United States
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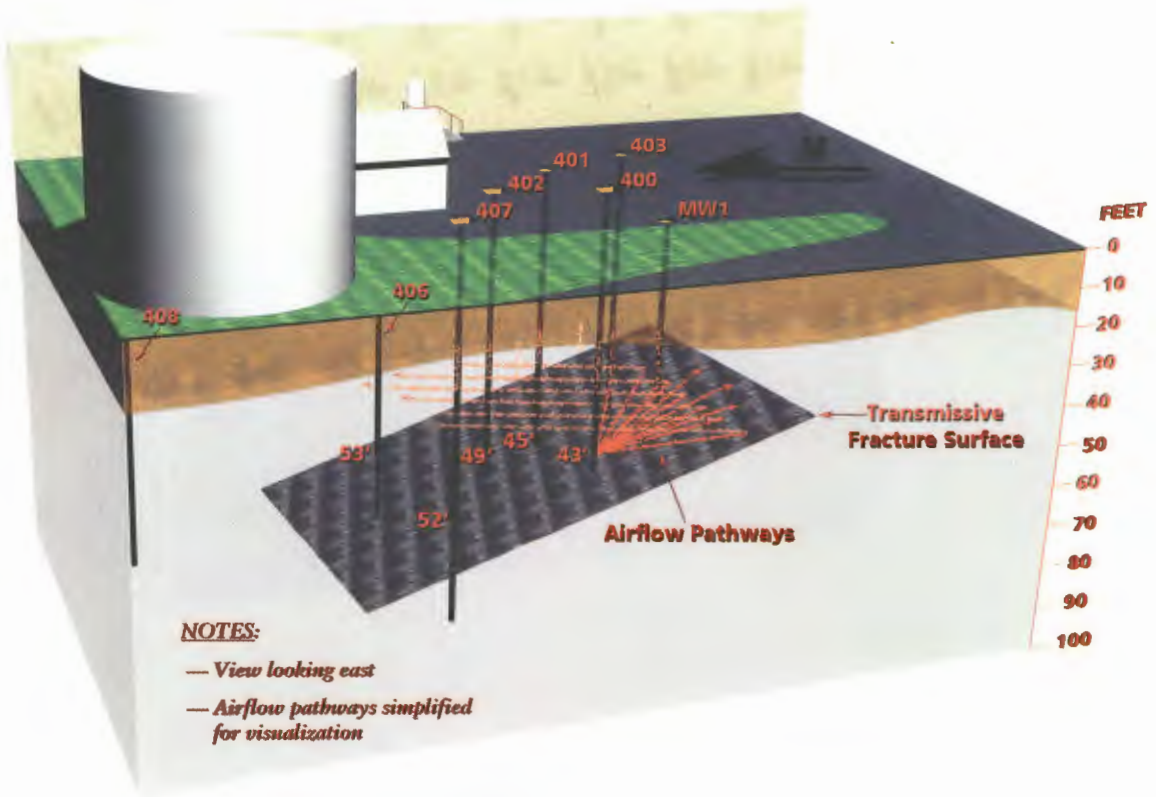
Earth Tech Inc.'s Enhanced In-Situ Bioremediation Process

Innovative Technology Evaluation Report



SITE
SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

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Earth Tech Inc.'s Enhanced In-Situ Bioremediation Process

Innovative Technology Evaluation Report

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

Notice

The information in this document has been funded by the U.S. Environmental Protection Agency (EPA) under Contract Nos. 68-C5-0036 and 68-COO-179 to Science Applications International Corporation (SAIC).It has been subjected to the Agency's peer and administrative reviews and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

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

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

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.

Hugh W. McKinnon, Director
National Risk Management Research Laboratory

Abstract

This report summarizes the findings of an evaluation of an enhanced in-situ bioremediation technology developed by the U.S. Department of Energy (DOE) at the Westinghouse Savannah River Plant site in Aiken, South Carolina and implemented by Earth Tech Inc. at the ITT Industries Night Vision (ITTNV) Division plant in Roanoke, Virginia. This evaluation was conducted between March 1998 and August 1999 under the U.S. Environmental Protection Agency Superfund Innovative Technology Evaluation (SITE) Program. The area focused on during the demonstration was immediately downgradient of a solvent release area. At this locality, several volatile organic compounds (VOCs) had been measured at concentrations above regulatory levels in both upper and lower fractured zones of the underlying shallow bedrock. Four specific VOC compounds were designated as "critical parameters" for evaluating the technology: chloroethane (CA), 1,1-dichloroethane (1,1-DCA), cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride (VC).

The primary objective of the demonstration was to evaluate Earth Tech's claim that there would be a minimum 75% reduction with a 0.1 level of significance (LOS) in the groundwater concentrations for each of the four critical analytes, following six months of treatment. The demonstration results indicated, that on an overall average, concentrations levels of all four critical VOCs were measured to be reduced from baseline to final events as follows: CA (35%); 1,1-DCA (80%); cis-1,2-DCE (97%); and VC (96%). The lower confidence limit (LCL) and upper confidence limit (UCL) were also calculated for percent contaminant reduction. The LCL can be thought of as the most conservative estimate of reduction. The UCL can be thought of as the best possible reduction the technology may have achieved. The 90% confidence intervals (LCL-UCL) for the four compounds were: CA (4 - 54%); 1,1-DCA (71 - 86%); cis-1,2-DCE (95 - 98%); and VC (92 - 98%). Therefore, cis-1,2-DCE and VC achieved the 75% reduction goal with a 0.1 LOS; 1,1-DCA was just under this goal at 71% LCL and CA reduction was barely significant at 4% LCL.

Acetone and isopropanol (IPA), the two non-chlorinated compounds analyzed for during the demonstration, were detected at significant levels in just one of the wells sampled. On an overall average, concentrations of acetone and IPA were measured to be reduced from baseline to final events in this upper zone well by 94% and 96%, respectively. The 90% confidence intervals (LCL-UCL) for acetone and IPA were 78-96% and 86-98%, respectively.

The lower fractured zone of the bedrock aquifer was the focus of the demonstration groundwater sampling. However, samples were also collected from an upper fractured zone at a reduced frequency. The data were useful for evaluating treatment of VOCs contained in fractures above the injection depth. The results indicated the technology had a greater impact in the upper fractured zone, where higher initial concentrations of the same VOCs were reduced by larger percentages.

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Abbreviations and Acronyms

ABT	Acoustic borehole televiewer
AODC	Acridine orange direct counts
AQCR	Air Quality Control Regions
AQMD	Air Quality Management District
ARARs	Applicable or Relevant and Appropriate Requirements
bls	Below land surface
CA	Chloroethane
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CO_2	Carbon dioxide
CH_4	Methane
cis-1,2-DCE	cis-1,2-Dichloroethene
CFR	Code of Federal Regulations
CSCT	Consortium for Site Characterization Technologies
cfu	Colony forming units
cfm	Cubic feet per minute
CWA	Clean Water Act
1,1-DCA	1,1-Dichloroethane
1,1-DCE	1,1-Dichloroethene
DNA	Deoxyribonucleic acid (RE: gene detection and approximation)
DNAPL	Dense non-aqueous phase liquid
DO	Dissolved oxygen
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
Earth Tech	Earth Tech, Inc. of Concord, MA
FS	Feasibility study
ft^2	Square feet
ft^3	Cubic feet
G&A	General and administrative
HSWA	Hazardous and Solid Waste Amendments
HP	Horsepower
ITER	Innovative Technology Evaluation Report
ITTNV	ITT Industries Night Vision
IW	Injection well
IM	Interim measure
IPA	Isopropanol, or Isopropyl alcohol
kW-hr	Kilowatt hours
LCSs	Laboratory control samples

Abbreviations and Acronyms (Cont'd)

LCL	Lower confidence limit
LEL	Lower explosive limit
LNAPL	Light non-aqueous phase liquid
LOS	Level of significance
MCLs	Maximum contaminant levels
MCLGs	Maximum contaminant level goals
mg/l	Milligrams per liter
MW	Monitoring well
MPN	Most probable number (RE: total culturable methanotrophs)
NAAQS	National Ambient Air Quality Standards
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPDES	National Pollutant Discharge Elimination System
NRMRL	National Risk Management Research Laboratory (EPA)
NSCEP	National Service Center for Environmental Publications
ND	Non-detectable, or not detected at or above the method detection limit
NPDWS	National primary drinking water standards
NTU	Normal turbidity unit
OSHA	Occupational Safety and Health Administration
ORD	Office of Research and Development (EPA)
OSWER	Office of Solid Waste and Emergency Response (EPA)
OSC	On-scene coordinator
ORP	Oxidation/reduction potential
O_2	Oxygen
PLFA	Phospholipid fatty acids
ppbv	Parts per billion by volume
ppmv	Parts per million by volume
PPE	Personal protective equipment
PQL	Practical quantitation limit
PLC	Programmable logic controller
psi	Pounds per square inch
PVC	Polyvinyl chloride
POTW	Publicly owned treatment works
QA/QC	Quality assurance/Quality control
QAPP	Quality assurance project plan
RFI	RCRA Facility Investigation
RI/FS	Remedial Investigation / Feasibility Study
RPM	Remedial project manager
RCRA	Resource Conservation and Recovery Act
RSK	R.S. Kerr Environmental Research Laboratory
SARA	Superfund Amendments and Reauthorization Act
SAIC	Science Applications International Corporation
scfh	Standard cubic feet per hour
SDWA	Safe Drinking Water Act
SM	Standard method
SG	Soil gas

Abbreviations and Acronyms (Cont'd)

SVE	Soil vapor extraction
SOP	Standard operating procedure
SW-846	Test methods for evaluating solid waste, physical/chemical methods
SWDA	Solid Waste Disposal Act
SITE	Superfund Innovative Technology Evaluation
S.U.	Standard units
3-D	Three dimensional
TR	Trace
1,1,1-TCA	1,1,1-Trichloroethane
TCE	Trichloroethene
TEP	Triethyl phosphate
TER	Technology Evaluation Report
TCH	Total culturable heterotrophs
TO-14	Total organics - method 14 (gas analysis)
TOC	Total organic carbon
µg/l	Micrograms per liter
µS/cm	Micro siemens per centimeter
UCL	Upper confidence level
USEPA	United States Environmental Protection Agency
VC	Vinyl chloride
VADEQ	Virginia Department of Environmental Management
VOCs	Volatile organic compounds

Acknowledgments

This report was prepared under the direction of Mr. Vicente Gallardo, the EPA Technical Project Manager for this SITE demonstration at the National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio. EPA review of this report was conducted by Mr. Gallardo, Dr. Ronald Lewis (retired), Dr. Tamara Marsh, and Dr. Ronald Herrmann. Ms. Deborah Goldblum of the EPA Region 3 is the project coordinator overseeing the RCRA Facility Investigation and Corrective Measures being performed at the ITT Night Vision site. Dr. Brian Looney of the Savannah River Technology Center provided helpful insight into the PHOSter™ technology capabilities.

The demonstration required the combined services of several individuals from Earth Tech Inc., ITTNV Industries, and Science Applications International Corporation (SAIC). Ms. Rosann Kryczkowski served as on-site project coordinator for ITTNV and Mr. Gregory Carter served as the on-site project coordinator for Earth Tech, Inc. Ms. Barbara Lemos served as the Earth Tech project manager. Dr. Scott Beckman of SAIC served as the SITE work assignment manager for the implementation of demonstration field activities and completion of all associated reports. The cooperation and efforts of these organizations and individuals are gratefully acknowledged.

This report was prepared by Joseph Tillman, Rita Stasik and Dan Patel of SAIC. Ms. Stasik also served as the SAIC Quality Assurance (QA) Coordinator for data review and validation. Andrew Matuson served as SAIC field manager. Joseph Evans (the SAIC QA Manager) internally reviewed the report. Field sampling and data acquisition was conducted by Mike Bolen, Andrew Matuson, Christina Paniccia, and Joseph Tillman of SAIC; and John Huisman of Matrix Environmental.

Executive Summary

This report summarizes the findings of an evaluation of the Earth Tech Enhanced In-Situ Bioremediation treatment process. The process was evaluated for its effectiveness for treating groundwater contaminated with elevated levels of volatile organic compounds, including chlorinated compounds. The study was conducted at the ITT Industries Night Vision (ITTNV) Division plant in Roanoke, Virginia. This evaluation was conducted under the U.S. EPA Superfund Innovative Technology Evaluation (SITE) Program.

Overview of Site Demonstration

The Enhanced In-Situ Bioremediation Process is a biostimulation technology developed by the U.S. Department of Energy (DOE) at the Westinghouse Savannah River Plant site in Aiken, South Carolina. DOE, who refers to their technology as PHOSter™, has licensed the process to Earth Tech, Inc. of Concord, MA (Earth Tech). Earth Tech is utilizing the process to deliver a gaseous phase mixture of air, nutrients, and methane to contaminated groundwater in fractured bedrock. These enhancements are delivered to groundwater via an injection well to stimulate and accelerate the growth of existing microbial populations, especially methanotrophs. This type of aerobic bacteria has the ability to metabolize methane and produce enzymes capable of degrading chlorinated solvents and their degradation products to non-hazardous constituents.

A pilot-scale technology demonstration of the enhanced in-situ bioremediation system was conducted from March 1998 to August 1999 at the ITTNV Division plant in Roanoke, Virginia. The ITTNV facility is an active manufacturing plant that produces night vision devices and related night vision products for both government and commercial customers. Groundwater contamination has been detected at several areas at the facility. The area focused on during the demonstration is immediately downgradient of a solvent release source area. At this locality, several volatile organic compounds (VOCs) have been measured at concentrations above regulatory levels in both an upper and lower fractured zone in the underlying shallow bedrock. Four specific VOC compounds were designated as "critical parameters" for evaluating the technology: chloroethane (CA); 1,1-dichloroethane (1,1-DCA); cis-1,2-dichloroethene (cis-1,2-DCE); and vinyl chloride (VC).

The pilot treatment system that Earth Tech installed within the area of contamination consisted of eleven monitoring points, including an injection well, four monitoring wells located within the anticipated radius of influence, two monitoring wells located outside of the anticipated radius of influence, and four soil vapor monitoring points. The four wells located in the anticipated radius of influence were designated as "critical wells", based on their location and the temporal and spatial variability for the four critical parameters measured within those wells. Collecting samples daily from these wells represented a conservative basis for ensuring sample independence based upon the groundwater gradient. During the demonstration, one of the monitoring wells was temporarily converted to a second injection well.

Over the duration of the demonstration combinations of air, nutrients, and methane were injected into the lower fractured zone approximately 43 feet below land surface. Although emphasis was placed on evaluating treatment effectiveness at the injection depth, groundwater in both the upper and lower fractured zones of the bedrock was sampled and analyzed by the SITE Program.

Conclusions from this SITE Demonstration

A number of conclusions may be drawn from the evaluation of the Earth Tech Enhanced Bioremediation process, based on extensive analytical data supplemented by field measurements. These include the following:

- On an overall average, concentrations levels of all four critical VOCs were measured to be reduced from baseline to final events as follows: CA (35%); 1,1-DCA (80%); cis-1,2-DCE (97%); and VC (96%). The 90% lower and upper confidence limit intervals (LCL-UCL) for the four compounds were: CA (4-54%); 1,1-DCA (71-86%); cis-1,2-DCE (95-98%); and VC (92-98%). Therefore, cis-1,2-DCE and VC achieved the 75% reduction goal with a 0.1 LOS; 1,1-DCA was just under this goal at 71% LCL and CA reduction was barely significant at 4% LCL.
- The results of the microbial analyses were highly variable, but did suggest that the treatment system was able to stimulate the indigenous microorganisms to degrade the target contaminants. The phospholipid fatty acid (PLFA) data, which provides a biomass measurement for the entire microbial community, was the most consistent of all the microbial data collected. PLFA increased by an order of magnitude following the first intermediate sampling event and then remained fairly constant throughout the remainder of the demonstration.
- Comparison of upper and lower zone data suggests that treatment effectiveness may have been greater in the upper zone. In the immediate area of treatment, the summed total for the four critical VOCs in upper zone wells was reduced on average by 91% from baseline to final sampling events, as compared to 39% for lower zone wells. This is believed to be due to the upward airflow pathways from the injection point at 43 feet below land surface up to shallower depths.
- Microbial data seemed to lend support to the above conclusion. For example, total culturable heterotroph (TCH) and PLFA concentrations in the upper fractured zone attained significantly higher levels than in the lower fractured zone. There was also significant concentration drops in total culturable methanotrophs as measured by the most probable number technique (MPN), TCH, and PLFA in the lower fractured zone six days after the injection system was turned off. However, there was not a significant drop concentration drop for those three parameters in the upper fractured zone. TCH and MPN levels actually increased in the upper zone six days after the injection system was turned off. The methane, oxygen, and nutrients could have migrated upward from the injection point to the upper fractured zone, thus lowering microbial levels in the lower zone and enriching the levels in the upper zone. Therefore, a depletion of methanotrophs could have occurred in the lower fractured zone at the same time a population increase occurred in the upper fractured zone.
- Acetone and IPA, the two non-chlorinated compounds analyzed for during the demonstration, were detected at significant levels in just one of the wells sampled. On an overall average, concentrations of acetone and IPA were measured to be reduced from baseline to final events in this upper zone well by 94% and 96%, respectively. The 90% confidence intervals (LCL-UCL) for acetone and IPA were 76- 98% - and 86-98%, respectively.
- There is evidence to suggests that anomalously high baseline groundwater elevations may have diluted VOC baseline concentrations, thus biasing low observed VOC reductions. The highest concentrations of critical VOCs were measured during a December 1997 pre-demonstration sampling event, during a period of depressed water levels. However, just three months later during the demonstration baseline sampling event heavy precipitation had caused the raising of the groundwater to peak elevations. An inverse relationship between groundwater levels and contaminant concentrations prior to start of treatment suggests that the critical VOC concentrations were diluted by more than half (i.e., from ~ 11,600 µg/l to ~ 5,500 µg/l). Thus, the VOC reductions reported for the demonstration may be conservative.

- VOC soil gas data were variable and inconclusive with respect to determining VOC sparging into the upper vadose zone as a result of injecting gases into the lower saturated zone. Of the four soil vapor monitoring points sampled, two showed order of magnitude increases for averaged total critical VOCs from baseline to six months after baseline (only one of which showed a steady increase). A third monitoring point showed an order of magnitude decrease over the same time period; a fourth showed no appreciable change.

- The estimated cost to remediate an approximate 23,000 ft^2 area to a depth of 40 feet of VOC-contaminated groundwater over a two year period is $370,000. This assumes that a 40- foot thick section of bedrock would be affected, thus an estimated 900,000 ft^3 of contaminated fractured bedrock is assumed treated. The cost would convert to $16/$ft^2$ or $0.40/$ft^3$ if the injection depth was 40 feet bls. If the injection campaign needs to be extended at the same site, the cost over a 3-, or 4-year period is estimated to increase to approximately $440,000 ($19/ft^2 or $0.48/$ft^3$), and $520,000 ($23/ft^2 or $0.57/$ft^3$), respectively.

Section 1.0
Introduction

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) Program, discusses the purpose of this Innovative Technology Evaluation Report (ITER), and describes Earth Tech's Enhanced In-Situ Bioremediation process. Key contacts are listed at the end of this section for inquiries regarding additional information about the SITE Program, this technology, and the site where the technology was demonstrated.

1.1 Background

A pilot-scale technology demonstration of the Enhanced In-Situ Bioremediation process was conducted from March 1998 to August 1999 at the ITT Industries Night Vision (ITTNV) Division plant in Roanoke, Virginia. The ITTNV facility is an active manufacturing plant that produces night vision devices and related night vision products for both government and commercial customers. Groundwater contamination has been detected at several areas at the facility. The area focused on during the demonstration is immediately downgradient of a solvent release source area. At this locality, several volatile organic compounds (VOCs) have been measured at concentrations above regulatory levels in both an upper and lower fractured zone in the underlying shallow bedrock. Four specific VOC compounds were designated as "critical parameters" for evaluating the technology: chloroethane (CA), 1,1-dichloroethane (1,1-DCA), cis-1,2-dichloroethene (cis 1,2-DCE), and vinyl chloride (VC).

The pilot treatment system that Earth Tech installed within the area of contamination consisted of eleven monitoring points (i.e., an injection well, four monitoring wells located within the anticipated radius of influence [designated as "critical wells"], two monitoring wells located outside of the anticipated radius of influence, and four soil vapor monitoring points). Over the duration of the demonstration combinations of air, nutrients, and methane were injected into the lower fractured zone approximately 43 feet below land surface. One of the monitoring wells was activated as a second injection well during the demonstration.

The primary objective of the demonstration was to evaluate Earth Tech's claim that there would be a minimum 75% reduction in groundwater concentrations in the treatment zone for each of the four critical VOCs, following six months of treatment. A statistical analysis recommended collecting 28 samples to confidently detect a 75% reduction at a 90% lower confidence level (LCL) for those VOCs within the critical wells, over the course of the demonstration. Collecting samples daily represented a conservative basis for ensuring sample independence based upon the groundwater gradient. This approach also took into account both temporal and spatial variability for the four critical analytes. Therefore, four wells sampled seven consecutive days yielded the 28 samples needed for evaluating Earth Tech's claim. For each critical analyte, the concentration for the baseline and final events were calculated by averaging the 28 values.

Although emphasis was placed on evaluating treatment effectiveness at the injection depth, groundwater in both the upper and lower fractured zones of the bedrock were sampled and analyzed by the SITE Program. This was conducted by sampling wells specially designed by Earth Tech to separately monitor the upper and lower fractured zones, and by sampling of existing wells screened in the upper fractured zone.

1.2 Brief Description of the SITE Program

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

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

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

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

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

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

1.3 The SITE Demonstration Program and Reports

For the first ten years in the history of the SITE program, technologies had been selected for evaluation through annual requests for proposals. EPA reviewed proposals to determine the technologies with promise for use at hazardous waste sites. Several technologies also entered the program from current Superfund projects, in which innovative techniques of broad interest were identified under the program.

In 1997 the program shifted from a technology driven focus to a more integrated approach driven by the needs of the hazardous waste remediation community. The SITE program now annually solicits applications for participation in the Demonstration program from parties responsible for clean up operations at hazardous waste sites. A team of stakeholders led by SITE program personnel will select sites and work with site representatives in bringing technologies for demonstration to their respective sites.

Once the EPA ha accepted an application, cooperative arrangements are established among EPA, the developer, and the stakeholders to set forth responsibilities for conducting the demonstration and evaluating the technology. Developers are responsible for operating their innovative systems at a selected site, and are expected to pay the costs to transport equipment to the site, operate the equipment on site during the demonstration, and remove the equipment from the site. EPA is responsible for project planning, sampling and analysis, quality assurance and quality control, preparing reports, and disseminating information. Typically, results of Demonstration Projects are published in three documents: the SITE Demonstration Bulletin, the Technology Capsule, and the ITER. The Bulletin describes the technology and provides preliminary results of the field demonstration. The Technology Capsule provides more detailed information about the technology and emphasizes key results of the SITE field demonstration. An additional report, the Technology Evaluation Report (TER), is available by request only. The TER contains a comprehensive presentation of the data collected during the demonstration and provides a detailed quality assurance review of the data. For the Earth Tech

Enhanced In-Situ Bioremediation process demonstration, there is a SITE Technology Bulletin, Capsule, and ITER; all of which are intended for use by remedial managers for making a detailed evaluation of the technology for a specific site and waste. A TER is also submitted for this demonstration to serve as verification documentation.

1.4 Purpose of the Innovative Technology Evaluation Report (ITER)

This ITER provides information on Earth Tech's pilot scale implementation of the Enhanced In-Situ Bioremediation process for treatment of VOC-contaminated groundwater in fractured bedrock. This report includes a comprehensive description of this demonstration and its results. The ITER is intended for use by EPA remedial project managers (RPMs), EPA on-scene coordinators (OSCs), contractors, and other decision-makers carrying out specific remedial actions. The ITER is designed to aid decision-makers in evaluating specific technologies for further consideration as applicable options in a particular cleanup operation.

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

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

1.5 Technology Description

The Enhanced In-Situ Bioremediation Process is a biostimulation technology developed by the U.S. Department of Energy (DOE) at the Westinghouse Savannah River Plant site in Aiken, S.C. DOE refers to their phosphate injection technology as PHOSter™ and has licensed the process to Earth Tech, Inc. (Earth Tech). Earth Tech is utilizing the process to deliver a gaseous phase mixture of air, nutrients, and methane to contaminated groundwater in fractured bedrock. These enhancements are delivered to groundwater via one or more injection wells to stimulate and accelerate the growth of existing microbial populations, especially methanotrophs. This type of aerobic bacteria has the ability to metabolize methane and produce enzymes capable of degrading chlorinated solvents and their degradation products to non-hazardous constituents.

The primary components of Earth Tech's treatment system consist of an injection well (or wells), air injection equipment, groundwater monitoring wells, and soil vapor monitoring points. **Figure 1-1** shows a 3-D representation of the treatment area (below the fractured bedrock surface), the injection well, and monitoring points.

The injection well is designed to deliver air, gaseous-phase nutrients, and methane to groundwater in the underlying bedrock For the system evaluated at the ITT Roanoke facility, the air was supplied by a compressor that was capable of delivering 15-30 pounds per square inch (psi) and approximately 10-100 standard cubic feet per hour (scfh) to the injection well 30-50 feet below land surface (bls). At smaller/shallower sites, a smaller compressor may suffice. The monitoring wells and soil vapor monitoring points were installed upgradient, down-gradient and cross-gradient relative to the injection well location to delineate the zone of influence and to monitor groundwater within and outside the zone of influence. The soil vapor monitoring points can be designed to release or capture vapors that may build up in the overburden. The monitoring wells were constructed in a manner to allow them to be converted to either injection wells or soil vapor extraction points.

The typical injection system consists of air, nutrient, and methane injection equipment (all housed in a temporary building or shed). A compressor serves as the air source, and includes a condensate tank ("trap") with a drain, an air line, coalescing filters and pressure regulators and valves.Methane and nitrous oxide provide the source of carbon and nitrogen, respectively. Both are provided in standard gas cylinders and are piped into the main air line using regulators and flow meters. Triethyl phosphate (TEP), the phosphorus source, is stored as a liquid in a

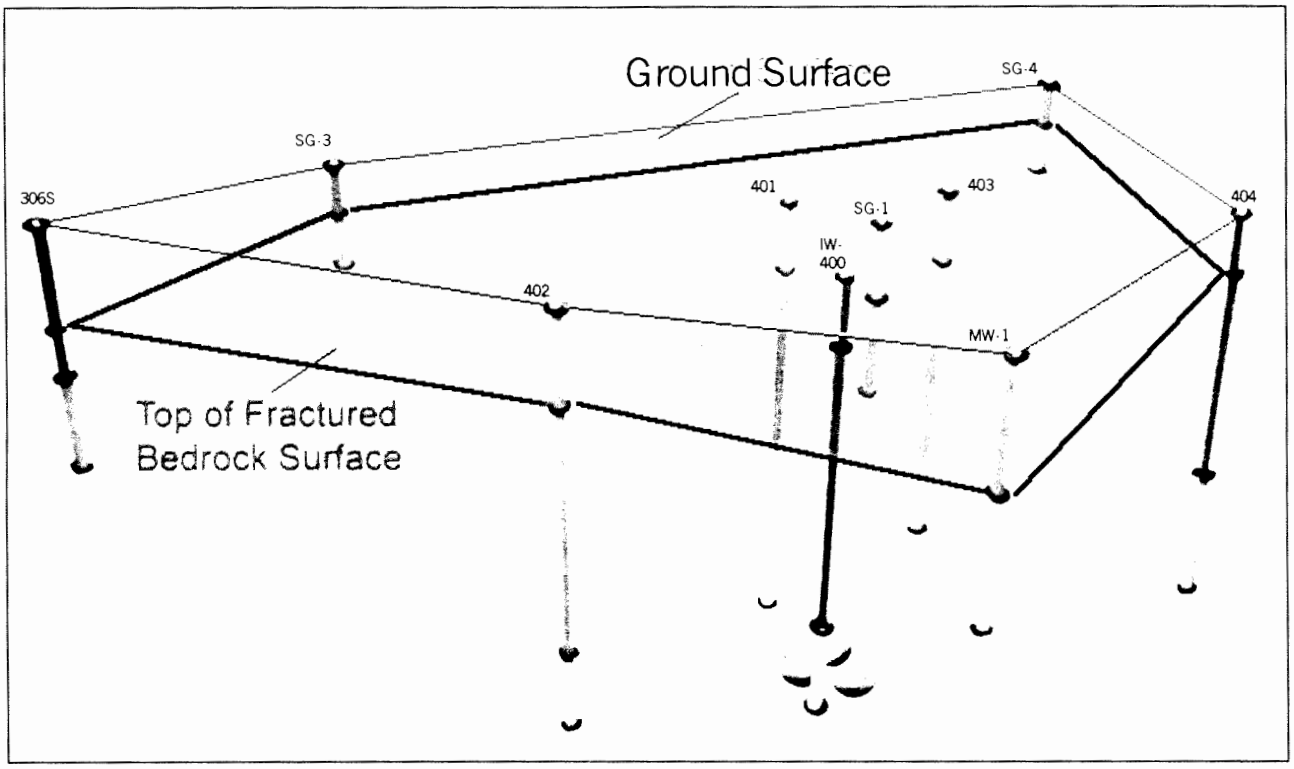

Figure 1-1. Treatment Area Showing Fractured Bedrock Surface, Injection Well and Monitoring Points.

(TEP), the phosphorus source, is stored as a liquid in a pressure rated steel tank. Air from the main line is diverted through the tank to volatilize the TEP for subsurface delivery. The air, nitrous oxide, and TEP are injected continuously while the methane is injected on a pulsed schedule. The methane is closely monitored just prior to injecting into subsurface wells to ensure that the injection concentration does not exceed 4% by volume, thus avoiding the methane lower explosive limit (LEL) of 5%.

1.6 Key Contacts

Additional information regarding Earth Tech's Enhanced In-Situ Bioremediation process, the ITTNV site, and the SITE Program can be obtained from the following sources:

Technology Licensee Contacts:
Greg Carter - Project Manager
Earth Tech Inc., C/O ITT Night Vision
7635 Plantation Road
Roanoke, VA 24019
(540) 563-0371

David Woodward - Senior Remediation Specialist
Earth Tech Inc.
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PHOSter™ Process Contact:
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Information on the SITE Program is available through the following on-line information clearinghouses:

- The SITE Home page (www.epa.gov/ORD/SITE) provides general program information, current project status, technology documents, and access to other remediation home pages.

- The OSWER CLU-In electronic bulletin board (http://www.clu-in.org) contains status information of SITE technology demonstrations. The system operator can be reached at (301) 585-8368.

Technical reports may be obtained by writing to USEPA/NSCEP, P.O. Box 42419, Cincinnati, OH 45242-2419, or by calling (800) 490-9198 or (513) 489-8190.

Section 2.0
Technology Applications Analysis

This section addresses the general applicability of the Earth Tech Inc. Enhanced In-Situ Bioremediation process to sites containing groundwater contaminated with volatile organic compounds. The analysis is based on results from and observations made during the SITE Program demonstration and from additional information received from Earth Tech Inc. Demonstration results are presented in Section 4 of this report. Earth Tech has presented a discussion of the applicability, additional studies and performance of the technology in **Appendix A**.

2.1 Key Features of the Enhanced In-Situ Bioremediation Process

The primary components of Earth Tech's treatment system consists of one or more injection wells, air injection equipment, groundwater monitoring wells, and soil vapor monitoring points. The injection wells at the demonstration site were designed to deliver air, nutrients, and methane to groundwater in shallow bedrock 30 to 50 feet below ground surface. The air is supplied by a compressor that is capable of delivering 15-30 psi and approximately 30-100 scfh to each injection well. The monitoring wells and soil vapor monitoring points are installed upgradient, downgradient and laterally to the injection well location(s) to delineate the zone of influence and to monitor groundwater within and outside the zone of influence. The soil vapor monitoring points can be designed to release vapors that may build up in the overburden. Monitoring wells can be constructed in a manner to allow them to be converted to either injection wells or soil vapor extraction points.

The injection system is comprised of air, nutrient, and methane injection equipment. The supply of enhancements are housed in a temporary building or shed. A compressor serves as the air source, and includes a condensate tank ("trap") with a drain, an air line, coalescing filters and pressure regulators and valves. The methane and nitrous oxide provide a source of carbon and nitrogen, respectively. Both of these gases are provided in standard air cylinders and are piped into the main air line using regulators and flow meters. TEP, the phosphorous source, is in liquid state and is stored in a steel tank. Air from the main line is diverted through the tank to volatilize the TEP for subsurface delivery. The air, nitrous oxide, and TEP are injected continuously while the methane is injected on a pulsed schedule. The methane is closely monitored at the injection well head to ensure that the injection concentration does not exceed 4% by volume, thus avoiding the methane LEL of 5%.

2.2 Operability of the Technology

The key factor influencing the effectiveness of Earth Tech's Enhanced In-Situ Bioremediation process is the placement and depth of injection. Although the injection of necessary supplements, including oxygen, nutrients, and carbon sources, is rather routine in unconsolidated materials, it is quite complex in fractured bedrock.

