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SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

Roy F. Weston, Inc. and IEG Technologies Corporation Unterdruck-Verdampfer-Brunnen (UVB) Technology

Innovative Technology Evaluation Report

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

Notice

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Foreword

The U. S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to 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 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 Corporation (IEG) and demonstrated in association with Roy F. Weston, Inc. This evaluation was conducted under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program. The UVB treatment technology was demonstrated over a period of 12 months from April 1993 to May 1994 at March Air Force Base (AFB) in Riverside, California.

This Innovative Technology Evaluation Report provides information from the SITE demonstration of the UVB technology that is useful for remedial managers, environmental consultants, and other potential technology users in implementing the technology at Superfund and Resource Conservation and Recovery Act (RCRA) hazardous waste sites.

The SITE demonstration for the UVB technology was designed with three primary and seven secondary objectives to provide potential users of the technology with the information necessary to assess the applicability of the UVB system at other contaminated sites. The demonstration program objectives were achieved through the collection of groundwater and soil gas samples, as well as UVB system process air stream samples over a 12-month period. To meet the objectives, data were collected in three phases: baseline sampling, long-term sampling, and dye trace sampling. Baseline and long-term sampling included the collection of groundwater samples from eight monitoring wells, a soil gas sample from the soil vapor monitoring well, and air samples from the three UVB process air streams both before UVB system startup and monthly thereafter. In addition, a dye trace study was implemented to evaluate the system's radius of circulation cell. This study included the introduction of fluorescent dye into the groundwater and the subsequent monitoring of 13 groundwater wells for the presence of dye three times a week over a 4-month period.

The technology was analyzed to identify its advantages, disadvantages, and limitations. The UVB technology was evaluated based on the nine criteria used for decision making in the Superfund feasibility study process. The overall effectiveness of the system depends upon the time available for mass exchange between dissolved and vapor phase, the concentration gradient, the temperature of the operating system, the interface area of the bubble (bubble size), and the contaminant gas-liquid partitioning (mass transfer coefficient). The technology employs readily available equipment and materials. Material handling requirements and site support requirements are minimal. The technology as presented at the SITE demonstration is limited to treatment of VOCs in the saturated zone and capillary fringe.

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Acronyms, Abbreviations, and Symbols

ACL	Alternative Concentration Limit
AFB	Air Force Base
Ag	Silver
Al	Aluminum
AMSL	Above mean sea level
APHA	American Public Health Association
ARAR	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
ATTIC	Alternative Treatment Technology Information Center
B	Boron
Ba	Barium
BACT	Best Available Control Technologies
Be	Beryllium
bgs	Below ground surface
BS	Blank spike
BSD	Blank spike duplicate
C	Degree Celsius
Ca	Calcium
CAA	Clean Air Act
Cd	Cadmium
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERI	Center for Environmental Research Information
CFR	Code of Federal Regulations
cm	Centimeter
cm/s	Centimeter per second
CMDTOCAA	Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air
Co	Cobalt
CO_2	Carbon dioxide
Cr	Chromium
CRADA	Cooperative Research and Development Agreement

Acronyms, Abbreviations, and Symbols (continued)

Cu	Copper
CWA	Clean Water Act
DCE	1,1-Dichloroethene
DOC	Dissolved organic carbon
DUP	Duplicate
EPA	U.S. Environmental Protection Agency
Fe	Iron
fpm	Feet per minute
ft^3	Cubic feet
ft/day	Feet per day
gpd/ft^2	Gallons per day per feet squared
gpm	Gallons per minute
HSWA	Hazardous and Solid Waste Amendments
IEG	IEG Technologies Corporation
IRP	Installation Restoration Program
ITER	Innovative Technology Evaluation Report
K	Potassium
K_h	Horizontal hydraulic conductivity
K_v	Vertical hydraulic conductivity
LDR	Land disposal restrictions
m	Meter
m^3	Cubic meter
MCAWW	Method for the Chemical Analysis of Water and Wastes
MCL	Maximum contaminant level
Mg	Magnesium
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
mm	Millimeter
Mn	Manganese
Mo	Molybdenum
MS	Matrix spike
MSD	Matrix spike duplicate
N_2	Nitrogen
NA	Not analyzed
Na	Sodium
NAAQS	National Ambient Air Quality Standards
NC	Not calculated

Acronyms, Abbreviations, and Symbols (continued)

Ni	Nickel
NI	Not installed
NPDES	National Pollutant Discharge Elimination System
NTIS	National Technical Information Service
O_2	Oxygen
O&M	Operations and maintenance
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
OU1	Operable Unit 1
$ppb_{v/v}$	Parts per billion on a volume to volume basis
PPE	Personal protective equipment
psia	Pounds per square inch absolute
POTW	Publicly owned treatment works
PRC	PRC Environmental Management, Inc.
PSD	Prevention of Significant Deterioration
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
RPD	Relative percent difference
s	Second
SARA	Superfund Amendments and Reauthorization Act (of 1986)
Sb	Antimony
scfm	Standard cubic feet per minute
SDWA	Safe Drinking Water Act
Se	Selenium
Si	Silicon
SIP	State Implementation Plan
SITE	Superfund Innovative Technology Evaluation
SVOC	Semivolatile organic compounds
SW-846	U.S. EPA Test Methods for Evaluating Solid Wastes
TDS	Total dissolved solids
TCE	Trichloroethene
TER	Technical Evaluation Report
TETC	The Earth Technology Corporation

Acronyms, Abbreviations, and Symbols (continued)

Ti	Titanium
µg/L	Micrograms per liter
UCL	Upper confidence limit
UVB	Unterdruck-Verdampfer-Brunnen
V	Vanadium
VISITT	Vendor Information System for Innovative Treatment Technologies
VOC	Volatile organic compounds
Weston	Roy F. Weston, Inc.
Zn	Zinc
in Hg	Inches of mercury
$\%_{v/v}$	Percent volume to volume basis
<	Less than
>	Greater than

Conversion Factors

	To Convert From	*To*	*Multiply By*
Length	inch	centimeter	2.54
	foot	meter	0.305
	mile	kilometer	1.61
Area:	square foot	square meter	0.0929
	acre	square meter	4,047
Volume:	gallon	liter	3.78
	cubic foot	cubic meter	0.0283
Mass:	pound	kilogram	0.454
Energy:	kilowatt-hour	megajoule	3.60
Power:	kilowatt	horsepower	1.34
Temperature:	(°Fahrenheit - 32)	°Celsius	0.556

Acknowledgments

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Executive Summary

This report summarizes the findings of an evaluation of the Unterdruck-Verdampfer-Brunnen (UVB) technology developed by IEG Technologies Corporation (IEG) and demonstrated in association with Roy F. Weston, Inc. This evaluation was conducted under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program. The UVB treatment technology was demonstrated over a period of 12 months from April 1993 to May 1994 at March Air Force Base (AFB) in Riverside, California.

This Innovative Technology Evaluation Report provides information from the SITE demonstration of the UVB technology that is useful for remedial managers, environmental consultants, and other potential technology users in implementing the technology at Superfund and Resource Conservation and Recovery Act (RCRA) hazardous waste sites. Section 1.0 presents an overview of the SITE program, describes the UVB technology, and lists key contacts. Section 2.0 discusses information relevant to the technology's application, including an assessment of the technology related to the nine feasibility study evaluation criteria used for decision making in the Superfund process, potential applicable environmental regulations, and operability and limitations of the technology. Section 3.0 summarizes the costs associated with implementing the technology. Section 4.0 presents the site characterization, demonstration approach, demonstration procedures, and the results and conclusions of the demonstration. Section 5.0 summarizes the technology status, and Section 6.0 includes a list of references. Appendices A and B present the Dye Trace Study Report conducted during the SITE demonstration and case studies provided by the developer.

The UVB Technology

The UVB technology is a patented in situ groundwater remediation technology (developed in Germany) that combines air-lift pumping and air stripping to clean aquifers contaminated with volatile organic compounds (VOC). A properly installed UVB system consists of a single well with two hydraulically separated screened intervals installed within a single permeable zone. The air-lift pumping occurs in response to negative pressure introduced at the wellhead by a blower. This blower creates a vacuum that draws water into the well through the lower screened portion of the well. Simultaneously, air stripping occurs as ambient air (also flowing in response to the vacuum) is introduced through a diffuser plate located within the upper screened section of the well, causing air bubbles to form in the water pulled into the well. The rising air bubbles provide the air-lift pump effect that moves water toward the top of the well and draws water into the lower screened section of the well. This pumping effect is supplemented by a submersible pump that ensures that water flows from bottom to top in the well. As the air bubbles rise through the water column, volatile compounds are transferred from the aqueous to the gas phase. The transfer of volatile compounds is further enhanced by a stripping reactor located immediately above the air diffuser. The stripping reactor consists of a fluted and channelized column that facilitates the transfer of volatile compounds to the gas phase by increasing the contact time between the two phases and by minimizing the coalescence of air bubbles. The rising air transports volatile compounds to the top of the well casing where they are removed by the blower. The blower effluent is treated before discharge using a carbon adsorption unit.

Once the upward stream of water leaves the stripping reactor, the water falls back through the well casing and returns to the aquifer through the upper well screen. This return flow to the aquifer, coupled with inflow at the well bottom, circulates groundwater around the UVB well. The extent of the circulation pattern is known as the radius of circulation cell, which determines the volume of water affected by the UVB system.

Waste Applicability

The UVB technology demonstrated at March AFB removed trichloroethene (TCE) and 1,1-dichloroethene (DCE) from groundwater. The developer claims that the technology can also clean aquifers contaminated with other organic compounds, including volatile and semivolatile hydrocarbons. Additionally, the developer claims that in some cases the UVB technology is capable of simultaneous recovery of soil gas from the vadose zone.

Demonstration Objectives and Approach

The SITE demonstration for the UVB technology was designed with three primary and seven secondary objectives to provide potential users of the technology with the information necessary to assess the applicability of the UVB system at other contaminated sites. The following primary and secondary objectives were selected to evaluate the technology:

<u>Primary Objectives:</u>

(P1) Determine the concentration to which the UVB technology reduces TCE and DCE in groundwater discharged from the treatment system

(P2) Estimate the radius of circulation cell of the groundwater treatment system

(P3) Determine whether TCE and DCE concentrations have been reduced in groundwater (both vertically and horizontally) within the radius of circulation cell of the UVB system over the course of the pilot study

<u>Secondary Objectives:</u>

(S1) Assess homogenization of the groundwater within the zone of influence

(S2) Document selected aquifer geochemical characteristics that may be affected by oxygenation and recirculation of treated groundwater

(S3) Determine whether the treatment system induces a vacuum in the vadose zone that suggests vapor transport

(S4) Estimate the capital and operating costs of constructing a single treatment unit to remediate groundwater contaminated with TCE and DCE

(S5) Document pre- and post-treatment off-gas volatile organic contaminant levels

(S6) Document system operating parameters

(S7) Evaluate the presence of aerobic biological activity in the saturated and vadose zones

The demonstration program objectives were achieved through the collection of groundwater and soil gas samples, as well as UVB system process air stream samples over a 12-month period. To meet the objectives, data were collected in three phases: baseline sampling, long-term sampling, and dye trace sampling. Baseline and long-term sampling included the collection of groundwater samples from eight monitoring wells, a soil gas sample from the soil vapor monitoring well, and air samples from the three UVB process air streams both before UVB system startup and monthly thereafter. In addition, a dye trace study was implemented to evaluate the system's radius of circulation cell. This study included the introduction of fluorescent dye into the groundwater and the subsequent monitoring of 13 groundwater wells for the presence of dye three times a week over a 4-month period.

Demonstration Conclusions

Based on the UVB SITE demonstration, the following conclusions may be drawn about the applicability of the UVB technology:

- Results of chemical analyses of samples from the UVB system wells indicate that the UVB treatment system removed TCE and DCE from the groundwater. The UVB system reduced TCE in the groundwater discharged from the treatment system to below 5 micrograms per liter (µg/L) in nine out of the 10 monthly monitoring events and on average by greater than 94 percent during the period in which the system operated without apparent maintenance problems. The mean TCE concentration in water discharged from the system was approximately 3 µg/L; however, the upper confidence limit at the 95 percent confidence level was calculated to be approximately 6 µg/L. The UVB system reduced DCE to less than 1 µg/L in groundwater discharged from the treatment system; however, the system's ability to remove DCE could not be meaningfully estimated due to the low (less than 4 µg/L) influent concentration of DCE.

- The radius of circulation cell of the groundwater treatment system was estimated by both direct and indirect methods. The radius of circulation cell was directly measured by conducting a dye trace study. Based on the dye trace study, the radius of circulation cell was measured to be at least 40 feet (12.2 meters [m]) in the downgradient direction. The radius of circulation cell was indirectly evaluated by (1) modeling of the groundwater flow, and (2) analyzing aquifer pump test data (step-test and constant rate). Groundwater flow modeling results indicate a radius of circulation cell of 83 feet (25.3 m). The drawdown measured in the observation wells during the pump tests provided information on the size and shape of the cone of depression at various pumping rates. The size and shape of the cone of depression observed during the pump tests was used to estimate the radius of circulation cell of the UVB system well operating at a constant rate of 20 gallons per minute (75.7 liters per minute). The observed drawdown data from the pump tests indicated a radius of circulation cell of about 60 feet (18.3 m). The pump test data are not directly applicable to determining the radius of circulation cell of the UVB circulation cell. An attempt was made to indirectly evaluate the radius of circulation cell using variations of target compound concentrations and fluctuations of dissolved oxygen in surrounding groundwater monitoring wells. However, these methods did not provide a reliable or conclusive estimate of the radius of circulation cell.

- TCE and DCE concentrations in samples from the shallow and intermediate zone wells were reduced both vertically and laterally except in the intermediate outer cluster well, which showed an increase in concentration. TCE concentrations were reduced laterally by an average of approximately 52 percent in the shallow and intermediate zones of the aquifer over a 12 month period. No reduction of either TCE of DCE was observed in the deep zone, which could be due to limited duration of monitoring in this zone.

- A convergence and stabilization of TCE and DCE concentrations was observed in samples from the shallow and intermediate zones of the aquifer, which suggest homogenization of the groundwater.

- No clear trends in the field parameters, general chemistry, and dissolved metals results were observed that would indicate significant precipitation of dissolved metals, changes in dissolved organic carbon, or the presence of dissolved salts caused by the increase in oxygen in the groundwater.

- Although the developer claims that the UVB system has applications to cleanups of both groundwater and soil gas, the system installed at Site 31 was designed to remove halogenated hydrocarbons from the groundwater only. The VOC concentrations and vacuum measurements in the vapor monitoring well indicate that migration of contaminants in the vadose zone was not significantly affected by operation of the UVB system as designed. Changes in system design and operating parameters may lead to significant transport of contaminants in the vadose zone.

- One-time capital costs for a single treatment unit were estimated to be \$180,000; variable annual operation and maintenance costs for the first year were estimated to be \$72,000, and \$42,000 for subsequent years. Based on these estimates, the total cost for operating a single UVB system for 1 year was calculated to be \$260,000. Since the time required to remediate an aquifer is site-specific, costs have been estimated for operation of a UVB system over a range of time for comparison purposes. Therefore, the cost to operate a single UVB system was calculated to be \$340,000 for 3 years, \$440,000 for 5 years, and \$710,000 for 10 years. Additionally, the costs for treatment per 1,000 gallons (3,785 liters [L]) of groundwater were estimated to be \$260 for 1 year, \$110 for 3 years, \$88 for 5 years, and \$71 for 10 years. The costs for treatment per 1,000 liters (264.2 gallons) of groundwater were estimated to be \$69 for 1 year, \$29 for 3 years, \$23 for 5 years, and \$19 for 10 years. The cost of treatment per 1,000 gallons (3,785 L) refers to the amount of groundwater pumped through the system. Potential users of the treatment technology should be aware that typically 60 to 90 percent of the water pumped through the system is recirculated water.

- The results from air monitoring of the UVB treatment system indicated that low concentrations of TCE are being removed from the groundwater. TCE concentrations reduced by the UVB system correlate to trends observed in target compounds concentrations in the inner cluster monitoring wells (that is, increasing concentration from the baseline event to the third monthly monitoring event with a subsequent decrease in concentrations).

- The temperature of the internal monitoring ports ranged from 18.5 to 44.7 degrees Celsius; the relative humidity ranged from 27 to 100 percent; the vacuum pressure ranged from 13.81 to 15.03 pounds per square inch absolute (9,709.81 to 10,567.59 kilograms per square meter); the air flow ranged from 100 to 898 standard cubic feet per minute (47.2 to 423.9 liters per second); and the velocity ranged from 1,109 to 9,999 feet per minute (563.4 to 5,079.5 centimeters per second).

- Bioactivity in the soil and groundwater was not significantly enhanced by the UVB system operation.

Other Case Studies

According to the developer, the UVB technology has been applied at about 80 sites in Europe, and 22 systems are operating in the United States. In Appendix B, the developer has provided two case studies from Germany involving trichloroethene, 1,1,1-trichloroethane, and dichloromethane; a case from North Carolina involving benzene, toluene, ethylbenzene, and xylene; and the developer's interpretation of the data collected during this SITE demonstration.

Technology Applicability

The technology was analyzed to identify its advantages, disadvantages, and limitations. The UVB technology was evaluated based on the nine criteria used for decision making in the Superfund feasibility study process. Table ES-1 presents the evaluation. The overall effectiveness of the system depends upon the time available for mass exchange between dissolved and vapor phase, the concentration gradient, the temperature of the operating system, the interface area of the bubble (bubble size), and the contaminant gas-liquid partitioning (mass transfer coefficient). The technology employs readily available equipment and materials. Material handling requirements and site support requirements are minimal. The technology as presented at the SITE demonstration is limited to treatment of VOCs in the saturated zone and capillary fringe.

Table ES-1. Feasibility Study Evaluation Criteria for the UVB Technology

CRITERION		UVB TECHNOLOGY ASSESSMENT
1	Overall Protection of Human Health and the Environment	The technology eliminates contaminants in the groundwater and prevents further migration of those contaminants with minimal exposure to on-site workers and the community. Air emissions are reduced by using carbon adsorption units.
2	Compliance with Federal Applicable or Relevant and Appropriate Requirements (ARARs)	Compliance with chemical-, location-, and action-specific ARARs must be determined on a site-specific basis. Compliance with chemical-specific ARARs is dependent on (1) treatment efficiency of the UVB system, (2) influent contaminant concentrations, and (3) the amount of treated groundwater recirculated within the system.
3	Long-Term Effectiveness and Permanence	Contaminants are permanently removed from the groundwater. Treatment residuals (activated carbon) require proper off-site treatment and disposal.
4	Reduction of Toxicity, Mobility, or Volume Through Treatment	Contaminant mobility is initially increased, which facilitates the long-term remediation of the groundwater within the system's radius of circulation cell. The movement of contaminants toward the UVB system within the system's capture zone prevents further migration of those contaminants and ultimately reduces the volume of contaminated media.
5	Short-Term Effectiveness	During site preparation and installation of the treatment system, no adverse impacts to the community, workers, or the environment are anticipated. Short-term risks to workers, the community, and the environment are presented by increased mobility of contaminants during the initial start-up phase of the system and from the system's air stream. Adverse impacts from the air stream are mitigated by passing the emissions through carbon adsorption units before discharge to the ambient air. The time for treatment using the UVB system are dependent on site conditions and may require several years.
6	Implementability	The site must be accessible to large trucks. The entire system requires about 500 square feet (46.5 square meters). Services and supplies may include a drill rig, carbon adsorption regeneration/disposal (or other off-gas treatment system), laboratory analysis, and electrical utilities.

Table ES-1. Feasibility Study Evaluation Criteria for the UVB Technology (continued)

	CRITERION	UVB TECHNOLOGY ASSESSMENT
7	Cost	Capital costs for installation are $180,000, and annual operation and maintenance costs are $72,000.
8	Community Acceptance	The small risks presented to the community along with the permanent removal of the contaminants make public acceptance of the technology likely.
9	State Acceptance	State acceptance is anticipated because the UVB system uses well-documented and widely accepted processes for the removal of VOCs from groundwater and for treatment of the process air emissions. State regulatory agencies may require permits to operate the treatment system, for air emissions, and to store contaminated soil cuttings and purge water for greater than 90 days.

Section 1
Introduction

This report summarizes the findings of an evaluation of the Unterdruck-Verdampfer-Brunnen (UVB) technology developed by IEG Technologies Corporation (IEG) and demonstrated in association with Roy F. Weston, Inc. This evaluation was conducted under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program. The UVB treatment technology was demonstrated over a period of 12 months from April 1993 to May 1994 at March Air Force Base (AFB) in Riverside, California.

This Innovative Technology Evaluation Report (ITER) provides information from the SITE demonstration of the UVB technology that is useful for remedial managers, environmental consultants, and other potential technology users in implementing the technology at Superfund and Resource Conservation and Recovery Act (RCRA) hazardous waste sites. Section 1.0 presents an overview of the SITE program, describes the UVB technology, and lists key contacts. Section 2.0 discusses information relevant to the technology's application, including an assessment of the technology related to the nine feasibility study evaluation criteria, potential applicable environmental regulations, and operability and limitations of the technology. Section 3.0 summarizes the costs associated with implementing the technology. Section 4.0 presents the site characterization, demonstration approach, demonstration procedures, and the results and conclusions of the demonstration. Section 5.0 summarizes the technology status, and Section 6.0 includes a list of references. Appendices A and B present the Dye Trace Study Report conducted during the SITE demonstration and case studies provided by the developer.

An accompanying document to the ITER, the Draft UVB Technology Evaluation Report (TER) (PRC 1995), has also been prepared. The TER includes a detailed presentation of the demonstration procedures used to collect and analyze samples, tabulated summaries of the demonstration results and quality assurance/quality control (QA/QC) program used to ensure the quality and usability of data. The document is intended to provide a record of all information generated during the UVB demonstration and is intended for use during the QA/QC review of the ITER.

This section provides background information about the EPA SITE program, discusses the purpose of this ITER, and describes the UVB technology. Additional information about the SITE program, the UVB technology, and the demonstration can be obtained by contacting the key individuals listed at the end of this section.

1.1 The SITE Program

SITE is a formal program established by 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's primary purpose is to maximize the use of alternatives in cleaning up hazardous waste sites by encouraging the development, demonstration, and use of new or innovative treatment and monitoring technologies. It consists of four major elements:

- Identify and remove obstacles to the development and commercial use of alternate technologies.
- Structure a development program that nurtures emerging technologies.
- Demonstrate promising innovative technologies to establish reliable performance and cost information for site characterization and cleanup decision-making.
- Develop procedures and policies that encourage the selection of available alternative treatment remedies

at Superfund sites, as well as other waste sites and commercial facilities.

Technologies are selected for the SITE Demonstration Program through annual requests for proposals. ORD staff review 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 advantage over existing technologies. Mobile technologies are of particular interest.

Once EPA has accepted a proposal, cooperative agreements between EPA and the developer establish responsibilities for conducting the demonstrations 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, operations, and removal of the equipment. 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 the demonstration are published in two basic documents: the SITE technology capsule and the ITER. The SITE technology capsule provides information on the technology, emphasizing key features of the results of the SITE demonstration. 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.

1.2 Innovative Technology Evaluation Report

This ITER provides information on the UVB technology and includes a comprehensive description of the demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision makers for implementing specific remedial actions. The ITER is designed to aid decision makers in evaluating specific technologies for further consideration as an option in a particular cleanup operation.

To encourage the general use of demonstrated technologies, the ITER provides information regarding the applicability of each technology to specific sites and wastes. The ITER includes information on cost and 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 material. The characteristics of other materials may differ from the characteristics of the treated material. Therefore, 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.

1.3 Technology Description

Roy F. Weston, Inc. in association with IEG Technologies Corporation (IEG), conducted the pilot-scale demonstration of the UVB technology (Figure 1-1). The UVB system is an in situ remediation technology for the cleanup of aquifers contaminated with volatile organic compounds (VOCs). The UVB system is a patented technology developed in Germany that consists of a single well with two hydraulically separated screened intervals installed within a single permeable zone. The UVB system combines air-lift pumping and air stripping to facilitate the removal of volatile compounds (Weston 1992). Air-lift pumping effects are enhanced by adding a submersible pump to transport water from the well bottom to the upper hydraulic section. Stripped volatile compounds are removed from the well head by a blower and are captured in a carbon adsorption unit before releasing the stripped air to the atmosphere. Once stripped of volatile compounds, treated water reinfiltrates into the aquifer through the upper screen of the UVB system. The movement of water through the UVB system creates a hydraulic circulation pattern in the aquifer, which constitutes the UVB circulation cell.

The air-lift effect occurs in response to negative pressure introduced at the well head by a blower. This blower creates a vacuum that draws water into the well through the lower screened portion of the well. Simultaneously, ambient air (also flowing in as a response to the applied vacuum) is introduced through a diffuser plate, causing bubbles to form in the water that is pulled into the well. The rising air bubbles provide the air-lift pump effect that moves water toward the top of the well and causes a suction effect at the well bottom. This pumping effect may

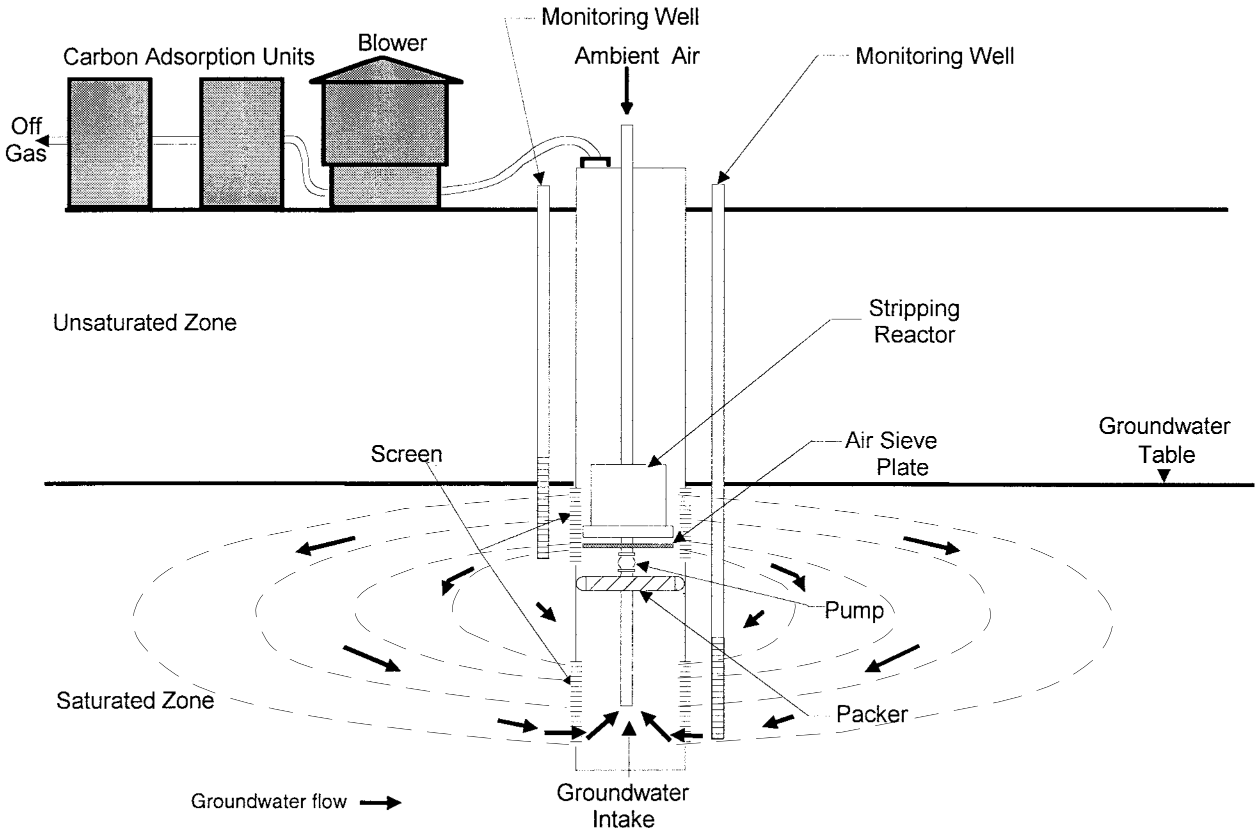

Figure 1-1. UVB technology conceptual diagram.

be supplemented by a submersible pump that ensures that water flows from bottom to top in the well. As the air bubbles rise through the water column, transfer of volatile compounds from the aqueous to gas phase occurs. The rising air transports volatile compounds to the top of the well casing where they are removed by the blower. The blower effluent is treated using a carbon adsorption unit before discharge to the ambient air.

The upper portion of the well is hydraulically separated from the lower portion by a packer, as shown in Figure 1-1. However, a small (3-inch or 7.6 centimeter [cm]) water inlet pipe inserted through the packer connects the two sections of the well. Water from the bottom of the aquifer flows into the well through a screened portion of the casing in response to a pressure gradient, air-lift pump effect, and a submersible pump. The pressure gradient from the upper well to the lower well results from the vacuum applied in the upper well. These forces then draw water up through the inlet pipe from the lower part of the well and into the upper part of the well, where it is introduced to the air diffuser.

Stripping is initiated by the air sieve pin hole plate that disperses air bubbles within the water column to increase transfer of volatile compounds from the aqueous to the gaseous phase. This process is further enhanced by a fluted and channelized column that facilitates the transfer of volatile compounds to the gaseous phase by increasing contact time between the two phases and by minimizing the coalescence of air bubbles. Volatilization is enhanced by the concentration gradient between the aqueous and gas phases and the negative (reduced) pressure in the upper hydraulic section of the UVB well. Volatilization depends on the solubility, molecular weight, and vapor pressure of the compounds treated and the nature of the air-water interface through which the compounds must pass. The effectiveness of vapor stripping depends on the time available for mass exchange between dissolved and vapor phases, the concentration gradient (between the two phases), the operating temperature, the interface area of the bubble (bubble size), and the contaminant gas-liquid partitioning (mass transfer coefficient).

The overall stripping zone of the UVB system extends from the diffuser plate to the top of the water column. To maximize volatilization in the stripping zone, the diffuser plate and stripping reactor are positioned at a depth that optimizes the reach of the stripping zone and the volume of air flow into the system. The down-well components of the UVB system have been designed with leveling ballast that allows the system to be free floating. This feature allows the system to compensate for fluctuations in groundwater elevation during operation and, thereby, maintain maximum volatilization.

The upward stream of water in the well is drawn up to a maximum height of about 3 feet (0.9 meters [m]) above the groundwater table in response to the vacuum and air-lift pumping. Once the hydrostatic head (height of the water column drawn up into the well casing) exceeds the sum of the buoyancy (air-lift) force and pressure head (vacuum) force in the well, the water falls back through the well casing and returns through the upper well screen to the aquifer. This return flow to the aquifer coupled with inflow at the well bottom circulates groundwater around the UVB well. The extent of the circulation pattern is known as the radius of circulation cell and determines the volume of water affected by the UVB system when there is negligible natural groundwater flow.

The radius of circulation cell and shape of the circulation pattern are directly related to the aquifer properties. The circulation pattern is further modified by natural groundwater flow that skews the pattern in the downgradient direction. Numerical simulation of the UVB operation indicates that the radius of circulation cell is largely controlled by anisotropy (horizontal [K_h] and vertical [K_v] hydraulic conductivity), aquifer thickness, and, to a lesser extent, well design (Small and Narasimhan 1993). In general, changes that favor horizontal flow over vertical flow such as a small ratio of screen length to aquifer thickness, anisotropy, horizontal heterogeneities such as low permeability layers, or increased aquifer thickness will increase the radius of circulation cell (Small and Narasimhan 1993).

According to the developer, the radius of circulation cell can be estimated using numerical algorithms and graphical solutions developed by Dr. Bruno Herrling of the University of Karlsruhe, Germany. The Herrling model is based on theoretical assumptions that relate K_h/K_v, well discharge rate, Darcy velocity of the groundwater flow, and aquifer thickness to the distance between the UVB well and the stagnation point (Herrling et al. 1991). The distance from the UVB system to the stagnation point determined by the Herrling model is essentially equivalent to the radius of circulation cell of the system. The model was not thoroughly assessed as part of the evaluation of the UVB technology; however, IEG believes the model is valid based on empirical data generated from operation of the UVB system at other sites in Germany and the United States. As a general rule, IEG estimates that the system radius of circulation cell is approximately 2.5 times the distance between the upper and lower screen intervals.

Groundwater within the radius of circulation cell includes both treated and untreated water. A portion of the treated water discharged to the upper screen is recaptured within the circulation cell. Treated water not captured by the system leaves the circulation cell in the downgradient direction. The percentage of treated water recycled within the UVB system (IEG estimates up to 90 percent) is related to the radius of circulation cell and is a function of the ratio of K_h/K_v. The larger the radius of circulation cell and the larger the K_h to K_v ratio values, the smaller the percentage of recycled water. The recycled treated water dilutes influent contaminant concentrations.

The developer presents the UVB technology as a highly efficient in situ system requiring minimal maintenance. According to IEG, the UVB technology in some cases is also capable of simultaneous recovery of soil gas from the vadose zone and treatment of contaminated groundwater from the aquifer as a result of the in situ vacuum. For soil gas recovery, a screened portion would extend from below the water table to above the capillary zone in the well (Weston 1992).

1.4 Key Contacts

Additional information on the UVB technology and the SITE program can be obtained from the following sources:

The UVB Technology

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The SITE Program

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Director, Land Remediation and
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26 West Martin Luther King Drive
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Information on the SITE program is available through the following on-line information clearinghouse: the Vendor Information System for Innovative Treatment Technologies (VISITT) (Hotline: 800-245-4505) database contains information on 154 technologies offered by 97 developers.

Technical reports may be obtained by contacting U. S. EPA/NSCEP, P. O. Box 42419, Cincinnati, Ohio 45242-2419, or by calling 800-490-9198.

Section 2
Technology Applications Analysis

This section evaluates the general applicability of the UVB technology to contaminated waste sites. Information presented in this section is intended to assist decision makers in screening specific technologies for a particular cleanup situation. This section presents the advantages, disadvantages, and limitations of the technology and discusses factors that have a major impact on the performance and cost of the technology. The analysis is based both on the demonstration results and on available information from other applications of the technology.

2.1 Feasibility Study Evaluation Criteria

This section assesses the UVB technology against the nine evaluation criteria used for conducting detailed analyses of remedial alternatives in feasibility studies under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (EPA 1988a).

