: none"> Hardhat, Level D PPE. HAZWOPER and site-specific training. Standard operating procedures. 	<ul style="list-style-type: none"> Daily safety inspections, visual survey
Noise	<ul style="list-style-type: none"> Hearing protection will be required near equipment during hammer operation if noise level is >85 dBA 	<ul style="list-style-type: none"> Daily safety inspections
Nuisance dust	<ul style="list-style-type: none"> Level D PPE or as required by area, spray container to wet area and keep dust down. 	<ul style="list-style-type: none"> Daily safety inspections, visual survey
Sanitation	<ul style="list-style-type: none"> PPE, solid, and hazardous wastes will be controlled as generated into U.S. Department of Transportation (DOT)-approved and labeled waste containers. 	<ul style="list-style-type: none"> Daily safety inspections, visual survey
Aboveground utilities	<ul style="list-style-type: none"> Hardhat, Level D PPE. HAZWOPER and site-specific training. Employees will visually inspect the area for aboveground utilities and avoid contact with the utilities with equipment or machinery. 	<ul style="list-style-type: none"> Daily safety inspections, visual survey
Traffic	<ul style="list-style-type: none"> Licensed operators for equipment and vehicles, Beale AFB traffic rules are to be followed. 	<ul style="list-style-type: none"> Daily safety inspections
Storage of material	<ul style="list-style-type: none"> Materials will be stored in labeled and appropriate containers. MSDSs for all chemicals used or anticipated on site are on file with the HSM Department. 	<ul style="list-style-type: none"> Daily safety inspections

Table C-1. Hazards Inventory and Hazards Analysis and Control (cont'd)

Safety and Health Hazards	Controls	Monitoring
Spills	<ul style="list-style-type: none"> Standard operating procedures (SOPs) for spills, absorbent materials will be on hand for containment and cleanup. Administrative controls. 	<ul style="list-style-type: none"> Daily safety inspections
Fire	<ul style="list-style-type: none"> Control of ignition sources. Control of flammable equipment (closed containers, immediate cleanup of spills, proper storage). Fire extinguisher on site. 	<ul style="list-style-type: none"> Daily safety inspections
Electric shock	<ul style="list-style-type: none"> Excavation permit required for clearance of underground utilities, ground equipment if specified, identification and clearance of overhead and underground utilities. 	<ul style="list-style-type: none"> Visual of all work areas, digging clearance based on underground survey results Daily safety inspections
Exposure to chemicals	<ul style="list-style-type: none"> Level D PPE. Washing face and hands prior to taking anything by mouth. Minimize contact. Eyewash on site. Equipment decontaminated (washed) upon removal from contaminated area. Medical clearance for HAZWOPER work. Exclusion zone around contaminated area and PPE doffing at boundary. 	<ul style="list-style-type: none"> Daily site safety inspections Mini ray or equivalent will be used every 30 minutes to monitor breathing zone
Temperature extremes/heat, cold stress	<ul style="list-style-type: none"> Administrative controls (see Sections 7.10 and 7.11). 	<ul style="list-style-type: none"> Temperature measurements as appropriate; heart rate monitoring as appropriate
Biological hazards: rattle snakes, black widow and brown-recluse spiders, scorpions, ticks, ants, bees, wasps, hornets, yellow jackets, and poison oak	<ul style="list-style-type: none"> PPE (boots, work clothes, taped pant legs, insecticide as necessary) 	<ul style="list-style-type: none"> Visual survey
Refueling generators	<ul style="list-style-type: none"> Control of ignition sources Control of flammable material (quantities limited to single day use). Generator will be turned off during refueling. Generator will be grounded. Fire extinguishers will be provided at refueling operations for generator. All personnel expected to use fire extinguishers must be adequately trained. PPE (modified Level D) safety glasses with side shields, eyewash at site for refueling, grounding and bonding of fuel tank during refueling. Administrative controls; parking of vehicles only in designated areas. 	<ul style="list-style-type: none"> Fire extinguishers will be inspected monthly

Table C-1. Hazards Inventory and Hazards Analysis and Control (cont'd)

Safety and Health Hazards	Controls	Monitoring
<i>Soil Sampling Using HSA Rig</i>		
General safety hazards	<ul style="list-style-type: none"> • Level D PPE. Buddy system. HAZWOPER and site-specific training. SOP for sample collection and use of equipment. 	<ul style="list-style-type: none"> • Daily safety inspections
Exposure to chemicals	<ul style="list-style-type: none"> • Level D PPE. Wash face and hands prior to taking anything by mouth. Minimize contact. 	<ul style="list-style-type: none"> • Daily safety inspections
Temperature extremes	<ul style="list-style-type: none"> • Administrative controls (see Sections 7.10 and 7.11). 	<ul style="list-style-type: none"> • Temperature measurement as appropriate
Fire	<ul style="list-style-type: none"> • Control of ignition sources. Control of flammable equipment (closed containers, immediate cleanup of spills, proper storage). Fire extinguisher. 	<ul style="list-style-type: none"> • Daily safety inspections
Electrical shock	<ul style="list-style-type: none"> • Excavation permit required for clearance of underground utilities. 	<ul style="list-style-type: none"> • Daily safety inspections
Noise	<ul style="list-style-type: none"> • Hearing protection will be required near equipment during hammer operation if noise level is >85 dBA. 	<ul style="list-style-type: none"> • Daily safety inspections
<i>Groundwater Sampling</i>		
General safety hazards	<ul style="list-style-type: none"> • Level D PPE. HAZWOPER and site-specific training. Standard operating procedures. 	<ul style="list-style-type: none"> • Daily safety inspections.
Exposure to chemicals	<ul style="list-style-type: none"> • Level D PPE. Wash face and hands prior to taking anything by mouth. Minimize contact. 	<ul style="list-style-type: none"> • Daily safety inspections
Exposure to elevated temperature and pressure liquids and vapors	<ul style="list-style-type: none"> • Temperature and pressure of environment inside monitoring well casing will be established to be safe, before removal of well cap. 	<ul style="list-style-type: none"> • Downhole temperature measurement, using thermocouple network; pressure monitoring using pressure gauge in well cap.
Air temperature extremes	<ul style="list-style-type: none"> • Administrative controls (see Sections 7.10 and 7.11). 	<ul style="list-style-type: none"> • Temperature measurement, as appropriate
<i>Steam Generation</i>		
Escaping superheated water or steam.	<ul style="list-style-type: none"> • All pressure regulators, valves, and pipelines will be tightly secured and compatible with elevated temperatures and pressures generated. 	<ul style="list-style-type: none"> • Daily safety inspections
Fire	<ul style="list-style-type: none"> • Control of ignition sources. Control of flammable equipment (closed containers, immediate cleanup of spills, proper storage). Fire extinguisher will be conveniently located. 	<ul style="list-style-type: none"> • Daily safety inspections
<i>Oxygen Injection</i>		
Fire	<ul style="list-style-type: none"> • Oxygen storage vessels removed from ignition sources and flammable materials (closed containers, immediate cleanup of spills, proper storage). 	<ul style="list-style-type: none"> • Daily safety inspections

Table C-1. Hazards Inventory and Hazards Analysis and Control (cont'd)