To optimize and accelerate contaminant breakdown, the natural subsurface conditions are converted to aerobic conditions through the injection of air. Gaseous-phase nutrients and methane are injected to further stimulate the growth of native microbial populations. During pilot testing at the ITTNV site, heterogeneities in the subsurface airflow were observed. In order to offset these heterogeneties, an existing monitoring well was converted into an additional injection well.

During startup of the demonstration air injection campaign, Earth Tech used a mixture of approximately 5% helium and 95% air by volume injected into the subsurface to evaluate the injection well zone of influence. Helium measurements were made in the surrounding monitoring wells and soil gas points. Methane, carbon dioxide and oxygen measurements were also taken. Helium tracer tests were also performed throughout the treatment period to evaluate the flow path changes over time and at the various injection rates. The periodic analysis of headspace was performed on the soil gas points and injection monitoring wells for the presence of methane, carbon dioxide, and oxygen. In addition, pressure readings at the monitoring points were recorded using magnehelic gauges.

At the Roanoke site, the supply of enhancements for Earth Tech's treatment system was contained inside a shed that was approximately 20 feet long and twelve feet wide. The shed provided ample room for compressed gas cylinders, a liquid triethyl phosphate tank, spare parts, and sampling equipment. The storage shed or building at a site must be large enough to contain a triethyl phosphate tank, and cylinders of nitrous oxide and methane. Although the TEP has a low freezing point (i.e., - 69 °F) and is kept in a closed system the shed needs to be heated during cold months to prevent any condensation buildup in system piping from freezing. At the Roanoke site the remediation is being conducted immediately adjacent to one of ITT's active facilities, therefore power to operate the air compressor is available from the electrical service. At a remote site, a generator used for injecting enhancements would have to be stored/secured within a shed or building. It should also be noted that the proximity of the ITTNV site to a facility building enabled the process injection piping to be buried underground.

2.3 Applicable Wastes

The Enhanced In-Situ Bioremediation (PHOSter™) process is amenable for treating petroleum hydrocarbons and organic solvents in groundwater that can be aerobically biodegraded (Looney, 2001), including some hard-to-degrade (i.e., recalcitrant) chlorinated VOCs. According to Earth Tech the mixture of air, methane, and gaseous phase nutrients that is injected into the subsurface provides an environment for methanotrophic degradation of chlorinated VOCs and aerobic degradation of non-chlorinated VOCs. Toxic products resulting from anaerobic degradation of chlorinated solvents (e.g., vinyl chloride) may be broken down completely in this aerobic methanotrophic environment.

The in-situ process can be applied to hydrogeologically complex sites where injected nutrient flow paths are uncertain and where low permeability is anticipated. For example, in fractured bedrock gaseous phase nutrient injection is more likely to affect a larger area than liquid nutrient injection. Regardless of the permeability of the material being treated, the gaseous-phase nutrients are much more likely to attain a better volumetric distribution as compared to a liquid. Liquid amendments tend to sorb to the soil as ions which restricts their distribution and has led to well clogging problems due to overstimulation and biofouling (Looney, 2001). The process is also applicable in situations where subsurface utilities limit or preclude the use of technologies requiring excavation.

2.4 Availability and Transportability of Equipment

The Enhanced In-Situ Bioremediation process can theoretically be implemented anywhere monitoring wells can be installed, which would include any location that can be accessed by a drill rig. Since all-terrain drill rigs are available, most locations would be accessible.

At the Roanoke site, the treatment system consisted of eleven monitoring points. These included seven groundwater wells and four soil vapor monitoring wells. Four of the groundwater wells were constructed with an outer casing that allows for monitoring an upper zone of fractured bedrock and an inner casing that connects to an isolated well screen that separately monitors a lower zone of fractured bedrock. These four wells extended to a depth of approximately 50 feet bls. The other three wells consisted of a single-cased screen; two of which are considered to monitor the upper fractured zone and the third considered to monitor the lower fractured zone.

All wells installed consisted of readily available construction materials typically used for well installation. The major difference between injection and monitoring well construction is the casing materials used. The injection wells are constructed with 1" I.D. galvanized steel riser pipe and 1" I.D. stainless steel screen. This added chemical stability was chosen to prevent any potential reaction between injected chemicals and well construction materials. For example, high concentrations of TEP could react with polyvinyl chloride (PVC). The monitoring wells and soil gas monitoring points, on the other hand, were constructed of PVC casings and screens. Also of note, the majority of the wells at the demonstration site were installed in a parking lot, and thus were flush mounted.

The main component of the air injection system is the manifold apparatus, which can be constructed of galvanized or stainless steel. At the Roanoke site, the majority of the manifold "T" assembly piping was buried underground. The manifold assembly is light and can be assembled and easily transported by one person if needed. The piping for the manifold, regulators, valves, and gauges are readily available supplies that may be purchased locally; or purchased from vendors and shipped overnight if necessary. Per Earth Tech, the only backup equipment that was needed to be kept readily available at the site for immediate replacement were the air flow meters. TEP is reactive with certain materials (i.e., some plastics and rubber) and can lead to plugging of air flow meters. Non-reactive materials should thus be considered for designing systems.

Enhancements associated with the process were shipped to the site by truck in a drum (in the case of TEP) or in smaller containers. The TEP is available from major chemical suppliers. When in use the TEP must be stored in a pressure-rated steel tank. The tank used at the Roanoke site was light and was easily transported by one person via a dolly. The methane is shipped in cylinders by truck and is available locally from a gas supplier. The cylinders must be secured (i.e., chained) when stored.

During the demonstration Earth Tech's system required periodic monitoring of basic groundwater parameters. The equipment used for these activities (e.g., water level indicators, YSI multi-meters, etc.) are portable and can be easily shipped or transported to a site.

2.5 Materials Handling Requirements

The major materials handling requirement for the Enhanced In-Situ Bioremediation process is containing and moving residuals from well installation activities. Examples would include drumming of soil cuttings, purge water, and decontamination water. The actual injection equipment is relatively small and easily mobilized. Steel cylinders of compressed gases (e.g., methane) can be transported just as the drums were with a two wheel dolly.

Installation of the injection system can be conducted by one person, if proficient with general plumbing assembly. All associated equipment is small and light enough to permit this individual to unload and transport the equipment to the assembly location.

Prior to beginning the demonstration a variety of activities were necessary to prepare the treatment system for start-up. For example, initial testing is required to identify fracture patterns, estimate the zone(s) of influence, and determine the optimum injection strategy. Helium is commonly used as a tracer for determining preferential flow paths. Injection strategies that may be chosen include constant injection versus pulsed injection, injecting a single enhancement versus a mixture of enhancements, and the depth of injection. Once the treatment injections are initiated, helium testing may need to be continued to determine flow path changes. Earth Tech has estimated that system assembly and initial testing requires ~100 hours of effort (see Section 3 for cost estimates).

Drilling services are generally subcontracted to a company which has both the required equipment (drill rigs, augers, samplers) and personnel trained in drilling operations and well construction. If work is to be performed on a hazardous waste site, drilling personnel must have the OSHA-required 40-hour health and safety training.

The Enhanced In-Situ Bioremediation process alone does not generate any hazardous residuals. However, small quantities of potentially hazardous residuals (e.g., well purge water) are generated during sampling activities. Residuals generated during the demonstration, including spent personal protective equipment (PPE), well purge water, and decontamination water, were placed in 55 gallon drums and disposed of by ITTNV.

2.6 Range of Suitable Site Characteristics

Locations suitable for on-site treatment using the Enhanced In-Situ Bioremediation process must be able to provide access for a drill rig and fixed or portable electrical power and potable water for cleanup activities. Electrical power is required for operating the compressor used for injecting the enhancements. If bladder pumps are to be utilized for low flow groundwater sampling techniques (i.e., micro purge) the electrical power would also be needed to operate compressors required to supply air to those pumps. Heat may be necessary to maintain a minimum temperature of above 32°F to protect equipment and personnel during cold temperatures. Overall, the Enhanced In-Situ Bioremediation process requires enough power to operate a large enough air compressor to sustain the desired injection flow rate. Earth Tech has indicated that the maximum size air compressor required to operate a full-scale injection system would be no more than 15 horsepower (HP). Although a gasoline operated air compressor can be used, electric utilities are preferred.

2.7 Limitations of the Technology

One of the main limitations of the Enhanced In-Situ Bioremediation process is that it can be difficult to predict how long the technology will need to be operated and what major adjustments need to be made to attain satisfactory levels. For example, the pilot-scale injection system used for the demonstration was expanded from one to two injection wells and the pilot test treatment duration was extended to over 18 months instead of the originally planned six-month time frame.

Per the developer, the PHOSter™ process is not ideally suited for lower zone contaminants based on the geometry of its effectiveness (Looney, 2001). This limitation was discovered during this SITE demonstration when lower zone contaminants were not being treated as effectively as contaminants in the upper zone. The geometry of the process's effectiveness can be best described as an inverted cone that begins at the point of injection. **Figure 2-1** illustrates this geometry for treatment of a typical unconsolidated aquifer. As shown in the illustration, separate phase Dense Non-Aqueous Phase Liquids (DNAPLs) would often not be effectively treated since they accumulate in thin layers at the aquifer bottom and would not be intimately contacted with the gaseous-phase nutrients that tend to rise upward (Looney, 2001).

On the other hand, the technology could be expected to work well for treating Light Non-Aqueous Phase Liquids (LNAPLs) since LNAPLs float atop the water table and would be intercepted by the upward sparging gaseous phase nutrients. As shown in Figure 2-1, if the types of media and contaminants most treatable by the process were ranked on a basis of "most certain to be effectively treated" to "least certain to be effectively treated, the ranking would be as follows (Looney, 2001):

- Vadose Zone Soils (i.e., bioventing soils above the water table)
- Capillary Fringe Soils that can be biosparged from below (i.e., LNAPLs)
- Dissolved and residual contaminants dispersed throughout the aquifer
- DNAPLs, due to the difficulty of getting nutrients to the contaminants

The pressure needed to inject the gaseous-phase nutrients is not as important of an inhibiting factor, as is the uncertainty of where a very deeply injected gas phase would migrate to. For instance, the probability that the gases could be trapped in deep pockets (thus preventing the nutrients from reaching a wide range of contaminants) would significantly increase the deeper the enhancements are injected.

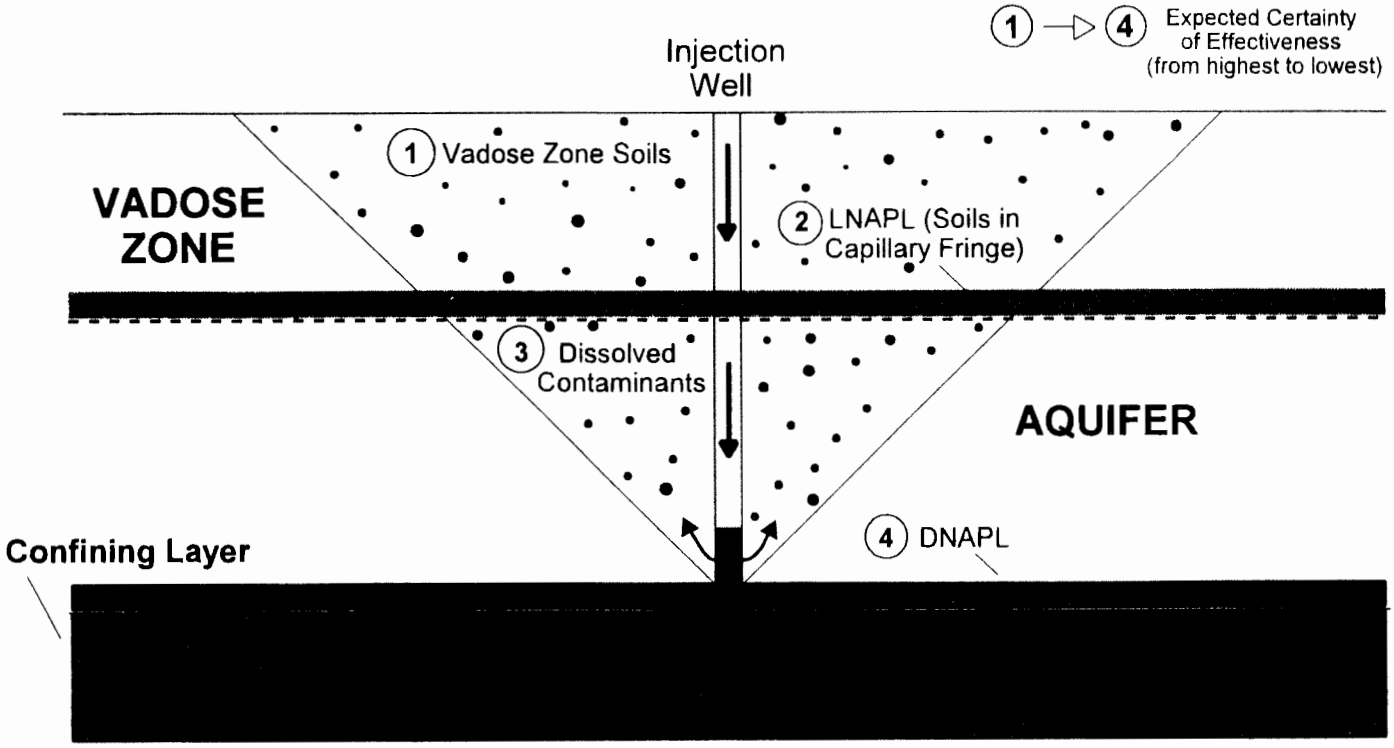

Figure 2-1. Process Effectiveness for Various Media

Generally speaking, the gaseous-phase injection technique is applicable to those sites that are amenable to bioventing and biosparging. Thus, this would include depths below the water table that are typically in the 10s of feet, not 100s (Looney, 2001). However, treatment at greater depths is possible under suitable geologic conditions. As an example, Earth Tech has reported successfully injection of enhancements at a depth of 100 feet bls at the ITTNV Roanoke facility.

It should also be noted that the limitations described above are expressed in terms of distance below water table (not ground surface) so that total depth of treatment including the vadose zone can be quite extensive at some sites (Looney, 2001).

The Enhanced In-situ Biological process requires minor daily monitoring and adjustment of injected gases (although the system can be designed to be automated with monitoring via telemetry). Initial testing is required to identify fracture patterns, estimate the zone(s) of influence, and determine the optimum injection strategy. The injection zones would need to be located beneath the treatment zone to be effective. Injected air, nutrients, and methane have a tendency to rise within the groundwater as long as these constituents remain in the gas phase. Consequently, injection wells may have to be installed relatively deep to attain the desired lateral influence. Soil vapor extraction (SVE) wells can be installed to improve lateral influence.

2.8 ARARS for the Enhanced In-Situ Bioremediation Process

This subsection discusses specific federal environmental regulations pertinent to the operation of the Enhanced In-Situ Bioremediation process including the transport, treatment, storage, and disposal of wastes and treatment residuals. These regulations are reviewed with respect to the demonstration results. State and local regulatory requirements, which may be more stringent, must also be addressed by remedial managers. Applicable or relevant and appropriate requirements (ARARs) include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act; (2) the Resource Conservation and Recovery Act; (3) the Clean Air Act; (4) the Clean Water Act; (5) the Safe Drinking Water Act, and (6) the Occupational Safety and Health Administration regulations. These six general ARARs are discussed below; specific ARARs that may be applicable to the Enhanced In-Situ Bioremediation process are identified in **Table 2-1**.

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

The CERCLA of 1980 as amended by the SARA of 1986 provides for federal funding to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment. As part of the requirements of CERCLA, the EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 Code of Federal Regulations (CFR) Part 300, and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination. SARA states a strong statutory preference for remedies that are highly reliable and provide long-term protection. It directs EPA to do the following:

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

In general, two types of responses are possible under CERCLA: removal and remedial actions. Superfund removal actions are conducted in response to an immediate threat caused by a release of a hazardous substance. Many removals involve small quantities of waste of immediate threat requiring quick action to alleviate the hazard. Remedial actions are governed by the SARA amendments to CERCLA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances or pollutants. The Enhanced In-Situ Bioremediation process could be part of a CERCLA remedial action since the toxicity of the contaminants of concern are reduced by enhancement of natural biodegradation processes.

Table 2-1. Federal and State ARARs for the Enhanced In-Situ Bioremediation Process.

Process Activity	ARAR	Description	Basis	Response
Waste characterization of untreated waste	RCRA: 40 CFR Part 261 (or the state equivalent)	Standards that apply to the identification and the characterization of wastes.	Chemical and physical properties of waste determine its suitability for treatment by the Enhanced In-Situ Bioremediation process.	Chemical and physical analyses must be performed to determine if waste is a hazardous waste.
Waste Processing	RCRA: 40 CFR Part 264 (or the state equivalent)	Standards apply to treatment of wastes in a treatment facility.	Not likely applicable or appropriate for the Enhanced In-Situ Bioremediation process.	When hazardous wastes are treated, there are requirements for operations, record keeping, and contingency planning.
	CAA: 40 CFR Part 50 (or the state equivalent)	Regulations govern toxic pollutants, visible emissions and particulates.	During process operations, any off-gas venting (i.e., from buildup of VOCs, methane, etc. in shallow soils) must not exceed limits set for the air district of operation. Standards for monitoring and record keeping apply.	Off-gases may contain volatile organic compounds or other regulated substances, although levels are likely to be very low.
Storage of auxiliary wastes	RCRA: 40 CFR Part 264 Subpart J (or the state equivalent)	Regulation governs the standards for tanks at treatment facilities.	Storage tanks for liquid wastes (e.g., decontamination waste) must be placarded appropriately, have secondary containment and be inspected daily.	If storing non-RCRA wastes, RCRA requirements may still be relevant and appropriate.
	RCRA: 40 CFR Part 264 Subpart I (or the state equivalent)	Regulation covers the storage of waste materials generated.	Potential hazardous wastes remaining after treatment (i.e., purge water) must be labeled as hazardous waste and stored in containers in good condition. Containers should be stored in a designated storage area and storage should not exceed 90 days unless a storage permit is obtained.	Applicable for RCRA wastes; relevant and appropriate for non-RCRA wastes.
Determination of cleanup standards	SARA: Section 121(d)(2)(ii); SDWA: 40 CFR Part 141	Standards that apply to surface & groundwater sources that may be used as drinking water.	Applicable and appropriate for the Enhanced In-Situ Bioremediation process used in projects treating groundwater for use as drinking water.	Remedial actions of surface and groundwater are required to meet MCL goals (MCLGs) or MCLs established under SDWA.
Waste disposal	RCRA: 40 CFR Part 262	Standards that pertain to generators of hazardous waste.	Waste generated by the Enhanced In-Situ Bioremediation process which may be hazardous is limited to contaminated drill cuttings, well purge water, PPE, and decontamination wastes.	Generators must dispose of wastes at facilities that are permitted to handle the waste. Generators must obtain an EPA ID number prior to waste disposal.
	CWA: 40 CFR Parts 403 and/or 122 and 125	Standards for discharge of wastewater to a POTW or to a navigable waterway.	Applicable and appropriate for well purge water and decontamination wastewater generated from process.	Discharge of wastewater to a POTW must meet pre-treatment standards; discharges to a navigable waterway must be permitted under NPDES.
	RCRA: 40 CFR Part 268	Standards regarding land disposal of hazardous wastes	Applicable for off-site disposal of auxiliary waste (e.g., drill cuttings).	Hazardous wastes must meet specific treatment standards prior to land disposal, or treated using specific technologies.

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

2.8.2 Resource Conservation and Recovery Act (RCRA)

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

RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. These regulations are only applicable to the Enhanced In-Situ Bioremediation process if RCRA defined hazardous wastes are present.

Hazardous wastes that may be present include contaminated soil cuttings and purge water generated during well installation and development, and the residual wastes generated from any groundwater sampling activities (e.g., PPE and purge water). If wastes are determined to be hazardous according to RCRA (either because of a characteristic or a listing carried by the waste), essentially all RCRA requirements regarding the management and disposal of this hazardous waste will need to be addressed by the remedial managers. Wastes defined as hazardous under RCRA include characteristic and listed wastes. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from specific and nonspecific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D. RCRA regulations do not apply to sites where RCRA-defined wastes are not present.

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

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

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

2.8.3 Clean Air Act (CAA)

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

National Ambient Air Quality Standards (NAAQS).

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. Emissions from vapor buildup in the near surface soils associated with the Enhanced In-Situ Bioremediation process may require monitoring and post-treatment to meet current air quality standards. Also, State air quality standards may require additional measures to prevent emissions, including requirements to obtain permits to install and operate a process (i.e., such as activated carbon and air stripping units) for control of VOCs.

2.8.4 Clean Water Act (CWA)

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

Since the Enhanced In-Situ Bioremediation process is in-situ and disposal of the purge water generated during the demonstration was shipped to a licensed disposal facility, CWA criteria did not apply for this demonstration.

2.8.5 Safe Drinking Water Act (SDWA)

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

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

If the groundwater were to be used for drinking purposes while providing no additional treatment, the quality of the water would need to meet NPDWS. Following treatment, Earth Tech has indicated that the population of microorganisms, that had been enhanced during treatment, revert back to pre-injection levels. Residual microorganisms would likely consist of heterotrophic bacteria, which have no reported health effects. 40 CFR 141.72 of the NPDWS states that in lieu of measuring the residual disinfectant concentration in the distribution system, heterotrophic bacteria, as measured by the heterotrophic plate count, may be performed. If heterotrophic bacteria concentrations are found above 500/100 ml in the distribution system, the minimum residual disinfectant concentration is not in compliance with the NPDWS.

The NPDWS also have turbidity standards which must be met. A standard of 1.0 normal turbidity unit (NTU), as determined by a monthly average must be met. Turbidity was not measured during the demonstration.

2.8.6 Occupational Safety and Health Administration (OSHA) Requirements

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

If working at a hazardous waste site, all personnel involved with the construction and operation of the Enhanced In-Situ Bioremediation treatment process are required to have completed an OSHA 40-hour training course and must be familiar with all OSHA requirements relevant to hazardous waste sites.

Workers on hazardous waste sites must also be enrolled in a medical monitoring program. The elements of any acceptable program must include: (1) a health history, (2) an initial exam before hazardous waste work starts to establish fitness for duty and as a medical baseline, (3) periodic examinations (usually annual) to determine whether changes due to exposure may have occurred and to ensure continued fitness for the job, (4) appropriate medical examinations after a suspected or known

overexposure, and (5) an examination at termination.

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

Section 3.0
Economic Analysis

3.1 Introduction

The purpose of this economic analysis is to estimate costs (not including profits) for commercial treatment of VOC-contaminated groundwater utilizing the Enhanced In-Situ Bioremediation Process. To reasonably estimate costs for the technology, the cost values presented in this section will be based on a treatment system consistent in size to the full-scale treatment system currently in operation at the ITTNV site. This system is comprised of a total of 16 groundwater wells, including three additional injection wells installed since the end of the demonstration. The original injection well used during the pilot demonstration is also part of the full-scale system, therefore there are a total of four injection wells being operated for the full-scale treatment.

Based on reductions of VOC concentrations that has occurred in specific wells, the areal extent of fractured bedrock impacted by the full-scale treatment system at the ITTNV site is estimated to be approximately 22,500 ft^2 (150 ft X 150 ft), which is about ½ acre (1 acre = 43,560 ft^2). The injection of enhancements is primarily occurring at 43 feet bls, which is the depth of the primary fracture zone. Therefore, assuming that a 40- foot thick section of bedrock would be affected, an estimated 900,000 ft^3 of contaminated fractured bedrock is assumed treatable for this cost estimate.

Based on demonstration results and observations, it will be assumed for this cost estimate that a minimum of four injection wells, operated on a pulsed injection mode for a minimum of two years, are required to reduce the target concentrations to acceptable regulatory levels at the site.

The costs associated with implementing the process, designed and operated by Earth Tech, have been broken down into 12 cost categories that reflect typical cleanup activities at Superfund sites. They include:

(1) Site Preparation
(2) Permitting and Regulatory Activities
(3) Capital Equipment
(4) Start-up and Fixed
(5) Labor
(6) Consumables and Supplies
(7) Utilities
(8) Effluent Treatment and Disposal
(9) Residuals Shipping, & Disposal
(10) Analytical Services
(11) Maintenance and Modifications
(12) Demobilization/Site Restoration

Before attempting to calculate costs for implementing the Enhanced In-Situ Bioremediation process over a two year period, costs for the initial first year's treatment must be determined to provide a basis estimate. The initial year estimate will have the highest cost due to drilling and well installation costs and the costs associated with procurement and assembly of almost all of the capital equipment. The increased total costs for all subsequent years of treatment are associated primarily with labor and analytical services.

Table 3-1 presents a categorical breakdown of estimated costs for an initial year of enhanced in-situ biological treatment of almost 900,000 ft^3 of VOC-contaminated fractured bedrock aquifer (which assumes treatment to affect 40 feet of aquifer thickness over a 150 ft X 150 ft area). **Table 3-2** uses those first year cost estimates to project approximate costs for two-, three-, and four-year treatment scenarios. **Figure 3-1** graphically illustrates the percentage of total cost that each of the twelve cost

Table 3-1. Cost Estimates for Initial Year of Enhanced In-Situ Bioremediation Treatment.

Cost Category	Quantity	Units	Unit Cost	$ - 1st Yr.	$/Category[1]
1. Site Preparation					**$99,000**
Injection/Monitoring Well Installation [2]	16	Each	$5,500	$88,000	
Soil Gas Probe Installation [2]	4	Each	$2,000	$8,000	
Building Enclosure (10' x 15')	1	Each	$1,200	$1,200	
Utility Connections	1	Each	$1,500	$1,500	
2. Permitting & Regulatory Activities					**$35,000**
Permits				$15,000	
Studies and Reports				$20,000	
3. Capital Equipment					**$36,000**
Air Compressor	1	Each	$4,000	$4,000	
Injection Equipment	1	Each	$5,000	$5,000	
Gauges & Regulators	NA	Total	$4,000	$4,000	
Vapor Monitoring Equipment	1	Each	$3,500	$3,500	
Water Quality Instrumentation (YSI)	1	Each	$6,000	$6,000	
Bladder Pumps/Tubing	24	Each	$500	$12,000	
Pump Flow Regulator	1	Each	$900	$900	
Building Heater	1	Each	$500	$500	
4. Startup & Fixed (10% of Capital Equipment)					**$3,600**
5. Labor					**$62,000**
Well/Probe Construction Oversight	300	Hours	$60	$18,000	
Startup Testing [3]	150	Hours	$60	$9,000	
Groundwater Sampling	80	Hours	$60	$4,800	
System Monitoring	500	Hours	$60	$30,000	
6. Consumables and Supplies					**$5,200**
Helium	3	Each	$60	$180	
Methane	20	Each	$100	$2,000	
Nitrous Oxide	20	Each	$50	$1,000	
Triethyl Phosphate	1	Each	$800	$800	
PPE	1	Each	$300	$300	
Rental - Compressors for Purging	8	Days	$120	$960	
7. Utilities (Electricity)	74,000	kW-hr	$0.07	$5,000	**$5,000**
8. Effluent Treatment & Disposal	NA	NA	NA	$0.00	**$0.00**
9. Residuals & Disposal					**$24,000**
Contaminated Solids [4]	30	Drums	$300	$9,000	
Contaminated Purge Water [4]	50	Drums	$300	$15,000	
10. Analytical Services					**$25,000**
VOCs in Groundwater	106	Each	$150	$15,900	
VOCs in Soil Gas [5]	18	Each	$290	$5,220	
Methane in Soil Gas	18	Each	$85	$1,530	
MPN counts	20	Each	$120	$2,400	
Sample Shipments	8	Each	$50	$400	
11. Maintenance & Modifications	50	Hours	$60	$3,000	**$3,000**
12. Demobilization/Site Restoration	40	Hours	$60	$2,400	**$2,400**
			Total Initial Year Cost		**$300,000**

[1] Cost values in totals column are rounded to two significant digits.
[2] Includes drilling costs using an air rotary rig, and well completion costs.
[3] Startup testing includes initial helium tracer tests and headspace field screening.
[4] Solids include drill cuttings and PPE. Purge water includes that generated during well development.
[5] The test method is TO-14 and the cost includes rental of SUMMA canisters and flow controllers.

Table 3-2. Cost Estimates for Enhanced In-Situ Bioremediation Extended Treatment Scenarios.

		CUMULATIVE		
Cost Category	Initial Year	2 Years	3 Years	4 Years
1. Site Preparation	**$99,000**	**$99,000**	**$99,000**	**$99,000**
Injection/Monitoring Well Installation[1]	$88,000	$88,000	$88,000	$88,000
Soil Gas Probe Installation[1]	$8,000	$8,000	$8,000	$8,000
Building Enclosure (10' x 15')[1]	$1,200	$1,200	$1,200	$1,200
Utility Connections[1]	$1,500	$1,500	$1,500	$1,500
2. Permitting/Regulatory Activities[1]	**$35,000**	**$35,000**	**$35,000**	**$35,000**
3. Capital Equipment[1]	**$36,000**	**$36,000**	**$36,000**	**$36,000**
4. Startup & Fixed[1]	**$3,600**	**$3,600**	**$3,600**	**$3,600**
5. Labor	**$62,000**	**$97,000**	**$130,000**	**$170,000**
Well/Probe Construction Oversight[1]	$18,000	$18,000	$18,000	$18,000
Startup Testing[1]	$9,000	$9,000	$9,000	$9,000
Groundwater Sampling	$4,800	$9,600	$14,400	$19,200
System Monitoring	$30,000	$60,000	$90,000	$120,000
6. Consumables & Supplies	**$5,200**	**$9,200**	**$13,000**	**$17,000**
Helium[1]	$180	$180	$180	$180
Methane	$2,000	$4,000	$6,000	$8,000
Nitrous Oxide	$1,000	$2,000	$3,000	$4,000
Triethyl Phosphate[1]	$800	$800	$800	$800
PPE[1]	$300	$300	$300	$300
Rental - Compressors	$960	$1,900	$2,900	$3,800
7. Utilities (Electricity)	**$5,000**	**$10,000**	**$15,000**	**$20,000**
8. Effluent Treatment & Disposal	**$0**	**$0**	**$0**	**$0**
9. Residuals Shipping & Disposal	**$24,000**	**$29,000**	**$35,000**	**$40,000**
Contaminated Solids[1]	$9,000	$9,000	$9,000	$9,000
Contaminated Purge Water	$15,000	$20,400	$25,800	$31,200
10. Analytical Services	**$25,000**	**$44,000**	**$63,000**	**$82,000**
VOCs in Groundwater	$15,900	$31,800	$47,700	$63,600
VOCs in Soil Gas[1]	$5,220	$5,220	$5,220	$5,220
Methane in Soil Gas[1]	$1,530	$1,530	$1,530	$1,530
MPN counts	$2,400	$4,800	$7,200	$9,600
Sample Shipments	$400	$800	$1,200	$1,600
11. Maintenance & Modifications	**$3,000**	**$6,000**	**$9,000**	**$12,000**
12. Demobilization/ Site Restoration[1]	**$2,400**	**$2,400**	**$2,400**	**$2,400**
TOTAL COSTS	**$300,000**	**$370,000**	**$440,000**	**$520,000**

Bolded costs are categorical totals which have been rounded to two significant digits.
[1] Designates a one time cost incurred for all scenarios.

