United States
Environmental Protection
Agency

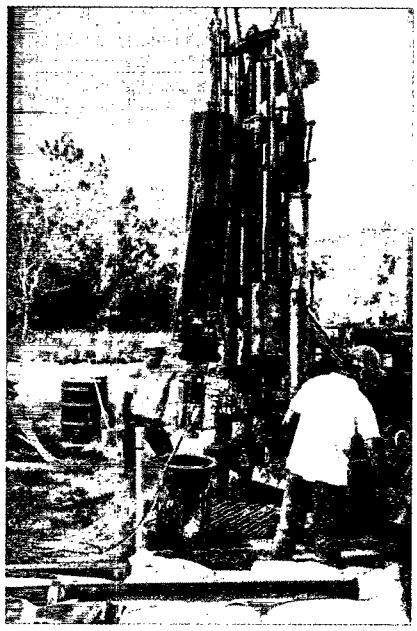
Office of Research and
Development
Washington DC 20460

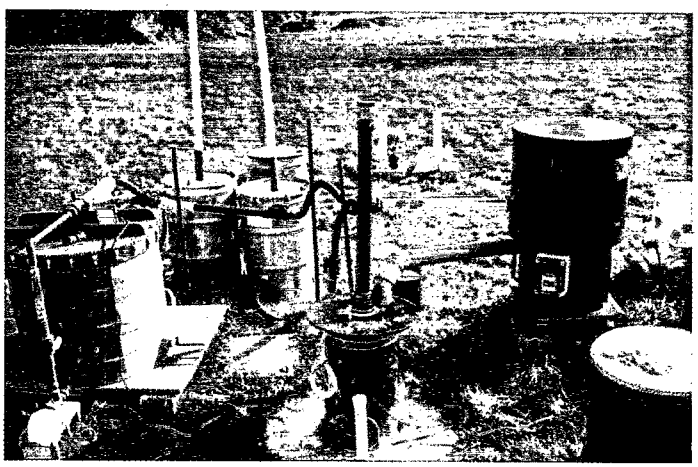
EPA/540/R-99/503
June 1999

EPA

ELI/SBP's UVB (Vacuum Vaporization Well) System for Treatment of VOC-Contaminated Soils

Innovative Technology Evaluation Report





SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/R-99/503
June 1999

ELI/SBP's UVB (Vacuum Vaporization Well) System for Treatment of VOC-Contaminated Soils

Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Printed on Recycled Paper

Notice

The information in this document has been funded by the U.S. Environmental Protection Agency (EPA) under Contract Nos. 68-C0-0048 and 68-C5-0001 to Science Applications International Corporation (SAIC). It has been subjected to the Agency's peer and administrative reviews and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

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

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

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

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

This report summarizes the findings of an evaluation of the Unterdruck-Verdampfer-Brunnen (UVB) technology developed by IEG Technologies (IEG) and licensed in the eastern U.S. by Environmental Laboratories Inc. (ELI) and SBP Technologies (SBP). This evaluation was conducted under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program. The UVB technology was demonstrated over a period of 14 months from July 1994 through October 1995 at the Sweden-3 Chapman Landfill in Sweden, NY. A modified microbial system employing an in-well biofilter was demonstrated, along with the ENSR/Larsen Biovault technology and the R.E. Wright Environmental, Inc. In Situ Bioventing System, as part of a multivendor bioremediation demonstration. The primary objective of the demonstration was to determine the effectiveness of the UVB process in reducing the concentrations of six target VOCs in the vadose zone to below New York State Department of Environmental Conservation Soil Cleanup Criteria (NYSDEC). The VOCs and criteria are: acetone 0.2 ppm; methyl ethyl ketone 0.6 ppm; 4-methyl-2-pentanone 2 ppm; cis-1,2-dichloroethene 0.6 ppm; trichloroethene 1.5 ppm; and tetrachloroethene 2.5 ppm. After 5.5 months, 65% of the approximately 50 soil samples from both the vadose zone and saturated zones met the NYSDEC criteria. Seventy percent met the criteria after 14 months.

Contents

Notice ii
Foreword iii
Abstract iv
Tables vii
Figures viii
Abbreviations and Acronyms ix
Acknowledgments xi
Executive Summary ES-1

1.0 Introduction 1-1
1.1 Background 1-1
1.2 Brief Description of Program 1-3
1.3 The SITE Demonstration Program and Reports 1-3
1.4 Purpose of the Innovative Technology Evaluation Report (ITER) 1-4
1.5 Technology Description 1-4
1.6 Key Contacts 1-5

2.0 Technology Applications Analysis 2-1
2.1 Key Features of the UVB Treatment System 2-1
2.2 Operability of the Technology 2-1
2.3 Applicable Wastes 2-2
2.4 Availability and Transportability of Equipment 2-2
2.5 Materials Handling Requirements 2-2
2.6 Site Support Requirements 2-3
2.7 Range of Suitable Site Characteristics 2-3
2.8 Limitations of the Technology 2-3
2.9 ARARS for the ELI/SBP UVB Treatment Process 2-3
2.9.1 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) 2-4
2.9.2 Resource Conservation and Recovery Act (RCRA) 2-4
2.9.3 Clean Air Act (CAA) 2-7
2.9.4 Clean Water Act (CWA) 2-7
2.9.5 Safe Drinking Water Act (SDWA) 2-7
2.9.6 Occupational Safety and Health Administration (OSHA) Requirements 2-8

3.0 Economics 3-1
3.1 Introduction 3-1
3.2 Conclusions 3-1
3.3 Issues and Assumptions 3-4
3.4 Basis for Economic Analysis 3-5

Contents (Cont'd)

3.4.1 Site and Facility Preparation Costs 3-5
3.4.2 Permitting and Regulatory Costs 3-7
3.4.3 Equipment Costs 3-7
3.4.4 Startup and Fixed Costs 3-8
3.4.5 Labor Costs 3-8
3.4.6 Supplies and Consumables Costs 3-8
3.4.7 Utilities Costs 3-8
3.4.8 Effluent Treatment and Disposal Costs 3-8
3.4.9 Residuals and Waste Shipping, Handling and Transport Costs 3-8
3.4.10 Analytical Costs 3-9
3.4.11 Facility Modification, Repair and Replacement Costs 3-9
3.4.12 Site Restoration Costs 3-9

4.0 Treatment Effectiveness During the Site Demonstration 4-1
4.1 Background 4-1
4.2 Detailed Process Description 4-2
4.3 Methodology 4-2
4.4 Performance Data 4-6
4.4.1 VOC Concentrations in Soil Initially and at Completion 4-6
4.4.2 Change in Mass of VOCs in Soil with Time 4-7
4.4.3 VOCs in Air Samples 4-15
4.4.4 Mass Removal of VOCs - Biodegradation Contribution 4-15
4.4.5 Other Supporting Evidence for Biodegradation 4-18
4.4.6 UVB Well Characteristics/In Situ Biofilter Behavior 4-19
4.4.7 Groundwater 4-19
4.4.8 Distinctions between Vadose and Saturated Zones 4-20
4.4.9 Process Residuals 4-20

5.0 Other Technology Requirements 5-1
5.1 Environmental Regulation Requirements 5-1
5.2 Personnel Issues 5-1
5.3 Community Acceptance 5-2

6.0 Technology Status 6-1
6.1 Previous Experience 6-1
6.2 Scaling Capabilities 6-1

Bibliography 7-1

Appendix-Vendors' Comments A-1

Tables

Table		Page
ES-1	Evaluation Criteria for the ELI/SBP UVB Treatment System	ES-4
2-1	Federal and State Applicable and Relevant and Appropriate Requirements (ARARs) for the ELI/SBP UVB Treatment Process	2-5
3-1	Estimated Costs for Pilot-Scale Treatment Using the ELI/SBP Treatment System	3-2
3-2	Estimated Costs in $/m^3 for Treatment Using the ELI/SBP Treatment System to Remediate 10,092 m^3 (Full-Scale)	3-4
4-1	NYSDEC Soil Cleanup Criteria for Demonstration	4-1
4-2	ELI/SBP Achievement of New York State Cleanup Criteria	4-6
4-3	Masses of Contaminants (gm) in Plot at Various Times	4-7
4-4	Mass of VOCs Removed in Air Stream by ELI/SBP Technology	4-16
4-5	Removal of Critical VOCs from Air Stream by Ex Situ Biofilters	4-16
4-6	Removals after 14 Months Using PQL for ND	4-17
4-7	Average Microbial Counts in ELI/SBP Demonstration Soil and Groundwater	4-19
4-8	Percent Removals Based in the In Situ Biofilter on VOC Concentrations	4-20
4-9	Vadose/Saturated Zones Approximate % Removals	4-21

Figures

Figure		Page
1-1	Northern area of site	1-2
3-1	Cost distribution	3-6
4-1	UVB System schematic	4-3
4-2	ELI/SBP treatment plot showing soil boring locations	4-5
4-3	Acetone masses at three times	4-8
4-4	MEK masses at three times	4-9
4-5	MIBK masses at three times	4-10
4-6	Cis-DCE masses at three times	4-11
4-7	TCE masses at three times	4-12
4-8	PCE masses at three times	4-13
4-9	Toluene masses at three times	4-14

Abbreviations and Acronyms

AQCR	Air Quality Control Regions
ATTIC	Alternative Treatment Technology Information Center
CAA	Clean Air Act
CERI	Center for Environmental Research Information
CFR	Code of Federal Regulations
cfm	Cubic feet per minute
Cis-DCE	Cis-1,2-dichloroethene
CWA	Clean Water Act
dscfm	dry standard cubic feet per minute
ELI/SBP	Environmental Laboratories, Inc. and SBP Technologies, Inc.
gm/cm^3	Gram per cubic centimeter
FS	Feasibility Study
ITER	Innovative Technology Evaluation Report
GAC	Granular Activated Carbon
HSWA	Hazardous and Solid Waste Amendments
LDR	Land Disposal Restriction
MDL	Method Detection Limit
MEK	2-Butanone (methyl ethyl ketone)
MIBK	4-Methyl-2-pentanone (methyl isobutyl ketone)
OSHA	Occupational Safety and Health Administration
ND	Non-Detectable, not detected, less than detection limit
NRMRL	National Risk Management Research Laboratory (EPA)
NYSCHWM	New York State Center for Hazardous Waste Management
NYSDEC	New York State Department of Environmental Conservation
ORD	Office of Research and Development (EPA)
OSWER	Office of Solid Waste and Emergency Response (EPA)
PCE	Tetrachloroethene
PID	Photoionization Detector
POTW	Publicly Owned Treatment Works
PPE	Personal Protective Equipment
PQL	Practical Quantitation Limit
PVC	Polyvinyl Chloride
POTW	Publicly Owned Treatment Works
QAPP	Quality Assurance Project Plan
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Amendments
SWDA	Solid Waste Disposal Act
SITE	Superfund Innovative Technology Evaluation
S.U.	Standard Units

Abbreviations and Acronyms (continued)

SUNY	State University of New York
TER	Technology Evaluation Report
TCE	Trichloroethene
VOC	Volatile Organic Compound
μg/Kg	Micrograms per kilogram
USEPA	United States Environmental Protection Agency

Acknowledgments

This report was prepared under the direction of Ms. Annette Gatchett and Ms. Michelle Simon, the EPA Technical Project Managers for this SITE demonstration at the National Risk Management Research Laboratory (formerly the Risk Reduction Engineering Laboratory) in Cincinnati, Ohio. The demonstration required the services of numerous personnel from the New York State Department of Environmental Conservation (NYSDEC), the New York State Center for Hazardous Waste Management (NYSCHWM), Environmental Laboratories, Inc., SBP Technologies, Inc., and Science Applications International Corporation. The cooperation and efforts of these organizations and personnel are gratefully acknowledged.

Executive Summary

This report summarizes the findings of an evaluation of the Environmental Laboratories, Inc. (ELI) and SBP Technologies, Inc. (SBP) UVB Treatment System (Vacuum Vaporization Well). The system was tested for the remediation of soil contaminated with volatile organic compounds (VOCs) at the inactive Sweden-3 Chapman landfill in Sweden, New York. This evaluation was conducted under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program and with the participation of the New York State Department of Environmental Conservation (NYSDEC) and the New York State Center for Hazardous Waste Management (NYSCHWM). Two other technologies also were evaluated at the same time and the same site: The ENSR/Larsen Biovault Treatment Process and the R. E. Wright Environmental, Inc. In Situ Bioventing Technology. The results of those evaluations are described in separate reports.

Overview of Site Demonstration

According to the developers, the ELI/SBP UVB Treatment Process is an in situ bioremediation technology that combines air stripping, extraction, sparging, and bioremediation to remove VOCs from soil and groundwater. The process was developed by IEG Technologie GmbH of Germany and is licensed in the eastern U.S. by Environmental Laboratories, Inc. (ELI) and SBP Technologies, Inc. (SBP). It is based on the circulation of groundwater through a centrally-located "Vacuum Vaporization" well and the surrounding soil formation. In addition to a pump, the well contains an in situ biofilter where microbial growth can be accelerated by organic contaminant biodegradation. The microbial growth is circulated via the groundwater to the saturated zone for in situ biodegradation of organic contaminants. Air drawn through the system to assist water circulation and to provide oxygen for biological activity also strips volatiles from the vadose zone. These volatiles may be removed by an aboveground carbon cartridge or, as in the demonstration, by an aboveground vapor-phase biofilter.

The UVB System consists of a submersible pump and an in-ground biofilter cartridge containing a special carbon-based support. The system is installed in a large diameter well drilled to the bedrock. Air is pumped through the biofilter and, together with the submersible pump, causes groundwater to circulate through the system and back through the formation.

The demonstration was conducted in a 50 x 50 ft plot at the Sweden-3 Chapman landfill site in Sweden, New York under EPA's SITE program from the middle of July 1994 to early December 1994. Based on preliminary assessment of the results to that time, the evaluation was continued to the following October. At the outset and during the demonstration, soil and groundwater were found to be very non-uniformly contaminated with trichloroethene (TCE), tetrachloroethene (PCE), cis-1,2-dichloroethene (cis-DCE), acetone, 2-butanone (MEK), 4-methyl-2-pentanone (MIBK), toluene, and other aromatic compounds. These characteristics were considerably different from those anticipated based on available characterization data for the site.

A primary objective of the demonstration was to determine the effectiveness of the UVB System in reducing the target VOC contaminants in the vadose zone soil to below the New York State Department of Environmental Conservation (NYSDEC) Soil Cleanup Criteria which are: acetone: 0.2 mg/Kg, MEK: 0.6 mg/Kg, MIBK: 2 mg/Kg, DCE: 0.6 mg/Kg, TCE: 1.5 mg/Kg, and PCE: 2.5 mg/Kg. (The criteria do not differentiate between cis- and trans-dichloroethene.) Specifically, the developers expected that 90% of the soil samples collected from the plot would meet the NYSDEC Soil Cleanup Criteria for the six target contaminants after six months (one season) of treatment. A second primary objective was to attempt to evaluate the developers' assertion that biodegradation would be the dominant mechanism for contaminant removal. Evaluation of this objective was qualitative in nature because the sampling procedures were not designed specifically for representative mass balances or to quantify the extent of biodegradation. Other, circumstantial evidence collected during the project was used to aid in assessing the role of biodegradation. As the result of a late start for the demonstration, unforeseen site and operational problems, and the unique nature of the process, the investigation was

extended from one season (~6 months) through the following warm season, a total of about fourteen months.

Conclusions from this SITE Demonstration

Based on this SITE pilot-scale Demonstration, the following primary conclusion may be drawn about the applicability of the ELI/SBP UVB Treatment Process:

- The technology was not able to reduce VOC contamination of the vadose and saturated zone soil in the targeted depth interval to levels that satisfy NYSDEC Soil Cleanup Criteria within 6 months. The technology did not meet the 90% objective after 14 months of essentially continuous operation. Compliance with the NYSDEC Cleanup Criteria for all six contaminants after 5.5 and 14 months were 65% and 70%, respectively.

The discussions presented below are possible and reasonable explanations as to the mechanism responsible for VOC removal. It should be noted that at the outset of the project, due to limited funding, soil samples were not collected to represent statistically valid average VOC concentrations for the site. These conclusions are, therefore, limited and qualitative because of the soil sampling procedures.

The soil samples collected do not represent a site average because the soil core sections were scanned for specific VOC "hot spots" and sampled in those areas, which may have created a known bias when the soil data were analyzed. This was done to minimize the chance of collecting "non-detect" VOC samples. Mass balances for soil data are therefore uncertain; however, some circumstantial evidence exists to suggest the following:

- The UVB Treatment Technology did achieve removals between 54% and 73% for the three ketones (acetone, MEK, and MIBK) from the soil over 14 months by a combination of stripping and other mechanisms. Stripping accounted for only a small portion of the apparent removal, and biodegradation potentially accounted for all or part of the remaining removal.
- Removal of the chlorinated volatile hydrocarbons (cis-DCE, TCE and PCE), appeared to be much lower (<40%) over the 14-month demonstration. The role of biodegradation could not be estimated.
- The accumulated results and observations (e.g., mass removal accounting, high cis-1,2-DCE concentrations, changes in CO_2 and O_2 concentration in air samples, and changes in microbial populations), did not provide strong evidence for biodegradation as a viable mechanism, particularly for the removal of chlorinated VOCs. The detection of vinyl chloride in the air stream and in groundwater suggests that anaerobic degradation may also have been underway.
- Although not a critical VOC for this demonstration, removal of toluene was effective, with calculated removal of 4% by all mechanisms after about 5.5 months and 87% after 14 months. Since stripping appeared to account for only a small portion of the toluene removal, biodegradation may account for a large portion of this removal.
- In the absence of controls, it cannot be stated with certainty that the UVB Treatment Process enhanced the natural VOC removal or accelerated bioremediation.

Other observations, which were not based upon the primary data collection procedures, include:

- The cost associated with applying this technology to the treatment of an assumed vadose zone of 480 m^3 (628 yd^3) was \$453/m^3 (\$347/yd^3). If treatment is assumed to occur throughout the vadose and saturated zones, a depth of 3.3 m (11 ft), then the treatment cost would decrease to \$247/m^3 (\$189/yd^3) for the 14-month demonstration.
- The cost associated with applying this technology to the treatment of 10,092 m^3 (13,200 yd^3) of vadose zone contaminated with VOCs as in the demonstration is approximately \$195/m^3 (\$149/yd^3) for a 14-month remediation period. Extending the duration of the remediation to 3 years or 5 years, as suggested by the developers, increases total cost to \$339/m^3 (\$259/yd^3) and \$491/m^3 (\$375/yd^3), respectively. Soil characteristics and VOC types and concentrations may make it necessary to extend the treatment period or increase the addition of amendments, which would increase the cost accordingly.
- Measurements of VOC concentrations in the circulating groundwater entering and leaving the in situ biofilter indicate that some removal is taking place. It was not determined whether this is due to adsorption on the carbonaceous substrate, biodegradation, other mechanisms, or a combination of mechanisms.
- In general terms, the concentrations of the critical VOCs in the groundwater samples obtained from monitoring wells appear to decrease with both time and distance from the central UVB well.
- The redesigned ex situ gas phase biofilters operated successfully for the last eight months of the project. While concentrations in the air stream were low, some removal (50% to 75%) appears to

have been achieved for all of the VOCs. Again, the removal mechanisms cannot be stated with certainty.

The ELI/SBP UVB Treatment System was evaluated based on the nine criteria used for decision-making in the Superfund Feasibility Study (FS) process. Table ES-1 presents this evaluation.

Table ES-1. Evaluation Criteria for the ELI/SBP UVB Treatment System (page 1 of 2)

Overall Protection of Human Health & the Environment	Compliance with Federal ARARs	Long-term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-term Effectiveness
Provides long-term protection by eliminating organic contaminants from soil and groundwater. Minimizes further groundwater contamination and off-site migration. May require measures to protect workers and community during drilling and treatment.	May require compliance with RCRA treatment, storage, and land disposal regulations (of a hazardous waste). Construction, well drilling and operation of on-site treatment unit may require compliance with location-specific ARARs. Emission controls may be needed to ensure compliance with air quality standards for volatile compounds. Wastewater discharge to POTW or surface bodies requires compliance with Clean Water Act regulations.	Potentially removes contamination source effectively. Treats contaminated vadose and saturated soil and groundwater. Involves some residuals treatment and disposal, e.g., extracted air, well cuttings, well development water.	Potentially reduces toxicity and mobility of soil contaminants through destructive treatment. Does not produce any known toxic intermediates as a result of biodegradation when properly conducted; vinyl chloride production must be controlled/minimized. May initially distribute contaminants throughout zone of influence.	May present short-term risks to workers and community, including noise exposure and exposure to airborne contaminants (e.g., dust, volatile organic compounds, etc.) released into the air during drilling and operation. These can be minimized with correct handling procedures. Potentially provides reduction in contamination levels; duration of treatment determines final contaminant levels.