2.1.1 Overall Protection of Human Health and the Environment

The UVB technology provides both short- and long-term protection to human health and the environment by removing contaminants in groundwater and by preventing further migration of contaminants in the groundwater. The UVB technology removes VOCs from groundwater by stripping them from the groundwater and transferring them to the gas phase for subsequent treatment. The treated groundwater is discharged back into the aquifer without bringing the water to the surface; thus, contaminants are removed from the groundwater with minimal exposure to on-site workers and the community. Exposure from air emissions is minimized through the removal of contaminants in the system's air process stream using carbon adsorption units before discharge to the atmosphere.

The UVB system creates a capture zone in the aquifer that limits the migration of contaminated groundwater. However, a portion of the groundwater can leave the circulation cell in the downgradient direction. The escaping groundwater may present a concern if high concentrations of dissolved contaminants are present. More than one pass through the system may be required to reach remediation goals for high concentrations of dissolved contaminants.

2.1.2 Compliance with ARARs

General and specific applicable or relevant and appropriate requirements (ARARs) identified for the UVB technology are presented in Section 2.2. Compliance with chemical-, location-, and action-specific ARARs should be determined on a site-specific basis; however, location- and action-specific ARARs generally can be met. Compliance with chemical-specific ARARs depends on the efficiency of the UVB system to remove contaminants from the groundwater. To meet chemical-specific ARARs, contaminated groundwater may require multiple passes through the treatment system. Contaminated concentrations may increase during initial operation; however, as the UVB circulating cell is established, the influent concentrations should be diluted to below levels requiring more than one pass.

2.1.3 Long-Term Effectiveness and Permanence

The UVB system permanently removes contaminants from the groundwater; however, treatment residuals (activated carbon) are not destroyed on-site and require proper off-site treatment and disposal. Treatment of dissolved phase VOCs in the groundwater and air emissions using air stripping and carbon adsorption units are permanent solutions for the removal of contaminants.

Both of these techniques are well-demonstrated and effectively remove volatile contaminants from groundwater and air. The UVB system removes dissolved phase VOCs by air stripping the groundwater in the wellbore followed by reinfiltration of the treated groundwater into the aquifer. The reinfiltration of treated water creates a recirculation pattern of groundwater in the surrounding aquifer. The continuous flushing of the saturated zone with recirculated treated water facilitates the partitioning of adsorbed, absorbed, and liquid contaminants to the dissolved phase through increased dissolution, diffusion, and desorption. Increased partitioning through these processes is driven by increased groundwater flow rates within the system's radius of circulation cell and an increase in the concentration gradient established by the reinjection and recirculation of treated water in the aquifer. These processes provide an effective long-term solution to aquifer remediation by affecting contaminants in the saturated zone. The magnitude of residual risk from adsorbed, absorbed, or liquid contaminants can be controlled by extending the length of time that the system operates, thereby allowing groundwater to recirculate through the treatment system in multiple passes.

2.1.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

Contaminant concentrations may increase during the initial operation of the UVB system due to increased groundwater flow and partitioning of VOCs to the dissolved phase. This initial period of increased concentrations is followed by a subsequent decrease in concentration. According to the developer, this contaminant concentration pattern is typical of the UVB operation and is the result of the system increasing the partitioning of contaminants to the dissolved phase. The partitioning of contaminants to the dissolved phase is enhanced by the higher than natural groundwater flow rates within the system's radius of circulation cell and by an increase in the concentration gradient established by the reinjection and recirculation of treated water within the aquifer.

The subsequent reduction of contaminant concentrations in the groundwater is due to the active removal of contaminants via air stripping. The treatment process reduces the concentration of dissolved phase VOC contaminants in the groundwater by transferring the contaminants from the groundwater to a gas phase where they are concentrated in carbon adsorption units for disposal or recycling. The reduction of contaminant concentrations may also be caused by the dilution of contaminated water with treated water. After being treated, the groundwater reinfiltrates into the aquifer, where it mixes with untreated groundwater in the radius of circulation cell. The percentage of treated water recycled within the UVB system (IEG estimates up to 90 percent) is related to the radius of circulation cell and is a function of the aquifer anisotropy (K_h/K_v ratio). The smaller the radius of circulation cell and the smaller the ratio K_h to K_v, the larger the percentage of recycled water.

In addition to reducing contaminant concentrations in the aquifer, the UVB system affects contaminant mobility. Initially, contaminant mobility within the UVB system's radius of circulation cell is increased by the partitioning of contaminants into solution (dissolved phase) and by the increased groundwater flow velocity near the UVB system. The increased contaminant mobility facilitates the long-term remediation of the groundwater within the system's radius of circulation cell. The developer claims that the UVB system also limits contaminant mobility by capturing contaminated groundwater from the migrating plume and recirculating treated water within the radius of circulation cell.

2.1.5 Short-Term Effectiveness

Potential short-term risks presented during system operation to workers, the community, and the environment include increased contaminant concentrations in the groundwater during initial operation of the UVB and exposure to contaminants in the system's air stream. Since all treatment of groundwater occurs in situ, potential initial increases in contaminant concentration do not pose a significant risk to on-site workers or the community. In addition, once the circulation cell has been established, concentrations should decrease due to active removal of contaminants by the treatment system and dilution caused by the reinfiltration and recirculation of treated groundwater within the system's radius of circulation cell. Because the technology removes VOCs through air stripping, abatement controls must be provided for these emissions. Adverse impacts from the air stream are mitigated by passing the emissions through carbon adsorption units before discharge to the ambient air.

Implementation of the UVB system involves (1) site preparation, (2) installation of the system well, internal air stripping well components, and carbon adsorption units,

(3) installation of monitoring wells (if not already present), and (4) operation, monitoring, and maintenance. Well installation activities can be completed using conventional drilling techniques. Minimal adverse impacts to the community, workers, or the environment are anticipated during site preparation or installation of the treatment system or monitoring wells. Additionally, exposure from air emissions during operation, monitoring, and maintenance are minimized through the removal of contaminants in the system's air process stream using carbon adsorption units before discharge to the ambient air.

2.1.6 Implementability

Site preparation and access requirements for the technology are minimal. The site must be accessible to large trucks. The space requirements for the above-ground components of the UVB system including the UVB system well, carbon adsorption units, blower, and piping are approximately 100 to 700 square feet; 300 square feet (27.9 m^2) is typical. The equipment and materials that constitute this remedial alternative are commercially available and are proven in conventional applications at sites with similar conditions. Installation and operation of the UVB system is anticipated to involve few administrative difficulties. Once the well has been completed, the treatment system can be operational within 1 day if all necessary equipment, utilities, and supplies are available. Operation and monitoring can be performed by a trained field technician and do not require a specialist. However, the system should be maintained by personnel intimately familiar with operation of the UVB. Other services and supplies required to implement the UVB system could include a drill rig, carbon adsorption regeneration/disposal, laboratory analysis to monitor system performance, and electrical utilities.

2.1.7 Cost

The assumptions and calculations for the UVB system costs are presented in Section 3.0. Capital cost to install a UVB system is $180,000. This cost includes site preparation, permitting and regulatory requirements, equipment costs, startup, and demobilization. Annual operation, monitoring and maintenance costs for the first year are estimated to be $72,000 and for subsequent years $42,000. Based on these estimates, the total cost for operating a single UVB system for 1 year was calculated to be $260,000. Since the time required to remediate an aquifer is site-specific, costs have been estimated for operation of the UVB system over a range of time for comparison purposes. Therefore, the cost to operate a single UVB system was calculated to be $340,000 for 3 years, $440,000 for 5 years, and $710,000 for 10 years. Additionally, the costs for treatment per 1,000 gallons (3,785 liters [L]) of groundwater were estimated to be $260 for 1 year, $110 for 3 years, $88 for 5 years, and $71 for 10 years. The cost of treatment per 1,000 gallons (3,785 L) refers to the amount of groundwater pumped through the system. Potential users of the treatment technology should be aware that IEG estimates typically 60 to 90 percent of the water pumped through the system is recirculated water.

2.1.8 State Acceptance

State acceptance is anticipated because the UVB system uses well-documented and widely accepted processes to remove VOCs from groundwater and to treat the process air emissions. Also, the UVB system is small and relatively easy to transport, operate, and manage. If remediation is conducted as part of Resource Conservation and Recovery Act (RCRA) corrective actions, state regulatory agencies may require that permits be obtained before implementing the system, such as a permit to operate the treatment system, an air emissions permit, and a permit to store contaminated soil cuttings and purge water for greater than 90 days if these items are considered hazardous wastes.

2.1.9 Community Acceptance

The system's low profile, limited space requirements, minimal maintenance and monitoring, and low noise level coupled with minimal short-term risks to the community and the permanent removal of contaminants through in situ processes make this technology likely to be accepted by the public.

2.2 Technology Performance Versus ARARs

This section discusses specific federal environmental regulatory requirements pertinent to the transport, treatment, storage, and disposal of treatment residuals generated during operation of the UVB system, and analyzes these regulations in lieu of the demonstration results. The regulations that apply to a particular remediation activity will depend on the type of remediation site and the type of waste being treated. Table 2-1 provides a summary of regulations discussed in this section. In addition to the federal requirements, state and local regulatory requirements, which may be more stringent, also must be addressed by remedial managers.

2.2.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA as amended by SARA provides for federal authority to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or the environment. Remedial alternatives that significantly reduce the volume, toxicity, or mobility of hazardous materials and that provide long-term protection are preferred. Selected remedies must also be cost effective and protective of human health and the environment.

Contaminated water treatment using the UVB system takes place on-site, while residual wastes generated during the installation, operation, and monitoring of the system may require treatment or disposal either on-site or off-site. On-site actions must meet all substantive state and federal ARARs.

Substantive requirements pertain directly to actions or conditions in the environment (for example, groundwater effluent and air emission standards). Off-site actions must comply with legally applicable substantive and administrative requirements. Administrative requirements, such as permitting, facilitate the implementation of substantive requirements. On-site remedial actions must comply with federal and, if 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) fund balancing where ARAR compliance would entail such cost in relation to the added degree of protection or reduction of risk afforded by that ARAR that remedial action at other sites would be jeopardized. These waiver options apply only to Superfund actions taken on site, and the waiver must be clearly justified. Off-site remediations are not eligible for ARAR waivers, and all substantive and administrative applicable requirements must be met.

The contamination addressed by the UVB demonstration at March AFB was attributed to past disposal of spent solvents. The UVB system was designed to remove VOCs from the groundwater by transferring the contaminants from the aqueous phase to the gaseous phase and subsequently treating the resulting air stream through carbon adsorption units. Spent granular activated carbon is generated during treatment of air emissions. Other sources of waste are soil and contaminated groundwater derived from system installation and regular monitoring of the aquifer. Given these wastes (typical of operation of a UVB system), the following additional statutes and regulations pertinent to use of a UVB system were identified: (1) RCRA, (2) the Clean Water Act (CWA), (3) the Safe Drinking Water Act (SDWA), (4) the Clean Air Act (CAA), and (5) Occupational Safety and Health Administration (OSHA) regulations. These five ARARs are discussed below. Specific ARARs that were applicable to the UVB technology demonstration are presented in Table 2-1.

2.2.2 Resource Conservation and Recovery Act

RCRA, as amended by the Hazardous and Solid Waste Amendments (HSWA) of 1984, regulates management and disposal of municipal and industrial solid wastes. The EPA and RCRA-authorized states (listed in 40 Code of Federal Regulations [CFR] Part 272) implement and enforce RCRA and state regulations.

The UVB system has been used to treat water contaminated with a variety of organic materials including solvents and petroleum hydrocarbons. Contaminated water treated by the UVB system will most likely be hazardous or sufficiently similar to hazardous waste so that RCRA standards may be requirements. Generally, RCRA does not apply to in situ groundwater treatment because the contaminated groundwater may not be considered hazardous waste while it is in the aquifer; the contaminated groundwater becomes regulated (“generated”) once it leaves the aquifer. The applicability of RCRA requirements to the UVB treatment system requires a determination of whether or not the

Table 2-1. Federal and State ARARs for the UVB Groundwater Treatment

Process Activity	ARAR	Description	Basis	Requirements
Remediate contaminated groundwater (cleanup standards)	SDWA 40 CFR Part 141 or state equivalent TCE - 5 μg/L DCE - 7 μg/L (40 CFR 141.61)	Establishes drinking water quality standards for public water supplies	The groundwater may be used as a source of drinking water.	Treatment must occur until cleanup standards are met or further remediation is technically impracticable.
Waste characterization (untreated waste)	RCRA 40 CFR Part 261 or state equivalent	Identifies whether the waste is a listed or characteristic hazardous waste	A requirement of RCRA prior to managing and handling the waste.	Chemical and physical analyses must be performed.
Waste processing	RCRA 40 CFR Parts 264 and 265 or state equivalent	Identifies standards applicable to the treatment of hazardous waste at permitted and interim status facilities	Treatment of hazardous waste must be conducted in a manner that meets the operating and monitoring requirements; the treatment process occurs in the well and a tank.	Equipment must be operated and maintained daily. Well and tank integrity must be monitored and maintained to prevent leakage or failure; the tank must be decontaminated when processing is complete.
Waste characterization (treated waste and spent carbon)	RCRA 40 CFR Part 261 or state equivalent	Identifies whether the waste is a listed or characteristic hazardous waste	A requirement of RCRA prior to managing and handling the waste; it must be determined if treated waste is still a RCRA hazardous waste.	Chemical tests must be performed on treated groundwater prior to reinjection. The spent carbon is considered a hazardous waste if it is derived from treatment of hazardous waste.
Storage after processing	RCRA 40 CFR Part 264 or state equivalent	Standards that apply to the storage of hazardous waste in tanks or containers	If spent carbon in the tanks is derived from the treatment of a RCRA hazardous waste, requirements for storage of hazardous waste in tanks and containers will apply.	The contaminated carbon must be stored in tanks or containers that are well maintained; container storage area, if used, must be constructed to control runon and runoff.
On-site/off-site disposal	RCRA 40 CFR Part 264 or state equivalent	Standards that apply to landfilling hazardous waste	Spent carbon may need to be managed as a hazardous waste if it is derived from treatment of hazardous waste.	Wastes must be disposed of at a RCRA-permitted hazardous waste facility, or approval must be obtained from EPA to dispose of wastes on site.
	RCRA 40 CFR Part 268 or state equivalent	Standards that restrict the placement of certain hazardous wastes in or on the ground	The hazardous waste may be subject to land disposal restrictions (LDR).	The waste must be characterized to determine if the LDRs apply; treated wastes must be tested and results compared to LDR.

Table 2-1. Federal and State ARARs for the UVB Groundwater Treatment (continued)

Process Activity	ARAR	Description	Basis	Requirements
Transportation for off-site disposal	RCRA 40 CFR Part 262 or state equivalent	Manifest requirements and packaging and labeling requirements prior to transporting	The spent carbon may need to be manifested and managed as a hazardous waste if it is derived from treatment of hazardous waste.	An identification number must be obtained from EPA.
	RCRA 40 CFR Part 263 or state equivalent	Transportation standards	Spent carbon may need to be transported as a hazardous waste if it is derived from treatment of hazardous waste.	A transporter licensed by EPA must be used to transport the hazardous waste according to EPA regulations
Wastewater injection	SDWA 40 CFR Parts 144 and 145	Standards that apply to the disposal of contaminated water in underground injection wells	Treated groundwater is placed into the aquifer.	If the technology is defined as underground injection and the treated groundwater still contains hazardous waste then a waiver from EPA or the state will be required.
Emissions from the off-gas treatment unit	CAA or state equivalent State Implementation Plan; OSWER Directive 9355.0-28	Controls air emissions that may affect attainment of ambient air quality standards	The UVB technology incorporates carbon filtration of the gases as part of the treatment system. Treated air is emitted to the atmosphere.	Treatment of the contaminated air must adequately remove contaminant so that air quality is not affected.

contaminated groundwater leaves the aquifer for treatment in the UVB system well. Potential pertinent RCRA requirements are discussed below.

The presence of RCRA-defined hazardous waste determines whether RCRA regulations apply to the UVB technology. If wastes generated while installing, monitoring, or operating the technology are determined to be hazardous according to RCRA, all RCRA requirements regarding the management and disposal of hazardous wastes must be addressed. RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. 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 nonspecific and specific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D.

If contaminated groundwater is determined to be a hazardous waste and is extracted (during system monitoring or is interpreted as extraction during system operation) for treatment, storage, or disposal, the requirements for a hazardous waste generator will apply. Requirements for hazardous waste generators are specified in 40 CFR Part 262 and include obtaining an EPA identification number. If hazardous wastes are treated by the UVB treatment system, the owner/operator of the treatment or disposal facility must obtain an EPA identification number and a RCRA permit from EPA or a RCRA-authorized state. RCRA requirements for permits are specified in 40 CFR Part 270. In addition to the permitting requirements, owners and operators of facilities that treat hazardous waste must comply with 40 CFR Part 264.

Air emissions from operation of the UVB are subject to RCRA regulations on air emissions from hazardous waste treatment, storage, or disposal operations and are addressed in 40 CFR Part 264 and 265, Subparts AA and BB. The air emission standards apply to treatment, storage, or disposal units subject to the RCRA permitting requirements of 40 CFR part 270 or hazardous waste recycling units that are otherwise subject to the permitting requirements of 40 CFR Part 270.

Spent granular activated carbon, soil, and purge and decontamination water generated during installation, operation, and monitoring of the treatment system must be stored and disposed of properly. If the water treated is a listed waste, treatment residues will be considered listed wastes (unless RCRA delisting requirements are met). If the treatment residues are not listed wastes, they should be tested to determine if they are RCRA characteristic hazardous wastes. If the residuals are not a RCRA hazardous waste and do not contain free liquids, they can be disposed of at a nonhazardous waste landfill. If the soil cutting, purge/decontamination water, or spent carbon is hazardous, the following RCRA standards apply.

Title 40 CFR Part 262 details standards for generators of hazardous waste. These requirements include obtaining an EPA identification number, meeting waste accumulation standards, labeling wastes, and keeping appropriate records. Part 262 allows generators to store wastes up to 90 days without a permit and without having interim status as a treatment, storage, and disposal facility. If treatment residues are stored on-site for 90 days or more, 40 CFR Part 265 requirements apply.

Any facility (on-site or off-site) designated for permanent disposal of hazardous wastes must be in compliance with RCRA. Disposal facilities must fulfill permitting, storage, maintenance, and closure requirements contained in 40 CFR Parts 264 through 270. In addition, any authorized-state RCRA requirements must be fulfilled. If treatment residues are disposed of off-site, 40 CFR Part 263 transportation standards apply.

Soils classified as hazardous waste are subject to land disposal restrictions (LDR) under both RCRA and CERCLA. Applicable RCRA requirements could include (1) a Uniform Hazardous Waste Manifest if the treated soils are transported, (2) restrictions on placing soils in land disposal units, (3) time limits on accumulating treated soils, and (4) permits for storing treated soils.

The UVB system could also be used to treat contaminated water at RCRA-regulated facilities. Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S (proposed). These subparts also apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective actions, 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. Thus, RCRA mandates requirements similar to CERCLA, and as proposed, allows treatment units such as the UVB treatment system to operate without full permits.

Water quality standards included in RCRA (such as groundwater monitoring and protection standards), CWA, and SDWA are appropriate cleanup standards and apply to discharges of treated water or reinjection of treated groundwater. The CWA and SDWA are discussed below.

2.2.3 Clean Water Act

The CWA is designed to restore and maintain the chemical, physical, and biological quality of navigable surface waters by establishing federal, state, and local discharge standards. Since all treated water is reinjected into the aquifer during operation of the UVB system, only purge and decontamination water generated during system monitoring may be regulated under the CWA if it is discharged to surface water bodies or publicly owned treatment works (POTW). On-site discharges to surface water bodies must meet substantive National Pollutant Discharge Elimination System (NPDES) requirements, but do not require an NPDES permit. Off-site discharges to a surface water body require an NPDES permit and must meet NPDES permit limits. Discharges to a POTW are considered an off-site activity, even if an on-site sewer is used. Therefore, compliance with substantive and administrative requirements of the national pretreatment program is required. General pretreatment regulations are included in 40 CFR Part 403. Any local or state requirements, such as state antidegradation requirements, must also be identified and satisfied.

2.2.4 Safe Drinking Water Act

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

The National Primary Drinking Water Standards are found at 40 CFR Parts 141 through 149. SDWA primary or health-based, and secondary or aesthetic maximum contaminant levels (MCL) will generally apply as cleanup standards for water that is, or may be, used for drinking water supply. In some cases, such as when multiple contaminants are present, alternative concentration limits (ACL) may be used. CERCLA and RCRA standards and guidance should be used in establishing ACLs (EPA 1987a).

To date, no UVB installation has been interpreted by federal or state agencies as underground injection since treated water is placed into the subsurface environment. If this interpretation is applied, water discharged from the UVB system will be regulated by the underground injection control program found in CFR 40 Parts 144 and 145. Injection wells are categorized in Class I through V, depending on their construction and use. Reinjection of treated water involves Class IV (reinjection) or Class V (recharge) wells and should meet requirements for well construction, operation, and closure. If the groundwater, after treatment, still contains hazardous waste then its reinjection into the upper portion of the aquifer would be subject to 40 CFR Part 144.13, which prohibits Class IV wells. Technically, the UVB technology could be considered a Class IV well because of the following definition in 40 CFR Part 144.6(d):

"(d) *Class IV*. (1) Wells used by generators of hazardous waste or of radioactive waste, by owners or operators of hazardous waste management facilities, or by owners or operators of radioactive waste disposal sites to dispose of hazardous waste or radioactive waste into a formation which within one-quarter (¼) mile of the well contains an underground source of drinking water.

(2) Wells used by generators of hazardous waste or of radioactive waste, by owners or operators of hazardous waste management facilities, or by owners or operators of radioactive waste disposal sites to dispose of hazardous waste or radioactive waste above a formation which within one-quarter (¼) mile of the well contains an underground source of drinking water.

(3) Wells used by generators of hazardous waste or owners or operators of hazardous waste management facilities to dispose of hazardous waste, which cannot be classified under paragraph (a)(1) or (d) (1) and (2) of this section (e.g., wells used to dispose of hazardous waste into or above a formation which contains an aquifer which has been exempted pursuant to §146.04)."

The sole-source aquifer protection and wellhead protection programs are designed to protect specific drinking water supply sources. If such a source is to be remediated using the UVB system, appropriate program officials should be notified, and any potential regulatory requirements should be identified. State groundwater antidegradation requirements and water quality standards may also apply.

2.2.5 Clean Air Act

The CAA and the 1990 amendments establish primary and secondary ambient air quality standards for protection of public health as well as emission limitations for certain hazardous air pollutants. Permitting requirements under CAA are administered by each state as part of State Implementation Plans (SIP) developed to bring each state into compliance with National Ambient Air Quality Standards (NAAQS). The ambient air quality standards for specific pollutants apply to the operation of the UVB system because the technology ultimately results in an emission from a point source to the ambient air. Allowable emission limits for operation of a UVB system will be established on a case-by-case basis depending on the type of waste treated and whether the site is in an attainment area of the NAAQS. Allowable emission limits may be set for specific hazardous air pollutants, particulate matter, hydrogen chloride, or other pollutants. If the site is in an attainment area, the allowable emission limits may still be curtailed by the increments available under Prevention of Significant Deterioration (PSD) regulations. Typically, an air pollution abatement device, such as a carbon adsorption unit, will be required to remove VOCs from the UVB system's process air stream before discharge to the ambient air.

EPA has developed a guidance document for control of emissions from air stripper operations at CERCLA sites, "Control of Air Emissions from Superfund Air Strippers at Superfund Groundwater Sites" (EPA 1989). The local SIP may include specific standards to control air emissions of VOCs in ozone nonattainment areas. The EPA guidance suggests that the sources most in need of controls are those with an actual emissions rate of total VOCs in excess of 3 pounds per hour (1.4 kilograms per hour), or 15 pounds per day (6.8 kilograms per day), or a potential (calculated) rate of 10 tons per year (9,072 kilograms per year) (EPA 1989). Based on the average conditions measured during the first 6 months of UVB system operation, the concentration of TCE in the pretreatment air emissions (before passing through the carbon adsorption units) was 2.0×10^{-5} pounds per hour (9.1×10^{-6} kilograms per hour), 4.8×10^{-4} pounds per day (2.2×10^{-4} kilograms per day), and 0.18 pounds per year (0.08 kilograms per year).

The ARARs pertaining to the CAA can be determined only on a site-by-site basis. Remedial activities involving the UVB technology may be subject to the requirements of Part C of the CAA for the prevention of significant deterioration (PSD) of air quality in attainment (or unclassified) areas. The PSD requirements will be applicable when the remedial activities involve a major source or modification as defined in 40 CFR Part §52.21. The PSD significant emission rate for VOCs is 40 tons per year (36,288 kilograms per year). Activities subject to PSD review must ensure application of best available control technologies (BACT) and demonstrate that the activity will not adversely impact ambient air quality.

2.2.6 Occupational Safety and Health Administration Requirements

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

All technicians operating the UVB treatment system are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. For most sites, minimum personal protective equipment (PPE) for technicians will include gloves, hard hats, steel toe boots, and coveralls. Depending on contaminant types and concentrations, additional PPE may be required. 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 8-hour day.

2.2.7 Technology Performance Versus ARARs During the Demonstration

Several ARARs discussed in Table 2-1 did not apply to the UVB treatment technology during the demonstration at March AFB. ARARs relevant to wastewater injection were not applicable during the demonstration because the technology was not defined as underground injection by the regulatory oversight agencies. This interpretation was based on site-specific conditions including the presence of a groundwater extraction system about one-half mile downgradient of the UVB system. If the technology is interpreted as a wastewater injection system by the regulatory agency, more stringent construction, operating, and monitoring requirements may be imposed.

Site investigation and remediation activities at March AFB are being performed by the base under CERCLA. Since treatment of groundwater using the UVB system took place on site, administrative requirements for the technology demonstration, such as permitting were not required. For the demonstration, groundwater was characterized as a RCRA hazardous waste because it resulted from the disposal of spent solvent (TCE and DCE). RCRA requirements outlined in Table 2-1 for the characterization, storage, transport, and disposal of wastes generated by the system were followed.

The chemical-specific ARAR for cleanup of TCE in groundwater (5 µg/L) was generally met. The UVB system reduced TCE in the groundwater discharged from the treatment system to below 5 µg/L in nine out of the 10 monthly sampling events and on average by greater than 94 percent in events where the system operated without maintenance problems. The mean concentration of TCE in water discharged from the system was approximately 3 µg/L with a 95 percent upper confidence limit concentration of approximately 6 µg/L. Based on the system’s removal efficiency documented during the demonstration, influent concentrations greater than 83 µg/L will require more than one treatment cycle through the system to meet the chemical-specific ARAR for TCE (5 µg/L).

2.3 Operability of the Technology

Where applicable, the UVB technology provides an effective long-term solution to aquifer remediation by removing contaminants from the saturated zone. In general, the UVB technology is applicable for the treatment of dissolved phase volatile compounds in groundwater. In addition, the system dynamics established by the recirculation of treated water make this technology suited for remediation of contaminant source areas. The technology employs readily available equipment and materials and once the UVB treatment system is installed and balanced, it requires minimal support from on-site personnel.

Several operating parameters influence the performance of the UVB treatment system. Its performance is most affected by its ability to strip volatile contaminants from groundwater, which depends on the solubility, molecular weight, and vapor pressure of the compounds treated and the nature of the air-water interface through which the compounds must pass. The UVB system effects the volatilization of VOCs by optimizing the air-water interface through the use of air-lift pumping and a stripping reactor. These processes increase the volatilization of dissolved contaminants to the vapor phase by increasing the contact time for mass exchange between the dissolved and vapor phases and by minimizing coalescence of air bubbles. In order to achieve the most efficient operation of the treatment system, several factors must be balanced. The vacuum in the upper portion of the system well and the supplemental pump must be balanced to a flow rate compatible with the hydraulic conductivity of the aquifer. In addition, the diffuser plate and stripping reactor must be positioned to provide the maximum stripping zone without overcoming the vacuum induced in the upper well. Routine maintenance checks must be performed to ensure the proper position and balance are sustained for the system to operate at maximum efficiency.

Over the year-long demonstration of the UVB system, four scheduled maintenance events were performed on the system. Maintenance generally consisted of removing the internal well components for inspection. Additionally, the system was balanced such that the stripping reactor operated at optimal depth in relation to the vacuum induced in the upper portion of the well. The leveling ballasts are designed so the internal components automatically adjust to fluctuations in the groundwater levels (and thus the induced vacuum). However, one of the buoyancy tanks was found to be leaking, which is suspected to have caused the system to be periodically out of balance during a 4-month interval. Except for the leaking ballast, the system proved to be relatively stable and required a minimum of attention over the course of the demonstration. In instances where the system was out of balance or required maintenance, it would be desirable to incorporate some means of on-line monitoring to assure that inefficient or out of compliance effluent conditions do not persist. If such means of monitoring are not available, it would be prudent to check the system at regular intervals.

2.4 Applicable Wastes

The UVB technology, demonstrated at March AFB, California, was designed to remove dissolved phase VOCs from the groundwater, in particular TCE and DCE. The developer claims that the technology can also clean up aquifers contaminated with other VOCs and semivolatile organic compounds (SVOC). Additionally, the developer claims that the in situ stripping of volatile contaminants may be combined with added nutrients and electron acceptors for in situ biodegradation.

According to the developer, the UVB technology may, in some cases, be capable of simultaneous recovery of soil gas from the vadose zone and treatment of contaminated groundwater from the aquifer as a result of the in situ vacuum. For soil gas recovery, the upper screened portion of the UVB well is completed from below the water table to above the capillary zone. Although the developer claims that the UVB technology reduces VOCs from soil gas in the vadose zone, the technology was evaluated only for its effects in the saturated zone.

2.5 Key Features of the UVB Treatment Technology

The UVB technology is an in situ groundwater remediation technology for the cleanup of aquifers contaminated with VOCs, which is an alternative method to pump-and-treat remediation of groundwater. The UVB technology is designed to remove VOCs from groundwater by transferring the contaminants from the aqueous phase to the gaseous phase and subsequently treating the resulting air stream through carbon adsorption units. Key features of the UVB treatment system include; a dual screen well, packer, submersible pump, air diffuser plate, stripping reactor, blower, and carbon adsorption units. Several unique features of the UVB system distinguish it from most air stripping or pump and treat technologies. According to the developer, air stripping in a UVB system occurs in situ, eliminating the need for conditioning the exhaust air due to high humidity. Additionally, since air stripping occurs under a vacuum, the amount of air required for the stripping process is much less than for traditional techniques.

The unique dual screen construction of a UVB well in conjunction with in situ air stripping allows the immediate reinfiltration of groundwater once it has passed the stripping reactor. As a result, remediation of the aquifer occurs without extraction of groundwater, lowering of the groundwater table, or generating wastewater typical of pump and treat. Also, groundwater in a UVB well can be pumped in part by air lift, which facilitates the partitioning of contaminants in solution to the gas phase.

The recirculation of treated water within the system's radius of circulation cell also distinguishes the system from other conventional pump and treat systems. The continuous flushing of the saturated zone with recirculated treated water facilitates the partitioning of adsorbed, absorbed, and liquid contaminants to the dissolved phase through increased dissolution, diffusion, and desorption. Increased partitioning through these processes is driven by increased groundwater flow rates within the system's radius of circulation cell and increased concentration gradient established by the reinjection and recirculation of treated water in the aquifer. This process provides an effective long-term solution to aquifer remediation by removing contaminants from multi loci in the saturated zone.

2.6 Availability and Transportability of Equipment

The UVB technology employs conventional, commercially available equipment and materials that are easily transported on flat-bed trailers. Once the installation of the well is complete, the treatment system can be in operation within a day if all necessary facilities, utilities, and supplies are available. On-site assembly and maintenance requirements are minimal. Demobilization includes decontaminating on-site equipment, disconnecting utilities, disassembling equipment, transporting equipment off site, and plugging and abandoning of the UVB system well. The system well is plugged and abandoned by overdrilling the well and pressure grouting the well bore to the surface. Plugging and abandonment of the monitoring wells is considered a separate activity since wells may be left in place for long-term monitoring.

2.7 Materials Handling Requirements

The materials handling requirements for the UVB system include managing drilling wastes, purge water, and decontamination wastes. The drilling wastes are produced during installation of the system well. The UVB system requires a 24-inch (61.0 cm) diameter bore, which produces about 3.14 cubic feet (ft^3) (0.1 m^3) of drilling waste per foot of bore. At the March AFB demonstration, the 24-inch (61.0 cm) bore was extended approximately 80 feet (24.4 m) and produced more than 251 ft^3 (7.1 m^3) of drilling waste. The drilling waste can be managed either in 55-gallon (208.2 L) drums or in roll-off type debris boxes. Disposal options for this waste depend on local requirements and on the presence or absence of contaminants. The options may range from on-site disposal to disposal in a hazardous waste or commercial waste landfill. Based on IEG's experience, installation of the UVB system does not require development of the system well; therefore, development water is not produced.

This analysis assumes that the monitoring wells are already installed; however, management of this drilling waste would be similar. Purge water is generated during development and sampling of the groundwater monitoring wells. Well purging usually continues until general water quality parameters stabilize. Typically, this requires removal of three to five well volumes from each monitoring well. Purge water can be managed in 55-gallon (208.2 L) drums. Disposal options again depend on local restrictions and on the presence or absence of contaminants. Options range from surface discharge through an NPDES outfall, to disposal through a POTW, to treatment and disposal at a permitted hazardous waste facility.

Decontamination wastes are generated during installation and sampling activities. Wastes generated during installation include decontamination water and may include residue and components of a decontamination pad for the drill rig. Decontamination pads typically consist of plywood and plastic sheeting; however, a gravel base may be needed. The amount of water needed to decontaminate a drill rig typically ranges from 100 to 300 gallons (378.5 to 1,135.5 L). Decontamination fluid is also generated during sampling activities from cleaning of the sampling equipment. The sampling decontamination fluid may consist of water and an organic solvent such as hexane or isopropanol. The amount of fluid needed at each well for each sampling event may require 5 gallons (18.9 L) of water and 100 to 200 milliliters of solvent. The solid decontamination wastes can be managed in a roll-off type debris boxes, and the liquid wastes can be managed in 55-gallon (208.2 L) drums. Disposal options are similar to those for drilling wastes and purge water.

2.8 Site Support Requirements

The site support requirements needed for the UVB system are space to set up the carbon adsorption units and electricity. The system requires standard 120/240 volts (200 amperes). An electrical pole, a 480-volt transformer, an electrical hookup between the supply lines, a pole, and the UVB treatment system are necessary to supply power. The space requirements for the above-ground components of the UVB system including the UVB system well, carbon adsorption units, blower, and piping used during the SITE demonstration are approximately 500 square feet (46.5 m^2). A concrete pad was provided for the unit, but is not absolutely necessary. A security fence was also provided for the unit during the SITE demonstration, but is recommended only if site security is not already provided. Other requirements for installation and routine monitoring of the system include decontamination fluids for drilling and sampling. These fluids can be transported to the site in portable tanks and containers.