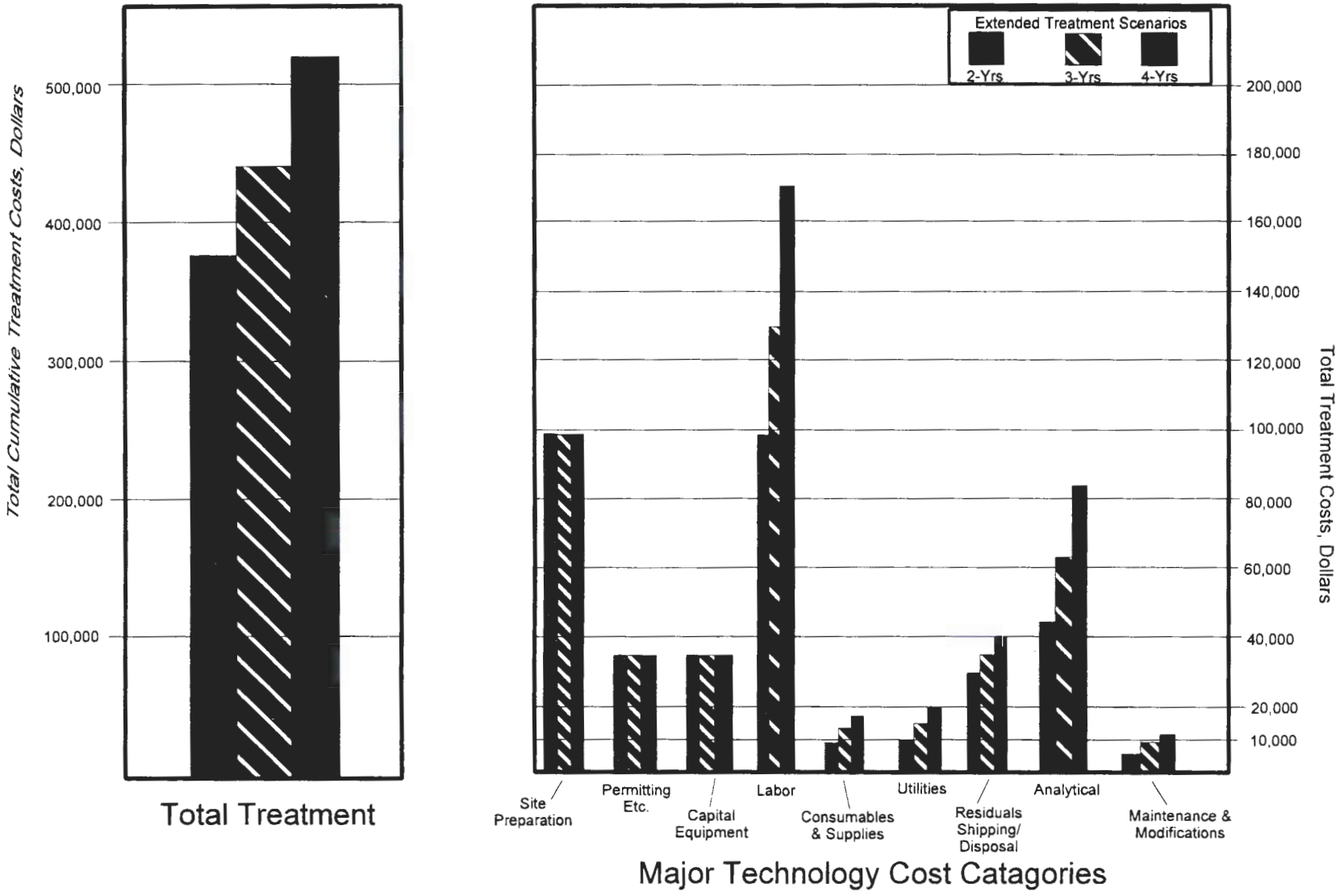

Figure 3-1. Cost Distributions - Enhanced In-Situ Bioremediation Treatment for 2-, 3-, & 4-Years (Cumulative).

components comprise, for each of the three cleanup scenarios. As with all cost estimates, there are associated factors, issues, and assumptions that caveat specific cost values. The major factors that can affect estimated costs are discussed in subsection 3.3. The issues and assumptions made regarding site characteristics are incorporated into the cost estimate. They are discussed in subsection 3.4.

The basis for costing each of the individual 12 categories in Table 3-1 is discussed in detail in subsection 3.5. Much of the information presented in this subsection has been derived from observations made and experiences gained from the SITE demonstration that was conducted over an approximate 18 month period at the ITTNV facility in Roanoke, Virginia. Other cost information has been acquired through subsequent discussions with Earth Tech and by researching current estimates for specific cost items related to the technology.

It should be emphasized that the cost figures provided in this economic analysis are "order-of-magnitude" estimates, generally + 50% / -30%.

3.2 Conclusions

- The estimated cost to remediate an approximate 23,000 ft^2 area of VOC-contaminated groundwater over a two year period is $370,000, which would convert to $16/$ft^2$ or $0.40/$ft^3$ assuming a 40 foot thick section of bedrock to be treated. If the injection campaign needs to be extended at the same site, the cost over a 3-, or 4-year period is estimated to increase to approximately $440,000 ($19/ft^2 or $0.48/$ft^3$), and $520,000 ($23/ft^2 or $0.57/$ft^3$), respectively.
- The largest cost components for the two-year application of the Enhanced In-Situ Bioremediation technology at a site having characteristics similar to those encountered at the ITTNV site are site preparation (27%) and labor (26%), together accounting for over half of the total cost. Analytical services, which can be quite variable, have been estimated to comprise approximately 12% of total costs and capital equipment has been estimated to comprise 10% of total costs.
- The cost of implementing the Enhanced In-Situ Bioremediation Process may be less or more expensive than the estimate given in this economic analysis depending on several factors. Such factors may include the depth and vertical extent of the contamination, the site geology, the contaminant concentration levels, the number of injection and monitoring wells needed to be installed, and the level of site characterization required by a regulatory agency.

3.3 Factors Affecting Estimated Cost

There are a number of factors that could affect the cost of treatment of VOC contaminated groundwater using enhanced in-situ bioremediation. It is apparent that the number of injection wells required to inject the enhancements and the number of wells required for monitoring the treatment have very significant impacts on up-front costs. The contaminant distribution pattern will affect the number of injection wells required to attain a sufficient area of influence to degrade the contaminants to acceptable levels. Spatially large sites would not only require more injection wells, but the wells may have to be installed deeper to increase the spatial dispersion of the gaseous-phase enhancements as they migrate upwards into shallower fracture zones. The increased drilling and well construction materials required for deeper wells would increase costs. Large sites would also likely require additional monitoring wells and soil gas vapor monitoring points for characterizing the treatment effectiveness.

3.4 Issues and Assumptions

This section summarizes the major issues and assumptions used to estimate the cost of implementing the Enhanced In-Situ Bioremediation Process at full-scale. In general, the assumptions are based on information provided by Earth Tech and observations made during the SITE demonstration.

3.4.1 Site Characteristics

The site characteristics used for this economic analysis will be considered similar to those found at the ITTNV site. The ITTNV demonstration pilot system consisted of eleven monitoring points, including an injection well, four monitoring wells located within the anticipated radius of influence, two monitoring wells located outside of the anticipated radius of influence, and four soil vapor monitoring points. Since that time the system has been expanded to include four injection wells. The approximate square footage for the affected area is approximately 23,000 ft^2, which is roughly ½ acre. Therefore this areal extent will also be used for this economic analysis.

Also for purposes of estimating costs, it will be assumed that the site consists of a fractured bedrock aquifer, and overall similar to the geology at the ITTNV site and that the groundwater contamination consists of chlorinated compounds. However, it will be assumed that only a very thin cover of soil overlies the shallow bedrock, therefore a 40 foot thick section of fractured bedrock, or roughly 900,000 ft^3 of bedrock aquifer will be treated. All other

performance factors depend primarily on the selection of the optimal injection method (continuous versus pulsed injection rates) and the selection and optimization of enhancements.

For estimating costs to fully remediate a site, the treatment duration has been considered a variable. It is assumed that a minimum of two years of continuous injection of enhancements and pulsed methane injection will be required to reduce the concentrations of the VOC compounds to below their respective regulatory MCL. Any additional treatment will be assumed to be conducted in one year increments, up to a total of four years. Thus cost estimates are provided for scenarios of two, three, and four years of treatment.

3.4.2 Design and Performance Factors

The only mechanical equipment operated during the injection campaign consists of an air compressor capable of supplying air to four or more injection wells at a rate of 30-40 scfh. All other performance factors depend primarily on the selection of the optimal injection method (i.e., continuous versus pulsed injection rates) and the selection and optimization of enhancements.

3.4.3 Financial Assumptions

All costs are presented in Year 2000 U.S. dollars without accounting for interest rates, inflation, or the time value of money. Insurance and taxes are assumed to be fixed costs lumped into "Startup and Fixed Costs" (see subsection 3.5.4). Licensing fees and site-specific royalties passed on by the developer, for using the DOE patented injection system and implementing technology-specific functions, would be considered profit. Therefore, those fees are not included in the cost estimate.

3.5 Basis for Economic Analysis

In this section, each of the 12 cost categories that reflect typical clean-up activities encountered at Superfund sites, will be defined and discussed. Combined, these 12 cost categories form the basis for the detailed estimated costs presented in Tables 3-1 and 3-2. The labor costs that are continually repeated from year to year are grouped into a single labor category (see subsection 3.5.5).

3.5.1 Site Preparation

Site preparation for implementing an in-situ bioremediation technology comprises a significant portion of the total treatment costs, especially for the initial year of operation. The site preparation phase can be subdivided into two subcategories. These include well/probe installation and site setup. Both of these site preparation tasks are considered to be one time occurrences for this cost estimate, since they should not have to be repeated if the site has been properly characterized. These two sub tasks and their associated estimated costs are discussed in the following subsections. The total non-labor cost of site preparation for the initial first year of treatment is estimated to be approximately $99,000. Each additional year of treatment should not incur additional costs.

3.5.1.1 Well/Probe Installation

The number and location of injection wells, monitoring wells, and soil gas probes required for treatment and monitoring is highly site-specific and depends on many factors. As a result, the high initial costs for this phase can vary greatly. If a sufficient number of monitoring wells already exist at a site, the high cost of installing wells can be greatly reduced. For this cost estimate, it is assumed that no wells are present in the area requiring treatment and that the monitoring system installed will consist of 4 injection wells, 12 monitoring wells, and four soil gas probes.

From discussions with Earth Tech, subcontracted well installation costs at the Roanoke site included costs of $40 per foot for air rotary drilling plus approximately $3,500 for well materials and setting wells into the bedrock. At the ITTNV site, three deeper injection wells have been installed to approximately 75 feet bls to widen the lateral dispersing of the enhancements. Each of these wells were designed with two injection points, one shallow and one deep. Some of the monitoring wells are set at shallower depths. For this cost estimate, the average well depth is assumed to be 50 feet, which would correlate to drilling costs of $2,000 per well and total well installation costs of $5,500 per well. Thus, for a 16 well system the total well installation costs are estimated to be $88,000.

3.5.1.2 Site Setup

The second phase of site preparation is site setup. If the treatment is being implemented at an active facility, there may be no need for a site trailer, although a small building or shed is necessary for storing consumables. As a result, the non-labor costs associated with this phase would most likely include those associated with the construction or assembly of a storage shed. The storage shed must be large enough to contain a triethyl phosphate tank, and cylinders of nitrous oxide and methane. The shed also needs to be heated during cold months to prevent any condensation buildup in system piping from freezing. The installation of the prefabricated shed at the ITTNV site has been estimated by Earth Tech to be $1,200.

The cost for supplying electrical power for the injection system can be quite variable. At the ITTNV site, electrical hookups, communications, and water supply were readily available and therefore costs (if any) were negligible. However, more often than not, utility hookups would be

necessary and for this cost estimate are estimated to be a one time charge of $1,500.

It is assumed that the model site is secured and cannot be easily vandalized. If security is an issue, then a fence would need to be erected. This could substantially increase site setup costs, especially for a large site. Assuming no costs for security, the total non-labor site setup costs (e.g., shed and utility hookups) for initiating the activities are estimated to total $2,700. The actual labor costs associated with site setup, and which would be conducted by the remediation contractor implementing the treatment system, is discussed in subsection 3.5.5.

3.5.2 Permitting and Regulatory Requirements

Several types of permits may be required for implementing a full-scale remediation. The types of permits required will be dependent on the type and concentration of the contamination, the regulations covering the specific location, and the site's proximity to residential neighborhoods. For the system installed at the ITTNV facility in Roanoke, Virginia an injection permit was not required. However a thorough eight week sampling program was required by the U.S. EPA to establish a statistically valid contamination baseline for the groundwater prior to installing the treatment system. The non-analytical costs incurred for ultimately receiving approval from the regulatory agency to install the treatment system are included under the Permitting and Regulatory Activities category. These costs would include the preparation of site characterization reports that establish a baseline for the site contamination, the design feasibility study for the pilot system, and numerous meetings with regulators for discussing comments and supplying related documentation for acquiring approval for installing and implementing the treatment.

The permitting fees for bioremediation are assumed to be about $15,000. It should be noted that actual permitting fees are usually waived for government-conducted research type projects.

Depending upon the classification of the site, certain RCRA requirements may have to be satisfied as well. If the site is an active Superfund site, it is possible that the technology could be implemented under the umbrella of existing permits and plans held by the site owner or other responsible party. Certain regions or states have more rigorous environmental policies that may result in higher costs for permits and verification of cleanup. Added costs may result from investigating all of the regulations and policies relating to the location of the site; and for conducting a historical background check for fully understanding the scope of the contamination. From previous experiences, the associated cost with these studies and reports is estimated to be $20,000.

3.5.3 Capital Equipment

Capital equipment for the Enhanced In-Situ Bioremediation technology would consist of an air compressor equipped with an air receiving tank, piping and other components comprising the injection system, and specialized field instrumentation used to monitor the system. Well construction material costs are not considered capital equipment since well materials are expendable (not reusable) and are inherently linked to specialized well installation services.

Most of the capital equipment cost data directly associated with the injection system has been supplied by Earth Tech. Some of the monitoring equipment costs are based on the SITE Program's experience during the demonstration and from other similar products. It is assumed that all equipment parts will be a one time purchase and will have no salvage value at the end of the project. Field monitoring equipment is assumed to be dedicated to the site.

Earth Tech has estimated that a total of about 4 cubic feet per minute (cfm) of gaseous phase enhancements are being injected into their full-scale system comprised of four injection wells. For any full-scale system, a 15 HP air compressor, which supplies up to 50 cfm at 100 psi, would be more than adequate. A compressor of such size could be purchased for slightly more than $4,000.

The primary injection components, which would include manifold(s) and associated piping would cost about $5,000 and the associated gauges and regulators have been estimated to cost another $4,000. The injection system at Roanoke is being monitored by a portable combustible gas monitor which costs approximately $3,500 and is dedicated to the project. It should be noted that a Programmable Logic Controller (PLC) could be installed on-line to continuously monitor combustible gas levels for approximately $10,000. The total cost for the injection system, including the combustible gas monitor, is estimated to be approximately $16,500.

For monitoring the treatment of groundwater during the demonstration, dedicated bladder pumps and tubing were installed in each of the wells to be sampled. For those wells that were constructed to monitor both the upper and lower fractured zones, a pair of bladder pumps were installed. Although the teflon® bladder pumps are relatively expensive, once installed they allow for relatively easy collection of groundwater samples by the low flow purging technique (the method used for the demonstration, which is preferred by EPA-NRMRL). A second advantage of using bladder pumps is that they eliminate the need to

decontaminate sample collection equipment between wells and reduce the chance of cross-contamination or the introduction of decontamination chemicals into the groundwater. In essence, much of the capital expenditure related to the use of dedicated bladder pumps is recouped by the reduced labor costs.

For this cost estimate, it is assumed that two bladder pumps will be installed in each of the twelve monitoring wells, one for each fractured zone. Each bladder pump and associated tubing costs about $500, therefore the total cost for 24 bladder pumps and associated tubing is estimated to be $12,000. A pump flow regulator, estimated to cost $900, is required to regulate compressed air as a cycle of pulses that corresponds to a desired groundwater flow rate out of the well.

Also during the demonstration, continual water quality data was collected from two wells at a time using two YSI multi-parameter water quality monitors. The use of these down well instruments allowed for the continuous monitoring for parameters of interest throughout the demonstration. Periodically, the instruments were rotated to different wells. Although this level of monitoring may not be a necessity to implement the Enhanced In-Situ Biological Process, the data collected from the units proved to be of great value to Earth Tech for refining their injection campaign.

Multi-parameter water quality monitors are fairly sophisticated and thus not commonly rented. Regardless of this fact, rental costs for such instrumentation for extended periods (as would be the case for a full-scale remediation) would equal or exceed the purchase price. Therefore, for this cost estimate, it will be assumed that one water quality instrument will be rotated among selected wells to collect continual data for parameters of interest. The cost for a multi-parameter meter and data logger, dedicated to a full-scale remediation project, is estimated at $6,000.

The total costs for capital equipment are estimated to be approximately $36,000.

3.5.4 Startup and Fixed Costs

From past experience, the fixed costs for this economic analysis are assumed to include only insurance and taxes. They are estimated to be 10 percent of the total capital equipment, or $3,600.

3.5.5 Labor

Included in this subsection are the core labor costs that are directly associated with the Enhanced In-Situ Bioremediation Process. These costs include the labor hours required to oversee drilling activities, assemble the treatment equipment and monitor system effectiveness; thus comprising the bulk of the labor required for the full implementation of the technology. Non-core labor costs (i.e., those associated with maintenance activities and site restoration) are discussed in subsections 3.5.11 and 3.5.12, respectively.

Labor costs for a minimum two-year cleanup scenario comprises the largest cost component (27%) of the total two-year treatment cost. The hourly labor rates presented in this subsection are loaded, which means they include base salary, benefits, overhead, and general and administrative (G&A) expenses. Travel, per diem, and standard vehicle rental have not been included in these figures. The labor tasks have been broken down into four subcategories, each representing distinct phases of technology implementation. They include 1) Well/Probe Construction Oversight; 2) Startup Testing; 3) Groundwater Sampling; and 4) System Monitoring.

3.5.5.1 Well/Probe Construction Oversight

Although drilling and well installation labor activities are performed by a drilling contractor, the remediation contractor at a site (such as Earth Tech) would be responsible for logging boreholes, monitoring for VOCs and explosive conditions, and ensuring that well construction and installation is conducted in accordance with design specifications. Roughly assuming that to drill through the bedrock and fully install a well or probe will take on average 1½ 10-hour days, an estimated 300 hours of oversight labor would be required for installing 20 monitoring points. Thus, a geologist's labor at a $60/hour rate would result in $18,000 in oversight labor.

3.5.5.2 Startup Testing

Startup testing includes the labor to procure the injection system parts, the associated monitoring equipment, and initial first year enhancement supplies (e.g., methane, TEP, etc.); arranging for and overseeing the electric utility hookup; installing the injection system components and associated monitoring equipment (e.g., dedicated bladder pumps for the wells), and conducting preliminary air and helium injection tests to determine fracture patterns and zone(s) of influence. Earth Tech approximated their labor hours for these tasks at 100 hours. Therefore for a full-scale system the total hours for startup testing has been increased by 1/3 to an estimated 150 hours for the initial year of treatment. The majority of startup testing should be a one time occurrence, therefore no additional labor is shown to occur in Table 3-2 for successive years of treatment.

3.5.5.3 Groundwater Sampling

It is assumed that, prior to installation of the Enhanced In-Situ Biological Treatment System, the contamination in the groundwater is fully characterized from a Remedial

Investigation/Feasibility Study (RI/FS), RCRA Facility Investigation (RFI), etc. Therefore, for this cost estimate, it will be assumed that the regulatory agency will require quarterly monitoring of the 12 monitoring wells. Since dedicated bladder pumps are to be used for collecting groundwater samples, the primary time constraint will be purging of the wells. During the demonstration, this process was time consuming because some of the wells had a very low recharge rate and several hours were needed for water quality parameters to stabilize. The process was sped up somewhat by utilizing two portable air compressors which enabled the purging of two wells at a time.

For this cost analysis, it will be assumed that both zones in the twelve monitoring wells can be purged and sampled in one 10-hour day by two people. Therefore, each quarterly sampling event would incur 20 hours of labor at $60/hr; or $1,200. Thus, for the initial year and all successive years of treatment, an annual labor cost of $4,800 would be incurred for groundwater sampling.

3.5.5.4 System Monitoring

System monitoring occurs as separate preplanned events at either a specific stage of the treatment process or in accordance with a specific time line. The labor for this event includes monitoring the system for explosive vapors, injection pressure, and flow rate of gases; taking pressure readings using magnehelic gauges; conducting soil gas and headspace screening for methane (CH_4), carbon dioxide (CO_2), and oxygen (O_2); conducting continuous field parameter monitoring in one or more wells; and taking water level readings. Earth Tech estimated that approximately 400 hours were spent monitoring the pilot system over the course of a year. Therefore, for a full scale system it is estimated that 500 hours annually would be required to conduct the system monitoring. At a rate of $60/hour, a total labor cost of $30,000 would be incurred for each year of system operation.

3.5.6 Consumables & Supplies

Consumables and supplies for a two-season cleanup scenario comprises a surprisingly small cost component for the Earth Tech system. Total costs of this category are associated with three subcategories of consumables and supplies: 1) Enhancements; 2) PPE; and 3) Equipment Rentals. Each of these sub category costs are discussed separately in the following subsections.

3.5.6.1 Enhancements

Enhancements include any consumable supply that is injected into the groundwater to specifically increase the viability of indigenous microbes. These materials include air, nitrous oxide, CH_4, and triethyl TEP. The TEP, which is purchased on a 55-gallon drum basis, is used modestly and the original supply is expected to last for the duration of full-scale treatment. Also included is helium, which is used as an initial tracer for delineating fracture patterns.

During the first year of full-scale treatment, Earth Tech has estimated that three cylinders of helium (at $60 per cylinder), 20 cylinders of CH_4 (at $100 per cylinder), and 20 cylinders of nitrous oxide (at $50 per cylinder) were expended. For each subsequent year of treatment an additional $3,000 would be incurred from the increased use of CH_4 and nitrous oxide. No subsequent costs are expected to be incurred by either helium or TEP. Helium is used almost exclusively for system startup testing. The initial bulk purchase of TEP at $800 per drum would supply enough TEP for the entire treatment duration.

3.5.6.2 Personal Protective Equipment (PPE)

PPE is routinely used for well drilling, groundwater sampling, residuals management, and maintenance activities; during which there is the potential to be exposed to contaminated soil and groundwater. Expendable items would primarily include nitrile gloves and tyvek® coveralls; and possibly respirator cartridges if the work is conducted in Level C or higher. Earth Tech has estimated purchase of PPE during the pilot system operation to be $300. Once a full-scale system is up and running, the limited PPE used during groundwater sampling and maintenance activities throughout the entire treatment duration is expected to be negligible in cost. Therefore, the $300 cost for PPE is assumed constant for all treatment scenarios. This value does not include cost for disposing of PPE.

3.5.6.3 Equipment Rentals

Equipment rentals include the costs for non-capital equipment required to efficiently perform the majority of monitoring activities for the site. Most of the monitoring equipment that will be used for a full-scale treatment system will be dedicated to the site and thus purchased. The only items that would be used sparingly, yet on a consistent basis, would be portable air compressors needed for injecting air into bladder pumps during the quarterly groundwater sampling episodes.

It is assumed that a minimum of two portable air compressors, costing a combined $120 per day, would be required for each sampling event. Therefore, the air compressor rental costs for quarterly sampling would sum to $960 annually. If the air compressors were to be gasoline or diesel powered (not recommended for VOC sampling) the fuel is assumed to be included into the rentals costs, with any additional fuel costs considered negligible.

3.5.7 *Utilities*

The predominate utility required for operating the injection system is the electricity required to generate compressed air. Certainly, the proximity of the demonstration site to a readily available facility power source and to outdoor electrical outlets enables utility logistics to be of a minor nature for the ongoing treatment at ITTNV in Roanoke. However, at a remote site, logistics can get complicated. It maybe even necessary to use a diesel powered air compressor if electrical hookup is not economically feasible.

Since the facility generator being used at the ITTNV site is supplying power for other normal functions besides Earth Tech's compressed air requirements, there is no accurate way for determining power usage for supplying the compressed air. Earth Tech has indicated that the maximum size air compressor required to operate a full-scale injection system would be no more than 15 HP. Assuming a 15 HP compressor that utilizes about 11.2 kilowatts (kW) of power is operated ~ 75% of the time, the number of kW-hrs used annually would be approximately 11.2 kW x 18 hrs/day x 365 days/yr = ~ 74,000 kW-hrs. Assuming a utility charge of $0.07/kWh, the cost of running the compressor continuously would = ~ $5,000 annually.

A small additional electrical cost may be needed to supply lighting to the supply shed and a security light, and possibly for a phone and facsimile hookup. Other than electricity, water may be needed for occasional decontamination activities; however those costs are considered negligible.

3.5.8 *Effluent Treatment and Disposal*

For this technology there is no effluent. Therefore, it is assumed that there will be no effluent treatment and disposal expense. Disposal of small amounts of decontamination wastewater, that may be generated from cleaning sampling equipment, is considered negligible.

3.5.9 *Residuals Shipping and Disposal*

The only residuals anticipated to be generated during a full-scale enhanced bioremediation treatment are contaminated drill cuttings, purge water, and PPE. For this cost estimate it is assumed that there will be a relatively high first year cost for this category since drill cuttings and a significant amount of purge water would be generated during the drilling, installation, and developing of the newly installed wells. Earth Tech has indicated that roughly 30 drums of combined contaminated drill cuttings/PPE ("solids") and 50 drums of contaminated purge water ("liquids") were generated during installation of the injection and monitoring wells; and that the drums were removed and disposed of for approximately $300 each. Therefore, the initial cost of residuals shipping and disposal for the initial year of operation is estimated at $24,000.

For each subsequent year, however, the costs of this category would be significantly less. There would be no additional drill cuttings (unless additional wells were to be installed) and purge water would be generated solely from low-flow purging of wells during quarterly sampling episodes. Generation of PPE during sampling activities would be considered negligible. Assuming that 1) a single well volume would be purged from each of the 12 monitoring wells during each sampling event 2) the wells to have a 4-inch inside diameter casing and 3) each well to have a 30 foot water column, roughly 20 gallons of purge water would be generated for each well. This would sum to a total of 240 gallons per sampling episode or 960 gallons of purge water generated annually. Therefore 18 drums would be disposed of annually following the first year of treatment, at an estimated total cost of $5,400. Thus, the total cost of residuals shipping and disposal would increase by that amount for each additional year of treatment.

3.5.10 *Analytical Services*

All groundwater and soil gas samples collected for the model site would be sent to an off-site analytical laboratory. The level of testing required to substantiate site cleanup is assumed to be significantly scaled down from the SITE Demonstration sampling plan. The reason for this is that the demonstration objectives focused on percent reduction claims that could only be adequately evaluated by a statistically-based population of pre- and post-treatment samples. On the other hand, remediation projects focus on attaining a specific cleanup concentration target level, not percent reduction.

For estimating the cost of analytical samples, it is assumed that the RI or RFI report has adequately delineated the contaminant concentration and distribution at the site. Therefore it is assumed that the on-site contractor will conduct quarterly groundwater monitoring over the duration of the treatment. For this cost estimate, the regulatory agency overseeing site activities will require at least one groundwater sample from both the upper and lower fractured zone, from each of the twelve monitoring wells, each and every quarter (for a total of 24 samples per quarter or 96 samples per year).

The technology licensee will likely have methanotroph counts by the most probable number (MPN) technique performed on the groundwater samples collected from certain wells and from specific zone intervals over the entire treatment duration; estimated at four analyses per quarter or 18 analyses per year. It will also be assumed that quarterly soil gas samples will be required to be

collected from the four soil vapor wells the first year only, at which time it would be demonstrated that venting of either VOCs or methane is not occurring in a significant manner. Therefore it is estimated that 18 soil gas (air) analyses will be performed for both VOCs and methane for the initial year of system operation only.

Assuming that quality assurance sampling and analysis for the groundwater samples is to be conducted at a 10% frequency, the total number of VOC analyses per year is estimated to be 106 and the total number of MPN analyses for the initial year is estimated at 20.

The resulting total of 106 groundwater samples, analyzed for total VOCs at an estimated amount of $150 per sample, would cost $15,900 annually. The resulting total of 20 MPN counts conducted at an estimated $120 per sample would cost $2,400 annually. The 18 soil gas samples would be analyzed for VOCs and methane at estimated costs of $290 and $85 each, respectively. The total air analysis costs for the project is thus estimated at $6,750.

An estimated eight sample shipments per year at $50 per shipment (four to a traditional environmental laboratory and four to a laboratory specializing in biological analyses) would conservatively cost $400 annually. The cost of shipping the soil gas samples to a air quality laboratory for the first year is considered negligible.

Total analytical costs for a two year treatment scenario is estimated at $44,000.

3.5.11 Maintenance and Modifications

Once the injection campaign has started, the system can be routinely monitored at an operating site by visual inspection of gauges and meters. For less accessible sites the system may have to be remotely monitored in combination with occasionally scheduled site visits. The labor hours for these activities are included in the system monitoring labor subcategory (subsection 3.5.5.4). Actual maintenance would occur only if the system malfunctioned and needed repair; or, if any of the monitoring equipment requires servicing. One such example would be the periodic servicing of a YSI water quality instrument, which requires cleaning and changing out of worn gaskets and membranes from time to time. For the purposes of this cost estimate maintenance labor will be estimated at 10% of the annual system monitoring labor estimate, which would be 50 hours or $3,000 per year.

3.5.12 Demobilization/Site Restoration

Demobilization and site restoration are performed at the conclusion of the treatment project, and would therefore consist of a one time labor cost. It is most likely that at the majority of sites the monitoring wells would remain operable for an indefinite time period and would not have to be abandoned to restore the site.

For this cost estimate, it is assumed that demobilization/site restoration will consist solely of removing all the above ground injection and monitoring equipment, as well as removing all remaining consumables and drummed waste residuals. These tasks are estimated to take two individuals two 10-hour days to complete. Therefore, the 40 hours of labor at $60/hour would incur a $2,400 one time cost for this category.

It should be noted that some states may require well abandonment at some point in time. These requirements can vary from simply grouting the well casings to actual removal of all well casings and related materials. This work would likely be subcontracted and could significantly impact site restoration costs.

Section 4.0
Demonstration Results

4.1 Introduction

4.1.1 Project Background

A pilot-scale technology demonstration of the Enhanced In-Situ Bioremediation process was conducted from March 1998 to August 1999 at the ITTNV Division plant in Roanoke, Virginia. The facility is an active manufacturing plant that produces night vision devices and related night vision products for both government and commercial customers. Groundwater contamination has been detected at several areas of the ITTNV Roanoke facility.

The area focused on during the demonstration is immediately downstream of a solvent release source area. At this locality, several VOCs have been measured at concentrations above regulatory levels in both upper and lower fractured zones of the underlying shallow bedrock. Four specific VOC compounds were designated as "critical parameters" for evaluating the technology: chloroethane, 1,1-dichloroethane, cis-1,2-dichloroethene, and vinyl chloride (CA, 1,1-DCA, cis-1,2-DCE, and VC).

The pilot treatment system that Earth Tech installed within the area of contamination consisted of eleven monitoring points, comprising seven groundwater wells and four soil vapor monitoring points. The groundwater wells consisted of an injection well, four monitoring wells located within the anticipated radius of influence, and two monitoring wells located outside of the anticipated radius of influence. Combinations of air, nutrients, and methane were injected approximately 43 feet bls and into the lower fractured zone over the duration of the demonstration (a period of 18 months).

Although an emphasis was placed on evaluating treatment effectiveness at the injection depth, both the upper and lower fractured zones of the bedrock were sampled and evaluated by the SITE Program. Earth Tech had determined that the upper and lower fracture zones were hydraulically interconnected, based primarily on pumping tests and downhole logging using an acoustic borehole televiewer (ABT) tool. A discussion of the pumping test results and usage of the ABT is included in **Appendix B**. It should also be noted that helium tracer tests, conducted prior to and during the demonstration, confirmed interconnection of upper and lower fracture zones.

4.1.2 Project Objectives

For all SITE demonstrations there are specific objectives that are defined prior to the initiation of field work; each of which is described in a Quality Assurance Project Plan (QAPP). These objectives are subdivided into two categories; primary and secondary. Primary objectives are those goals of the project that need to be achieved to adequately compare demonstration results to the claims made by the developer. The field measurements required for achieving primary objectives are referred to as critical measurements. Secondary objectives are other goals of the project for acquiring additional information of interest about the technology, which are not imperative for verifying developer claims. The field measurements required for achieving secondary objectives are referred to as noncritical measurements.

Table 4-1 presents the one primary and seven secondary objectives of the demonstration, and summarizes the method(s) by which each were evaluated. Except for the cost estimate (*Objective 8*), which is discussed in Section 3, each of these objectives is addressed in this section.

Table 4-1. Demonstration Objectives.