Table ES-1. Evaluation Criteria for the ELI/SBP UVB Treatment System (page 2 of 2)

Implementability	Cost	Community Acceptance	State Acceptance
Major equipment is limited to blower system, control panel, and in situ and ex situ biofilters. Support equipment includes drill rigs for wells and monitoring equipment (e.g., for air flow, pH, and temperature). UVB wells can be constructed in <2 weeks. Requires heavy equipment, e.g., crane, to install and position system. Once on-site, the blower and control system can be assembled and ready within 3 days after the central well and casing are installed. After treatment is complete, the system can be demobilized in three days. The biofilter and piping can be cleaned and reused or discarded. Granular carbon can be returned to suppliers for regeneration.	Demonstration cost was \$453/m^3 (\$347/yd^3) for treatment of 50 x 50 ft of vadose zone to a depth of about 6 ft, remediating a total of 480 m^3 (628 yd^3) of soil. Actual cost is site-specific and dependent upon the volume of soil, soil characteristics, contaminants present, and original and target cleanup levels. Cost data in this table are for treating VOC-contaminated soil similar to the SITE demonstration soil. Remediation of 10,092 m^3 (13,200 yd^3) of a site similar to that of the demonstration, using 22 wells and treatment duration of 14 months, 3 years, and 5 years, was estimated to cost \$195/m^3 (\$149/yd^3), \$339/m^3 (\$259/yd^3), and \$491/m^3 (\$375/yd^3), respectively.	Minimal short-term risks presented to the community make this technology favorable to the public. Public knowledge of common bioremediation application (e.g., wastewater treatment) eases community acceptance for hazardous waste treatment using this technology. Use of naturally-occurring microorganisms makes treatment by this technology a favorable option to the community. Noise from blower operation may impact community in the immediate vicinity, but is readily minimized.	If remediation is conducted as part of a RCRA corrective action, state regulatory agencies may require permits to be obtained before implementing the system. These may include a permit to operate the treatment system, an air emissions permit (if volatile compounds are present), a permit to store contaminated soil for more than 90 days, and a wastewater discharge permit.

Section 1.0
Introduction

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) Program, discusses the purpose of this Innovative Technology Evaluation Report (ITER), and describes the IEG Technologie GmbH "Unterdruck-Verdampfer-Brunnen (UVB)" Technology (Vacuum Vaporization) licensed to the team of Environmental Laboratories, Inc. and SBP Technologies, Inc. For additional information about the SITE Program, this technology, and the demonstration site, key contacts are listed at the end of this section.

1.1 Background

Preliminary discussions between the New York State Department of Environmental Conservation (NYSDEC) and the U.S. Environmental Protection Agency (EPA) in 1992 led to an agreement to evaluate several bioremediation technologies at one site. The New York State Center for Hazardous Waste Management (NYSCHWM), under the leadership of the former Director, Dr. Ralph Rumer, brought together a panel of interested experts in 1993 to develop a suitable protocol for such a group of demonstrations and to identify potentially suitable sites. The original plan was for the NYSDEC to issue a Request for Proposal for four different types of technologies: ex situ bioremediation alone; ex situ coupled with additional technology (e.g., physical/chemical); in situ bioremediation alone; and in situ bioremediation coupled with additional technology. It was agreed that NYSDEC would provide funding to the selected developers for site preparation and installation and operation of their systems while EPA would provide the funds to develop an independent Quality Assurance Project Plan (QAPP) and to carry out an independent evaluation of the results from each developer's demonstration.

The Sweden-3 Chapman Site, located in Sweden, New York, near Rochester, was selected for the demonstration after considering others. It is an inactive 2-acre landfill that was used to dispose of construction and demolition debris and hazardous wastes between 1970 and 1978. Studies conducted in 1992, after 2,300 buried drums were removed, identified three areas of heavily contaminated soil. The focus of the demonstration was on the largest of these, referred to as the "northwestern source area" (Figure 1-1) which had been found in earlier soil and groundwater examinations to be contaminated with trichloroethene (TCE), tetrachloroethene (PCE), acetone, 2-butanone (MEK), 4-methyl-2-pentanone (MIBK), toluene, xylenes and various other substituted hydrocarbons.

The ELI/SBP UVB Treatment Process was one of three technologies selected through New York State's competitive bidding process. The others were an ex situ biovault technology developed by ENSR Consulting and Engineering and Larsen Engineers and an in situ bioventing technology offered by R.E. Wright Environmental, Inc.

Although originally expected to provide oversight services only, it was quickly apparent that EPA's evaluation contractor, Science Applications International Corporation (SAIC), would need to play a larger role to assure the validity and uniformity of the data that would be generated by the three simultaneous pilot-scale demonstrations. To limit costs, SAIC was supported in the expanded sampling and analysis effort by faculty and graduate students of the State University of New York (SUNY) at Buffalo who were funded by the NYSCHWM. The added personnel provided much needed manpower and they gained valuable actual experience in field activities under the guidance of vendor and contractor personnel.

Because of time and financial constraints, it was necessary to rely on existing site characterization data, some of which were several years old, in selecting the areas to be used by each of the three developers and in planning the objectives and process design for the technologies. Combined with the large tracts that were necessary to evaluate three distinct technologies, this proved to be unfortunate when soil geology and chemical contamination observed during the demonstration (for any of the developers) proved to be significantly different from the historical data, primarily in the relative concentrations of the VOCs and their distribution over the tract - both laterally and vertically.

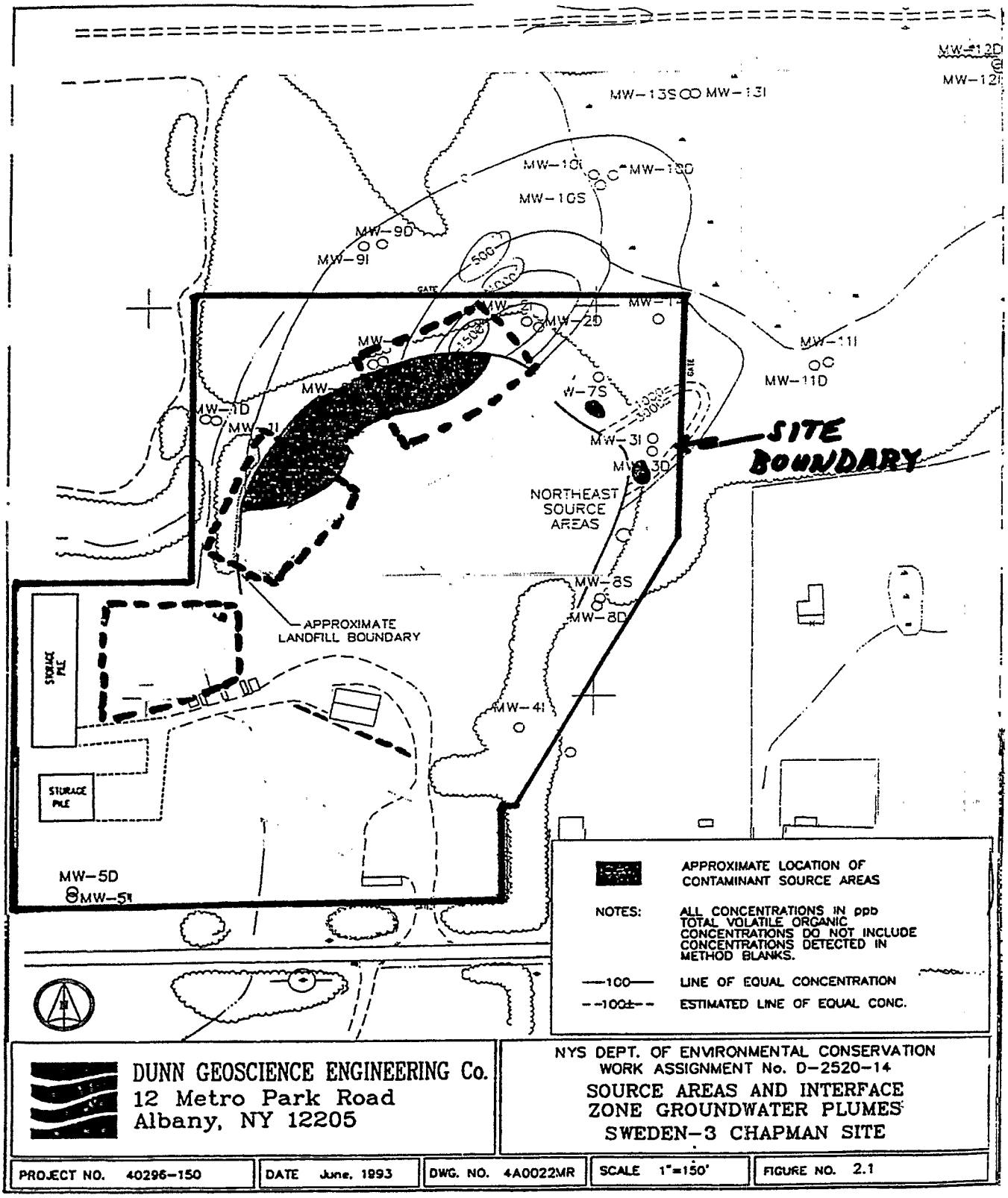


Figure 1-1. Northern area of site.

The ELI/SBP UVB SITE Demonstration was conducted to evaluate the developers' treatment process for vadose zone soil contaminated with volatile organic compounds (VOCs). A single UVB Well System was utilized for this demonstration. The system (shown later in Figure 4-1) consists of a submersible pump and an in-ground biofilter cartridge containing a special carbon-based support, which are installed in a wide bore well drilled to the bedrock. Air is pumped to the biofilter and, together with the submersible pump, causes groundwater to circulate through the system and back into the formation thus contributing to stripping volatiles from the water.

One primary objective of the Demonstration was to determine the effectiveness of the technology in reducing VOC contamination in the vadose zone sufficiently to meet NY State Department of Environmental Conservation (NYSDEC) Cleanup Criteria. As a remediation goal to evaluate this objective, the developers expected that 90% of the soil samples collected from the anticipated vadose zone in the plot after 6 months of operation would be below NYSDEC Cleanup Criteria for six target VOCs (acetone, MEK, MIBK, TCE, PCE and DCE), as shown later in Table 4-1. In addition, as a second primary objective, the developers asserted that biodegradation would be the dominant mechanism of contaminant removal from the formation. As a secondary objective, ELI/SBP also expected that groundwater would exhibit significant reductions in VOC concentrations as a result of circulation through the in situ biofilter. Finally, as an adjunct to the project, the developers also sought to evaluate the effectiveness of ex situ biofilters in removing VOCs from the air extracted from the formation.

1.2 Brief Description of Program

The SITE Program is a formal program established by the EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA). The SITE Program promotes the development, demonstration, and use of new or innovative technologies to clean up Superfund sites across the country.

The SITE Program's primary purpose is to maximize the use of alternatives in cleaning hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of three major elements:

- the Demonstration Program,
- the Consortium for Site Characterization Technologies, and
- the Technology Transfer Program.

The objective of the Demonstration Program is to develop reliable performance and cost data on innovative technologies so that potential users can assess the technology's site-specific applicability. Technologies evaluated are either available commercially or close to being available for full-scale remediation of Superfund sites. SITE demonstrations usually are conducted at hazardous waste sites under conditions that closely simulate full-scale remediation conditions, thus assuring the usefulness and reliability of the information collected. Data collected are used to assess: (1) the performance of the technology; (2) the potential need for pre- and post-treatment of wastes; (3) potential operating problems; and (4) the approximate costs. The demonstration also provides opportunities to evaluate the long term risks and limitations of a technology.

Existing and new technologies and test procedures that improve field monitoring and site characterizations are explored in the Consortium for Site Characterization Technologies (CSCT) Program. New monitoring technologies, or analytical methods that provide faster, more cost-effective contamination and site assessment data are supported by this program. The CSCT Program also formulates the protocols and standard operating procedures for demonstration methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Demonstration and CSCT Programs through various activities. These activities increase awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer activities is to develop interactive communication among individuals requiring up-to-date technical information.

1.3 The SITE Demonstration Program and Reports

Technologies are selected for the SITE Demonstration Program through annual requests for proposals. This solicitation ended in 1995. ORD staff reviews the proposals to determine which technologies show the most promise for use at Superfund sites. Technologies chosen must be at the pilot- or full-scale stage, must be innovative, and must have some technological and/or cost advantage over existing technologies. Mobile technologies are of particular interest.

Once the EPA has accepted a proposal, cooperative agreements between the EPA and the developer establish responsibilities for conducting the demonstration and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is expected to pay any costs for transport, operation, and removal of the equipment. The EPA is responsible for

project planning, sampling and analysis, quality assurance and quality control, preparing reports, disseminating information, and transporting and disposing of treated waste materials.

The results of Demonstration Programs are published in three documents: the SITE Demonstration Bulletin, the Technology Capsule, and the Innovative Technology Evaluation Report (ITER). The Bulletin provides preliminary results of the field demonstration and the Technology Capsule provides relevant information on the technology, emphasizing key features of the results of the SITE field demonstration. The ITER provides detailed information on the technology investigated and the results of the SITE field demonstration. An additional report, the Technology Evaluation Report (TER), which is not formally published, contains the raw data collected during the demonstration and provides a quality assurance review of the data. Both the SITE Technology Capsule and the ITER are intended for use by remedial managers making a detailed evaluation of the technology for a specific site and waste.

1.4 Purpose of the Innovative Technology Evaluation Report (ITER)

This ITER provides information on the ELI/SBP UVB Treatment Process for treatment of VOCs in soils and includes a comprehensive description of this demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision-makers carrying out specific remedial actions. The ITER is designed to aid decision-makers in evaluating specific technologies for further consideration as applicable options in a particular cleanup operation. This report represents a critical step in the development and commercialization of a treatment technology.

To encourage the general use of demonstrated technologies, the EPA provides information regarding the applicability of each technology to specific sites and wastes. The ITER includes information on cost and desirable site-specific characteristics. It also discusses advantages, disadvantages, and limitations of the technology.

Each SITE demonstration evaluates the performance of a technology in treating a specific waste matrix. The characteristics of other wastes and other sites may differ from the characteristics of the treated waste. Therefore, a successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.5 Technology Description

The UVB Treatment Process combines in situ air stripping with bioremediation to remove VOCs from soils. The system used by the developers (see Figure 4-1) at the site consisted of an aboveground blower connected to a specially adapted groundwater well. The upper portion of the well contained a negative-pressure in situ stripping reactor and an integrated bioreactor (fixed film activated carbon bioreactor with slow-release inorganic nutrients), both located above the expected seasonal high water table. The lower portion of the well, below a packer, contained buoyancy chambers and a submersible pump to allow for fluctuations in the water table and to insure a constant supply of groundwater to the bioreactor.

In operation, the aboveground blower induces a suction in the stripper, drawing in ambient air through a centrally located pipe as well as from the surrounding vadose zone soil formation, while raising the level of water already present in the bioreactor. The ambient air infiltrating the surrounding soil formation contains any VOCs that may have volatilized. It also increases the oxygen concentration of the groundwater/soil matrix and stimulates indigenous microbes to enhance the biodegradation of contaminants. The ambient air bubbles through the raised groundwater, stripping VOCs in the process. The VOC laden air is then exhausted by the aboveground blower through a combination of vapor-phase bioreactors and an activated carbon filter on the positive pressure side of the blower.

After treatment in the stripper reactor, the elevated groundwater is discharged back into the upper soil stratum and percolates through the vadose zone back to the natural level of the groundwater, again picking up any contaminants that are adsorbed onto the soil matrix. This sets up a groundwater circulation loop that eventually returns the re-contaminated groundwater to the bottom of the UVB treatment system for another pass. This circulation cell constantly transports contaminants, nutrients, oxygen and indigenous bacteria through the affected soil profile. The relative contributions of the physical "stripping" effect and the biological effect vary according to site specific conditions.

Dewatering is not considered essential for efficient operation of this system. Treatment of the phreatic and capillary fringe zones occur simultaneously. The system can be operated in either a standard flow mode, as described above, or in a reverse-flow circulation mode through the addition of a support pump. Flow modes can be readily converted in the field, according to the developers.

The in situ bioreactor utilizes indigenous microflora on a fixed-film which can be augmented with other types of contaminant-degrading microbes, depending on site conditions. The biodegradation of contaminants can be further stimulated by the addition of either liquid or gaseous-phase inorganic nutrients and/or alternative electron acceptors. Injection of heated air increases the biodegradation rate as well as the rate of VOC desorption and movement and can enhance the biodegradation of organic contaminants in regions normally subject to cold winter climates.

1.6 Key Contacts

Additional information on the ELI/SBP UVB Treatment System and the SITE Program can be obtained from the following sources:

Technology Developers

James G. Mueller, Ph.D.
Dames & Moore
One Continental Towers
1701 Golf Road, Suite 1000
Rolling Meadows, IL 60008
(847) 228-0707 Ex 131
Fax: (847) 228-1328

Richard Desrosiers
Mactec, Inc.
1819 Denver West Drive, Suite 400
Golden, CO 80401
(303) 278-3100
Fax: (303) 278-5000

The SITE Program

U.S. EPA SITE Project Manager
Ms. Michelle Simon
U.S. EPA NRMRL
26 W. Martin Luther King, Jr. Dr.
Cincinnati, OH 45268
(513) 569-7469
Fax (513) 569-7676
Email: simon.michelle@epamail.epa.gov

Mr. Robert A. Olexsey, Director
Land Remediation and Pollution Control Division
U.S. Environmental Protection Agency
26 W. Martin Luther King, Jr. Drive
Cincinnati, Ohio 45268
(513) 569-7861

Information on the role of the New York State in this project may be obtained from the following sources:

NYSDEC Program Manager
Mr. James Harrington, P.E.
New York State Dept. of Environmental Conservation
50 Wolf Road
Albany, New York 12233
(518) 485-8792
Fax: (518) 457-7743

NYSCHWM Program Director
Prof. Scott Weber
Jarvis Hall
SUNY at Buffalo
Buffalo, New York 14260
(716) 645-2114
Fax: (716)-645-3667

Information on the SITE Program is available through the following on-line information clearinghouses:

- The SITE Home page (www.epa.gov/ord/site) provides general program information, current project status, technology documents, and access to other remediation home pages.
- The OSWER CLU-In electronic bulletin board (http://www.clu-in.com) contains information on the status of SITE technology demonstrations. The system operator can be reached at (301) 585-8368.

Technical reports may be obtained by writing to USEPA/NSCEP, P.O. Box 42419, Cincinnati, OH 45242-2419, or by calling 800-490-9198.

Section 2.0
Technology Applications Analysis

This section of the report addresses the general applicability of the ELI/SBP UVB Technology to contaminated waste sites. The analysis is based primarily on the results of this pilot-scale SITE demonstration; information on other similar applications of the technology was not available. SITE demonstration results are presented in Section 4 of this report. The vendors' had the opportunity to discuss the applicability and performance of the technology (and alternate interpretations of the data) in Appendix A.

2.1 Key Features of the UVB Treatment System

The ELI/SBP UVB Treatment System is designed to remove volatile organic compounds (VOCs) and, to some extent, semi-volatile organics (SVOCs) from the saturated zone and from groundwater by a combination of stripping, sparging, extraction, and biodegradation. Biological degradation by naturally-occurring microorganisms reportedly takes place on the in situ biofilter (carbonaceous matrix) and also throughout the saturated zone when microorganisms from the biofilter are dispersed throughout the zone of influence (up to ~40 ft radius) with the circulating groundwater. Biological activity is enhanced by introducing nutrients as needed and supplying oxygen via the air management system. The developers believe that the technology is capable of effectively removing both halogenated and nonhalogenated VOCs by the combined mechanisms.

The developers also claim that the technology can remove VOCs from the vadose zone and the capillary fringe by stripping and/or extraction into the groundwater, where biodegradation may also occur. This aspect was of primary interest for this demonstration.

2.2 Operability of the Technology

The effectiveness of the ELI/SBP UVB Treatment System is dependent on the stimulated growth of naturally-occurring microorganisms on the in situ biofilter and subsequent transfer of these VOC-degrading bacteria to the water table in the zone of influence by the circulating groundwater. Microbial activity may be influenced by soil and groundwater pH and temperature, oxygen availability, water table depth, and available nutrients, all of which, except for water table depth and temperature, can be controlled by the air and water management systems.

The air transfer system consists of an aboveground vacuum blower by which ambient air is drawn into the groundwater as it leaves the in situ biofilter. For the demonstration, air flow was initially maintained at ~50 dscfm on the basis of available soil characterization data, but was later increased to about 180 dscfm. In addition, some air also may be drawn into the formation from the surface. The combined air intake increases the dissolved oxygen concentration before the groundwater is recirculated to the formation. After leaving the blower, the extracted air passes through a water separator. For the demonstration, two ex situ gas phase biofilters were installed in parallel on the exhaust line. During the first ten months of the demonstration, these biofilters created a back pressure and little air appeared to pass through them. The design was modified during the winter of 1994 to a spiral wound biofilter which was successful in allowing approximately equal flows of air through each of two parallel legs. At the same time, the water separator was also modified to provide spray humidification for the air entering the biofilters. Finally, for additional security, each leg of the exhaust line after the biofilter was also equipped with an adsorbent carbon drum to assure that no VOCs escaped to the atmosphere.

Water circulation was accomplished by a submersible pump located at the base of the central UVB well (16 inch diameter), which forced water up through the in situ biofilter. Because of unexpected large fluctuations in the height of the water table, an expandable packer was added between the pump and the in situ biofilter to assure that the water entering the biofilter was groundwater drawn in through the lower screen of the well casing. This modification also simplified the effort involved in manually raising or lowering the in situ treatment system to

accommodate the water table, which fluctuated as much as 4 ft. If necessary, nutrients and pH-adjusting chemicals could be injected into the water in the UVB well through a narrow tube.

For the demonstration, the drain on the water separator was equipped with a sampling tap and with a totalizer water meter so that the volume of water lost from the system could be documented. The discharged water was stored on-site in a 500-gal storage tank.