2.9 Limitations of the Technology

The limitations of the UVB technology are that it requires a minimum depth to groundwater of 5 feet and a minimum aquifer thickness of 10 feet. In such areas, it may be difficult to establish a stripping zone of adequate size to remove contaminants from the aqueous phase. The technology has further limitations in very thin aquifers; the saturated zone must be of sufficient thickness to provide space for the upper and lower portions of the system. In addition, the thickness of the saturated zone affects the radius of circulation cell; the smaller the aquifer thicknesses, the smaller the radius of circulation cell.

The majority of water being drawn from the aquifer into the lower screen section is treated water reinfiltrated from the upper section. This recirculation of cleaned water significantly decreases the contaminant levels in the water treated by the system. As the UVB system continues to operate, the circulation cell moves outward, which further decreases the contaminant levels in the water treated by the system. Although the recirculation of water facilitates the long-term remediation of contaminants in the aquifer, excessive recirculation will cause a significant decrease of influent concentrations and increase the time required to remediate the aquifer.

High concentrations of volatile compounds may require more than one pass through the system to achieve remediation goals. This may initially be a problem since a portion of the treated water is not captured by the system and leaves the circulation cell in the downgradient direction. However, as the UVB circulation cell is established, the influent concentrations should be diluted to below levels requiring more than one pass, thereby limiting the potential migration of contaminants above target concentrations from the system.

SITE did not evaluate the applicability of this technology for inorganic and semivolatile compounds.

Section 3
Economic Analysis

This section presents cost estimates for using the UVB technology to treat groundwater. Cost estimates presented in this section are based primarily on data compiled during the SITE demonstration and additional costs provided by Weston. Costs have been assigned to one of 12 categories applicable to typical cleanup activities at Superfund and RCRA sites (Evans 1990). This section provides a discussion of each category including the general and specific impacts on the overall cost and the assumptions used in calculating the cost estimate. Costs are presented in October 1994 dollars and are considered to be order-of-magnitude estimates, with an accuracy of plus 50 percent and minus 30 percent.

3.1 Basis of Economic Analysis

This section describes the factors that affect the costs associated with the UVB treatment system and establishes the assumptions used in this economic analysis. A number of factors affect the estimated costs of treating groundwater with the UVB treatment system. The factors affecting capital equipment costs are related to both site conditions and system design and are generally fixed. Annual operations and maintenance (O&M) costs are highly variable due to the time-dependent nature of UVB operation. Typical contaminated groundwater sites may require 1 to 10 years of system operation to be remediated by the UVB treatment system operation. The time required for remediation is dependent on several factors discussed in detail in Section 3.1.1. Due to the variable nature of the time required to remediate a site, annual O&M costs have been presented for operating the UVB treatment system for 1, 3, 5, and 10 years. These costs represent average quotes from vendors providing the necessary services.

3.1.1 Operation, Maintenance, and Monitoring Factors

The costs associated with using the UVB technology are influenced by operation, maintenance, and monitoring factors. The maintenance and monitoring costs depend in part on the duration of operation of the system because increased time for remediation requires more maintenance and more monitoring. The duration of operation for the remediation of a site using the UVB treatment system depends on a number of factors including: (1) the mass and physical characteristics of contaminants present, (2) efficiency of the UVB treatment system in removing specific contaminants, and (3) the aquifer hydraulic conductivity. As discussed in Section 1.3, the aquifer hydraulic conductivity affects the aerial extent of contamination that can be treated by defining the radius of circulation cell of the UVB system. Similarly, the hydraulic conductivity affects the amount of treated water that is recycled through the system (recirculated water), which determines the quantity of untreated water pulled into the circulation cell.

The mass and characteristics of contaminants in the aquifer to be remediated affect the operation time by influencing the exchange of contaminants from the dissolved to vapor phase. Groundwater with high concentrations of contaminants and contaminants in phases other than the dissolved phase may require multiple passes of recirculated water through the treatment system to meet the target concentrations. The increased time needed for multiple passes through the treatment system will increase the total cost of the operation, maintenance, and monitoring factors.

The treatment efficiency of each UVB treatment well system is dependent on adjustments to design factors (such as screen lengths and vacuum pressure gradient). Systems that are not properly adjusted will not achieve maximum efficiency in removing contaminants. Low removal efficiencies will also require multiple passes of recirculated water through the treatment system to meet target concentrations. Again, the increased time needed for multiple passes through the treatment system will increase the total cost of the operation, maintenance, and monitoring factors.

The aquifer conductivity affects the operation time by controlling (1) the radius of circulation cell of the treatment system, (2) the volume of water that can be pumped through the treatment system per unit time, and (3) the amount of recirculated water passing through the system. The radius of circulation cell is directly proportional to the ratio of the horizontal to vertical conductivity of the aquifer. Anisotropic conditions within the aquifer will result in differences in hydraulic conductivity and groundwater flow within the aquifer. High ratios of K_h/K_v indicate a large radius of circulation cell, and low ratios of K_h/K_v indicate a small radius of circulation cell. Aquifers with low horizontal hydraulic conductivity may require the UVB treatment system to operate at a reduced rate. Furthermore, low K_h/K_v ratios indicate a high degree of recirculation through the system and a small amount of untreated water entering the system. High K_h/K_v ratios indicate a low degree of recirculation through the system and a large amount of untreated water entering the system. The developer reports typical recirculation amounts of 60 to 90 percent. Small radii of influence may require multiple treatment units to be installed if the aerial extent of contamination exceeds the radius of circulation cell, and small treatment volumes or high degrees of recirculation may increase the operation time required to remediate an aquifer. Extra treatment units and extended treatment time will increase the total cost of the operation, maintenance, and monitoring factors.

Routine maintenance of the UVB system is recommended at least four times per year (once per quarter). System maintenance may be increased during the initial startup phase of operation to ensure the system is working properly. After the initial startup period, however, there are no daily requirements for operation and maintenance.

Requirements for monitoring the system's performance and contaminant concentrations will vary between sites. Most sites will require monitoring of the treated and untreated groundwater, the system's effluent air stream, and the groundwater in surrounding monitoring wells. Section 3.3 provides additional information regarding operation, maintenance, and monitoring factors.

This economic analysis assumes the aquifer conditions, system well design, system maintenance schedule, and monitoring frequency used during the SITE demonstration. The conditions observed and assumptions made during the SITE demonstration and for this economic analysis are discussed in the following section.

3.1.2 Site Conditions and System Design Factors

The number of UVB treatment systems employed at the site will affect the duration and costs of a groundwater remediation project. The need to use more than one treatment system is determined based on the site conditions. This analysis assumes that only one UVB treatment system will be operated.

The UVB treatment system can treat groundwater containing VOCs. This analysis assumes that the UVB technology will treat groundwater contaminated with TCE.

System design costs typical for Superfund sites include site preparation (such as removal of debris), construction activities (such as access roads), and installation of monitoring wells. These costs are not included in this analysis because they are assumed to have been incurred while characterizing the extent of groundwater contamination. Added costs will be incurred if additional preparation, construction, or monitoring well installation activities are necessary.

Assumptions for site conditions and system design include the following:

- The site is a Superfund site
- The aquifer has been characterized during previous investigations
- Suitable site access roads exist
- Utility supply lines, such as electricity and telephone lines, exist on site

- A single UVB treatment system will be used for treatment
- The treatment system operates automatically
- Contaminated groundwater is located in a shallow aquifer no more than 40 feet (12.2 m) below ground surface
- The saturated zone has a depth of approximately 40 feet (12.2 m)
- The flow rate through the UVB system is 20 gpm (75.7 liters per minute)
- The unit operates 95 percent of the time with only 5 percent downtime for maintenance and repairs
- One technician will be required to collect all required samples and perform minor equipment repairs at the same frequency used for monitoring
- One treated and one untreated groundwater sample will be collected from the UVB well once a month to monitor system performance for the first year and quarterly thereafter
- Three groundwater samples will be collected from surrounding wells once a month for the first year and quarterly thereafter to monitor the system's effect on the aquifer
- Labor costs associated with major repairs are not included
- Because of the nature of the UVB technology, no site cleanup or restoration activities will be required during demobilization except for well plugging and dismantling the carbon adsorption unit.

3.2 Costs Included in the Price of Purchasing the UVB Treatment System

According to IEG, several costs usually associated with groundwater remediation projects are included in the price of purchasing the UVB treatment system. Construction costs for installing the UVB treatment system are incurred only with the installation of a 16-inch (40.6 cm) system well and then installing the downhole components of the UVB treatment system. The construction costs are discussed in Section 3.3.1, Site Preparation Costs, and the UVB system purchase costs are discussed in Section 3.3.3, Capital Equipment Costs. System design costs include designing the treatment system to determine optimal airflow. These costs are included in the cost of purchasing the UVB treatment system.

Mobilization involves transporting all equipment to the site and assembling it. IEG includes mobilization in the cost of purchasing the UVB treatment system. Mobilization of the equipment necessary for installing a 16-inch (40.6 cm) system well is assumed to be included in the cost of constructing the well. Any additional support equipment needed at the remediation site is assumed to be supplied by the customer or by independent vendors. The cost for this additional support equipment is included with site preparation costs.

3.3 Cost Categories

Cost data associated with the UVB technology have been assigned to the following 12 categories: (1) site preparation; (2) permitting and regulatory requirements; (3) capital equipment; (4) startup; (5) labor; (6) consumables and supplies; (7) utilities; (8) effluent treatment and disposal; (9) residuals and waste shipping and handling; (10) analytical services; (11) maintenance and modifications; and (12) demobilization (Evans 1990). Costs associated with each of these categories are discussed below.

3.3.1 Site Preparation Costs

Site preparation costs include administrative costs, electrical hookup, and 16-inch (40.6 cm) system well installation. For this analysis, administrative costs, such as developing a work plan and other site planning activities, are estimated to be $10,000.

This analysis assumes that electric lines exist at the site. One pole, one 480-volt transformer, and an electrical hookup between the lines, pole, and the UVB treatment system are necessary. Based on costs incurred at the SITE demonstration, electrical hookup costs are estimated to be about $5,000.

According to Weston, the cost incurred at the SITE demonstration for installing an 80-foot (24.4 m), 16-inch (40.6 cm) system well was about $450 per foot ($1,475 per meter). This analysis also assumes an 80-foot (24.4 m), 16-inch (40.6 cm) system well (24-inch [61.0 cm] bore) will be installed for a total cost of $36,000. The total drilling cost does not include disposal of the drill cuttings (see Section 3.3.9)

Total site preparation costs are estimated to be $51,000.

Mobilization costs are typically incurred as a site preparation cost. Mobilization involves transporting all equipment to the site and assembling it. IEG includes such costs in the price of purchasing the UVB treatment system. Mobilization of system well installation equipment described above is assumed to be included in the cost of constructing the well. Any additional support equipment needed at the remediation site is assumed to be supplied by the customer or by independent vendors. These costs are included with the above drilling costs.

3.3.2 Permitting and Regulatory Requirements Costs

Permitting and regulatory costs will vary, depending on whether treatment occurs at a Superfund or a RCRA corrective action site, on state and local requirements, and on how treated effluent and any solid wastes generated (such drill cuttings and spent activated carbon) are disposed. Superfund sites require remedial actions to be consistent with ARARs including federal, state, and local standards and criteria. In general, ARARs must be determined on a site-specific basis. RCRA corrective action sites will require additional permitting, monitoring, and records.

Permitting and regulatory costs are assumed to be about 5 percent of the total capital equipment costs for a treatment operation that is part of a Superfund remedial action (Evans 1990). For this analysis, permitting and regulatory costs are estimated to be $5,400. Costs at a RCRA corrective action site are estimated to be an additional 5 percent higher. The permitting and regulatory costs include preparation of required regulatory documents.

3.3.3 Capital Equipment Costs

Capital equipment costs include the UVB treatment system and an off-gas air treatment system. The UVB treatment system includes: a vacuum pump, piping, a downhole submersible pump, air diffuser plate, stripping reactor, buoyancy tanks, 16-inch (40.6 cm) double-cased stainless steel screens and casing, well pack materials, and a wellhead seal. According to Weston, the capital equipment costs of the UVB treatment system will be about $100,000.

Construction costs for installing the UVB treatment system are incurred only with the installation of a 16-inch (40.6 cm) system well and then installing the downhole components of the UVB treatment system. The well installation costs are discussed in Section 3.3.1, Site Preparation Costs, and costs for installation of the downhole components are included previously with the price of purchasing the UVB treatment system.

The off-gas air treatment system includes two activated carbon units, ancillary piping connecting the carbon units to the UVB blower, and carbon. According to IEG, the cost for this equipment will be about $8,100. Monthly carbon adsorption unit rental costs are discussed in Section 3.3.6, Consumables and Supplies Costs. The costs of disposing of or recharging the carbon are discussed in Section 3.3.8, Effluent Treatment and Disposal Costs. Total capital equipment costs will be about $110,000, which includes carbon adsorption units and the UVB system.

3.3.4 Startup Costs

Startup costs are incurred during all activities to operate the UVB treatment system and include operator training, optimization, and shakedown costs. Optimization and shakedown activities include initial startup, trial runs, final equipment inspection, and the associated labor for conducting these activities. These costs are included in the price of purchasing the UVB treatment system (Section 3.3.3, Capital Equipment Costs) and are not presented as a separate cost item in this analysis.

Operator training costs are assumed to include providing a 40-hour health and safety training course and developing a health and safety program for the Superfund site. This analysis assumes that one operator must be trained. These startup training costs are estimated to be about $10,000.

3.3.5 Labor Costs

Labor costs include the total staff needed for operation and maintenance of the UVB treatment system and an annual health and safety refresher course with medical monitoring. An annual health and safety refresher course will cost about $2,000 per person. The labor wage rates provided in this analysis include overhead and fringe benefits.

These costs assume that one technician collects monthly samples and inspects the off-gas treatment system. The technician will collect samples of untreated and treated groundwater and three groundwater samples from surrounding monitoring wells for a total of five groundwater samples. The samples will be collected monthly for the first year and quarterly thereafter. This analysis assumes a relatively fast recharging rate in the monitoring wells and minimal purge volumes (approximately 50 gallons [189.3 L] per well). This analysis also assumes that sampling activities will be conducted in Level D PPE. Sampling activities are estimated to require about 12 hours per sampling event. The fully loaded hourly labor rate for the technician is estimated to be about $31.50 for a total annual cost of about $4,500.

Total annual labor costs for the first year are estimated to be $6,500 for operation inspections and health and safety requirements. For each additional year thereafter, total annual labor costs are estimated to be $3,500 for operation inspections and health and safety requirements.

3.3.6 Consumables and Supplies Costs

Consumables and supply costs only include renting activated carbon units. Costs for PPE are included with the labor costs (Section 3.3.5) presented above, and the costs for sampling equipment are assumed to be incurred during site characterization studies. The monthly rental costs for activated carbon units will be about $570 per unit. The off-gas treatment units used for this demonstration were two 1,800-pound (816.5 kilograms [kg]) vapor phase activated carbon units. This analysis assumes two activated carbon units will be used per year for a total annual cost of about $14,000.

3.3.7 Utilities Costs

Total utility costs are based on the power used to operate the entire UVB treatment system. This includes pumps and the vacuum pump. Electrical usage at the SITE demonstration was 3.67 kilowatts per hour of operation. This analysis assumes the treatment system will operate 24 hours per day 95 percent of the time. At this rate, total annual electrical usage will be about 30,542 kilowatts. This analysis assumes that electricity costs about $0.07 per kilowatt-hour, inclusive of usage and demand charges. Total annual electricity costs are estimated to be about $2,000.

Electrical costs can vary by as much as 50 percent depending on the geographical location and local utility rates. This analysis assumes that no alternative sources of electrical power, such as a diesel-powered generator, will be used as backup.

3.3.8 Effluent Treatment and Disposal Costs

The UVB treatment system off gas is treated by two granulated activated carbon units. The costs of purchasing the initial fill of carbon are discussed in Section 3.3.3, Capital Equipment Costs, and the costs of renting this equipment are covered in Section 3.3.6, Consumables and Supplies Costs. The cost of replacing the carbon is discussed in this section because of its close association with treating the off gas effluent stream. No other effluent or wastes are generated by the operation of the UVB treatment system.

This analysis assumes the activated carbon units will be replaced every 6 months. Based on vendor quotes, the cost for reactivating carbon is about $500 for each unit. This cost includes transportation, reactivation, and a change-out unit. Total annual carbon replacements costs will be about $2,000.

3.3.9 Residuals and Waste Shipping and Handling Costs

No residuals or wastes are generated from the operation of the UVB treatment system. Drill cuttings, however, will be generated during installation and removal of the system well, and purge water will be generated from periodic sampling activities. Disposal of wastes generated during removal of the system well are addressed in Section 3.3.12, Demobilization Costs. Disposal of drilling wastes (cuttings) from installation activities are assumed to occur in the first year after installation. This cost estimate assumes that the cuttings are not characteristically hazardous but that the cuttings are disposed of at a licensed hazardous waste disposal facility. The cost for disposal of the cuttings is estimated to be $2,600 and includes transportation, treatment, and disposal as a bulk solid in a landfill.

For the purge water, this analysis assumes contaminant concentration will be below RCRA regulatory levels that require storage and treatment as a hazardous waste. This purge water will be collected in 55-gallon (208.2 L) carbon-steel drums and disposed of at an off-site industrial wastewater treatment and disposal facility. This analysis assumes that about 150 gallons (567.8 L) of purge water will be generated during each sampling event and stored on site until a total of 600 gallons (2,271.0 L) are accumulated, requiring 12 55-gallon (208.2 L) carbon steel drums. Each drum costs about $30, for a total one-time cost of $360. After accumulating 600 gallons (2,271.0 L) of purge water, a licensed waste hauler will transfer the wastes from the drums into a tanker truck. This analysis assumes that the purge water will be transported about 100 miles (161 kilometers [km]) to the nearest industrial wastewater treatment facility. Transportation costs (including pumping and labor costs) are estimated to be $700 per trip, and disposal costs are estimated to be $0.25 per gallon ($0.07 per L).

Total annual residuals and waste shipping costs in the first year of operation are estimated to be $6,200. Total annual costs for the subsequent years are estimated to be $850.

3.3.10 Analytical Services Costs

Analytical costs include laboratory analyses, data reduction and tabulation, quality assurance/quality control (QA/QC), and reporting. This analysis assumes the following samples will be collected each month of the first year to be analyzed for VOCs by EPA SW-846 Method 8260: one sample of untreated groundwater, one sample of treated groundwater, three samples from outlying groundwater monitoring wells, and QA/QC samples consisting of a trip blank, a field and equipment blank, a field duplicate, and matrix spike and matrix spike duplicate (MS/MSD) samples. Monthly laboratory analysis will cost about $2,300; data reduction, tabulation, data validation, and reporting is estimated to cost about $750 per month. Total annual analytical services costs in the first year are estimated to be about $36,000.

For each successive year after the first year, samples will be collected quarterly. One untreated groundwater sample, one treated groundwater sample, three outlying groundwater monitoring well samples, and QA/QC samples consisting of a trip blank, a field and equipment blank, a field duplicate, and MS/MSD samples will be collected during each quarterly sampling event. Assuming the same costs outlined above, the total annual analytical services costs will be about $12,000 for each year after the first year.

3.3.11 Maintenance and Modifications Costs

IEG provides maintenance for a cost of $2,000 per quarter. This analysis assumes the site owner or operator will procure the IEG maintenance agreement. Total annual maintenance and modification costs are estimated to be $8,000.

3.3.12 Demobilization Costs

Site demobilization includes shutdown, disassembly, well plugging and abandonment, and transportation and disposal of equipment to a licensed hazardous waste disposal facility. Well plugging and abandonment procedures consist of overdrilling the well and pressure grouting the boring to the ground surface. Demobilization will occur at the end of the groundwater remediation project and is estimated to take about 5 days to complete. This analysis assumes the UVB technology will have no salvage value at the end of the project. The majority of demobilization costs apply to waste disposal, which is estimated to be about $4,400. This estimate assumes that the waste is not characteristically hazardous. The wastes requiring disposal include the casing and filter pack from overdrilling, the UVB system itself, and ancillary piping and equipment associated with the carbon adsorption units. The total volume of waste is assumed to be 20 cubic yards (15.3 m^3). The cost for waste disposal includes transportation and labor. Labor costs associated with all activities other than well plugging and abandonment during demobilization will include two technicians working five 8-hour days and are estimated to be about $2,500; labor costs associated with well plugging and abandonment are accounted for in the waste disposal cost. Total demobilization costs are estimated to be about $6,900 in current 1994 dollars. Because groundwater remediation projects can take many years to complete, demobilization costs will have to be adjusted to future dollars, once the term of the project can be estimated, to determine actual demobilization costs.

3.4 Estimated Cost of the UVB System

This section presents the estimated costs in October 1994 dollars for using the UVB system under the conditions described in the previous sections. Table 3-1 presents a breakdown of costs for the 12 categories previously identified. The table presents fixed costs and annual variable costs, and compares the costs for groundwater treatment projects lasting 1, 3, 5, and 10 years. The cost of treatment per 1,000 gallons (3,785 L) refers to the amount of groundwater pumped through the system (not to the volume of contaminated water in the aquifer). Potential users of the treatment technology should be aware that typically 60 to 90 percent of the water pumped through the system is recirculated water. The cost estimate for each category was rounded to two significant figures. The total costs were also rounded to two significant figures. One-time capital costs for a single treatment unit were estimated to be $180,000; variable annual operation and maintenance costs were estimated to be $75,000. Based on these estimates, the total cost for operating a single UVB system for 1 year was calculated to be $260,000. Since the time required to remediate an aquifer is site-specific, costs have been estimated for operation of a UVB system over a range of time for comparison purposes. Therefore, the cost to operate a single UVB system was calculated to be $340,000 for 3 years, $440,000 for 5 years, and $710,000 for 10 years. Additionally, the costs for treatment per 1,000 gallons (3,785 L) of groundwater were estimated to be $260 for 1 year, $110 for 3 years, $88 for 5 years, and $71 for 10 years. (The costs for treatment per 1,000 L of groundwater were estimated to be $69 for 1 year, $29 for 3 years, $23 for 5 years, and $19 for 10 years.)

Table 3-1. Costs Associated with the UVB Technology

Cost Categories	Costs in 1994 $[a]
Site Preparation [b]	$51,000
Permitting and Regulatory Requirements [b]	5,400
Capital Equipment [b]	110,000
Startup [b]	10,000
Labor [c,d]	6,500 (3,500)
Consumables and Supplies [c]	14,000
Utilities [c]	2,000
Effluent Treatment and Disposal [c]	2,000
Residual and Waste Shipping and Handling [c,e]	6,200 (850)
Analytical Services [c,f]	36,000 (12,000)
Maintenance and Modifications [c]	8,000
Demobilization [b]	6,900
Total One-Time Costs	180,000
First Year Operation and Maintenance Costs	75,000
Subsequent Years Operation and Maintenance Base Costs	42,000
Total Cost of Project Lasting 1 Year [g]	260,000
Total Cost of Project Lasting 3 Years [g]	340,000
Total Cost of Project Lasting 5 Years [g]	440,000
Total Cost of Project Lasting 10 Years [g]	710,000
Costs per 1,000 Gallons (3,785 L) Treated (1 Year) [h]	260
Costs per 1,000 Gallons (3,785 L) Treated (3 Years) [h]	110
Costs per 1,000 Gallons (3,785 L) Treated (5 Years) [h]	88
Costs per 1,000 Gallons (3,785 L) Treated (10 Years) [h]	71

Notes:
[a] Costs have been rounded to two significant figures
[b] One-time cost
[c] Annual variable operation and maintenance cost
[d] Figure presents annual cost of the first year of operation. Annual cost for successive years is estimated to be $3,500.
[e] Figure presents annual cost of the first year of operation. Annual cost for successive years is estimated to be $850.
[f] Figure presents annual cost of the first year of operation. Annual cost for successive years is estimated to be $12,000.
[g] Estimated annual inflation rate is 4 percent
[h] Annually treats about 1,000,000 gallons (3,785,000 L) (assuming 5 percent downtime)

Section 4
Treatment Effectiveness

This section documents the background, field and analytical procedures, results, and conclusions used to assesses the ability of the UVB technology to remove VOCs from contaminated groundwater. This assessment is based on the UVB SITE demonstration at March AFB and on case studies supplied by the technology developer. Because the results of the SITE demonstration are of known quality, conclusions are drawn mainly from the demonstration results.

4.1 Background

EPA conducted a SITE demonstration of the UVB system at Site 31 on March AFB, which is located near Riverside, California (Figure 4-1). The U.S. Air Force contracted with Weston and IEG to demonstrate the UVB technology at March AFB. The U.S. Army Corps of Engineers Omaha District initiated installation of the technology through Black & Veatch Waste Science. The Air Force invited the SITE program to evaluate the demonstration project. The environmental setting at March AFB and Site 31 are described in Sections 4.1.1 and 4.1.2. An overview of the demonstration objectives and approach is presented in Section 4.1.3

4.1.1 March AFB

In April 1993, Site 31 at March AFB was selected for the SITE demonstration of the UVB technology. March AFB is located on approximately 7,000 acres (2,832.9 hectares) in the northern end of the Perris Valley, east of the city of Riverside, in Riverside County, California. The base is approximately 60 miles (96.5 km) east of Los Angeles and 90 miles (144.8 km) north of San Diego.

March AFB was officially commissioned on March 1, 1918 as a World War I aviation training facility and is one of the oldest bases in the western United States. The base has since steadily grown and has been home to West Coast bombing and gunnery training, the Strategic Air Command, and Air Mobility Command. In 1993, March AFB was designated by Congress under the Base Closure and Realignment Act to realign its forces from active duty personnel to Air Force Reserve and National Guard Force units. Realignment activities are scheduled to be completed in 1996 and the base will be redesignated “March Air Reserve Base” at that time.

March AFB has long been engaged in a wide variety of operations that involve the use, storage, and disposal of hazardous materials. Base operations such as aircraft maintenance, fuel storage operations, and fire-training exercises have generated a variety of hazardous wastes which, combined with past waste disposal practices, have resulted in contamination of soil and groundwater at several areas on base.

In 1983, March AFB initiated Installation Restoration Program (IRP) activities to locate, investigate, and remediate hazardous waste sites. The IRP provides a procedural framework for developing, implementing, and monitoring response actions at March AFB in accordance with pertinent federal regulations and applicable state laws. To more effectively manage the IRP program, three separate operable units were created based on geographic location and similarity of the sites. The three operable units consist of 42 sites that are undergoing comprehensive site investigation and characterization activities. March AFB has taken a leadership role in implementing and expediting IRP activities and is one of the model IRP bases for the U.S. Air Force. This role includes actively assessing mechanisms for accelerating the remedial investigation/feasibility study (RI/FS) process in an effort to move more quickly to a record of decision, and to implement the selected remedial actions.

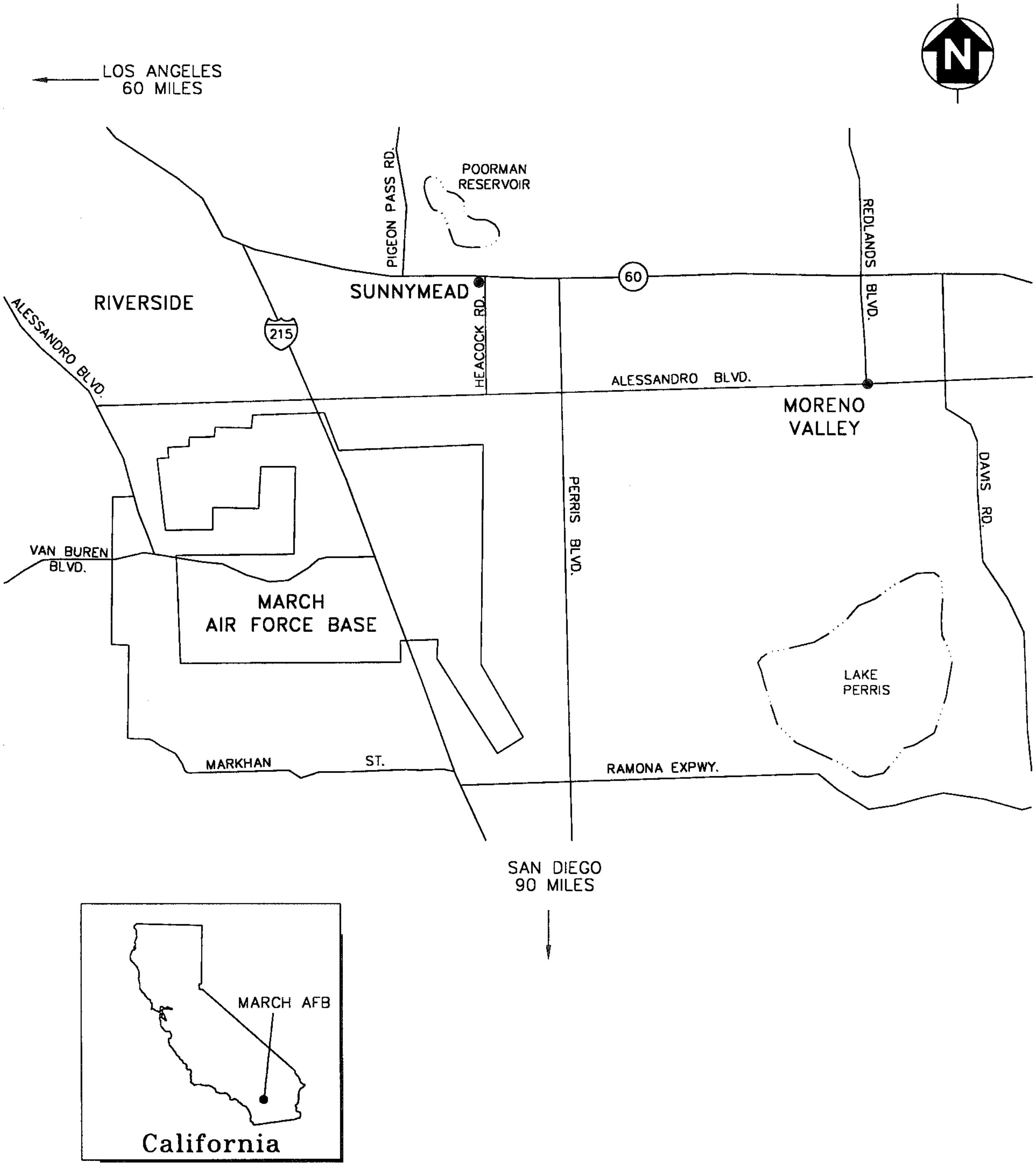


Figure 4-1. March AFB location map.

March AFB has committed to the pilot-scale application of various innovative remedial technologies to accelerate the selection, design, and installation of full-scale alternative remedial technologies and implementation of remedial activities. Within this framework, the UVB technology was selected as an interim remedial action to treat contaminated groundwater at Site 31.

Site 31 is managed within Operable Unit 1 (OU1), which consists of a total of 14 sites. Site 31 (an unconfirmed solvent disposal area) is located off Graeber Street on the east side of Building 1211 (Figure 4-2). The practice of discharging solvents on the ground reportedly occurred from about the mid-1950s to the mid-1970s at the site. In addition, floor drains from maintenance shops may have leaked solvents to the subsurface. Site investigative activities confirm the presence of elevated levels of VOCs, specifically TCE and DCE, in the groundwater and soil gas.

4.1.2 Site 31

Characterization of the geology, hydrology, and contaminants at Site 31 is based on the observations and results from the UVB SITE demonstration, investigation results from Site 31 documented in the report by The Earth Technology Corporation (TETC), "Installation Restoration Program, Draft Final Remedial Investigation/Feasibility Study Report For Operable Unit 1, March Air Force Base, California (TETC 1994), and data generated on the UVB system by Weston and documented in its report, "Pilot Study for Innovative Technology UVB-Vacuum Vaporization Well, Site 31 March Air Force Base, California" (Weston 1994). Based on the site characterization data, the UVB system was installed approximately 100 feet (30.5 m) south of Building 1211 in an area containing high (>400 µg/L) concentrations of TCE in the groundwater.

4.1.2.1 Geology

The geologic interpretation of Site 31 is based on field observations while installing groundwater monitoring wells during SITE demonstration activities and on previous investigative results provided by March AFB. A detailed description of the site and regional geology is presented in the draft final RI/FS report for OU1 (TETC 1994).

March AFB lies within the northern portion of the Peninsular Range geomorphic province, as defined by the California Division of Mines and Geology. The base lies between two major fault zones: the Elsinore-Chino fault zone to the southwest and the San Jacinto fault zone to the northeast. These northwest trending fault zones have been active recently and can act as barriers to groundwater movement (TETC 1994).

The region around March AFB is characterized by rugged mountain ranges composed of igneous and metamorphic rocks, broad erosional plains composed of deeply eroded sedimentary and crystalline basement rocks, and a broad, flat valley composed of younger alluvial material. The main base lies in the Perris Valley where alluvium is found at the surface (TETC 1994).

Sites 31 is located within the northern portion of Perris Valley at an elevation of approximately 1,505 feet (458.7 m) above mean sea level. Perris Valley is an alluvial filled valley that slopes gently at approximately 20 feet per mile (3.8 meters/kilometers [m/km]) to the south-southeast (TETC 1994). The alluvium consists of poorly consolidated deposits of clay, silt, sand, and cobble-sized particles derived from the surrounding crystalline basement rock. Lithologic logs from the site suggest that the alluvium overlies weathered granitic bedrock. The contact between the alluvium and weathered bedrock is undulating and varies in depth from 95 to 100 feet (29.0 to 30.5 m) below ground surface (bgs) in the northern and eastern portions of the Site 31 to 150 to 165 feet (45.7 to 50.3 m) bgs in the southern and western portion of the site. The thickness of the weathered bedrock at the site is highly variable and is estimated to be approximately 50 feet (15.2 m) in the vicinity of the UVB system based on the results of a seismic reflection survey conducted at Site 31 (Tetra Tech 1993a).