Objective	Description	Method of Evaluation
Primary Objective		
Objective 1	Evaluate the performance of the Earth Tech Enhanced Bioremediation process to determine that, on average, there will be a 75% reduction (with a 90% confidence interval) in the groundwater concentrations of each of the individual target chlorinated organic contaminants after six months of treatment. The target analytes were: • 1,1-Dichloroethane (1,1-DCA) • Chloroethane (CA) • cis-1,2-Dichloroethene (cis-1,2-DCE) • Vinyl Chloride (VC).	Collection of groundwater samples at baseline (immediately before system start-up) and after six months of operation (final) from four critical wells (MW-1, IW-400, MW-401 and MW-403); and collection of these wells over a seven-day period, with one sample recovered from each critical well on each day of sampling (resulting in a total of 28 critical samples at both the baseline and final events). Determination of chlorinated volatile organic compound concentrations in groundwater via EPA SW-846 Methods 5030/8021.
Secondary Objectives		
Objective 2	Evaluate changes (baseline to final) in detectable chlorinated volatile organic compounds, acetone, and isopropyl alcohol, as a result of the methanotrophic process, in seven individual wells within the study area.	Collection of groundwater samples at baseline (immediately before system start-up) and after six months of operation (final) from all seven wells over a seven-day period, with one sample recovered from each critical well on each day of sampling (a total of 28 samples for both baseline and final events).
Objective 3	Evaluate changes in detectable chlorinated volatile organic compounds, acetone, and isopropyl alcohol at two intermediate events during the demonstration. The intermediate sampling to occur after anticipated changes in operating parameters (i.e., after air-only injection and after air/nutrient injection.	Collection of groundwater samples from critical wells during two intermediate events that correspond to changes in the types of injected materials. The samples to be collected over a four-day period, with one sample recovered from each of the four wells on each day of sampling (a total of 16 samples for both intermediate events).
Objective 4	Determine the presence and extent (if any) of chlorinated volatile organic compounds, acetone and isopropyl alcohol in vadose zone soil gas that may be attributable to the injection of gas-phase amendments into the saturated zone. Monitor methane, ethane and ethene periodically as indicators of anaerobic degradation and/or gas injection.	Collect vadose zone soil gas headspace samples from four soil gas monitoring points (SG-1, SG-2, SG-3, and SG-4) during baseline, final, and intermediate events. Analyze the samples for chlorinated VOCs to determine if sparging is occurring. Analyze also for methane, ethane, ethene, and CO_2 to serve as indicators of methane buildup and degradation type.
Objective 5	Evaluate changes in chlorinated VOCs, acetone, and IPA in the shallow zone of the aquifer.	Collect and analyze a limited number of samples from the upper zone of wells IW-400, MW–401, MW-402, and MW-404.
Objective 6	Track changes in the microbial community over the course of the six-month demonstration in groundwater samples as an indicator of microbial activity within the solid-phase of the aquifer.	Collect samples from all seven monitoring wells during baseline, final and intermediate events and analyze for Total Heterotrophs, Total Methanotrophs, and PLFA.
Objective 7	Characterize changes in the groundwater characteristics that may affect, control, or be modified by process performance over the course of the demonstration (e.g., nutrients, total organic carbon, dissolved gases (methane, ethane, ethene), iron, oxygen concentration, oxidation-reduction potential and pH.	Analyze groundwater samples for nitrate, nitrite, phosphate, total organic carbon, total carbon, ammonia, total phosphorous, total iron, sulfide, sulfate, bicarbonate, carbonate, chloride, potassium, sodium, and dissolved gasses (methane, ethane, ethene).
Objective 8	Collect and compile information and data pertaining to the cost of implementation of the Earth Tech Enhanced In-Situ Biological process.	Acquire cost estimates from past SITE experience and from the developer. Evaluate treatment costs for the pilot-system used at Roanoke, and for a larger full-scale system. Break down estimates into 12 cost categories that reflect typical cleanup activities at Superfund sites. (See Section 3)

4.2 Detailed Process Description

The Enhanced In-Situ Bioremediation process is a biostimulation technology developed by the U.S. DOE at the Westinghouse Savannah River Plant site in Aiken, South Carolina. DOE has licensed the process to Earth Tech. Earth Tech is utilizing the patented process to deliver a gaseous phase mixture of air and gaseous-phase nutrients, and methane to contaminated groundwater in fractured bedrock. These enhancements are delivered to contaminated groundwater via one or more injection wells to stimulate and accelerate the growth of existing microbial populations, especially methanotrophs. This type of aerobic bacteria has the ability to metabolize methane and produce enzymes capable of degrading chlorinated solvents and their degradation products to non-hazardous constituents.

The primary components of Earth Tech's treatment system consists of one or more injection wells (IW), air injection equipment, groundwater monitoring wells (MW), and soil gas monitoring points (SG). The injection wells are designed to deliver air, nutrients, and methane to groundwater in shallow bedrock 30 to 50 feet below ground surface. The air was supplied by a compressor that was capable of delivering 15-30 psi and approximately 10-100 scfh to the injection wells.

The monitoring wells and soil vapor monitoring points were installed upgradient, downgradient and laterally to the injection well location(s) to delineate the zone of influence and to monitor groundwater within and outside of the zone of influence. The soil vapor monitoring points can be designed to release vapors that may build up in the overburden. The monitoring wells can be constructed in a manner to allow them to be converted to either injection wells or soil vapor extraction points.

The injection system (**Figure 4-1**) is comprised of air, nutrient, and methane injection equipment. The supply of enhancements is housed in a temporary building or shed. A compressor serves as the air source, and includes a condensate tank ("trap") with a drain, an air line, coalescing filters and pressure regulators and valves. The methane and nitrous oxide provide a source of carbon and nitrogen, respectively. Both of these gases are provided in standard air cylinders and are piped into the main air line using regulators and flow meters. TEP, the phosphorus source, is in liquid state and is stored in a steel tank. Air from the main line is diverted through the tank to volatilize the TEP for subsurface delivery. The air, nitrous oxide, and TEP are injected continuously while the methane is injected on a pulsed schedule. The methane is closely monitored at the injection well head to ensure that the injection concentration does not exceed 4% by volume, thus avoiding the methane LEL of 5%.

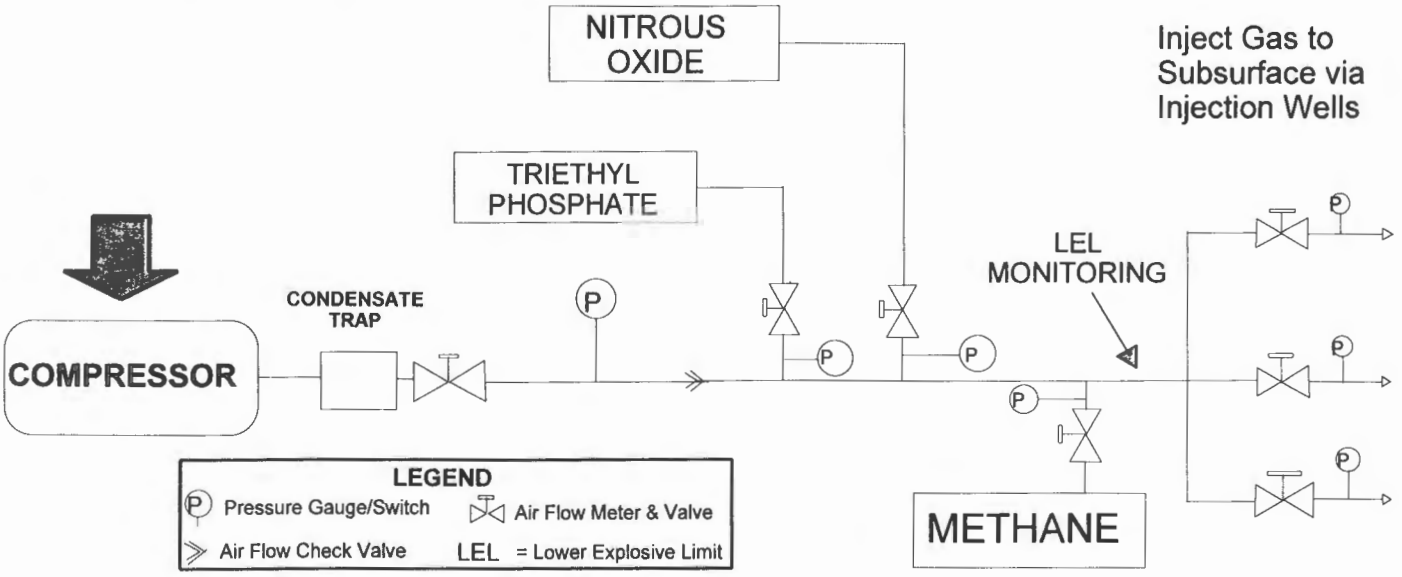

Figure 4-1. Injection System Process Schematic.

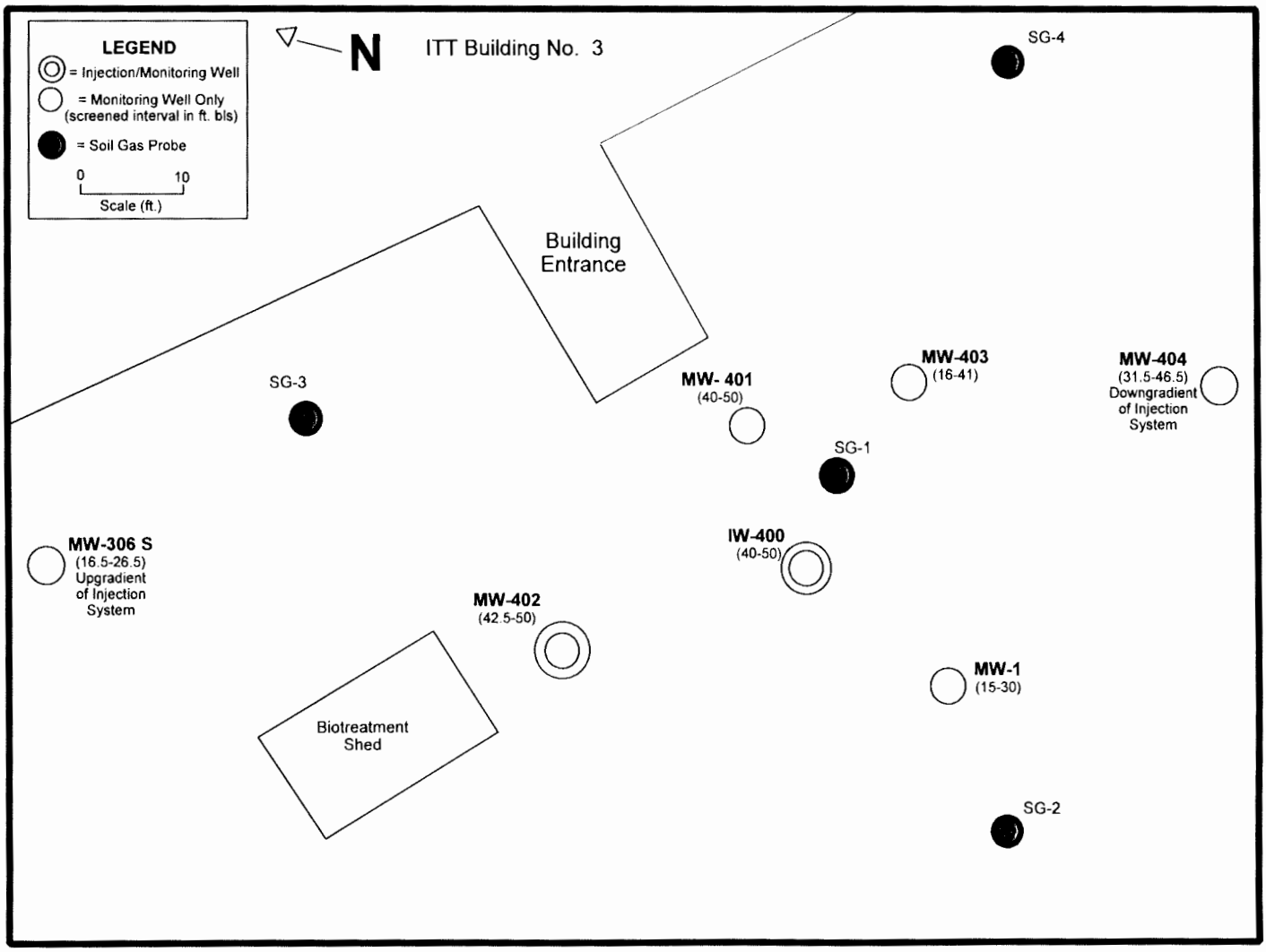

Figure 4-2. Study Area and Monitoring Point Locations for Earth Tech's Treatment System.

Figure 4-2 shows the demonstration study area and the locations of eleven monitoring points comprising the treatment system installed by Earth Tech. Four of the monitoring wells (IW-400, MW-401, MW-402, and MW-404) are considered nested well pairs. Each of these wells is constructed with an outer casing that allows for monitoring an upper zone of fractured bedrock (occurring at about 10½ - 35½ feet bls) and an inner casing that connects to an isolated well screen that separately monitors a lower zone of fractured bedrock (occurring at about 40-50 feet bls). MW-1, MW-306 S and MW-403 consist of a single-cased screen; MW-1 and MW-306 S are considered to monitor the upper fractured zone. MW-403 is considered to monitor the lower fractured zone.

As shown in Figure 4-2, the study area is located adjacent to one of ITTNV's major manufacturing buildings (Building 3). Groundwater contamination in this general area is comprised of both chlorinated and non-chlorinated groups of VOCs. An underground contamination source from a tank spill is located in the vicinity of MW-306 S. VOCs from this spill source have entered the low-permeability silty-clay overburden and have migrated to the underlying bedrock.

Several VOC compounds have been detected above their respective Federal Maximum Contaminant Level (MCL) in MW-306 S and in the downgradient wells to the south. These compounds include actual solvents, such as trichloroethene (TCE) and 1,1,1-trichloroethane (1,1,1-TCA), as well as several of their breakdown products. It was Earth Tech's intent to evaluate the effectiveness of the Enhanced In-Situ Biological process for reducing the mass of VOCs in the demonstration study area, then to potentially expand the treatment into the waste solvent source area and to other source areas at the facility.

A phased approach was planned for the injection campaign to help optimize system operating conditions. Based on dissolved oxygen (DO) and redox measurements, Earth Tech initiated an air only injection phase to change the subsurface environment from anaerobic to aerobic. After approximately eight weeks of air only injection, Earth Tech initiated continuous injection of air and nutrients. Approximately ten weeks into this phase, Earth Tech determined through field measurements that methane was being depleted. As a result, the continuous air and nutrient injection was supplemented by intermittent methane injection. Helium tracer tests were also conducted by Earth Tech during the initial air only injection phase for estimating the injection well zone of influence. Earth Tech continued these tracer tests throughout the demonstration to determine flow path changes.

4.3 Field Activities

4.3.1 Pre-Demonstration Activities

In December of 1997, the SITE Program characterized the contaminants of interest at the proposed demonstration site. Groundwater samples were collected from monitoring wells IW-400, MW-401, MW-402, MW-403 and MW-1. The following conclusions were made:

(1) Detectable levels of chlorinated VOCs were found at each monitoring station;

(2) Detectable levels of isopropyl alcohol (IPA) were encountered at each monitoring station;

(3) The presence and levels of contaminants encountered were consistent with historical data from the site;

(4) 1,1-DCA exhibited the lowest variability of all of the chlorinated VOCs;

(5) Although TCE is a source contaminant at the site, it was only detected in MW-402;

(6) The absence of TCE in other wells, and presence of high concentrations of other chlorinated VOCs is likely due to natural anaerobic degradation of TCE (anaerobic biodegradation does not completely mineralize chlorinated solvents, thus it can result in the production of other chlorinated compounds of similar or greater toxicity).

4.3.2 Sample Collection and Analysis

This subsection describes the general procedures that were used to collect and analyze groundwater samples collected from the seven monitoring wells and the soil gas samples collected from the four soil vapor wells. The sampling strategy developed for the demonstration was based on a statistical design relating to the primary objective (refer to Table 4-1). The statistical design recommended collection of 28 valid samples for conservatively attaining a 90% confidence interval for estimating the baseline to final percent reduction (SAIC,1998). Thus for the baseline and final events, the SITE Program collected one sample (excluding QA samples) from each of the four critical wells per day for seven consecutive days. Collecting samples daily represented a conservative basis for ensuring sample independence based upon the groundwater gradient. This approach also took into account both temporal and spatial variability for the four critical analytes. Therefore, four wells sampled seven consecutive days yielded the 28 samples needed for determining a 75% reduction with a 0.1 level of significance (LOS). For each critical analyte, the concentration for the baseline and final events were calculated by averaging the 28 values.

Table 4-2 presents a summary of the laboratory analyses conducted on samples collected from each sampling point. All wells were purged prior to collecting grab samples using low flow purge techniques, which normally do not require removal of a specific volume of water. However, USEPA Region 3 required that at least one well casing volume be removed. Prior to the demonstration, the SITE team calculated the volume needed to be removed from each of the wells to be sampled. Each of the nested monitoring well pairs were equipped with a set of dedicated bladder pumps, one each for the upper and lower zone. Due to the construction design of the injection wells, bladder pumps could not be fitted down their narrow casings. Thus, a peristaltic pump was used for collecting groundwater samples from the injection wells.

4.3.3 Process Monitoring

Process monitoring was conducted by the SITE field team on a routine daily basis during the baseline, final, and two intermediate sampling events. In addition, Earth Tech conducted monitoring of their system during the entire duration of the demonstration. **Table 4-3** summarizes the SITE process monitoring conducted during the demonstration, the frequency of that monitoring, the criteria for determining stabilized groundwater, and the equipment used.

Table 4-2. Summary of Laboratory Analyses Conducted for the Demonstration.

PARAMETER	TEST METHOD	SAMPLE EVENT			
		Baseline [1] *March 4-12, '98*	**First Intermediate** [2] *April 28-May 1, '98*	**Second Intermediate** [2] *July 13-16, '98*	**Final** [1] *July 28 - Aug.3, '99*
Chemical Analyses of Groundwater					
Chlorinated VOCs	SW-846 5030/8021A	7 samples each from seven lower zone wells	4 samples each from seven lower zone wells	4 samples each from seven lower zone wells	7 samples each from seven lower zone wells
Acetone/Isopropanol	SW-846 8015				
Dissolved gases	RSK 175				
Nitrate/Nitrite-Nitrogen	EPA 352.1	2 samples each from four upper zone wells	1 sample each from four upper zone wells	1 sample each from four upper zone wells	2 samples each from four upper zone wells
Nitrite-Nitrogen	SM 4500-NO_2B				
Phosphate (total, ortho)	EPA 365.1				
Bicarbonate	SM 2320B	1 sample each from seven lower zone wells	1 sample each from seven lower zone wells	1 sample each from seven lower zone wells	1 samples each from seven lower zone wells
Fluoride	SM 4500C				
Carbonate	SM 2320B				
Total Organic Carbon	EPA 415.1 (modified)				
Chloride	EPA 325.3				
Sulfate	EPA 375.4				
Sulfide	EPA 376.1				
Total Sodium	SM 311113				
Total Potassium	EPA 258.1				
Total Carbon	EPA 415.1 (modified)				
Ammonia-Nitrogen	EPA 350.1				
Total Phosphorus	EPA 300.0				
Metals[3]	SW-846 3010/6010				
Biological Analyses of Groundwater					
Total Heterotrophs	SOP	2 samples each from seven lower zone wells	1 sample each from five lower zone wells	1 sample each from five lower zone wells	2 samples each from seven lower zone wells
Total Methanotrophs	SOP				
DNA	SM 9215 M				1 sample each from four upper zone wells
PLFA	SOP GCLIP				
				1 sample each	1 sample each
Chemical Analyses of Soil Gas [4]					
		Baseline	**First**	**Second**	**Fourth Event**
Chlorinated VOCs	Modified TO-14	2 daytime samples each from four soil vapor wells	2 daytime samples each from four soil vapor wells	2 daytime samples each from four soil vapor wells	---
Methane, Ethane, Ethene	Modified TO-14				

[1] Samples were collected on seven consecutive days.
[2] Sample were collected on four consecutive days.
[3] Arsenic, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, nickel, and zinc.
[4] The baseline soil gas sampling event was conducted in conjunction with groundwater sampling. The first and second intermediate soil gas sampling events were conducted on April 22-23, 1998 and July 9-10, 1998, respectively. A fourth soil gas sampling event was conducted September 9-10, 1998 and consisted of two daytime and two nighttime samples collected on consecutive days (in anticipation of the final groundwater sampling event). However, the demonstration was extended into 1999 and a fifth soil gas sampling event was not conducted.

Table 4-3. Summary of Field Measurements Conducted for the Demonstration.

PARAMETER	Criteria for stabilized Groundwater	Measurement Method	Measurement Locations	Frequency
pH	± 0.1 S.U.	YSI multi-parameter probe	At all groundwater sampling locations, including: ♦ MW-1, ♦ MW-306 S, ♦ IW-400, ♦ MW-401, ♦ MW-402, ♦ MW-403, ♦ MW-404.	Prior to collecting any groundwater samples
Temperature	± 0.1 °C	YSI multi-parameter probe		
Specific Conductance	± 10 µmho/cm	YSI multi-parameter probe		
Redox Potential	± 10%	YSI multi-parameter probe		
Dissolved Oxygen	± 10%	YSI multi-parameter probe		
Turbidity	Until reasonably clear of sediment	Visual		

S.U. = Standard units.

4.3.4 Process Residuals

Other than potentially contaminated soil cuttings generated during well and soil probe installation, there are minimal residuals directly associated with the Enhanced In-Situ Bioremediation treatment process. Contaminated groundwater is generated as a result of well purging activities. Contaminated groundwater is also usually generated when sampling the monitoring wells, however if low flow purge techniques (i.e., micropurge) are used the volume of contaminated water can be greatly minimized (USEPA Region 1, 1996). PPE residuals are commonly generated during borehole drilling, well installation, groundwater sampling, and maintenance activities.

4.4 Performance and Data Evaluation

This subsection presents in summary form the performance data obtained during the Earth Tech SITE Demonstration conducted from March, 1998 to July, 1999.

4.4.1 Groundwater VOC Results

To adequately evaluate Earth Tech's treatment system, the SITE Program selected specific monitoring wells to collect and analyze the majority of samples for selected VOC compounds. The selections were based on review of historical site data, results from a pre-demonstration sampling episode, and on a statistical analysis.

Emphasis was placed on sampling the lower fractured zone of bedrock (the targeted injection zone) and the four monitoring wells located within the anticipated lateral radius of influence. These wells were designated as "critical wells" and included IW-400L, MW-401L, MW-403L, and MW-1. The first three wells are designated with an "L" since the critical samples were collected at the midpoint of the well screens that monitor the lower zone of fractured bedrock (approximately 40- 50 feet bls). MW-1 is screened from a depth of approximately 15-30 feet bls and monitors the upper zone of fractured bedrock. All three of the non-injection wells are within 25 feet of injection well IW-400 and all four wells are within 50 feet of one another (refer back to Figure 4-2).

4.4.1.1 Critical VOC Results

There were four specific contaminants associated with the critical wells that exhibited minimal acceptable temporal and spatial variability for evaluating the technology. These "critical parameters" were chloroethane (CA), 1,1-Dichloroethane (1,1-DCA), cis-1,2-Dichloroethene (cis-1,2-DCE), and Vinyl Chloride (VC).

The primary objective of the demonstration was to evaluate the performance of the Earth Tech Enhanced Bioremediation process to determine that, on average, there will be a 75% reduction (with a 90% confidence interval) in the groundwater concentrations of each of the individual target chlorinated organic contaminants after six months of treatment. The statistical design recommended collection of 28 samples to confidently detect a 75% reduction for these compounds within individual wells, from baseline to final events. Thus, for both baseline and final events, one groundwater sample was collected and analyzed from each of the four critical wells for seven consecutive days (28 samples per event). For each critical analyte, the concentration for the baseline and final events were calculated by averaging the 28 values.

Table 4-4 presents the 28 baseline and 28 final values for each of the four critical compounds for samples collected over a seven consecutive day period from each of the four critical wells. Also presented are the results from two intermediate sampling events in which one groundwater sample was collected and analyzed from each of the four critical wells for four consecutive days (a total of 16 samples per event). Collective results and statistics for the critical VOCs for all four critical wells and for the four events are presented at the bottom of Table 4-4.

The collective average percent change values listed in the "Final" column for the four critical wells indicate that concentrations of the four critical VOCs were reduced from baseline to final events as follows: CA (35%); 1,1-DCA (80%); cis-1,2-DCE (97%); and VC (96%). The lower confidence limit (LCL) and the upper confidence limit (UCL) were also calculated for percent reduction. The LCL can be thought of as the most conservative estimate of reduction. The UCL can be thought of as the best possible reduction the technology may have achieved. The 90% confidence intervals (LCL-UCL) for the four compounds were: CA (4 -54%); 1,1-DCA (71-86%); cis-1,2-DCE (95-98%); and VC (92-98%). Therefore, cis-1,2-DCE and VC achieved the 75% reduction goal with a 0.1 LOS; 1,1-DCA was just under this goal at 71% LCL and CA reduction was barely significant at 4% LCL.

To depict a visual trend of the treatment effectiveness over the course of the demonstration, the averaged critical VOC data in Table 4-4 has been plotted in **Figure 4-3** to correspond with the injection phase being used during that time period. Prior to the demonstration, there was evidence that anaerobic degradation of TCE was naturally occurring at the site due to the presence of methane and the absence of TCE in some of the wells. Thus, at the outset of the demonstration (March 1998), Earth Tech initiated an air-only injection phase involving the continuous injection of air at ~30-40 scfh into injection well IW-400. The purpose of the air-only injection was to help evaluate if methanotrophic degradation of chlorinated VOCs could be stimulated through the addition of oxygen to the subsurface.

During this initial five-week period of continuous air injection, an apparent sharp decrease in concentration for each critical compound is reflected in all four plots in Figure 4-3. The similar patterns exhibited by all four plots suggest that biological degradation was occurring. However, nutrient results from previous sampling events indicated that the subsurface may have been nutrient deficient and significant fluctuations in groundwater elevation around the same time period created difficulty for determining if and how much of the sharp decrease in contaminant concentration was in fact due to biological degradation (i.e., as opposed to groundwater dilution).

To address the potential groundwater dilution issue, the water levels in the four critical wells have been plotted against the totaled average critical VOCs concentrations of the four critical wells (**Figure 4-4**). As illustrated the highest concentrations of critical VOCs were measured during the December 1997 Pre-demonstration sampling event, during a period of depressed water levels. However, just three months later during the Baseline sampling event heavy precipitation had caused the raising of the groundwater to peak elevations. The inverse relationship between groundwater levels and contaminant concentrations prior to the start of treatment suggests that the critical VOC concentrations were diluted by more than half (i.e., from ~ 11,600 µg/l to ~ 5,500 µg/l).

During the initial five-week period of continuous air injection, this inverse relationship did not occur. Instead, the water levels in certain wells dropped slightly with the continued decrease in contaminant concentration (Figure 4-4). This suggests that groundwater level was not a factor for the drop in contaminant concentration. Following the air-only injection phase, Earth Tech initiated a "Nutrient Addition" phase immediately following the first intermediate sampling event. This uninterrupted addition of air and nutrients was continued for approximately nine weeks, at which time the SITE Program conducted a second intermediate sampling event. The plots in Figure 4-3 indicate average contaminant levels to actually increase for three of the four compounds during the nutrient addition phase. The lone exception was VC whose average concentration essentially remained constant. During this same time period the groundwater lowered considerably (~2½ to 4 ft. as shown in Figure 4-4). This may have contributed to the apparent VOC increase.

Between the second intermediate and final sampling events (~12-month period), Earth Tech made adjustments to their injection system. During this period of time, continuous air and nutrient injection was conducted and methane was injected on a pulsed schedule. Groundwater sampling by Earth Tech indicated that satisfactory VOC reductions were not occurring in some demonstration wells due to a limited delivery of amendments (i.e., low methane levels indicated that TEP levels were not adequate and DO was not increasing to levels needed for sustaining aerobic conditions). Therefore, during the last seven months of the demonstration, MW-402 was converted to a second injection well. With modifications in place, average concentrations for three of the four critical compounds

Table 4-4. Critical VOC Results for Critical Wells.

Sample Location (Screened Interval)	CRITICAL VOC															
	CA (µg/l)				1,1- DCA (µg/l)				cis-1,2-DCE (µg/l)				VC (µg/l)			
	Sampling Event															
	BL	1st & 2nd Intermediate		Final	BL	1st & 2nd Intermediate		Final	BL	1ST & 2nd Intermediate		Final	BL	1st & 2nd Intermediate		Final
MW-1 (15'-30')	530	370	470	290	1,300	970	1,200	167	8,300	1,800	1,500	18	2,600	1,100	660	6.6
	790	400	550	428	1,900	810	1,300	200	11,000	2,200	2,000	22	3,750	1,100	970	11
	670	460	640	271	1,700	1,200	1,700	140	11,000	4,300	2,700	18	3,100	1,800	1,500	8.6
	850	550	720	293	2,200	1,300	1,800	152	15,000	1,700	3,100	17	5,000	2,100	1,800	10
	1,300	—	—	271	3,800	—	—	142	16,000	—	—	13	8,100	—	—	6.7
	760	—	—	289	1,800	—	—	119	12,000	—	—	7.3	3,600	—	—	3.8
	730	—	—	306	1,800	—	—	118	10,000	—	—	ND	3,400	—	—	5
Avg.[1]	**800**	**450**	**600**	**310**	**2,100**	**1,100**	**1,500**	**150**	**12,000**	**2,500**	**2,300**	**14**	**4,200**	**1,500**	**1,200**	**7.4**
CV[2]	*0.30*	*0.18*	*0.18*	*0.18*	*0.39*	*0.21*	*0.20*	*0.19*	*0.23*	*0.49*	*0.31*	*0.56*	*0.44*	*0.33*	*0.42*	*0.35*
%Change[3]	—	*- 45*	*- 26*	*- 62*	—	*- 48*	*- 28*	*- 93*	—	*- 79*	*- 80*	*- 100*	—	*- 64*	*- 71*	*- 100*
90% LCL[4]	—	*- 26*	*- 1*	*- 50*	—	*- 27*	*0*	*- 90*	—	*- 66*	*- 72*	*- 100*	—	*- 44*	*- 53*	*- 100*
IW-400 L (40'-50')	150	83	100	232	760	590	120	283	370	530	270	272	170	190	35	116
	160	62	190	230	690	370	260	269	300	360	890	160	170	130	120	90
	170	67	260	259	650	400	490	272	290	300	1,900	193	140	120	270	90
	240	68	320	222	750	300	670	264	330	250	2,500	148	190	81	250	75
	230	—	—	227	750	—	—	337	280	—	—	133	170	—	—	67
	200	—	—	242	680	—	—	275	130	—	—	119	95	—	—	74
	170	—	—	257	590	—	—	312	66	—	—	108	55	—	—	69
Avg.[1]	**190**	**70**	**220**	**240**	**700**	**420**	**390**	**290**	**250**	**360**	**1,400**	**160**	**140**	**130**	**170**	**83**
CV[2]	*0.19*	*0.13*	*0.44*	*0.06*	*0.09*	*0.30*	*0.63*	*0.09*	*0.44*	*0.34*	*0.72*	*0.35*	*0.35*	*0.35*	*0.66*	*0.21*
%Change[3]	—	*- 63*	*+15*	*+26*	—	*- 40*	*- 45*	*- 59*	—	*+43*	*+450*	*- 36*	—	*- 8*	*- 19*	*- 41*
90 % LCL[4]	—	*- 55*	*0*	*4*	—	*- 19*	*- 3*	*- 54*	—	*0*	*0*	*- 4*	—	*0*	*0*	*- 20*
MW-401 L (40'-50')	150	83	48	267	700	500	190	186	290	440	120	281	170	160	28	119
	140	78	100	245	570	450	310	273	250	310	380	165	160	120	120	89
	220	56	120	306	770	320	390	354	270	250	180	220	190	89	110	110
	245	63	130	302	695	290	350	318	335	210	330	165	210	61	89	82
	160	—	—	284	530	—	—	325	250	—	—	142	170	—	—	80
	200	—	—	261	750	—	—	320	110	—	—	111	130	—	—	63
	190	—	—	300	580	—	—	366	150	—	—	143	110	—	—	74
Avg.[1]	**190**	**70**	**100**	**280**	**660**	**390**	**310**	**310**	**240**	**300**	**250**	**180**	**160**	**110**	**90**	**90**
CV[2]	*0.21*	*0.18*	*0.37*	*0.08*	*0.14*	*0.26*	*0.28*	*0.20*	*0.33*	*0.33*	*0.49*	*0.33*	*0.21*	*0.40*	*0.48*	*0.23*
%Change[3]	—	*- 62*	*- 47*	*+51*	—	*- 41*	*- 53*	*- 53*	—	*+28*	*+7*	*- 26*	—	*- 34*	*- 47*	*- 46*
90 % LCL[4]	—	*- 52*	*- 22*	*+21*	—	*- 21*	*- 36*	*- 43*	—	*0*	*0*	*0*	—	*- 1*	*- 15*	*- 31*
MW-403 L (16'-41')[5]	160	94	81	43	300	140	170	20	8.8	86	200	13	6.8	37	98	1.2
	140	110	68	26	380	140	100	11	7.2	130	87	6.0	7.1	53	53	1.0
	160	70	56	27	500	220	100	13	6.4	120	78	5.8	6.9	44	36	1.0
	180	61	67	25	480	260	120	13	5.0	130	74	5.3	5.2	52	30	0.9
	125	—	—	25	360	—	—	15	4.3	—	—	4.8	4.6	—	—	0.5
	96	—	—	23	270	—	—	14	3.7	—	—	3.8	2.6	—	—	1.1
	100	—	—	23	250	—	—	14	4.3	—	—	4.5	2.9	—	—	1.1
Avg.[1]	**140**	**84**	**68**	**27**	**360**	**190**	**120**	**14**	**5.7**	**120**	**110**	**6.2**	**5.2**	**47**	**54**	**1.0**
CV[2]	*0.23*	*0.27*	*0.15*	*0.25*	*0.27*	*0.32*	*0.27*	*0.19*	*0.33*	*0.18*	*0.55*	*0.49*	*0.37*	*0.16*	*0.57*	*0.24*
%Change[3]	—	*- 39*	*- 50*	*- 80*	—	*- 48*	*- 66*	*- 96*	—	*+1,960*	*+1,840*	*+8*	—	*+800*	*+950*	*- 81*
90 % LEL[4]	—	*- 16*	*- 37*	*- 74*	—	*- 25*	*- 53*	*- 95*	—	*+1,220*	*+460*	*0*	—	*+460*	*+170*	*- 74*
Collective Results for the Critical Wells: MW-1, IW-400L, MW-401L,and MW-403L																
Samp. Tot.	28	16	16	28	28	16	16	28	28	16	16	28	28	16	16	28
Avg.[1]	**330**	**170**	**250**	**210**	**950**	**520**	**580**	**190**	**3,100**	**820**	**1,000**	**89**	**1,100**	**450**	**390**	**45**
CV[2]	*0.92*	*1.0*	*0.92*	*0.54*	*0.82*	*0.71*	*1.0*	*0.66*	*1.7*	*1.4*	*1.1*	*1.0*	*1.8*	*1.5*	*1.5*	*0.97*
%Change[3]	—	*- 49*	*- 26*	*- 35*	—	*- 45*	*- 39*	*- 80*	—	*- 74*	*- 67*	*- 97*	—	*- 60*	*- 66*	*- 96*
90 % LEL[4]	—	*- 12*	*0*	*- 4*	—	*- 15*	*0*	*- 71*	—	*- 44*	*- 35*	*- 95*	—	*- 13*	*- 26*	*- 92*

[1] Average values are rounded to two significant digits.