Typical soil and contaminant characteristics must be established at the outset of the project, including soil porosity and permeability for air and water, moisture content, nutrient availability, pH, metals content, etc. The depth of the water table is particularly important because it determines the relative importance of the saturated and vadose zones in treatment, the estimated zone of influence for groundwater circulation, and, presumably, the mechanisms that predominate. The water table also determines the positioning of the in situ system, which has a limited adjustment range, as noted.

Once the air flow and groundwater circulation rates had been established (and air flow through the ex situ biofilters had been adjusted), the system operated relatively automatically and unattended for the major portion of the demonstration. Local weather-related power failures occasionally did result in system shutdowns until the next weekly visit. The major operational difficulty was the unexpected fluctuations in the water table, which resulted in the need to reposition the in situ system more frequently than anticipated during the course of the demonstration.

During the demonstration, the in situ system was operated in the upward mode, i.e., with water drawn in to the UVB well at the base and discharged to the soil via the upper screen which is intended to be at the water table, but the developers advise that operation can be reversed if desired based on geological conditions. In addition, the developers suggest that heated air could be introduced to overcome cold weather; this was not evaluated.

2.3 Applicable Wastes

According to the developers, the UVB Treatment System is primarily applicable to the saturated zone and to groundwater contaminated with VOCs and semivolatile organic compounds, including fuels, solvents, etc. The developers also claim that contaminated vadose zone and the capillary fringe can be remediated by a combination of soil vapor extraction, stripping, and flushing/extraction into the groundwater. Contaminant volatility and water solubility may affect the mechanism of contaminant removal from each zone.

2.4 Availability and Transportability of Equipment

The ELI/SBP Treatment System requires the use of a drill rig with large auger flights to install the UVB well, which was 16 inches in diameter for the demonstration. The same drill rig or a crane is also needed to install and position the in situ system, consisting of the air sparger, the in situ biofilter, the expandable packer, and the submersible pump. In addition, smaller wells may need to be installed for groundwater monitoring purposes.

The aboveground system, consisting of the air blower, water separator, ex situ biofilters, and carbon adsorption drums, requires a level pad area, ideally concrete, of about 50 ft x 50 ft. (It is assumed that a trailer also would be placed near the system for an extended site remediation.) All pipe connections were made from locally-available 2 inch PVC piping.

All equipment was transported to the demonstration site by truck for which access must be available. For remediation of a larger site, multiple systems would probably be necessary and could require multiple vehicles.

Demobilization required the removal and decontamination of the in situ system before it could be returned to the ELI facility. This was accomplished for the demonstration using steam and water on an available decontamination pad. The biofilter support material (carbonaceous) was removed by ELI/SBP at the conclusion of field activities. All PVC piping was disposed of as non-hazardous. The adsorbent carbon drums were returned to the vendor and regenerated after testing confirmed the carbon was not hazardous.

According to NYSDEC requirements, monitoring well casings were removed and the wells filled with a bentonite/cement mixture. Attempts to remove the casing from the 16-inch diameter UVB well were not successful, even using a large crane, and only a portion of the casing could be removed. The aboveground portion was decontaminated with water, cut into sections and left on site for disposal during site remediation.

Water from the water separator was treated by the NYSDEC with an available adsorbent carbon system and discharged on-site after testing for residual contaminants.

2.5 Materials Handling Requirements

The major materials handling requirement for the UVB technology was construction of the large diameter UVB well. Well cuttings from this well and from the twelve monitoring wells that were installed were placed in 55 gallon drums, labeled, and stored on-site for disposal during site remediation in accordance with instructions from the NYSDEC. Purge water removed from the monitoring

wells before sampling was also stored in labelled 55 gallon drums in accordance with NYSDEC instructions.

Depending on the contaminants present, the excavation of the soil from the UVB well may require special precautions to protect the site and/or operating personnel. For the demonstration, the removed soil was placed on a plastic sheet until it could be containerized. A PID was used frequently to monitor the concentration of volatile hydrocarbons in the vicinity of the drill rig during operation. Under warm, dry conditions, local air concentrations of VOCs or dust may require additional precautions, such as spraying with water.

As noted in the previous section, the only two waste streams generated during operation are the extracted air stream and any water removed from the water separator. Both of these streams were treated with activated carbon.

2.6 Site Support Requirements

Locations suitable for on-site treatment using the UVB Treatment System must be able to provide relatively uninterrupted electrical power for operation of the blower and the submersible pump. The UVB system used in the demonstration employed 3-phase 460 Volts, which required installation of a three-phase converter by a contractor. It does not appear that sufficient power could be readily provided by diesel generators. In addition, a limited amount of distilled water was needed to maintain the moisture level in the ex situ and in situ biofilters until the circulation pattern was created.

2.7 Range of Suitable Site Characteristics

In addition to having roads adequate for heavy equipment (trucks, drill rigs and crane), the site should be free of overhead lines and underground pipes or tanks that could interfere with drill rig or crane operation.

The saturated zone should consist of permeable soil that will enable a reasonable circulation of air and water. For the demonstration, the soil character was such that the radius of influence achieved probably was somewhat less than the anticipated 40 ft. Ideally, the water table above the bedrock should be thick enough to allow the in situ system to float in the well (this was not possible at the Sweden-3 Chapman site). In addition, large fluctuations of the water table require more frequent repositioning of the in situ system and may even exceed the adjustment range of the system, which was about 4 ft for the demonstration.

For successful treatment, the vadose zone must have sufficient thickness and contain minimal fracturing and man-made conduits such as underground utilities so that "short circuiting" by air from the surface is minimized. Air permeability should be in the range customarily used for soil vapor extraction, i.e., greater than 10^{-7}.

Although the in situ system should be minimally impacted by changes in ambient weather since groundwater usually remains at a relatively constant temperature, the intake of ambient air can affect the groundwater temperature and the operating temperature of the in situ biofilter. In addition, if the site (vadose and saturated) is shallow, ambient temperatures may have an impact on soil and groundwater temperature, which can affect the rates of both biodegradation and soil vapor extraction. The developers claim that cold temperatures can be overcome by injecting heated air if necessary.

As with most biological processes, the pH of the soil and groundwater should be in the range of 7 to 9 standard units and the concentrations of heavy metals and other potentially toxic constituents should not be excessive; these levels would need to be established by laboratory testing and/or acclimation of the microbial population.

2.8 Limitations of the Technology

The technology is intended primarily for groundwater and the saturated zone; any treatment of the vadose zone is almost incidental and probably occurs by soil vapor extraction. A very high (i.e., near the ground surface) water table can adversely affect treatment efficiency by allowing contaminated air to escape rather than enter the UVB well system. A narrow saturated zone interval will make it difficult to maintain the in situ UVB system since little buoyancy would be provided by the column of water. In addition, excessive fluctuation in the water table also can make frequent repositioning of the in situ UVB system necessary or even exceed the range of the unit.

For the technology to be effective, the saturated zone must have the porosity for a reasonable radius of circulation to develop for the aerated and bacteria-laden water. While some groundwater flow probably helps to establish the circulation cell, excessive flow could remove contaminants from the radius of influence before degradation can occur.

As with all biodegradation treatments, excessive concentrations of certain heavy metals or even of the VOCs being treated could result in toxicity to the biological system in the soil formation or on the in situ biofilter. Very low ambient temperatures may also slow biodegradation, particularly if the water table is relatively shallow; the developers claim that heated air can be injected to overcome this potential problem.

2.9 ARARS for the ELI/SBP UVB Treatment Process

This subsection discusses specific federal environmental regulations pertinent to the operation of the ELI/SBP UVB Treatment Process including the transport, treatment, storage, and disposal of wastes and treatment residuals.

These regulations are reviewed with respect to the demonstration results. State and local regulatory requirements, which may be more stringent, must also be addressed by remedial managers. Applicable or relevant and appropriate requirements (ARARs) include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act; (2) the Resource Conservation and Recovery Act; (3) the Clean Air Act; (4) the Clean Water Act; (5) the Safe Drinking Water Act, and (6) the Occupational Safety and Health Administration regulations; These six general ARARs are discussed below; specific ARARs that may be applicable to the UVB Treatment Process are identified in Table 2-1.

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

The CERCLA of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 provides for federal funding to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment. As part of the requirements of CERCLA, the EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 Code of Federal Regulations (CFR) Part 300, and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

SARA states a strong statutory preference for remedies that are highly reliable and provide long-term protection. It directs EPA to do the following:

- use remedial alternatives that permanently and significantly reduce the volume, toxicity, or the mobility of hazardous substances, pollutants, or contaminants;
- select remedial actions that protect human health and the environment, are cost-effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible; and
- avoid off-site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist [Section 121(b)].

The UVB Treatment Process can meet each of these requirements. Volume, toxicity, and mobility of contaminants in the waste matrix are reduced as a result of treatment. Volatile organic compounds are biodegraded or removed by other mechanisms. The principal by-products of these reactions are innocuous and generally consist of carbon dioxide, water, and inorganic salts. The need for off-site transportation and disposal of solid waste is eliminated by on-site treatment of the soils.

In general, two types of responses are possible under CERCLA: removal and remedial action. Superfund removal actions are conducted in response to an immediate threat caused by a release of a hazardous substance. Many removals involve small quantities of waste of immediate threat requiring quick action to alleviate the hazard. Remedial actions are governed by the SARA amendments to CERCLA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances or pollutants. The UVB Technology is likely to be part of a CERCLA remedial action. Remedial actions are governed by the SARA amendments to CERCLA.

On-site remedial actions must comply with federal and more stringent state ARARs. ARARs are determined on a site-by-site basis and may be waived under six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken on-site, and justification for the waiver must be clearly demonstrated.

2.9.2 Resource Conservation and Recovery Act (RCRA)

RCRA, an amendment to the Solid Waste Disposal Act (SWDA), is the primary federal legislation governing hazardous waste activities. It was passed in 1976 to address the problem of how to safely dispose of the enormous volume of municipal and industrial solid waste generated annually. Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are also applicable to CERCLA activities. The Hazardous and Solid Waste Amendments (HSWA) of 1984 greatly expanded the scope and requirements of RCRA.

RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. These regulations are only applicable to the UVB Treatment Process if RCRA-defined hazardous wastes are present.

Table 2-1. Federal and State Applicable and Relevant and Appropriate Requirements (ARARs) for the ELI/SBP UVB Treatment Process

Process Activity	ARAR	Description of Regulation	Specific Applicability to the UVB Treatment Process	General Applicability
Waste characterization of untreated wastes	RCRA: 40 CFR Part 261 (or state equivalent)	Standards that apply to identification and characterization of wastes.	Chemical and physical properties of waste determine its suitability for treatment by the UVB Treatment Process.	Chemical and physical analyses must be performed to determine if waste is a hazardous waste.
Well installation	CAA: 40 CFR Part 50 (or state equivalent)	Regulations govern toxic pollutants, visible emissions and particulates.	Applies to well installation and construction activities.	Emission of volatile compounds or dusts may occur.
Waste processing	RCRA: 40 CFR Part 264 (or state equivalent)	Standards apply to treatment of wastes in a treatment facility.	Applicable or appropriate for UVB Treatment Process.	When hazardous wastes are treated, there are requirements for operations, recordkeeping, and contingency planning.
	CAA: 40 CFR Part 50 (or state equivalent)	Regulations govern toxic pollutants, visible emissions and particulates.	During UVB operations, off-gases must not exceed limits set for the air district of operation. Standards for monitoring and recordkeeping apply.	Off-gases may contain volatile organic compounds or other regulated substances.
Storage of auxiliary wastes	RCRA: 40 CFR Part 264 Subpart J (or state equivalent)	Regulation governs standards for tanks at treatment facilities.	Storage tanks for liquid wastes (e.g., decontamination waste) must be placarded appropriately, have secondary containment and be inspected daily.	If storing non-RCRA wastes, RCRA requirements may still be relevant and appropriate.
	RCRA: 40 CFR Part 264 Subpart I (or state equivalent)	Regulation covers storage of waste materials generated.	Potential hazardous wastes remaining after treatment, spent carbon, drilling wastes (e.g., soil cuttings), purge water, and decontamination wastes must be labeled as hazardous waste and stored in containers in good condition. Containers should be stored in a designated storage area and storage should not exceed 90 days unless a storage permit is obtained.	Applicable for RCRA wastes; relevant and appropriate for non-RCRA wastes.

Table 2-1 (Cont'd). Federal and State Applicable and Relevant and Appropriate Requirements (ARARs) for the ELI/SBP UVB Treatment Process

Process Activity	ARAR	Description of Regulation	Specific Applicability to the UVB Treatment Process	General Applicability
Determination of cleanup standards	SARA: Section 121(d)(2)(ii); SDWA: 40 CFR Part 141	Standards that apply to surface and groundwater sources that may be used as drinking water.	Applicable and appropriate for UVB Treatment Process in projects that require groundwater to be treated.	Remedial actions of surface and groundwater are required to meet Maximum Contaminant Level Goals (MCLGs) or Maximum Contaminant Levels (MCLs) established under SDWA.
Waste disposal	RCRA: 40 CFR Part 262	Standards that pertain to generators of hazardous waste.	Waste generated by the UVB Treatment Process which may be hazardous is limited to spent carbon, drilling wastes (e.g., soil cuttings), purge water and decontamination wastes.	Generators must dispose of wastes at facilities that are permitted to handle the waste. Generators must obtain an EPA ID number prior to waste disposal.
	CWA: 40 CFR Parts 403 and/or 122 and 125	Standards for discharge of wastewater to a POTW or to a navigable waterway.	Applicable and appropriate for decontamination wastewaters.	Discharge of wastewaters to a POTW must meet pre-treatment standards; discharges to a navigable waterway must be permitted under NPDES.
	RCRA: 40 CFR Part 268	Standards regarding land disposal of hazardous wastes	Applicable for off-site disposal of auxiliary waste (e.g., PVC piping).	Hazardous wastes must meet specific treatment standards prior to land disposal, or must be treated using specific technologies.

If soils are determined to be hazardous according to RCRA (either because of a characteristic or a listing carried by the waste), essentially all RCRA requirements regarding the management and disposal of this hazardous waste will need to be addressed by the remedial managers. Wastes defined as hazardous under RCRA include characteristic and listed wastes. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from specific and nonspecific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D. RCRA regulations do not apply to sites where RCRA-defined wastes are not present.

Unless they are specifically delisted through delisting procedures, hazardous wastes listed in 40 CFR Part 261 Subpart D currently remain listed wastes regardless of the treatment they may undergo and regardless of the final contamination levels in the resulting effluent streams and residues. This implies that even after remediation, treated wastes are still classified as hazardous wastes because the pre-treatment material was a listed waste.

For generation of any hazardous waste, the site responsible party must obtain an EPA identification number. Other applicable RCRA requirements may include a Uniform Hazardous Waste Manifest (if the waste is transported off-site), restrictions on placing the waste in land disposal units, time limits on accumulating waste, and permits for storing the waste.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S (partially promulgated). These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective action, remediating groundwater, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites and provides information regarding requirements for modifying permits to adequately describe the subject treatment unit.

2.9.3 Clean Air Act (CAA)

The CAA establishes national primary and secondary ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. It also limits the emission of 189 listed hazardous pollutants such as vinyl chloride, arsenic, asbestos and benzene. States are responsible for enforcing the CAA. To assist in this, Air Quality Control Regions (AQCR) were established. Allowable emission limits are determined by the AQCR, or its sub-unit, the Air Quality Management District (AQMD). These emission limits are based on whether or not the region is currently within attainment for National Ambient Air Quality Standards (NAAQS).

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. Fugitive emissions from the UVB Treatment Process may come from (1) well installation and construction activities (VOCs and dust), (2) periodic sampling activities, and (3) off-gas during system operation. The off-gas treatment system must be designed to meet the current air quality standards. State air quality standards may require additional measures to prevent emissions, including requirements to obtain permits to install and operate the UVB treatment system and off-gas treatment.

2.9.4 Clean Water Act (CWA)

The objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the nation's waters by establishing federal, state, and local discharge standards. If treated water is discharged to surface water bodies or Publicly Owned Treatment Works (POTW), CWA regulations will apply. A facility desiring to discharge water to a navigable waterway must apply for a permit under the National Pollutant Discharge Elimination System (NPDES). When a NPDES permit is issued, it includes waste discharge requirements. Discharges to POTWs also must comply with general pretreatment regulations outlined in 40CFR Part 403, as well as other applicable state and local administrative and substantive requirements.

Wastewater generated from the UVB process that may need to be managed includes that generated from equipment decontamination and from well purging and the water separator. This water can be discharged to a local POTW or into surface waters. Depending on the levels of contaminants and permit limitations, treatment may be required prior to discharge.

2.9.5 Safe Drinking Water Act (SDWA)

The SDWA of 1974, as most recently amended by the Safe Drinking Water Amendments of 1986, requires the EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorized national drinking water standards and a joint federal-state system for ensuring compliance with these standards.

The National Primary Drinking Water Standards are found in 40 CFR Parts 141 through 149. Parts 144 and 145 discuss requirements associated with the underground injection of contaminated water. If underground injection of wastewater is selected as a disposal means, approval from EPA for constructing and operating a new underground injection well is required.

2.9.6 Occupational Safety and Health Administration (OSHA) Requirements

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

All technicians involved with the construction and operation of the UVB Treatment Process are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. Workers on hazardous waste sites must also be enrolled in a medical monitoring program. The elements of any acceptable program must include: (1) a health history, (2) an initial exam before hazardous waste work starts to establish fitness for duty and as a medical baseline, (3) periodic examinations (usually annual) to determine whether changes due to exposure may have occurred and to ensure continued fitness for the job, (4) appropriate medical examinations after a suspected or known overexposure, and (5) an examination at termination.

For most sites, minimum PPE for workers will include gloves, hard hats, steel-toe boots, and Tyvek® coveralls. Depending on contaminant types and concentrations, additional PPE may be required, including the use of air purifying respirators or supplied air. Noise levels are not expected to be high, except during well installation which will involve the operation of drilling equipment. During these activities, noise levels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an eight-hour day. If noise levels increase above this limit, then workers will be required to wear hearing protection. The levels of noise anticipated are not expected to adversely affect the community, but this will depend on proximity to the treatment site.

Section 3.0
Economics

3.1 Introduction

The primary purpose of this economic analysis is to provide a cost estimate (not including profit) for commercial remediation of soil contaminated by volatile organic compounds (VOCs) utilizing the Environmental Laboratories, Inc. (ELI) and SBP Technologies, Inc. (SBP) UVB Treatment System (Vacuum Vaporization Well). This analysis is based on the assumptions and costs provided by ELI/SBP, and on the results and experiences gained from the SITE demonstration that was conducted over a 14-month period at the Sweden-3 Chapman site. The SITE demonstration evaluated one UVB well. Based on the site characteristics such as the soil type and depth to groundwater, the treatment area for this one UVB well was approximately 263 m^2 or 2,827 ft^2 (9.14 meter or 30 foot radius), which enclosed most of the demonstration treatment area of 50 feet by 50 feet (15.2 meters by 15.2 meters). The ELI/SBP Vacuum Vaporization Process is applicable principally to soils and groundwater contaminated with VOCs. Based on the demonstration site, this is assumed to be 1.83 meters (6 feet) for this economic analysis.

Economic calculations were done for both the SITE demonstration treatment area/volume, as well as for a full-scale remediation of the Sweden-3 Chapman site using this technology. A number of factors affect the cost of treatment. These include, but are not limited to: soil type, contaminant type and concentration, depth to groundwater, soil moisture, air permeability of the soil, and site geology. This economic analysis assumes that the ELI/SBP System will remediate saturated and vadose soil with the same characteristics as the SITE demonstration soil at the Sweden-3 Chapman site.

The SITE demonstration treated a volume of approximately 480 m^3 (628 yd^3) of soil contaminated with VOCs. This is assuming that the vadose zone is on average 1.83 meters (6 feet) deep. The SITE demonstration soil was classified as a glacial till with a permeability of 1×10^{-4} cm/sec. The SITE demonstration treated the soil for 14 months. Results of the demonstration are presented in Section 4 of this report.

For the full-scale remediation, it was assumed that 22 UVB wells would be needed to treat an area of 5,518 m^2 (59,400 ft^2). Assuming a vadose zone of 1.83 meters (6 feet), the treatment volume is 10,092 m^3 (13,200 yd^3). It is assumed that all of the wells will operate at once. If ELI/SBP decide to use an alternate approach, such as staggered treatment, the costs may be different. ELI/SBP estimate that typical site treatment times will be 3 to 5 years. Treatment times will depend on site characteristics, as well as on-line factors. For the SITE demonstration the on-line factor was approximately 60%. Full-scale costs are given for treatment times of 14 months (the SITE demonstration treatment time), for 3 years, and for 5 years.

3.2 Conclusions

Estimated costs for one UVB well treating a total volume of 480 m^3 (628 yd^3) of vadose zone soils, assuming a 1.83 meter or 6 foot vadose zone, are approximately \$453/m^3 (\$347/yd^3) for a 14-month period at the Sweden-3 Chapman site in Sweden, NY. Estimated costs for treating a total volume of 10,092 m^3 (13,200 yd^3) of vadose zone soils utilizing 22 UVB wells at the Sweden-3 Chapman site in Sweden, NY are approximately \$195/m^3 (\$149/yd^3) for a 14-month period, \$339/m^3 (\$259/yd^3) for a 3-year period, and \$491/m^3 (\$375/yd^3) for a 5-year period. Tables 3-1 and 3-2 summarize these costs by categories and list each category's cost as a percent of the total cost for the 480-m^3 and 10,092- m^3 cases, respectively. Those costs that are assumed to be the obligation of the responsible party or site owner have been omitted from this cost estimate and are indicated by a line (--) in Tables 3-1 and 3-2. Categories with no costs associated with this technology are indicated by a zero (0) in Tables 3-1 and 3-2. The categories and their contents are discussed at length in Section 3.4.