The stratigraphy at Site 31 consists of alternating layers of clay, silt, silty sand, and sand. Lithologic descriptions of the individual borings advanced during demonstration activities are shown on logs presented in the UVB Technology Evaluation Report (TER) (PRC 1995). In general, correlation of boring logs across the site is poor, which is indicative of the nature of the underlying alluvial deposits. The upper 40 feet (12.2 m) of the alluvial deposits consisted predominantly of interbedded silt and silty sand. From 40 to 50 feet (12.2 to 15.2 m) bgs, a relatively clean (trace to little silt- and clay-sized particles) sand was encountered. The sand interval appears to

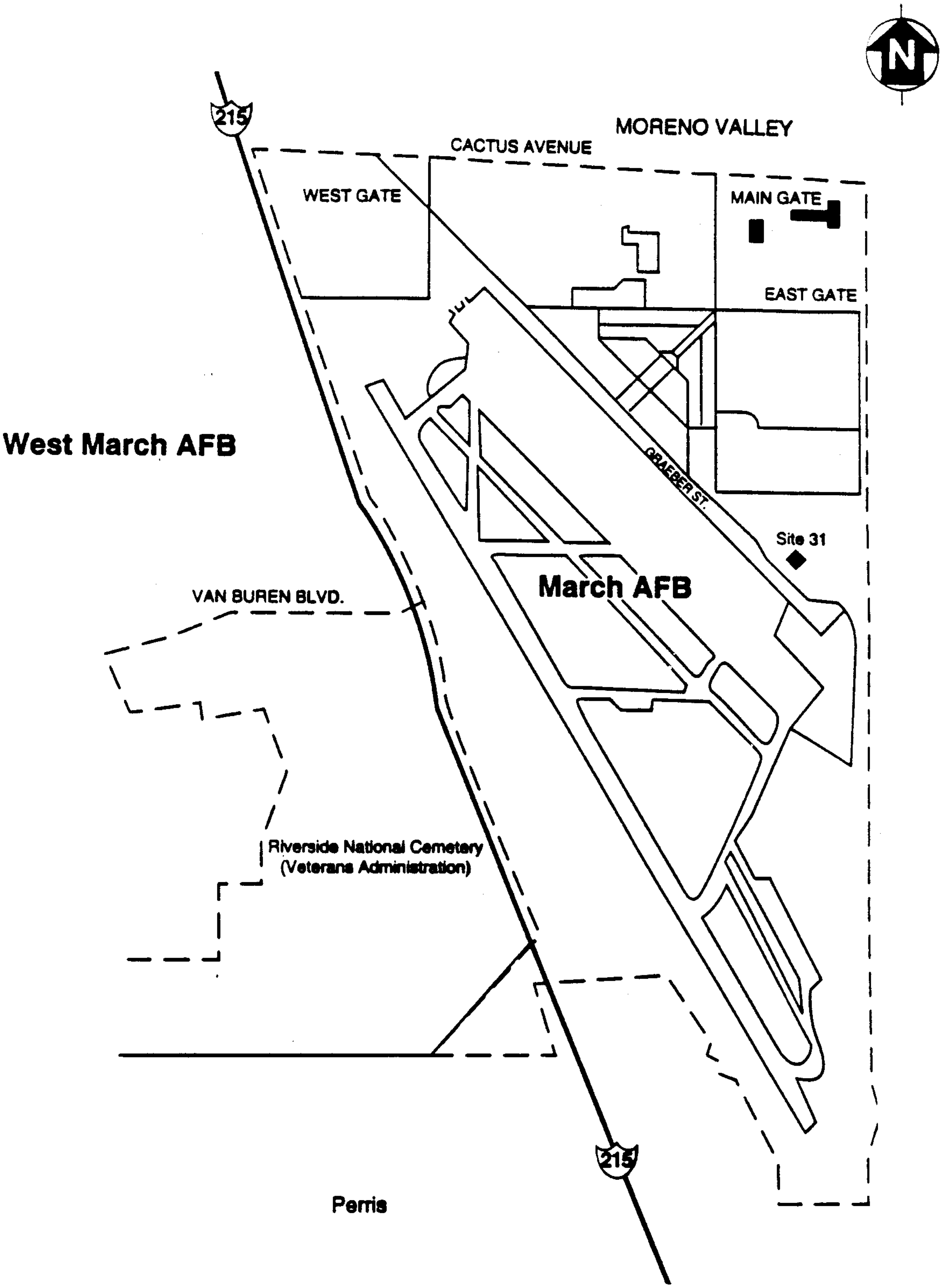


Figure 4-2. Site 31 location map.

correlate with adjacent borehole logs, which suggests that it is laterally continuous in the vicinity of the UVB system. This sand interval is underlain by silty sand extending from approximately 50 to 65 feet (15.2 to 19.8 m) bgs which in turn overlies a second relatively clean sand layer extending from approximately 65 to 75 feet (19.8 to 22.9 m) bgs. The second clean sand interval is interpreted to be lenticular, pinching out to the north and south toward the UVB well and outer cluster wells. The discontinuous nature of the layer is also suggested by the poor correlation with adjacent boring logs. The lithology below this interval consists of interbedded silts and sands, and minor clays. Prominent within this zone is a clay encountered at 120 feet (36.6 m) bgs, which has been interpreted to act as a confining layer beneath the site (TETC 1994). A cross section showing the generalized stratigraphy at the site from the system well to the outer cluster wells is presented on Figure 4-3.

Based on geological reconnaissance of the base and surrounding area during IRP activities, two major sets of near-vertical fractures were identified (Tetra Tech 1993b). A primary and moderately subordinate fracture set trending north-northwest and north-northeast were interpreted and appear to be closely related to the fracture systems that permeate the bedrock surrounding the base (Tetra-Tech 1993b). The physical characteristics of the fault and fracture traces, such as width of the specific fracture traces, presence or absence of fault gouge, and degree of filling of fracture channels have been roughly approximated in the field. These measurements suggest that the width of these zones may vary between 10 feet to 200 feet (3.0 to 61.0 m) and that near-surface fractures may have openings of an eighth of an inch (3.2 millimeters) or more. In some instances, the fractures may be filled with varying amounts of clay minerals or caliche (Tetra Tech 1993b).

Based on a seismic reflection survey conducted at Site 31, a northwest/southeast trending fault approximately parallel to Graeber Street has been interpreted (Tetra Tech 1993a). The seismic reflection data from Site 31 indicate an offset of approximately 9 feet (2.7 m) in a prominent clay layer at 115 feet (35.1) bgs and in unweathered bedrock at 170 feet (51.8 m) bgs. A cross section showing the interpreted seismic profile is presented on Figure 4-4. The fault has been interpreted to have a surface projection located immediately south of well 4MW14, approximately 40 feet (12.2 m) northeast of the UVB system. In addition, recent unpublished geophysical investigative results from March AFB support the presence of the interpreted fault through the base (IT Corporation 1994). Preliminary data from this investigation appear to correlate with the geophysical investigation conducted at Site 31 (Tetra Tech 1993a). This correlation suggests that a well-developed fracture zone parallel to Graeber Street (southeast trending) may be present. If present, this fracture zone could provide a preferential conduit for groundwater flow at the site.

4.1.2.2 Hydrogeologic Conditions

Data collected during UVB SITE demonstration indicate that hydrogeologic conditions at Site 31 exert a controlling influence over the movement of groundwater and likely the subsequent distribution of contaminants during the demonstration. The primary hydrogeologic factors affecting the demonstration results are groundwater flow direction and anisotropy and heterogeneity of the aquifer.

Hydrogeology

Groundwater beneath Site 31 occurs in two distinct zones: an upper unconfined water table zone and a lower semiconfined zone (TETC 1994). Depth to groundwater beneath Site 31 in the upper unconfined zone is approximately 40 feet (12.2 m) bgs. A prominent sand unit occurs at a depth between 40 to 50 feet (12.2 to 15.2 m) bgs. This unit ranges from 5 to 10 feet (1.5 to 3.0 m) thick and appears to be a highly conductive water-bearing unit. Borehole data suggest that a clayey sand and sandy clay layer occurs at about 120 feet (36.6 m) bgs that acts as a confining layer beneath Site 31. This clay layer appears to be a barrier to the vertical flow of groundwater at Site 31. Depth to water in the lower semiconfined zone is approximately 45 feet (13.7 m) bgs. The lower semiconfined zone consists of saturated alluvial deposits and the underlying weathered bedrock. Comparison of static groundwater levels in well screens in the upper unconfined zone and lower semiconfined zone suggests that the two zones are hydraulically separated. Furthermore, a step-drawdown test and long-term constant rate pump test conducted in the upper confined zone showed no effects on the lower semiconfined zone (TETC 1994).

Aquifer characteristics of the upper unconfined zone as calculated from the pump tests indicate that: (1) average site hydraulic conductivity is 90.5 gallons per day per foot squared (gpd/ft^2) (4.26 x 10^{-3} cm/s); (2) effective porosity

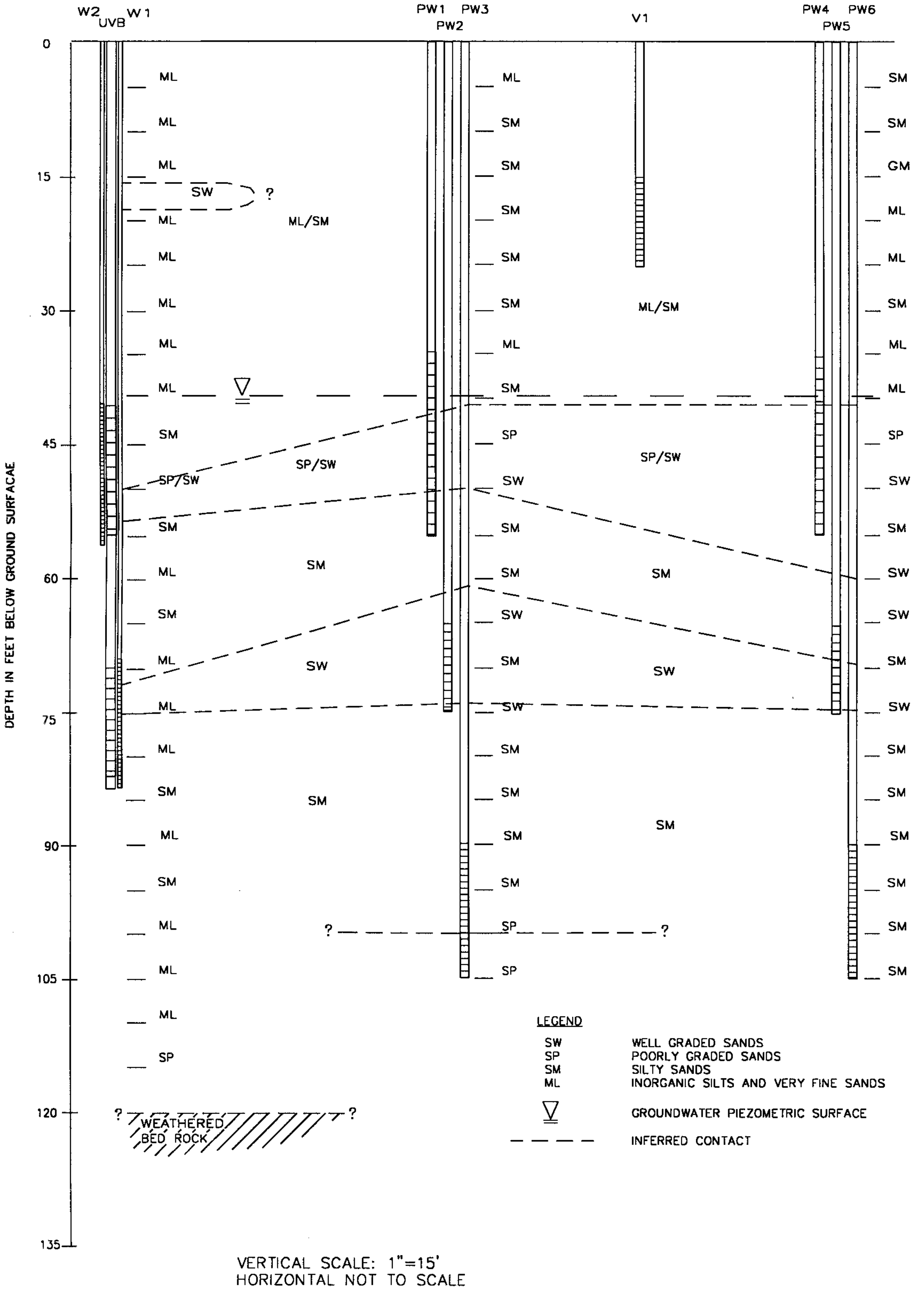


Figure 4-3. Generalized stratigraphic cross section.

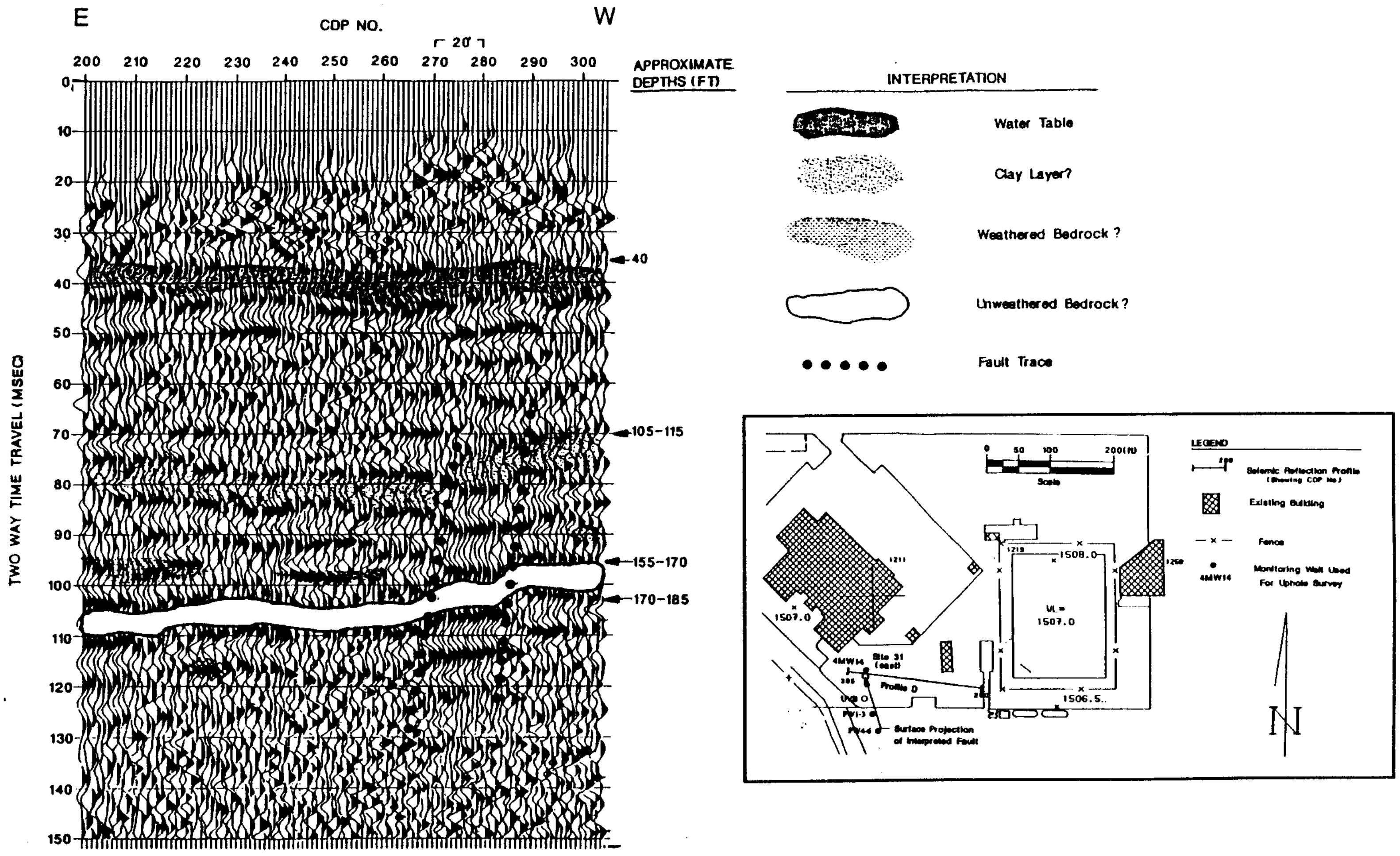


Figure 4-4. Interpreted seismic cross section.

is 27.2 percent; and, (3) transport velocity is 0.62 feet per day (ft/day) (2.19×10^{-4} cm/s) (TETC 1994). Groundwater gradient and direction calculated from the wells screened in the upper unconfined zone suggest that groundwater flows to the southeast at a gradient of approximately 0.014 (Figure 4-5). Results from a dye trace study conducted as part of the SITE demonstration also suggest flow in the south-southeast direction at a maximum velocity of 0.75 to 0.77 ft/day (2.65×10^{-4} to 2.72×10^{-4} cm/s) (Appendix A). After the UVB was shut down, the natural gradient was measured in January 1995 to be 0.07.

Groundwater Flow Direction

The downgradient direction of groundwater flow was originally determined to be to the southeast based on a preliminary contour map of the November 1992 groundwater elevations at Site 31 (TETC 1994). This flow direction corresponds to the general groundwater gradient over the majority of the base, gently sloping to the southeast. After heavy rains during the winter of 1992-93, an apparent change in groundwater flow direction was observed at the site (TETC 1994). This change was interpreted to be in response to recharge along the Heacock Storm Drain, located along the eastern boundary of the base. Recharge from the storm drain appears to have caused localized groundwater mounding, which in turn locally affects the direction of groundwater flow. The mounding of groundwater in response to the recharge appears to have temporarily redirected the groundwater flow toward the west-southwest along the eastern portion of the base, which includes Site 31. However, wells west of Site 31 did not appear to have been affected by groundwater recharge from Heacock Storm Drain, and data from these wells continue to indicate a groundwater flow direction to the southeast.

Groundwater level elevations were collected before, during, and after the UVB demonstration. Based on contouring of the groundwater elevations, the potentiometric surface appears relatively flat with generally less than 1 foot (0.3 m) change of gradient across Site 31. Due to the relatively flat gradient and the linear distribution of groundwater monitoring wells at the site, the localized groundwater flow direction could not be precisely determined during the demonstration. However, groundwater levels measured during operation of the UVB system suggest that wells PW1 through PW6 are downgradient (southeast) of the treatment system. After startup of the UVB system, additional wells screened across the groundwater table were installed in the immediate vicinity of the treatment system. These additional wells allowed the accurate measurement of the groundwater gradient after the UVB system was shut down on December 4, 1994. Figure 4-5 presents the interpreted potentiometric surface map of the groundwater elevation data collected from Site 31 wells on December 9, 1994. The map indicates that groundwater flow is toward the southeast.

Modeling of groundwater flow at March AFB suggests that the site is located on a groundwater trough (Tetra-Tech 1994). The convergence of groundwater flow directions in the trough appears to have caused a saddling effect on the groundwater gradient. Several interpretations for the change in gradient direction at the site have been proposed, including shallow bedrock and structural discontinuity (Tetra Tech 1994). However, since interpretation of boring log data from the site suggests that bedrock is at least 110 to 120 feet (33.5 to 36.6 m) bgs, it is unlikely that bedrock has significantly affected the groundwater gradient at the site. In addition, the semiconfining layer between the measured unconfined water table elevation and the bedrock should effectively mask the influence of the bedrock. Changes in gradient could be caused by changes in the topographic elevation of the semiconfining or changes in permeability of the semiconfining bed.

Anisotropy and Heterogeneity

In addition to the natural groundwater gradient direction, the anisotropy and heterogeneity of the aquifer play a significant role in controlling the movement of groundwater and subsequent distribution of contaminants. These factors are magnified especially when an induced flow, such as the UVB circulation cell, is placed on the aquifer. Induced groundwater flow resulting from operation of the UVB system will be influenced by the anisotropy and heterogeneity of the aquifer and locally may not flow in the undisturbed downgradient groundwater flow direction.

Since the aquifer consists of alluvial deposits, anisotropic conditions are likely present. The vertical hydraulic conductivity at the site is assumed to be an order of magnitude less than horizontal hydraulic conductivity. In addition to anisotropic conditions in the alluvial deposits, structural controls, such as fractures and faults, may significantly affect groundwater flow in the aquifer.

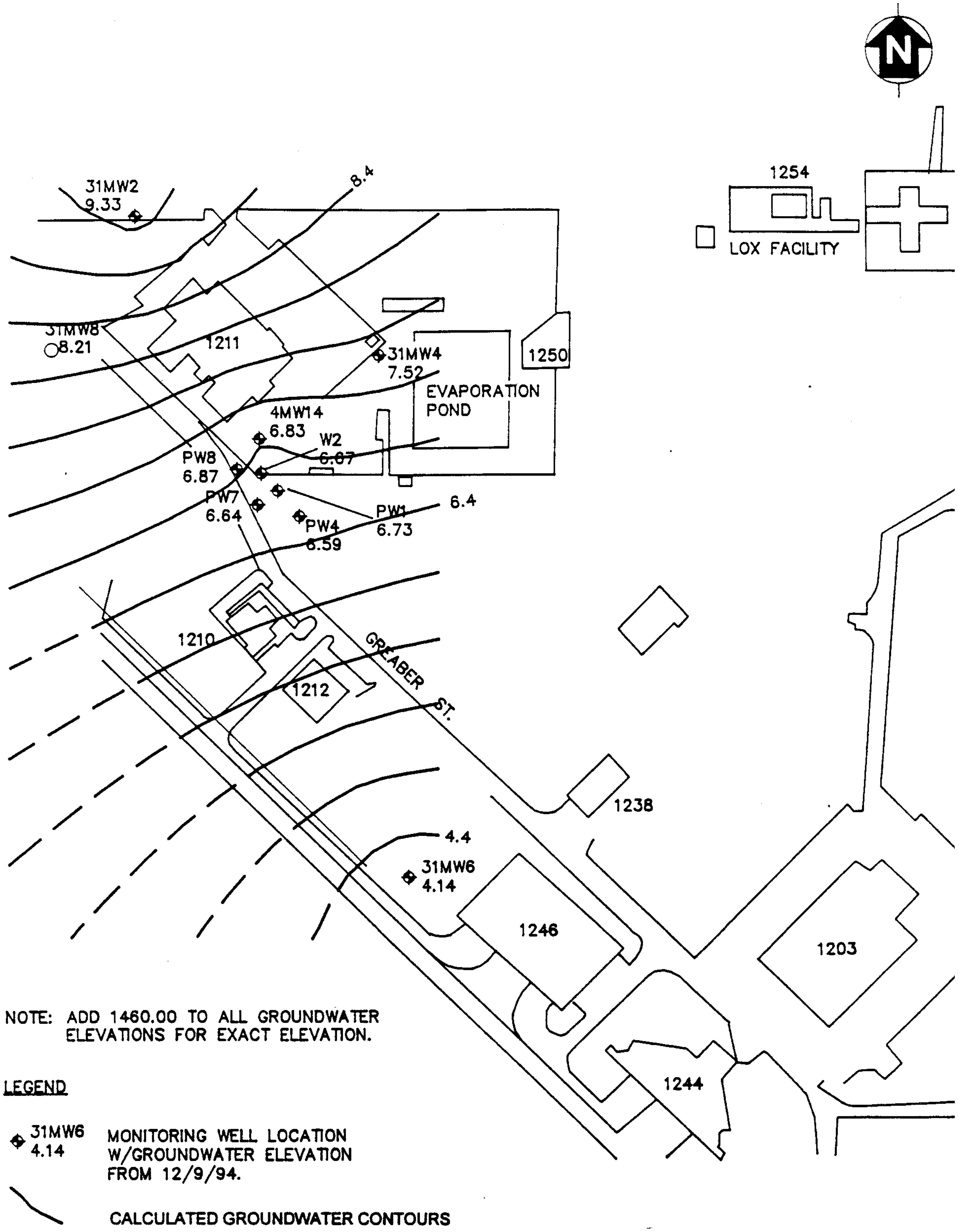


Figure 4-5. Potentiometric surface map.

Pump test data from the base appear to indicate a second prominent anisotropic property that may be related to faulting at the base. The data appear to indicate the existence of vertical-oriented hydraulic-flow discontinuities (Tetra Tech 1993b). The presence of faulting at the base has led to a hypothesis of a double-porosity, fractured aquifer system that is characterized by a system of fine-pore matrix lithology and higher-permeability secondary fracture porosity. An interpreted zone of higher conductivity is currently being used for a base-wide groundwater model and appears to provide the best match for the observed groundwater data collected at the base (Tetra Tech 1994).

4.1.2.3 Site Contamination

Contaminant characterization activities conducted at Site 31 have included soil gas surveys, advancement of soil borings and collection of soil samples for chemical and geotechnical analyses, and placement of groundwater monitoring wells and sample collection for chemical analyses. The investigative findings from these activities indicate that subsurface conditions at Site 31 are fairly complex and that soil, soil gas, and groundwater contain elevated levels of VOCs, in particular, TCE.

Soil

More than 100 surface and subsurface soil samples have been collected at Site 31 during investigations. Chemical data from the samples indicate that few organic compounds have been detected. Based on the analytical data, it appears that VOCs in the soil are limited to one location immediately south to southeast of Building 1211. Samples from borings in these location show detectable concentrations of TCE ranging from 0.0066 milligrams per kilogram (mg/kg) to 0.046 mg/kg, and DCE at a concentration of 0.0075 mg/kg. A review of the soil samples results and the site’s history suggests that these areas are suspected source areas for VOC contamination in the groundwater (TETC 1994). The location of the source area relative to the UVB system is presented in Figure 4-6.

Soil Gas

To further characterize and locate potential contaminant source areas, two soil gas investigations were conducted at Site 31 during January, 1992 and September, 1993 (TETC 1994). During the investigations, soil gas samples were collected from depths of 5, 10, 20, and 30 feet (1.5, 3.0, 6.1, and 9.1 m) bgs. Soil gas concentrations of up to 342 µg/L TCE and 200 µg/L DCE along with minor concentrations of tetrachloroethene, chloroform, and 1,1,1-TCE were detected, predominantly along the southern and eastern sides of Building 1211. The highest concentrations of TCE in the soil gas appeared to be concentrated at the 20-foot (6.1 m) sample interval and coincide with the elevated groundwater concentrations south of Building 1211.

Groundwater

Twenty-two groundwater monitoring wells are present at Site 31 (Figure 4-7). Chemical analysis of groundwater samples from these wells indicates that elevated concentrations of chlorinated hydrocarbons are present, in particular TCE and DCE. Before the UVB was installed, concentrations of up to 2,000 µg/L TCE and 210 µg/L of DCE have been detected in groundwater samples at Site 31. Table 4-1 presents a compilation of TCE concentrations in groundwater from Site 31. Based on the tabulated results, the highest concentrations of TCE appear to be located in samples collected immediately south of Building 1211. An interpretation of TCE concentrations from in situ groundwater sampling collected during remedial investigation activities is presented as Figure 4-8. This interpretation indicates the presence of a second area of elevated TCE concentrations located northeast of the UVB system.

Prior to system startup, the distribution of TCE vertically within the aquifer at Site 31 appeared somewhat stratified, with the highest concentrations detected in shallow and intermediate screened wells (approximately 40 to 80 feet [12.2 to 24.4 m] bgs) and the lowest concentrations detected in deep screened wells (approximately 90 to 105 feet [27.4 to 32.0 m] bgs). Due to the long (40 feet [12.2 m]) screen intervals of many of the monitoring wells, contaminant stratification cannot be assessed in more detail. Well-specific screen intervals, depths, and locations for all Site 31 monitoring wells are presented in Table 4-2.

4.1.3 Demonstration Objectives and Approach

The SITE demonstration was designed to address primary and secondary objectives selected for evaluation of the UVB technology. These objectives were selected to provide potential users of the UVB technology with the necessary technical information to assess the applicability

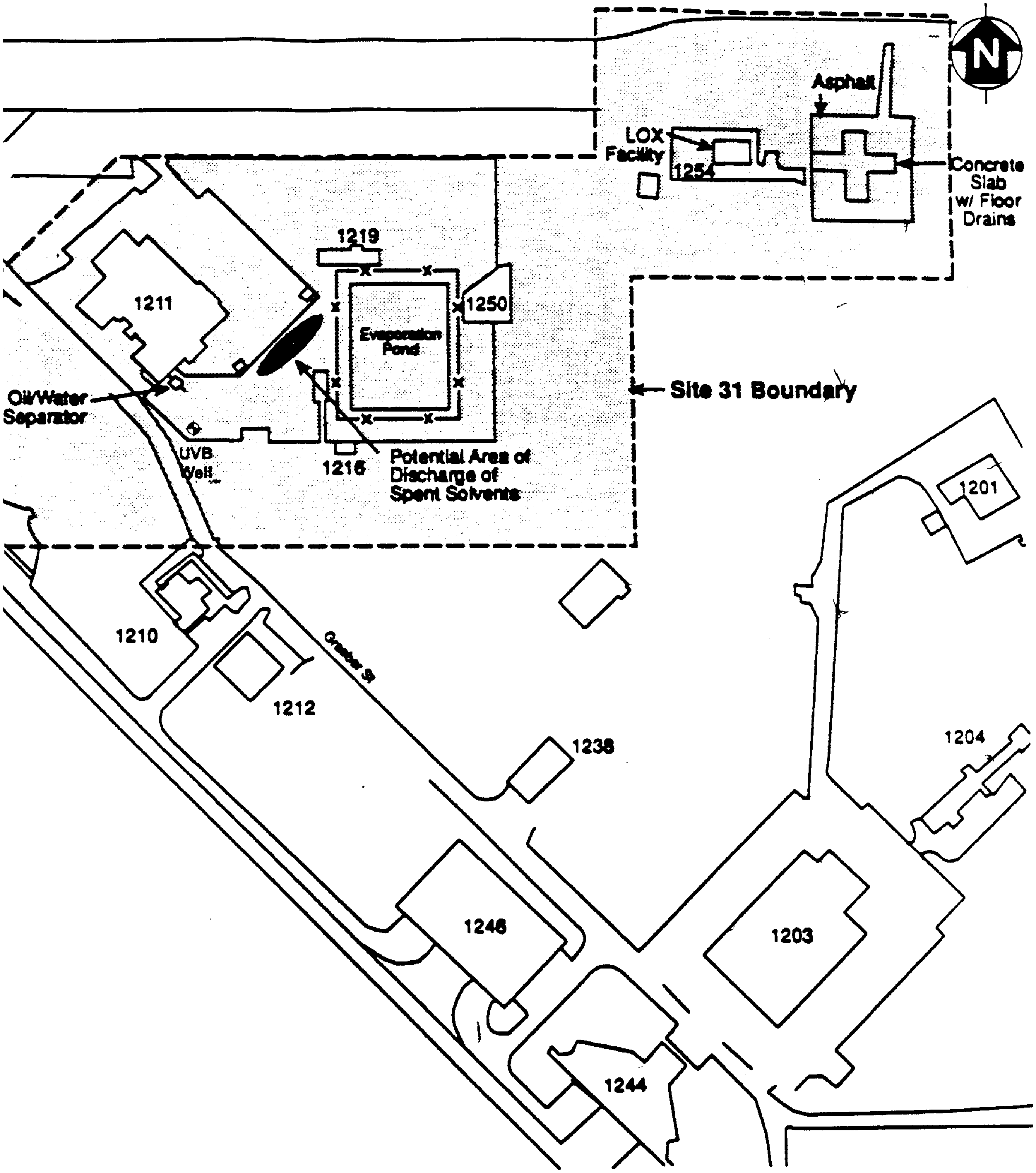


Figure 4-6. Site 31 source locations.

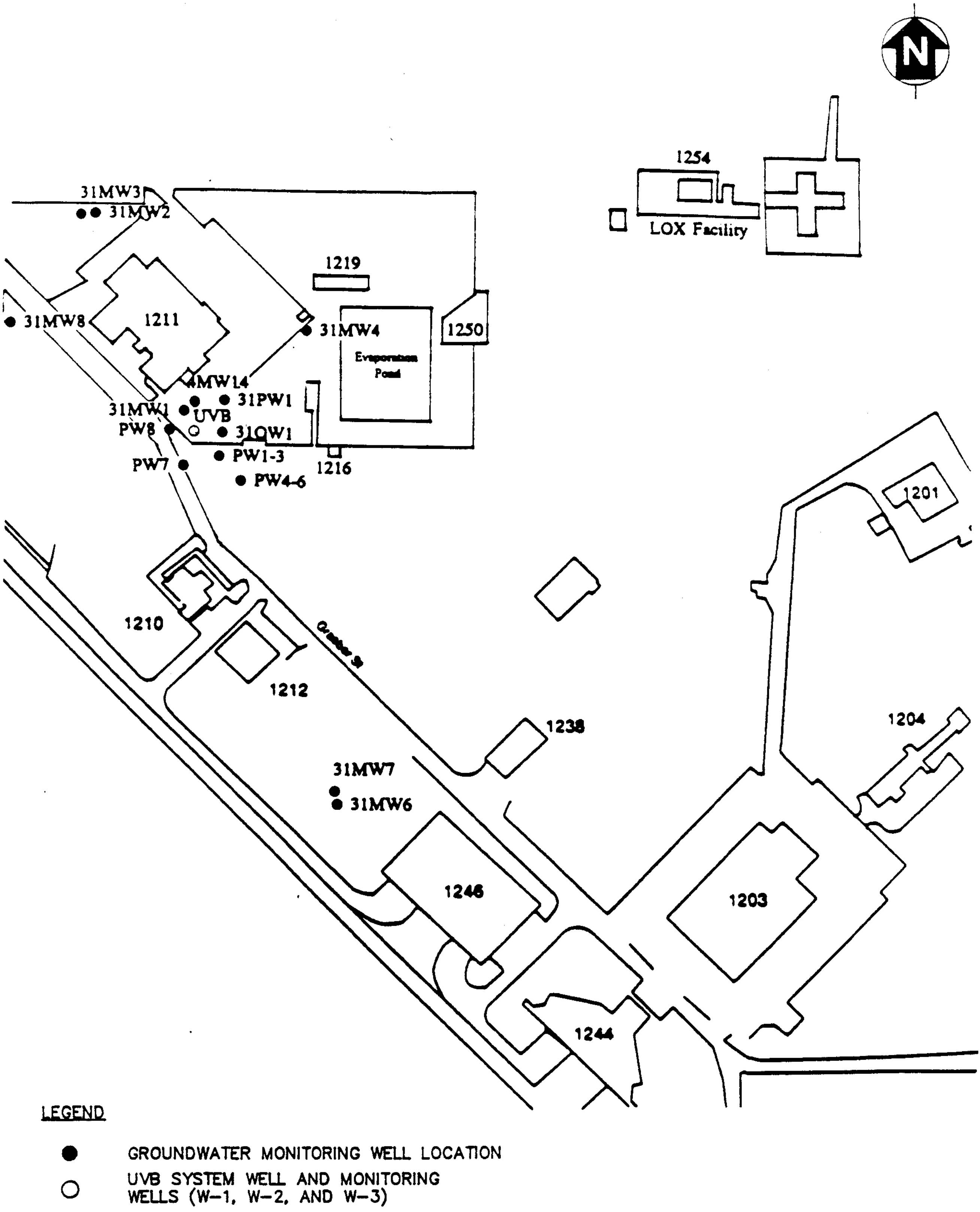


Figure 4-7. Well location map.