[2] Coefficient of Variance (sample standard deviation/sample mean).

[3] % Change represents the average % reduction (-) or increase (+).

[4] Represents the 90% Lower Confidence Level (LCL) for the average reduction (-) or increase (+).

[5] The shallower screen interval is due to the lower fractured zone occurring at a higher elevation at the MW-403 L location.

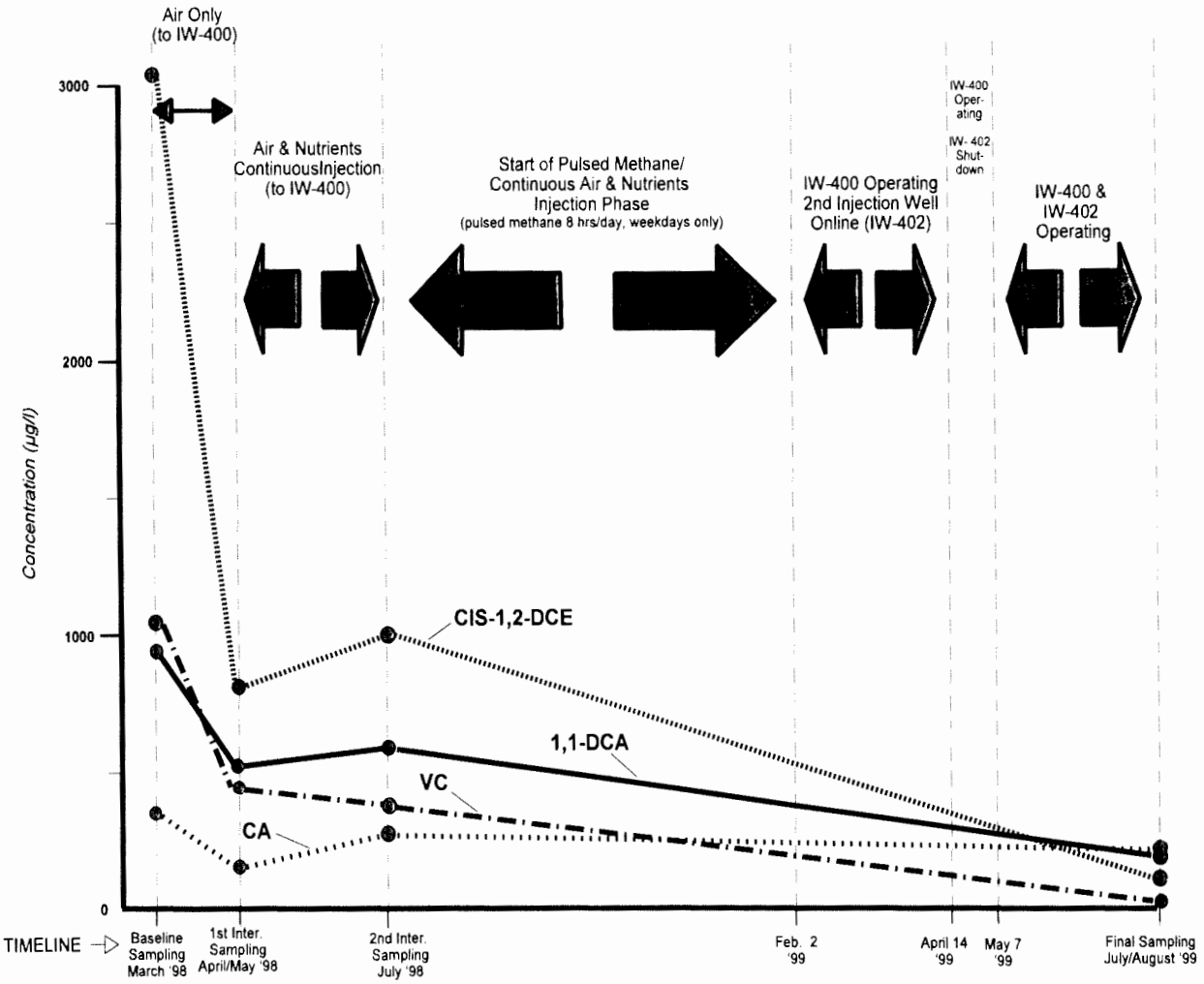

Figure 4-3. Critical VOC Concentrations Measured Over the Duration of the Demonstration.

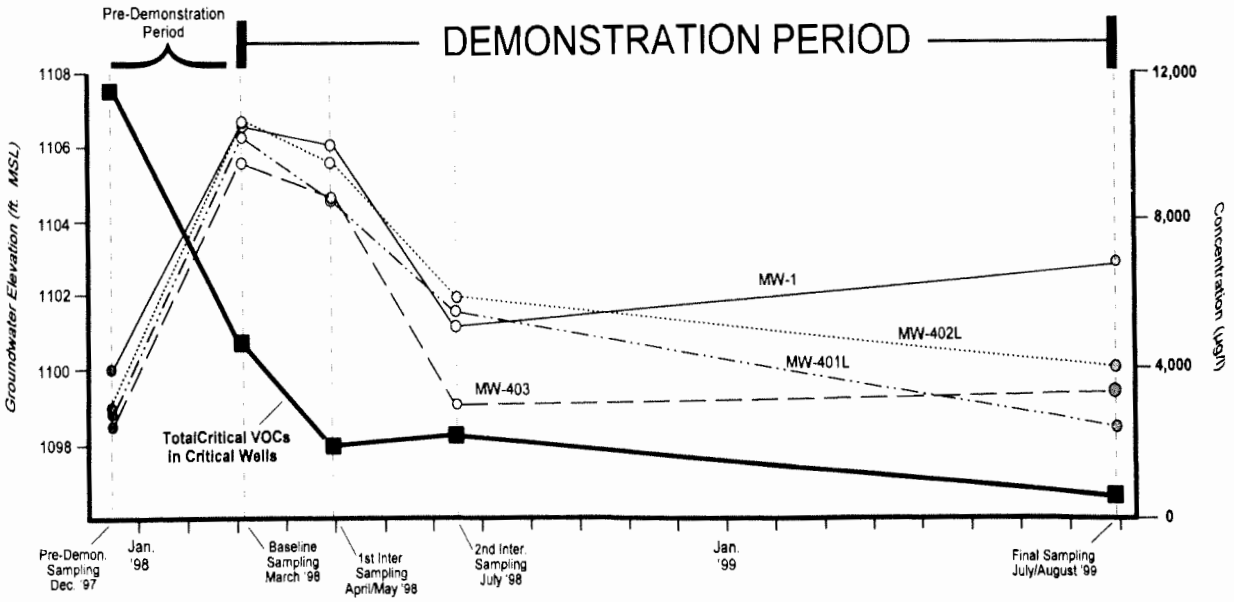

Figure 4-4. Groundwater Elevations Vs. Critical VOC Concentrations for Select Wells.

appear to significantly decrease to below the second intermediate levels (except for CA).

CA was measured to only slightly decrease on average due to an increase in concentration of that compound in the shallower screened MW-1. Although CA baseline concentrations were lower than the other three critical compounds, there is no readily apparent explanation for the relatively poorer reductions in CA concentrations. In fact, Earth Tech had anticipated CA to be the easiest of the four compounds to degrade since it is less complex molecularly. There was not a significant change in the static groundwater elevations of the four critical wells from the second intermediate to final sampling events. Thus, the groundwater level is not believed to have been a factor in the decrease in critical VOC concentrations (Figure 4-4). However, the apparent short-term dilution effect on VOC concentrations, caused by anomalously high baseline groundwater elevations, may have biased low the critical VOC baseline concentration. As a result, observed reductions in critical VOCs concentrations may be conservative.

4.4.1.2 Non-Critical VOC Results

In addition to the four critical compounds, there were five additional VOCs analyzed in the same four wells at the same frequency. These "non-critical" compounds included 1,1-Dichloroethene (1,1-DCE), 1,1,1-Trichloroethane (1,1,1-TCA), Trichloroethene (TCE), Acetone, and Isopropanol (IPA). These compounds exhibited a statistically unacceptable spatial and temporal variability during the pre-demonstration sampling. As a result, less rigorous quality assurance was conducted for these five parameters.

Table 4-5 presents the 28 baseline and 28 final values for each of the five non-critical compounds for samples collected over a seven consecutive day period from each of the four critical wells. Also presented are the results from two intermediate sampling events in which one groundwater sample was collected and analyzed from each of the four critical wells for four consecutive days (a total of 16 samples per event).

The collective results and statistics for the non-critical VOC results for all four critical wells and for the four events is presented at the bottom of Table 4-5. The collective average percent change values listed in the "Final" column for the four critical wells indicates that concentrations of four of the five non-critical VOCs were reduced from baseline to final events as follows: 1,1-DCE (94%); 1,1,1-TCA (75%); acetone (91%), and IPA (95%). The 90% confidence intervals (LCL-UCL) for these four VOCs were: 1,1-DCE (87-97%); 1,1,1-TCA (48-86%); acetone (78-96%), and IPA (86 -98%). TCE, which was non-detectable in many of the baseline samples was shown on average to increase significantly (i.e., > 600% with a 90% LCL of + 47%). However, the variability in the TCE data from non-detectable to detectable on consecutive days in the same well (e.g., MW-401L) may indicate a constant flux in the concentration of that compound.

4.4.1.3 Upper Versus Lower Fractured Zones

Although the lower fractured zone of the bedrock aquifer was the focus of the demonstration groundwater sampling, samples were also collected from the upper fractured zone that occurs approximately between 10.5 and 36.5 feet bls. There was a reduced number of upper zone samples collected and therefore the results obtained do not constitute a statistically valid sample set. However the data is still useful for evaluating the potential reduction of VOC compounds contained in fractures located well above the treatment injection depth.

In **Tables 4-6** and **4-7**, groundwater VOC data for monitoring wells in the immediate area of treatment injection has been averaged and segregated into "upper" and "lower" fractured zones, respectively. Both tables include the zone-segregated wells IW-400, MW-401, and MW-402. Table 4-6 additionally includes MW-1, which is the closest well to IW-400 that monitors the upper zone solely. Table 4-7 additionally includes MW-403, which is the closest well to IW-400 that monitors the lower zone solely. All of the wells in both tables are within 25 feet of injection well IW-400 and are within 50 feet of one another (refer back to Figure 4-2).

Comparison of the totaled average critical VOCs in Tables 4-6 and 4-7 indicates that the upper fractured zone contained significantly higher initial concentrations of critical VOCs than did the lower fractured zone. The data also indicate that although the air-nutrient-methane enhancements were injected into the lower fractured zone, substantial reductions of VOC concentrations have apparently occurred in the upper fractured zone.

Table 4-5. Non-Critical VOC Results for Critical Wells.

Sample Location (Screened Interval)	NON-CRITICAL VOC																			
	1,1-DCE (µg/l)				1,1,1- TCA (µg/l)				TCE (µg/l)				Acetone (mg/l)				IPA (mg/l)			
	Sampling Event																			
	BL	1st & 2nd Intermed.		Final	BL	1st & 2nd Intermed.		Final	BL	1ST & 2nd Intermed.		Final	BL	1st & 2nd Intermed.		Final	BL	1st & 2nd Intermed.		Final
MW-1 (15'-30')	140	34	81	0.7	650	48	130	1.8	ND	ND	79	3.2	130	—	64	5.1	190	—	—	5.1
	230	39	83	2.1	785	180	190	2.3	ND	ND	80	ND	230	100	150	16	280	97	100	14
	210	40	87	0.7	720	580	280	1.0	ND	ND	82	6.4	180	160	260	21	230	170	220	19
	260	56	100	1.9	1,100	960	350	2.0	ND	ND	86	1.7	280	190	—	18	370	190	—	14
	280	—	—	0.3	1,700	—	—	0.5	ND	—	—	0.3	415	—	—	21	555	—	—	19
	190	—	—	0.7	710	—	—	0.6	ND	—	—	0.5	270	—	—	13	330	—	—	10
		—	—	0.6	610	—	—	0.6	ND	—	—	0.5	230	—	—	17	260	—		13
Avg.[1]	**220**	**42**	**88**	**1.0**	**900**	**440**	**240**	**1.3**	**0**	**0**	**82**	**1.8**	**250**	**150**	**160**	**16**	**320**	**150**	**160**	**13**
CV[2]	*0.22*	*0.23*	*0.10*	*0.71*	*0.43*	*0.93*	*0.41*	*0.6*	—	—	*0.04*	*1.3*	*0.36*	*0.31*	*0.62*	*0.35*	*0.38*	*0.32*	*0.53*	*0.37*
%Change[3]	—	*- 80*	*- 59*	*- 100*	—	*- 51*	*- 74*	*- 100*	—	—	—	—	—	*- 39*	*- 36*	*- 94*	—	*- 52*	*- 49*	*- 96*
90% LCL[4]	—	*- 74*	*- 50*	*- 99*	—	*0*	*- 57*	*- 100*	—	—	—	—	—	*- 8*	*0*	*- 91*	—	*- 25*	*- 2*	*- 94*
IW-400L (40'-50')	ND	10	ND	7.8	51	ND	12	159	ND	39	21	120	ND	1.3	160	3.6	3.2	3	120	1.3
	17	8	12	6.7	55	94	160	133	14	26	9.6	102	ND	0.7	180	2.8	2.8	1.3	110	0.6
	17	6.9	14	7.5	59	91	290	143	17	40	5.2	90	ND	0.5	280	1.8	2.8	0.8	260	ND
	6.8	6.4	16	5.3	82	110	380	110	18	54	4.1	68	ND	ND	270	1.2	3.4	ND	—	0.5
	6.8	—	—	4.5	78	—	—	100	18	—	—	64	ND	—	—	1.4	3.1	—	—	0.8
	ND	—	—	4.8	58	—	—	96	14	—	—	64	ND	—	—	1.2	1.5	—	—	0.6
	ND	—	—	4.7	53	—	—	108	14	—	—	62	ND	—	—	1.3	ND	—	—	0.9
Avg.[1]	**6.8**	**7.8**	**11**	**5.9**	**62**	**74**	**210**	**120**	**14**	**40**	**10**	**81**	**0**	**0.6**	**220**	**1.9**	**2.4**	**1.3**	**160**	**0.7**
CV[2]	*1.1*	*0.20*	*0.68*	*0.24*	*0.20*	*0.68*	*0.76*	*0.20*	*0.46*	*0.29*	*0.77*	*0.28*	—	*0.86*	*0.28*	*0.49*	*0.51*	*0.99*	*0.51*	*0.59*
%Change[3]	—	*+15*	*+54*	*+13*	—	*+18*	*+240*	*+95*	*4*	*+190*	*- 27*	*+500*	—	—	—	—	—	*- 47*	*+6,700*	*- 72*
90 % LCL[4]	—	*0*	*0*	*0*	—	*0*	*0*	*+46*	—	*+37*	*0*	*+210*	—	—	—	—	—	*0*	*+1,100*	*- 53*
MW-401L (40'-50')	ND	9.7	5.1	9.4	67	—	72	184	ND	63	432	205	ND	0.8	0.4	2.5	2.1	2	0.7	2.1
	17	7.3	15	7.2	83	93	170	136	28	38	110	138	ND	0.6	1.1	2.5	ND	1.2	1.1	1.1
	17	8.6	13	7.7	82	130	180	160	ND	93	110	117	ND	ND	0.9	2.0	2	0.5	1.3	1.1
	7.2	6.9	8.6	6.6	99	120	160	131	30	85	100	91	ND	ND	0.6	1.5	3	ND	0.6	1.6
	7.2	—	—	7.2	92	—	—	117	ND	—	—	86	ND	—	—	1.6	ND	—	—	1.7
	ND	—	—	4.5	66	—	—	101	12	—	—	66	ND	—	—	1.7	ND	—	—	2.0
	12	—	—	7.7	67	—	—	129	17	—	—	75	ND	—	—	1.5	ND	—	—	1.8
Avg.[1]	**8.6**	**8.1**	**10**	**7.2**	**79**	**110**	**150**	**140**	**12**	**70**	**91**	**110**	**0**	**0.4**	**0.8**	**1.9**	**1.0**	**0.9**	**0.9**	**1.6**
CV[2]	*1.2*	*0.16*	*0.43*	*0.20*	*0.17*	*0.17*	*0.34*	*0.20*	*1.1*	*0.35*	*0.35*	*0.43*	—	*1.2*	*0.41*	*0.23*	*1.3*	*0.94*	*0.36*	*0.24*
%Change[3]	—	*- 6*	*+21*	*- 17*	—	*+44*	*+83*	*+72*	—	*+460*	*+630*	*+790*	—	—	—	—	—	*- 9*	*- 9*	*+61*
90 % LCL[4]	—	*0*	*0*	*0*	—	*+5*	*+5*	*+33*	—	*0*	*0*	*0*	—	—	—	—	—	*0*	*0*	*0*
MW-403L (16'- 41')[5]	*ND*	1.7	2.2	0.5	6.5	28	9.4	3.2	ND	2.8	2.7	2.9	ND	3	6	11	ND	3	5	7.2
	0.3	2.2	1.9	0.5	6.7	25	8.3	3.6	0.7	4.3	3.8	2.6	ND	5	3	2.5	ND	—	4	1.9
	0.3	2.2	2.1	0.6	10	34	17	4.2	0.7	6.9	6.5	2.5	ND	0.8	2	1.4	ND	0.8	3	1.2
	0.2	3.3	2.2	0.5	11	45	23	4.8	0.8	11	7	2.6	ND	ND	1	0.8	ND	ND	1.3	0.5
	0.1	—	—	0.2	9.7	—	—	4.9	0.6	—	—	2.8	ND	—	—	0.4	ND	—	—	ND
	0.3	—	—	0.5	2.9	—	—	4.8	0.8	—	—	2.5	ND	—	—	0.3	ND	—	—	ND
	0.3	—	—	0.6	1.9	—	—	5.0	1.0	—	—	2.6	ND	—	—	0.2	ND	—	—	ND
Avg.[1]	**0.2**	**2.4**	**2.1**	**0.5**	**7.0**	**33**	**14**	**4.4**	**0.6**	**6.3**	**5.0**	**2.6**	**0.0**	**2.2**	**3**	**2.4**	**0.0**	**1.3**	**3.3**	**1.5**
CV[2]	*0.56*	*0.29*	*0.07*	*0.28*	*0.51*	*0.27*	*0.41*	*0.16*	*0.49*	*0.57*	*0.42*	*0.06*	—	*1.0*	*0.72*	*1.7*	—	*1.2*	*0.47*	*1.7*
%Change[3]	—	*+1,000*	*+910*	*+133*	—	*+380*	*+110*	*- 37*	—	*+860*	*+670*	*+310*	—	—	—	—	—	—	—	—
90 % LEL[4]	—	*+350*	*+400*	*+3*	—	*+110*	*0*	*- 8*	—	*+92*	*+170*	*+130*	—		—	—	—	—	—	—
Collective Results for MW- 1, IW-400L, MW-401L,and MW-403L																				
Samp. Tot.	28	16	16	28	28	16	16	28	28	16	16	28	28	16	16	28	28	16	16	28
Avg.[1]	**59**	**15**	**28**	**3.6**	**260**	**170**	**150**	**66**	**6.7**	**29**	**47**	**49**	**62**	**31**	**92**	**5.6**	**80**	**34**	**64**	**4.3**
CV[2]	*1.7*	*1.1*	*1.3*	*0.87*	*1.6*	*1.5*	*0.82*	*1.0*	*1.4*	*1.1*	*0.93*	*1.1*	*1.9*	*2.1*	*1.2*	*1.3*	*1.9*	*2.0*	*1.4*	*1.4*
%Change[3]	—	*- 74*	*- 52*	*- 94*	—	*- 35*	*- 42*	*- 75*	—	*+330*	*+600*	*+640*	—	*- 50*	*+48*	*- 91*	—	*- 58*	*- 20*	*- 95*
90 % LEL[4]	—	*- 48*	*- 1*	*- 87*	—	*0*	*0*	*- 48*	—	*0*	*+19*	*+47*	—	*0*	*0*	*- 78*	—	*0*	*0*	*- 86*

[1] Average values are rounded to two significant digits.
[2] Coefficient of Variance
[3] % Change represents the average % reduction (-) or increase (+).
[4] Represents the 90% Lower Confidence Level (LCL) for the average reduction (-) or increase (+).
[5]The shallower screen interval is due to the lower fractured zone occurring at a higher elevation at the MW-403 L location.

Table 4-6. Critical VOCs in Upper Fractured Zone in Immediate Treatment Area (µg/l)[1].

Parameter	Well I.D.	Fracture Zone Interval	SAMPLING EVENT				Percent Change[4]
			Baseline [2]	First Intermediate [3]	Second Intermediate [3]	Final [2]	
Chloroethane	MW-1	15-30	800	450	600	310	-61 %
	IW-400	0-26.5	620	450	140	310	- 50 %
	MW-401	0-31.6	200	120	170	63	- 69 %
	MW-402	0-36.5	220 J	100	160	350	+ 59 %
	Average		**460**	**280**	**270**	**260**	**- 44 %**
1,1-DCA	MW-1	15-30	2,100	1,100	1,500	150	- 93 %
	IW-400	0-26.5	1,200	680	390	65	- 95 %
	MW-401	0-31.6	520	440	520	52	- 90 %
	MW-402	0-36.5	2,100	1,600	700	1,100	- 48 %
	Average		**1,500**	**960**	**780**	**340**	**- 77 %**
cis-1,2-DCE	MW-1	15-30	12,000	2,500	2,300	14	- > 99 %
	IW-400	0-26.5	5,400	1,700	280	6.7	- > 99 %
	MW-401	0-31.6	2,300	2,700	2,200	22	- 99 %
	MW-402	0-36.5	8,000	8,500	2,700	1,400	- 83 %
	Average		**6,900**	**3,900**	**1,900**	**360**	**- 95 %**
Vinyl Chloride	MW-1	15-30	4,200	1,500	1,200	7.4	- > 99 %
	IW-400	0-26.5	1,600	560	77	4.1	- > 99 %
	MW-401	0-31.6	1,000	800	590	7.5	- 99 %
	MW-402	0-36.5	5,100	4,100	1,300	320	- 94 %
	Average		**3,000**	**1,700**	**790**	**85**	**- 97 %**
Total Average Critical VOCs Average of all 16 Samples			**11,860** **3,000**	**6,840** **2,200**	**3,740** **930**	**1,045** **260**	**- 91 %** **- 91 %**

[1] All values have been rounded to two significant digits. SW-846 5031/8021A were the analytical methods used.
[2] Baseline and final concentration values for the MW-1 represent the average of 7 sample results collected over 7 consecutive days. Baseline and final values for the other three wells represent the average of two sample results collected on two separate days, one of which being the average of duplicates.
[3] Intermediate concentration values for MW-1 represent the average of 4 results collected over 4 consecutive days. Baseline and final values for the other three wells represent the average of two sample results collected on two separate days, one of which being the average of duplicates.
[4] Percent Change compares Final to Baseline Sampling Events.
J = estimated value.

Table 4-7. Critical VOCs in Lower Fractured Zone in Immediate Treatment Area (µg/l)

Parameter	Well I.D.	Fracture Zone Interval	SAMPLING EVENT				Percent Change[4]
			Baseline [2]	First Intermediate [3]	Second Intermediate [3]	Final [2]	
Chloroethane	IW-400	40-50	190	70	220	240	+ 26 %
	MW-401	40-50	190	70	100	280	+ 47 %
	MW-402	42.5-50	180	250 J	320	590	+ 330 %
	MW-403	16-41	140	84	68	27	- 81 %
	Average		**180**	**120**	**180**	**280**	**+ 56 %**
1,1-DCA	IW-400	40-50	700	420	390	290	- 59 %
	MW-401	40-50	660	390	310	310	- 53 %
	MW-402	42.5-50	1,100	1,300	1,500	1,400	+ 27 %
	MW-403	16-41	360	190	120	14	- 96 %
	Average		**700**	**580**	**580**	**500**	**- 29 %**
cis-1,2-DCE	IW-400	40-50	250	360	1,400	160	- 36 %
	MW-401	40-50	240	300	250	180	- 25 %
	MW-402	42.5-50	4,800	6,000	5,200	1,800	- 63 %
	MW-403	16-41	5.7	120	110	6.2	+ 8.8 %
	Average		**1,300**	**1,700**	**1,740**	**540**	**- 59 %**
Vinyl Chloride	IW-400	40-50	140	130	170	83	- 41 %
	MW-401	40-50	160	110	87	88	- 45 %
	MW-402	42.5-50	640	780	870	480	- 25 %
	MW-403	16-41	5.2	47	54	1.0	- 81 %
	Average		**240**	**270**	**300**	**160**	**- 33 %**
Total Average Critical VOCs Average of all 16 Samples			**2,420** **610**	**2,670** **660**	**2,800** **700**	**1,480** **370**	**- 39 %** **- 39 %**

[1] All values have been rounded to two significant digits. SW-846 5031/8021A were the analytical methods used.
[2] Baseline and final concentration values for the lower zone represent the average of 7 sample results collected over 7 consecutive days.
[3] Intermediate concentration values for the lower zone represent the average of 4 results collected over 4 consecutive days.
[4] Percent Change compares Final to Baseline Sampling Events.
J = estimated value.

Direct comparison of the upper and lower zone data further suggest that the treatment effectiveness may have been greater in the upper zone. **Figure 4-5**, which plots the total average critical VOC concentrations measured for both zones for all four events, indicates a more steady and consistent reduction for upper zone VOC contaminants throughout the entire demonstration. This is believed to be due to upward airflow pathways from the injection point at 43 feet bls up to shallower depths.

The averages presented in Tables 4-6 and 4-7 differ markedly from each other. When the data averages for each of the critical compounds are plotted versus each of the four sampling events, as in **Figures 4-6** and **4-7**, vastly contrasting patterns are shown. For example, the apparent reductions for each of the four critical compounds in the upper fractured zone are consistent and fairly uniform. For each compound there appears to be a steady decrease in upper zone concentration over the duration of the demonstration, following an initial sharp decline during the air injection campaign (Figure 4-6). However, the patterns for concentrations of the same contaminants in the lower fractured zone are inconsistent and not uniform. Only the reduction trend for 1,1-DCA shows any similarity to the upper zone trends. The apparent insignificant change or even rise in lower zone VOC concentrations during the early stages of treatment seem to suggest that there may have been difficulty maintaining adequate enhancement levels in the lower primary fracture zone (which occurs at about 43 feet bls). ORP measurements, an indicator of redox potential, were negative from all lower zone wells during the baseline, 1st intermediate, and 2nd intermediate sampling events. This suggests anaerobic conditions prevailed, and that the enhancements failed to create an aerobic environment. However, ORP readings were taken after injection had ceased for at least twelve hours.

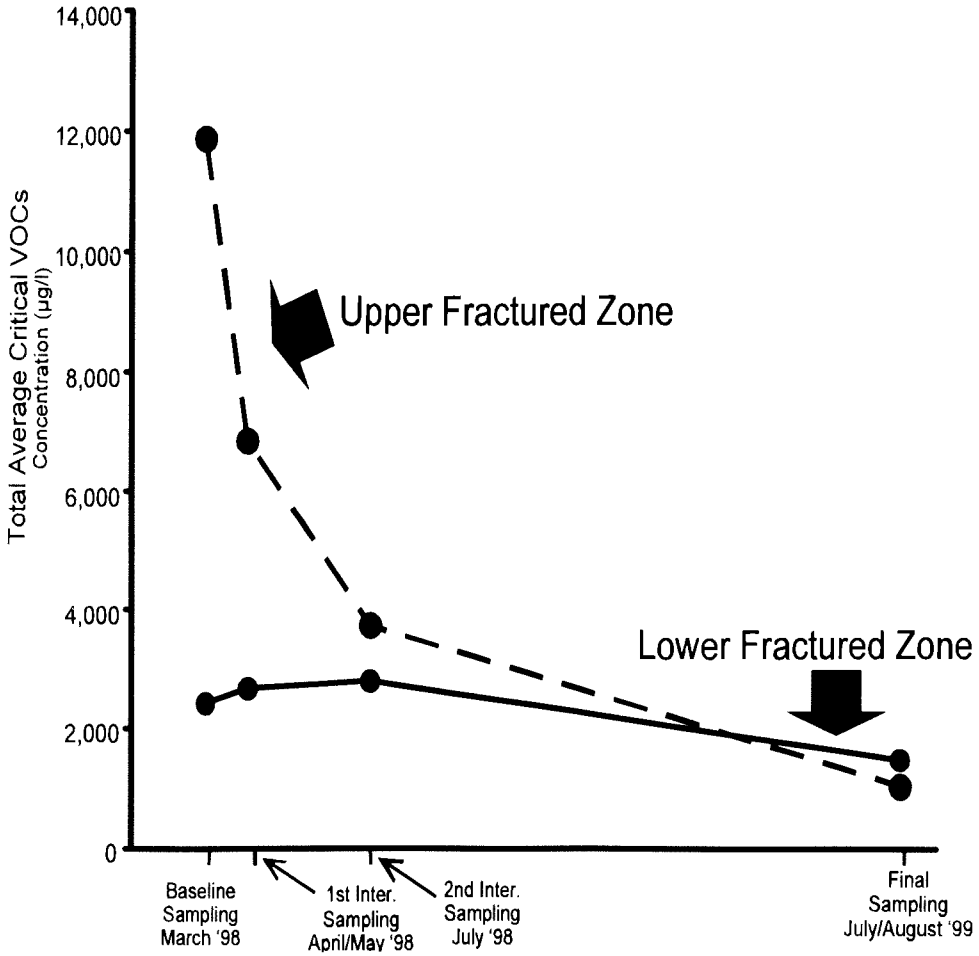

Figure 4-5. Treatment Effectiveness - Upper Vs. Lower Fractured Zones.

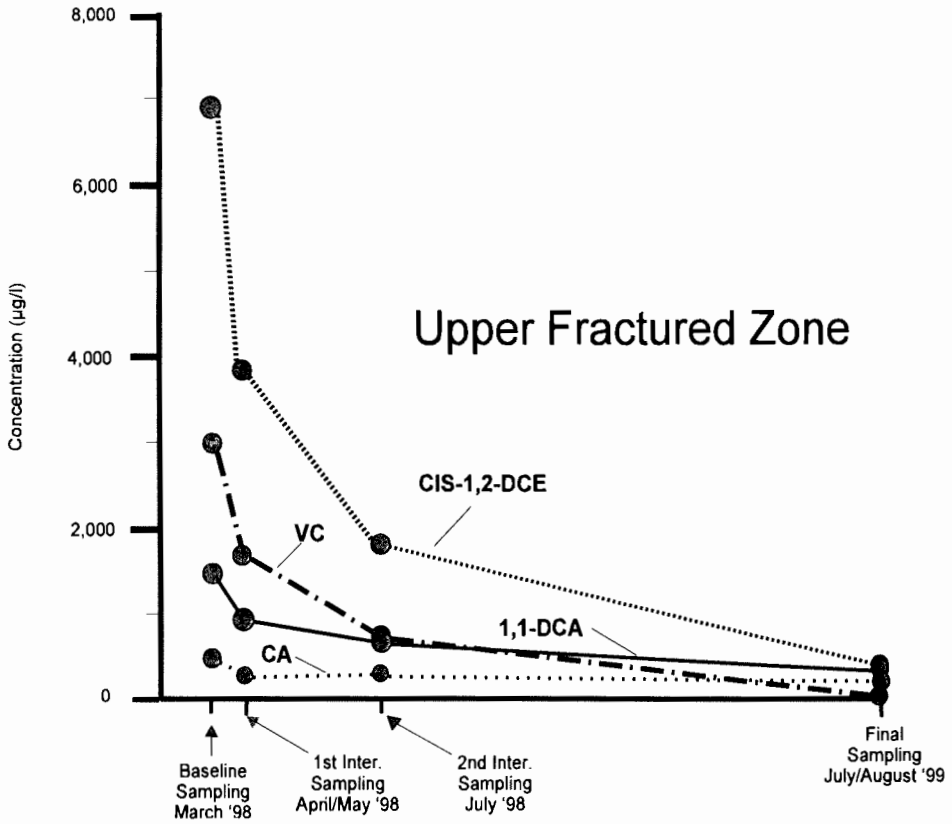

Figure 4-6. Treatment Effectiveness on Individual VOCs in the Upper Fractured Zone (Both Critical and Noncritcal Wells).