A large percentage of the 10,092-m^3 14-month, 3-year, and 5-year treatment cost is for labor (16.7%, 27.8%, and

Table 3-1. Estimated Costs for Pilot-scale Treatment Using the ELI/SBP Treatment System

Total Treatment Area: 263 m^2 (2,827 ft^2)
Treatment Depth: 1.83 meters (6 feet)
Total Treatment Volume: 480 m^3 (628 yd^3)
Treatment Time: 14 months

	$/m³	$/yd³	%
Site and Facility Preparation Costs			
Site design and layout		---	
Survey and site investigations	---	---	
Legal searches	---	---	
Access rights and roads	---	---	
Preparations for support facilities	---	---	
Auxiliary buildings	---	---	
Technology-specific requirements	140.00	107.69	
Transportation of waste feed	---	---	
Total Site and Facility Preparation Costs	**140.00**	**107.69**	**31.1%**
Permitting and Regulatory Costs			
Permits	---	---	
System monitoring requirements	---	---	
Development of monitoring and protocols	---	---	
Total Permitting and Regulatory Costs	**---**	**---**	**---**
Equipment Costs			
Annualized equipment cost	---	---	
Monitoring equipment	20.83	15.92	
Support equipment cost	6.25	4.78	
Equipment rental/lease	64.85	49.58	
Total Equipment Costs	**91.93**	**70.29**	**20.3%**
Startup and Fixed Costs			
Working capital	---	---	
Shakedown testing	4.83	3.69	
Insurance and taxes	3.48	2.66	
Initiation of monitoring programs	---	---	
Contingency	---	---	
Total Startup and Fixed Costs	**8.31**	**6.35**	**1.8%**
Labor Costs			
Senior scientist	24.99	19.11	
Engineer	28.33	21.66	
Project manager	32.57	24.90	
On-site technician	27.99	21.40	
Rental car	---	---	
Travel	---	---	
Total Labor Costs	**113.88**	**87.07**	**25.1%**
Supplies and Consumables Costs			
PPE	10.41	7.96	
Health and safety plan	10.40	7.96	
Small hand tools	0.42	0.32	
Consumables (plumbing, site maintenance, etc.)	10.41	7.96	
Blowers and groundwater pumps	6.46	4.94	
Total Supplies and Consumables Costs	**38.11**	**29.14**	**8.4%**

Table 3-1(Cont'd). Estimated Costs for Pilot-scale Treatment Using the ELI/SBP Treatment System

Total Treatment Area: 263 m^2 (2,827 ft^2)
Treatment Depth: 1.83 meters (6 feet)
Total Treatment Volume: 480 m^3 (628 yd^3)
Treatment Time: 14 months

	$/m^3	$/yd^3	%
Utilities Costs			
Sanitary	2.19	1.67	
Electricity	15.87	12.13	
Water	0.47	0.36	
Total Utilities Costs	**18.53**	**14.16**	**4.1%**
Effluent Treatment and Disposal Costs			
On-site facility costs	---	---	
Off-site facility costs			
-wastewater disposal	---	---	
-monitoring activities	0	0	
Total Effluent Treatment and Disposal Costs	**---**	**---**	**---**
Residuals & Waste Shipping, Handling & Transport Costs			
Preparation	---	---	
PPE	1.04	0.80	
Well cuttings	---	---	
Development water	---	---	
Carbon	---	---	
Total Residuals & Waste Shipping, Handling and Transport Costs	**1.04**	**0.80**	**0.2%**
Analytical Costs			
Operations (for developer's purposes, not regulatory)	19.99	15.29	
Environmental monitoring (regulatory)	---	---	
Total Analytical Costs	**19.99**	**15.29**	**4.4%**
Facility Modification, Repair, & Replacement Costs			
Design adjustments	0	0	
Routine maintenance (materials & labor)	0[a]	0[a]	
Equipment replacement	0	0	
Total Facility Modification, Repair, & Replacement Cost	**0[a]**	**0[a]**	**0[a]**
Site Restoration Costs			
Site cleanup and restoration	---	---	
- Technology specific	20.77	15.88	
Permanent storage	---	---	
Total Site Restoration Costs	**20.77**	**15.88**	**4.6%**
TOTAL OPERATING COSTS	**$453**	**$347**	

[a] Maintenance materials are listed as spare parts under "Spare Parts and Consumables".

Maintenance labor is included in the on-site labor under "Labor".

Table 3-2. Estimated Costs in $/m^3 for Treatment Using the ELI/SBP Treatment System to Remediate 10,092/m^3 (Full-scale)

Treatment Area =	5,518 m^2		5,518 m^2		5,518 m^2	
Treatment Depth =	1.83 m^2		1.83 m^2		1.83 m^2	
Total Treatment Volume =	10,092 m^3		10,092 m^3		10,092 m^3	
Treatment Time =	14 months		3 Years		5 Years	
Approximate Total Project Period =	16 months		3.17 Years		5.17 Years	
	$/m^3	%	$/m^3	%	$/m^3	%
Site Facility Preparation Costs	78.88	40.5	78.88	23.3	78.88	16.1
Permitting & Regulatory Costs	--	--	--	--	--	--
Equipment Costs	43.96	22.5	101.41	29.9	164.08	33.3
Startup & Fixed Costs	4.26	2.2	9.78	2.9	15.81	3.2
Labor Costs	32.51	16.7	94.10	27.8	156.84	32.0
Supplies & Consumables Costs	15.13	7.7	19.99	5.9	25.30	5.2
Utilities Costs	7.88	4.1	20.25	6.0	33.73	6.9
Effluent Treatment & Disposal Costs	--	--	--	--	--	--
Residuals Shipping, Handling, & Transport Costs	0.20	0.2	0.55	0.2	0.89	0.2
Analytical Costs	1.31	0.7	3.05	0.9	4.80	0.9
Facility Modifications, Repair, & Replacement Costs	0*	0*	0*	0*	0*	0*
Site Restoration Costs	10.57	5.4	10.57	3.1	10.57	2.2
Total Costs ($/m^3)	195		339		491	
Total Costs ($/yd^3)	149		259		375	

Maintenance labor is included under "Labor Costs". Maintenance Materials are included under "Supplies and Consumables Costs".

32.0%, respectively). As experience at a site is gained over the first few years, it may be possible that labor intensive activities can be done more efficiently. Thus, fewer man-hours may be required in later years for operating the system and reviewing field data (i.e., in years 3, 4, and 5).

If the ELI/SBP System actually remediates to the bedrock at the demonstration site, then the treatment depth would increase to 11 feet. This would increase the treatment volume of the SITE demonstration to 880 m^3, and the full-scale treatment volume to 18,500 m^3. Based on an 11 foot treatment depth, this would make the SITE demonstration 14-month treatment costs 247/m^3 ($189/yd^3), and the full-scale 14-month, 3-year, and 5-year treatment costs $106/m^3, $185/m^3, and $268/m^3, respectively.

Costs presented in this report are order-of-magnitude estimates as defined by the American Association of Cost Engineers, with an expected accuracy within +50% and -30%; however, because this is a new technology, the range may actually be wider.

3.3 Issues and Assumptions

The cost estimates presented in this analysis are representative of charges typically assessed to the client by the vendor, but do not include profit. In general, assumptions are based on information provided by the developer and observations made during this and other SITE demonstration projects.

Many actual or potential costs that exist were not included as part of this estimate. They were omitted because site-specific engineering designs that are beyond the scope of this SITE project would be required. Also, certain functions were assumed to be the obligation of the responsible party or site owner and were not included in the estimates. These costs are site-specific. Thus, calculations are left to the reader so that relevant information may be obtained for specific cases. Whenever possible, applicable information is provided on these topics so that the reader can independently perform the calculations required to acquire relevant economic data.

Other important assumptions regarding operating conditions and task responsibilities that could significantly impact the cost estimate results are presented below:

- The cost estimate assumes that the site has been characterized during previous investigations.
- This cost estimate assumes that treatability studies or pilot studies have already been performed.

- It is assumed that the site has suitable access roads.
- It is assumed that the site has electrical and telephone supply lines.
- This cost estimate assumes that the soil being remediated is similar to the VOC-contaminated soil treated during the SITE demonstration.
- It is assumed, based on the SITE demonstration, that each UVB well can treat a 9.14-meter radius.
- This cost estimate assumes that operating labor time on-site during treatment is 4 hrs/week and 24 hrs/week for the 480-m^3 and 10,092-m^3 cases, respectively. This labor time includes maintenance labor.
- It is assumed that the 480-m^3 case will require 11.5 pre-treatment days for site preparation and shakedown testing, and it will require 3.5 post-treatment days for site demobilization.
- It is assumed that the 10,092-m^3 case will require 42 pre-treatment days for site preparation and shakedown testing, and it will require 19 post-treatment days for site demobilization.
- This cost estimate assumes that the pre-treatment and post-treatment working days are 8-hour days for both cases.
- It is assumed that drilling costs do not include disposal costs for well cuttings and development water.

3.4 Basis for Economic Analysis

In order to compare the cost-effectiveness of technologies in the SITE Program, EPA breaks down costs into twelve categories:

- Site and facility preparation costs,
- Permitting and regulatory costs,
- Equipment costs,
- Startup and fixed costs,
- Labor costs,
- Consumables and Supplies costs,
- Utilities costs,
- Effluent treatment and disposal costs,
- Residuals and waste shipping, handling, and transport costs,
- Analytical costs,
- Facility modification, repair, and replacement costs, and
- Site restoration costs.

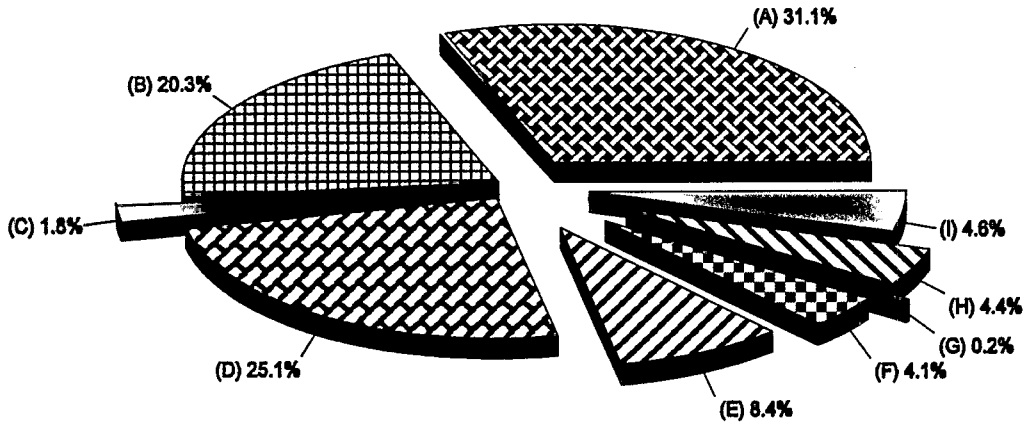
These 12 cost categories reflect typical cleanup activities encountered on Superfund sites. Each of these cleanup activities is defined and discussed, forming the basis for the detailed estimated costs presented in Tables 3-1 and 3-2. The estimated costs for the 480-m^3 case are shown graphically in Figure 3-1. The 12 cost factors examined and assumptions made are described in detail below.

3.4.1 Site and Facility Preparation Costs

For the purposes of these cost calculations, "site" refers to the location of the contaminated waste. It is assumed that preliminary site preparation will be performed by the responsible party (or site owner). The amount of preliminary site preparation required will depend on the site. Site preparation responsibilities include site design and layout, surveys and site logistics, legal searches, access rights and roads, preparations for support and decontamination facilities, utility connections (except for a phase converter for the 480-m^3 case), and fixed auxiliary buildings. Since these costs are site-specific, they are not included as part of the site preparation costs in this cost estimate.

For the purposes of these cost calculations, only technology-specific site preparation costs are included. These are limited to: UVB well installation, monitoring well installation, UVB internal components installation, in situ bioreactor installation, ex situ bioreactor installation, installation of an electrical phase converter (for the 480-m^3 case only), and installation of a fence (for the 10,092-m^3 case only). The developers' estimates of these costs are presented below:

- <u>UVB Well Installation.</u> A total of $11,000/UVB well for drilling. This includes drilling a 0.76-meter (30-inch) hole 8.22-meter (27-feet) deep via a bucket rig, and a borehole with 0.41-meter (16-inch) mild black steel casing, sand pack, concrete/grout seals, and development. Labor requirements are 2 workers for 20 hours each per UVB well, in addition to the labor included in well drilling cost. Labor rates are $60/hr and $85/hr for a field technician and an engineer, respectively.
- <u>Monitoring Wells.</u> A total of $21,086 for 15 monitoring wells. This includes drilling/installing 5.08-cm (2-inch) PVC wells as shallow/deep well clusters, development, screens, riser pipe, sand, grout, protective casing, locks, and seals. Labor requirements for installing the 15 monitoring wells are 2 workers for 16 hours each. Labor rates are $60/hr and $85/hr for a field technician and an engineer, respectively. (Note: this cost is directly scaled-up for 22 monitoring wells for the full-scale cost calculations.)



Unit Cost = $347/yd³

(A) Site and Facility Preparation
(B) Equipment
(C) Startup & Fixed Costs
(D) Labor
(E) Supplies & Consumables
(F) Utilities
(G) Residuals & Waste Shipping, Handling & Transport
(H) Analytical Services
(I) Site Restoration
(J) Permitting & Regulatory ①
(K) Effluent Treatment & Disposal ①
(L) Facility Modification, Repair & Replacement ②

① These costs are not included in this economic analysis.
② These costs are included under "Labor" or "Supplies and Consumables" categories.

Figure 3-1. Cost Distribution

- UVB Internal Components. UVB equipment costs are included under equipment costs. Labor requirements for UVB internal components installation are 2 workers for 24 hours each per UVB well. Labor rates are $60/hr and $85/hr for a field technician and an engineer, respectively.
- In Situ Bioreactor. This includes the in situ bioreactor ($1,700/UVB well), carbon as support media ($945/UVB well), crane service to install the in situ bioreactor ($1,000/UVB well), and labor (2 workers for 16 hours each per UVB well). Labor rates are $60/hr and $85/hr for a field technician and an engineer, respectively. ELI/SBP claims that newer designs will not require a crane or as many labor hours.
- Ex Situ Bioreactor. Labor requirements for installing the ex situ bioreactor are 2 workers for 16 hours each per UVB well. Labor rates are $60/hr and $85/hr for a field technician and an engineer, respectively.
- Phase Converter. The UVB System requires three phase power. For the SITE demonstration a licensed electrician (at a labor cost of $1,040) installed a phase convertor ($2,405). This cost is very site-specific, and is not included for the full-scale costs. For the full-scale costs, it is assumed that all electrical connections and conversions are the site owner's responsibility.

In addition, the cost of a fence is included for the full-scale case only. The fence to enclose the treatment area (1,500 linear feet or 457 linear meters) is estimated to cost $5/linear ft ($16.40/linear meter), based on past SITE project experience, for a total of $7,500.

3.4.2 Permitting and Regulatory Costs

Permitting and regulatory costs are generally the obligation of the responsible party (or site owner), not that of the vendor. These costs may include actual permit costs, system monitoring requirements, the development of monitoring and analytical protocols, and health and safety monitoring. Permitting and regulatory costs can vary greatly because they are site- and waste-specific. Permits that may need to be considered for this technology include drilling permits, building permits, and water and/or air discharge permits. No permitting costs are included in this analysis; however, depending on the treatment site, this may be a significant factor since permitting activities can be very expensive and time-consuming.

3.4.3 Equipment Costs

Equipment costs include purchased equipment, purchased support equipment, and rental/lease equipment. Support equipment refers to pieces of purchased equipment and/or sub-contracted items that will only be used for one project.

Purchased Equipment Costs

The purchased equipment costs are presented as annualized equipment costs, prorated based on the amount of time the equipment is used for the project. The annualized equipment cost is calculated using a 10-year equipment life and a 10% annual interest rate. The annualized equipment cost is based upon the writeoff of the total initial capital equipment cost and scrap value (assumed to be zero) using the following equation:

$$\textit{Capital recovery} = (V - V_s)\,\frac{I(1+I)^n}{(1+I)^n - 1}$$

where

V	is the cost of the original equipment,
V_s	is the salvage value of the equipment,
n	is the equipment life (10 years), and
I	is the annual interest rate (10%).

For the 480-m^3 case there are no purchased equipment costs. Instead, ELI/SBP provide a lease cost for the UVB well internal components. ELI/SBP approximate this cost at $27,311 for 14 months for one UVB well. For the 10,092-m^3 case, ELI/SBP estimate the capital cost for one UVB system to be $82,600. This cost is used to calculate the prorated annualized purchased equipment cost for the 10,092- m^3 case.

Support Equipment Costs

For this cost estimate, support equipment includes monitoring equipment and a crane rental to raise/lower the bioreactor due to groundwater level changes. ELI/SBP estimate the monitoring equipment costs to be: groundwater flow meter ($1,200); air flow meter ($1,647); field HACH testing kits ($600 for the 480-$m^3$ case and $13,200 for the 10,092-$m^3$ case); dissolved oxygen meter ($619); magnetic gauges ($150); oxygen, carbon dioxide, and lower explosive level meter ($2,241) and miscellaneous equipment including water level meter and PID/OVA meter ($3,543). The support monitoring equipment will not be used on subsequent projects, therefore these costs are not prorated.

A crane is required to adjust the location of the UVB well. ELI/SBP estimate the crane costs at $750/adjustment. Based on the SITE demonstration, it is approximated that this crane will be required once per quarter for the 480-m^3 case and once per month for the 10,092-m^3 case.

Rental Equipment Costs

For the 480-m^3 cost estimate, rental/lease equipment includes: a UVB well for $27,311 for 14 months (as

mentioned above), an office trailer at $225/month for 15 months, and a telephone at $30/month for 15 months.

For the 10,092-m^3 cost estimate, rental/lease equipment includes: an office trailer at $225/month and a telephone at $30/month. It is assumed that these will be rented for 16 months, 38 months, or 62 months for the 14-month, 3-year, and 5-year treatment times, respectively.

3.4.4 Startup and Fixed Costs

Working capital is based on the amount of money currently invested in supplies and consumables. The working capital cost of supplies and consumables is not expected to be a significant cost, and is not included here. ELI/SBP include transportation costs for the UVB internal components and bioreactors in their equipment costs that are listed above in the "Site Preparation" and "Equipment" costs sections.

Based on their SITE demonstration experience, ELI/SBP have estimated that startup and shakedown testing will require 2 workers for 16 hours each per UVB well. Labor rates are $85/hr for an engineer and $60/hr for a field technician. This is in addition to the installation and set-up labor listed above under the "Site and Facility Preparation" section.

Insurance and taxes together are assumed for the purposes of this estimate to be 10% of the total annual capital equipment costs. The cost for the initiation of monitoring programs has not been included in this estimate. Depending on the site and the location of the system, however, local authorities may impose specific guidelines for monitoring programs. The stringency and frequency of monitoring required may have significant impact on the project costs. No contingency costs are included. Often these costs will equal the costs of insurance and taxes. Contingency costs allow for any unforeseen or unpredictable cost conditions, such as strikes, storms, floods, and price variations.

3.4.5 Labor Costs

Hourly labor rates for operation include base salary, benefits, overhead, and general and administrative expenses, but no travel, per diem, or car rental costs, since these costs are site specific. ELI/SBP estimate that for the 480-m^3 case quarterly visits to the site and/or field data evaluation would require: a senior scientist for 24 hrs/qtr at a rate of $125/hr, a field technician, an engineer or a geologist for a total of 40 hrs/qtr at a rate of $85/qtr, and a project manager for 24 hrs/qtr at a rate of $115/hr. For the 10,092-$m^3$ case these labor requirements were projected to be: a senior scientist for 144 hrs/qtr at a rate of $125/hr, a field technician, an engineer or a geologist for a total of 240 hrs/qtr at a rate of $85/qtr, and a project manager for 204 hrs/qtr at a rate of $115/hr.

For this cost estimate, operating labor time on-site is assumed to be 4 hrs/week for the 480-m^3 case, and 24 hrs/week for the 10,092-m^3 case. This is assumed to be a field technician at a labor rate of $60/hr. This labor time includes routine maintenance labor.

3.4.6 Supplies and Consumables Costs

Supplies cost for this cost estimate is limited to personal protective equipment (PPE), a health and safety plan, small hand tools, blowers, groundwater pumps, and consumables related to plumbing, site maintenance, and miscellaneous items. ELI/SBP estimate these costs to be: PPE at $5,000 for the 480-$m^3$ case and $31,250 for the 10,092-$m^3$ case; preparation of a health and safety plan at $5,000 for both cases; small hand tools at $200 for both cases; replacement blowers at $2,500 each (one for the 480-m^3 case, and two for the 10,092-m^3 case); replacement groundwater pumps at $600 each (one for the 480-m^3 case, and two for the 10,092-m^3 case) and consumables at $5,000 for the 480-$m^3$ case and $110,000 for the 10,092-$m^3$ case. ELI/SBP do not expect any costs for amendments or microbes, therefore these costs are not included.

3.4.7 Utilities Costs

Utilities required are limited to electricity, water, and sanitary. ELI/SBP estimate the electricity required for each UVB well to be 1,058 kWhrs/wk. If a phase converter is required (as was for the SITE demonstration) ELI/SBP estimates its electrical usage at 1,210 kWhrs/wk. Electricity rate is assumed to be $0.06/kWhr. ELI/SBP estimate the water and sanitary costs for both cases to be $15/month and $70/month, respectively.