Table 4-1. Historical Site 31 Groundwater TCE Concentrations

Well Location	TCE Concentration µg/L																								
	Sumr 92 t	Aug 92 e	Fall 92 t	Sept 92 e	Dec 92 e	Wntr 93 t	Feb 93 e	Sprg 93 t	May 93 w	Jun 93 w	Sumr 93 t	Jul 93 w	Aug 93 w	Fall 93 t	Sept 93 w	Oct 93 w	Nov 93 w	Feb 94 w	Wntr 94 t	Mar 94 w	Sprg 94 t	Jun 94 w	Aug 94 w	Sumr 94 t	Oct 94 w
W1	NI	NI	NI	NI	NI	NI	NI	NI	33	180	NA	83	300	NA	100	41	19	27	NA	18	NA	6.5	53	NA	29
W2	NI	NI	NI	NI	NI	NI	NI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
W3	NI	NI	NI	NI	NI	NI	NI	NI	5.9	1.2	NA	ND	12	NA	1.0	1.1	1.7	7.1	NA	ND	NA	11	15	NA	0.89
PW1	NI	NI	NI	NI	NI	NI	NI	NI	400	1500	820	700	1200	500	960	910	310	540	93	NA	69	110	110	71	89
PW2	NI	NI	NI	NI	NI	NI	NI	NI	NA	NA	1400	NA	NA	1200	NA	NA	NA	NA	NA	NA	200	NA	NA	110	NA
PW3	NI	NI	NI	NI	NI	NI	NI	NI	NA	NA	300	NA	NA	270	NA	NA	NA	NA	240	NA	194	NA	NA	100	NA
PW4	NI	NI	NI	NI	NI	NI	NI	NI	480	810	1300	750	1200	500	740	1600	610	760	190	NA	160	250	270	170	210
PW5	NI	NI	NI	NI	NI	NI	NI	NI	NA	NA	320	NA	NA	540	NA	NA	NA	NA	150	NA	91	NA	NA	87	NA
PW6	NI	NI	NI	NI	NI	NI	NI	NI	NA	NA	190	NA	NA	160	NA	NA	NA	NA	120	NA	100	NA	NA	100	NA
PW7	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NA	85	86	130	95	120	NA	110
PW8	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NA	170	81	110	92	76	NA	98
31MW1	NI	NI	NI	NI	17	NA	NA	<3	3.4	26	23	21	22	20	34	24	17	NA	15	NA	NA	NA	NA	NA	NA
31MW2	NI	<1	NI	NI	NI	<5	NA	<3	NA	NA	<3	NA	NA	<3	NA	NA	NA	NA	5	NA	NA	NA	NA	NA	NA
31MW3	NI	1.3	NI	NI	NI	<5	NA	<3	NA	NA	<3	NA	NA	<3	NA	NA	NA	NA	4	NA	NA	NA	NA	NA	NA
31MW4	NI	NI	NI	360	NI	NA	NA	410	170	610	260	220	270	240	150	230	220	110	150	320	140	210	180	100	160
31MW5	NI	NI	NI	NI	<1	NA	NA	<3	NA	NA	<3	NA	NA	<3	NA	NA	NA	NA	<3	NA	NA	NA	NA	NA	NA
31MW6	NI	NI	NI	NI	24	NA	NA	17	NA	NA	14	NA	NA	23	NA	NA	NA	NA	26	NA	18	NA	NA	35	NA
31MW7	NI	NI	NI	NI	<1	NA	NA	4	NA	NA	<3	NA	NA	<3	NA	NA	NA	NA	6	NA	NA	NA	NA	NA	NA
31MW8	NI	NI	NI	NI	NI	NA	<1	23	NA	NA	24	NA	NA	16	NA	NA	NA	NA	11	NA	15	NA	NA	9.7	NA
310W1	NI	NI	NI	NI	NI	NA	NA	1100	940	830	630	650	1000	640	910	870	485	450	84	250	100	580	340	140	250
31PW1	NI	NI	NI	NI	NI	NA	NA	1200	NA	NA	1400	NA	NA	260	NA	NA	NA	140	160	160	47	110	77	16	48
4MW7	NA	NA	59.6	NA	NA	81	NA	85	NA	NA	47	NA	NA	61	NA	NA	NA	NA	55	NA	35	NA	NA	15	NA
4MW12	NA	NA	<1	NA	NA	3	NA	<3	NA	NA	<3	NA	NA	<3	NA	NA	NA	NA	<3	NA	NA	NA	NA	NA	NA
4MW14	656	NA	520	NA	NA	250	NA	180	160	580	110	1200	1500	350	1700	1500	1700	1700	100	110	140	180	170	130	130
28MW3	NA	NA	10.3	NA	NA	8	NA	6	NA	NA	6	NA	NA	9	NA	NA	NA	NA	6	NA	6.3	NA	NA	NA	NA

t - Tetra-Tech, Inc.
w - Roy F. Weston, Inc.
e - The Earth Technologies Corporation

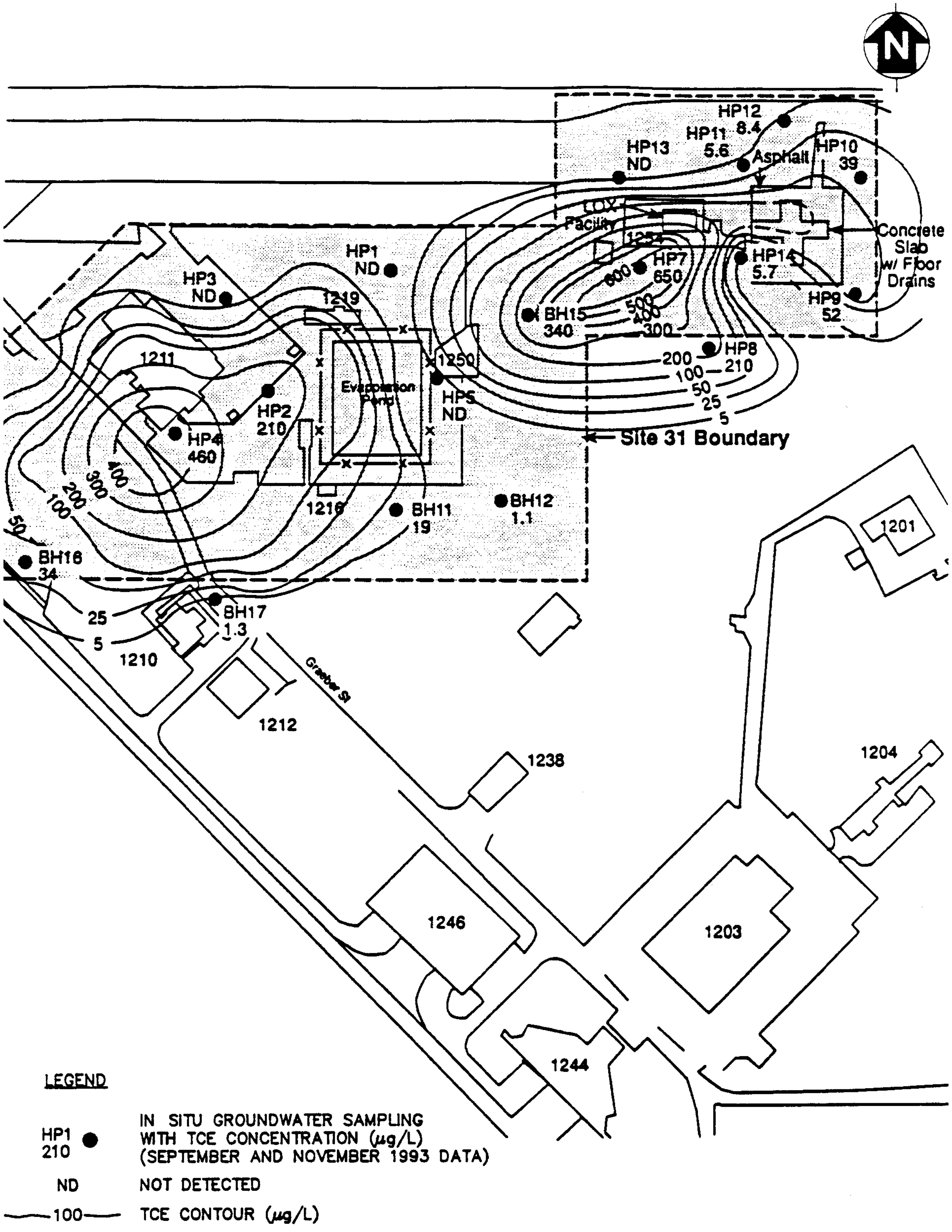


Figure 4-8. Site 31 TCE plume from in situ data.

Table 4-2. Groundwater Monitoring Well Completion and Location Data

Well ID	Date Installed	Screen Length (feet)*	Screen Interval (feet bgs)*	Sand Pack Interval (feet bgs)*	Well Depth (feet bgs)*	Well Elevation (feet AMSL)	Northing Coordinate	Easting Coordinate
W1	4/25/93	10	70 - 80	67 - 84	85	1508.07	2269282.10	6258393.30
W2	4/25/93	15	40 - 55	36 - 58	56	1506.70	2269280.80	6258391.50
W3	4/25/93	15	40 - 55	36 - 58	56	1506.91	2269282.10	6258393.30
PW1	4/14/93	20	38 - 58	33 - 58	58	1505.60	2269255.34	6258415.73
PW2	4/16/93	10	65 - 75	58 - 77	75	1505.70	2269251.32	6258418.84
PW3	4/8/93	15	90 - 105	86 - 109	105	1505.52	2269247.08	6258421.02
PW4	4/13/93	20	38 - 58	33 - 59	58	1504.91	2269217.58	6258447.58
PW5	4/15/93	10	68 - 78	57 - 78	78	1505.03	2269213.23	6258451.05
PW6	4/7/93	15	91 - 106	85 - 106	106	1505.16	2269209.51	6258454.15
PW7	12/29/93	20	35 - 55	32 -55	55	1505.47	2269234.65	6258386.16
PW8	12/28/93	20	35 - 55	32 - 55	55	1505.69	2269286.43	6258356.53
31MW1	1/12/93	10	143 - 153	146 - 161	153	1507.57	2269318.88	6258379.03
31MW2	8/5/92	20	42 - 62	36 - 62.5	62	1508.36	2269657.31	6258208.81
31MW3	8/5/92	10	97 - 107	91 - 109	107	1508.39	2269655.28	6258564.30
31MW4	7/28/92	20	78 - 98	70 - 100	98	1507.61	2269454.64	6258564.30
31MW5	11/16/92	20	47 - 67	42 - 67	67	1051.76	2268225.10	6259623.88
31MW6	12/1/92	20	41 - 61	36 - 60	61	1503.38	2268690.80	6258605.54
31MW7	11/30/92	10	98 - 108	91 - 110	108	1503.34	2268701.78	6258595.67
31MW8	11/19/92	20	57 - 77	49 - 79	77	1505.51	2269461.42	6258087.69
31OW1	1/19/92	20	61 - 81	54 - 82	81	1507.62	2269286.36	6258433.92
31PW1	1/19/92	40	52 - 92	39 - 92	92	1507.25	2267463.66	6258430.49
4MW14	6/5/89	40	35 - 75	24 - 77	75	1507.71	2269331.38	6258388.92

Notes:

*Approximate measurements
1 foot = 0.3048 meter

of the treatment system to other contaminated sites. For the SITE demonstration of the UVB technology, three primary and seven secondary objectives were selected and are summarized below:

Primary Objectives:

(P1) Determine the concentration to which the UVB technology reduces TCE and DCE in groundwater discharged from the treatment system

(P2) Estimate the radius of circulation cell of the groundwater treatment system

(P3) Determine whether TCE and DCE concentrations have been reduced in groundwater (both vertically and horizontally) within the radius of circulation cell of the UVB system over the course of the pilot study

Secondary Objectives:

(S1) Assess homogenization of the groundwater within the zone of influence

(S2) Document selected aquifer geochemical characteristics that may be affected by oxygenation and recirculation of treated groundwater

(S3) Determine whether the treatment system induces a vacuum in the vadose zone that suggests vapor transport

(S4) Estimate the capital and operating costs of constructing a single treatment unit to remediate groundwater contaminated with TCE and DCE

(S5) Document pre- and post-treatment off-gas volatile organic contaminant levels

(S6) Document system operating parameters

(S7) Evaluate the presence of aerobic biological activity in the saturated and vadose zones

The demonstration program objectives were achieved by collecting monthly samples from the groundwater, soil gas, and the UVB system process air stream over a 12-month period. To meet the demonstration objectives, data were collected and analyzed using the methods and procedures summarized in Section 4.2.

4.2 Demonstration Procedures

This section describes the methods and procedures used to collect and analyze samples for the SITE demonstration of the UVB technology. The field and analytical methods used to collect and analyze samples were conducted in accordance with the procedures outlined in Sections 4.2.2 and 4.2.3. The activities associated with the UVB SITE demonstration included (1) demonstration preparation, (2) demonstration design, (3) groundwater and soil gas sample collection and analysis, and (4) field and laboratory QA/QC.

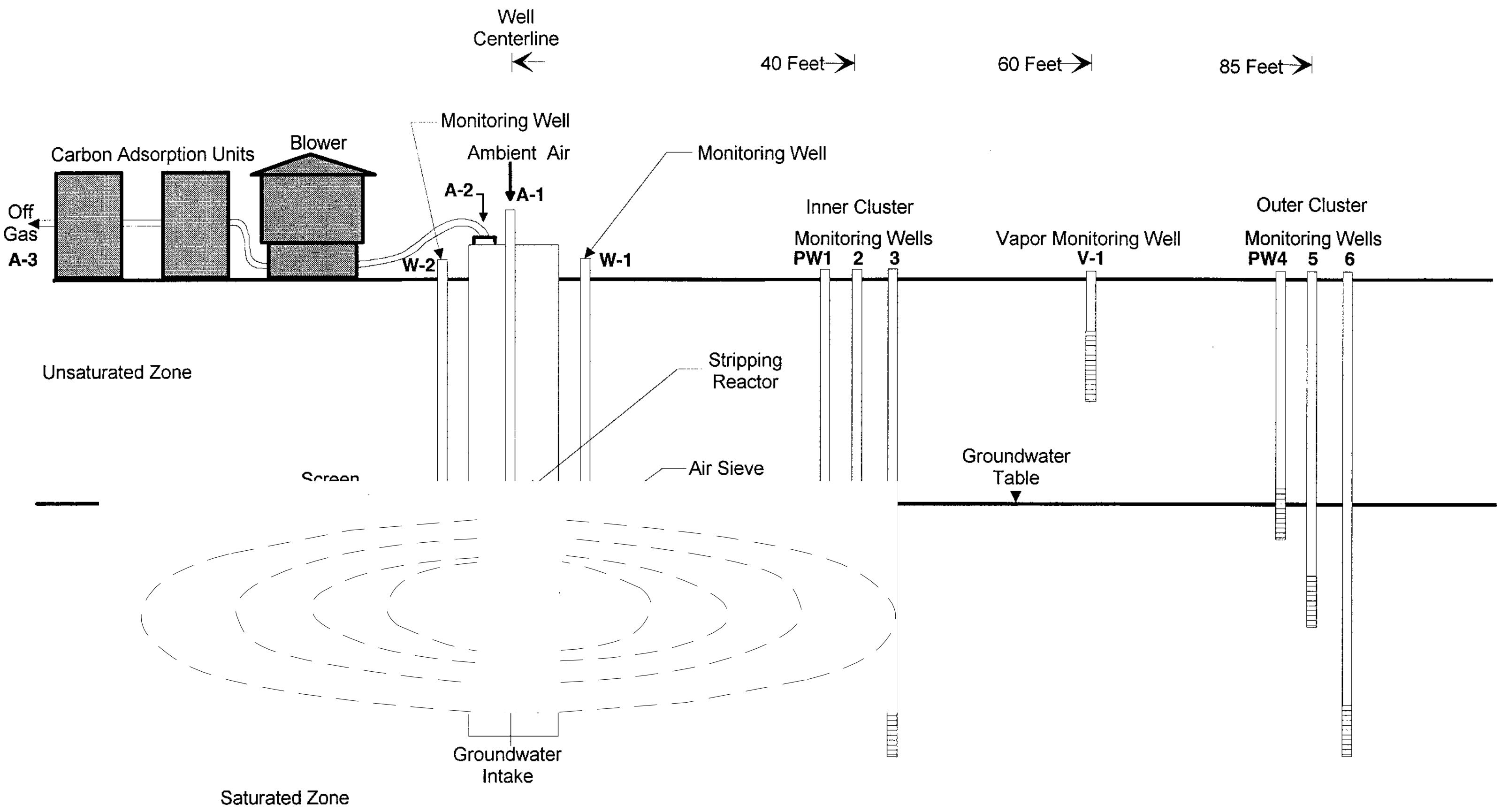
4.2.1 Demonstration Preparation

Predemonstration activities included drilling seven soil borings and the subsequent installation and completion of six groundwater monitoring wells and one soil gas well to evaluate the UVB system. The groundwater monitoring wells were placed in two clusters, with each cluster containing three wells: a shallow, intermediate, and deep screen well (Figure 4-9). The well clusters were placed such that the outer cluster served as a control set for comparison with inner cluster results. Based on the preliminary estimate of the UVB system's radius of circulation cell of approximately 50 feet (15.2 m), the monitoring well clusters were placed at approximately 40 and 90 feet (12.2 to 27.4 m) from the UVB system well. The soil gas well was located approximately 65 feet (19.8 m) from the UVB system well.

A second phase of site preparation activities was conducted before the dye trace study began. Field activities associated with the dye trace study included the installation of two additional groundwater monitoring wells and the setup of a field laboratory for analysis of fluorescent dyes. The two wells were located approximately 40 feet (12.2 m) from the UVB system well and were completed as shallow screen monitoring wells.

4.2.2 Demonstration Design

This section describes the sampling and analysis program and sample collection frequency and locations. The purpose of the demonstration design was to collect and analyze samples of known and acceptable quality to achieve the objectives stated in Section 4.1.3.



Notes:

Depth to water: approximately 40 feet (bgs)
W1 screened from approximately 70 to 80 feet (bgs).
W2 screened from approximately 40 to 55 feet (bgs).
PW1 and PW4 screened from approximately 38 to 58 feet (bgs).
PW2 and PW5 screened from approximately 65 to 75 feet (bgs).
PW3 and PW6 screened from approximately 90 to 105 feet (bgs).
All cluster wells are set 5 feet apart.
Not to scale.
1 foot = 0.3048 meters

Legend:

→ Groundwater flow

Figure 4-9. Sampling locations conceptual diagram.

4.2.2.1 Sampling and Analysis Program

To meet the demonstration objectives, the sampling and analysis program was divided into three phases: (1) baseline sampling, (2) long-term sampling, and (3) dye trace sampling.

Baseline sampling included the collection of groundwater samples from eight monitoring wells and one soil gas sample from the soil vapor monitoring well before system start-up. This sampling provided documentation of baseline conditions at the site and was used in achieving the demonstration objectives. Groundwater samples were analyzed for VOCs, dissolved metals, and general chemistry parameters. The air sample was analyzed for VOCs and fixed gases oxygen (O_2), nitrogen (N_2), and carbon dioxide (CO_2). An overview of the sampling and analysis conducted for baseline sampling is shown in Tables 4-3 and 4-4.

Long-term sampling included monthly collection of groundwater samples from eight monitoring wells, a soil gas sample from the soil vapor monitoring well, and air samples from the three UVB process air streams. These samples were collected for 6 consecutive months after system start-up. Groundwater samples were analyzed for VOCs, dissolved metals, and general chemistry parameters. All air samples from system air sampling ports were analyzed for VOCs. The air samples from the vadose zone were analyzed for VOCs and fixed gases. The fixed gas determinations were performed to evaluate the potential for increasing microbiological activity in the vadose zone. Samples from the ambient air and contaminated air before treatment were also analyzed for fixed gases. At the end of the 6-month period, sampling of the soil gas and system process air stream was terminated and an additional 6 months of modified monthly groundwater sampling was performed. The modified sampling events consisted of the collection and analysis of groundwater samples from shallow and intermediate depth monitoring wells for VOCs only. Tables 4-3 and 4-4 provide an overview of the sampling and analysis performed for long-term air and groundwater sampling.

Dye trace sampling was conducted to further evaluate of the system's radius of circulation cell. After fluorescent dyes were injected into the UVB-generated groundwater circulation cell, groundwater samples were collected from 13 wells three times a week for a 4-month period. Samples were collected for both qualitative and quantitative analysis of fluorescence. Table 4-5 provides an overview of the frequency performed for the dye trace sampling. A more detailed description of the dye trace study project background, dye study design, field procedures, analytical methods, quality assurance/quality control, data interpretation, results, and conclusions is presented in the Dye Trace Study Report presented in Appendix A.

4.2.2.2 Sampling and Measurement Locations

Sampling locations were selected based on the configuration of the treatment system and project objectives; analytical parameters were selected based on the contaminant to be treated and project objectives. The locations at which samples were collected and field measurements taken during the demonstration are shown on Figures 4-7 and 4-9. Tetra Tech collected groundwater samples at eight locations and vapor samples at one location for the baseline sampling events. Groundwater was collected from eight locations and vapor samples from four locations for long-term sampling events. Groundwater samples were collected from 13 locations for the dye trace study. The eight baseline and long-term groundwater monitoring locations are identified on Figures 4-7 and 4-9 as wells W1, W2, and PW1 through PW6.

The 13 dye trace study groundwater monitoring locations are also identified on Figure 4-7 as W1, W2, PW1 through PW8, 4MW14, 31PW1, and 31OW1. Wells PW1 through PW6 were installed in clusters of three, at three different depths in the aquifer and at two separate radii from the in situ stripping well. One cluster is within the originally estimated radius of circulation cell of the UVB system, and the other cluster is outside the originally estimated radius of circulation cell. Thus, the rationale for placement of the wells was to install one cluster within the expected radius of circulation cell of the UVB system well, while the other cluster acted as a control set. The well depths were placed to monitor (1) the upper portion of the aquifer in the discharge zone of the UVB system well, (2) in the middle of the aquifer in the intake zone of the UVB system well, and (3) in the lower portion of the aquifer below the UVB system well.

The four air monitoring locations are identified on Figure 4-9 as A1 through A3 and V1. These locations measured system air as follows: A1 is ambient air, A2 is contaminated air prior to treatment, A3 is post-treatment air, and V1 is soil vapor from the vadose zone.

Table 4-3. Groundwater Sampling and Analysis Overview

Location	Parameters	Frequency	Classification	Type	Method	Purpose
Monitoring wells within borehole annulus (W1, W2), monitoring well cluster within the radius of circulation cell (PW1, PW2, PW3), and monitoring well cluster outside of the radius of circulation cell (PW4, PW5, PW6)	VOC	Baseline and monthly thereafter for 12 months for wells W1, W2, PW1, PW2, PW4, and PW5	Critical	Analytical	8260 (SW-846)	P1, P3, S1
	Water Level		Critical	In field analytical	Manufacturers's Specifications	P1, P2, P3
	Dissolved Oxygen		Noncritical	In field analytical	360.1 (MCAWW)	S1, S2, S7
	Oxidation/Reduction Potential	Baseline and monthly thereafter for 6 months for wells PW3 and PW6	Noncritical	In field analytical	2580B (APHA)	S2
	pH		Noncritical	In field analytical	150.1 (MCAWW)	S2
	Specific Conductance		Noncritical	In field analytical	120.1 (MCAWW)	S2
	Temperature		Noncritical	In field analytical	170.1 (MCAWW)	S1, S7
	Dissolved Organic Carbon	Baseline and monthly thereafter for 6 months for all wells	Noncritical	Analytical	415.1 (MCAWW)	S2, S7
	Alkalinity		Noncritical	Analytical	310.1 (MCAWW)	S2
	Total Dissolved Solids		Noncritical	Analytical	160.1 (MCAWW)	S2
	Dissolved Metals[a]		Noncritical	Analytical	3010/6010, 3020/7421, 7740, 7060, 7470 (SW-846)	S2

Notes:

[a] Dissolved metals analyte list includes: Al, Sb, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Mg, Mn, Mo, Ni, K, Si, Ag, Na, Ti, V, Zn

P1-3 This identifier indicates that parameters are compatible with primary objective numbers 1, 2, 3

S1-7 These identifiers indicate that parameters are compatible with one or more secondary objectives, numbers 1 through 7

SW-846 (EPA 1987b)
MCAWW (EPA 1983)
APHA (APHA 1992)

Table 4-4. Air and Soil Vapor Sampling Overview

Location	Parameters	Frequency	Classification	Type	Method	Purpose
Vapor Monitoring Well V1 (soil gas)	VOC	Baseline and monthly thereafter for 6 months	Noncritical	Analytical	TO-14 CMDTOCAA	S3
	Vacuum		Noncritical	In field analytical	-	S3, S7
	N_2, O_2, CO_2		Noncritical	Analytical	Fixed Gases ASTM	S7
Ambient Air Sampling Port A1 (air)	VOCs	Monthly for 6 months	Noncritical	Analytical	TO-14 CMDTOCAA	S5
	Temperature		Noncritical	In field analytical	-	S5
	N_2, O_2, CO_2		Noncritical	Analytical	Fixed Gases ASTM	S7
Stripped Air Sampling Port A2 (air)	VOCs	Monthly for 6 months	Noncritical	Analytical	TO-14 CMDTOCAA	S5
	Temperature		Noncritical	In field analytical	-	S5
	N_2, O_2, CO_2		Noncritical	Analytical	Fixed Gases ASTM	S7
Post-Treatment Air Sampling Port A3 (air)	VOCs	Monthly for 6 months	Noncritical	Analytical	TO14 CMDTOCAA	S5

Notes:

S1-7 These identifiers indicate that parameters are compatible with one or more secondary objectives, numbers 1 through 7
TO-14 EPA Method TO-14
ASTM (ASTM 1990)
CMDTOCAA (EPA 1988b)

Table 4-5. Dye Tracer Study Sampling Overview

Location	Parameters	Frequency	Classification	Type	Method	Purpose
PW1, PW2, PW7, PW8, and 31OW1	Rhodamine WT and Fluorescein	Day One: sample every hour for 8 hours; sample every 2 hours for 8 hour; sample every 4 hours for 8 hours. Day Two: sample once every 8 hours for 24 hours Days Three, Four, and Five: once every 24 hours	Critical	Analytical	Fluorescence[c]	P2
W1, W2, PW1, PW2, PW3[a], PW4, PW5, PW6[a] PW7, PW8, 31OW1, 31PW1[b], 4MW14[b]	Rhodamine WT and Fluorescein	Sample 3 times per week on nonconsecutive days	Critical	Analytical	Fluorescence[c]	P2

Notes:

P2	This identifier indicates that parameters are compatible with primary objective number 2
[a]	Wells were added to sampling program during the dye tracer study
[b]	Samples were collected from the top and bottom of the well's screened interval
[c]	Qualitatively and quantitatively analyzed for fluorescence using methods and procedures outlined in the dye trace study report (Appendix A)

4.2.3 Sampling Methods

This section describes the sampling or measurement procedures at each sampling location.

4.2.3.1 Groundwater Samples

Groundwater samples were collected from monitoring wells at the locations identified in Section 4.2.2.2 and depicted on Figures 4-7 and 4-9. Monitoring wells sampled during baseline and long-term sampling events were purged prior to sampling using a submersible pump or bailer. Before purging, the static water level was measured using an electric sounder and recorded on the well purging and sampling form. After the static level was measured, a stainless steel Grundfos Redi-Flo2 submersible pump was lowered down the well and set at the mid point of the water column in the well casing. Monitoring wells were purged of at least three well volumes and until groundwater parameters stabilized (that is, pH, specific conductance, and temperature were within 10 percent of previous readings). Purge water samples were collected and analyzed in the field for pH, specific conductivity, temperature, and reduction/oxidation potential after each well volume. Dissolved oxygen was measured during sampling. These parameters were recorded on the summary sheet for water sampling.

Groundwater samples were collected immediately after the well was purged. Samples were collected from the mid-screen interval of the well using a disposal acrylic bailer lowered into place by a nylon rope. New bailers were used at each sample location to eliminate the potential for cross contamination. Groundwater was immediately dispensed from the bailer directly into precleaned sample containers (provided by a commercial supplier). The samples collected for laboratory analysis were preserved appropriately for the tests to be performed.

When samples for determination of organic compounds were collected, the sample was introduced into the vials gently to reduce agitation that might drive off volatile compounds. The samples were collected directly into the vial without introducing any air bubbles. Each vial was filled until a meniscus appeared over the top. The screw-top lid with the septum (Teflon side toward the sample) was then tightened onto the vial. After tightening the lid, the vial was inverted and tapped to check for air bubbles. If any air bubbles were present, the sample was recollected by filling a new, preserved vial. Samples collected for dissolved metals analysis were filtered in the field through a 0.45 micron filter using a peristaltic pump.

During the dye trace study, groundwater grab samples and passive dye receptors, known as carbon bugs, were collected for qualitative and quantitative analysis of fluorescence. The methods and procedures used to collect and analyze the both the grab and carbon bug samples are discussed in the dye trace study report presented in Appendix A.

4.2.3.2 Gas Samples

Gas samples were periodically collected at locations shown on Figure 4-9 to monitor changes and relative differences between ambient air, treated and untreated air, and soil gas. Gas samples were collected in 6-liter SUMMA canisters. The canisters were attached to the specified sampling locations via disposable Teflon tubing. The tubing was purged with the air stream to be sampled before it was attached to the SUMMA canister. The canisters were allowed to fill for 7 to 15 seconds. Gas samples were analyzed for VOCs or fixed gases.

4.2.4 Quality Assurance and Quality Control Program

Quality control checks and procedures were an integral part of the UVB SITE demonstration to ensure that the QA objectives were met. These checks and procedures focused on the collection of representative samples absent of external contamination and on the generation of comparable data. The QC checks and procedures conducted during the demonstration were of two kinds: (1) checks controlling field activities, such as sample collection and shipping, and (2) checks controlling laboratory activities, such as extraction and analysis. The results of the field quality control checks are summarized in the TER (PRC 1995).

4.2.4.1 Field Quality Control Checks

As a check on the quality of field activities including sample collection, shipment, and handling, three types of field QC checks (field blanks, trip blanks, and equipment blanks) were collected. In general, these QC checks assessed the representativeness of the samples, and ensured that the degree to which the analytical data represent actual site conditions was known and documented. Any QC results that fail acceptance criteria and could not readily be corrected in the laboratory were reported to the project manager or QA manager as soon as possible to effect corrective action. If a field QC check sample exceeded the established criteria for any analytical parameter, analytical results of that parameter for all associated samples having the analyte concentration above the quantitation limit were flagged during post-laboratory validation.

4.2.4.2 Laboratory QC Checks

Laboratory QC checks were designed to determine precision and accuracy of the analyses, to demonstrate the absence of interferences and contamination from glassware and reagents, and to ensure the comparability of data. Laboratory-based QC checks consisted of method blanks, matrix spikes/matrix spike duplicates, samples/ sample duplicates, surrogate spikes, blank spikes/blank spike duplicates, and other checks specified in the analytical methods. The laboratory also performed initial calibrations and continuing calibration checks according to the specified analytical methods. The results of the laboratory internal QC checks for critical parameters are summarized on a method-specific basis in the TER (PRC 1995).

Routine QC was performed for the noncritical general chemistry parameters. At least one laboratory duplicate and check standard was run for every batch (minimum of one per 20 samples) for alkalinity and total dissolved solids (TDS). Laboratory blanks were also run for these parameters. Duplicate samples were run for all other noncritical analyses at a frequency of 10 percent or at least one per batch. The relative percentage difference (RPD) acceptance criteria for duplicate analyses was 20 percent. Additionally, check standards and laboratory blank samples were run for metals analyses. The results of the laboratory internal QC checks for noncritical analyses are also presented in the TER (PRC 1995).

4.3 Demonstration Results and Conclusions

This section presents the operating conditions, results and discussion, data quality, and conclusions of the SITE demonstration of the UVB treatment system. The SITE demonstration provides the most extensive UVB performance data to date and serves as the foundation for conclusions on the system's effectiveness and applicability to other cleanups. The demonstration results have been supplemented by information provided by the vendor on other sites undergoing remediation using the UVB treatment system.

4.3.1 Operating Conditions

This section summarizes the configuration of the UVB system, operating parameters, and system maintenance performed on the UVB during the 12-month demonstration. During the SITE demonstration, the UVB treatment system was operated at conditions determined by the developer. To document the UVB system's operating conditions, groundwater influent and effluent and system process air stream were periodically monitored and sampled. The system operated continually, 24 hours a day, 7 days a week over the demonstration period with the exception of periodic maintenance checks. The UVB technology was presented by the developer as a highly efficient in situ system requiring minimal maintenance for the remediation of volatile organic compounds in the groundwater, unsaturated zone, and the capillary fringe. The UVB system installed at Site 31 was designed to remove chlorinated hydrocarbons from the groundwater and did not address removal of other contaminants from either the unsaturated zone or capillary fringe.

4.3.1.1 UVB Treatment System Configuration

The UVB well installed at Site 31 consisted of a 16-inch (40.6 cm) diameter dual screen well installed in a 26-inch (66.0 cm) diameter bore hole and was completed to a depth of 83.7 feet (25.5 m) bgs. The two screen sections of the well were separated by 14.7 feet (4.5 m) of steel casing. The lower (influent) screen section was 12 feet (3.7 m) long and was composed of steel bridge-slot casing. The upper (effluent) screen section extended 13.8 feet (4.2 m) and was constructed with 4 feet (1.2 m) of bridge-slot casing and 9.8 feet (3.0 m) of double-cased stainless steel screen filled with 3/8-inch (1.0 cm) Teflon beads. Final completion of the well included the placement of a gravel pack and a bentonite and cement slurry. The well was completed at the surface with a concrete pad and bolted well head. The as-built configuration of the UVB treatment well showing the depth of screen intervals and well construction materials is provided as Figure 4-10.