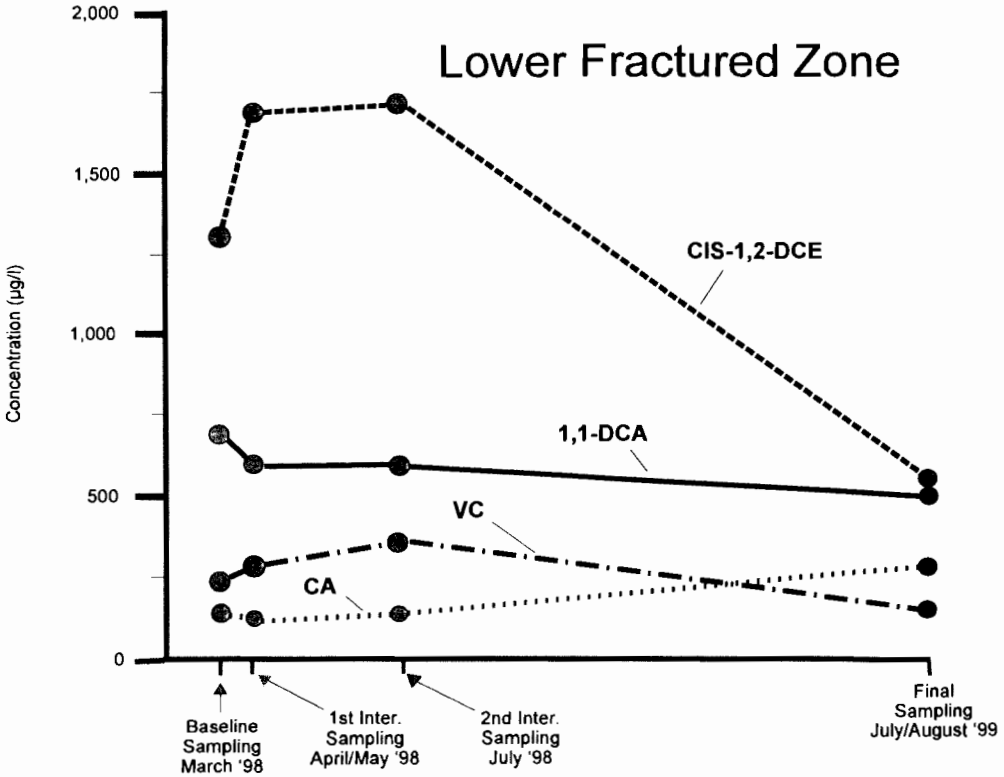

Figure 4-7. Treatment Effectiveness on Individual VOCs in the Lower Fractured Zone (Both Critical and Noncritcal Wells).

4.4.2 Groundwater Nutrient Results

In order to characterize changes in the groundwater characteristics that may have been affected, controlled, or modified by the Earth Tech process performance over the course of the demonstration, several non-VOC water quality parameters were analyzed for on a limited basis (*Objective 7*). One sample from each well/zone was collected and analyzed during each sampling event.

Table 4-8 presents selected results of specific nutrient parameters that may indicate limiting factors in the growth and sustainability of the microbial communities or reflect technology enhancement effectiveness. Total organic carbon (TOC) and total carbon dissolved in groundwater characterizes the amount of overall organic matter potentially available for microbial degradation. The full results for all water quality type parameters analyzed are presented in the TER.

Total phosphorus was not detected in any of the wells until the 2nd Intermediate event, therefore levels detected afterwards should reflect injected TEP. The highest levels of total phosphorus were measured in IW-400 (the primary injection point) and nearby MW-401L during the final sampling event (i.e., 79 and 15 mg/l, respectively). This may indicate the injected TEP had substantially dissipated in concentration away from the injection point.

Table 4-8. Selected Water Quality Results for Critical Wells (mg/l)[1].

Well ID (Zone)	Parameter	SAMPLING EVENT and SAMPLE COLLECTION DATE			
		Baseline March 9, 1998	**First Intermediate** April 29, 1998	**Second Intermediate** July 16, 1998	**Final** July 30, 1999
MW-1 (Upper)	Chloride	170	13	190	240
	Total Phosphorus	< 0.1	< 0.1	<0.1	0.2
	Sulfate	9.6	16	13	120
	Total Carbon	390	250	610	100
	Total Organic Carbon	310	150	440	43
IW-400 L (Lower)	Chloride	18	660	190	30
	Total Phosphorus	< 0.1	< 0.1	< 0.1	79
	Sulfate	< 3	4.0	14	< 5
	Total Carbon	49	32	620	210
	Total Organic Carbon	16	6.5	460	190
MW-401 L (Lower)	Chloride	26	15	15	30
	Total Phosphorus	< 0.1	< 0.1	1.2	15
	Sulfate	< 3	5.2	7.7	6
	Total Carbon	60	35	83	78
	Total Organic Carbon	18	6.4	8.3	37
MW-403 L (Lower)	Chloride	22	29	18	120
	Total Phosphorus	< 0.1	< 0.1	2.4	0.2
	Sulfate	3.2	15	17	11
	Total Carbon	120	52	85	23
	Total Organic Carbon	2.2	17	11	4.6
Average	**Chloride**	**59**	**180**	**100**	**110**
	Total Phosphorus	**< 0.1**	**< 0.1**	**0.9**	**24**
	Sulfate	**3.2**	**10**	**13**	**34**
	Total Carbon	**160**	**92**	**350**	**100**
	Total Organic Carbon	**87**	**45**	**230**	**69**

[1] Values below the detection limit are considered zero for averaging. All values have been rounded to two significant digits.

Sulfate is consumed during anaerobic processes, thus levels of sulfate would be expected to be low during anaerobic conditions and rise as conditions turned aerobic. Sulfate levels slightly increased in all four critical wells following the post-baseline air injection campaign, consistent with this premise. Sulfate substantially increased at the injection well location (IW-400L) during the final event, but remained relatively stable in the lower zones of the the critical wells MW-403 and MW-401.

Both total carbon and TOC can serve as an indicator of carbon utilization by the microbes and thus would be expected to decrease in concentration. In general terms, both of these parameters mimicked the critical VOC reduction in that they decreased during the initial air only injection campaign, stabilized or slightly increased during the 10-week period of continuous air and nutrient injection, then decreased by the end of the demonstration.

4.4.3 Groundwater Dissolved Gases Results

Of great interest for enhancement monitoring are the measurements of dissolved CO_2, CH_4, ethene, and ethane gases collected over the course of the demonstration. **Figure 4-8** plots the average dissolved gases concentrations for those four parameters, as measured in both the upper and lower fractured zones.

CO_2 is a product of both anaerobic and aerobic processes, thus CO_2 can be used as an indicator of relative biological activity occurring throughout the demonstration. CO_2 levels were consistently higher in the upper fractured zone throughout the demonstration. The slight dip in CO_2 measured for both upper and lower zones during the first intermediate sampling event lends support to the possibility that the concentration drop in VOCs at this same time was more likely due to groundwater dilution rather than biological activity (see Figures 4-3 and 4-4).

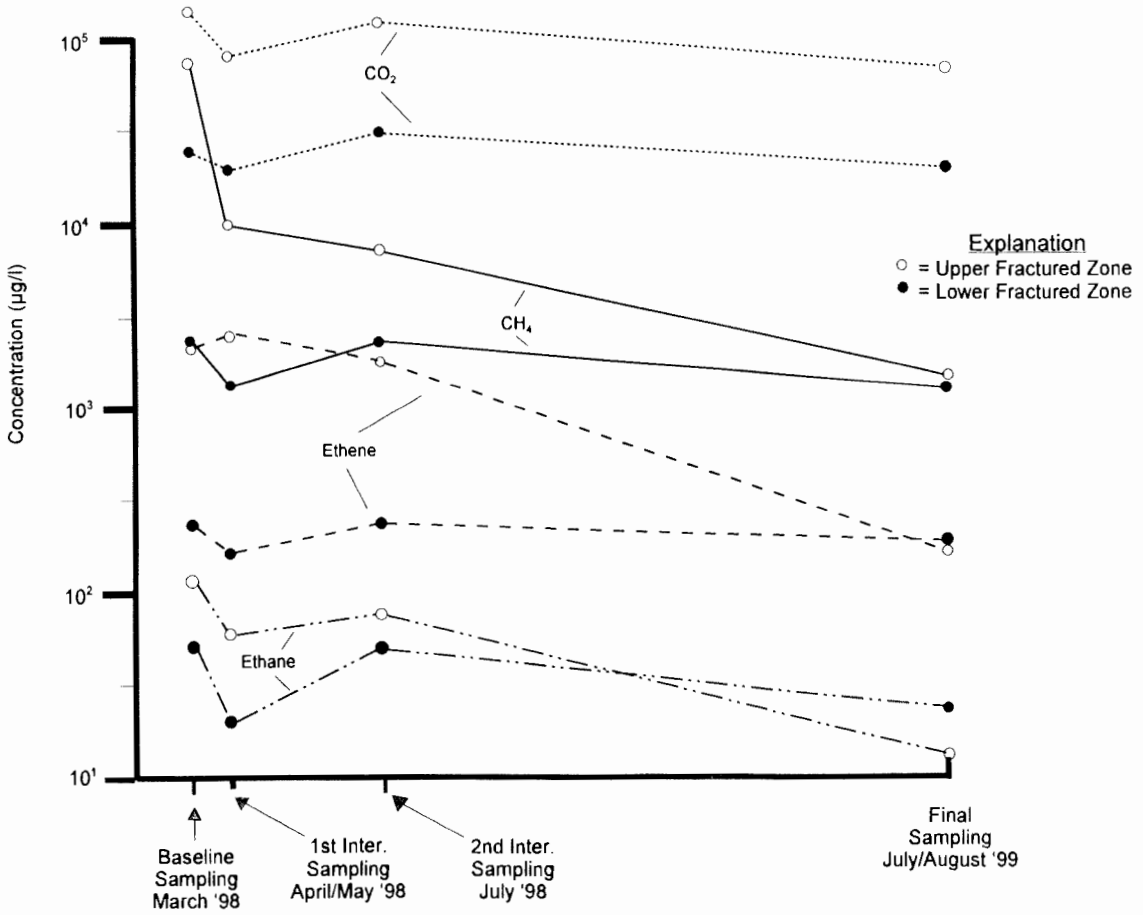

Figure 4-8. Dissolved Gases in Upper and Lower Fractured Zones.

Methane, ethane, and ethene are generally associated with the anaerobic degradation of organic matter. Furthermore, methanotrophic bacteria require methane as a metabolite. In an anaerobic groundwater environment, there is an adequate amount of methane to sustain methanotrophic processes, however oxygen is absent so methanotrophic processes are not established. When aerobic conditions are established (i.e., during the air-only injection phase) and methanotrophic processes begin, methane becomes quickly depleted and levels decrease. Therefore, it was necessary to augment the groundwater with methane to continue and sustain the methanotrophic process.

The plots for methane, ethane, and ethene for both zones in Figure 4-8 generally show that the relatively higher baseline levels of these compounds dropped over the course of the demonstration. This drop, which is much more evident in the upper fractured zone, is consistent with the establishment of aerobic conditions from the original anaerobic conditions.

4.4.4 Groundwater Field Monitoring Results

Pertinent groundwater characteristics were recorded with a "multi-parameter meter" to determine if groundwater conditions had stabilized prior to sample collection. The parameters measured included temperature, pH, specific conductance, oxidation/reduction potential (ORP), and DO. This recorded data is useful for determining the effect of injections on these biological controlling parameters. **Tables 4-9** and **4-10** present summaries of the field monitoring results collected during all four sampling

Table 4-9. Field Measurement Summary for Upper Zone Wells.[1]

Well ID (Zone)	Parameter	SAMPLING EVENT			
		Baseline March 1998	**First Intermediate** April/May 1998	**Second Intermediate** July 1998	**Final** July/Aug. 1999
MW-1 (Upper)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	15 (7) 2,800 (7) 6.5-6.8 (7) - 120 (7) 11 (7)	15 (3) 1,000 (4) 6.7-6.8 (4) - 83 (4) 5.3 (3)	18 (4) 1,300 (4) 6.5-6.6 (4) - 95 (4) 22 (4)	19 (7) 1,300 (7) 6.4-6.5 (6) - 80 (7) 4.7 (7)
MW-306S (Upper)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	12 (6) 8,700 (6) 6.5-6.8 (7) - 92 (7) 6.7 (7)	19 (4) 3,500 (4) 6.5-6.7 (4) - 86 (4) 7.3 (4)	25 (4) 4,500 (4) 6.4-6.5 (4) - 100 (4) 11 (4)	22 (7) 1,300 (7) 6.4-7.0 (7) - 47 (7) 10 (7)
IW-400 U (Upper)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	15 (2) 2,800 (2) 6.7 (2) - 110 (2) 2.3 (2)	17 (1) 960 (1) 6.7 (1) - 85 (1) 4.8 (1)	20 (1) 500 (1) 6.7 (1) - 68 (1) 2.8 (1)	20 (2) 1,200 (2) 6.4 (2) - 99 (2) 3.3 (2)
MW-401 U (Upper)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	14 (2) 1,900 (2) 6.8 (2) - 110 (2) 11 (2)	16 (1) 720 (1) 6.9 (1) - 85 (1) 2.9 (1)	20 (1) 990 (1) 6.6 (1) - 150 (1) 7.9 (1)	22 (2) 990 (2) 6.5 (2) - 72 (2) 16 (2)
MW-402 U (Upper)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	15 (2) 5,100 (2) 6.5-6.6 (2) - 83 (2) 4.7 (2)	16 (1) 2,500 (1) 6.6 (1) - 110 (1) 9.9 (1)	21 (1) 2,800 (1) 6.4 (1) - 150 (1) 10 (1)	19 (2) 730 (2) 6.7 (2) - 120 (2) 6.0 (2)
IW-404 U (Upper)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	8.5 (2) 1,200 (2) 7.0-7.1 (2) - 4.5 (2) 20 (2)	20 (1) 750 (1) 7.1 (1) + 2.0 (1) 37 (1)	30 (1) 830 (1) 7.0 (1) - 86 (1) 41 (1)	22 (1) 1,900 (1) 6.5 (1) + 130 (1) 3.3 (1)
Average	**Temp. (°C)** **Spec. Cond. (µS/cm)** **pH (SU)** **ORP (milliVolts)** **DO (%)**	**13** **3,800** **6.5-7.1** **- 87** **9.3**	**17** **1,600** **6.5-7.1** **- 89** **11**	**22** **1,800** **6.4-7.0** **-110** **16**	**21** **1,100** **6.4-7.0** **- 58** **7.2**

[1] All values, except for the pH range, are averages of the number of measurements in parenthesis. All values rounded to two significant digits.

Table 4-10. Field Measurement Summary for Lower Zone Wells.[1]

Well ID (Zone)	Parameter	SAMPLING EVENT			
		Baseline March 9, 1998	**First Intermediate** April/May 1998	**Second Intermediate** July 1998	**Final** July 30, 1999
IW-400 L (Lower)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	16 (7) 1,100 (5) 7.1-7.3 (7) - 110 (7) 3.7 (7)	17 (4) 380 (4) 7.0-7.2 (4) - 70 (4) 2.2 (4)	21 (4) 1,500 (4) 6.6-6.7 (4) - 126 (4) 12 (4)	19 (7) 450 (6) 7.2-7.3 (7) - 86 (7) 7.6 (7)
MW-401 L (Lower)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	16 (7) 1,100 (6) 7.0-7.2 (7) - 150 (7) 14 (7)	17 (4) 380 (4) 7.1-7.2 (4) - 110 (4) 1.5 (4)	18 (4) 450 (4) 6.8-7.0 (4) - 110 (4) 2.8 (4)	19 (7) 460 (7) 6.1-7.0 (7) - 140 (7) 4.8 (7)
MW-402 L (Lower)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	16 (7) 1,000 (6) 6.9-7.1 (7) - 110 (7) 11 (7)	16 (4) 440 (4) 7.0-7.1 (4) - 85 (4) 3.3 (4)	18 (4) 510 (4) 6.8-6.9 (4) - 110 (4) 4.2 (4)	18 (7) 580 (7) 6.8-6.9 (7) - 160 (7) 2.8 (7)
MW-403 (Lower)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	16 (7) 1,000 (7) 6.9-7.2 (7) - 130 (7) 4.9 (7)	18 (4) 400 (4) 7.0-7.2 (4) - 61 (4) 30 (4)	19 (4) 450 (4) 6.8-6.9 (4) - 98 (4) 39 (4)	19 (7) 630 (7) 6.6-6.9 (7) - 100 (7) 7.5 (7)
MW-404 L (Lower)	Temp. (°C) Spec. Cond. (µS/cm) pH (SU) ORP (milliVolts) DO (%)	16 (7) 1,100 (6) 7.0-7.1 (7) - 140 (7) 3.0 (7)	18 (3) 390 (4) 7.1-7.2 (4) - 110 (4) 1.3 (4)	17 (4) 380 (4) 7.0-7.2 (4) - 70 (4) 2.2 (4)	19 (7) 530 (7) 6.7-6.8 (7) - 100 (7) 3.3 (7)
Average	**Temp. (°C)** **Spec. Cond. (µS/cm)** **pH (SU)** **ORP (milliVolts)** **DO (%)**	**16** **1,100** **6.9-7.3** **-130** **7.3**	**17** **400** **7.0-7.2** **- 87** **7.7**	**19** **660** **6.6-7.2** **- 100** **12**	**19** **530** **6.1-7.3** **- 120** **5.2**

[1] All values, except for the pH range, are averages of the number of measurements in parenthesis. All values rounded to two significant digits.

events for the upper zone and lower zone wells, respectively. The data should be interpreted with caution since the number of measurements available for averaging is variable. Nonetheless, there are some consistent trends apparent.

For all wells sampled, there appears to have been a significant drop in specific conductance following the baseline sampling event, consistent with the average drop of total critical VOCs shown on Figure 4-4. Except for injection well IW-400, specific conductance remained fairly stable during the first and second intermediate sampling events. During the final event sampling, specific conductance was significantly lower than baseline measurements for all wells except for the upper zone of injection well IW-400.

ORP did not appear to be significantly altered during the demonstration. However DO levels appeared to be measured in most cases at higher levels in the upper fractured zone as compared to the lower fractured zone. The process did not appear to alter groundwater pH.

4.4.5 Groundwater Microbial Results

In order to track changes in the microbial community over the course of the demonstration a set of microbial analyses were performed on groundwater samples as a measure of the Earth Tech treatment system's ability to stimulate indigenous microorganisms (*Objective* 6). Although microbial communities are established and operate on solid substrates within subsurface lithologies, changes in numbers and populations on the solid phase will impact and mirror changes in the aqueous groundwater phase. Analysis of groundwater would therefore reflect relative changes in microbial communities responsible for contaminant degradation over the course of the demonstration.

There were five specific types of microbial analyses performed on groundwater samples, which included:

- PLFA (Phospholipid fatty acids)

- TCH (Total Culturable Heterotrophs)
- MPN (Total Culturable Methanotrophs as defined by the "Most Probable Number" technique)
- DNA (gene detection and approximation)
- AODC (Acridine orange direct counts)

For this ITER, the first three listed parameters are presented in summary form. All of the microbial data is presented in the TER. In **Tables 4-11** and **4-12**, summarized groundwater data for MPN, TCH, and PLFA is presented as segregated results for the "upper" and "lower" fractured zones, respectively. The MPN analyses are an estimation of the microbial density of methanotrophic bacteria (i.e., metabolize their sole source of carbon and energy by the conversion of methane into methanol). TCH are used to enumerate culturable heterotrophic bacteria or fungi present within a given sample. TCH, expressed as colony forming units (cfu), represent the number of cells in a sample capable of forming colonies on a suitable agar medium. PLFA provides a biomass measurement for the entire microbial community, including anaerobic, aerobic, culturable and non-culturable organisms.

The data averages in Tables 4-11 and 4-12 are highly variable. The variability between the two baseline event samples and between the two final event samples are particularly notable. The treatment injection system was not activated until March 16, 1998 (after the baseline event) and was shut off on July 27, 1999 (prior to the final sampling event). Nonetheless, as was done with the VOC data, the upper and lower zone microbial data can be plotted separately to show any general trends for evaluating the ability of Earth Tech's treatment system to stimulate indigenous microorganisms.

Figures 4-9 and **4-10** show the averaged concentrations of MPN, TCH, and PLFA measured during the four sampling events of the demonstration, for the Upper and Lower Fractured Bedrock zones, respectively. Although the aforementioned variability is significant, the general trends in both upper and lower zones exhibit a similar pattern to the critical VOC concentration changes that were previously shown in Figure 4-3. This is especially true between the second baseline and first intermediate samples, where there is an apparent sharp decrease in concentration for MPN, TCH, and PLFA reflected in the lower fractured zone during the initial five week period of continuous air injection. This decrease was followed by substantial increases in MPN and PLFA concentrations during the phase of continuous injection of air and nutrients. TCH concentrations remained fairly constant.

A second and rather obvious observation that can be made about the upper versus lower fractured zone comparison is that the TCH and PLFA concentrations in the upper fractured zone attained significantly higher levels than in the lower fractured zone. TCH in the upper fractured zone sharply increased between May and July of 1998 to levels that were an order of magnitude higher than those measured in the lower fractured zone. Then, during the final sampling event, TCH was measured at about the same levels in both zones.

Thirdly, methanotroph populations apparently were better stimulated in the lower zone as compared to the upper zone. MPN concentrations in the upper fractured zone appear to stabilize between July of 1998 and July of 1999 at about 10^3; following a substantial increase between March and April of 1998 (Figure 4-9). MPN concentrations in the lower fractured zone appear to steadily increase between April of 1998 and July of 1999, and are shown to peak at about 10^6 during the final sampling event (Figure 4-10). Since groundwater samples were not collected for over one year it is not possible to know when the MPN population in the lower fractured zone attained the thriving population level of 10^6 cells/ml.

A fourth observation from the comparison plots reveals that during the final event sampling there were significant concentration drops in MPN, TCH, and PLFA in the lower fractured zone six days after the injection system was turned off. However, this did not occur in the upper fractured zone. In fact, levels of TCH and MPN were measured to spike upwards in the samples collected six days after the injection system was turned off.

This occurrence in microbial drop off may be further evidence of the presence of upward airflow pathways, in which injected methane would migrate from the injection point at 43 feet bls to the upper fractured zones. Thus, the lower fractured zone would become quickly methane depleted once methane injection was stopped, however the upper zone could remain methane enriched for an indefinite period from the upward migration of gaseous phase methane. Therefore, a depletion of MPN could occur in the lower fractured zone at the same time an increase of MPN occurred in the upper fractured zone.

4.4.6 Soil Gas Results

Vadose zone soil gases were collected from the four Soil Gas Probe locations (e.g., SG-1, SG-2, SG-3, and SG-4) that were installed into the overburden and screened from ~5-10 ft. bls. The gases were analyzed for chlorinated volatile organics, acetone/IPA, methane (CH_4), ethane, and ethene. The samples were collected

Table 4-11. Microbial Results (MPN, TCH, and PLFA) for Upper Fractured Zone.[1]

Well ID	Unit [2]	SAMPLING EVENT					
		Baseline '98		First Intermed. '98	Second Intermed. '98	Final '99	
		March 5	*March 10*	*April 28*	*July 13*	*July 28*	*August 3-5*
MW-1	MPN TCH PLFA	480 8,200 2,000	92 280,000 960	92 82,000 24,000	4,800 290,000 160,000	4,200 1,000,000 140,000	40 8,300,000 180,000
MW-306 S	MPN TCH PLFA	48 1,800 9,000	5 3,800,000 1,700	48 95,000 3,700	300 120,000 260,000	42 130,000,000 580,000	--- 220,000,000 77,000
IW-400 U	MPN TCH PLFA	--- --- ---	--- --- ---	--- --- ---	--- --- ---	--- --- ---	400 --- 90,000
MW-401 U	MPN TCH PLFA	--- --- ---	--- --- ---	--- --- ---	--- --- ---	--- --- ---	400 --- 97,000
MW-402 U	MPN TCH PLFA	--- --- ---	--- --- ---	--- --- ---	--- --- ---	--- --- ---	30,000 --- 600,000
MW-404 U	MPN TCH PLFA	--- --- ---	--- --- ---	--- --- ---	--- --- ---	--- --- ---	4,800 --- 17,000
Averages	**MPN** **TCH** **PLFA**	**260** **5,000** **5,500**	**49** **2,000,000** **1,300**	**70** **89,000** **14,000**	**2,600** **66,000,000** **210,000**	**2,000** **430,000** **360,000**	**7,100** **110,000,000** **180,000**

[1] Values represent the mean of three plate counts and are rounded to two significant digits.
[2] MPN = Most probable number for total culturable methanotrophs as measured in cells/ml. TCH = Total culturable heterotrophs as measured in cfu/ml. PLFA = quantity of phospholipid fatty acids (e.g., biomass) as measured in total picomoles.

Table 4-12. Microbial Results (MPN, TCH, and PLFA) for Lower Fractured Zone.[1]

Well ID	Unit [2]	SAMPLING EVENT					
		Baseline '98		First Intermed. '98	Second Intermed. '98	Final '99	
		March 5	*March 10*	*April 28*	*July 13*	*July 28*	*August 3*
IW-400 L	MPN TCH PLFA	5 500 41	48 530,000 200	92 120,000 140	92 1,100,000 110,000	9,200 530,000 83,000	22,000 150,000 17,000
MW-401 L	MPN TCH PLFA	48 2,200 500	48 1,300,000 380	300 350,000 1,500	3,000 250,000 90,000	30 180,000 6,300	4,800 18,000 7,100
MW-402 L	MPN TCH PLFA	48 4,300 180	2,200 70,000 5,400	480 3,000 100	22,000 13,000 9,500	560 120,000 4,200	40 230,000 10,000
MW-403 L	MPN TCH PLFA	92 2,200 190	480 500,000 510	92 200,000 240	3,000 38,000 13,000	22,000,000 25,000 24,000	2,200 320,000 22,000
MW-404 L	MPN TCH PLFA	480 TNC[3] 30	92 480,000 540	480 22,000 230	300 8,300 4,200	220,000 2,700 1,700	150 20,000 800
Averages	**MPN** **TCH** **PLFA**	**130** **NC[3]** **190**	**570** **580,000** **1,400**	**290** **140,000** **440**	**5,700** **280,000** **45,000**	**4,400,000** **170,000** **24,000**	**5,800** **150,000** **11,000**

[1] Values represent the mean of three plate counts and are rounded to two significant digits.
[2] MPN = Most probable number for total culturable methanotrophs as measured in cells/ml. TCH = Total culturable heterotrophs as measured in cfu/ml. PLFA = quantity of phospholipid fatty acids (e.g., biomass) as measured in total picomoles.
[3] TNC = Too numerous to count. NC = Not calculated.

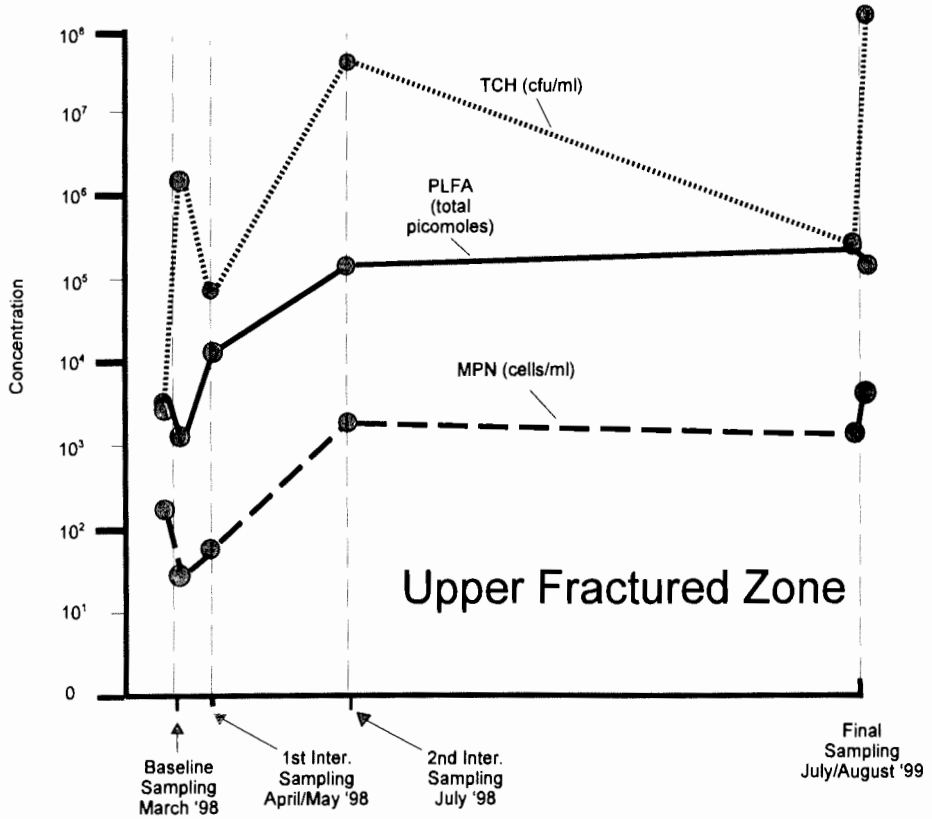

Figure 4-9. MPN, TCH, and PLFA Concentrations in Upper Fractured Zone.

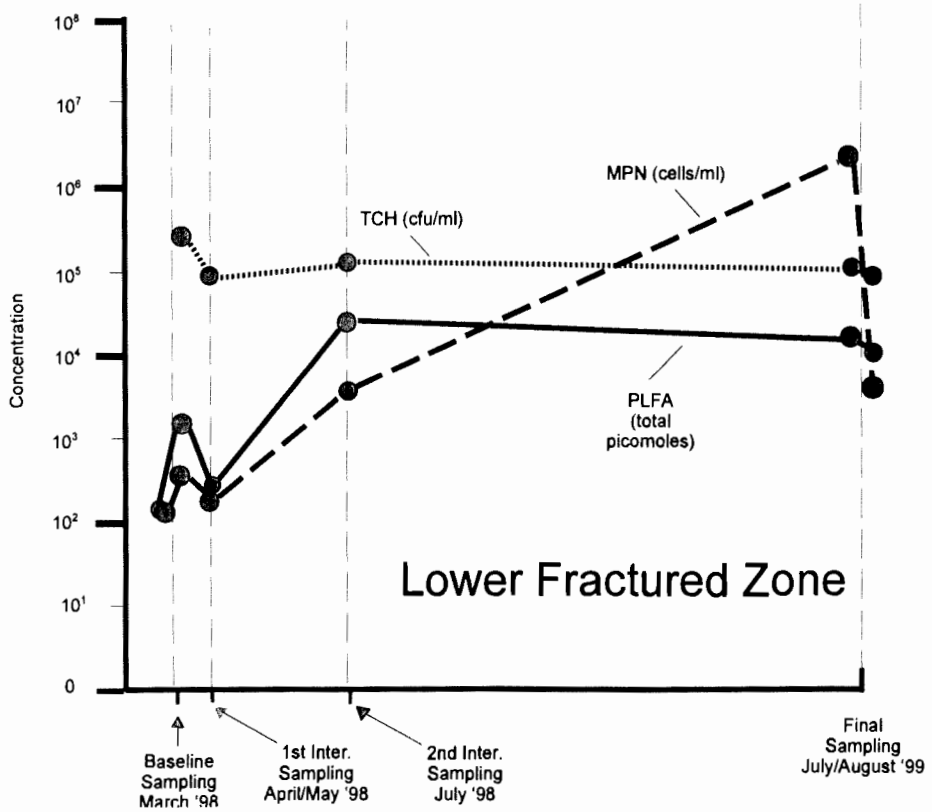

Figure 4-10. MPN, TCH, and PLFA Concentrations in Lower Fractured Zone.

on four different occasions in 1998: during baseline conditions in March, in April and July (just prior to the two intermediate groundwater sampling events), and in September. Soil gas samples were not collected in 1999.

It was hoped that the soil gas results would determine: (1) if VOCs were being stripped into the unsaturated zone as a result of the injection of gases into the saturated zone; (2) if methane was building up in the clay overburden during injection phases; and (3) if a presence and/or change in concentration of methane, ethane, ethene, and CO_2 may be an indicator of aerobic and anaerobic degradation (*Objective 5*).

Table 4-13 summarizes the results of the soil gas headspace sampling events for the four critical VOCs (e.g., CA; 1,1- DCA; cis-1,2-DCE; and VC) separately for each of the four soil vapor monitoring probes. Results are reported in parts per billion by volume (ppbv). Other volatile compounds, as part of the TO-14 scan, were also analyzed as well. Full results are presented in the TER. For each of the four events, there were at minimum two daytime soil gas measurements. For the third intermediate event, there were two additional nighttime measurements. The purpose of the nighttime measurements was to determine if any off-gassing was affected by the variability in temperature and humidity typically experienced between daytime and nighttime.