3.4.8 Effluent Treatment and Disposal Costs

ELI/SBP claim that this system does not generate waste once installed, except for off-gas treatment. They claim that all groundwater is treated in situ. During the 14-month SITE demonstration, no water was collected in the knockout tank. No effluent treatment and disposal costs are included.

3.4.9 Residuals and Waste Shipping, Handling and Transport Costs

It is assumed that the only residuals or solid wastes generated from this process will be used PPE, well cuttings, and development water. The disposal cost for 208-L (55-gal) drums of used PPE is estimated at $500/208-L drum based on SITE demonstration experience. For this cost estimate, it is assumed that one 208-L drum of used PPE will be generated per 14 months for the 480-m^3 case and that four 208-L drums of used PPE

will be generated per 14 months for the 10,092-m^3 case. Waste disposal costs (including storage, transportation and treatment costs) for all other residuals are assumed to be the obligation of the responsible party (or site owner). The SITE demonstration generated approximately 10.4 m^2 (112 ft^2) of well cuttings and 2,271 liters (600 gallons) of development water. No costs are included for regenerating the carbon beds, replacing the carbon, or disposing used carbon. During the SITE demonstration the carbon did not require regeneration or replacement.

3.4.10 Analytical Costs

Only spot checks executed at ELI/SBP's discretion (to verify that equipment is performing properly and that cleanup criteria are being met) are included in this cost estimate. The client may elect, or may be required by local authorities, to initiate a planned sampling and analytical program at their own expense. The cost for ELI/SBP's spot checks is estimated at $100 per sample. For the purposes of this cost estimate, it is assumed that there will be 16 samples/qtr analyzed for the 480-m^3 case and 22 samples/qtr analyzed for the 10,092 m^3 case. Labor costs for evaluating field data are included under the "Labor" cost section.

The analytical costs associated with environmental monitoring have not been included in this estimate due to the fact that monitoring programs are not typically initiated by ELI/SBP. Local authorities may, however, impose specific sampling and monitoring criteria whose analytical requirements could contribute significantly to the cost of the project.

3.4.11 Facility Modification, Repair and Replacement Costs

Maintenance costs are assumed to consist of maintenance labor and maintenance materials. Maintenance labor and materials costs vary with the nature of the waste and the performance of the equipment. The labor cost component for this effort has already been accounted for in the "Labor" cost category as weekly on-site labor. ELI/SBP estimate the repair and maintenance labor requirements to be 32 hours per quarter for the 480-m^3 case.

Maintenance materials include blowers, groundwater pumps, and consumables related to plumbing, site maintenance and miscellaneous items. These costs are already accounted for under the "Supplies and Consumables" cost category.

3.4.12 Site Restoration Costs

Site restoration requirements will vary depending on the future use of the site and are assumed to be the obligation of the responsible party. Therefore, the only site restoration costs included are: the cost for drillers to decommission the wells ($5,490 for the 480-$m^3$ case and projected to be $8,050 for the 10,092-$m^3$ case); the cost for a crane to remove the wells ($770 for the 480-$m^3$ case and projected to be $16,980 for the 10,092-$m^3$ case); and the cost for a dumpster ($350 for the 480-$m^3$ case and projected to be $7,700 for the 10,092-$m^3$ case). ELI/SBP estimate labor requirements for these activities to be 2 workers for 28 hours each for the 480-m^3 case, and this is projected to 8 workers for 19 days (8 hrs/day) each for the 10,092-m^3 case. Labor rates are $60/hr.

Section 4.0
Treatment Effectiveness During the SITE Demonstration

This section presents the results of the SITE demonstration of the ELI/SBP UVB in situ bioremediation technology at the Sweden-3 Chapman landfill during the period from July 1994 through October 1995.

4.1 Background

The Sweden-3 Chapman landfill site was a privately owned facility used for the disposal of construction debris and industrial hazardous wastes between about 1970 and 1978. Sampling indicated that the soil and groundwater at the site were seriously contaminated with volatile organic compounds (VOCs) and innumerable drums. As part of an interim cleanup started in 1989, approximately 2300 drums in various conditions and with various contents were removed from the site. The site was then capped with several feet of fill. Subsequent soil analyses indicated that considerable concentrations of various VOCs were still present in various portions of the site and were migrating with the groundwater. After considering desirable site characteristics and alternate sites for the cooperative Multi-Vendor Bioremediation Demonstration, the Sweden-3 Chapman site was selected for use.

The primary objectives for the demonstration were designed in collaboration with ELI/SBP and the other developers and were used to examine claims that were agreed to by all participants. Based on the NYSDEC desire to clean up the soil at the site, it was agreed that one primary objective would be evidence of cleanup of the vadose zone soil to predefined NYSDEC Cleanup Criteria. The agreed-to goal then was that 90% of the VOC analyses of soil samples from the test plot after 5.5 months of remediation would meet the specified NYSDEC Soil Cleanup Criteria shown in Table 4-1 for the six critical VOCs.

To evaluate this claim, it was planned to obtain soil cores of the expected vadose zone below the overburden (9 to 15 ft below ground surface, bgs) at 25 points non-uniformly distributed across the ELI/SBP plot at the end of the anticipated six months of treatment. In fact, it was found that vadose and saturated zones both were present in most borings of the 9 to 15 ft zone and varied in depth in every sampling event. Consequently, separate samples were obtained of each zone for VOCs and other analyses on the basis of observation. A subsample of each boring interval, selected from the area indicating the highest VOC concentration by immediately passing a field PID probe over the core, was sent for VOC analysis by EPA Method 8260. This field sub-sampling selection procedure was implemented to minimize the possibility of "non-detect" samples and, therefore, is not necessarily representative of average site contaminant concentrations. The laboratory composited subsamples from each portion of the sub-element in methanol. The results for the six noted VOCs in the samples were then compared to the NYSDEC Cleanup Criteria and achievement of the claim measured in terms of total samples. In addition to the sampling in December 1994, after approximately six months of treatment, sampling also was carried out initially (July 1994), after about 3 months (October 1994), after 10 months (May 1995), and at the actual end of the demonstration (September 1995), after 14 months to document the progress of the treatment.

Table 4-1. NYSDEC Soil Cleanup Criteria for Demonstration

Compound	Criterion μg/Kg (ppb)
acetone	200
2-butanone (MEK)	600
4-methyl-2-pentanone (MIBK)	2000
1,2-dichloroethene (DCE)	600
trichloroethene (TCE)	1500
tetrachloroethene (PCE)	2500

The NYSDEC Soil Cleanup Criteria used for this study refer only to "1,2-dichloroethene," which is presumably the

sum of the cis- and the trans- isomers. The trans- isomer is rarely found as an industrial waste or a biodegradation product while the cis- isomer is known to be a degradation product of other chlorinated ethenes. Therefore, although analyses included both isomers, only the cis- isomer was evaluated as one of the critical VOCs and the 600 µg/Kg criterion was used.

The second primary objective of the project was to attempt to demonstrate whether bioremediation was, in fact, a major mechanism by which the critical VOCs were removed from the site. Because of the anticipated uncertainties (1) in converting soil VOC concentrations to masses because of the known bias created by the sampling procedures; (2) in measuring VOC masses stripped and/or sparged by the air used by the UVB technology; (3) in assessing changes attributable to rainfall and groundwater migration onto and off the test plot over the course of the demonstration, and (4) other, unknown factors, it was agreed that this objective would only be evaluated in a qualitative sense. To assist in this evaluation, supportive evidence such as the production of cis-1,2-dichloroethene, vinyl chloride, and carbon dioxide; the consumption of oxygen; and increases in microbial colonies would be used to support any conclusion.

4.2 Detailed Process Description

The ELI/SBP UVB (Vacuum Vaporization) Technology uses a combination of air extraction/injection and groundwater pumping through one or more central wells to create a circulation loop between the upper and the lower limbs of the saturated zone. Indigenous bacteria can then proliferate on the biofilter in the central well, with some of the bacteria being transferred back throughout the radius of influence with the returning water. The lithology of the formation is a major factor in determining the uniformity and radius of the circulation loop around the central well. Movement of air and water are induced by a submersible pump and an air lift pump. The air lift pump also disperses air into the water as it exits the biofilter, which contributes to additional removal of VOCs by air stripping and/or sparging. Removal of VOCs from the vadose zone occurs primarily as a result of this air movement. Figure 4-1 provides a schematic of one configuration of the UVB system, essentially as used in the demonstration.

For the demonstration, a single central well was installed using a truck-mounted auger. A 16-inch casing was grouted into the bedrock (approximately 20 feet bgs), and was equipped with screening for introduction and removal of groundwater at the base and in the vicinity of the expected water table, approximately 9-15 feet bgs. The UVB unit includes an air lift pump and flotation chambers which are intended to facilitate repositioning of the biofilter as the water table fluctuates. The biofilter consists of an activated carbon substrate so that adsorption can assist biodegradation. An inflatable packer separates the lower limb and the upper limb of the well so that the water must pass through the in situ biofilter. Other wells are not required for the UVB Technology to be operated, but monitoring wells are desirable to estimate the distance and uniformity of the zone being treated.

An aboveground vacuum blower is used to draw ambient air into the biofilter to provide aerobic conditions for biodegradation. A portion of the air also escapes into the formation with the recirculating groundwater and serves to strip and sparge VOCs from the formation. The air is withdrawn through the vacuum blower, which is equipped with a water separator tank. For the demonstration, two small capacity biofilters were installed in parallel on the exhaust air line to enable ELI/SBP to evaluate biodegradation of the extracted VOC vapors. Finally, a carbon adsorption drum was added after each of the biofilters to assure that no VOC vapors escaped to the environment.

Operational difficulties were encountered with the initial design because of a high and fluctuating water table and excessive back pressure in the gas-phase biofilters. As a result, design changes were made after the December 1994 sampling event to simplify positioning of the in-well biofilter in response to water table fluctuations. The gas-phase biofilter system was also totally redesigned to minimize back pressure.

Auxiliary equipment included the water separator tank, aboveground gas-phase biofilters, and carbon adsorption drums on the exhaust side of the blower. The blower and pump operated automatically and unattended. An operator was required to make intermittent measurements of the water table level and, when necessary, to oversee the repositioning of the in-well biofilter system. Initially, repositioning of the well system required a crane or drill rig; the design changes made in December 1994 allowed repositioning to be done with a block and tackle.

4.3 Methodology

The protocol devised to evaluate the ELI/SBP technology included sampling of the soil in the expected vadose zone of the test plot at the beginning of the demonstration (Event 0), after about three months (Event 1) to provide data for an intermediate stage, and after about six months (Event 2). When the project was extended, two additional sampling events were added: after 10 months (Event 3) and at the new end of the demonstration (Event 4), after a total of approximately 14 months. At the outset of the project in July 1994, the 50 ft x 50 ft plot surface was divided into a 3 by 3 grid (~16 ft by ~16 ft) and 2 inch diameter soil borings from the expected vadose zone were removed and immediately screened with a field PID instrument. On the basis of volatile hydrocarbon

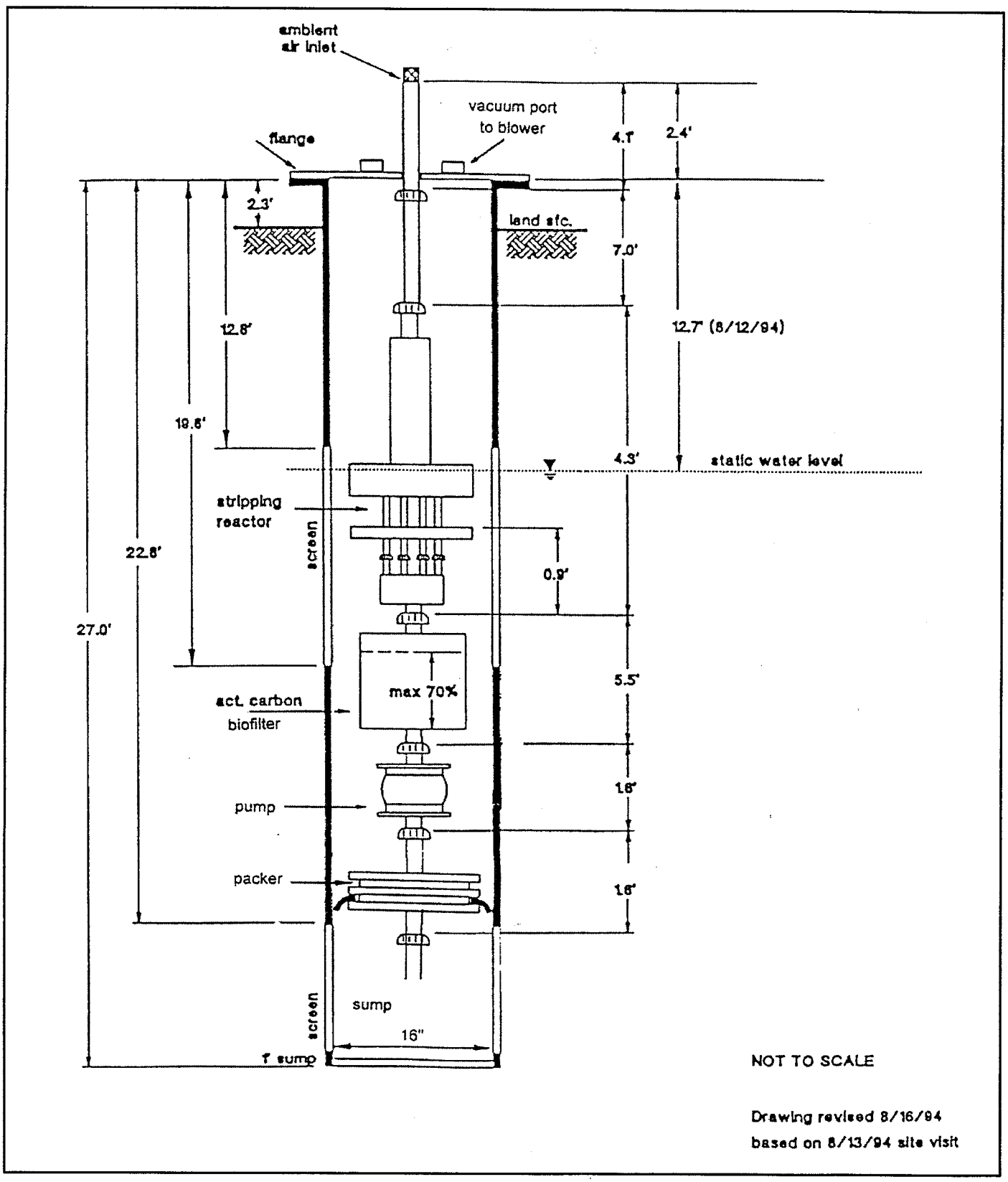


Figure 4-1. UVB System schematic.

distribution indicated by the PID readings, an additional 16 soil sampling points were selected in what appeared to be the more contaminated portion of the plot. Figure 4-2 provides a schematic of the resulting 25 sampling points. (The sampling point locations were also used later to define the surface areas when calculating volume elements for VOC mass calculations.) All soil borings for all subsequent events were obtained as close as possible to these 25 locations using 2-ft split spoons and a truck-mounted drill rig.

A number of four inch diameter groundwater wells were also installed with the same truck-mounted drill rig; screened casings were installed so that shallow and deep wells were paired at radii of about 20 ft, 30 ft, and 40 feet in the northeastern direction and 20 ft in the southwestern direction from the UVB well. These wells were screened at ~7 to 10 ft and at ~16 to 20 ft (bgs), respectively. Plans to install a third well at each groundwater well location so that gaseous contaminants could be captured were abandoned because of the very shallow vadose zone.

Further, although soil cores were obtained in each of the 25 locations, visual observation indicated that some of the 2-ft split spoon cores were vadose zone while others were saturated zone. Consequently, a field decision was made to sample each zone separately; each 2-ft core was scanned with a PID and a subsample was then removed from the segment of the core with the highest PID reading for VOC analyses. Where more than one 2-ft core represented the vadose or saturated zone, the laboratory was instructed to composite these cores in methanol (1:1) before completing the analysis by SW 846 Method 8260. After the rapid transfer of VOC samples had been completed, the remaining soil (vadose or saturated) was composited in the field for various other parameters (e.g., phosphorus, nitrogen, metals, microbial populations, etc.) requested by the developers.

The ~5 ½ month (Event 2) samples were used to evaluate ELI/SBP's ability to achieve the NYSDEC Cleanup Criteria, and the final (14 month) samples were also evaluated against the same objectives. The change in concentration of each VOC from the beginning to the end of the demonstration also was used to calculate an estimated value for the mass of each VOC removed by all mechanisms. The volume of each sub-plot element was calculated on the basis of the core length and the surface area assigned to that sub-element. Density of the soil in the plot was determined twice over the course of the project so that the vadose or saturated zone soil volumes could be converted to mass when calculating the mass of VOCs in each sub-element and then in the total plot. Masses rather than concentrations were used in all calculations to account for the different vadose and saturated zone depths; in effect this provided weighted concentrations. All summarized results are reported on a dry weight basis.

To account for any stripping and sparging of VOCs by the air extracted from the system by the vacuum blower, and also to evaluate the effectiveness of the ex situ biofilter(s) on the exhaust line, the agreed-to plan also called for VOC analyses of the air before and after the ex situ biofilter(s) and before the carbon adsorption drums at several times over the course of the demonstration (initially, 3, 13, 20, 36, and 64 weeks). SUMMA canisters (6L) were used to collect these samples, which were then analyzed by EPA Method TO-14 for VOCs. Combined with temperature, barometric pressure, differential pressure for the sampling, and air flow data for the system provided by the developer from operating logs, these concentration data allowed calculation of the average mass removal of each VOC in the extracted air stream over the course of the demonstration and the portion removed by the ex situ biofilters. Because of previous SITE program experience, a water impinger was included in the sampling train before the SUMMA canister. However, very little water was collected in these impingers and the removal of VOC mass in this water was consistently negligible. The SUMMA canister air samples were also analyzed for oxygen, carbon dioxide, and total non-methane hydrocarbons by EPA Method TO-13 during each sampling event.

VOCs could also leave the ELI/SBP plot in the water separator on the blower. The volume of water discharged automatically from the separator was documented during each sampling event using a totalizing meter and the water was analyzed for VOCs (SW-846 Method 8260) at the end of the demonstration. Using the total volume of water, the mass of VOCs lost in the water was then estimated; the mass lost in this water was small.

All participants recognized at the outset of the project that transfer of VOCs into the groundwater could be another significant route for loss of VOCs from the vadose and, particularly, the saturated soil. However, the intent of this project was to evaluate the effectiveness of the UVB system in removing VOCs (including chlorinated VOCs) from the vadose zone. Consequently, although no effort was made to measure the flow of groundwater over the duration of the project or the mass of VOCs leaving - or entering - the test plot by groundwater migration, each pair of shallow and deep groundwater wells was sampled to determine if there was evidence of a circulation loop both in the lateral and the vertical direction. The unexpected influx of surface water and the unexpectedly high water table encountered during portions of the project make interpretation of these results even more tenuous.

ELI/SBP was responsible for operating its system, obtaining monitoring data and making any adjustments necessary for optimization. Soil and groundwater samples obtained by EPA's contractor were used to provide soil and

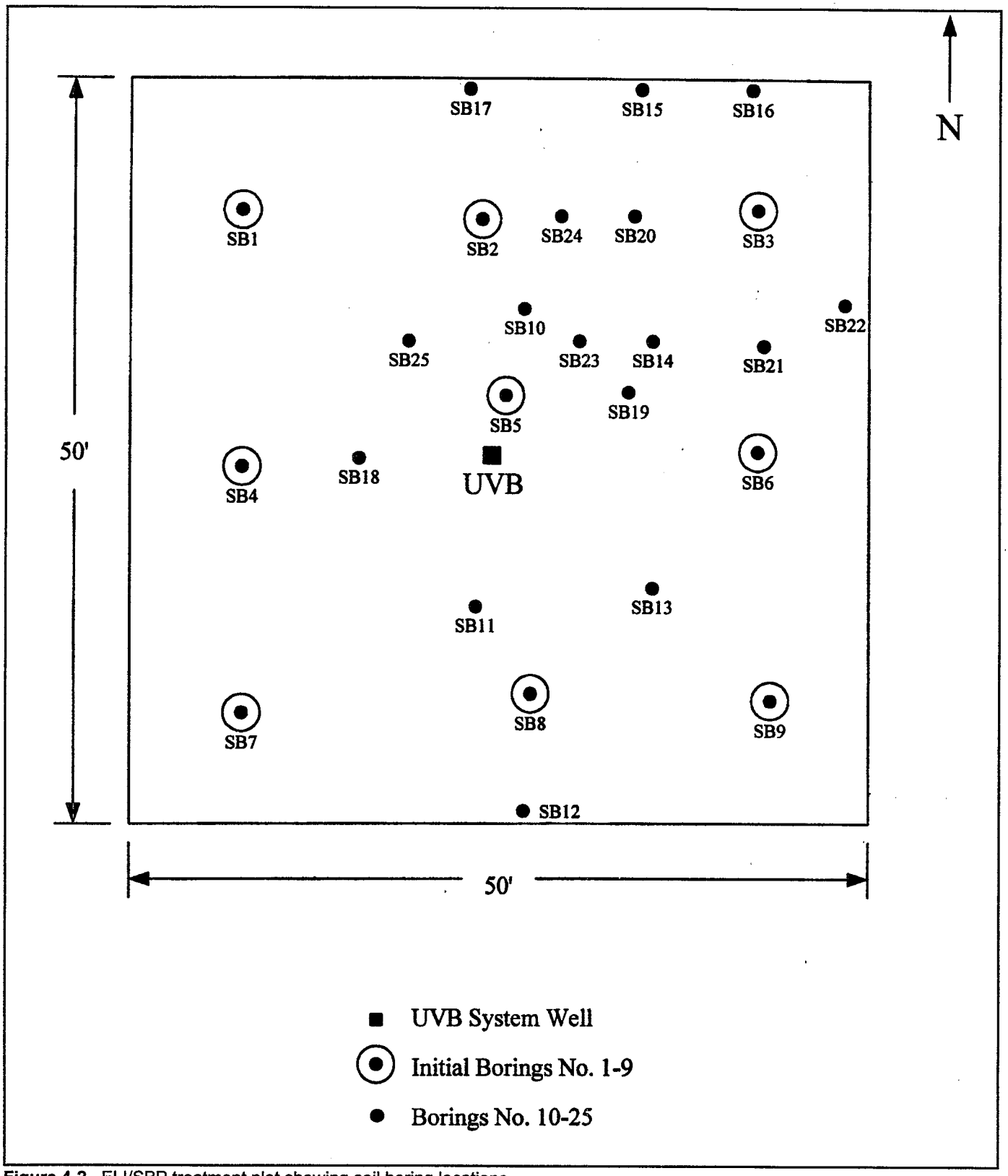


Figure 4-2. ELI/SBP treatment plot showing soil boring locations.

groundwater characteristics (pH, metals, nitrogen forms, phosphorus, microbial counts, etc.) that aided in making these decisions.