The upper and lower screen sections were separated within the well by an inflatable packer installed at 66.7 feet (20.3 m) bgs. The packer was pierced by an intake pipe that provided flow from the lower screen section to the

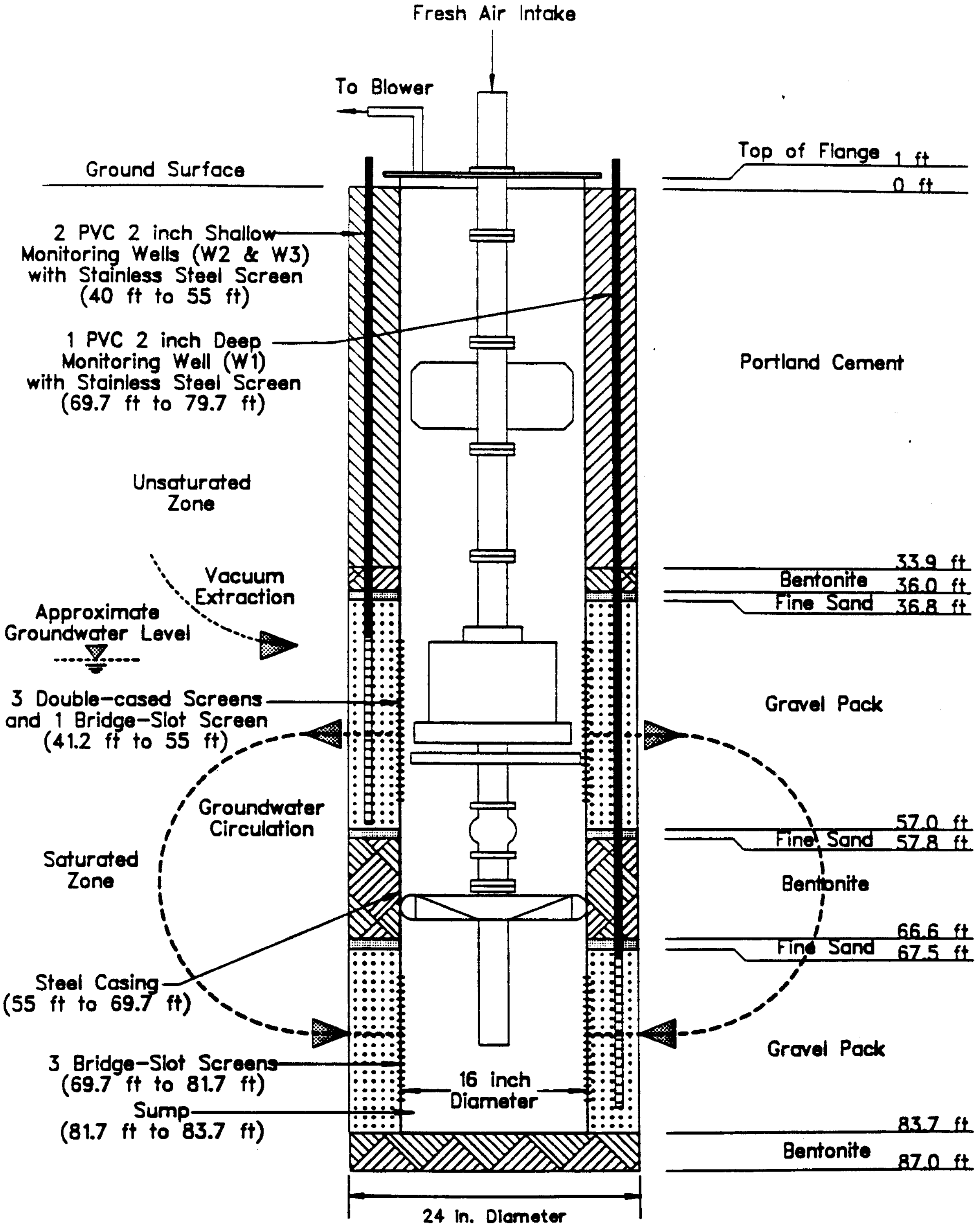


Figure 4-10. As-built UVB configuration.

groundwater stripping unit located in the upper section of the well. The internal stripping unit components consisted of a Grundfos Model KP 300 MI submersible pump, a pinhole (diffuser) plate, a double-wall stripper reactor, internal centralizers and leveling ballast, and an air intake pipe. A diagram showing the as-built internal components of the UVB system well is presented as Figure 4-11. The discharge throat of the pump was equipped with a 15-millimeter orifice flow restrictor that provided a constant upward flow rate of approximately 22 gallons per minute (83.3 liters per minute) (Weston 1994). To minimize downhole corrosion, the stripping unit components were constructed with high density polyethylene or aluminum. The downhole components of the system well were free-floating and were self-adjusting to fluctuations in groundwater elevation.

The above-ground components of the UVB treatment system included a blower, moisture separator, process air stream piping, electrical supply, and two 1,800-pound (816.5 kg) vapor phase carbon adsorption units. The configuration of the above-ground UVB system components is shown in Figure 4-12.

4.3.1.2 Operating Parameters

The UVB system was sampled and monitored by Weston on a regular basis to evaluate the system's performance. System operating parameters monitored by the developer included relative humidity, air temperature, linear flow velocity, pressure in the system's air streams, and VOC removal in the groundwater discharged from the system. These parameters were collected from the UVB treatment well's fresh air intake pipe and the four sampling ports, V1 through V4, installed in the air stream piping by the developer (Figure 4-12). A summary of the operating parameter results measured during the demonstration is presented in Section 4.3.2.2.6.

4.3.1.3 System Maintenance

Routine maintenance and inspection of the UVB system were performed by the developer four times during the 12-month demonstration period. The system was shut down during routine maintenance and inspection for 1.5 to 4 hours. Items inspected during routine maintenance included: the direction of rotation of the blower fan, fan belt wear, bearings of the blower motor for wear, water content in the moisture knockout pot, cables holding the packer in place, air pressure in the packer, air hose for wear, pinhole plate for iron buildup and biofilm, vacuum gauge readings, binding or clogging in the fresh air pipe, buoyancy of the UVB system, and air to water ratio (air flow rate and water flow rate). The internal stripping components were removed by hand and required at least two technicians. In addition to routine maintenance, the system was inspected and operating parameters monitored during regular scheduled sampling activities to provide an indication of system performance. A summary of maintenance activities performed by Weston is provided in Table 4-6. In general, maintenance conducted on the UVB system during the demonstration consisted of adjustments to optimize stripping condition within the well. Air stripping of VOCs was optimized by maximizing both the length of the stripping column and the volume of air introduced to the well through the diffuser plate. These functions are controlled by changing the depth of the stripping unit and the vacuum at the well head.

System maintenance and inspection was conducted by the developer throughout the demonstration with the exception of the period from December 7, 1993 to February 3, 1994. From May 4 to December 7, 1993, the system operated with few problems, requiring only scheduled maintenance.

The only problem identified during this period was the displacement of the inflatable packer identified on November 4, 1993. Displacement of the well packer may have allowed the recirculation of water within the UVB well casing, possibly causing a greater dilution effect on the influent contaminant concentrations. However, the sixth monthly sampling event conducted on October 25, 1993 did not exhibit anomalously low influent concentrations. From December 7, 1993 to February 3, 1994, no maintenance was conducted due to developer contractual renegotiations with the March AFB.

After maintenance and inspection resumed in February 1994, several additional problems potentially affecting system performance were documented. From February 3 to May 17, 1994 the system was documented four different times as having low intake air flow rate and operating at a depth 2 to 3 feet (0.6 to 0.9 m) lower than preferred by the developer. Because of the increased depth of the stripping unit, the vacuum applied during this period may have been unable to overcome the additional pressure head from the increased water column. Subsequently, little or no air may have been introduced to the diffuser plate (as documented

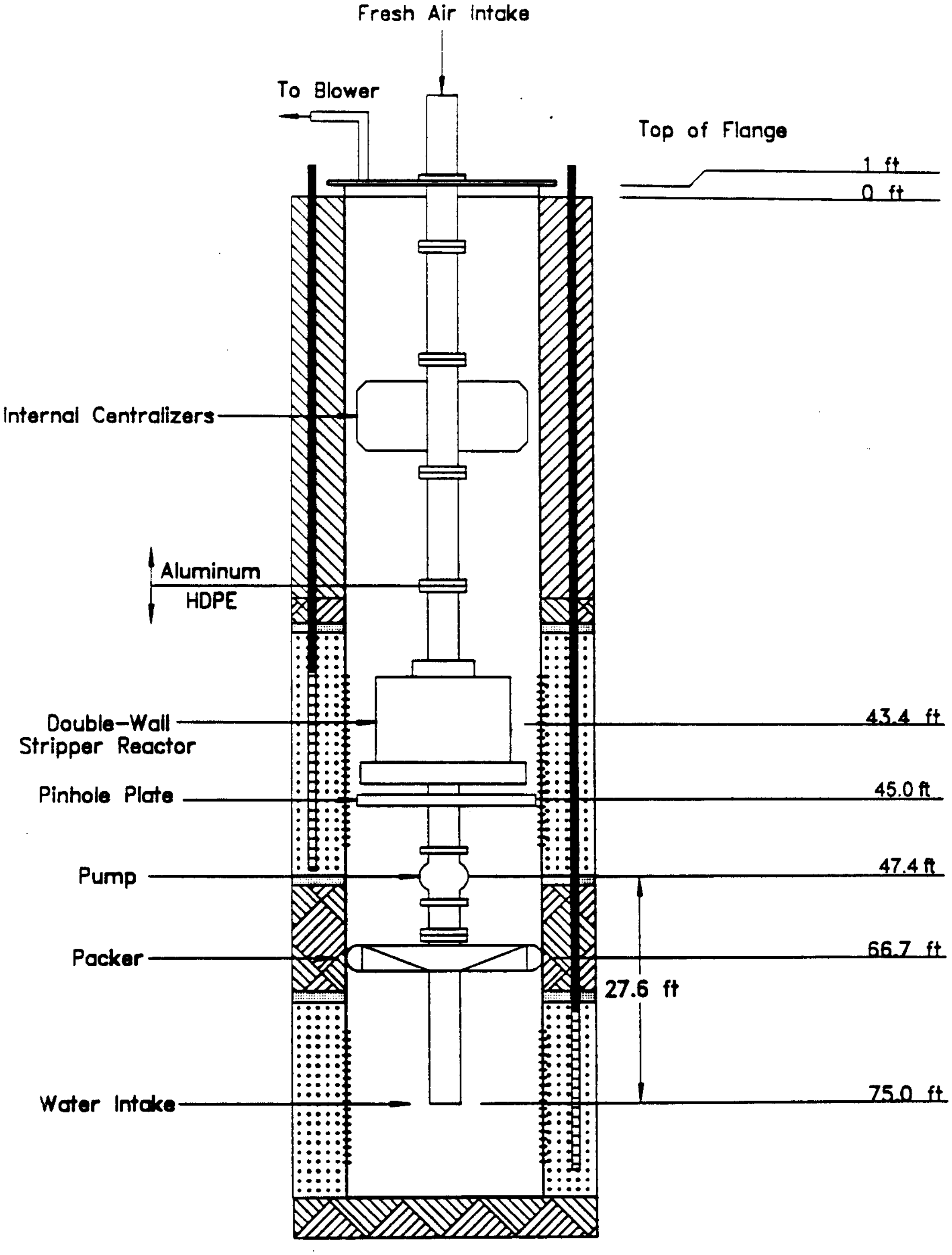


Figure 4-11. As-built UVB internal components.

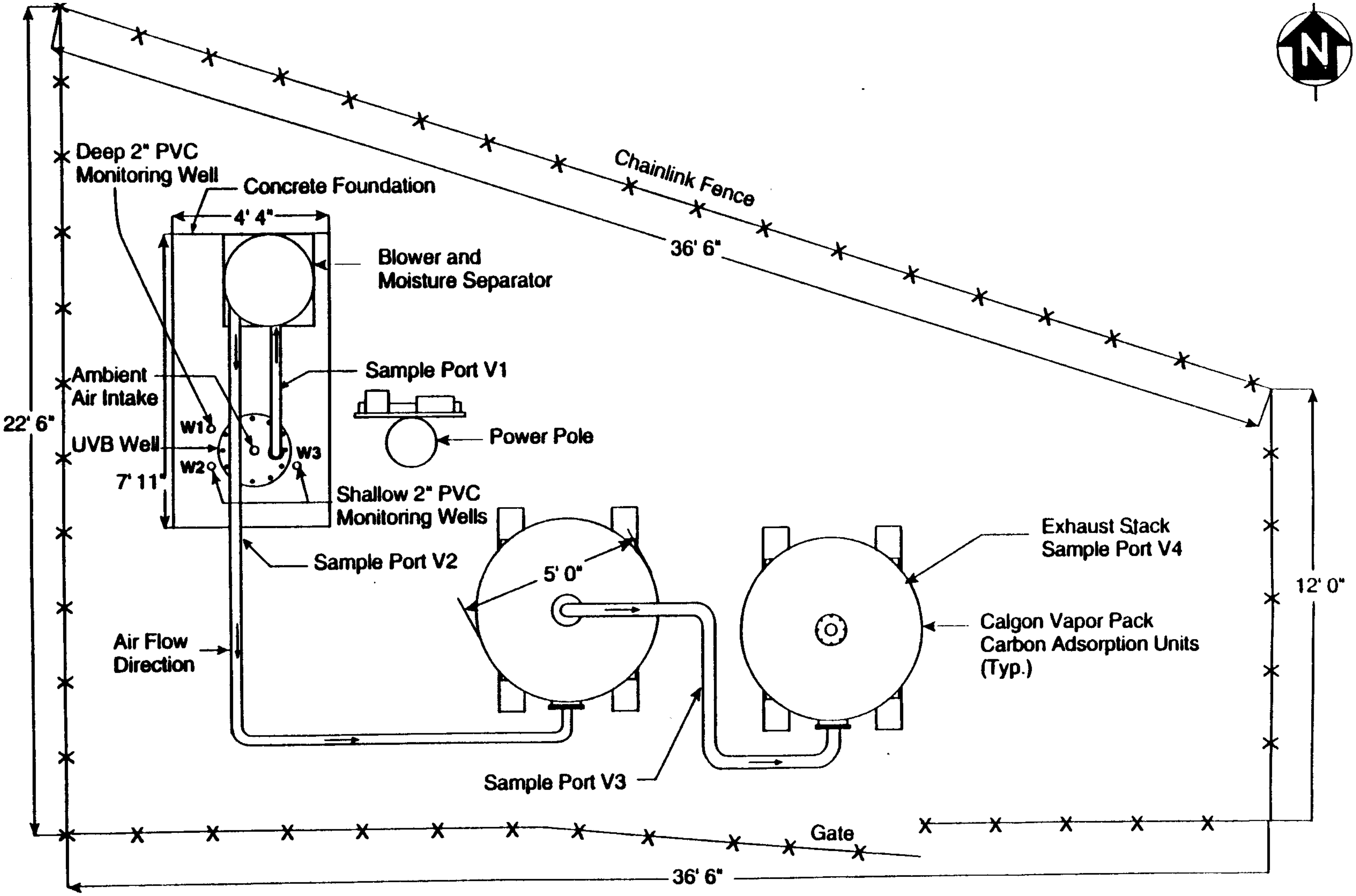


Figure 4-12. Aboveground system components.

Table 4-6. Maintenance Summary

Date	Weston Maintenance Log
May 4, 1993	System turned on.
July 20, 1993	System components pulled to perform routine maintenance. Total down-time of system: 2 hours, 15 minutes.
Sept 14, 1993	System components pulled to perform routine maintenance. Total down-time of system: approximately 4 hours.
Nov 4, 1993	System operating at a lower than desired depth. Discovered that inflatable packer appears to have raised inside of UVB well casing 2-3 feet (0.6-0.9 m). Deflate packer, push down to desired depth, and reinflate. Packer motion within the well may indicate short-circuiting across the packer within the well.
Dec 7, 1993	System components pulled to perform routine maintenance. Total down-time of system: approximately 4 hours.
Dec 7, 1993 through Feb 3, 1994	System was not monitored during this period due to contract renegotiation.
Jan 10, 1994	Pull system components to perform maintenance in preparation for up-coming dye study. Also change original 15 mm flow restrictor for 20 mm flow restrictor. Total down-time of system: 3 hours, 20 minutes.
Jan 11, 1994	Pull system components to fine-tune previous maintenance. Replace newly installed 20 mm flow restrictor with original 15 mm flow restrictor. Total down-time: 1 hour, 25 minutes.
Feb 3, 1994	Very low intake air flow recorded. May indicate insufficient air-stripping capabilities within the well.
Feb 18, 1994	No intake air flow recorded. Stripping components appear to be operating at a depth approximately 2 feet (0.6 m) lower than preferred. May indicate insufficient air-stripping capabilities within the well. Raise system and secure in place at desired intake air flow rate.
Feb 24, 1994	Base personnel report that discharge pipe from system had "fallen off." Base personnel shut system blower off, but did not shut off submersible pump. Weston personnel arrive at site on February 25, 1994, reinstall discharge pipe, and turn on blower. Total down-time of blower only: 20 hours, 50 minutes. After restarting system, notice that riser pipe is riding unusually low. Raise pipe and secure at optimal air intake flow rate.
Mar 18, 1994	Very low intake air flow recorded. May indicate insufficient air-stripping capabilities within the well. Raise system and secure in place at desired intake air flow rate.
May 11, 1994	During biweekly sampling of wells W1 and W3, notice that riser is only approximately 3 feet (0.9 m) above flange, as opposed to normal height of approximately 6 feet (1.8 m) above flange. Unable to secure pipe after raising up. Leave as is.

Table 4-6. Maintenance Summary (continued)

Date	Weston Maintenance Log
May 17, 1994	Pull system components for routine maintenance. During removal of components, notice that the third (lowest) buoyancy tank has a hole. This hole has allowed buoyancy tank to fill with water. This filling with water caused components to operated at a lower than optimal depth (as noted several times since February 3, 1994). Replace buoyancy tank. System appears to be operating at preferred elevation and intake air flow. Total down-time of system: 2 hours.
Aug 26, 1994	Riser pipe is riding higher than normal. Adjust to preferred level. System appears to respond favorably to adjustment.
Oct 26, 1994	System shut off completely by Tetra Tech in order to safely perform additional drilling near the UVB. System restarted on November 3, 1994. Total down-time of system : 135 hours, 30 minutes.
Dec 2, 1994	System shut off and pilot program completed at 0815. Components left in place pending decision by March AFB on final disposition of system.

in the maintenance records), causing a decrease in air-stripping efficiency of the system. The developer attempted to alleviate this problem by securing the system in place at the desired depth and air intake flow rate. This solution appeared to have had mixed success and required additional adjustments to the depth of the stripping unit until the system was removed for maintenance on May 17, 1994. During this maintenance, the leveling ballast reportedly had filled with water, causing the stripping unit to operated at a depth lower than preferred by the developer. After fixing the leveling ballast, no additional problems were encountered with the depth of the stripping unit. Since the system maintenance problems were encountered immediately after monitoring and inspection resumed, it is possible that problems may have also been present while the system was not being monitored. However, with the exception of the effluent sample collected in the eighth monthly monitoring event, no anomalous data were apparent during this period to suggest significant reduction in system performance.

The level of system performance from December 7, 1993 to May 17, 1994 appears to have affected the effluent results of at least two monthly monitoring events. Review of TCE concentrations in the samples collected from the system effluent in the eighth (December 27, 1993) and twelfth (April 27, 1994) monthly monitoring events indicates that stripping efficiencies were significantly reduced. Since collection of this anomalous data correlates with documented and inferred maintenance problems, effluent concentrations during these events may not be indicative of optimal operation of the UVB system and will not be used to evaluate of the stripping efficiency of the system. No other correlations between increased effluent concentration and reduced system performance due to maintenance problems were apparent.

4.3.2 Results and Discussion

This section presents the results of the SITE demonstration of the UVB technology at Site 31, March AFB, California. The results are presented by project objective and have been interpreted in relation to each objective. The specific primary and secondary objectives are shown at the top of each section in italics followed by a discussion of the objective-specific results. Data quality and conclusions based on these results are presented in Sections 4.3.3 and 4.3.4.

4.3.2.1 Primary Objectives

Primary objectives were considered critical for the evaluation of the Weston/IEG UVB treatment system. Three primary objectives were selected for the SITE demonstration of the UVB technology. The results for each primary objective are discussed in the following subsections.

Primary Objective P1

Determine the concentration to which the UVB technology reduces TCE and DCE in groundwater discharged from the treatment system.

This objective was achieved by collecting 12 monthly samples at the influent (W1) and effluent (W2) sampling locations and analyzing the samples for TCE and DCE. The analytical results for TCE and DCE in the system influent and effluent wells are summarized in Table 4-7. These results indicate that the UVB treatment system effectively removed target compounds from the groundwater. DCE was reduced to below 1 µg/L (the analytical method detection limit) in all sampling events in the groundwater discharged from the treatment system. However, the UVB system's ability to remove DCE could not be meaningfully estimated due to the low (less than 4 µg/L) influent concentration of DCE. Additionally, TCE was reduced by greater than 93 percent in all events except the fifth, eighth, and twelfth monthly monitoring events.

TCE concentrations in the system's effluent for the eighth monthly monitoring event showed no indication of contaminant reduction. This lack of TCE reduction appears to be a direct result of operating conditions, as discussed in Section 4.3.1.3. Additionally, maintenance performed on the system after samples were collected during the twelfth monthly monitoring event indicated that the system required adjustments to the depth of the stripping reactor. During this event, TCE showed a reduction of only 37 percent, significantly less than previous events. This decrease in contaminant reduction appears to be related to the UVB system operating at a lower depth than preferred by the developer. The results from the fifth monthly monitoring event may also reflect slightly diminished operating performance of the UVB; however, no maintenance problems were identified immediately before or after the event. During the demonstration, TCE concentrations in samples from the influent well ranged from 14 µg/L to 220 µg/L with an arithmetic mean of approximately 56 µg/L. Influent TCE concentrations were significantly lower than TCE concentrations detected in samples from the surrounding groundwater monitoring wells located both up-gradient and downgradient of the system. The persistently low influent concentrations of target compounds observed during the demonstration are most likely due to groundwater recirculation caused by the UVB system. According to the developer, up to 90 percent of the effluent water is recaptured by the UVB system, diluting contaminant levels in the influent groundwater.

Not including the eighth and twelfth monthly monitoring events, TCE was reduced on average by greater than 94 percent in the groundwater discharged from the UVB treatment system. The mean concentration of TCE in samples of the discharged groundwater was approximately 3 µg/L with only one event (third month) above 5 µg/L. During the third monthly monitoring event, TCE was reduced by 93 percent, which is approximately the mean reduction efficiency observed during the demonstration. This reduction suggests the system was operating at normal conditions and that the elevated (16 µg/L) effluent concentration of TCE may be due to the high influent concentration of TCE (220 µg/L) noted during the event.

The upper confidence limit (UCL) for TCE in samples of the treated groundwater (excluding the eighth and twelfth monthly monitoring events) was determined at the 95 percent confidence level using a one-tailed Student's t-test. The UCL was calculated using the following equation:

$$UCL_{t,95} = x + (ts/\text{square root of } n)$$

Where:

x = Sample arithmetic mean contaminant concentration
t = Student's t-test statistic value for a one-tail test at the 95 percent confidence level
s = Sample standard deviation
n = Sample size (number of measurements)

The following parameters were calculated from the TCE concentration data presented in Table 4-7 to determined the UCL.

TCE
x = 3.06
t = 1.833
s = 4.65
n = 10

For the calculation of the mean and standard deviation, sample concentrations below the method detection limit were assigned the concentration value of the detection limit (1 µg/L). Given the parameters above, the UCL for TCE in the treated effluent at the 95 percent confidence level was calculated to be approximately 6 µg/L.

TCE concentrations in the treated water appeared normally distributed and were usable to calculate the UCL. However, the UCL for DCE at the 95 percent confidence internal was not calculated because of the lack of significant DCE concentrations in the system influent (mean concentration of 1.6 µg/L) and subsequent treatment of DCE in all sampling events to below the method detection limit (1 µg/L).

Primary Objective P2

Estimate the radius of circulation cell of the groundwater treatment system.

The radius of circulation cell of the UVB system was estimated using both direct and indirect methods. Because of the heterogeneous and anisotropic conditions and potential structural control of groundwater flow at Site 31, use of both methods was necessary to provide an accurate estimate of the radius of circulation cell. The radius of circulation cell was estimated directly by conducting a dye trace study, which consisted of injecting fluorescent dyes into the groundwater and subsequently monitoring the surrounding wells to document dye movement or lack thereof. The radius of circulation cell was further evaluated indirectly by (1) modeling the groundwater flow of the UVB system, (2) analyzing aquifer pump test data, and (3) assessing changes in target compound concentrations and the fluctuation of dissolved oxygen measured in samples from the surrounding groundwater monitoring wells. The results of both the direct and indirect methods used to estimate the UVB system's radius of circulation cell are discussed below. A summary of the results used to estimate the radius of circulation cell is provided at the end of the section.

Direct measurement of the radius of circulation cell - Dye Trace Study

The UVB system's radius of circulation cell was estimated by conducting a dye trace study that included the analysis of groundwater grab samples and passive receptors for fluorescein and rhodamine WT dyes in wells W1, W2,

Table 4-7. Treatment Sytem TCE and DCE Removal Summary

Trichloroethene (μg/L)

Well	Description	1st 5/93	2nd 6/93	3rd 7/93	4th 8/93	5th 9/93	6th 10/93	7th 11/93	8th 12/93	9th 1/94	10th 2/94	11th 3/94	12th 4/94
W-1	Intermediate System Well	57	60	220	35	31	30	22	34	31	14[a]	26	110
W-2	Shallow System Well	<1	<1	16	2.4	4	<1	<1	38*	2	1[a]	1.2	69*
Percent Reduction(1)		>98	>98	93	93	87	>97	>95	-12	94	93	95	37

1,1-Dichloroethene (μg/L)

Well	Description	1st 5/93	2nd 6/93	3rd 7/93	4th 8/93	5th 9/93	6th 10/93	7th 11/93	8th 12/93	9th 1/94	10th 2/94	11th 3/94	12th 4/94
W-1	Intermediate System Well	4	3	3	1.2	<1	<1	<1	<1	<1	<1[a]	<1	<1
W-2	Shallow System Well	<1	<1	<1	<1	<1	<1	<1	<1*	<1	<1[a]	<1	<1*
Percent Reduction(1)		>75	>67	>67	>17	NC	NC	NC	NC	NC	NC	NC	NC

Notes:

(1) Percent reduction = $[[C_{(W-1)} - C_{(W-2)}] / C_{(W-1)}] \times 100$; where $C_{(W-1)}$ = deep well concentration and $C_{(W-2)}$ = shallow well concentration.

[a] Temperature of samples at time of delivery was 9 °C

NC Not calculated

* Concentration potentially affected by system maintenance problems

PW1 through PW8, 31OW1, 31PW1, and 4MW14. The results of the dye study provided both qualitative and quantitative information on the system's circulation cell. The qualitative results demonstrate the interconnection between the UVB system and wells PW1, PW2, and PW3. The quantitative results provide information for calculation of aquifer characteristics, groundwater velocities, and radius of circulation cell of the UVB system. A discussion of the qualitative and quantitative results is provided below. A detailed presentation of the results and conclusions of the dye trace study is provided in the dye trace study report, Appendix A.

The results from the dye trace study show that a circulation cell developed between wells W1 and PW2 over a distance of about 40 feet (12.2 m). Hydraulic interconnection was demonstrated between wells W2 and PW3 over a distance of about 45 feet (13.7 m); however, the results do not indicate whether this interconnection is primarily due to UVB system circulation or to natural groundwater flow in the downgradient direction. The absence of dye in wells other than those installed in the downgradient direction (southeast) shows that the circulation cell developed less than 40 feet (12.2 m) in all other directions. Thus, the radius of circulation cell of the UVB circulation cell was shown to be at least 40 feet (12.2 m) in the downgradient (southeast) direction and less than 40 feet (12.2 m) in all other directions. The interpreted extent of the radius of circulation cell is depicted in Figure 4-13.

Indirect measurement of the radius of circulation cell - Modeling

Groundwater modeling is commonly applied to evaluate and design groundwater treatment systems. Most models are based on multiple assumptions of the hydrogeologic conditions at the site. However, these assumptions may not accurately depict subsurface conditions, especially at a complex anisotropic and heterogeneous sites such as Site 31. Although limited in accuracy, groundwater modeling of the UVB system may provide valuable information on the extent of the system's radius of circulation cell.

Since the UVB system creates a three-dimensional flow pattern with both vertical and horizontal flow components, the developer claims that standard numerical capture zone models do not apply to the UVB circulation cell. Although standard numerical models may not accurately describe the circulation zone of the UVB system, they will provide a conservative estimate of the maximum extent of the radius of circulation cell since the circulation cell of vertical wells will be significantly smaller than those associated with traditional capture wells of equivalent discharge (Ross et al. 1992).

The radius of circulation cell of the UVB system at Site 31 has been estimated by the developer using the equations and graphical solutions developed by Dr. Bruno Herrling (Herrling et al. 1991). These equations and graphical solutions have been developed over several years and are based on theoretical and empirical data generated during operation of the system at other sites. A detailed description of this model is presented in Appendix B. The assumptions and calculations for the estimation of the radius of circulation cell at Site 31 using the Herrling model were prepared by Weston and are documented in the draft treatment selection report for the UVB treatment system (Weston 1994). Based on the Herrling model, the UVB system circulation cell at Site 31 has a radial distance of approximately 83 feet (25.3 m) (Weston 1994). This distance, according to the developer, approximates the widest part of a roughly elliptical circulation cell.

The Herrling model indicates that the shape of the circulation cell depends on the anisotropy (horizontal (K_h) over vertical (K_v) conductivity: K_h/K_v) and the distance between injection and extraction intervals. These parameters also influence the amount of water recirculated by the treatment system. The magnitude of the ratio of K_h and K_v is directly proportional to the effective radius of the treatment system. Therefore, smaller ratio values result in a larger percentage of recycled water and, consequently, a smaller effective radius. Increasing the distance between the system influent and effluent will also increase the radius of circulation cell by reducing the amount of recirculation of flow between the extraction and injection zones. The radius of circulation cell depends on the distance between the upper and lower screens. The distance between the upper and lower screens is restricted by the thickness of the aquifer. Natural groundwater flow also influences the circulation pattern by skewing the cell in the direction of groundwater flow. According to the developer, the Herrling model has been validated based on empirical data gathered during implementation of the UVB system at other sites. The SITE demonstration did not assess other models nor did it evaluate the validity the Herrling model.

Based on data generated during operation of the UVB system at other sites, the developer claims that wells

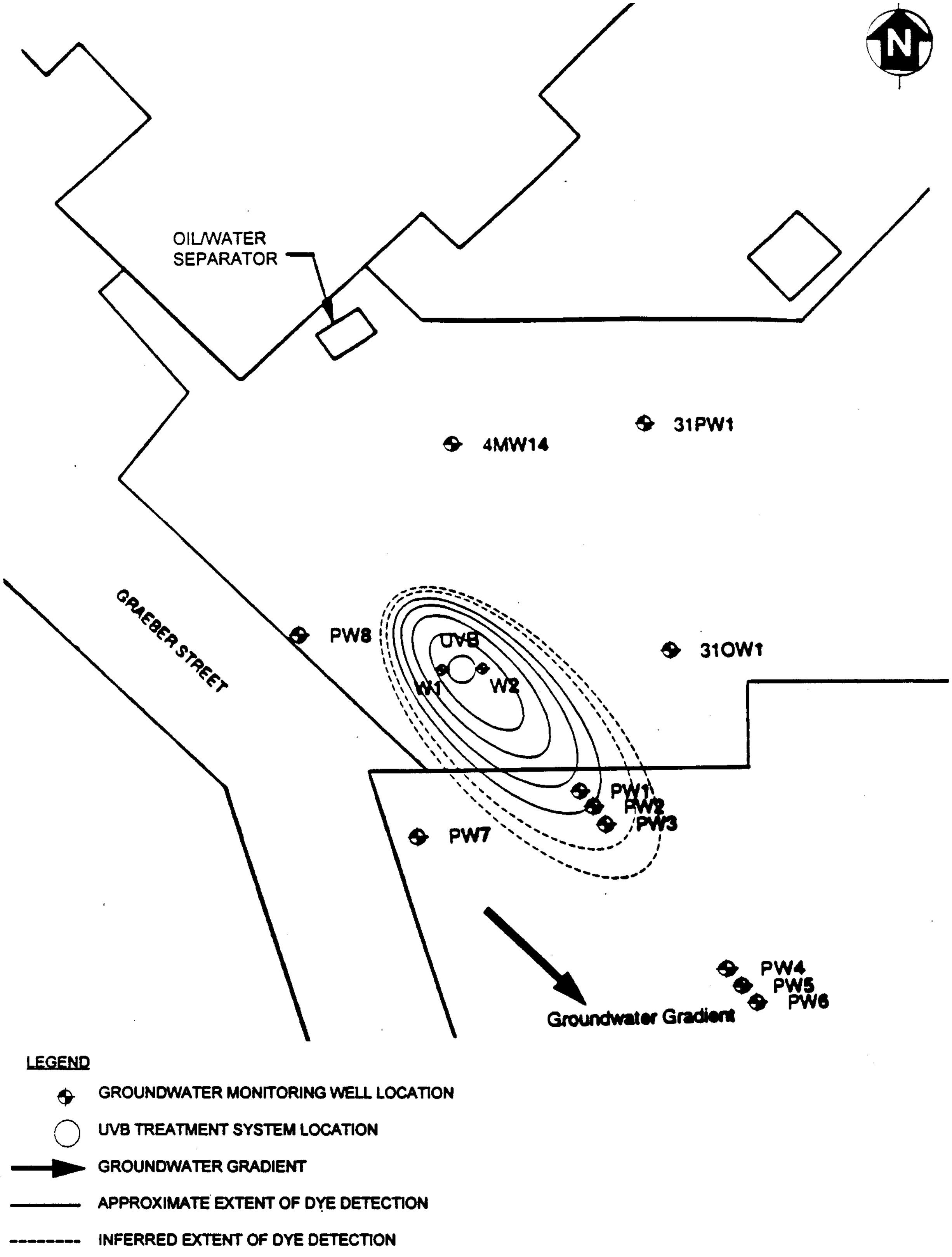


Figure 4-13. Estimated UVB radius of circulation cell plan view.

within the system's radius of circulation cell will exhibit an increase in contaminant concentration followed by a decrease. The increase in dissolved contaminant concentrations reportedly is related to the dynamics of the UVB system, which facilitates the partitioning of contaminants through dissolution, diffusion, and desorption. The increased partitioning of contaminants to the dissolved phase through these processes is driven by increased groundwater flow rates within the system's radius of circulation cell and by the increased concentration gradient established by the reinjection and recirculation of treated water within the aquifer. According to the developer, the subsequent decrease in contaminant concentration is due to the removal of contaminants by the UVB system. During the SITE demonstration, contaminant levels in both inner and outer well clusters showed an increase, followed by a decrease, in target compound concentrations. This may suggest, as interpreted by the developer's claims, that both well clusters are within the system's circulation cell and that the radius of circulation cell of the UVB system extends to at least 90 feet (27.4 m).