Safety and Health Hazards	Controls	Monitoring
Pressurized system	<ul style="list-style-type: none"> All pressure regulators, valves, and supply pipelines will be secured and compatible with pure oxygen use. Flame arrestors installed in vapor lines. Oxygen and steam mixing in subsurface and at wellhead only to reduce corrosion rate. Automatic shutdown of oxygen supply in event of major treatment system failure. 	<ul style="list-style-type: none"> Daily safety inspections, where practical
<i>Servicing Downhole Pumps</i>		
Exposure to chemicals	<ul style="list-style-type: none"> Level D+ PPE. Wash face and hands prior to taking anything by mouth. Minimize contact. 	<ul style="list-style-type: none"> Safety inspections during all pump removal and handling
Hot liquids or vapors	<ul style="list-style-type: none"> Temperature and pressure of environment inside monitoring well casing will be established to be safe, before removal of well cap. 	<ul style="list-style-type: none"> Downhole temperature measurement, using thermocouple network; pressure monitoring using pressure gauge in well cap
<i>Treatment System</i>		
Exposure to chemicals	<ul style="list-style-type: none"> Level D PPE. Wash face and hands prior to taking anything by mouth. Minimize contact. 	<ul style="list-style-type: none"> Safety inspections prior to and upon completion of sampling procedure
Hot liquids and/or vapors	<ul style="list-style-type: none"> Temperature of environment inside treatment line upstream from sampling point will be established to be safe, before unsealing of sample port. 	<ul style="list-style-type: none"> Safety inspection prior to sample procedure
<i>Geophysical Monitoring</i>		
Electric shock	<ul style="list-style-type: none"> Electrode arrays will be isolated prior to maintenance procedure. 	<ul style="list-style-type: none"> Safety inspection at geophysical control center, prior to maintenance procedure
<i>Postdemonstration Sampling</i>		
General hazards (as above)	<ul style="list-style-type: none"> As installation and setup. 	-
<i>Demobilization Activities</i>		
General hazards (as above)	<ul style="list-style-type: none"> As installation and setup. 	-

3.1 Task-Specific Hazard Analysis

Table C-1 presents task-specific hazards, relevant hazard control, and required monitoring for all of the planned tasks. In general, given these tasks, the potential for unacceptable exposure to site contaminants appears to be low. Physical hazards also are minimal. It is the responsibility of the Project Manager and the HSM to verify that planned hazard controls are sufficient, and if not, to take appropriate steps to assure safety.

3.2 Chemical Exposure

The likelihood of exposure to the chemicals during the demonstration is low, because known and expected concentrations of contaminants of concern (COCs) in soil and groundwater are well below PELs. Exposure to chemicals may occur during well installation, soil sample collection, groundwater sample collection, downhole pump or other treatment system maintenance, and during demobilization from the site. Table C-2 provides information on the significant suspected COCs, exposure limits, health effects, and exposure routes.

Table C-2. Chemical Exposure

COC	Exposure Limit(s)	Health Effect	Exposure Route
<i>cis</i> -1,2-DCE	ACGIH TLV: 200 ppm	Carcinogen Eyes, skin, respiratory system, blood, CNS, bone marrow	Inhalation, skin absorption, ingestion, eye contact
PCE	PEL: 25 ppm ACGIH TLV: 25 ppm ACGIH STEL: 100 ppm	Eyes, skin, respiratory system, liver, kidneys, CNS	Inhalation, skin absorption, ingestion, skin/eye contact
TCE	PEL: 100 ppm ACGIH TLV: 50 ppm ACGIH STEL: 100 ppm	Eyes, skin, respiratory system, liver, kidneys, CNS	Inhalation, skin absorption, ingestion, skin/eye contact
Vinyl Chloride	PEL: 1 ppm ACGIH TLV: 12 ppm ACGIH STEL: 25 ppm	Carcinogen Eyes, skin, respiratory system, liver, kidneys, CNS	Inhalation, skin absorption, ingestion, eye contact

ACGIH = American Conference of Governmental Industrial Hygienists.

CNS = central nervous system.

DCE = dichloroethylene.

PCE = tetrachloroethylene.

PEL = permissible exposure limit.

STEL = short-term exposure limit.

TCE = trichloroethylene.

TLV = threshold limit value.

3.3 Physical Hazards

A variety of physical hazards may be present during the HPO demonstration. Other hazards include overhead power lines, underground utilities, slips, trips, falls, plant traffic, heat stress, temperature extremes, weather conditions, and biological hazards. These hazards are not unique and are familiar to hazardous waste workers. Section 7, Safe Work Practices, discusses in further detail control measures and procedures to be followed to prevent accidents from other physical hazards.

3.4 Hazards Associated with Pure Oxygen Use

The storage of compressed pure oxygen in cylinders for co-injection with steam at the site has the potential to present a fire or explosion hazard. Cylinders will be stored according to standard safe practices at an adequate distance from potential ignition sources and combustible materials. All pressure regulators, valves, and supply lines will be tight and compatible with pure oxygen use. In addition, flame arrestors will be installed in all vapor lines; oil and grease will be eliminated from all pipes, valves, and pumps that may contact potentially combustible vapors; and

oxygen delivery lines will be configured so as to only permit steam and oxygen mixing in the subsurface. Oxygen delivery systems will have an automatic shutdown control in the event of major operational failures in the treatment system.

4. Hazard Communication, Training, and Medical Surveillance Requirements

4.1 Hazard Communication

Hazard communication will be governed by SES Environmental Compliance and Health and Safety (EC&HS) Procedure 8, Hazard Communication, and 29 CFR 1910.1200. As a minimum, the following steps will be taken:

- All hazardous materials on site will be labeled to comply with the hazard communication standard:
 - Clear labeling as to the contents,
 - The appropriate hazard warning, and
 - The name and address of the manufacturer.
- MSDSs will be available on site for all hazardous materials that are present.
- Site-specific training will include the hazards posed by site chemicals, protective measures, and emergency procedures.
- Copies of MSDSs for all hazardous chemicals (chemicals brought on site) will be maintained in the work area. MSDSs will be available to all employees for review during each work shift.

4.2 Training

Personnel who participate in field activities associated with this project are subject to the training requirements presented in Table C-3.

Table C-3. Training Requirements

Training	Worker	Supervisor	Site Visitor
Hazardous Waste Safety (40-hour, 3-day OJT)	X	X	No
Hazardous Waste Safety Refresher (8 hour)	X	X	No
Hazardous Waste Safety Supervisors Training (8 hour)	No	X	No
First Aid/CPR (Red Cross Equivalent)	X	X	No
SES General Employee Training (Exemption for less than 10 days on site)	X	X	No
Site-Specific Health and Safety Training and Security Orientation	X	X	No
Safety Briefing (daily and whenever conditions or tasks change)	X	X	X
Temperature Extremes/Hearing Conservation	X	X	No
Resource Conservation and Recovery Act (RCRA) Generator Training	No	X	No
Confined Space	NA	NA	NA
Bloodborne Pathogens	No	No	No

CPR = cardiopulmonary resuscitation.

OJT = on-the-job training.

X = Required.

Two versions of the site-specific safety training will be used. The site worker version will contain full information on site hazards, hazard controls, and emergency procedures. A shortened version will be used for visitors who will be on site for short times and who will not do hands-on work. This shortened version will contain the hazard information that is directly relevant to the purpose of the visit. Signatures of those attending and the type of briefing must be entered in the field logbook before site access will be granted. The site-specific training will include the following site-specific information:

- Names of site health and safety personnel and alternates
- Contents of the HASP
- Hazards and symptoms of contaminant exposure
- Hazards and symptoms of chemicals present in the workplace
- Physical hazards in the workplace
- Location and availability of written hazard communication program
- Site and task PPE (including purpose, donning, doffing, and proper use)
- Safe work practices to minimize risks
- Safe use of engineering controls and equipment
- Medical surveillance requirements
- Site control measures
- Reporting requirements for spills and emergencies
- Personnel decontamination procedures
- Contingency plans (including communications, phone numbers, emergency exits, and assembly point)
- Spill containment procedures (including reporting and cleanup methods)
- Emergency equipment locations and use (including fire extinguishers and spill kits).

Safety briefings will be held when conditions or tasks change and as required. These briefings will be conducted by the HSM and/or operations manager and will be attended by all site workers and supervisors. These briefings will address site-specific safety issues and will be used as

an opportunity to refresh workers on specific procedures and to address new hazards and controls.