4.4 Performance Data

This section presents the performance data gathered by the testing methods described above. Results are presented and interpreted in the following paragraphs.

4.4.1 VOC Concentrations in Soil Initially and at Completion

Using the 25 sampling locations identified in the initial sampling, approximately 50 soil samples of the zones designated visually as vadose and as saturated were collected initially and during each of the succeeding sampling events over approximately 14 months of operation of the ELI/SBP UVB System. Each soil boring was taken as close as possible to the approximate center of each sub-element on the grid, considering the limitations of the available drilling equipment and the proximity of the grouted holes from earlier borings. Core sections for analysis were selected by scanning the core for the highest reading using a field PID. Each core was then analyzed for a full suite of VOCs according to SW-846 Method 8260 but only the critical VOCs for this study (and toluene as an indicator of other aromatic VOCs) are presented and discussed in detail in this Innovative Technology Evaluation Report. The complete VOC summaries are available in the Technology Evaluation Report (TER). High concentrations of toluene and other alkyl benzenes, including ethyl benzene, xylenes, and various trimethylbenzenes, suggest that the contamination is indicative of past disposal of waste hydrocarbon solvents on the site. Also, because the concentrations of non-critical VOCs (e.g., toluene) often were very much higher (~10X) than the critical contaminants, rather high detection limits were reported for some of the samples. This had a major impact on the ability to evaluate and interpret the results of the pilot-scale demonstration.

Because of the interference by the aromatic VOCs and the resulting high detection limits, a non-statistical approach has been taken to the interpretation of the results. All data are presented in two forms, first using the Practical Quantitation Limit (PQL) and then using a hypothetical value of "0" where a value of "ND" had been reported for that critical VOC. Considering the sources of error in the sampling, transfer (into jars, during shipping and then during subsampling into methanol), and analysis of the soil samples, it is believed that this approach provides the reader with a range of maximum and minimum values which are more useful than a statistical approach that would impart some quantified confidence level to the data. Where the two approaches yield large differences in masses, it indicates that many of the concentrations were reported as "ND".

For purposes of determining whether the VOC concentration for a particular sub-element core sample satisfied the NYSDEC Soil Cleanup Criteria (first primary objective) at Event 2 and then at Event 4, the end of the demonstration, only the higher value, based on the Practical Quantitation Limit (PQL), was used. However, because the high detection limits (PQLs) reported for acetone and 2-butanone (MEK) usually exceeded the NYSDEC Soil Cleanup Criteria, these values could not be used in assessing the success of the treatment. The detection limits for 4-methyl-2-pentanone (MIBK) and for all of the chlorinated ethenes were usually below the NYSDEC Cleanup Criteria and allowed the results to be used in assessing whether the sample met each of the NYSDEC Cleanup Criteria. Table 4-2 provides a summary of the results for the six critical contaminants relative to the Cleanup Criteria. Using the measurable values and PQL values that were less than the Criteria, the ELI/SBP

Table 4-2. ELI/SBP Achievement of New York State Cleanup Criteria

Compound	# Met Criteria	# Usable Points (*)	% Met Criteria
Results after 5 Months			
Acetone	0	11	0
MEK	0	12	0
MIBK	21	23	91
DCE	14	32	44
TCE	27	31	87
PCE	29	31	94
Total	91	140	65
Results after 14 Months			
Acetone	0	19	0
MEK	4	25	16
MIBK	45	46	98
DCE	22	46	48
TCE	45	46	98
PCE	44	46	96
Total	160	229	70

Note: (*) Data for samples reported as non-detectable were not used in the evaluation if the detection limit was above the NYSDEC criterion.
Developer is intentionally "credited" with any samples that were uncontaminated initially.

technology achieved a 65% compliance with the NYSDEC Soil Cleanup Criteria after 5.5 months. Although contaminant concentrations did continue to decrease over the remainder of the project, even after 14 months of treatment only a 70% compliance was achieved. In each case, these values are well below the 90% claim. For comparison, it may be noted that the concentration data at the outset of the project indicate a 67% compliance before the technology was undertaken. Although these compliance results appear to imply little improvement, significant removal of at least some of the contaminants was achieved over 14 months, even if the residual levels still exceeded the NYSDEC Cleanup Criteria. Changes in VOC masses (discussed later), probably are a more useful indicator of treatment effectiveness.

4.4.2 Change in Mass of VOCs in Soil with Time

The mass of a VOC in the vadose or saturated zone of a particular sub-element was calculated by multiplying the concentration found in that sub-element, the volume of the sub-element based on the surface area and the length of the zone, the experimentally determined density, and the moisture content (to correct to dry weight), as shown in the following equation:

$$Mass_v = conc_v \times volume \times density \times (\% \ solids/100)$$

with units of:

$$mg = \mu g/Kg \times cm^3 \times gm/cm^3 \times 10^{-6}$$

where $mass_v$ and $conc_v$ refer to an individual VOC. The total mass of a particular VOC in the entire test plot, initially and at any later time in the demonstration, needed to estimate mass changes over time, is then obtained by adding the masses in all vadose and saturated zones. Although sampling procedures may be biased when calculating total mass in soil, the use of the same procedure at the beginning and at the end of the demonstration should allow for comparable data when calculating overall percent removal efficiencies.

A summary of the masses calculated at the various sampling times is given in Table 4-3. All calculated VOC masses were highest during the 3-month sampling event (Event 1) and then appeared to decrease over the remaining 11 months of the investigation. This phenomenon has been observed in another study of the UVB Technology, but the non-representative "hot spot" sampling must be considered to be another possible explanation (although it was not observed in the other two technologies). Toluene, included as an indicator of other aromatic VOCs found to be prominent in the test plot, exhibited similar behavior.

Graphical presentation of the initial and final mass results for each critical VOC, calculated from the experimental concentrations and the PQLs for ND determinations, as shown in Figures 4-3 to 4-9, clearly shows the very non-uniform distribution, as well as the decrease in specific VOCs over the course of the 14 months of the demonstration. The non-uniformity may reflect heterogeneities in site geology and hydrogeology, local residues of VOCs from drums of chemicals that were removed, movement with groundwater, or sampling and analytical problems. For each sample point, the mass value represents the sum of the masses calculated as present in the vadose and the saturated zone using the PQL value for all "ND" results.

Table 4-3. Masses of Contaminants (gm)* in Plot at Various Times

Compound	Time (months)				
	0	3	5.5	10	14
Acetone	3,700	4,200	2,700	1,900	960
MEK	6,300	8,800	5,300	4,400	2,100
MIBK	2,200	3,500	2,300	970	440
DCE	1,900	3,900	1,500	1,400	1,200
TCE	1,500	8,200	4,500	660	3,200
PCE	380	3,500	680	890	350
Toluene	58,000	100,000	55,000	20,000	7,400

* Masses calculated from concentrations and volume elements. For non-detect values, the Practical Quantitation Limits were used.

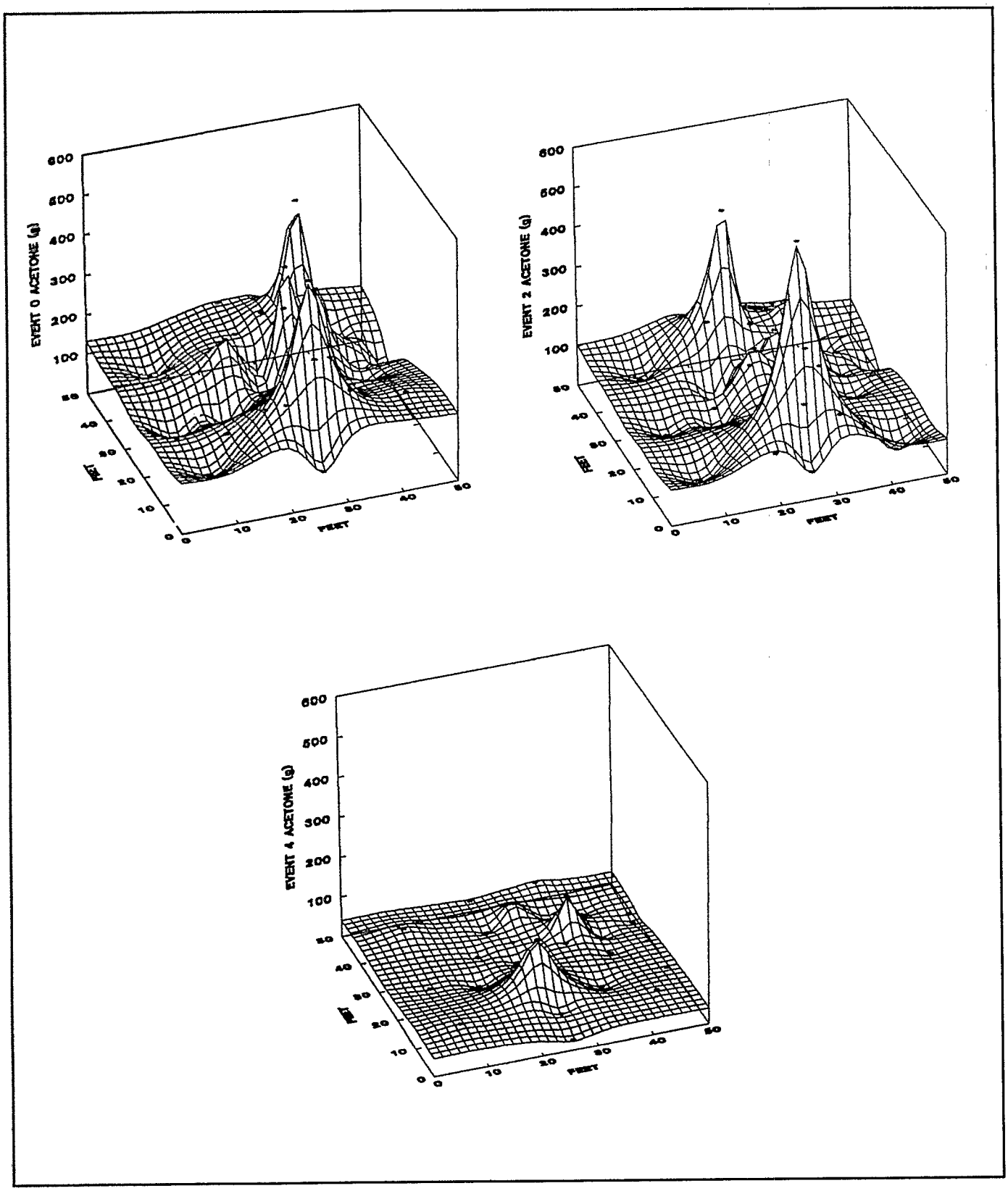


Figure 4-3. Acetone masses at three times.

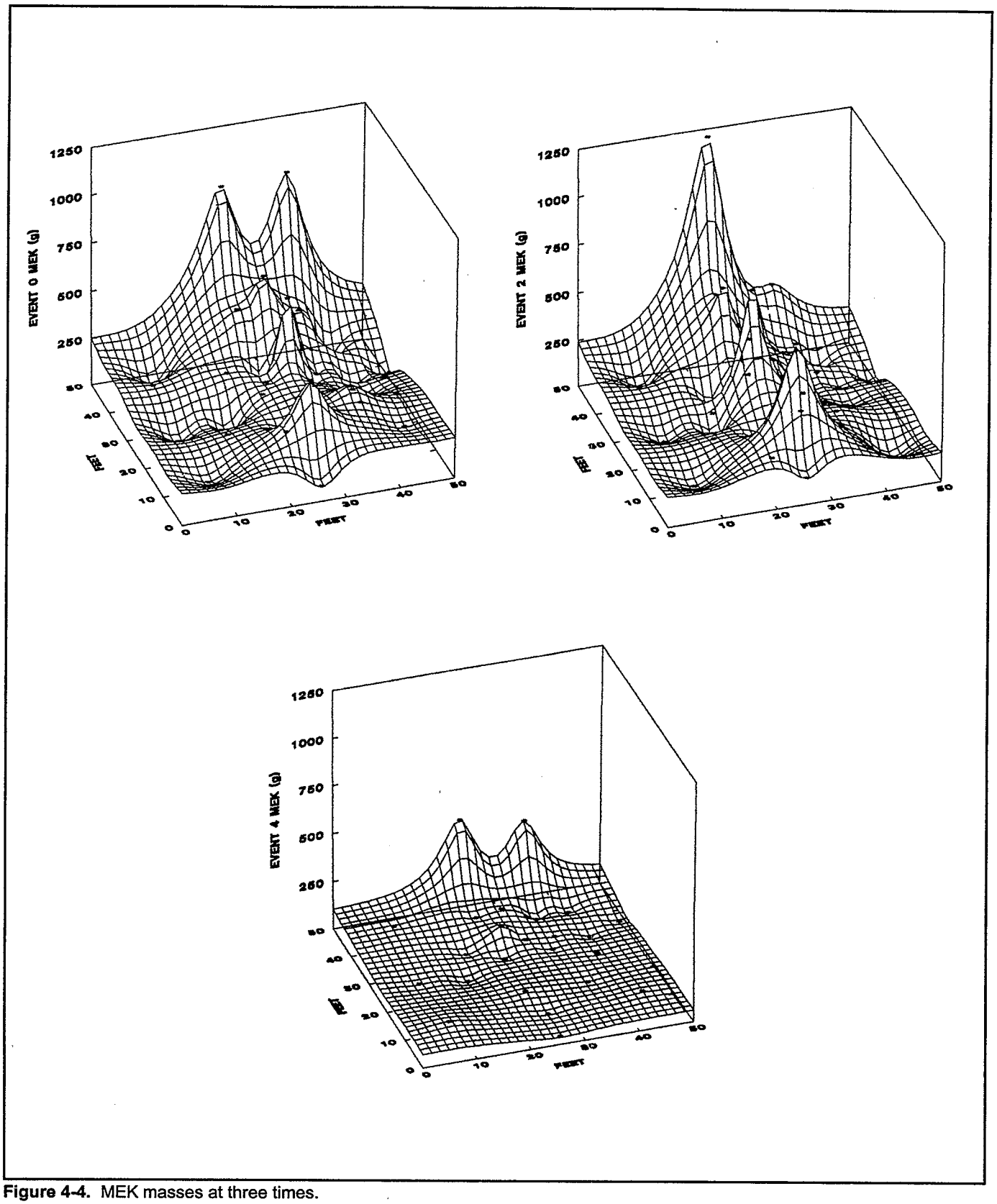


Figure 4-4. MEK masses at three times.

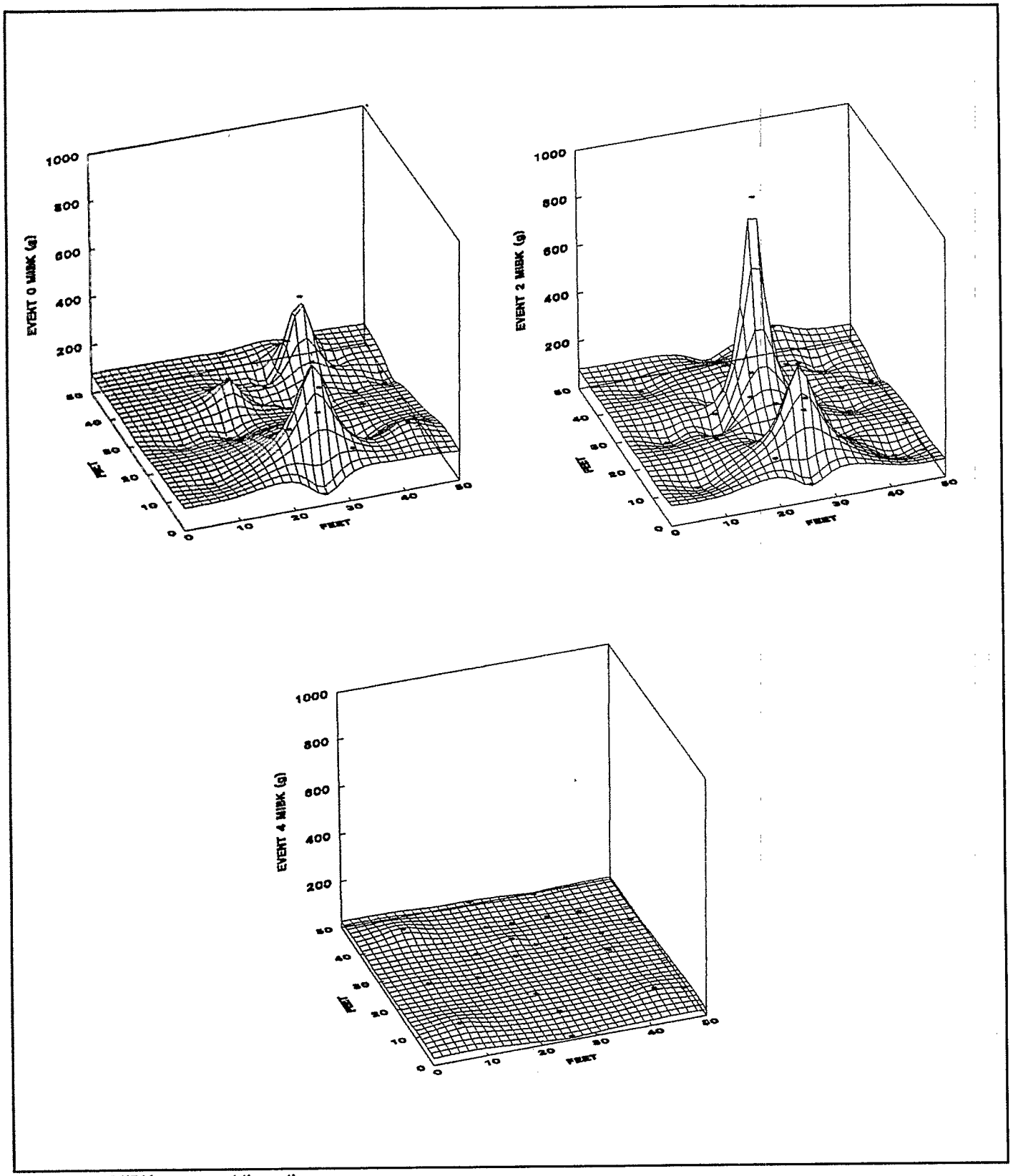


Figure 4-5. MIBK masses at three times.