In addition to the individual results presented, the data in Table 4-13 has also been summarized to show the summation of the critical VOC concentrations. Based on the variability in the data, only generalizations have been made. Because all of the samples were collected from soil gas wells screened at the same approximate depth, results can be shown on a plan view to investigate any correlations the soil gas results may have to injection and monitoring well proximity.

The averaged critical VOC totals shown in parentheses in Table 4-13 have been inserted in boxes adjacent to the appropriate soil gas monitoring location in **Figure 4-11**. Also included on Figure 4-11 are the upper fractured zone critical VOC groundwater results for all wells sampled, including those that were outside of the anticipated zone of influence (i.e., MW-306 S, MW-402, and MW-404).

The VOC soil gas data is variable and inconclusive with respect to determining whether VOCs have been stripped into the vadose zone as a result of the injected gases into the saturated zone. There is little correlation between the summed average VOC soil gas concentrations and upper zone groundwater data for the three 1998 sampling events. The soil gas location having the most consistent higher levels of the four critical VOCs (as a summed total) was SG-1, which is the closest soil vapor monitoring probe to the primary injection wells IW-400. Of the four soil vapor monitoring points sampled, two (SG-2 and SG-3), showed order of magnitude increases in averaged total critical VOCs from baseline to the last soil gas sampling event six months after baseline, while one of the points (SG-1) showed an order of magnitude decrease and a fourth point (SG-4) showed no appreciable change over the same time period.

The summed average critical VOCs for SG-2 were observed to increase steadily from the baseline event in March of 1998 (12 ppbv) until the last soil gas sampling event in September of 1998 (1,400 ppbv). The summed average critical VOCs for SG-3 were measured at approximately 1,500 ppbv for the baseline event in March of 1998 and 14,000 ppbv for the last soil gas sampling event in September of 1998; however the increase was not steady as evidenced by the April and July averages. The summed average critical VOCs for SG-1, the soil gas probe nearest to the injection well IW-400, showed an order of magnitude decrease over the same time period. There was no appreciable change in the small concentrations of critical VOCs measured in the somewhat distant SG-4 monitoring point.

Table 4-14 summarizes the results of the soil gas headspace sampling events for methane, ethane, and ethene separately for each of the four soil vapor monitoring probes. Results are reported in parts per million by volume (ppmv). As was the case with the VOCs, for each of the four events there were at minimum two daytime soil gas measurements. For the third intermediate event, there were two additional nighttime measurements. Of the three gases, only CH_4 was consistently measured above method detection limits. The average of the two CH_4 measurements recorded for each of the four events have been inserted adjacent to the appropriate monitoring location in **Figure 4-12**. Averaged methane concentrations in soil gas peaked during baseline sampling in three of four monitoring points and levels remained essentially the same in the fourth monitoring point; indicating that there was no CH_4 buildup in soil due to injections of this enhancement into the subsurface. This also suggests that there was anaerobic degradation occurring prior to injection.

Table 4-13. Critical VOCs in Soil Gas (ppbv).[1]

Vapor Probe I.D.	Parameter	SAMPLING EVENT				
		Baseline March '98 [2]	1st Intermediate April 22-23, '98 [2]	2nd Intermediate July 9-10, '98 [2]	3rd Intermediate Sept. 9-10,'98 [3]	
SG-1	CA	69 / 110	< 1.5 / 280	< 19 / < 76	< 7.6 / < 2.5	< 3.8 / < 5.1
	1,1-DCA	33 / 52	2.2 / 480	970 / 4,300	1,200 / 37	750 / 930
	cis- 1,2-DCE	91 / 150	1.3 / 170	130 / 580	87 / 17	41 / 40
	VC	4,500 / 5,700	4.3 / 3,000	< 20 / < 78	15 / < 2.6	< 3.9 / 4.4[TR]
	Totals [4]	**4,700 / 6,000 (5,400)**	**7.8 / 3,900 (2,000)**	**1,100 / 4,900 (3,000)**	**1,300 / 390 (850)**	**790 / 970 (880)**
SG-2	CA	ND / 7.3	< 1.5 / < 1.5	< 13 / < 19	< 19 / < 19	< 19 / < 19
	1,1-DCA	ND / 12	3.4 / 20	220 / 330	1,300 / 1,500	1,300 / 1,400
	cis- 1,2-DCE	ND / 0.74	2.3 / 5.5	<8.4 / <13	< 13 / < 13	< 13 / < 13
	VC	3.3 / ND	1.8 / 9.8	<13 / <20	< 20 / < 20	< 20 / < 20
	Totals [4]	**3.3 / 20 (12)**	**7.5 / 35 (21)**	**220 / 330 (280)**	**1,300 / 1,500 (1,400)**	**1,300 / 1,400 (1,400)**
SG-3	CA	74 / 95	< 380 / < 38	< 3.8 / < 7.6	320 / 620	400 / 530
	1,1-DCA	120 / 160	910 / 260	6.4 / 140	1,700 / 7,000	3,800 / 7,100
	cis- 1,2-DCE	230 / 340	4,200 / 1,500	20 / 490	1,800 / 7,800	4,300 / 7,400
	VC	660 / 1,300	23,000 / 5,500	3.8[TR] / 100	1,100 / 8,800	3,000 / 3,600
	Totals [4]	**1,100 / 1,900 (1,500)**	**28,000 / 7,300 (18,000)**	**30 / 730 (380)**	**4,900 / 24,000 (14,000)**	**12,000 / 19,000 (16,000)**
SG-4	CA	ND / ND	< 1.5 / < 1.5	< 3.8 / < 3.8	< 0.38 / < 1.9	0.39 / < 2.5
	1,1-DCA	15 / 3.8	< 0.99 / 8.2	< 2.5 / < 2.5	1.9 / 15	2.3 / 20
	cis- 1,2-DCE	3.1 / 1.9	< 1.0 / 100	< 2.5 / < 2.5	0.94 / 5.6	0.57 / 7.6
	VC	5.7 / 5.0	1.9 / 63	< 3.9 / < 3.9	0.35[TR] / 49	16 / 41
	Totals [4]	**24 / 11 (20)**	**1.9 / 170 (86)**	**ND/ ND (ND)**	**3.2 / 70 (37)**	**19 / 69 (44)**

[1] All values have been rounded to two significant digits.
[2] Results consist of two daytime measurements taken on consecutive days.
[3] Four values are given; the first two consist of two daytime measurements taken on consecutive days. The second two consist of two nighttime measurements taken after the first day measurement and preceding the second.
[4] Three totals are given; one for each round of sampling and a third (in parentheses) being the average total for both sampling rounds. Values < detection limit are considered zero for summing totals.
ND = Not detected at or above method detection limit.
[TR] = Trace.

Figure 11. Critical VOC Concentrations in Soil Gas and Upper Zone Groundwater.

Table 4-14. Methane, Ethane, and Ethene in Soil Gas (ppmv).[1]

Vapor Probe I.D.	Parameter	SAMPLING EVENT				
		Baseline *March '98* [2]	**1st Inter.** *April 22-23, '98* [2]	**2nd Inter.** *July 9-10, '98* [2]	**3rd Inter.** *Sept. 9-10, '98* [3]	
SG-1	**Methane**	180,000 / 160,000	7.2 / 62	6.0 / 120	23 / 7.7	7.7 / 4.8
	Ethane	900 / 800	ND / 0.67	ND / 1.2	ND / ND	ND / ND
	Ethene	570 / 520	ND / ND	ND / ND	ND / ND	ND / ND
SG-2	**Methane**	86 / 2.7	4.7 / 7.3	3.1 / 2.6	3.2 / 4.0	3.1 / 4.5
	Ethane	0.5 / ND	ND / ND	ND / ND	ND / ND	ND / ND
	Ethene	0.7 / ND	ND / ND	ND / ND	ND / ND	ND / ND
SG-3	**Methane**	7,600 / 13,000	10,000 / 610	6.1 / 29	1,900 / 3,700	1,600 / 2,900
	Ethane	19 / ND	25 / 1.8	ND / ND	7.2 / 15	9.2 / 14
	Ethene	99 / 140	260 / 37	ND / ND	26 / 170	24 / 72
SG-4	**Methane**	24 / 22	130 / 2,500	4.1 / 5.7	7.0 / 7.0	6.8 / 7.0
	Ethane	ND / ND	1.3 / 14	ND / ND	ND / ND	ND / ND
	Ethene	ND / 0.2	ND / 40	ND / ND	ND / ND	ND / ND

[1] All values have been rounded to two significant digits.
[2] Results consist of two daytime measurements taken on consecutive days
[3] Four values are given; the first two consist of two daytime measurements taken on consecutive days. The second two consist of two nighttime measurements taken after the first day measurement and preceding the second.
[4] Values < detection limit (i.e., ND) are considered zero when summing.
ND = Not detected at or above method detection limit.
TR = trace

4.4.7 Data Quality Assurance

A review of the critical sample data and associated quality control (QC) analyses was performed to determine whether the data collected were of adequate quality to provide proper evaluation of the project's technical objectives. The critical parameters included groundwater concentrations of four volatile compounds: chloroethane, 1,1-dichloroethane, cis-1,2-dichloroethene and vinyl chloride, analyzed from select wells during the pre- and post-treatment sampling/analysis events. The results of the measurements designed to assess the data quality objectives are summarized in the following subsections, along with a discussion of the impact of the data quality for achieving the project's technical objectives.

4.4.7.1 Accuracy

Accuracy was assessed by the analysis of spiked samples for the project. During the baseline event a total of six spikes were analyzed, with the average recovery values for the four compounds ranging from 88-102%. A total of 10 spiked samples were analyzed during the final event with average recoveries ranging from 94-106%. Of the 64 critical compound recovery values, only four individual data points exceeded the control limits established in the QAPP (80-120%); three of these data points were from the analysis of a single spike, indicating a possible problem with that specific analysis result. The spike data are summarized in **Table 4-15** and indicate that spiked analyses achieved the overall QA objectives for accuracy.

An additional check on analytical accuracy included the use of Laboratory Control Samples (LCSs) as a second-source standard. These standards were analyzed periodically throughout the project and recovery values compared to the limits established in the QAPP. The analysis of these standards was designed to assess trends in recovery values over time, in the absence of matrix effects, to evaluate the potential for a shift in analytical bias.

Second source standard summary data is presented in **Table 4-16**. Average recoveries of the LCSs varied less than 10% in most cases, as shown in the data below. Chloroethane recovery values for LCSs analyzed during the baseline and final events increased 12%. However, as the data shows this did not represent a shift in bias, but rather a series of recovery results all within expected method variability.

Figure 4-12. Methane Concentrations in Soil Gas.

Table 4-15. Spiked Sample Summary Data - Overall Accuracy Objective.

CRITICAL COMPOUND	Accuracy Data: Average % Spike Recoveries (Std. Deviation)	
	Baseline	**Final**
1-1 Dichloroethane	88 (6.5)	101 (9.1)
Chloroethane	102 (4.4)	106 (12)
cis-1,2-Dichloroethane	96 (5.1)	94 (10)
Vinyl Chloride	102 (9.3)	96 (7.2)

Table 4-16. Second Source Standard Summary Data.

CRITICAL COMPOUND	Accuracy Data: Average % LCS Recoveries (Std. Deviation)			
	Baseline	**1st Intermediate**	**2nd Intermediate**	**Final**
1-1 Dichloroethane	98 (5.6)	100 (3.4)	95 (5.5)	106 (8.9)
Chloroethane	100 (7.5)	106 (5.6)	102 (4.0)	112 (6.1)
cis-1,2-Dichloroethane	100 (4.7)	98 (4.2)	98 (7.2)	96 (16)
Vinyl Chloride	98 (6.5)	106 (2.8)	105 (2.2)	100 (9.3)

4.4.7.2 Precision

Precision objectives were assessed by the analysis of the spiked duplicate samples. Of the 32 RPD values generated during the baseline and final sampling/analysis events, only one MS/MSD had an RPD value (for one compound, cis-1,2-dichloroethene) which exceeded the 20% control limit. Overall, precision objectives met QAPP objectives. As a further assessment, for which control limits were not established, select field samples from each event were collected in duplicate. These field duplicates also had most RPD values (29 of 32) below 20%. One of the four baseline field duplicate pairs with low concentrations of cis-1,2-dichloroethene had an RPD of 40 and two field duplicate pairs from the final event had RPD values above 20%. Again, these results indicate that precision objectives for the project were achieved.

4.4.7.3 Detection Limits

Detection limits were achieved for the critical parameters for all samples. There was a few minor issue regarding the qualification of some estimated data reported at concentrations below the detection limits, but this did not impact overall project objectives.

4.4.7.4 Completeness

Completeness objectives, specified in the QAPP as 90% for this project, were achieved.

4.4.7.5 Comparability

Comparability, as stated in the QAPP, is achieved through the use of standard, EPA-approved methods. One issue investigated during this demonstration was a change in laboratory software used in volatile analysis for the critical compounds. The software change resulted in a difference in the calibration protocol used. Although there was a difference in the way calibration curves were generated between the first and subsequent events (dependent and independent variables were switched), based on the linearity of the compounds being evaluated, this issue did not negatively affect data quality and therefore did not impact overall project objectives.

4.4.7.6 Representativeness

Representativeness refers to the degree with which a sample exhibits average properties of the site at the particular time being evaluated. This is addressed prior to the start of the project through the QAPP procedures for sampling. Field duplicates are used to assess representativeness, and also provide insight into the homogeneity, or heterogeneity, of the matrix. Field duplicate samples have inherent in the result combined field and analytical variability. For this project, as discussed earlier, field duplicate results indicated samples were representative of the matrix.

In summary, data generated from the baseline and final event are considered to be of sufficient quality to provide for proper evaluation of the project technical objectives.

Section 5.0
Other Technology Requirements

5.1 Environmental Regulation Requirements

State and local regulatory agencies may require permits prior to implementing an in-situ biodegradation technology. Most federal permits will be issued by the authorized state agency. An air permit issued by the state Air Quality Control Region may be required if it is anticipated that the air emissions from potential surface venting are in excess of regulatory criteria, or of toxic concern. Wastewater discharge permits may be required if any wastewater generated from well purging and decontamination activities were to be discharged to a POTW. If remediation is conducted at a Superfund site, federal agencies, primarily the U.S. EPA, will provide regulatory oversight. If off-site disposal of contaminated waste (contaminated drill cuttings) is required, the waste must be taken to the disposal facility by a licensed transporter.

Section 2 of this report discusses the environmental regulations that may apply to the Enhanced In-Situ Bioremediation process.

5.2 Personnel Issues

The number of personnel required to install the Enhanced In-Situ Bioremediation technology should depend on the size of the treatment system and the time desired for the installation. Drilling and well installation labor activities are performed by a drilling contractor. Normally, there are a minimum of two contractor personnel assigned to a drill rig (head driller and helper). There may be a third contractor representative who conducts well completion and development following well installation. The remediation contractor at a site (such as Earth Tech) would be responsible for logging boreholes, monitoring for VOCs and explosive conditions, and ensuring that well construction and installation is conducted in accordance with design specifications. These activities would require the services of at least one individual (preferably a geologist).

The site contractor would need one to two individuals to procure the injection system parts, the associated monitoring equipment, and initial first year enhancement supplies (e.g., methane, TEP, etc.); arranging for and overseeing the electric utility hookup; installing the injection system components and associated monitoring equipment (e.g., dedicated bladder pumps for the wells), and conducting preliminary air and helium injection tests to determine fracture patterns and zone(s) of influence. Estimated labor requirements for a full-scale treatment system are discussed in detail in Section 3 of this report.

Personnel are also required for sample collection and groundwater monitoring. During the demonstration sampling events, two to three SITE team members were required to conduct field measurements and sample preparation. Personnel present during sample collection activities at a hazardous waste site must have current OSHA health and safety certification.

For most sites, PPE for workers will include steel-toed shoes or boots, safety glasses, hard hats during drilling operations, and chemical resistant gloves. Depending on contaminant types, additional PPE (such as respirators) may be required. For example, respiratory protective equipment may be needed in instances when VOCs are measured in the breathing zone (i.e., above the well head) exceeding predetermined levels.

Noise levels would be a short-term concern during drilling operations and may be of concern during injection phases (i.e., a loud compressor for larger systems could create appreciable noise). Thus, noise levels should be monitored for such equipment to ensure that workers are not exposed to noise levels above the time weighted average of 85

decibels over an 8-hour day. If this level is exceeded and cannot be reduced, workers would be required to wear hearing protection and a hearing conservation program would need to be implemented.

5.3 Community Acceptance

The short-term risk to the community is minimal since the compressed gases are secured in a building or shed and the treatment occurs in-situ (i.e., underground). As with any gas that has flammable characteristics there is a potential to create an explosive environment, therefore methane is closely monitored to ensure that the injection concentration does not exceed 4 % by volume, thus avoiding the lower explosive limit of 5 %. The level of environmental disturbances would be dependent on the number of wells required and the locations of those wells. Other than noise generated during drilling to install monitoring wells, noise would only occur during operations requiring an air compressor (i.e., periods of gaseous phase injection and sample collection if bladder pumps are used).

Section 6.0
Technology Status

6.1 Previous Experience

The Enhanced In-Situ Bioremediation Process is currently being employed at multiple sites throughout the country, by Earth Tech and other approved DOE licensees. Earth Tech has indicated, however, that the ITTNV Roanoke Building 3 site is the first locality where the technology is being implemented in a clay and fractured bedrock environment. Earth Tech is evaluating the feasibility of using the process for remediation of other areas of the ITTNV facility. Injection air testing is currently being planned at two source areas associated with Building 1.

6.2 Ability to Scale Up

At the demonstration study area, Earth Tech has expanded the existing injection system into the source area. Operation of the pilot system used during the demonstration system was halted in November 1999 to allow the system expansion to be completed. The expanded system, considered as full-scale, was restarted in December 1999 with injection of air, nutrients, and methane in four wells (IW-400, IW-406, IW-407 and IW-408). Of these wells, only IW-400 has continued functioning as an injection well from the pilot study. MW-402, which had been used as an injection well during the pilot demonstration, has been taken off-line.

Earth Tech has provided additional information (including analytical data) regarding their expanded system in Appendix A. Figure 1 of Appendix A shows the locations of the full-scale monitoring and injection wells.

Section 7.0
References

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Appendix A - Earth Tech's Claims and Discussion

Note: Information contained in this appendix was provided by Earth Tech, Inc. and has not been independently verified by the U.S. EPA SITE Program

Abstract

Additional data collected by Earth Tech (consultant to ITT Night Vision) prior to and after the Superfund Innovative Technology Evaluation (SITE) program demonstration indicate that the evaluated cometabolic bioremediation technology has destroyed more volatile organic compounds (VOCs) over a larger area than identified through the SITE demonstration. The results from groundwater monitoring indicate significant (90 to 99.96%) total VOC reductions in the pilot test area and at locations 75 feet hydraulically downgradient, since the initiation of the injection campaign.

A.1 Introduction

An in-situ enhanced bioremediation pilot study was implemented at a source area at the Building 3 manufacturing facility at ITT Night Vision in Roanoke, Virginia. When evaluating the technology options for remediation of the target source area, particular emphasis was placed on treatment technologies that could be applied in-situ given the site restrictions with above-ground and underground utilities and structures. After review of a range of technologies, in-situ enhanced cometabolic bioremediation was selected as the technology best suited to the contaminants (VOCs), clay and fractured rock hydrogeology, and logistical factors present at the site. The chosen technology, developed at the Westinghouse Savannah River Plant site (Hazen, 1995[1]) and licensed by the U.S. Department of Energy, is an injection system used to deliver a gaseous phase mixture of air, nutrients (nitrous oxide and triethyl phosphate), and a carbon source (methane) to the targeted subsurface zone to stimulate the growth of methanotrophs. These bacteria produce enzymes (methane monooxygenase) that degrade VOCs including the more recalcitrant chlorinated solvents and their daughter products to non-hazardous constituents. This technology had previously been successfully performed in the laboratory and field projects in unconsolidated clay, silt and sand formations. Prior to the start of this pilot test, this technology had not been performed in a clay and fractured rock environment per discussions with the technology developer.

A.2 Project Objective

The purpose of this pilot test, which was implemented as a Resource Conservation and Recovery Act (RCRA) Interim Measure (IM), was to document the effectiveness of the system in reducing VOC concentrations in groundwater in the pilot test area. The effectiveness of the pilot test study would determine whether this technology would be expanded in this source area and potential application at other sites with similar conditions.

A.3 Project Activities

This project began with the submittal of an Interim Measures Workplan to the United States Environmental Protection Agency (USEPA) and the Virginia Department of Environmental Quality (VADEQ) for review and approval in December 1996. This workplan described the cometabolic bioremediation pilot test. Following regulatory review and comments, a revised Interim Measures Workplan was submitted in May, 1997 and subsequently approved by the USEPA and VADEQ which allowed for the initiation of the field work. The first activity in the Workplan was the acquisition of background groundwater quality data, which included weekly sampling of selected monitoring wells over an eight week period between June and August 1997. The next step was to begin the injection of the nutrients, which was planned for the Fall 1997; however, this was delayed to allow for the SITE program staff to become involved in the project.

ITT Night Vision applied to have the site evaluated as part of the SITE Demonstration program and on October 15, 1997 representatives of the program visited the site and provided verbal acceptance of the project into the SITE Demonstration program. The SITE program performed preliminary background sampling in December 1997 to establish the critical VOCs, monitoring wells and number of samples needed to statistically evaluate the project. In February 1998 the SITE program completed a Test Plan establishing the SITE Demonstration methods for this project. Program personnel collected groundwater samples to establish the baseline for the demonstration during the first two weeks of March 1998.

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[1] Hazen,T.C.1995. *Preliminary Technology Report for the In Situ Bioremediation Demonstration (Methane Biostimulation) of the Savannah River Integrated Demonstration Project, DOE/OTD.* U.S. Dept. of Energy Report, WSRC-TR-93-670, Westinghouse Savannah River Company, Aiken, S.C.

During the SITE Demonstration program, a phased injection of the amendments was performed to evaluate and optimize the addition of air (oxygen source), nitrous oxide and triethyl phosphate (nutrient sources) and methane (carbon source) in a single injection well. The air only injection phase was initiated in March 1998 following the SITE program baseline data collection. Groundwater samples were collected by Earth Tech during the air only injection phase in a few selected wells. At the conclusion of 6 weeks of air only injection, SITE program staff performed a groundwater sampling event at the end of April 1998. Earth Tech split groundwater samples with the SITE program in selected IM monitoring wells during this sampling event. Injection was suspended for the SITE program groundwater sampling events.

Following the air only injection phase, the air plus nutrient (nitrous oxide and triethyl phosphate) injection phase was initiated and conducted over a 10-week period ending in July 1998. At the end of this air and nutrient injection period, the SITE program performed a groundwater sampling event and Earth Tech split samples with the SITE program. At the end of July 1998, the third and final injection phase was initiated consisting of air, nutrient, and methane injection. During this phase, the back pressure at the single injection well (IW-400) appeared to have decreased which allowed for increased air and gaseous phase media injection. This reduced back pressure was attributed to the lower water table elevation resulting from decreased precipitation.

Earth Tech performed groundwater sampling events after 4 and 14 weeks of air, nutrient, and methane injection at selected monitoring wells during the Fall of 1998. The groundwater results from these sampling events indicated that some wells within the SITE Demonstration project area were not showing satisfactory VOC reductions, which was attributed to the limited delivery of the amendments. Therefore, the injection of gaseous phase media was temporarily suspended during January 1999 to expand the treatment system by adding injection of the air, nutrients, and methane to MW-402. Injection was initiated in MW-402 and re-established in IW-400 in February 1999.

Earth Tech conducted a groundwater sampling event in April 1999 to evaluate the progress of the two injection wells. From late July through early August 1999, the SITE program performed the final groundwater sampling event for the demonstration. Once this data was received by Earth Tech and significant VOC reductions were confirmed in the pilot test area, plans were made for expansion of the system to full scale within the source area. This was accomplished by installing three additional injection wells in the source area.

This more aggressive approach was aimed at targeting the center of the source area to accelerate VOC mass removal to the ultimate goal of reaching drinking water standards, if technically feasible. Increased subsurface amendment injection and airflow pathways created by the newly installed injection wells made injection in MW-402 unnecessary. Thus, MW-402 has only been used for monitoring purposes following the restart of the expanded system. Operation of the system was halted in November 1999 to allow the system expansion to be completed and was restarted in December 1999 with injection of air, nutrients and methane in four wells (IW-400, IW-406, IW-407 and IW-408). **Figure 1** shows the locations of the site monitoring and injection wells.

Groundwater samples were collected during May 2000 from the Building No. 3 IM monitoring wells to determine the affect of operating the system at full scale for approximately 6 months. At the end of August 2000 a limited groundwater sampling event was performed to assess the monitoring wells that had contained the highest VOC concentrations.

A.4 Results and Discussion

This section focuses on the VOC laboratory results for groundwater samples collected by Earth Tech prior to and following the SITE program's involvement period. The results show more significant VOC reductions over a larger area and suggest that drinking water standards are being reached in groundwater from selected monitoring wells.

Baseline Comparison

Background groundwater quality analyses were performed on groundwater samples collected over an eight-week period by Earth Tech from the following wells: MW-1, MW-306O, MW-306S, IW-400, MW-401, MW-402, MW-403, MW-404, and MW-405. The data from these sampling events are included in **Table A-1**. In addition to these wells, groundwater samples were collected and analyzed less frequently from IW-400S, MW-401S, MW-402S, MW-404S, and MW-405S; these results are also included in Table A-1. This area is larger than the demonstration site and includes monitoring wells within the entire source area and downgradient locations. The target VOCs for remediation, as identified by Earth Tech's baseline sampling events are as follows: acetone, isopropanol, parent chlorinated hydrocarbons (trichloroethene, 1,1,1-trichlorethane), and daughter products (cis-1,2 dichloroethene, 1,1-dichloroethene, vinyl chloride, 1,1-dichloroethane, and chloroethane).

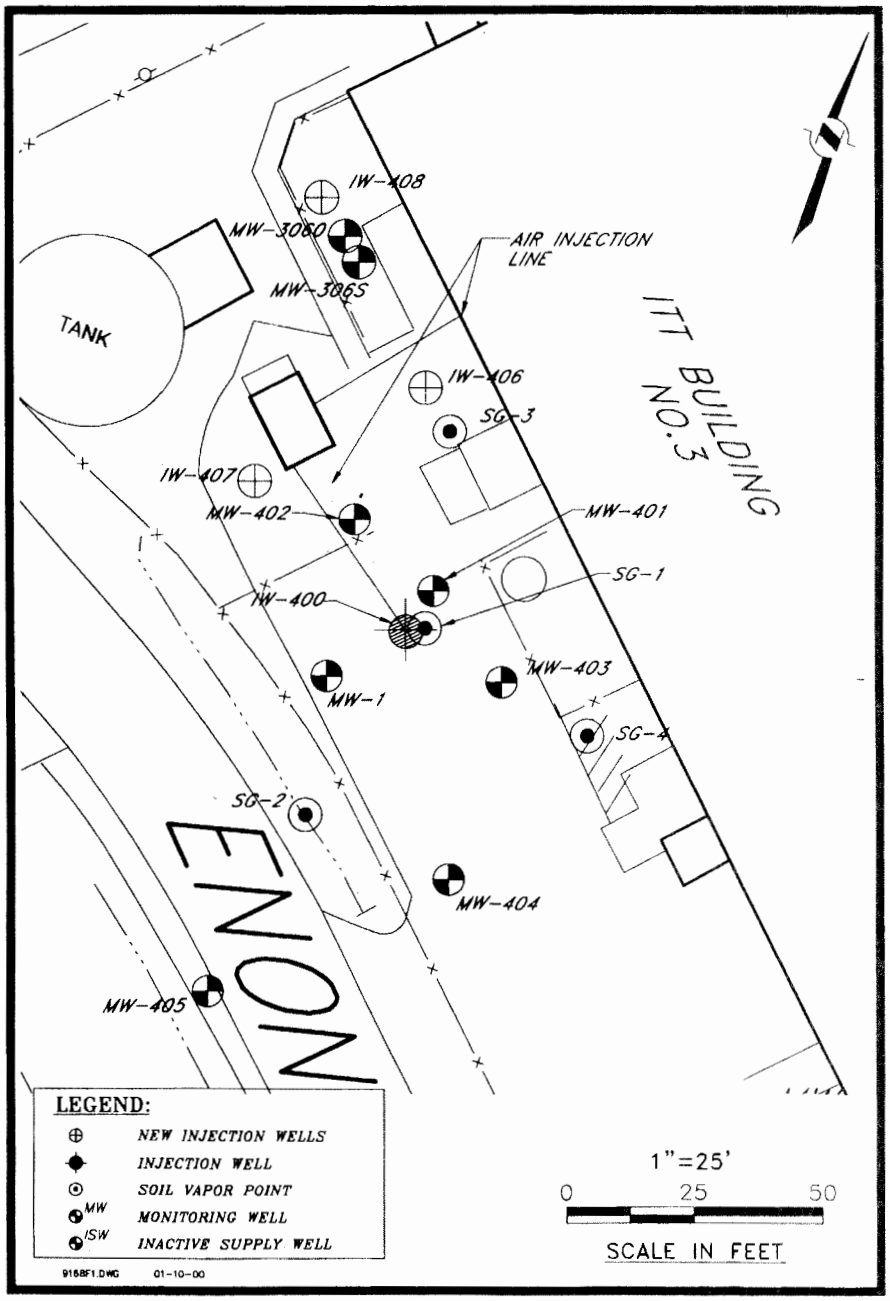


FIGURE 1
NEWLY INSTALLED INJECTION WELL LOCATIONS
BUILDING NO. 3 – INTERIM MEASURE
ITT NIGHT VISION

EARTH TECH
196 Baker Avenue • Concord, Massachusetts 01742 • (978) 371-4000
JANUARY, 2000 MODIFIED BY GRAPHIC IMAGINATIONS

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA.