Documentation of the required training will be maintained in the on-site project files. This documentation will include copies of all appropriate training certificates, copies of medical clearance reports, and entries in project logs showing the topics covered, trainer, and signatures of those attending on-site training.

All personnel will be required to attend site-specific General Employee Training (GET) provided by SES unless exempted by the exclusion that individuals working 10 or fewer days at the site do not need to attend GET as long as they are escorted by a GET-trained individual.

4.3 Medical Surveillance

All employees performing on-site hazardous waste related work will be enrolled in a medical surveillance program to meet the requirements of 8 CCR 5192 (f) [29 CFR 1910.120(f) and 1926.65(f)]; SES EC&HS Procedures 12 (Medical Surveillance) and 20 (Hazardous Waste). This medical surveillance will be documented on site with copies of medical clearance to perform work pursuant to 29 CFR 1910.120.

The frequency of employee medical exams shall be as follows:

- Prior to assignment.
- Once every 12 months for routine site workers and at least once every 2 years for workers who make infrequent site visits.
- At termination of employment or reassignment to an area where the employee would not be covered, if the employee has performed fieldwork since his/her last examination and has not had an examination within the last 6 months.
- As soon as possible upon notification by an employee that he/she has developed signs or symptoms indicating possible overexposure to hazardous substances or health hazards, or that the employee has been injured or exposed above the PEL or published exposure levels in an emergency situation.

4.4 Records

- A system of reports and logs will be used to document activities related to site Safety and Health. The following documents will be generated.
- Training logs will contain information covered and the signatures of the trainer and those attending. These logs will contain documentation of pre-entry (project start) training, routine (“tailgate”) safety briefings, and visitor training.

- Safety inspection logs will contain the dates of inspections, identity of the person performing the inspection, the examined areas/activities/equipment, any deficiencies, and any corrective actions taken.
- Employee/visitor register will be a sign-in log for all site employees and visitors. It will contain the names of all personnel who perform on-site work or visit the site. It will not contain the names of delivery or similar personnel.
- Environmental and personal exposure monitoring/sampling results will be maintained in a log that will contain monitoring data, location and time of monitoring, types of work being done, calibration records, and the identities of personnel performing monitoring.
- Refer to Sections 2 through 4 of the SES ESHS for detailed training and protection procedures.

5. Site Control and Personal Protective Equipment

5.1 Site Control

The HSM will be responsible for establishing the site control zones, as necessary, around the controlled area that presents physical, chemical, or other hazards. Implementation of the site control zones will help to minimize the number of employees potentially exposed and to minimize the potential for the spread of contamination. The HSM will monitor the implementation of the required site control work rules and will report any deviations from prescribed practice to the Project Manager or stop work, as appropriate.

If necessary, site control zones will be established in a number of locations over the site. The exact locations will vary depending on site conditions; therefore, it is not possible to predetermine the size or exact locations of site control zones. The suspected low contaminant concentrations, small size, and short duration of the HPO demonstration are such that setup of exclusion, contaminant reduction, and support zones probably will be unnecessary. However, the procedures entailed in the operation of such site control zones are documented in this section as part of the overall HASP.

All visitors to the site must sign the visitor's log and undergo a health and safety briefing from the HSM before going on site. An escort must accompany all visitors unless prior approval has been granted.

5.1.1 Exclusion Zone

The exclusion (contamination) zone is the area where the greatest potential exists for exposure to contamination or physical hazards. The number of people and equipment in the exclusion zone will be minimized to control physical hazards and the spread of contamination.

The following standard rules will apply to all entry into the exclusion zone:

- The HSM or Field Operations Manager must approve (and log) entry into the exclusion zone.
- All personnel entering the exclusion zone will wear the prescribed level of protective clothing.
- All items and related paraphernalia intended to be placed on the face or in the mouth (i.e., cigarettes, lighters, matches, chewing tobacco, food, and cosmetics) are prohibited in the exclusion zone.
- All personnel in the exclusion zone will follow the buddy system.

Exclusion zones will be established where the spread of contamination is a potential hazard and will be appropriate to the hazard and surroundings.

5.1.2 Contamination Reduction Zone

A contamination reduction (buffer) zone will be established, as necessary, outside the exclusion zone to provide a transition from and a buffer between the exclusion zone and the support zone. A formal personnel contamination reduction zone will be established only if Level D+ PPE or respiratory protection is used.

All personnel entering the contamination reduction zone will wear the prescribed level of protective clothing required for that zone. All items intended to be placed on the face or in the mouth (i.e., cigarettes, chewing tobacco, food, and cosmetics) are prohibited in the contamination reduction zone. Removal of protective clothing, personnel decontamination and equipment decontamination will occur in the contamination reduction zones.

5.1.3 Support Zone

The support zone is the clean and relatively safe area of the site that surrounds the exclusion and contamination reduction zones. Generally, the support zone is considered to include all the area of a site that is not enclosed within an exclusion or contamination reduction zone.

Work in the support zone requires current hazardous waste safety training and medical surveillance. Note that these requirements do not apply to paperwork or similar activities inside on-site office trailers.

5.2 Personal Protective Equipment

SES's PPE program is controlled by EC&HS Procedures 13 and 20 and 29 CFR 1910 Subpart I, Personal Protective Equipment. The HSM may raise or lower the level of PPE worn by the teams, depending upon the site-specific hazards encountered in the field. Prior to lowering the level of PPE, the Project Manager and the HSM will be contacted/consulted and the results documented. If site conditions are such that the level of PPE is insufficient or work must be stopped, the HSM will take appropriate action immediately and the appropriate personnel (see above) will be contacted afterwards. Criteria indicating a possible need for reassessment of the PPE selection include the following:

- Commencement of an unplanned (hazard not previously assessed) work phase.
- Working in unplanned temperature extremes.
- Evidence of contamination such as discolored soil or elevated instrument readings near the soil.
- Exceedance of action limits for exposure.
- Changing of the work scope so that the degree of contact with contaminants changes.

5.2.1 Types of Equipment

This section presents the types of protective clothing that may be used for the project. Requirements for task-specific levels of protective clothing are presented in the Hazard Analysis and Control table (Table C-1). Levels of protection that may be used to protect against chemical and physical hazards at this site include:

Level C PPE

- Full-face respirator and air purifying cartridges capable of filtering out organic vapors, acid gasses.
- Hooded chemical-resistant clothing (polyethylene-coated Tyvek[®] or equivalent)
- Two pair chemical-resistant gloves (nitrile and exam gloves)
- Safety boots
- Shoe covers
- Hardhat (if overhead hazards are present)

Level D+ PPE

- Tyvek[®] or equivalent coveralls
- Nitrile or polyvinyl chloride (PVC) gloves
- Safety boots
- Boot covers
- Hardhat (if overhead hazards are present)
- Safety glasses with side shields

Level D PPE

- Coveralls/field clothes
- Safety boots
- Safety glasses with side shields
- Hardhat (if overhead hazards are present)
- Nitrile or equivalent gloves if contaminated materials are handled.

5.2.2 Cleaning, Storage, and Program Verification

If site tasks require the use of chemical protective clothing, disposable clothing will be disposed as specified in the Waste Management Plan. Used chemical protective clothing will be rendered unfit for further use by tearing or cutting. Unused chemical protective clothing will be stored in clean staging areas until needed. The HSM will verify that the PPE in use is appropriate and is being used properly.

6. Monitoring

Assessment of ambient conditions and employee exposures will be performed, as appropriate, to verify that safe conditions are maintained. Action levels, with appropriate actions, have been established for this monitoring. All personal exposure-monitoring records will be maintained in accordance with 29 CFR 1910.20. The specific minimum monitoring requirements and action levels are presented in Table C-4.