An alternate interpretation of these data suggests that peaks in target compound concentrations are the result of the downgradient migration of a high concentration contaminant plume originating from the vicinity of the UVB well. As discussed above, this increase in contaminant concentration may be caused by the dynamics of the UVB system. As the sources of increased contamination (adsorbed, absorbed, or liquid contaminants) are depleted as a result of increased diffusion and advection, contaminants are no longer readily available for partitioning to the dissolved phase. This will result in decreased contaminant levels in the groundwater as the slug migrates downgradient.

The results of the SITE demonstration indicate a correlation between contaminant peaks in the inner and outer well clusters and groundwater flow velocity and direction. Given the calculated maximum groundwater velocity from the dye trace study, the occurrence of peak concentrations matches the travel time for groundwater to move downgradient from the UVB system well to the inner and outer cluster of wells. Since the movement of contaminants may be controlled by ambient groundwater flow, the data may support the alternate interpretation and suggest that a slug of contamination originating at the UVB system is moving toward the inner and outer cluster of wells. This interpretation suggests that neither the inner nor the outer cluster of wells is in the radius of circulation cell of the UVB system and that the radius of circulation cell is limited (less than 40 feet [12.2 m]) since contaminant transport may be controlled by groundwater flow in the downgradient direction. The data further support this conclusion, as indicated by the convergence and stabilization of target compound concentrations shown in Figures 4-14 and 4-15. Samples from wells within the radius of circulation cell should continue to show decreasing concentrations of target compounds throughout the remediation process. A clear trend in the convergence and stabilization of contaminant concentration data has been documented; however, it is possible that contaminant concentrations within the radius of circulation cell may continue to decrease over time and that the system was not monitored over a long enough period to show the full effects of the UVB system on contaminant concentration.

An additional interpretation of the data is that the observed contaminant concentration peaks correspond to the growth of the UVB system's circulation cell. According to the developer, the three-dimensional circulation cell progressively builds on itself like an onion skin. The observed data could be interpreted to reflect the advancement of the circulation cell as it builds outward. As the circulation cell front moves past a monitoring well, a subsequent increase and decrease of dissolved contaminant concentration would be observed due to the dynamics of the UVB system as discussed above. This interpretation of the data would suggest that both inner and outer well clusters are within the UVB system's radius of circulation cell. This interpretation appears to be a possible explanation of the observed data, assuming that the circulation cell grows in the downgradient direction at the rate of groundwater flow. However, the developer claims the full circulation cell requires approximately 1 month to become established for most sites, which is much faster than the observed results would indicate. It is possible that hydrogeologic conditions at Site 31 have slowed establishment of the circulation cell; however, it appears unlikely that it would slow to coincide with groundwater flow velocity and direction.

<u>Indirect measurement of the radius of circulation cell</u> - <u>Dissolved Oxygen Distribution</u>

The developer claims that samples from monitoring wells within the system radius of circulation cell will show an increase in dissolved oxygen concentrations. The field measurement results for dissolved oxygen are presented in Figure 4-16. The dissolved oxygen data are considered suspect due to low and erratic readings of the instrument. In addition, several dissolved oxygen meters were used during the demonstration, which may attribute to the variability of the data. Although the data are of suspect quality and should be used with qualification, a consistent trend in the dissolved oxygen concentrations in wells W1 and W2 was observed that is considered meaningful since it occurred throughout the demonstration, regardless of instrumentation. This trend indicates that the system influent dissolved oxygen concentrations were continually higher than effluent dissolved oxygen levels. This trend appears to indicate that the UVB system is removing dissolved oxygen from the groundwater and appears to contradict the developer's claim of increased oxygenation within the UVB system's circulation cell. Due to the suspect quality of dissolved oxygen data and the lack of observable trends in dissolved oxygen in the surrounding monitoring wells, however, the UVB system's radius of circulation cell could not be meaningfully estimated based on variations in dissolved oxygen concentrations.

<u>Estimation of the radius of circulation cell</u>

Based on the dye tracer study, the radius of circulation cell was measured to be at least 40 feet (12.2 m) in the downgradient direction. Modeling of the radius of circulation cell by the developer further suggests that it may extend to a distance of approximately 83 feet (25.3 m). However, site-specific data from the pump test indicate that it is more likely less than 60 feet (18.3 m). The results of the dye tracer study appear to further suggest that the shape of the circulation cell is narrow and elongated in a downgradient direction (southeast). Target compound distribution suggests that the radius of circulation cell of the UVB system may be less than 40 feet (12.2 m) or greater than 90 feet (27.4 m) depending on the interpretation of the data. Due to the number of variables independent of effects of the UVB system on the aquifer that may influence target compound concentrations and dissolved oxygen measurements, these methods did not provide a reliable or conclusive estimate of the radius of circulation cell of the UVB system.

Primary Objective P3

Determine whether TCE and DCE concentrations are reduced in groundwater (both vertically and horizontally) within the radius of circulation cell of the UVB system over the course of the pilot study.

This objective was achieved by collecting and analyzing groundwater samples for TCE and DCE from wells W1, W2, and PW1 through PW6 prior to treatment system startup and at approximately 1-month intervals throughout the duration of the pilot study (12 months). Due to the lack of apparent target compound concentration trends attributable to operation of the UVB system in the deep wells, monitoring of wells PW3 and PW6 was discontinued after the first 6 months of the demonstration. TCE and DCE results from the demonstration are presented in Tables 4-8 and 4-9 and are plotted as a function of time in Figure 4-14 and Figure 4-15.

Based on the data used to estimate the radius of circulation cell at Site 31, the inner well cluster is likely to be within the estimated radius of circulation cell of the UVB system, while the outer well cluster was determined to likely lie outside the estimated radius of circulation cell. However, since the outer well cluster was installed downgradient of the UVB system, it is possible that the data collected from these wells may be representative of target compound concentrations in the outer portion of the radius of circulation cell. Review of the analytical results from the inner and outer well clusters revealed several trends in target compound concentrations.

Samples from shallow and intermediate inner cluster wells (PW1 and PW2) showed a sharp increase in TCE concentrations in the second monthly monitoring event. TCE concentrations peaked in samples from these wells in the third monthly monitoring event followed by a gradual decrease in concentrations from the fourth to the ninth monthly monitoring events. After the ninth monthly monitoring event, TCE concentrations in samples from the inner cluster shallow and intermediate wells appeared to converge and stabilize to below baseline levels for the remainder of the demonstration at an average concentration of approximately 293 µg/L. The intermediate zone well samples showed the greatest change, exhibiting a reduction in TCE concentration of approximately 64 percent from the baseline concentration of 750 µg/L while samples from the shallow zone well exhibited a reduction of 39 percent from baseline concentrations of 530 µg/L. During the demonstration, the magnitude of reduction of TCE appeared to correlate with the baseline concentrations; the higher the baseline concentration, the larger the increase and subsequent decrease in concentration observed.

Target compound concentrations in the shallow and intermediate outer cluster wells (PW4 and PW5) showed a

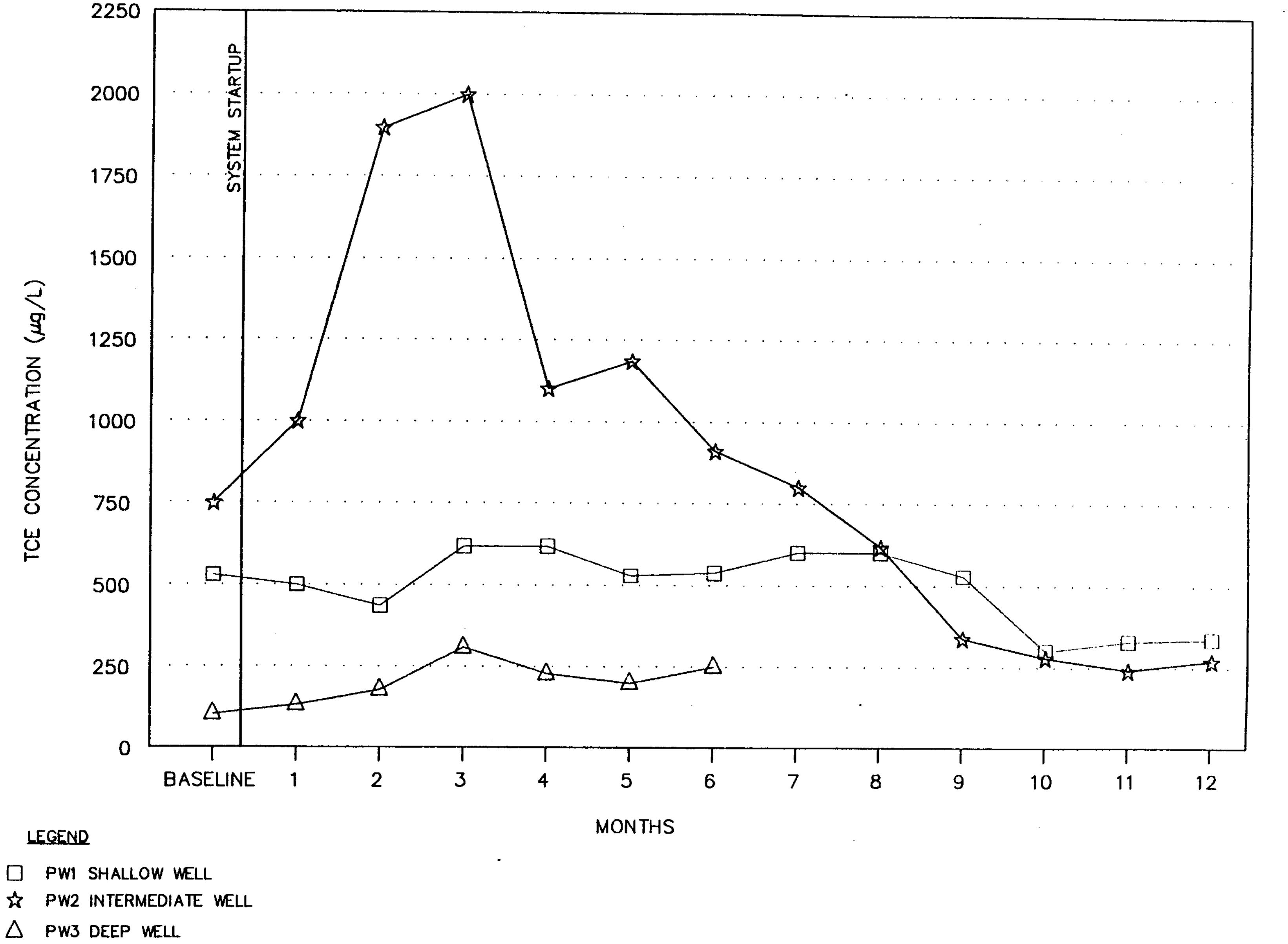


Figure 4-14. TCE concentration versus time.

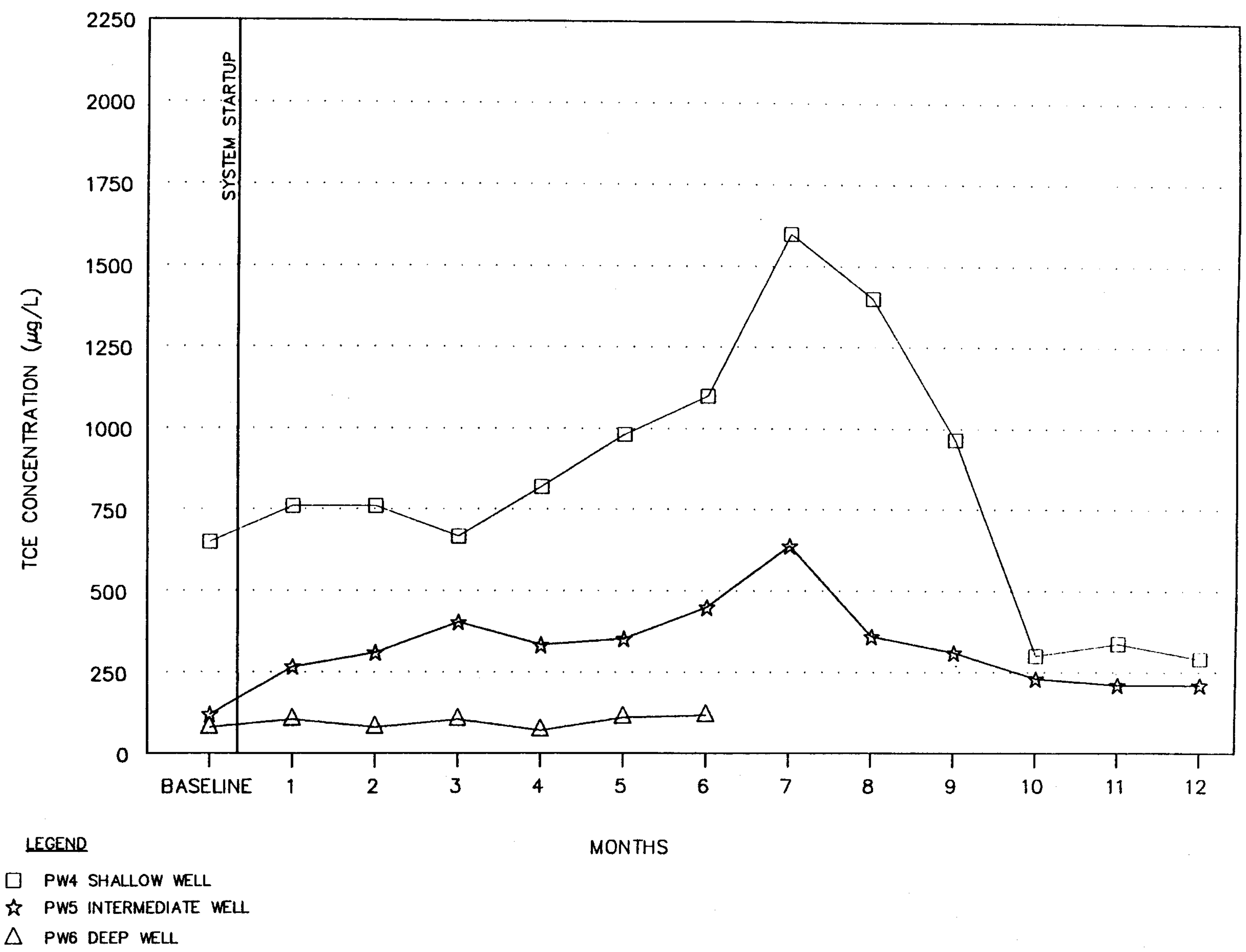


Figure 4-14. TCE concentration versus time (continued).

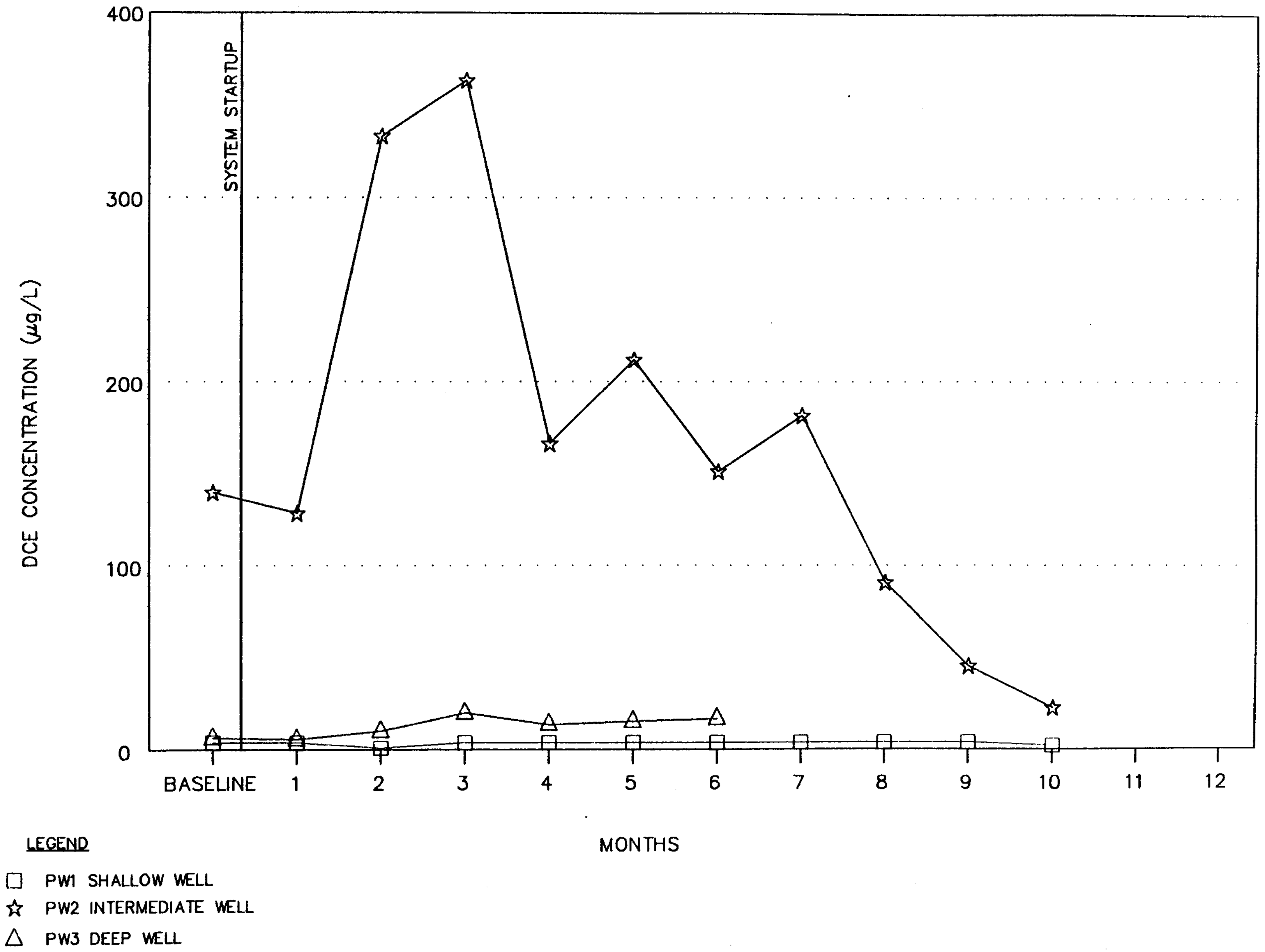


Figure 4-15. DCE concentration versus time.

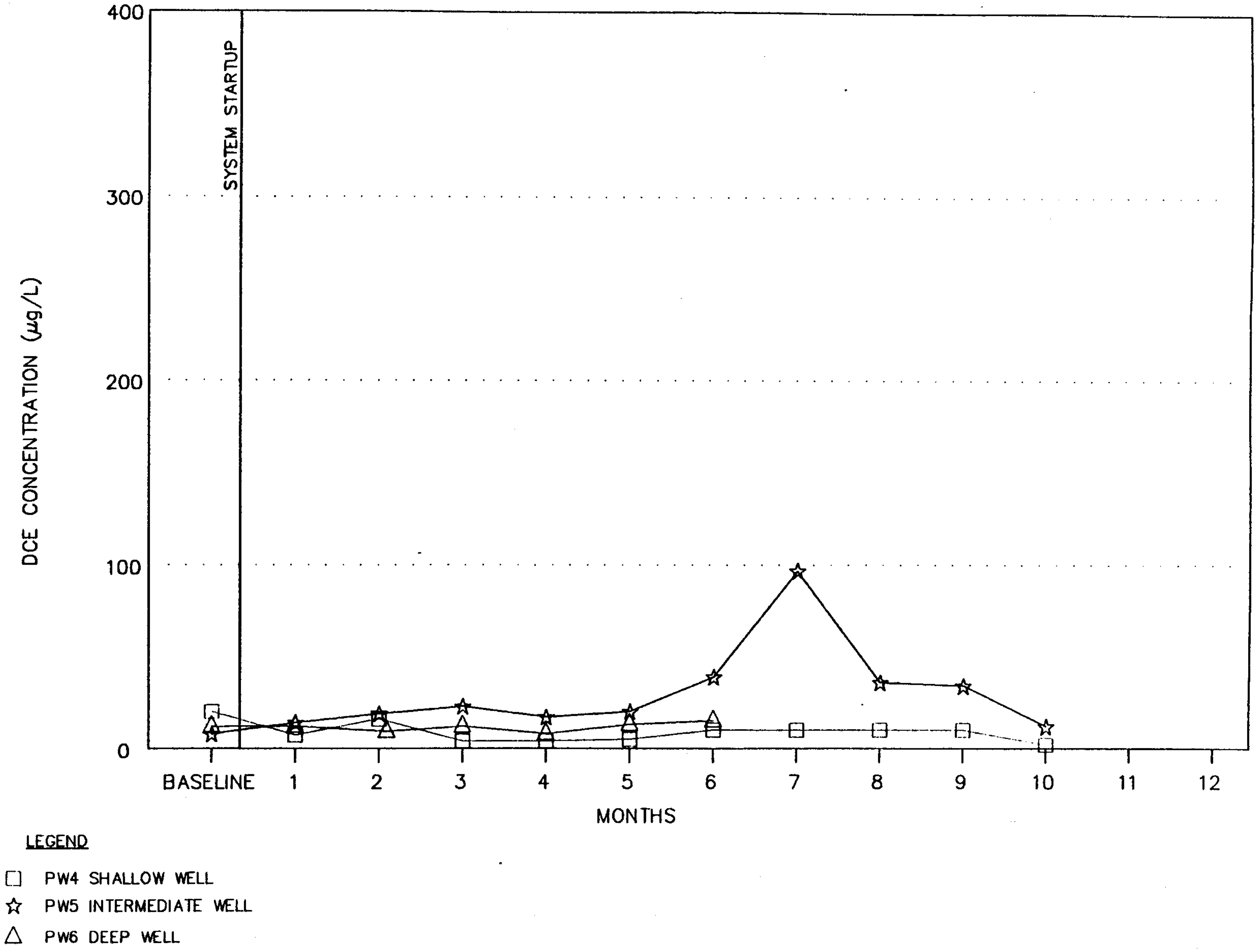


Figure 4-15. DCE concentration versus time (continued).

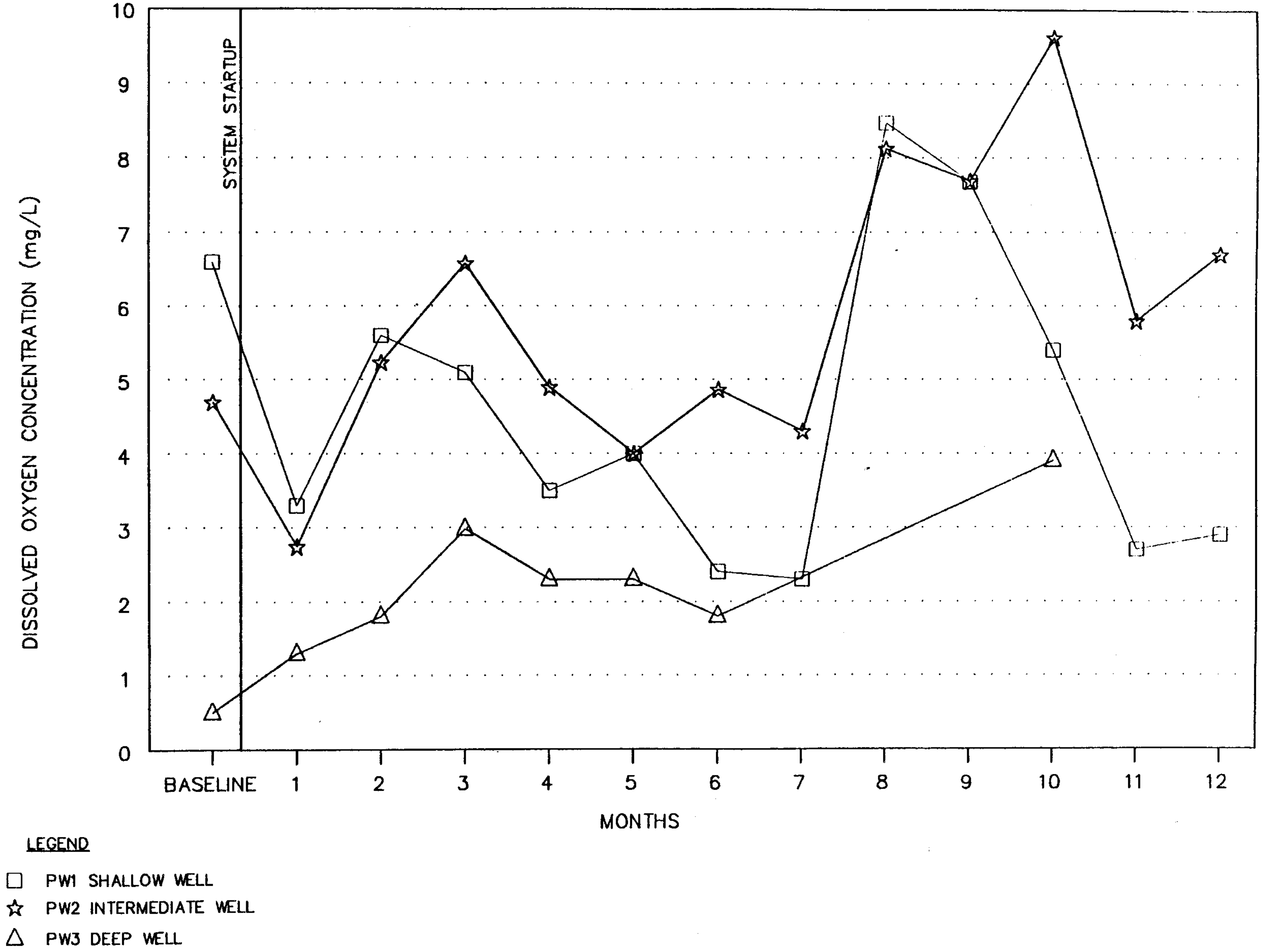


Figure 4-16. Dissolved oxygen concentration versus time.

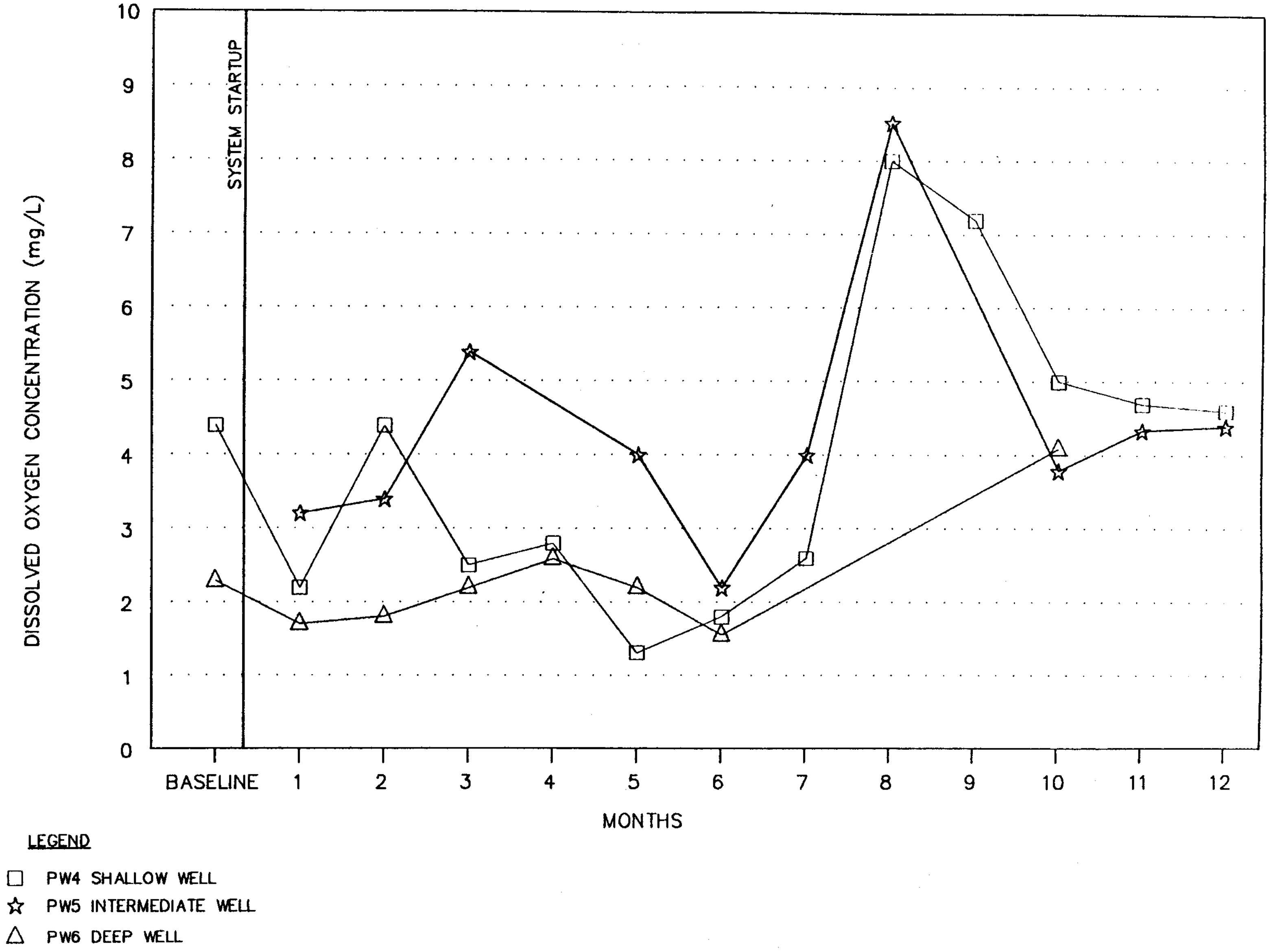


Figure 4-16. Dissolved oxygen concentration versus time (continued).

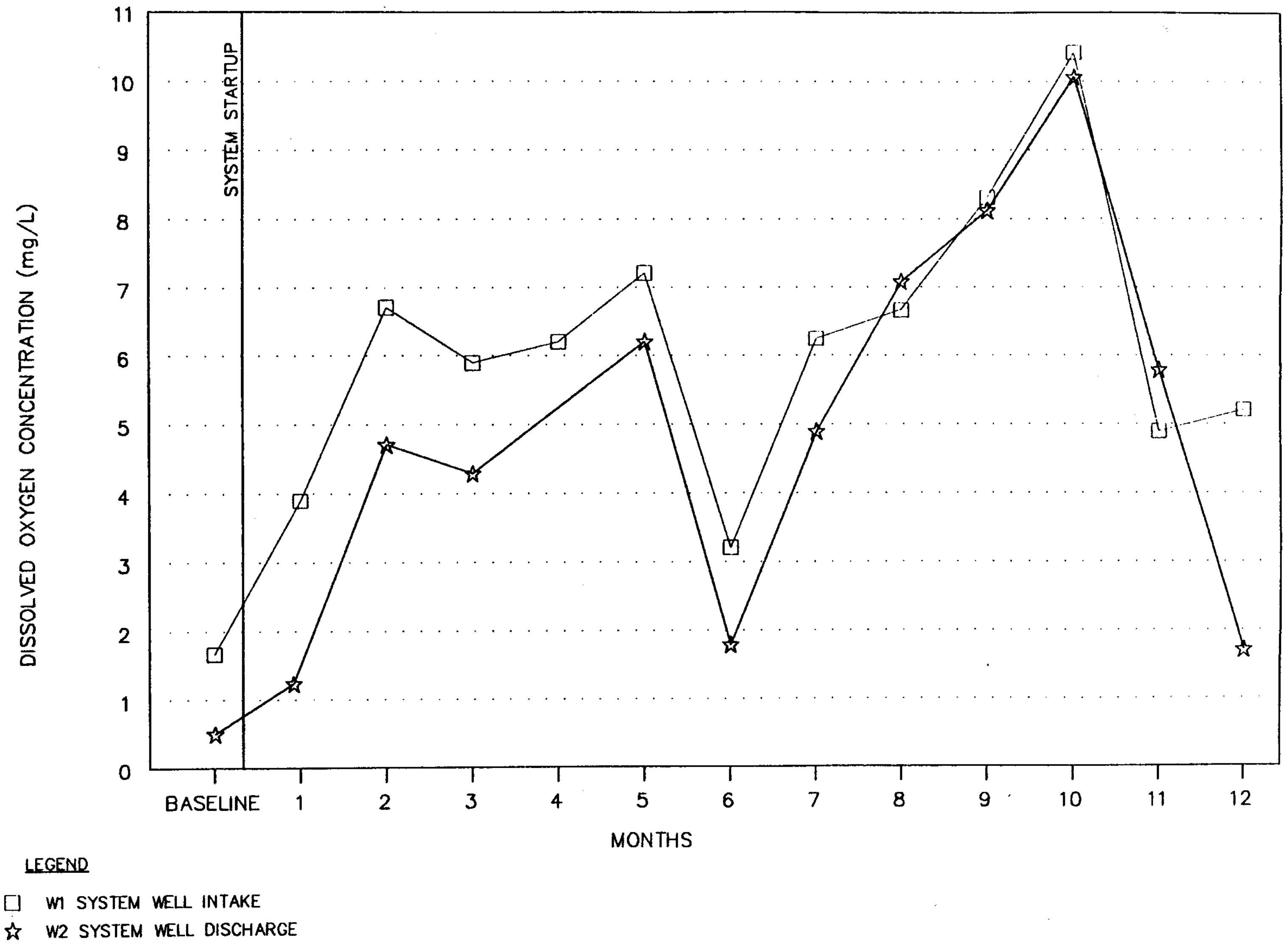


Figure 4-16. Dissolved oxygen concentration versus time (continued).

similar trend to that observed in the inner well cluster: increasing concentrations from baseline levels followed by a subsequent decrease in concentrations. TCE concentrations in the shallow and intermediate outer cluster wells showed a gradual increase in concentrations in the fourth monthly monitoring event and peaked in the seventh monthly monitoring event. After peaking, TCE concentrations decreased sharply until the tenth monthly monitoring event and appeared to converge and stabilize at a concentration of approximately 263 µg/L for the remainder of the demonstration. Although concentrations in outer cluster shallow well samples were reduced to below baseline levels, the intermediate well samples continued to exhibit elevated target compound concentrations above baseline levels. The shallow well samples exhibited a reduction in TCE concentrations of 55 percent from the baseline concentration of 650 µg/L, while the intermediate well samples showed an increase of 43 percent from the baseline concentration of 120 µg/L. These changes suggest that TCE concentrations are homogenizing vertically in the outer cluster shallow and intermediate zone wells.