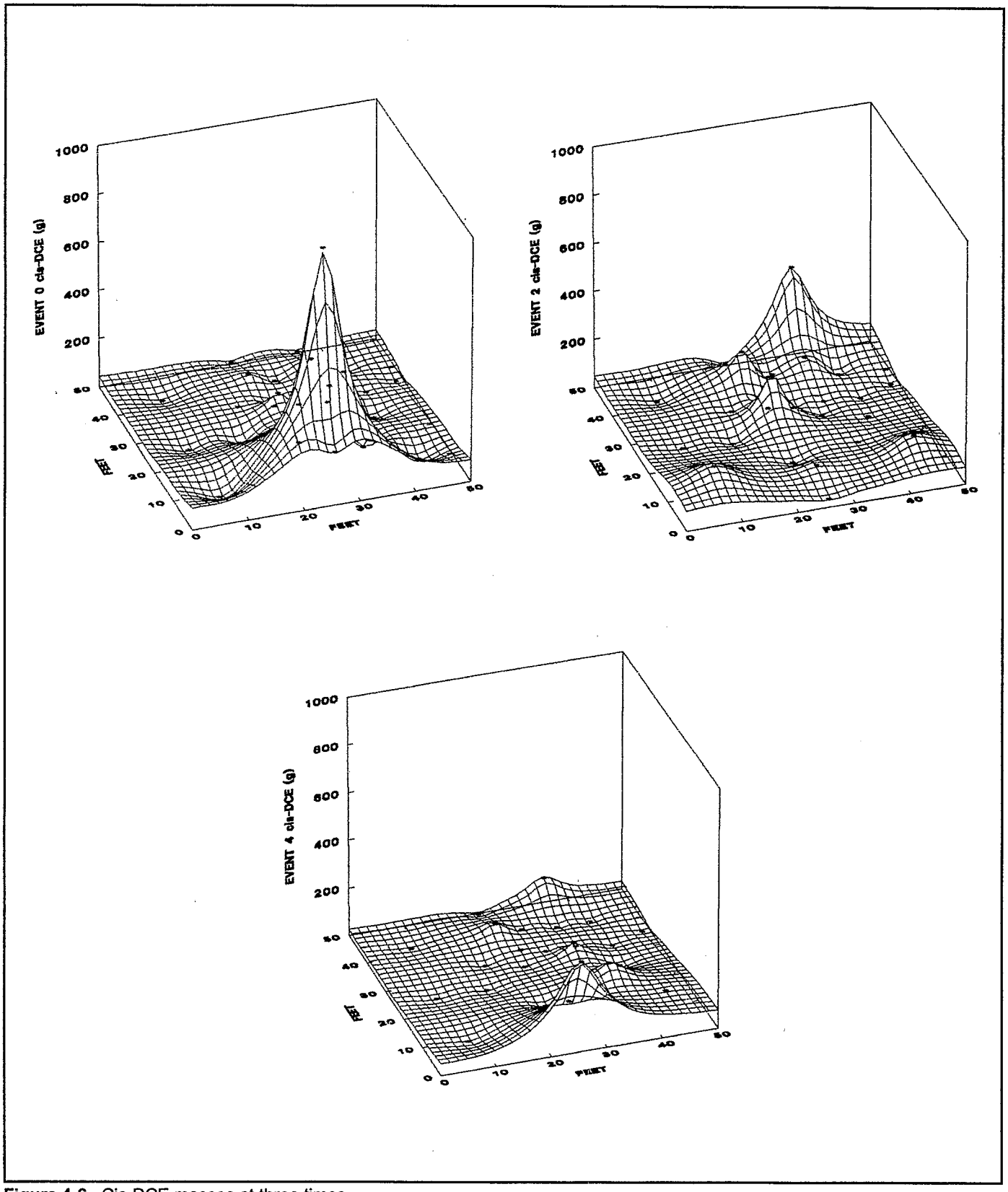


Figure 4-6. Cis-DCE masses at three times.

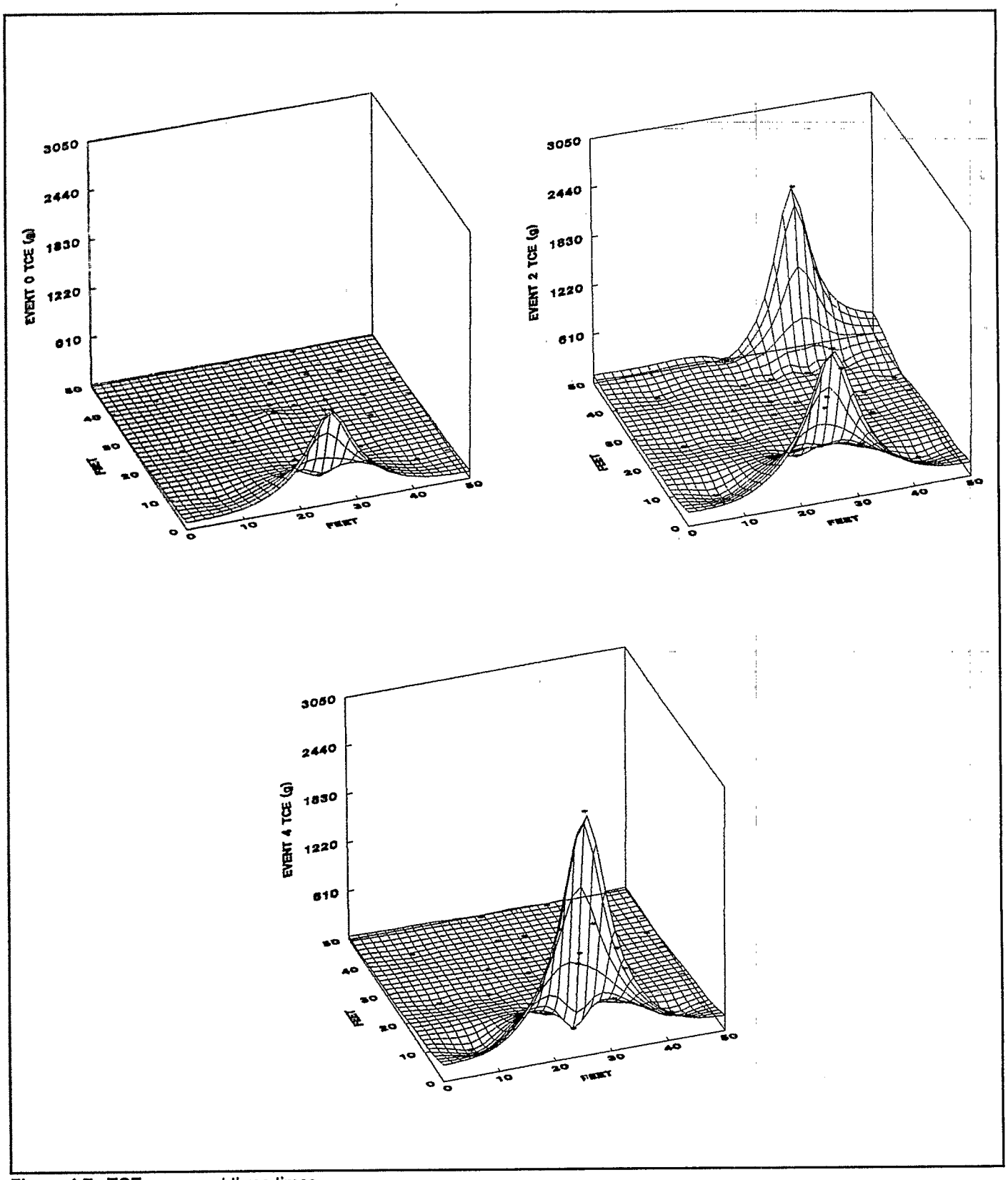


Figure 4-7. TCE masses at three times.

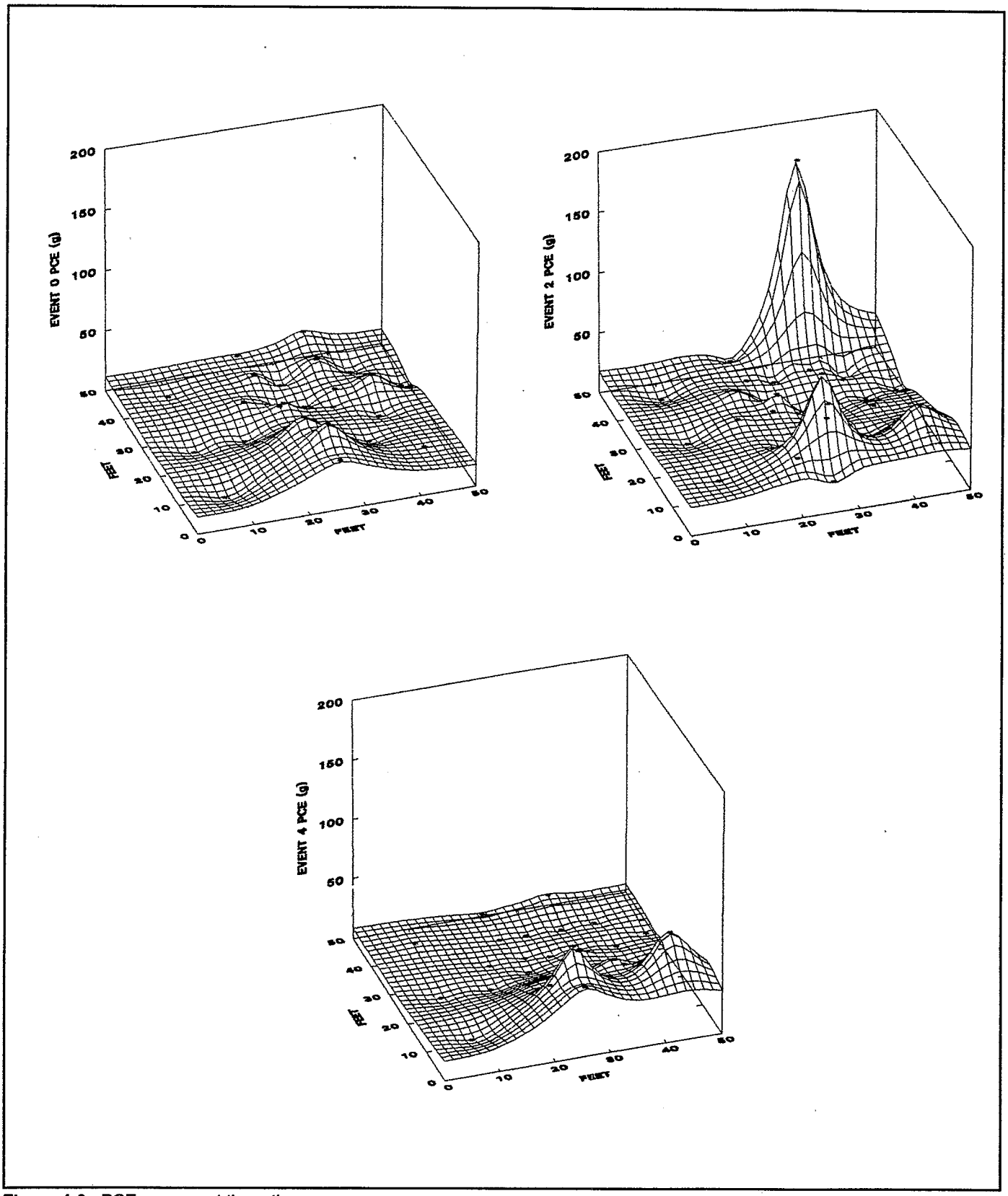


Figure 4-8. PCE masses at three times.

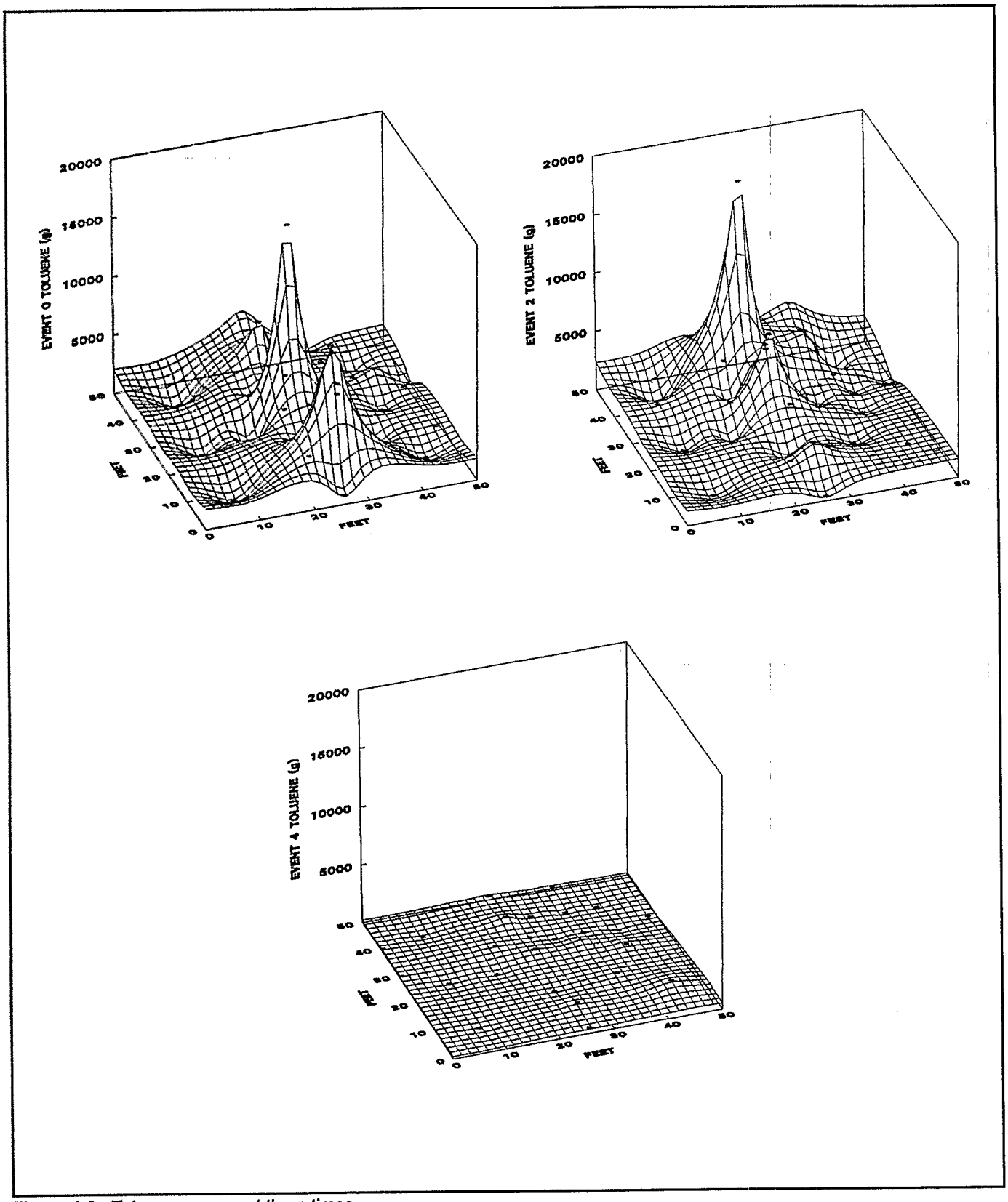


Figure 4-9. Toluene masses at three times.

The Technology Evaluation Report (TER) contains tables which, in addition to a summary of the achievement of the NYSDEC Cleanup Criteria, present the concentration and mass data for all soil samples initially, after 3 months, 5½ months, 10 months, and at the end of the demonstration (14 months). Tables are provided using both the PQL values and "0" for "ND" values to provide the reader with the high and low masses that could be present. In addition to the six critical VOCs, concentration and mass data are also provided for toluene. Since toluene was found at significant concentrations in essentially all samples, the masses calculated using PQL or "0" are approximately the same.

4.4.3 VOCs in Air Samples

Samples of the air exhausted from the ELI/SBP extraction manifold were collected in 6L SUMMA canisters (1) after the water separation tank and before the ex situ biofilters and (2) after the ex situ biofilter(s) and before the carbon adsorption drums so that the effectiveness of the ex situ treatment could also be evaluated. This procedure was carried out in duplicate at the start of the project, after ~3 weeks, ~13 weeks, ~20 weeks, ~36 weeks, and finally at the end of the demonstration (~64 weeks). Air samples were analyzed for VOCs by Method TO-14 and for oxygen, carbon dioxide, and non-methane hydrocarbons by EPA Method TO-13.

The VOC concentrations leaving the in situ system were then converted to instantaneous mass flow (mg/min) at the time of sampling using temperature and differential pressure to calculate flow during sampling. These instantaneous mass flows were then plotted using ELI/SBP's records for air flow through the system over the course of the demonstration (taking into consideration inoperative time due to power failures, maintenance shutdowns, etc.) to estimate the total mass of each VOC removed in the air stream over the course of the demonstration (Table 4-4) using a bar graph approach. In addition to the critical VOCs and toluene, the air samples (and groundwater samples but not the soil samples) also did contain significant concentrations of vinyl chloride, suggestive of anaerobic biodegradation of chlorinated ethenes.

The air results provide the basis for several interesting observations. First, the presence of acetone and MEK, even if at relatively low concentrations, makes it difficult to accept the "0" values for "ND" in the soil samples; clearly some concentrations of these VOCs must have been present. Second, there was a significant and relatively rapid decrease in the concentration of all VOCs, particularly early in the demonstration. This suggests that pre-existing VOCs were being removed during the early air sampling and/or that volatilization becomes a less important removal mechanism as other mechanisms, e.g., biodegradation, accelerate. Third, while no vinyl chloride was detected in the soil, even when low detection limits were ultimately attained, the detection of significant concentrations of vinyl chloride in the air suggests that anaerobic biodegradation of chlorinated ethenes is taking place, due to (1) incomplete success in achieving an aerobic environment throughout the soil, or (2) anaerobic degradation before the ELI/SBP process became operative. Transfer from outside the test area could also be an explanation for vinyl chloride and other VOCs in the air stream.

From a comparison of VOC concentrations or masses in the air before and after the ex situ biofilters, it is clear that little if any VOC-contaminated air was passing through the biofilters during the first six months of operation of the UVB Treatment Process. Very low air flows through the biofilters also supported this conclusion. When the biofilters were redesigned and installed before the April 1995 sampling event to minimize back-pressure, air flow data confirmed that improved passage of air was occurring, with air flows of ~95 dry standard cubic feet/minute (dscfm) now being achieved through each of the two parallel biofilters. Comparison of VOC concentrations before and after the parallel biofilters now indicated removals in the range of 50% to 80%, as shown in Table 4-5. It is not possible to state whether the observed removals were due to adsorption, biodegradation, other mechanisms, or a combination.

Only very low concentrations of the critical VOCs were found in the water collected in the impingers in the sampling train before the SUMMA canisters. Consequently, the contribution of this water to VOC mass removed by stripping was insignificant (<1% of the mass in the air). Similarly, when the combined water from the water separation tank was analyzed at the end of the project, very low concentrations of VOCs were found and the calculated masses were, again, insignificant.

4.4.4 Mass Removal of VOCs-Biodegradation Contribution

Removal of an individual VOC, v, over the course of the project BY ALL MECHANISMS is calculated by comparing the initial mass to the final mass of that VOC in the soil:

$$\% \text{ Removal}_v = 100 \times (\text{Mass}_{v,i} - \text{Mass}_{v,f})/\text{Mass}_{v,i}.$$

These results are summarized in Table 4-6 and are presented for the two scenarios described earlier, with ND = PQL and with ND = 0, to provide the range of high and low masses that might be present in the formation. Because only a very shallow vadose zone was found to be present, the weighted masses for vadose and saturated zones between 9 and 15 ft bgs have been combined.

Table 4-4. Mass of VOCs Removed in Air Stream by ELI/SBP Technology*

Type of Analysis	Compound	Mass (g) Removed Over 14 Months
Critical	Acetone	120
	MEK	58
	MIBK	69
	cis-DCE	2,200
	TCE	510
	PCE	120
Non-Critical	Toluene	1,900
	Vinyl Chloride	260

* Elapsed operating days: 425; blower operation: 24 hours/day.

Table 4-5. Removal of Critical VOCs from Air Stream by Ex Situ Biofilters

	5/95 Inlet	Biofilter A Outlet		Biofilter B Outlet	
Compound	Mass Flow (mg/min)	Mass flow (mg/min)	% Removal	Mass flow (mg/min)	% Removal
Acetone	.24	.08	65	.07	70
MEK	<.02	.15	--	.12	--
MIBK	<.005	<.02	--	<.003	52
cis-DCE	.40	.07	82	.22	46
TCE	.11	<.02	77	.04	61
PCE	.10	.04	53	<.02	74
Toluene	.26	.05	81	.07	73
VC	.006	<.002	54	<.02	--

	10/95 Inlet	Biofilter A Outlet		Biofilter B Outlet	
Compound	Mass Flow (mg/min)	Mass flow (mg/min)	% Removal	Mass flow (mg/min)	% Removal
Acetone	.26	.09	65	.06	78
MEK	.32	.10	68	.06	81
MIBK	.38	.18	54	.10	73
cis-DCE	12.55	5.61	55	4.86	61
TCE	2.16	.95	56	.80	63
PCE	.89	.37	58	.35	60
Toluene	17.83	.23	54	7.54	58
VC	2.43	1.20	51	1.06	56

Table 4-6. Removals after 14 Months Using PQL for ND

Compound	Mass in Soil (gm)		Overall Percent Removal	Mass (gm) Removed in Air and Water	Contribution (%) to Removal Attributable to Bioremediation	Removal by Bioremediation (%)
	Initial	Final				
Acetone	3,700	960	74	120	96	71
MEK	6,300	2,100	67	58	99	66
MIBK	2,200	440	80	69	96	77
DCE	1,900	1,200	37	2,200	____	____
TCE	1,500	3,200	--	510	____	____
PCE	380	350	8	120	____	____
Toluene	58,000	7,400	87	1,900	96	84

Using "0" for ND

Compound	Mass in Soil (gm)		Overall Percent Removal	Mass (gm) Removed in Air and Water	Contribution (%) to Removal Attributable to Bioremediation	Removal by Bioremediation (%)
	Initial	Final				
Acetone	2,000	610	70	120	92	64
MEK	4,500	1,600	64	58	98	63
MIBK	280	130	54	69	54	29
DCE	1,800	1,200	33	2,200	____	____
TCE	1,500	3,100	--	510	____	____
PCE	350	320	9	120	____	____
Toluene	58,000	7,400	87	1,900	96	84

Subtracting the total mass of a VOC removed by air stripping over the course of the demonstration ($Mass_{v,a}$), as determined by the SUMMA canister sampling of the air stream leaving the UVB well, from the total mass removed ($Mass_{v,i}$ - $Mass_{v,f}$), and, noting that removal in the impinger and separator water was insignificant, the resulting value is an estimate of the removal by bioremediation.

$$\% \text{ Bioremoval}_v = 100x(Mass_{v,i}-Mass_{v,f}-Mass_{v,a})/Mass_{v,i}$$

Although it is recognized that considerable masses of VOCs may be present in the groundwater and may have been removed from the vadose zone and from the saturated zone both by the natural water flow and by the water circulation induced by the UVB system, that route has not been included in the analysis. (Changes in VOC concentrations in the several pairs of groundwater monitoring wells are discussed, albeit briefly, in Section 4.4.7.)