Table C-4. Monitoring Requirements and Action Limits

Hazard or Measured Parameter	Interval	Limit	Action
Breathing zone chemicals	As needed	>5 ppm	Withdraw; contact Health and Safety Manager; do not re-enter until authorized by Health and Safety Manager

Organic vapor concentrations shall be measured using a photoionization detector (PID) (11.7 eV). Organic vapor monitoring will be conducted at the commencement of intrusive activities, before handling soil samples, and at each well when the well cap is removed. If organic vapors are detected at the borehole or top of the well casing above action guidelines defined in Table C-4, organic vapor measurements will be taken in the breathing zone near the borehole or monitoring well top of casing. If organic concentrations are detected above action guidelines in the applicable breathing zone for a continuous period of one minute, project personnel will leave the area and contact the HSM or Project Manager for further instructions. The PID organic vapor meter will be calibrated daily; using the technique specified by the manufacturer.

7. Safe Work Practices

This section presents those general safety rules that apply to all operations performed by SES and its subcontractors. The provisions of the plan are mandatory for all on-site employees and visitors.

7.1 General Safety Requirements

The following rules apply to all site activities.

- Daily safety briefings (“tailgate”) will be held during field activities to reiterate safety precautions and to inform personnel of new hazards or procedures.
- The HSM or Field Operations Manager will conduct and document daily safety inspections.
- Personnel will perform only those tasks that they believe they can do safely.
- Personnel will notify the HSM of any medical conditions (e.g., allergic to bee stings, diabetes, pregnancy) that require special consideration.
- Personnel will maintain proper workplace housekeeping to minimize the potential for trips and other accidents.
- Contact with potentially contaminated substances will be avoided. Site personnel in the exclusion zone will avoid creating dust, walking through puddles, pools, mud, kneeling on the ground, and placing equipment on the ground.
- All injuries and accidents will be reported to the HSM, who will perform further notifications.
- All workers in potentially hazardous areas will abide by a buddy system. Members of a buddy team will maintain radio, verbal or visual contact.

7.2 Ergonomics–Lifting and Carrying Heavy Objects

Potential hazards related to the interaction of personnel with their working environment may be present at this site. The primary ergonomic hazards that may exist may be lifting heavy loads, equipment vibrations, and physical obstacles associated with traversing walkways and work surfaces. Personnel should always position themselves properly and lift from the legs when attempting to lift equipment. Personnel should rely on their buddy to assist in lifting loads that are too heavy for one person to properly lift and carry. Back strain, the most common ergonomic hazards in the field, may be easily avoided, provided the on-site workers always ask for assistance when they need it.

If any ergonomic symptoms are encountered in the field, the HSM should be notified immediately.

7.3 Walking/Working Surfaces–Trip and Fall Hazards

Workers will be informed of any potential trip hazards through regular health and safety meetings. Whenever possible, trip and fall hazards will be eliminated or clearly identified with yellow caution tape. Field equipment and supplies will be kept orderly and out of pathways or potentially harmful situations. Impalement hazards to workers will be neutralized as soon as they are identified.

The following practices will minimize accidents:

- Personnel will maintain proper workplace housekeeping to minimize the potential for trips and other accidents.
- Contact with potentially contaminated substances will be avoided. Site personnel in the exclusion zone will avoid walking through puddles, pools, mud, kneeling on the ground, and placing equipment on the ground.

7.4 Underground Hazards

Any underground utilities (cables, pipes, etc.) will be located prior to onset of drilling or excavation work.

7.5 Drum/Container Handling

Any drums used for the project will meet DOT requirements and will be handled and labeled to comply with SES waste management procedures.

7.6 Electrical Safety

This work will be conducted in conformance with 29 CFR 1910, Subpart S.

- All portable electrical equipment will be double insulated or grounded and connected through a ground fault circuit interrupter.
- Grounding and bonding for the fuel gas generator will be in place to prevent the buildup of static and potential sparks or explosion when refueling the generator.
- Conductive materials (drill rig equipment) will be kept clear of energized power lines. The following minimum distances will be observed; 0-50 kV – 3.1 m; 51-100 kV – 3.66 m; 101-200 kV – 4.57 m; 201-300 kV – 6.1 m; 301-500 kV – 7.62 m; 501-750 kV – 10.67 m; 750-1000 kV – 13.72 m.

7.7 Lockout/Tagout

All potentially hazardous servicing or equipment repair will be governed as documented in ESHS Section 6, Lock Out/Tag Out, 29 CFR 1910.147.

7.8 Illumination

Routine fieldwork will be conducted during daylight hours (no earlier than 15 minutes after sunrise and no later than 15 minutes before sunset) and natural illumination will be used. Any work conducted during non-daylight hours will be illuminated to meet the following minimums stated in 29 CFR 1910.120(m): general work areas, 5 foot-candles; stairs and ladders, 10 foot-candles; offices, 50 foot-candles; and first aid areas, 30 foot-candles.

7.9 Sanitation

Sanitation will comply with 29 CFR 1910.120(n):

- Means for washing hands and faces prior to eating will be provided at the work site.
- Potable drinking water will be provided in labeled, sanitary dispensers.
- Toilets (if not accessible on site) shall be provided according to the following; >200 employees = 2 toilets, 21 to 199 employees = 1 toilet seat and 1 urinal per 40 workers.

7.10 Cold Stress

Critical factors in preventing cold stress disorders are adequate clothing and staying dry. The HSM and Project Manager will ensure the capability to quickly move individuals who become wet to a sheltered, warm area. The following specific steps will be taken (adapted from ACGIH TLV booklet).

- If ambient temperatures are less than 40°F, site training will include prevention of cold injury, cold injury symptoms, and cold injury first aid.
- A heated break area will be provided if ambient temperatures are less than 32°F.
- As a minimum, breaks will be taken in a warm area every 120 minutes if ambient temperatures are less than 32°F.
- Workers will be allowed to take unscheduled breaks, if needed, in a warm area.
- No outdoor work will be performed if the equivalent chill temperature (temperature combined with the effect of wind) is less than -29°F.

7.11 Heat Stress

Activities being conducted during the HPO demonstration at the site may be physically demanding during much of the investigative efforts. Physical demands placed on investigative personnel may be compounded through the use of PPE, moderate to heavy workloads, ambient air temperatures, relative humidity, and exposure to nonionizing radiation.

Two important factors will help personnel function in hot environments: acclimatization and consumption of fluids. Acclimatization of worker to hot environmental conditions may require time. Especially prior to as well as after acclimatization, workers should concentrate on maintaining a balanced diet, consuming plenty of fluids throughout the day, while outside of contaminated areas, and remaining aware of sign of heat-related stress. Headaches, dizziness, high body temperature, and increased heart rate are all early warning signals of heat stress. It is imperative that the HSM be informed if a worker experiences these signs. All activities that take place in the field at the investigative site require that use of a buddy system and, as field activities continue, all personnel should be apprised of their buddy's condition with respect to heat stress.

If necessary, in the judgment of the HSM, a work/rest regimen will be instituted by SES to help in combating heat-related disorders. The HSM will implement the work/rest regimen in accordance with best professional judgment using the ACGIH heat stress TLV as a guideline. If a work/rest regimen becomes necessary, physiological monitoring also will be instituted. This monitoring will consist of monitoring employees' pulse rates before and after each break. To reenter the exclusion zone, an employee's pulse rate must be no greater than 150% of his or her resting pulse.

7.12 Soil Sampling Equipment

It is anticipated that a hollow-stem auger (HSA) rig will be used to collect soil and groundwater samples. Per site requirements, the device must be inspected by SES before mobilizing to the Beale AFB fenced security area. This inspection will focus on the following items:

- Guarding of belts and shafts,
- Leaks of any kind,
- Traffic cones and signage,
- Fire extinguisher, and
- General safety overview.

7.13 Noise

The noise associated with subsurface soil sample collection operations is expected to be minimal. For this project a HSA rig is proposed for use. It is SES's policy to take a conservative approach and require all personnel within the exclusion zone to wear hearing protection during hammer operations. Site personnel will be informed of this requirement during the initial site briefing before the onset of field activities.