DCE concentrations in samples from the shallow and intermediate inner and outer cluster wells exhibited a similar trend to TCE concentrations except that DCE, for the most part, was not detected above the method detection limit in the inner and outer cluster shallow well samples. DCE concentrations in the inner cluster intermediate zone well samples appeared to converge and stabilize at an average concentration of approximately 19 µg/L, a reduction of about 86 percent from the baseline concentration of 140 µg/L. DCE concentrations in the outer cluster intermediate well samples appeared to converge and stabilize at a concentration of 15 µg/L, an increase 88 percent from the baseline concentration of 8 µg/L.

TCE and DCE concentrations in the deep inner and outer cluster wells (PW3 and PW6) were not monitored for the full duration of the demonstration. Based on the TCE and DCE results in samples from these wells, no trends in the target compound data were observed in samples from well PW6; however, well PW3 indicated a peaking of target compound concentrations in the third monthly monitoring event. This trend appears similar to other wells in the inner cluster, except that target compound concentrations remained above background levels. Target compound concentrations in samples from well PW6 also remained above baseline levels at the termination of monitoring. Due to the limited duration of monitoring of the deep wells, the reduction of target compound concentrations in this zone could not be definitively assessed.

The system influent well (W1) also showed a similar trend to that observed in the inner well cluster: increasing concentrations from the baseline levels, peaking in the third monthly monitoring event, followed by a subsequent decrease in concentrations. After peaking, concentrations of target compounds decreased and stabilized with the exception of the twelfth monthly monitoring event, which exhibited a sharp increase in concentration. Over the course of the demonstration, the average TCE concentration in samples from well W1 was 56 µg/L. This concentration is significantly less than the average concentration measured in samples from well PW2, the closest well screened at a similar depth, of 950 µg/L. Influent concentrations are controlled by the amount of mixing and the contaminant concentration of treated and untreated groundwater. The relatively low influent target compound concentrations as compared to contaminant levels in surrounding wells suggest that influent concentrations were strongly controlled by recirculation of the system effluent. Comparison of TCE concentrations in wells W1 and PW2 samples suggest that on average as much as 94 percent dilution in the system influent has occurred (assuming that concentrations in PW2 are representative of TCE concentrations in the intermediate zone of the aquifer).

Based on the results presented in Tables 4-8 and 4-9, target compound concentrations in the shallow and intermediate zone wells were reduced both vertically and horizontally except in the intermediate outer cluster well, which showed an increase in concentrations. Concentrations of target compounds in these zones appeared to homogenize as indicated by the convergence and stabilization of target compound concentrations. Variations in target compound concentrations were noted in the deep aquifer zone; however, there was no evidence of reduction or homogenization of the concentrations. This may be due to the limited duration of monitoring of these wells.

4.3.2.2 Secondary Objectives

Secondary objectives provided additional information that is useful, but not critical, for the evaluation of the UVB system. Seven secondary objectives were selected for the SITE demonstration of the UVB system. The results of each secondary objective are discussed in the following subsections.

Table 4-8. Aquifer TCE Concentration Summary

Well	Description	Trichloroethene Concentration (μg/L) Baseline 4/93	1st 5/93	2nd 6/93	3rd 7/93	4th 8/93	5th 9/93	6th 10/93	7th 11/93	8th 12/93	9th 1/94	10th 2/94	11th 3/94	12th 4/94
W1	Intermediate System Well	22	57	60	220	35	31	30	22	34	31	14[e]	26	110
W2	Shallow System Well	1	<1	<1	16	2.4	4	<1	<1	38	2	1[e]	1.2	69
PW1	Shallow Inner Cluster Well	530[a]	500	440	620	608	530	540[a,b]	600	600	530	300[e]	330	340[c]
PW2	Intermediate Inner Cluster Well	750	1,000	1,900	2,000	1,100	1,200	910	800	620	340	280[e]	240	270
PW3	Deep Inner Cluster Well	100	130	180	310	230	200	250	NA	NA	NA	NA[e]	NA	NA
PW4	Shallow Outer Cluster Well	650	760	760	680	818	980	1,100	1,600	1,400	970	300[e]	340	290[d]
PW5	Intermediate Outer Cluster Well	120	270	310	390	330	350	450	640	360	310	230[e]	210	210
PW6	Deep Outer Cluster Well	110	130	110	130	92	140	150	NA	NA	NA	NA[e]	NA	NA

Notes:

[a] Relative percent difference is outside specified QC limits
[b] Matrix spike recovery is outside specified QC limits
[c] Matrix spike duplicate sample exceeded holding time
[d] Dilution and matrix spike/matrix spike duplicate samples exceeded holding time
[e] Temperature of samples at time of delivery was 9 °C

Table 4-9. Aquifer DCE Concentration Summary

Well	Description						1,1-Dichloroethene Concentration (μg/L)							
		Baseline 4/93	1st 5/93	2nd 6/93	3rd 7/93	4th 8/93	5th 9/93	6th 10/93	7th 11/93	8th 12/93	9th 1/94	10th 2/94	11th 3/94	12th 4/94
W1	Intermediate System Well	<1	4	3	3	1.2	<1	<1	<1	<1	<1	<1[d]	<1	<1
W2	Shallow System Well	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1[d]	<1	<1
PW1	Shallow Inner Cluster Well	<4	<4	<1	<4	<4	<4	<4	<4[b,c]	<4	<4	<2[d]	<2	<2
PW2	Intermediate Inner Cluster Well	140	130	330	360	170	210	150	180	93	44	23[d]	16	18
PW3	Deep Inner Cluster Well	6	5	10	20	14	15	17	NA	NA	NA	NA[d]	NA	NA
PW4	Shallow Outer Cluster Well	20	7	16	<4	<4	<5	<10[a]	<10	<10	<10	<2[b,d]	<2	<2
PW5	Intermediate Outer Cluster Well	8	14	19	23	17	20	39	97	36	34	12[d]	15	17
PW6	Deep Outer Cluster Well	12	12	10	12	7.9	13	15	NA	NA	NA	NA[d]	NA	NA

Notes:

[a] Relative percent difference is outside QC criteria
[b] Matrix spike recovery is outside QC criteria
[c] Reanalysis exceeded holding time
[d] Temperature of samples at time of delivery was 9 °C

Secondary Objective S1

Assess homogenization of the groundwater within the zone of influence.

Aquifer homogenization was assessed by examining the levels and relative distribution of TCE and DCE within the zone of influence as quantified from baseline and monthly sampling and analysis activities. The results of baseline sampling indicated that TCE and DCE stratification was present in the shallow and intermediate zones of the aquifer. Following the peaks in target compound concentration in the third and seventh monthly monitoring events, a converging and stabilizing trend was observed in both the inner and outer cluster of wells in the shallow and intermediate zones as depicted on Figures 15 and 16. The stabilization of target compound concentration in the inner and outer cluster wells (approximately 293 µg/L in the inner cluster and 263 µg/L in the outer cluster) suggests that aquifer homogenization has occurred. The target compound concentrations were not homogenized in the deep wells during the monitoring period. The TCE concentration in the inner deep well ranged from 130 to 310 µg/L, and the TCE concentration in the outer deep well ranged from 92 to 150 µg/L. The variable range in the inner deep well suggests that concentrations were effected in a similar manner as the intermediate and shallow inner wells. The TCE concentration in the outer deep well was more stable throughout the monitoring period, which suggests that the UVB system effects were minimal for that well.

Secondary Objective S2

Document selected aquifer geochemical characteristics that may be affected by oxygenation and recirculation of treated groundwater.

This objective was achieved by analyzing groundwater from monitoring wells W1, W2, and PW1 through PW6 for dissolved oxygen, dissolved organic carbon, specific conductance, alkalinity, oxidation/reduction potential, pH, total dissolved solids, and dissolved metals. The results documenting the selected geochemical characteristics are presented in the TER (PRC 1995). These results were used to assess the potential oxidation of mineral surfaces and precipitation of dissolved metals; changes in dissolved organic carbon; and the presence of dissolved salts caused by increased oxygen in the groundwater.

Groundwater conductivity values measured in the field appeared to decrease with depth and appeared correlate with the analytical results for TDS. Additionally, pH measurements showed a trend of increasing with depth. These observed trends do not appear related to UVB system operation. Total dissolved solid results exhibited a general increasing trend from the baseline monitoring event, which may indicate a steady increase in groundwater flow in the aquifer because of UVB system operation. No clear trends were apparent from the alkalinity or dissolved organic carbon results. The temperature data is relatively consistent and apparently not affected by the UVB system. No clear trends were apparent from the field measurements of dissolved oxygen, temperature, or redox potential. However, the presence of an iron-orange colloidal/precipitant substance observed in well W2 after the second monitoring event suggests changes in conditions favorable to precipitation of metals. This condition appeared to be localized adjacent to the UVB system. Iron-orange precipitant suggests that iron is precipitating out of solution due to either and increase in pH or increase in redox potential.

Groundwater analytical results for dissolved metals exhibited no clear trends in the data to indicate the precipitation of dissolved metals. The data are variable for barium, chromium, cobalt, iron, nickel, potassium, selenium, vanadium, and zinc. Fluctuations in some of these metal concentrations may be related to well construction activities or other sources of contamination. The data for boron, calcium, magnesium, manganese, molybdenum, silicon, and sodium were relatively constant and do not indicate effects from the UVB system. The data for aluminum, antimony, arsenic, beryllium, cadmium, copper, lead, mercury, silver, tin, and thallium contained too many results below the method detection limit to allow a meaningful evaluation of the data.

Secondary Objective S3

Determine whether the treatment system induces a vacuum in the vadose zone that suggests vapor transport.

This objective was achieved by periodically reading the vacuum gauge and collecting soil gas samples for analysis of VOCs in the vapor monitoring well, V1. Readings were taken before treatment system startup and at monthly intervals for 6 months. The results of the vacuum measurements and soil gas samples are presented in Table 4-10.

Table 4-10. Soil/Vapor Well Summary

Description	Units	Baseline	1st 5/93	2nd 6/93	3rd 7/93	4th 8/93	5th 9/93	6th 10/93
				Soil/Vapor Well V-1				
Volatile Organic Compounds								
Trichloroethene	$\text{ppb}_{v/v}$	32,500	40,900	27,600	33,600	50,400	51,800	48,900
1,1-Dichloroethene	$\text{ppb}_{v/v}$	<50.0	<50.0	<50.0	<50.0	<100	<100	<100
Tetrachloroethene	$\text{ppb}_{v/v}$	984	1,340	954	1,130	1,225	1,212	1,170
1,1,1-Trichloroethane	$\text{ppb}_{v/v}$	<50.0	<50.0	<50.0	394	107	<100	<100
Chloroform	$\text{ppb}_{v/v}$	66	91	73.0	92.0	<100	<100	<100
Benzene	$\text{ppb}_{v/v}$	<50.0	<50.0	<50.0	58.0	<100	<100	<100
Fixed Gases								
Carbon Dioxide	$\%_{v/v}$	4.60	5.72	5.58	5.88	6.68	6.87	6.67
Oxygen	$\%_{v/v}$	14.1	13.5	13.9	14.4	13.4	13.3	14.2
Nitrogen	$\%_{v/v}$	78.6	78.4	87.3	82.2	81.0	84.2	77.6
Vacuum	in Hg	<1	<1	<1	<1	<1	<1	<1

Notes:

$\text{ppb}_{v/v}$	Parts per billion on a volume to volume basis
$\%_{v/v}$	Percent on a volume to volume basis

No indications of the presence of a vacuum in the vapor monitoring well were observed during the demonstration. Results from vapor monitoring well V1 indicate that VOCs were present in the vadose zone. TCE was present in the soil vapor in all monitoring events, while DCE was not detected in any monitoring event. The concentration of TCE was consistently high with TCE concentrations averaging 40,800 parts per billion on a volume to volume basis. The consistent and high concentration of TCE in the vadose zone suggests that significant volatilization of TCE has occurred in the subsurface. The constant VOC concentrations and the lack of observed indications of a vacuum suggest that the UVB system has little or no effect on volatile organic compounds in the vadose zone in the vicinity of well V1.

Although the developer claims that the UVB system has applications to cleanups of both groundwater and soil gas, the system installed at Site 31 was designed to remove VOCs from the groundwater only. The critical design feature that allows the cleanup of both the groundwater and soil gas in the vadose zone is the placement of the upper effluent screen. The top of the upper screen of the UVB well installed at Site 31 was located immediately above the groundwater table, thus inhibiting the removal of a significant volume of soil gas from the vadose zone. Given the design features of the UVB well installed at Site 31, the UVB well did not significantly affect transport of contaminants in the vadose zone as indicated by the results from the SITE demonstration.

Secondary Objective S4

Estimate the capital and operating costs of constructing a single treatment unit to remediate groundwater contaminated with TCE and DCE.

This objective was achieved by using capital cost information provided by the developer, measuring electricity consumption, and estimating labor requirements. A detailed estimate of the capital and operating costs of constructing a single treatment unit to remediate groundwater contaminated with TCE and DCE is presented in Section 3.0. Cost have been assigned to one of 12 categories applicable to typical cleanup activities at Superfund and RCRA sites and include fixed and annual variable costs. One-time capital costs for a single treatment unit were estimated to be $180,000; variable annual operation and maintenance costs for the first year were estimated to be $72,000, and $42,000 for subsequent years. Based on these estimates, the total cost for operating a single UVB system for 1 year was calculated to be $260,000. Since the time required to remediate an aquifer is site-specific, costs have been estimated for operation of a UVB system over a range of time for comparison purposes. Therefore, the cost to operate a single UVB system was calculated to be $340,000 for 3 years, $440,000 for 5 years, and $710,000 for 10 years. Additionally, the costs for treatment per 1,000 gallons (3,785 L) of groundwater were estimated to be $260 for 1 year, $110 for 3 years, $88 for 5 years, and $71 for 10 years. The costs for treatment per 1,000 liters (264.2 gallons) of groundwater were estimated to be $69 for 1 year, $29 for 3 years, $23 for 5 years, and $19 for 10 years. The cost of treatment per 1,000 gallons (3,785 L) refers to the amount of groundwater pumped through the system. Potential users of the treatment technology should be aware that typically 60 to 90 percent of the water pumped through the system is recirculated water.

Secondary Objective S5

Document pre- and post-treatment off-gas volatile organic contaminant levels.

This objective was achieved by periodically collecting process air samples from locations A1, A2, and A3 (Figure 4-9) and chemically analyzing the samples for VOCs. Sample point A1 is the ambient air sampling port, A2 is the groundwater stripped sampling port, and A3 is the post air-treated sampling port. The results of the air analysis is presented in Table 4-11.

The results from air monitoring of the UVB treatment system indicated that low concentrations of TCE are being removed from the groundwater. TCE concentrations detected in the pre-air treatment samples correlate to trends observed in target compounds concentrations in the inner cluster monitoring wells: increasing concentration from the baseline event to the third monthly monitoring event with a subsequent decrease in concentrations. The post-air treatment samples from the fifth and sixth monitoring events exhibited higher concentrations than did pre-air treatment samples. This apparent contradiction may be attributed to analytical variability when the sample concentration is at or near the method detection limit.

Secondary Objective S6

Document system operating parameters.

Table 4-11. UVB Process Air TCE Removal Summary

Sample	Description	Trichloroethene $ppb_{v/v}$ 1st 5/93	 2nd 6/93	 3rd 7/93	 4th 8/93	 5th 9/93	 6th 10/93
A-1	Ambient Air	<1.00	1.08	1.40	1.56	2.92	2.02
A-2	Pre-Air Treatment	4.32	3.26	6.76	6.02	1.82	<1.00
A-3	Post-Air Treatment	<1.00	<1.00	2.16	1.80	2.08	2.60
Percent Reduction[1]		76.9	69.3	68.0	70.1	-14	-160

Notes:

(1) Percent reduction = $[[C_{(A-2)} - C_{(A-3)}] / C_{(A-2)}] \times 100$; where $C_{(A-2)}$ = pre-air treatment and $C_{(A-3)}$ = post-air treatment
" Hg Inches of mercury
$ppb_{v/v}$ Parts per billion on a volume to volume basis

The following process data were provided by Weston:

- Relative humidity measured at the fresh air well intake, before the blower, after the blower, between primary and secondary carbon canisters, and from the carbon adsorption unit exhaust stack
- Temperature measured at the fresh air well intake, before the blower, after the blower, between primary and secondary carbon canisters, and from the carbon adsorption unit exhaust stack
- Linear flow velocity measured at the fresh air well intake, before the blower, after the blower, between primary and secondary carbon canisters, and from the carbon adsorption unit exhaust stack
- Pressure measured at the fresh air well intake, after the blower, between primary and secondary carbon canisters, and from the carbon adsorption unit exhaust stack

A summary of the system operating parameters results is shown in Table 4-12.

Secondary Objective S7

Evaluate the presence of aerobic biological activity in the saturated and vadose zone.

This objective was achieved by periodically collecting and analyzing air samples from the vadose zone well (V1) and process air stream locations A1 and A2, and by collecting and analyzing groundwater samples from wells W1 and W2 and PW1 through PW6. Air samples were analyzed for fixed gas: nitrogen, oxygen, and carbon dioxide, and groundwater samples were analyzed for dissolved oxygen, temperature, and dissolved organic carbon. The fixed gas results are summarized Table 4-13.

Based on discussions with EPA staff who have extensive experience in assessing the presence of subsurface bioactivity, it was deemed acceptable to assume that the source of increased CO_2 levels, combined with a reduction in O_2 levels, in the soil gas was due to increased bioactivity in the soil, groundwater, or both. Carbon dioxide concentrations measured in the vapor monitoring well, V1, indicate that carbon dioxide has increased by more than 2 percent since baseline monitoring. Several fluctuations in O_2 level were observed; however, there was

Table 4-12. System Operating Parameters

Sample Location	Temperature (°C)		Relative Humidity (%)		Vacuum (psia)		Air Flow (scfm)		Velocity (fpm)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Air Intake	18.4	5.5 - 37.1	75	19 - 100	14.15	13.70 - 14.57	157	13 - 568	2905	220 - 9999
V1	20.4	10.9 - 27.2	84	44 - 100	13.96	13.70 - 14.12	199	64 - 279	2301	752 - 3217
V2	28.4	17.4 - 47.0	66	20 - 100	14.96	14.46 - 15.03	235	76 - 847	2639	877 - 9287
V3	25.7	13.5 - 40.2	72	31 - 100	14.81	14.71 - 14.84	225	63 - 782	2522	691 - 8519
V4	23.4	10.8 - 35.0	70	38 - 100	14.71	14.70 - 14.72	253	74 - 898	2833	802 - 9999

Notes:

psia	Pounds per square inch absolute = 703.1 kilograms per square meter
scfm	Standard cubic feet per minute
fpm	Feet per minute = 0.5080 centimeters per second

no evidence of a downward trend of these concentrations. The minor changes in CO_2 and O_2 measured suggest that bioactivity in the soil and groundwater was not significantly enhanced by operation of the UVB system.

Additionally, CO_2 concentrations measured at the UVB system's intake and after the blower reveal minor fluctuations of relative CO_2 concentration. These results also suggest that bioactivity due to increased dissolved oxygen levels in the groundwater was not significantly enhanced due to operation of the UVB system.

4.3.3 Data Quality

This section summarizes the data quality for groundwater and air samples collected and analyzed during the UVB SITE demonstration. This data quality assessment was conducted to incorporate the analytical data validation results and the field data quality QC results, evaluate the impact of all QC measures on the overall data quality, and remove all unusable values from the investigation data set. The results of this assessment were used to produce the known, defensible information employed to define the investigation findings and draw conclusions.

A validation review of the analytical data for groundwater and air samples collected during the UVB SITE demonstration was conducted to ensure that all laboratory data generated and processed are scientifically valid, defensible, and comparable. Data were validated using both field QC samples and laboratory QC analyses. The field samples included equipment blanks, field blanks, and trip blanks. Laboratory samples included method blanks, surrogate recoveries, initial and continuing calibration, matrix spike/matrix spike duplicate, and samples/sample duplicate. Results from these samples were used to calculate the precision, accuracy, representativeness, comparability, and completeness of the data.

Summaries of analytical quality control data are provided in the TER (PRC 1995) to facilitate validation and analysis of the data. In general, all data quality indicators met the QA objectives, specified in the Quality Assurance Project Plan (QAPP) (PRC 1993) for the UVB SITE demonstration, indicating that general data quality was good and that the sample data are usable as reported. All data quality indicators associated with the baseline and first, seventh, eighth, ninth, eleventh, and twelfth monthly sampling events met all acceptance criteria specified in the QAPP (PRC 1993). Data quality outliers from the other sampling events are identified and discussed in Table 4-14. None of the outliers discussed in Table 4-14 were determined to inhibit the usefulness of the demonstration data in evaluating the demonstration project objectives.

Table 4-13. System Operating Parameters

Sample	Analysis	Percent (volume/volume)						
		Baseline	1st 5/93	2nd 6/93	3rd 7/93	4th 8/93	5th 9/93	6th 10/93
A1	Oxygen	NA	19.0	21.7	20.0	20.6	21.1	20.6
	Nitrogen	NA	78.4	86.8	80.4	79.8	75.1	75.7
	Carbon Dioxide	NA	0.048	0.056	0.056	0.050	0.041	0.048
A2	Oxygen	NA	19.6	19.4	19.5	21.1	22.1	20.0
	Nitrogen	NA	77.0	86.3	78.8	78.9	82.0	77.1
	Carbon Dioxide	NA	0.049	0.047	0.063	0.068	0.042	0.040
A3	Oxygen	NA	18.2	19.1	20.2	21.7	20.5	20.3
	Nitrogen	NA	77.0	86.0	79.6	80.9	76.0	75.6
	Carbon Dioxide	NA	0.063	0.049	0.054	0.060	0.041	0.042
V1	Oxygen	14.1	13.5	13.9	14.4	13.4	13.3	14.2
	Nitrogen	78.6	78.4	87.3	82.2	81.0	84.2	77.6
	Carbon Dioxide	4.60	5.72	5.58	5.88	6.68	6.87	6.67

Table 4-14. Data Quality Outliers

SAMPLING EVENT	DATA QUALITY OUTLIER	IMPACT ON DATA QUALITY
Critical Parameters		
2	The matrix spike recoveries for TCE in the PW4 sample were outside the acceptance limits because of inappropriately low spike levels.	Data are considered usable as reported because the blank spike and blank spike duplicate results were acceptable along with all other TCE quality control (QC) indicators
6	The matrix spike sample from PW1 had a slightly high TCE recovery (140 percent).	The reported TCE concentration in sample PW1 may be biased slightly high, and should be considered a maximum value. The result has been flagged as usable with qualification.
10	Because of a shipping error, samples were delivered to the laboratory 2 days after sampling and the temperature of the cooler was 9 degrees °C.	Although the analytical method requires that samples be shipped at 4 °C (± 2 °C), the slightly higher than specified temperature probably did not significantly affect the reported sample concentrations. The affected data have been appropriately flagged.
	Matrix spike recoveries for DCE were reported as 132 percent; slightly higher than the acceptable range of 70 to 130 percent.	The reported DCE concentrations may be biased slightly high. The affected data have been appropriately flagged.
Non-Critical Parameters		
2	RPDs for analysis of selenium, iron, and cobalt in W2; boron in PW1; and chromium and molybdenum in PW4 are outside QC criteria; however, this is not unusual when contaminants are present at or near detection limits. The poor duplicate precision for boron in sample PW1 was probably the result of random boron contamination due to digestion in borosilicate glassware.	The data associated with these RPDs have been flagged and are usable with qualification.

Table 4-14. Data Quality Outliers (continued)

SAMPLING EVENT	DATA QUALITY OUTLIER	IMPACT ON DATA QUALITY
Non-Critical Parameters		
2	Low concentrations of benzene were detected in samples from the system deep well and in the daily field blank and trip blank, which suggests that benzene may be a field contaminant.	No impact; benzene is not a contaminant of interest.
3	RPD for analysis of several metals in samples PW1-SD and PW4-SD are outside quality control criteria; however, this is not unusual when contaminants are present at or near detection limits.	The data associated with these RPDs have been flagge and are usable with qualification.
	Silicon was detected in the preparation blank and is believed to be a laboratory contaminant from the borosilicate glassware used for digestion.	The impact to most of the silicon results is minimal beca silicon concentrations are significantly higher than that f in the preparation blank; therefore, the data should be considered usable as reported.
4	RPD of several metals in samples W2 and PW4 are outside quality control criteria; however, this is not unusual when contaminants are present at or near detection limits.	The data associated with these samples have been flag and are usable with qualification.
	Spike sample recovery results for several metals in samples PW1 and W2 are also outside quality control criteria. Spike recoveries for these elements were within 1 percent of the lower acceptance level and do not indicate a significant impact on data quality.	The data associated with the low spiked recoveries have been flagged and are usable with qualification.
5	RPDs of several metals in samples W2, PW1, and PW4 are outside quality control criteria; however, this is not unusual when contaminants are present at or near detection limits.	The data associated with these samples have been flag and are usable with qualification.
	Iron and zinc in sample PW4 exhibited high RPDs not associated with near-detection limit concentrations.	The results have been flagged and are usable as conservative high concentration limits.

Table 4-14. Data Quality Outliers (continued)

SAMPLING EVENT	DATA QUALITY OUTLIER	IMPACT ON DATA QUALITY
6	General chemistry analysis for TDS exceeded the specified holding time by 6 days.	The TDS results have been flagged as exceeding holding times and are usable with qualification.
	Matrix spike recoveries for metals were within the acceptance criteria, with the exception of calcium and silicon in sample PW4 and calcium in sample W2.	Noncompliant recoveries were less than 10 percent outside the acceptance limit, so there is believed to be minimal impact to the data.
	Relative percent differences of several metals in sample PW1 are outside QC criteria; however, this is not unusual when contaminants are present at or near detection limits.	The data associated with these samples have been flagged and are usable for qualification.
	TDS and dissolved organic carbon (DOC) analyses exceeded holding times by 1 and 5 days, respectively.	The TDS and DOC results have been flagged as exceeding holding times and are usable with qualification.
	DOC matrix spike recovery in sample W2 and RPD in sample PW1 were outside the acceptance limit.	Results from these samples have been flagged and are usable with qualification.

Additionally, QC control charts of precision and accuracy for VOCs, as determined by MS recoveries and MS/MSD RPDs, were prepared to assess potential trends in analytical system bias. These charts did not reveal noticeable trends in system bias, suggesting that trends noted from demonstration data are due to contaminant concentration changes in the environmental media sampled.

4.3.4 Conclusions

This section presents the conclusions of the UVB SITE demonstration at March AFB, California. The conclusion are presented in relation to each objective. For the SITE demonstration of the UVB technology, three primary and seven secondary objectives were selected. The conclusions for each objective are summarized below:

Primary Objectives:

P1 *Determine the concentration to which the UVB technology reduces TCE and DCE in groundwater discharged from the treatment system.*

The UVB effectively removed target compounds from the groundwater. The UVB system reduced TCE in the groundwater discharged from the treatment system to below 5 µg/L in nine out of the 10 monthly monitoring events and on average by greater than 94 percent during events in which the system operated without apparent maintenance problems. The mean concentration of TCE in the water discharged from the system was approximately 3 µg/L; however, the upper confidence limit for TCE in the treated groundwater at the 95 percent confidence level was calculated to approximately 6 µg/L.

The UVB system reduced DCE to less than 1 µg/l in groundwater discharged from the treatment system; however, the system's ability to remove DCE cannot be meaningfully estimated due to the low (less than 4 µg/l) influent concentration of DCE.

P2 *Estimate the radius of circulation cell of the groundwater treatment system.*

The radius of circulation cell was evaluated directly and indirectly by conducting a dye tracer study, modeling of groundwater flow, analyzing site-specific aquifer pump data and assessing changes in target compound concentrations and dissolved oxygen levels. The results indicate that the radius of circulation cell is at least 40 feet (12.2 m) in the downgradient direction and may extend as far as 90 feet (27.4 m) depending on the interpretation of data.

Based on the dye tracer study, the radius of circulation cell was measured to be at least 40 feet (12.2 m) in the downgradient direction. Modeling of the radius of circulation cell by the developer further suggests that it may extend to a distance of approximately 83 feet (25.3 m). The results of the dye tracer study appear to further suggest that the shape of the circulation cell is narrow and elongated in a downgradient direction (southeast). An aquifer test performed on well 31OW1 indicated that a pumping well's radius of circulation cell is 60 feet.

Target compound distribution suggests that the radius of circulation cell of the UVB system may be less than 40 feet (12.2 m) or greater than 90 feet (27.4 m) depending on the interpretation of the data. Due to the number of variables independent of effects of the UVB system on the aquifer that may influence target compound concentrations and dissolved oxygen measurements, these methods did not provide a reliable or conclusive estimate of the radius of circulation cell of the UVB system.

P3 *Determine whether TCE and DCE concentrations have been reduced in groundwater (both vertically and horizontally) within the radius of circulation cell of the UVB system over the course of the 12-month pilot study.*

Based on the demonstration results, target compound concentrations in the shallow and intermediate zone wells were reduced both vertically and horizontally except in the intermediate outer cluster well, where samples showed an increase in concentrations. TCE concentrations in samples from these wells were reduced by an average of approximately 52 percent. Concentrations of target compounds in these zones appeared to homogenize, as indicated by the convergence and stabilization of target compound concentrations. Variations in target compound concentrations were noted in the deep aquifer zone; however, there was no evidence of reduction or homogenization of the concentrations. This may be due to the limited duration of monitoring of these wells.

S1 *Assess homogenization of the groundwater within the zone of influence.*

A convergence and stabilization of TCE and DCE concentrations was observed in the shallow and intermediate zones of the aquifer, which suggests homogenization of contaminant concentrations in the groundwater.

S2 *Document selected aquifer geochemical characteristics that may be affected by oxygenation and recirculation of treated groundwater.*

No clear trends were observed to indicate significant precipitation of dissolved metals, changes in dissolved organic carbon, or the presence of dissolved salts caused by the increase in oxygen in groundwater.

S3 *Determine whether the treatment system induces a vacuum in the vadose zone that suggests vapor transport.*

Although the developer claims that the UVB system has applications to cleanup of both groundwater and soil gas, the system installed at Site 31 was designed to remove halogenated hydrocarbons from groundwater only. The VOC concentrations and vacuum measurements in the vapor monitoring well indicate that transport of contaminants was not significantly affected by operation of the UVB system as currently designed. Changes in system design and operating parameters may, however, lead to significant transport of contaminants in the vadose zone.

S4 *Estimate the capital and operating costs of constructing a single treatment unit to remediate groundwater contaminated with TCE and DCE.*

One-time capital costs for a single treatment unit were estimated to be $180,000; variable annual operation and maintenance costs for the first year were estimated to be $72,000, and $42,000 for subsequent years. Based on these estimates, the total cost for operating a single UVB system for 1 year was calculated to be $260,000. Since the time required to remediate an aquifer is site-specific, costs have been estimated for operation of a UVB system over a range of time for comparison purposes. Therefore, the cost to operate a single UVB system was calculated to be $340,000 for 3 years, $440,000 for 5 years, and $710,000 for 10 years. Additionally, the costs for treatment per 1,000 gallons (3,785 L) of groundwater were estimated to be $260 for 1 year, $110 for 3 years, $88 for 5 years, and $71 for 10 years. The costs for treatment per 1,000 liters (264.2 gallons) of groundwater were estimated to be $69 for 1 year, $29 for 3 years, $23 for 5 years, and $19 for 10 years. The cost of treatment per 1,000 gallons (3,785 L) refers to the amount of groundwater pumped through the system. Potential users of the treatment technology should be aware that typically 60 to 90 percent of the water pumped through the system is recirculated water.

S5 *Document pre- and post-treatment off-gas volatile organic contaminant levels.*

The results from air monitoring of the UVB treatment system indicated that low concentrations of TCE were removed from the groundwater. TCE concentrations reduced by the UVB system correlate to trends observed in target compound concentrations in the inner cluster monitoring wells (that is, increasing concentrations from the baseline event to the third monthly monitoring event with a subsequent decrease in concentrations).

S6 *Document system operating parameters.*

The temperature of the internal monitoring ports ranged from 18.5 to 44.7 ^{o}C; the relative humidity ranged from 27 to 100 percent; the vacuum ranged from 13.81 to 15.03 pounds per square inch absolute (9,709.8 to 10,567.6 kilograms per square meter); the air flow ranged from 100 to 898 standard cubic feet per minute (47.2 to 423.9 liters per second); and the velocity ranged from 1,109 to 9,999 feet per minute (563.4 to 5,079.5 cm/s). According to the developer, the water flow rate was maintained at 22 gpm (5 cubic meters per hour or 83.3 liters per minute).

S7 *Evaluate the presence of aerobic biological activity in the saturated and vadose zones.*

Bioactivity in the soil and groundwater did not appear to be significantly enhanced by UVB system operation.

Section 5
UVB Technology Status

The UVB technology is a process patented by IEG mbH, D-72770, Reutlingen, Germany. The UVB is an in situ system for remediation of contaminated aquifers, especially those contaminated with volatile and semivolatile organic compounds (SVOCs) or heavy metals (Weston 1992). According to the developer, the UVB technology combines chemical, physical, and biological processes for the treatment of adsorbed, dissolved, and free phase VOC and SVOCs. Since its inception in 1986, the UVB technology has been applied at some 80 sites in Europe. Additionally, the developer claims that the technology has achieved regulatory acceptance in the U.S. at both the state and federal levels. A UVB system was first installed at a U.S. site in September 1992; currently, 22 UVB systems are operating in eight states.

The developer has provided four select case studies that document operation of the UVB system at sites in the U.S. and Germany. The case studies provided by the developer are present in Appendix B. Two of the cases are from sites in Germany and involve the remediation of chlorinated hydrocarbons (TCE, 1,1,1-trichloroethane, and dichloromethane) in groundwater. The two cases from the U.S. document the remediation of groundwater contaminated with benzene, toluene, ethylbenzene, and xylene at an underground storage tank site in Troutman, North Carolina, and Weston's interpretation of the data collected at March AFB, California independent of the SITE demonstration from May 4, 1993 to December 2, 1994.

Section 6
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