This estimate of VOC mass removal from the soil also is limited by the sampling procedures. Sample cores were sectioned for analysis by selecting "hot spots" as determined by a field PID. Hot spots in the soil were potentially recognized with the PID by the high concentration of TCE or other VOCs such as toluene. There were possibly hot spots containing even higher concentrations of cis-DCE in the collected soil cores, but these may not have been sampled due to the higher concentrations of TCE or toluene detected and subsequently selected for sampling and analysis. (The PID will not distinguish between cis-DCE and TCE and the relative response factor for these two compounds is unknown. It may be that one compound will respond much better than the other, meaning concentrations cannot be compared based on PID response. The response factor for toluene is known to be considerably higher than that for chlorinated hydrocarbons.)

It could, consequently, be argued that the sampling procedures missed the cis-DCE "hot spots" because of the higher concentration of or better response to TCE or toluene "hot spots". The true average soil concentrations for these compounds may be more than detected for the cis-DCE and less for the TCE or toluene. This could explain why cis-DCE concentrations in the air samples are so much greater than concentrations in the soil samples. This same argument would suggest that average TCE (or toluene) soil concentrations may be lower. Higher soil

concentrations of cis-DCE and lower TCE concentrations would mean that the biodegradation mechanism is actually less significant than noted by the collected data. For this reason, comparing total mass data is inadequate to establish the role of biodegradation.

For the ELI/SBP technology, the mass balance approach does indicate that extensive removal from the plot is only achieved for the ketones, even after 14 months of treatment, using the initial (Event 0) samples as the baseline. Of the calculated removal, at least for acetone and MEK, bioremediation potentially accounts for the major portion (between 96% and 99%), based on the low removal by stripping. Because of a high frequency of "ND" values for MIBK, both the removal efficiency (between 80% and 54%) and any estimate of biodegradation (96% to 54%) should be considered very skeptically. After only 5.5 months, at the originally planned completion of the project, residual masses of acetone, MEK, and cis-1,2-DCE indicated removal, while the calculated masses of the critical VOCs found in the soil were higher than the original masses for the remaining three of the six critical VOC contaminants: MIBK, TCE and PCE (see Table 4-3). As noted earlier, this could be the result of the nonrepresentative sampling approach or inexperience during the first sampling and analysis effort that allowed VOCs to escape at some point during the procedure. However, this behavior was not observed in the other two vendors' tests. The unique characteristics of the UVB treatment process also may have redistributed contaminants, as has been observed in other evaluations of the technology. This was, in fact, one of the major reasons for continuing the test for a longer time period.

Even using the results after 14 months of total treatment, it is not possible to reach conclusions concerning the role of biodegradation for the chlorinated VOCs based on the mass balance calculations. The large mass of DCE found in the air stream exceeded the removal (between 37% and 33%) from the soil, making it impossible to make any statement concerning biodegradation. Some portion of the DCE mass found in the soil and in the air may be the result of accelerated biodegradation of TCE and PCE due to the UVB process, but this cannot be confirmed. Another contributing factor to these anomalous results may be that a portion of the cis-DCE found in the air samples may reflect cis-DCE in the pore spaces from pre-demonstration natural biodegradation of various chlorinated VOCs. Cis-DCE is an initial biodegradation product of TCE and PCE. Since cis-DCE is not widely used as a commercial chemical, it is unlikely that the observed cis-DCE in the soil or the air was the result of disposal at the site in earlier years. A mass balance calculation also cannot be carried out for TCE since the total mass found in the final samples after 14 or 5.5 months exceeded the initial mass without even considering the calculated mass removed in the air stream. For PCE, concentrations were low at all sampling times and the total removal from the soil is small (7% to 9%) and far exceeded by the calculated mass (118 gm) in the air stream. The vinyl chloride observed in the air samples may be the result of further biodegradation of the cis-DCE, but vinyl chloride is usually considered to be the result of anaerobic, but not aerobic, biodegradation.

The results for toluene provide a less ambiguous data base from which to reach some conclusions, particularly since essentially all soil samples contained measurable concentrations. The comparable calculations indicate that approximately 4% of the toluene is removed from the soil by all mechanisms over 5.5 months and 87% is removed after 14 months. Of the 87% removed after 14 months, only 4% is accountable by stripping based on mass balance comparisons; consequently, it may be concluded that as much as 96% of the 87%, or 84%, is removed by other mechanisms such as biodegradation. As noted earlier, losses to groundwater, to surface water flushing, and by surface vaporization could not be measured and are not included in this analysis. And, as noted earlier, sampling bias also may be a factor contributing to the assumption that the removal mechanism is biodegradation.

4.4.5 Other Supporting Evidence for Biodegradation

Several factors were identified at the outset of the project to provide at least circumstantial supporting evidence that biodegradation was or was not a major mechanism for removal of the critical VOCs. These included the production of cis-DCE and/or vinyl chloride, changes in oxygen and carbon dioxide concentrations, and changes in microbial counts.

As discussed in the previous section, the cis-DCE results are not clear, but biodegradation of TCE and PCE to cis-DCE could be a contributing explanation. The vinyl chloride results also would be useful except that (a) the ELI/SBP system is intended to be operating under aerobic conditions where vinyl chloride should not be the expected product, and (b) vinyl chloride concentration in the air was high at the beginning of the demonstration when vinyl chloride would be easily stripped from the pores in the soil, but also was measured as high at the end of the 14- month study.

Observed decreases in oxygen concentrations and increases in carbon dioxide in the extracted air would normally be used to suggest that biodegradation is occurring. However, over the course of the UVB demonstration, oxygen concentrations in the extracted air remained fairly consistent at ~21% and carbon dioxide concentrations were usually quite low. These results do not provide support for the presence of accelerated biodegradation by the ELI/SBP technology; however, since the UVB process continually introduces air, large changes

in oxygen and carbon dioxide probably should not have been expected. Shutdown tests may have provided more valuable evidence of changes in oxygen and carbon dioxide. In addition, considering the high concentrations of toluene and other aromatic hydrocarbons, it would not be necessary to attribute any changes preferentially to biodegradation of the six critical VOC contaminants.

Similarly, neither high levels nor large increases were observed in the counts of total heterotrophs found in soil samples over the course of the demonstration. This is somewhat surprising when one considers the high concentration of other VOCs present in the soil. TCE-degrader counts also were low, and appeared to decrease over the course of the demonstration (Table 4-7). Total heterotrophs and TCE-degraders in groundwater from the monitoring wells both decreased over the course of the project and, consequently, also do not provide evidence for biodegradation. There were wide variations in all microbial counts for different soil and groundwater samples, making interpretation even more unreliable.

4.4.6 UVB Well Characteristics/In Situ Biofilter Behavior

The biofilter in the central UVB well contained 200 lbs of a carbon-based medium through which groundwater flowed at ~8 gpm as part of the circulation loop. This is considered by the developers to be the main source of biodegradation of VOCs in the groundwater. Samples of the water entering and leaving the biofilter were tested for VOCs during each sampling event. The results indicate (a) a decrease in VOC concentrations by passage through the biofilter and (b) a decrease in the concentrations of the VOCs entering the biofilter over the course of the demonstration. The highest VOC concentration, observed for cis-DCE during the initial sampling time, was still less than 500 µg/L; over the course of the demonstration the concentrations decreased until they were all essentially below the PQLs during the final sampling event in September 1995. ELI/SBP planned to carry out a supplemental study to determine the portion of the removal that can be attributed to adsorption and that portion that might be assumed to be the result of biodegradation on the biofilter; however, the results of that study are not available. The results for the estimated percent removals for each VOC over time are shown in Table 4-8; actual VOC concentrations decreased from several hundred ppb initially to 100 ppb or less by Event 4 (14 months) when removals could no longer be calculated for the critical VOCs.

4.4.7 Groundwater

At the outset of the demonstration, four pairs of groundwater monitoring wells were installed in an effort to observe changes in VOC concentrations at different distances and times as the demonstration progressed. Each pair consisted of a shallow well with screening above the expected water table (~7 - 10 ft bgs) and the second one with screening near the bedrock (20 ft bgs). Shallow and deep wells were chosen because of the different solubilities and densities of the ketones and the chlorinated VOCs. One set of wells was installed 20 ft southwest of the central UVB well, in what was believed to be the up-gradient direction. The other three pairs were installed in the northeast or down gradient direction at distances of 20 ft, 30 ft and 40 ft (see Figure 4-2). Only wells at 20 ft and 30 ft were expected to be within the radius of influence of the treatment process. In addition, a pair of shallow and deep wells was also installed close to the large UVB well to serve as the "0" distance well pair. All wells were sampled approximately coincident with the removal of soil cores throughout the demonstration. Plans to install vapor sampling wells at each location were abandoned because of the shallow vadose zone.

The VOC concentration results obtained over the course of the demonstration were very variable. Coupled with changes in the water table, any attempt at assessment of the changes would be very uncertain. Qualitatively, while some contaminants actually increased in some wells during

Table 4-7. Average Microbial Counts in ELI/SBP Demonstration Soil and Groundwater

Soil	Initial cfu/gm	6 Month cfu/gm	14 Month cfu/gm
Total Heterotrophs	580,000	1,300,000	3,900,000
TCE-Degraders	160,000	100,000	11,000
Groundwater	cfu/ml		
Total Heterotrophs	2,700,000	470,000	550,000
TCE-Degraders	56,000	13,000	1,000

cfu = colony forming units

Table 4-8. Percent Removals for the In Situ Biofilter Based on VOC Concentrations

Event:	Initial	"1"	"2"	"3"	"4"
Compound	0 Months	3 Months	5.5 Months	10 Months	14 Months
Acetone	16	--	--	--	ND
MEK	--	--	--	--	ND
MIBK	--	--	--	--	ND
cis-DCE	38	0	14	92	ND
TCE	33	41	33	92	ND
PCE	--	--	--	--	ND
Toluene	33	71	45	97	0
VC	13	--	--	--	ND

ND = reflects influent and effluent values below PQL

some of the samplings, there were also indications of decreases in others. Any definitive observations or conclusions concerning the groundwater are left to ELI/SBP, who sampled more frequently. It is important to note that vinyl chloride was present in concentrations as high as 37,000 µg/L in some of the groundwater samples and seemed to increase during the demonstration. The potential production of vinyl chloride will need to be examined carefully in other installations.

4.4.8 Distinctions between Vadose and Saturated Zones

Because of the unexpectedly high water table, the soil samples that were obtained from the ELI/SBP plot often were not from only the vadose zone. A rapid, visual determination was made by the field geologist as to whether a particular 2-ft split spoon core was vadose, saturated or a mixture. Vadose and saturated soils were then submitted for separate VOC analyses. Since the vadose zone was often small, the data and comparisons presented earlier in this report re-combine the masses for saturated and vadose zone samples to evaluate the effect of the technology on both zones within the 9-15 ft bgs zone originally expected to represent vadose zone only.

It is, however, interesting to consider the possible different effects that might be observed on the two separate zones. For example, the water-soluble ketones might be expected to concentrate in the saturated zone where biodegradation is apt to occur while the less water soluble chlorinated ethenes might be expected to concentrate in the vadose zone where soil vapor extraction and stripping would be expected to play a larger role. When the masses for each VOC in the soil samples for each sampling event were assigned to vadose or saturated zones on the basis of the visual designation, it appears, as shown in Table 4-9, that the initial removal or loss occurs preferentially in the vadose zone while the longer term (14 month) removal appears to be more uniform in the two zones. Clearly other factors, such as the high-biased sampling noted earlier and the inclusion of PQL values for "ND" results, the temperature, the remaining concentration of each VOC in each zone, the water table, the modifications to the system, etc. all could be influencing the results.

In addition, the impact of these designations as vadose or saturated zones on the apparent achievement of the NYSDEC Soil Cleanup Criteria was also assessed but found to be negligible. Thus, where the overall achievement after the second event (5.5 months) was 65%, the vadose zone compliance was 63%; after 14 months the values were 70% and 67%, respectively. Once again, however, the limitations of this analysis must be kept in mind.

4.4.9 Process Residuals

Since the ELI/SBP process is primarily an in situ process (excluding the ex situ gas phase biofilter), there should be no actual residuals during treatment. However, because extracted air could have contained unacceptable concentrations or total masses of VOCs, ELI/SBP agreed that it would be prudent to install adsorbent carbon on the exhaust line after the ex situ biofilter(s). Monitoring by PID demonstrated that the carbon was effective in removing any VOCs over the course of the demonstration, with no VOCs detected in the final exhaust gas. At the end of the demonstration, the carbon was tested and, on the basis of results that showed it to be non-hazardous, it was returned to the supplier for steam regeneration.

Similarly, the water accumulated in the water separator tank and automatically transferred to an on-site storage tank probably would require some treatment before it was discharged, even though it was pretreated by passage through two drums (600 lb/drum) of granular activated carbon. Several options were considered by NYSDEC for

Table 4-9. Vadose/Saturated Zones Approximate % Removals

	% Removal											
	Event 1			Event 2			Event 3			Event 4		
VOC	tot.	vad.	sat.	tot.	vad.	sat.	tot.	vad.	sat.	tot.	vad.	sat.
acetone	-13	0	-34	28	69	-36	48	34	69	74	72	77
MEK	-40	-39	-41	15	69	-77	29	19	45	66	71	59
MIBK	-56	-27	-103	-4	26	-55	57	53	63	80	84	73
c-DCE	-107	-33	-347	22	80	-168	28	54	-58	36	71	-79
TCE	-431	-	-288	-192	74	-247	57	32	62	-104	-164	-92
PCE	-826	-819	-834	-81	69	-250	-135	-91	-185	-7	33	-21
Toluene	-73	-38	-194	4	78	-252	66	75	36	87	93	66

Note: negative data given only to emphasize variability.

this waste stream and the decision was made by NYSDEC to treat it again with activated carbon before it was discharged to the site. The carbon used for pretreatment was returned to the supplier for steam regeneration after testing.

Another waste that was generated by the ELI/SBP process was well cuttings generated during installation of the large (16-inch) well and the additional monitoring wells. These wastes were placed in 55 gallon drums and will be disposed of as part of the final site remediation. Personal protective equipment used by ELI/SBP personnel, by the driller, and by the sampling teams was also containerized for eventual disposal.

When the demonstration was completed, the NYSDEC required that the UVB well casing be removed. This was undertaken using a drill rig and a crane but was only partially successful and the effort was abandoned, with the concurrence of the NYSDEC. The portion that could be removed was cut into sections and stored in 55 gallon drums for disposal during site remediation. The aboveground PVC manifold and other piping were disposed through a local salvage firm. The vacuum blower system was steam-cleaned on-site and retained by ELI/SBP for reuse at another installation. Casings were also removed from some of the monitoring wells, cut into sections and stored in 55 gallon drums for disposal. Several wells were left operational for future sampling by the NYSDEC.

Section 5.0
Other Technology Requirements

This section discusses potential permitting requirements for operation of the UVB treatment system. It also presents health and safety requirements and potential hazards to be addressed to assure the safety of workers and the community during operation of the technology.

5.1 Environmental Regulation Requirements

Before implementing the ELI/SBP UVB treatment process as part of a remediation at another site, it usually will be necessary to obtain a number of permits from state, federal or local regulatory agencies. A permit may be required to operate the system and, in many states, a separate permit will be required to exhaust air with or without treatment. Similarly, depending on how the separator (knockout) and monitoring well development and purge water are managed, permits may also be required for those activities. Permits usually will be required for installation and closure of the large UVB well and groundwater monitoring wells. Permits also may be needed for storage and disposal of any well cuttings; if these wastes are determined to be hazardous, on-site storage limitations may also be imposed.

Section 2 of this report discusses the environmental regulations that apply to this technology. Table 2-1 presents a summary of the Federal and state ARARs for the UVB technology.

5.2 Personnel Issues

The number of ELI/SBP personnel required is largely determined by the extent of a planned remediation. During the demonstration, two to four workers were required for about 1 week to install the wells and the manifold and to make the aboveground blower system operational. Once the system is operational, and the flow of air adjusted, only minimal labor is necessary for routine field monitoring and minor system adjustments. This can probably be accomplished in about 1 day/week by a single technician trained to operate and adjust the system under supervision by telephone. Major changes, such as those created by power failures or significant changes in the water table are something of a problem, as experienced during the demonstration, and may require more extensive readjustment of the system to restore optimum conditions. Such efforts will require more manpower.

The health and safety issues for personnel operating the ELI/SBP technology are generally the same as those that apply to any hazardous waste treatment facility and are most important during installation of the system. The regulations covering these issues are documented in 40 CFR 264 Subparts B through G and Subpart X.

Emergency response training for operation of the ELI/SBP treatment system is the same as the general training required for operation of any treatment, storage and disposal (TSD) facility as detailed in 40 CFR 264, Subpart D. Training must address fire-related issues such as extinguisher operation, hoses, sprinklers, hydrants, smoke detectors, and alarm systems, as appropriate, although these issues should be of little risk since the system will usually be outside. Training must also address contaminant-specific issues such as hazardous material spill control and the use of decontamination equipment. Other issues include self-contained breathing apparatus use, evacuation and emergency response planning, and coordination with outside emergency personnel (e.g., fire/ambulance).

For most sites, personal protective equipment (PPE) for workers will include gloves, hard hats, steel-toed boots and Tyvek® suits. Depending on contaminant types and concentrations, additional PPE may be required, such as during the purging and sampling of groundwater monitoring wells. Noise levels should be monitored, particularly in the vicinity of the blower, to ensure that workers are not exposed to noise levels above a time weighted average of 85 decibels over an 8-hour day. If this level is exceeded and cannot be reduced, workers would be required to wear additional hearing protection.

5.3 Community Acceptance

Potential hazards related to the community include exposure to volatile organic pollutants that could be emitted by the venting of exhaust air if VOCs are still present and exposure to particulate matter that might be released to the air during site preparation and/or well installation. Air emissions of VOCs can be controlled by the ex situ biofilter and/or activated carbon or other post-treatment systems. Particulate matter can be controlled by wetting down the area before and while it is being disturbed; this latter problem would be of short duration.

Noise from the blower may be a factor to neighbors since the blower operates around the clock. Berming or an enclosure may be necessary to assure that the community is not disturbed.

Section 6.0
Technology Status

This section discusses the experience of the developers in performing treatment using the UVB treatment process. It also examines the capability of the developers in using the technology at sites with contaminant mixtures.

6.1 Previous Experience

In addition to the demonstration performed on oxygenated and chlorinated VOCs at the Sweden-3 Chapman site, ELI/SBP have also carried out several site remediations where the principal VOC contaminants were hydrocarbons, particularly gasoline from leaking storage tanks. Other licensees also have implemented remediation of other configurations of the UVB treatment system.

6.2 Scaling Capabilities

ELI/SBP have installed and operated the UVB treatment system on a scale larger than that of the demonstration at several sites where hydrocarbons were the primary contaminants. The system has not previously been tested at either the pilot-scale or full-scale on soils contaminated with chlorinated VOCs.

Bibliography

Fliermans, C.B., et al, "Mineralization of Trichloroethylene by Heterotrophic Enrichment Cultures," Applied and Enviro. Microbiol., 54, 1709 (1988).

Fogel, M.M., A.R. Taddeo, and S. Fogel, "Biodegradation of Chlorinated Ethenes by a Methane-Utilizing Mixed Culture," Applied and Enviro. Microbiol., 51, 720 (1986).

Freedman, D.L. and J.M. Gossett, "Biological Reductive Dechlorination of Tetrachloroethylene and Trichloroethylene to Ethylene under Methanogenic Conditions," Applied and Enviro. Microbiol., 55, 2144 (1989).

Janssen, D.B., et al, "Degradation of trans-1,2-dichloroethene by mixed and pure cultures of methanotrophic bacteria," Appl. Microbiol, Biotechnol., 29 392 (1988).

Newman, A.W. and M.M. Matinson, "Let Biodegradation Promote In Situ Soil Venting," Remediation, Summer, 277 (1992).

Parsons, F., P.R. Wood, and J. DeMarco, "Transformations of Tetrachloroethene and Trichloroethene in Microcosms and Groundwater," JAWWA, February, 56 (1984).

U.S. Environmental Protection Agency, "Applications Analysis Report - Accutech Pneumatic Fracturing Extraction and Hot Gas Injection, Phase I," EPA/540/AR-93/509 July 1993.

Vogel, T.M. and P.L. McCarty, "Biotransformation of Tetrachloroethylene to Trichloroethylene, Dichloroethylene, Vinyl Chloride, and Carbon Dioxide under Methanotrophic Conditions," Applied and Enviro. Microbiol., 49, 1080 (1985).

Wackett, L.P. and D.T. Gibson, "Degradation of Trichloroethylene by Toluene Dioxygenase in Whole-Cell Studies with Pseudomonas putida F1," Applied and Enviro. Microbiol., 54, 1703 (1988).

Wilson, J.T. and B.H. Wilson, "Biotransformation of Trichloroethylene in Soil," Applied and Enviro. Microbiol., 49, 242 (1985).

Appendix
Vendors' Comments

Vendors did not provide input for this section.

United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

Please make all necessary changes on the below label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left-hand corner.

PRESORTED STANDARD
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

Official Business
Penalty for Private Use
$300

EPA/540/R-99/503