7.14 Forklift Operations

If forklifts are required to move materials generated as part of this project the following procedures will be followed at a minimum in accordance with 29 CFR 1910.178:

- Only approved trucks will be used.
- Only trained and authorized operators shall be permitted to operate equipment:
 - Unauthorized personnel shall not be permitted to ride on forklifts.
 - No person shall be allowed to stand or pass under the elevated portion, whether loaded or empty.
 - When left unattended, load engaging means shall be fully lowered, controls shall be neutralized, power shall be shut off, and brakes set.
 - An overhead guard shall be used as protection against falling objects.
 - Only stable or safely arranged loads within the rated capacity of the truck shall be handled.
 - All traffic regulations shall be observed.
 - The driver shall be required to slow down and sound the horn at cross aisles and other locations where vision is obstructed.
 - The truck shall be operated at a speed that will permit it to be brought to a stop in a safe manner.
 - Stunt driving and horseplay shall not be permitted.

7.15 Biological Hazards

Field conditions may present a variety of animal and botanical hazards. Examples of these hazards may be but are not limited to snakebites, spider bites, and scorpion stings. To protect from snakes and insects, long pants will be worn and cuffs will be tucked into socks or taped to shoes. Use insect repellent as necessary. Employees will not handle or otherwise disturb wildlife.

7.16 Equipment Handling and Mobilization

Trained personnel will handle equipment according to manufacturers' specifications or standard operating procedures. To avoid pinch points, guards are to be provided if feasible, or workers are to avoid equipment moving parts that could get trap clothing and body parts. All equipment will be operated with all guards provided by the manufacturer and in compliance with 29 CFR 1910, Subpart O and Environmental Management (EM) 385-1-1 Section 16.B. If any guarding must be removed for servicing, the equipment will be disabled to preclude movement or release of energy. Other concerns that may be associated with equipment include the following:

- Traffic: vehicles are to be operated by authorized and trained personnel and are to follow Beale AFB road policies.
- Pressurized systems: assure pressure valves and equipment is in operating order, visually inspect for faulty equipment and if necessary institute tag-out procedures.

- Mechanical energy: visually inspect equipment, observe equipment lines for visual safety hazards (pinched lines, leaking fuel).
- Ensure that the equipment is handled according to the manufacturers' specifications and that it is used by trained personnel.
- To prevent shock hazards from survey and any other equipment, ensure that the equipment is properly grounded and bonded and is not used in heavy rains or other conditions that could result in electrocution.

7.17 Nuisance Dust

During this project nuisance dust is an anticipated concern. Dust combined with rodent feces in this area has been known to carry the Hanta virus. Procedures to minimize dust such as wetting the work area may be implemented by the HSM. However, should working conditions, based on the professional judgment of the HSM, indicate a high level of dust that warrants protection, the guidelines for Respiratory Protection Program in the SES EC&HS procedures shall be followed.

7.18 Pressure Systems

Pressurized systems and equipment will be handled according to manufacturers' specification or operating procedures. Operators of pressurized systems shall be trained in proper operation of equipment and safe handling procedures. If the system needs to be shut down, the equipment will be disabled to preclude movement or release of energy. Other concerns that may be associated with equipment include the following:

- Pressurized systems: assure pressure valves and equipment is in operating order, visually inspect for faulty equipment and if necessary institute tag-out procedures.
- Mechanical energy: visually inspect equipment, observe equipment lines for visual safety hazards (pinched lines, leaking fuel).
- Ensure that the equipment is handled according to the manufacturers' specifications and is used by trained personnel.
- To prevent shock hazards from equipment, ensure that the equipment is properly grounded and bonded and is not used in heavy rains or other conditions that could result in electrocution.

8. Decontamination Procedures

8.1 Chemical Contamination Avoidance

One of the most important aspects of decontamination is the prevention of contamination. Good contamination prevention should minimize worker exposure and help ensure valid sample results by precluding cross-examination. Procedures for chemical contamination avoidance include:

- Do not walk through areas of obvious or known contamination.
- Do not directly handle or touch contaminated materials.
- Make sure that there are no cuts or tears on PPE.
- Particular care should be taken to protect any skin injuries.
- Stay upwind of airborne contaminants.
- Do not carry cigarettes, cosmetics, gum, etc., into contaminated areas.
- When required by the HSM, cover instruments with clear plastic leaving openings for sampling.
- Care should be taken to limit the amount of contamination that comes in contact with the sampling equipment (i.e., soil probes or tires).
- If contaminated tools are to be placed on noncontaminated equipment for transport to a decontamination area, plastic should be used to keep the equipment clean.

8.2 Equipment Decontamination

Sampling equipment used during the HPO demonstration at Beale AFB that is potentially contaminated will be decontaminated to prevent migration of hazardous material outside the site. A specific decontamination area will not be defined for the limited amount of equipment decontamination required for this project. All equipment will be decontaminated at the sampling location, and decontamination solutions will be containerized and stored in the Satellite Accumulation Area (SAA).

8.3 Personnel Decontamination

A system of procedures will be used to control the spread of contamination from the exclusion (contamination) zone and to ensure that workers are sufficiently free of contamination to preclude adverse health effects. PPE removal and personnel decontamination are part of this system. This section presents basic requirements for personnel decontamination keyed to the level of protection. These requirements may be modified by the HSM if improvements are needed. Refer to Section 3 (“Hazard Assessment”) for task-specific PPE.

8.3.1 Level D Protection Decontamination

Station 1: Removal of disposable gloves and boot covers, if worn
Deposit disposable gloves and boot covers in a designated container.
Note that this step is necessary only if gloves and boot covers are in use.

Station 2: Field wash
Wash face and hands prior to taking anything by mouth. This may be done with soap and water or disposable disinfectant towels.

8.3.2 Level D+ Protection Decontamination

Station 1: Tape removal
Remove all tape (if used) from outer clothing and place in appropriate waste container.

Station 2: Boot covers, outer disposable garment, and gloves removal
Carefully remove boot covers, outer contamination-resistant garment, and gloves.

Station 3: Field wash
Wash hands and face prior to eating, drinking, smoking, etc. This step may be accomplished with soap and water or disposable disinfectant wipes.

8.3.3 Level C Protection Decontamination

Station 1: Segregated equipment drop
Deposit equipment used on site (tools, sampling devices, containers, monitoring instruments, clipboards, etc.) on plastic sheets or in different containers with plastic liners. Segregation of the equipment at the drop site reduces the possibility of cross-contamination.

Station 2: Outer boot and glove removal
Remove tape from outer boots and outer gloves. Remove outer boot covers and outer gloves. Deposit gloves and boot covers in plastic trash bags.

Station 3: Cartridge change
If a worker has left the exclusion zone for the sole purpose of changing a canister/cartridge of the respirator, this is the last step of the decontamination procedure. Once the worker's canister/cartridge has been replaced, the outer boots and gloves will be replaced and retaped so that all potential pathways to the skin are sealed.

- Station 4:** Disposable outer garment removal
Remove disposable outer garment, deposit in a plastic trash bag, and dispose in accordance with the project Field Sampling Plan.
- Station 5:** Respiratory protection and disposable inner glove removal
The respirator is the next-to-last item for removal. The cartridges/canisters are placed in a plastic trash bag and disposed of in accordance with the project Waste Management Plan. The respirator is placed in a plastic bag dedicated for used respirators only. Remove disposable inner gloves last and deposit them in a plastic trash bag, in accordance with the project Waste Management Plan.
- Station 6:** Field wash
Wash hands and face prior to eating, drinking, smoking, etc. This step may be accomplished with soap and water or disposable disinfectant wipes.

8.4 Emergency Decontamination

If emergency life-saving first aid and/or medical treatment are required, normal decontamination procedures may need to be abbreviated or omitted. The emergency takes precedence over any contamination. The HSM or designee will accompany contaminated victims to the medical facility to inform medical personnel what chemicals are involved. For minor medical problems or injuries, the normal decontamination procedures will be followed.

8.5 Disposal Procedures

All discarded materials, waste materials, or other objects shall be handled in accordance with the generators waste management plan for the project to preclude the potential for spreading chemical and/or radiological contamination, creating a sanitary hazard, or causing litter to be left on site. The waste will be properly packaged or containerized and stored in the approved SAA. All potentially contaminated materials (e.g., clothing, gloves, etc.) will be bagged as necessary, labeled, and segregated for disposal. All noncontaminated materials shall be collected and bagged for appropriate disposal as normal domestic waste. SES will survey all wastes before the wastes are removed from the site.

9. Emergency Plan

All SES and subcontractor personnel working on the HPO demonstration at Beale AFB will follow the emergency plan outlined in this section. The site will have posted the “Emergency Dial 911 poster.”

The HSM and/or Project Manager will be responsible for the implementation of the emergency plan whenever conditions at the site warrant such action. The HSM and Project Manager will be responsible for coordination of the evacuation, emergency treatment, and emergency transport of site personnel as necessary, and for notification of emergency response units and the appropriate management staff.

9.1 Emergency Contacts

The following personnel have been assigned to the steam injection project at Beale AFB. They will be contacted in the event of an emergency onsite. A copy of these contacts will be kept in all field vehicles.

Field Contacts

Hank Sowers	SES Health and Safety Manager	661-322-6478
Steve Carroll	SES Project Manager	661-619-2270 (cell)
Sam Yoon	Battelle Health and Safety	614-424-4569

Emergency Telephone Numbers

Jorge Sanchez	911 or 530-634-2593
Emergency Medical Services	911 or 530-634-2000
Police	911 or 530-634-2000
Fire Department	911 or 530-634-2000
Rideout Memorial Hospital	530-749-4300

Information and Response Organizations

National Response Center	800-424-8802
California EPA	800-858-7550
U.S. EPA (EPA Region 9)	415-556-1488
RCRA Hotline	800-424-9346
Poison Control Center	800-777-6476
Center for Disease Control	404-488-4100

If 911 is called, the dispatcher must be told that it is a SES-related emergency and the Beale AFB site officials must be contacted (via two-way radio).

9.2 Evacuation

As appropriate, at the start of each workday, the HSM will inform all site personnel of the evacuation route(s) and meeting location(s) applicable to areas in which work will be conducted that

day. In the event of an emergency situation, such as fire, explosion, or significant release of toxic gases in the exclusion zone, all personnel will evacuate and assemble near the support zone (defined in Section 5.1.3). Once assembled, personnel shall remain there until released by SES Safety and Health Personnel. The location shall be upwind of the site where possible. For efficient and safe site evacuation and assessment of the emergency situation, the emergency coordinator will have authority to initiate action if outside services are required. Under no circumstances will incoming personnel or visitors be allowed to proceed into the area once the emergency signal has been given. The HSM or designee must ensure that access for emergency equipment is provided and that all equipment has been shut down and secured after the alarm has sounded. Once the safety of all personnel is established, the emergency response groups, as necessary, will be notified by telephone of the emergency.

9.3 Potential or Actual Fire

In the event of a fire or explosion, 911 shall be called to notify the Beale fire department prior to initiating any activities to extinguish a fire. Also notify the Beale AFB Point of Contact, Jorge Sanchez at (530) 634-2593. When the dispatcher answers the 911 call, provide the following information:

- Where the emergency is located.
- Nature of the emergency.
- Number of personnel injured.
- What emergency action/first-aid is being administered.
- Identity of the caller and name of any injured person(s).

9.4 Personnel Injury

A first aid kit will be readily available at the project work site. The HSM will ensure that supplies are adequately maintained. Emergency first aid will be applied on site as deemed necessary. The HSM will complete the accident/incident report in accordance with Section 9.9.4 of this HASP. Directions to the local hospital are shown on Figure C-1.

The ambulance/rescue squad shall be contacted (call 911) for transportation to the hospital as necessary in an emergency situation. Only in nonemergency situations will an injured person be transported to the hospital by means other than an ambulance.

9.5 Overt Personnel Chemical Exposure or Decontamination and First Aid

Skin Contact: Use copious amounts of warm soapy water. Wash/rinse affected area thoroughly, and then provide appropriate medical attention. Emergency eyewash is located in the support zone or the decontamination reduction zone. Eyes should be rinsed for a minimum of 15 minutes upon chemical contamination. Contact the HSM.

Rideout Memorial Hospital

726 Fourth Street, Marysville, CA 95901

Phone” 530-749-4300

For Emergency Dial 911

Take “B” Street South to Warren Shingle Blvd.

Take a right on Warren Shingle and go west to Gaven Mandry Dr.

Take a right on Gaven Mandry and go north to N. Beale Rd.

Take N. Beale Rd. about 8 miles into Rt. 70 and S. Yuba City

Take a left on Fourth St. and proceed about a quarter mile to Rideout Memorial Hospital
Emergency Center.

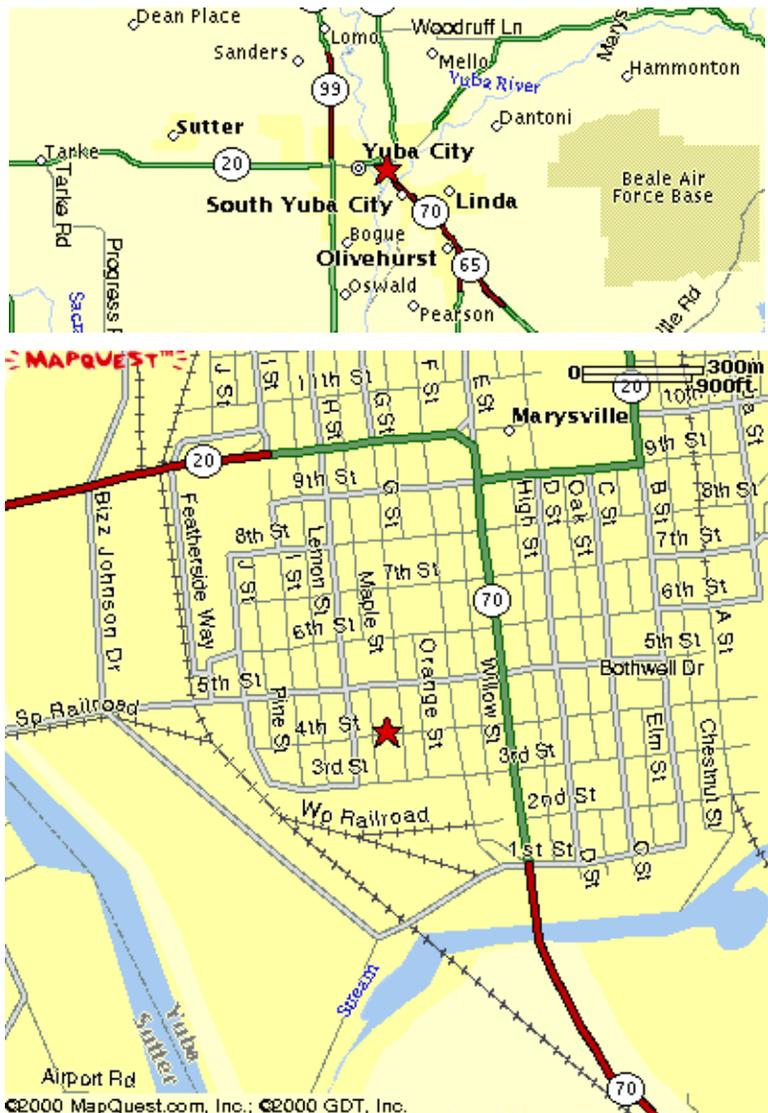


Figure C-1. Directions to Local Hospital for Emergency

- Inhalation:** Move to fresh air and/or, if necessary, decontaminate, call 911, and contact HSM.
- Ingestion:** Decontaminate, call 911, and contact HSM.
- Puncture Wound or Lacerations:** Decontaminate, stabilize, and contact HSM.

9.6 Alarm Signals

Alarm signals for the Beale AFB facility in response to specific emergency situations are given in Table C-5.

Table C-5. Alarm Signals and Responses at Beale AFB

Alarm	Signal	Action/Response
Attack Warning	Wailing rise and fall siren	This sound means an air attack is imminent. When you hear this, take cover in the nearest take-cover area.
Natural Disaster	Long continuous siren	Evacuate the building immediately and report to your designated assembly point.
Building Evacuation	High pitch pulsating siren	Stay clear of building

9.7 Adverse Weather Conditions

In the event of adverse weather conditions, the HSM or designee will determine if work can continue without compromising the health and safety of field personnel. Some of the items to be considered prior to determining if work should continue are the following:

- Potential for heat stress and heat related illnesses.
- Potential for cold stress and cold related illnesses.
- Potential for electric storms/dust storms.

Site activities will be limited to acceptable weather conditions. Inclement working conditions include high winds and extreme temperatures. Work shall be stopped during any high or excessive winds. Observe daily weather report and evacuate if necessary in case of inclement weather conditions.

9.8 Accident/Incident Reporting

For reporting purposes, the term "accident" refers to fatalities; lost time injuries; injuries requiring first aid; spill or exposure to hazardous materials (toxic, explosive, flammable, or corrosive); fire; explosion; damage to property; or potential occurrence of the above. All accidents, incidents, and emergencies shall be reported by the HSM to the Project Manager promptly. In addition, the Project Manager documents the incident on a SES Supervisor's Accident Report.

Also notify the Beale AFB Point of Contact, Jorge Sanchez, through the Project Manager of events significant enough to be classified as “Occurrences”. The HSM will evaluate accidents and near misses to determine if they should be regarded as “Occurrences” within 2 hours of the event. Such events will be categorized as one of the following:

- Emergency,
- Unusual occurrence,
- Off-normal, or
- None of the above.

9.9 Spill Release Control Measures and Reporting

9.9.1 Communication System for Reporting Spills

Telephone and verbal communications, and two-way radios are used for reporting spills to the HSM and the Project Manager. Telephones, two-way radios, telephone pagers, public address system, and the base’s alarm are used for summoning response personnel to spills.

Maintaining the spill prevention program is principally the responsibility of local emergency groups, base emergency groups, Local Emergency Directors (LEDs), and Incident Commander (IC). Also notify the Beale AFB Point of Contact. These disciplines rely on each other for full cooperation and support of maintaining and implementing an emergency response program.

9.9.2 Immediate Local Action Required

Various potential hazards and conditions can be encountered at any time, making prompt “on-the-spot” action by the individual discovering the emergency an absolute necessity. However, when the emergency condition obviously requires additional trained assistance, the correct Beale AFB emergency response groups must be notified promptly, and the Point of Contact also should be notified. Local emergency response teams are assigned to each building to respond to a spill situation. The local emergency group is responsible for being prepared to effectively cope with any spill and to obtain and assist the efforts of installation emergency response groups as required. It is the responsibility of the Project Manager to ensure that well-trained and well-equipped site and local personnel are maintained in all areas and can respond to the spill situations in the areas for which they are assigned.

9.9.3 Site Emergency Direction

To insure that all emergency response groups function as a team in cases of serious emergency, provision for notifying and directing the emergency response efforts must be properly and adequately made. This authority is given to the IC who is normally the Project Manager on duty at the time an emergency occurs. It is recognized that the IC has many responsibilities: therefore, in times of emergency, he or she must rely heavily upon the performance of trained local and site emergency response groups.

Although written procedures contain the basic aspects of the emergency planning, it is recognized that emphasis must always be directed toward training in basic emergency work. Reliance must

be placed upon the abilities of informed emergency personnel to deal with various situations, as they arise, in areas other than their own. This philosophy and practice provides for versatile emergency response groups, which can effectively handle with any emergency situation.

9.9.4 Spill Control Measures

Inert absorbent materials and neutralizing agents may be used in spill response activities. Foams are useful for vapor control during an acid spill but may cause problems during freezing weather. The applicable response organizations have training and actual spill response experience in using absorbent materials and neutralizing agents. Additional spill response equipment is available, such as patch kits, sewer plugs, and oil skimmers. Training for new equipment will be provided to the appropriate response personnel as required.

GENERAL GUIDELINES FOR RESPONDING TO HAZARDOUS MATERIALS RELEASES OR SPILLS

General

Rigid guidelines cannot be issued for handling all hazardous materials releases. Each incident must be specifically evaluated and appropriately responded to. Personnel safety must be the primary concern. Environmental concerns and property damage are secondary.

The Project Manager must be immediately notified of all releases. The Project Manager is in charge of all emergency activities and may delegate responsibility as deemed necessary. The Project Manager will determine whether or not the local emergency group responds to any incident.

The following guidelines may be used in responding to spills. A full response is not necessary for all releases. However the Project Manager and the Environmental Compliance/Environmental Monitoring and Permitting Department must be notified of all releases. All telephone numbers are presented in the Beale AFB Emergency Directory (see Section 9.1 of this HASP).

1. Any persons, upon receiving a report that spill has occurred, are to obtain all available information:
 - a. Time
 - b. Name and telephone number of person reporting spill
 - c. Exact location
 - d. What was spilled
 - e. How much was spilled
 - f. Current status of spill
 - g. Has material entered drain
 - h. Has the PM been notified.
2. Make the following initial notifications, if they have not been made:
 - a. Project Manager
 - b. Environmental Compliance/Environmental Monitoring and Permitting Department
 - c. Environmental Management Directorate Point of Contact.
3. Project Manager will evaluate available information and request any necessary organizations to respond to the scene (This may be done after arrival at the site).
 - a. Chemical operation's spill response crew
 - b. Health physics
 - c. Industrial safety
 - d. Industrial hygiene
 - e. Environmental monitoring
 - f. Others as deemed necessary.

4. Appropriate response forces will respond to site with mobile telephone pagers (or radios) and any necessary protective gear (rubber boots, rubber gloves, rubber rain suit, half face respirator with “GMCH” combination cartridges, monogoggles, and face shield (a full face mask respirator with GMCH cartridges will replace the half face respirator, monogoggles, and face shield).
5. Approach the site from the upwind side and:
 - a. Report to the Command Post.
 - b. Determine what has happened.
 - c. Determine the materials and contaminants involved.
 - d. Determine hazards and potential hazards.
 - e. Determine whether or not leak has stopped.
 - f. Determine the spread of the materials.
 - g. Determine location of storm drains and if any materials entered the drains.
 - h. Determine any other site-specific information.
6. Obtain any necessary PPE and safety equipment requirements for anyone working in the contaminated areas.
7. Consider the following factors:
 - a. Toxic gas and vapors.
 - b. Chemical reactions.
 - c. Flammability (sparks and electrical equipment).
 - d. Criticality.
 - e. Proper cleanup and transfer equipment and containers for the spilled materials.
 - f. Crowd and traffic control (barricading contaminated areas).
 - g. Creation of dust containing toxic materials during cleanup.
8. Make appropriate recommendations to the Project Manager on:
 - a. Stopping leaks.
 - b. Containing spilled materials.
 - c. Absorbing and/or neutralizing spilled materials.
 - d. Transferring large volumes of spilled materials.
 - e. Take no action.
 - f. Factors in Item 7.

Project Manager should issue appropriate instructions.
9. Verify with Environmental Flight Center (EFC) that sufficient sampling of spilled material and any affected body of water is being performed. Notify EFC of possible contaminants that might be in spilled material and that should be considered in laboratory analysis.
10. Make sure the following information is obtained:
 - a. What happened?
 - b. Names and quantities of materials and contaminants.
 - c. Who is the generator/spiller?
Name _____, Department No. _____, and Telephone No. _____
 - d. Where the spilled material went?
 - e. What time did the incident occur?
 - f. Have violations of discharge permits possible occurred or reportable quantities of hazardous materials been involved?
11. Notify the generator/spiller of the following responsibilities:
 - a. He/she should request disposal/treatment of wastes generated by the cleanup activities.
 - b. He/she may be required to complete a “Problem Report” or “Environmental Incident Report.”
 - c. Response crews may request a charge number for cleanup expenses.
 - d. He/she should develop and implement appropriate corrective actions to prevent incident reoccurrence.
12. After situation is brought under control, provide full details of incident to Environmental Coordinator and Environmental Compliance Department Manager. The Project Manager should be provided with any necessary status report.

9.9.5 Spill Response Training

Specific spill response training is provided principally through three employee-training programs required for all employees involved with the handling of hazardous materials. The first is the Hazard Communication Standard, as required by OSHA 29 CFR 1910.1200, which requires employees to understand the hazards of materials to which they are exposed or are potentially exposed. At SES, this program is provided through the 40-hour HAZWOPER training and annual refreshers to involved individuals by ensuring proper identification of hazardous materials and health and safety procedures, and by making MSDSs available to employees, and instituting job specific training programs.

This training is available to employees and consists of modules comprised of the following subject areas:

- **Corrosives:** This module presents the hazards which corrosives pose, describes exposure symptoms, discusses containers and storage, outlines personal safety precautions, and explains what to do in the event of an emergency.
- **Poisons:** This module discusses the different forms of poisons, safe handling procedures, and proper storage. It emphasizes personal protection as well as emergency methods and first aid.
- **Solvents:** This module concentrates on the health and safety precautions to take when working with solvents. Proper handling, use, and storage of solvents are discussed.
- **Gases:** This module places emphasis on compressed gases due to their widespread use and the physical hazards they pose. It discusses proper moving and storing of gas cylinders, the effects of different gases on the body, personal protection and what to do in an emergency.
- **Oxidizers:** This module addresses the proper safety and health measures to be taken when employees are handling oxidizers. Proper handling, use, and storage of oxidizers are discussed, including information on the use of protective equipment.
- **Carcinogens:** This module describes protection, which is dependent upon a system of safeguards—personal protective gear, engineering controls, administrative controls, or a combination of these three. It covers each control in addition to routes of entry, industrial hygiene, labels, warning signs and posters, MSDSs, and monitoring.
- **Respiratory Protection:** In order to protect the respiratory tract against irritating and poisonous gases, fumes, smoke, and dusts, the worker must be knowledgeable in the proper use of the respirator. Information on the various types of respirators, the requirements to ensure a good fit, and emergency action are presented in this module.

Additional employee training required by OSHA 29 CFR 1910.120 for hazardous waste operations and emergency response personnel includes training on emergency equipment, PPE, container management, containing and cleanup of spills, incident management, medical surveillance, and decontamination.

9.9.6 Site Contingency Plan Overview

The Site Contingency Plan at the demonstration site is to provide and maintain emergency plans dedicated to personal safety, environmental protection, and safe equipment operation. The Site Contingency Plan will be implemented immediately whenever a condition arises that may threaten human health, the environment, or plant processes. These conditions include releases, fires, or explosions.

The Site Contingency Plan will be implemented in the following situations:

1. Fire and/or explosion:
 - a. A fire causes the release of toxic fumes or other hazardous waste constituents
 - b. A fire spreads that could possibly ignite materials at other locations onsite, thus releasing hazardous contaminants or causing heat induced explosions releasing hazardous contaminants
 - c. Use of water or water and chemical fire suppressant could result in contaminated runoff
 - d. An imminent danger exists that an explosion could involve hazardous waste
 - e. An imminent danger exists that an explosion could result in the release of toxic material
 - f. An explosion has occurred that may have resulted in the release of hazardous contaminants.

2. A spill or release of oil, or toxic, or hazardous contaminants:
 - a. The spill could result in the release of flammable liquids or vapors, thus causing a fire or explosion hazard
 - b. The spill could cause the release of toxic liquids or fumes
 - c. The spill can be contained on site, but the potential exists for soil, groundwater, or surface water contamination
 - d. The spill cannot be contained on site, resulting in off-site soil, groundwater, or surface water contamination.

Decontamination of Spills

Operation procedures require that inert absorbent be on hand at all times to contain a spill. When a spill or leak is adequately contained, cleanup procedures begin immediately. SES Emergency Response Coordinator, EFC Point of Contact, and the IC if necessary should be notified in order to provide safe cleanup guidelines and equipment. Subsequently, the contents of a spilled or leaking container are transferred to a sound container or drum that may be placed in an overpack drum. The EM Department evaluates the occurrence and determines if a reportable quantity was released and then provides guidance for the reporting and notification.

If the spill is in a hazardous waste storage area, no additional hazardous wastes will be transferred in the area until the area is properly cleaned. Other on-site storage areas contain sufficient space to accommodate the waste for several weeks.

Storage and Treatment of Released Material

Immediately after an emergency, all intact containers (i.e., drums, polybottles, etc.) will be inspected for leaks, bulges, or any other indication that the containers may have been compromised. If the container is in good condition, it will be moved to a temporary location where containment and weather protection are afforded.

If the container has been compromised, the remaining contents will be transferred to a new container and will be placed in a temporary location. All labeling will be replaced as necessary.

In the event that a spill or release escaped the building and contaminates the soil, the following steps will be taken to assure that all soil containing hazardous constituents has been removed and containerized:

1. Soil showing visible contamination will be excavated immediately.
2. A statistically valid sampling plan that considers the soil type, properties of the spilled material, area affected, volume of the spill, and other factors will be developed.
3. The sampling plan will guide the confirmatory sampling and any additional excavation.
4. Background value(s) will be determined by applying the sampling plan to a similar by unaffected area nearby.
5. Excavation will cease when the analyses show results less than the mean plus two standard deviations of the Beale AFB background value(s).

Any recovered waste, contaminated water, or other contaminated material will be sampled, analyzed, characterized, and placed in appropriate containers. Temporary storage will be located within an unaffected area until repairs are completed or a new permanent site is located. No new hazardous waste storage operations or activities, beyond recovery activities, will be initiated without obtaining prior Beale AFB EFC and regulatory agency approval.

Decontamination of Equipment

Following its use in an emergency or routine maintenance situation, all equipment is cleaned/decontaminated of hazardous substance and toxic chemical or residual excavated materials before being returned to storage. Heavy equipment is brushed off, then decontaminated by use of water hoses, portable high pressure water, or steam cleaners. Decontamination solutions are stored in proper containers for analysis and proper disposal. All large scale or heavy equipment decontamination will take place in a diked decontamination pad/area to control liquid runoff and solids generation.

Expendable supplies (such as disposable PPE) are inventoried and replaced as part of the decontamination activities for the next emergency. Decontamination activities are performed after the

generated residues are containerized and sampled, as necessary, to insure that only compatible materials are stored together.

Completion of the site cleanup includes maintaining equipment and replenishing supplies. Completion activities are reported to the building and the Spill Committee Representative before resuming normal operations.

Decontamination of Personnel

The plant or base emergency truck, ambulances, and fire apparatus carry emergency equipment to decontaminate injured personnel and responders, to the emergency or spill if necessary. Emergency decontamination equipment generally consists of responder protective equipment, decontamination solutions, solution containment devices, and contaminated clothing storage bags.

Safety showers or sanitary showers in affected buildings are used for gross decontamination of responders. Decontamination solutions are stored in proper containers for analysis.

10. Environmental Compliance Plan

This HASP is based upon state regulations and SES policies and procedures. Some actions that are indicated are beyond those required by state regulations and represent the application of Best Management Practices by SES.