Well ID	Federal MCL	MW-1							
Sample Date		15-May-00	13-Apr-99	21-Oct-98	17-Aug-98	5-Apr-98	5-Apr-98	20-Aug-97	13-Aug-97
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	ND[1] J	ND [5]	ND [100]	ND [100]	ND [100]	130	ND [1000]	ND [1000]
1,1-Dichloroethane	NL	3.2 J	97	330	270	450	570	ND [1000]	ND [1000]
1,1-Dichloroethene	7	ND[1] J	ND [5]	ND [100]	ND [100]	ND [100]	ND [100]	ND [1000]	ND [1000]
Acetone	NL	ND[50] J	420	5,700	5,000	9,500	7,300	72,000	92,000
Chloroethane	NL	3.2 J	ND[5] R	ND [100]	ND [100]	ND [100]	ND [100]	ND [1000]	ND [1000]
Isopropanol	NL	ND[50] R	ND[250] R	11,000	14,000	14,000	13,000	100,000	160,000
Trichloroethene	5	ND[1] J	ND [5]	ND [100]	ND [100]	ND [100]	ND [100]	ND [1000]	ND [1000]
Vinyl chloride	2	ND[1] J	6.6	140	100	390	350	ND [1000]	1,200
cis-1,2-Dichloroethene	70	ND[1] J	41	120	130	660	600	ND [1000]	ND [1000]
Total VOCs		6.4	579.6	17,290	14,400	25,000	21,950	172,000	253,200
Ethylene	NL	-	ND [80]	ND [800]	-	ND [800]	ND [800]	-	-
Methane	NL	-	520	1,000	-	2,300	2,400	-	-

Well ID	Federal MCL	MW-1							
Sample Date		6-Aug-97	30-Jul-97	17-Jul-97	17-Jul-97	10-Jul-97	1-Jul-97	24-Jun-97	30-Sep-96
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	ND [1000]	ND [2000]	ND [2500]	ND [2500]	ND [2000]	ND [1000]	ND [500]	3,200
1,1-Dichloroethane	NL	ND [1000]	ND [2000]	ND [2500]	ND [2500]	ND [2000]	1,400	1,700	1600 J
1,1-Dichloroethene	7	ND [1000]	ND [2000]	ND [2500]	ND [2500]	ND [2000]	ND [1000]	ND [500]	ND [500]
Acetone	NL	63,000	ND [100000]	ND [130000]	ND [130000]	ND [100000]	ND [10000]	36,000	67,000
Chloroethane	NL	ND [1000]	ND [2000]	ND [2500]	ND [2500]	ND [2000]	1,300	1,100	ND [500]
Isopropanol	NL	140,000	110,000	260,000	280,000	200,000	90,000	100,000	210000 J
Trichloroethene	5	ND [1000]	ND [2000]	ND [2500]	ND [2500]	ND [2000]	ND [1000]	ND [500]	ND [500]
Vinyl chloride	2	ND [1000]	ND [2000]	ND [2500]	ND [2500]	ND [2000]	ND [1000]	ND [500]	**2800 J**
cis-1,2-Dichloroethene	70	ND [1000]	ND [2000]	ND [2500]	ND [2500]	ND [4000]	ND [2000]	ND [1000]	**12000 J**
Total VOCs		203,000	110,000	260,000	280,000	200,000	92,700	138,800	296,600
Ethylene	NL	-	-	ND [800]	-	-	-	-	1,400
Methane	NL	-	-	4,000	-	-	-	-	11,000

Notes: MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID	Federal MCL	MW-1							
Sample Date		22-Jul-96	16-Jul-96	9-Jul-96	2-Jul-96	4-Apr-96	13-Dec-94	16-Dec-91	23-Apr-91
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	**1,100**	ND [1000]	**1,100**	**1,800**	**510**	ND [500]	ND [500]	ND
1,1-Dichloroethane	NL	1,000	ND [1000]	1,100	2000 J	900	1,100	2,000	1,300
1,1-Dichloroethene	7	ND [500]	ND [1000]	ND [250]	ND [1000]	ND [500]	ND [500]	ND [500]	ND
Acetone	NL	200,000	54,000	80000 J	150000 J	30,000	190,000	980,000	430,000 B
Chloroethane	NL	ND [500]	ND [1000]	ND [250]	ND [1000]	ND [500]	ND [500]	ND [1000]	ND
Isopropanol	NL	400,000	230,000	400000 J	670000 J	130,000	190000 J	-	38,000 J
Trichloroethene	5	ND [500]	ND [1000]	ND [250]	ND [1000]	ND [500]	ND [500]	ND [500]	**260**
Vinyl chloride	2	**6,300**	**2,900**	**5,400**	**8,900**	**1,700**	ND [500]	**58,000**	**34,000**
cis-1,2-Dichloroethene	70	**5,300**	**3,300**	**5,200**	**8,600**	**5,100**	ND [500]	-	**30,000**
Total VOCs		613,700	290,200	492,800	841,300	168,210	381,100	1,040,000	535,060
Ethylene	NL	-	-	-	-	2800 J	-	-	-
Methane	NL	-	-	-	-	8000 J	-	-	-

Notes: MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [] = Analyte not detected at or above reported detection limit. Number within brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier. - = Constituent not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID	Federal MCL	MW-306O							
Sample Date		30-Aug-00	15-May-00	12-Apr-99	12-Apr-99	21-Oct-98	19-Aug-98	5-Apr-98	18-Aug-97
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	180	ND [5]	**6,200**	**7,100**	**3,300**	**19,000**	**220**	43
1,1-Dichloroethane	NL	380	60	ND [500]	ND [500]	390	1400	220	180
1,1-Dichloroethene	7	**40**	5.8	ND [500]	ND [500]	**140**	ND [500]	**72**	**47**
Acetone	NL	ND [500]	ND [250]	ND [25000]	ND [25000]	ND [100]	ND [25000]	ND [100]	ND [100]
Chloroethane	NL	140	ND [5]	ND[500] R	ND[500] R	ND [2]	ND [500]	ND [2]	ND [2]
Isopropanol	NL	ND[500]	ND[250] R	ND[25000] R	ND[25000] R	ND [100]	ND [25000]	ND [100]	ND [100]
Trichloroethene	5	**2,200**	**350**	**52,000**	**64,000**	**17,000**	**58,000**	**30**	**6.7**
Vinyl chloride	2	**420**	**23**	ND [500]	ND [500]	**250**	ND [1000]	**120**	**84**
cis-1,2-Dichloroethene	70	**1,500**	**400**	**8,800**	**10,000**	**2,200**	**5,800**	16	34
Total VOCs		4,906	839	67,000	81,100	23,280	84,200	678.0	394.7
Ethylene	NL	-	-	ND [40]	-	ND [800]	-	ND [800]	-
Methane	NL	-	-	190	-	820	-	6,400	-

* trans-1,2-dichloroethylene was detected at 46 ug/L.

Well ID	Federal MCL	MW-306S							
Sample Date		30-Aug-00	15-May-00	12-Apr-99	22-Oct-98	22-Oct-98	19-Aug-98	5-Apr-98	20-Aug-97
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	70	61	ND [10000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]
1,1-Dichloroethane	NL	80	120	ND [10000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]
1,1-Dichloroethene	7	ND [25]	ND [25]	ND [10000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]
Acetone	NL	1,200,000	1,400,000	760,000	ND [3E+06]	ND [3E+06]	ND [3E+06]	ND [3E+06]	ND [3E+06]
Chloroethane	NL	31	ND [25]	ND [10000] R	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]
Isopropanol	NL	1,300,000	740,000 R	2,000,000 R	5,300,000	5,100,000	6,100,000	3,900,000	5,800,000
Trichloroethene	5	**1,400**	**650**	ND [10000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]
Vinyl chloride	2	**500**	**610**	ND [10000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]
cis-1,2-Dichloroethene	70	**1,000**	**2,100**	**16,000**	ND[50000]	ND[50000]	ND [50000]	**56,000**	**54,000**
Total VOCs		2,503,050	2,143,541	2,776,000	5,300,000	5,100,000	6,100,000	3,956,000	5,854,000
Ethylene	NL	-	-	ND [20]	2,500	2,600	-	2,300	-
Methane	NL	-	-	900	2,100	2,300	-	10,000	-

Notes: MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID	Fed. MCL	MW-306O									
VOCs (ug/L or ppb)		11-Aug-97	4-Aug-97	28-Jul-97	16-Jul-97	8-Jul-97	1-Jul-97	25-Jun-97	29-Sep-96	5-Apr-96	13-Dec-94
1,1-Dichloroethane	NL	44	70	61	44	51	85	38	16	360	1,300
1,1-Dichloroethene	7	180	220	270	200	180	210	130	260 J	450	460
Acetone	NL	47	60	50	36	42	68	24	46	200	63
Chloroethane	NL	ND [50]	ND [100]	ND [100]	ND [100]	ND [50]	ND [250]	ND [250]	ND [250]	ND [250]	1200 J
Isopropanol	NL	ND [1]	ND [2]	2.2 J	2.2	1.4 J	ND [5]	ND [5]	ND [5]	ND [5]	ND [10] J
Trichloroethene	5	110	100	ND [100]	ND [100]	ND [50]	ND [250]	ND [250]	ND [250]	ND [250]	1300 J
Vinyl chloride	2	7.4	8	3.2	8.5	7.2	11	7.2	ND [5]	48	12
cis-1,2-Dichloroethene	70	99	150	220	160	170	300	160	79	150	65
Total VOCs		35	48	61	45	52	64	26	32	79	33
Ethylene	NL	516.4	658.0	672.4	525.7	503.6	738.0	385.2	433.0	1,287	4,453
Methane	NL	-	-	-	ND [800]	-	-	-	ND [930]	310 J	-
		-	-	-	1,700	-	-	-	2,400	2300 J	-

	Fed. MCL	MW-306S										
VOCs (ug/L or ppb)		13-Aug-97	6-Aug-97	30-Jul-97	17-Jul-97	10-Jul-97	3-Jul-97	25-Jun-97	30-Sep-96	30-Sep-96	4-Apr-96	4-Apr-96	14-Dec-94
1,1,1-Trichloroethane	200	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [5000]	ND [5000]	ND [10000]	ND [10000]	ND [2000]
1,1-Dichloroethane	NL	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [5000]	ND [5000]	ND [10000]	ND [10000]	ND [2000]
1,1-Dichloroethene	7	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [5000]	ND [5000]	ND [10000]	ND [10000]	ND [2000]
Acetone	NL	ND [3E+06]	ND [500000]	ND [3E+06]	ND [3E+06]	ND [3E+06]	ND [3E+06]	ND [3E+06]	350,000	270,000	520,000	590,000	310,000
Chloroethane	NL	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [5000]	ND [5000]	ND [10000]	ND [10000]	ND [2000]
Isopropanol	NL	6,400,000	6,600,000	5,800,000	6,500,000	6,600,000	5,000,000	3,600,000	6300000 J	4900000 J	8,100,000	9,200,000	16000000 J
Trichloroethene	5	ND [50000]	ND [50000]	ND [50000]	64,000	ND [50000]	72000	ND [50000]	7,800	5,600	ND [10000]	ND [10000]	20000
Vinyl chloride	2	ND [50000]	ND [50000]	ND [50000]	88,000	ND [50000]	ND [50000]	ND [50000]	22000 J	21000 J	32,000	31,000	7,800
cis-1,2-Dichloroethene	70	54,000	ND [50000]	70000	52000	ND [100000]	1000000	ND [100000]	95000	88,000	99,000	130000	670000
Total VOCs		6,454,000	6,600,000	5,870,000	6,684,000	6,600,000	5,172,000	3,600,000	6,774,600	5,282,600	8,751,000	9,951,000	16,540,500
Ethylene	NL	-	-	-	4,500	-	-	-	2,800	2,300	1900 J	2300 J	-
Methane	NL	-	-	-	9,000	-	-	-	7,500	5,700	7300 J	8000 J	-

Notes: MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID		IW-400S				MW-401S				
Sample Date	Federal MCL	31-Aug-00	15-May-00	27-Oct-98	20-Aug-98	15-May-00	22-Oct-98	17-Aug-98	17-Jul-98	22-Aug-97
VOCs (ug/L or ppb)										
1,1,1-Trichloroethane	200	ND [1]	2.7 J	ND[1000]	ND [2000]	4.6 J	ND [2]	ND [5]	ND [500]	ND [200]
1,1-Dichloroethane	NL	13	20 J	ND[1000]	ND [2000]	21 J	42	59	510	ND [200]
1,1-Dichloroethene	7	ND [1]	ND[1] J	ND [1000]	ND [2000]	ND[1] J	ND [2]	ND [5]	ND [500]	ND [200]
Acetone	NL	ND [50]	ND[50] J	50,000	ND [100000]	ND[50] J	100	400	23,000	20000 J
Chloroethane	NL	38	2.7 J	ND [1000]	ND [2000]	ND[1] J	55	ND [10]	ND [500]	ND [200]
Isopropanol	NL	ND [50]	85 R	72,000	210,000	82 R	200	750	47,000	30,000
Trichloroethene	5	1	ND[1] J	ND[1000]	ND [2000]	3.9 J	ND[2]	ND [5]	ND [500]	ND [200]
Vinyl chloride	2	ND [1]	ND[1] J	ND[1000]	ND [2000]	ND[1] J	3.6	7	ND [500]	ND [200]
cis-1,2-Dichloroethene	70	2.4	1.8 J	ND[1000]	ND [2000]	1.6 J	14	31	1,900	ND [200]
Total VOCs		54	112	122,000	210,000	115	167.6	1,247	72,410	50,000.0
Ethylene	NL	-	-	-	-	-	-	-	-	-
Methane	NL	-	-	-	-	-	1100	-	-	-

Well ID		MW-402S				
Sample Date	Federal MCL	31-Aug-00	15-May-00	26-Oct-98	18-Aug-98	22-Aug-97
VOCs (ug/L or ppb)						
1,1,1-Trichloroethane	200	82	140	ND [10000]	ND [10000]	ND [10000]
1,1-Dichloroethane	NL	150	170	29,000	ND [10000]	ND [10000]
1,1-Dichloroethene	7	ND [10]	ND [50]	ND [10000]	ND [10000]	ND [10000]
Acetone	NL	520	4,300	580,000	ND [500000]	580000 J
Chloroethane	NL	78	57	ND [10000]	ND [10000]	ND [10000]
Isopropanol	NL	1,200	3,800 R	2,100,000	810,000	940,000
Trichloroethene	5	520	1,800	ND [10000]	ND [10000]	ND [10000]
Vinyl chloride	2	ND [10]	ND [50]	ND [10000]	ND [10000]	25,000
cis-1,2-Dichloroethene	70	520	2,800	ND [10000]	ND [10000]	31,000
Total VOCs		2,320	8,800	2,709,000	810,000	1,556,000
Ethylene	NL	-	-	ND [100]	-	-
Methane	NL	-	-	830	-	-

Notes: MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID	Federal MCL	MW-404S				
Sample Date		15-May-00	26-Oct-98	18-Aug-98	17-Jul-98	22-Aug-97
VOCs (ug/L or ppb)						
1,1,1-Trichloroethane	200	ND [1]	ND [1]	ND [1]	ND [1]	ND [10]
1,1-Dichloroethane	NL	3.5	ND [10]	2.1	1.6	30
1,1-Dichloroethene	7	ND [1]	ND [1]	ND [1]	ND [1]	ND [10]
Acetone	NL	ND [50]	140	ND [50]	ND [50]	ND [500]
Chloroethane	NL	ND [1]	ND [1]	ND [1]	ND [1]	ND [10]
Isopropanol	NL	92 R	630	ND [50]	ND [50]	ND [500]
Trichloroethene	5	ND [1]	ND [1]	ND [1]	ND [1]	ND [10]
Vinyl chloride	2	ND [10]	ND [10]	3.9	1	29
cis-1,2-Dichloroethene	70	1.8	ND [10]	4.7	4	64
Total VOCs		97	770	11	6	123.0
Ethylene	NL	-	-	-	-	-
Methane	NL	-	-	-	-	-

Well ID	Federal MCL	MW-405S			
Sample Date		15-May-00	27-Oct-98	19-Aug-98	22-Aug-97
Volatile Organic Compounds					
1,1,1-Trichloroethane	200	ND [1]	ND [1]	ND [2]	ND [500]
1,1-Dichloroethane	NL	12	45	97	ND [500]
1,1-Dichloroethene	7	ND [1]	ND [2]	ND [2]	ND [500]
Acetone	NL	ND [50]	ND [50]	170	71000 J
Chloroethane	NL	ND [1]	7.4	ND [2]	ND [500]
Isopropanol	NL	73 R	87	300	ND [25000]
Trichloroethene	5	ND [1]	ND [2]	ND [2]	ND [500]
Vinyl chloride	2	ND [1]	ND [2]	ND [2]	ND [500]
cis-1,2-Dichloroethene	70	1.1	2.3	2.3	ND [500]
Total VOCs		86.1	141.7	569.3	71,000
Ethylene	NL	-	-	-	-
Methane	NL	-	4,600	-	-

Notes: MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID	Federal MCL	IW-400							
Sample Date		31-Aug-00	15-May-00	13-Apr-99	20-Aug-98	16-Jul-98	29-Apr-98	18-Aug-97	13-Aug-97
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	210	760	260	12	ND [2500]	64	ND [1000]	ND [1000]
1,1-Dichloroethane	NL		300	540	46	ND [2500]	370	2,400	2,000
1,1-Dichloroethene	7	3.7	ND [50]	ND [10]	ND [1]	ND [2500]	ND [10]	ND [1000]	ND [1000]
Acetone	NL	ND [100]	4,000	1,300	ND [50]	150,000	760	98,000	75,000
Chloroethane	NL	140	200	26 R	8.5	ND [2500]	ND [10]	ND [1000]	ND [1000]
Isopropanol	NL	470	3,900 R	1,600 R	72	240,000	1,800	190,000	150,000
Trichloroethene	5	150	1,000	77	3.7	ND [2500]	15	ND [1000]	ND [1000]
Vinyl chloride	2	82	110	180	4.1	ND [2500]	120	1,400	1,000
cis-1,2-Dichloroethene	70	220	400	300	35	ND [2500]	290	2,600	1,900
Total VOCs		1,376	11,070	4,283	181.3	390,000	3,419	294,400	229,900
Ethylene	NL	-	-	100	-	-	-	-	-
Methane	NL	-	-	180	-	-	-	-	-

Well ID	Federal MCL	MW-401							
Sample Date		15-May-00	15-May-00	13-Apr-99	22-Oct-98	17-Aug-98	16-Jul-98	29-Apr-98	20-Aug-97
Constituent (ug/L or ppb)		Bldg. 3 IM*	Bldg. 3 IM**	Spring '99	Fall '98	Bldg. 3 IM	Bldg. 3 IM	Spring '98	Bldg. 3 IM
Volatile Organic Compounds									
1,1,1-Trichloroethane	200	160	170	230	120	170	180	100	ND [100]
1,1-Dichloroethane	NL	70	75	480	310	460	380	460	1,000
1,1-Dichloroethene	7	2.2	2.3	10	ND [10]	ND [5]	ND [10]	ND [10]	ND [100]
Acetone	NL	ND [100]	ND [100]	ND [250]	ND[1000]	410	540	620	14,000
Chloroethane	NL	7.4	9.2	7 R	ND [20]	25	110	69	210
Isopropanol	NL	ND[100] R	ND[100] R	800 R	1,400	670	1,300	1,200	19,000
Trichloroethene	5	220	240	120	ND[20]	73	100	35	ND [100]
Vinyl chloride	2	38	40	310	76	42	80	120	280
cis-1,2-Dichloroethene	70	110	110	420	199	320	310	310	590
Total VOCs		620.6	652.4	2,386.7	2,096	2,170	3,000	#REF!	35,080
Ethylene	NL	-	-	ND [40]	-	-	-	-	-
Methane	NL	-	-	370	830	-	-	-	-

* Bromomethane was detected at 13 ug/L. ** Bromomethane was detected at 5.9 ug/L.

Notes: All concentrations presented in µg/l or ppb. MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID	Federal MCL	IW-400							
Sample Date		6-Aug-97	30-Jul-97	30-Jul-97	16-Jul-97	10-Jul-97	1-Jul-97	25-Jun-97	25-Jun-97
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	ND [1000]	ND [2000]	ND [2000]	ND [2500]	ND [5000]	2,600	ND [5000]	ND [5000]
1,1-Dichloroethane	NL	2,100	2,100	2,300	6,600	ND [5000]	4,800	ND [5000]	ND [5000]
1,1-Dichloroethene	7	ND [1000]	ND [2000]	ND [2000]	ND [2500]	ND [5000]	ND [2500]	ND [5000]	ND [5000]
Acetone	NL	96,000	100,000	100,000	ND [130000]	ND [250000]	180,000	ND [250000]	ND [250000]
Chloroethane	NL	ND [1000]	ND [2000]	ND [2000]	ND [2500]	ND [5000]	ND [2500]	ND [5000]	ND [5000]
Isopropanol	NL	180,000	180,000	200,000	210,000	500,000	350,000	280,000	290,000
Trichloroethene	5	ND [1000]	ND [2000]	ND [2000]	ND [2500]	ND [5000]	ND [2500]	ND [5000]	ND [5000]
Vinyl chloride	2	1,500	2,300	2,300	6,200	ND [5000]	7,000	ND [5000]	ND [5000]
cis-1,2-Dichloroethene	70	3,200	5,400	4,700	2,800	ND [10000]	5,800	ND [10000]	ND [10000]
Total VOCs		282,800	289,800	309,300	225,600	500,000	550,200	280,000	290,000
Ethylene	NL	-	-	-	4,400	-	-	-	-
Methane	NL	-	-	-	10,000	-	-	-	-

Well ID	Federal MCL	MW-401									
Sample Date		13-Aug-97	6-Aug-97	6-Aug-97	30-Jul-97	16-Jul-97	10-Jul-97	1-Jul-97	1-Jul-97	25-Jun-97	25-Jun-97
VOCs (ug/L or ppb)											
1,1,1-Trichloroethane	200	ND [200]	220	ND [200]	ND [500]	ND [500]	ND [500]	720	1,100	4,000	3,200
1,1-Dichloroethane	NL	1,700	1,700	1,700	2,100	1,800	1,000	1,500	2,200	2,600	2,200
1,1-Dichloroethene	7	ND [200]	ND [200]	ND [200]	ND [500]	ND [500]	ND [500]	ND [500]	ND [500]	ND [1000]	ND [1000]
Acetone	NL	ND [10000]	16,000	17,000	66,000	ND [25000]	ND [25000]	32000	37000	ND [50000]	ND [50000]
Chloroethane	NL	210 J	ND [200]	ND [200]	ND [500]	ND [500]	ND [500]	ND [500]	ND [500]	ND [1000]	ND [1000]
Isopropanol	NL	19,000	28,000	32,000	97,000	57,000	71,000	54,000	70,000	150,000	130,000
Trichloroethene	5	ND [200]	ND [200]	ND [200]	ND [500]	ND [500]	ND [500]	ND [500]	ND [500]	ND [1000]	ND [1000]
Vinyl chloride	2	460	490	510	1,300	660	800	730	1,100	1,500	1,400
cis-1,2-Dichloroethene	70	1,400	1,600	1,600	2,900	1,800	1,300	2,200	3,100	6,800	5,500
Total VOCs		22,770	48,010	52,810	169,300	61,260	74,100	91,150	114,500	164,900	142,300
Ethylene	NL	-	-	-	-	1,000	-	-	-	-	-
Methane	NL	-	-	-	-	3,600	-	-	-	-	-

Notes: MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID	Federal MCL	MW-402							
Sample Depth (Feet BGS)									
Sample Date		30-Aug-00	15-May-00	15-May-00	13-Apr-99	26-Oct-98	18-Aug-98	16-Jul-98	29-Apr-98
Volatile Organic Compounds									
1,1,1-Trichloroethane	200	270	350	460	1,200	ND [500]	2,600	3,600	3,800
1,1-Dichloroethane	NL	280	260	390	1,700	ND [500]	2,800	1,500	1,300
1,1-Dichloroethene	7	7.1	ND [20]	ND [20]	ND [200]	ND [500]	ND [2000]	ND [500]	ND [500]
Acetone	NL	230	2,800	3,700	ND [10000]	15,000	ND [100000]	11,000	ND [25000]
Chloroethane	NL	110	180	380	ND [200] R	ND [500]	ND [2000]	ND [500]	ND [500]
Isopropanol	NL	2,200	3,100 R	4,300 R	24,000 R	38,000	150,000	37,000	59,000
Trichloroethene	5	230	550	890	370	ND [500]	ND [2000]	1,400	1,100
Vinyl chloride	2	120	63	120	760	ND [500]	ND [2000]	ND [500]	ND [500]
cis-1,2-Dichloroethene	70	370	260	330	2,700	ND [500]	5,100	4,700	4,900
Total VOCs		3,817	7,563	10,570	30,730	53,000	160,500	59,200	70,100
Ethylene	NL	-	-	-	ND [80]	250	-	-	-
Methane	NL	-	-	-	620	1,900	-	-	-

Well ID	Federal MCL	MW-403							
Sample Depth (Feet BGS)									
Sample Date		15-May-00	13-Apr-99	27-Oct-98	20-Aug-98	16-Jul-98	29-Apr-98	20-Aug-97	20-Aug-97
Volatile Organic Compounds									
1,1,1-Trichloroethane	200	1.6	1.2	ND [50]	ND [250]	22	ND [50]	ND [200]	ND [200]
1,1-Dichloroethane	NL	15	11	ND[200]	530	120	210	1,100	1,100
1,1-Dichloroethene	7	ND [1]	ND [1]	ND [50]	ND [250]	ND [10]	ND [50]	ND [200]	ND [200]
Acetone	NL	ND [50]	ND [50]	6,700	ND [250]	710	3,800	22,000	22,000
Chloroethane	NL	11	7.9 R	ND [50]	ND [250]	55	ND [50]	ND [200]	ND [200]
Isopropanol	NL	ND[50] R	ND [50]	11,000	21,000	1,300	4,600	40,000	40,000
Trichloroethene	5	3.5	1.5	ND [50]	ND [250]	ND [10]	ND [50]	ND [200]	ND [200]
Vinyl chloride	2	ND [1]	ND [1]	ND [50]	ND [250]	25	ND [50]	ND [200]	ND [200]
cis-1,2-Dichloroethene	70	9.1	1.3	ND[200]	ND [250]	62	190	ND [200]	ND [200]
Total VOCs		40.2	22.9	17,700	21,530	2,294	8,710	63,100	63,100
Ethylene	NL	-	ND [80]	-	-	-	-	-	-
Methane	NL	-	1,400	4,000	-	-	-	-	-

Notes: MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID	Federal MCL	MW-402								MW-402
Sample Date		20-Aug-97	13-Aug-97	6-Aug-97	30-Jul-97	17-Jul-97	10-Jul-97	10-Jul-97	1-Jul-97	25-Jun-97
VOCs (ug/L or ppb)										
1,1,1-Trichloroethane	200	3,300	4,400	5,700	13,000	3,200	4,600	4,700	13,000	8,700
1,1-Dichloroethane	NL	2,100	2,100	2,300	3,100	ND [1000]	ND [1000]	ND [1000]	1,800	1,900
1,1-Dichloroethene	7	ND [250]	ND [500]	ND [250]	ND [500]	ND [1000]	ND [1000]	ND [1000]	ND [1000]	ND [500]
Acetone	NL	20,000	28,000	22,000	39,000	ND [50000]	ND [50000]	ND [50000]	ND [50000]	ND [25000]
Chloroethane	NL	ND [250]	ND [500]	ND [250]	ND [500]	ND [1000]	ND [1000]	ND [1000]	ND [1000]	ND [500]
Isopropanol	NL	51,000	51,000	50,000	94,000	74,000	120,000	93,000	92,000	99,000
Trichloroethene	5	900	1,300	1,500	4,500	1,400	2,300	2,500	6,300	3,100
Vinyl chloride	2	700	1,200	1,400	2,500	1,600	1,700	1,800	2,900	2,500
cis-1,2-Dichloroethene	70	4,900	5,700	7,500	13,000	3,500	4,200	4,500	9,800	8,300
Total VOCs		82,910	93,700	90,400	169,100	83,700	132,800	106,500	125,800	123,500
Ethylene	NL	-	-	-	-	ND [800]	-	-	-	-
Methane	NL	-	-	-	-	2,000	-	-	-	-

Well ID	Federal MCL	MW-403							
Sample Date		13-Aug-97	13-Aug-97	6-Aug-97	30-Jul-97	15-Jul-97	10-Jul-97	30-Jun-97	24-Jun-97
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	ND [500]	ND [500]	ND [1000]	ND [500]	ND [2000]	ND [2000]	ND [2000]	ND [1000]
1,1-Dichloroethane	NL	1,200	1,200	1,300	940	2,100	ND [2000]	ND [2000]	1,200
1,1-Dichloroethene	7	ND [500]	ND [500]	ND [1000]	ND [500]	ND [2000]	ND [2000]	ND [2000]	ND [1000]
Acetone	NL	35,000	41,000	46,000	36,000	ND [100000]	ND [100000]	ND [100000]	ND [50000]
Chloroethane	NL	ND [500]	ND [500]	ND [1000]	ND [500]	ND [2000]	ND [2000]	ND [2000]	ND [1000]
Isopropanol	NL	91,000	99,000	92,000	79,000	200,000	170,000	150,000	100,000
Trichloroethene	5	ND [500]	ND [500]	ND [1000]	ND [500]	ND [2000]	ND [2000]	ND [2000]	ND [1000]
Vinyl chloride	2	ND [500]	ND [500]	ND [1000]	ND [500]	ND [2000]	ND [2000]	ND [2000]	1,200
cis-1,2-Dichloroethene	70	ND [500]	ND [500]	ND [1000]	ND [500]	ND [2000]	ND [4000]	ND [4000]	ND [2000]
Total VOCs		127,200	141,200	139,300	115,940	202,100	170,000	150,000	102,400
Ethylene	NL	-	-	-	-	1,800	-	-	-
Methane	NL	-	-	-	-	5,400	-	-	-

Notes: MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID	Federal MCL	MW-404							
Sample Date		15-May-00	5-Apr-99	26-Oct-98	18-Aug-98	16-Jul-98	29-Apr-98	18-Aug-97	11-Aug-97
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	2.2	ND [1]	ND[10]	2.4	ND [1]	ND [1]	ND [20]	ND [20]
1,1-Dichloroethane	NL	17	6.7	ND[10]	16	11	17	240	280
1,1-Dichloroethene	7	ND [1]	ND [1]	ND [1]	ND [1]	ND [1]	ND [1]	ND [20]	ND [20]
Acetone	NL	88	ND[10]	ND[10]	ND [50]	ND [50]	ND [50]	1,400	1,600
Chloroethane	NL	3.6	ND[1] R	14	ND [1]	19	ND [1]	100	120
Isopropanol	NL	ND[50] R	ND[50] R	130	ND [50]	ND [50]	ND [50]	1,600	2,500
Trichloroethene	5	4.8	ND [1]	ND [1]	ND [1]	1.2	ND [1]	ND [20]	ND [20]
Vinyl chloride	2	**3.1**	ND [1]	ND [1]	ND [1]	1.2	ND [1]	ND [20]	ND [20]
cis-1,2-Dichloroethene	70	6.5	1.4	1.3	2.1	ND [1]	ND [1]	ND [20]	ND [20]
Total VOCs		125	8.1	145.3	20.5	32.4	17.0	3,340	4,500
Ethylene	NL	-	ND [100]	-	-	-	-	-	-
Methane	NL	-	810	840	-	-	-	-	-

Well ID	Federal MCL	MW-405							
Sample Date		15-May-00	11-Apr-99	27-Oct-98	19-Aug-98	18-Aug-97	18-Aug-97	11-Aug-97	11-Aug-97
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	ND [1]	ND [1]	ND [1]	ND [1]	ND [200]	ND [200]	ND [250]	ND [250]
1,1-Dichloroethane	NL	17	5.9	6.6	21	830	710	600	670
1,1-Dichloroethene	7	ND [1]	ND [1]	ND [1]	ND [1]	ND [200]	ND [200]	ND [250]	ND [250]
Acetone	NL	ND [50]	ND [50]	ND [50]	ND [50]	15000 J	16000 J	14,000	13,000
Chloroethane	NL	10	3.4 R	44	88	ND [200]	ND [200]	ND [250]	ND [250]
Isopropanol	NL	73 R	ND[50] R	ND [50]	ND [50]	12,000	12,000	26,000	21,000
Trichloroethene	5	1.2	ND [1]	ND [1]	1.4	ND [200]	ND [200]	ND [250]	ND [250]
Vinyl chloride	2	1.2	ND [1]	ND [1]	ND [1]	ND [200]	ND [200]	ND [250]	ND [250]
cis-1,2-Dichloroethene	70	1	ND [1]	ND [1]	ND [1]	ND [200]	ND [200]	ND [250]	ND [250]
Total VOCs		103.4	9.3	50.6	110.4	27,830	28,710	40,600	34,670
Ethylene	NL	-	ND [80]	-	-	-	-	-	-
Methane	NL	-	4,200	3,800	-	-	-	-	-

Notes: All concentrations presented in µg/l or ppb. MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

Table A-1. Summary of Detected VOCs in Groundwater, Building No. 3 Area, ITT Night Vision - Roanoke, VA (Cont'd).

Well ID	Federal MCL	MW-404							
Sample Date		4-Aug-97	28-Jul-97	15-Jul-97	15-Jul-97	8-Jul-97	8-Jul-97	30-Jun-97	24-Jun-97
VOCs (ug/L or ppb)									
1,1,1-Trichloroethane	200	ND [10]	ND [25]	ND [50]	ND [50]	ND [10]	ND [10]	ND [20]	ND [50]
1,1-Dichloroethane	NL	150	240	140	160	130	120	210	380
1,1-Dichloroethene	7	ND [10]	ND [25]	ND [50]	ND [50]	ND [10]	ND [10]	ND [20]	ND [50]
Acetone	NL	ND [500]	1,400	ND [2500]	ND [2500]	770	900	ND [1000]	2,600
Chloroethane	NL	40	77	64 J	56 J	57	58	91	110
Isopropanol	NL	1,200	3,200	3,600	3,400	960	1,300	1,900	7,800
Trichloroethene	5	ND [10]	ND [25]	ND [50]	ND [50]	ND [10]	ND [10]	ND [20]	ND [50]
Vinyl chloride	2	40	ND [25]	ND [50]	ND [50]	35	34	180	290
cis-1,2-Dichloroethene	70	ND [10]	ND [25]	ND [50]	ND [50]	ND [20]	ND [20]	140	480
Total VOCs		1,400	4,917	3,804	3,616	1,952	2,412	2,521	11,660
Ethylene	NL	-	-	ND [800]	-	-	-	-	-
Methane	NL	-	-	4,100	-	-	-	-	-

Well ID	Federal MCL	MW-405								
Sample Date		4-Aug-97	4-Aug-97	28-Jul-97	28-Jul-97	15-Jul-97	8-Jul-97	30-Jun-97	30-Jun-97	24-Jun-97
VOCs (ug/L or ppb)										
1,1,1-Trichloroethane	200	ND [250]	ND [250]	ND [250]	ND [250]	ND [500]	ND [500]	ND [500]	ND [500]	ND [500]
1,1-Dichloroethane	NL	1,100	750	1,200	1,200	1,200	1,900	1,600	1,200	1,300
1,1-Dichloroethene	7	ND [250]	ND [250]	ND [250]	ND [250]	ND [500]	ND [500]	ND [500]	ND [500]	ND [500]
Acetone	NL	16,000	14,000	17,000	20,000	ND [25000]	36,000	49,000	28,000	30,000
Chloroethane	NL	420 J	460 J	690 J	630 J	720 J	ND [500]	740	800	810
Isopropanol	NL	25,000	23,000	22,000	22,000	31,000	51,000	72,000	41,000	55,000
Trichloroethene	5	ND [250]	ND [250]	ND [250]	ND [250]	ND [500]	ND [500]	ND [500]	ND [500]	ND [500]
Vinyl chloride	2	ND [250]	ND [250]	ND [250]	ND [250]	ND [500]	ND [500]	ND [500]	ND [500]	720
cis-1,2-Dichloroethene	70	ND [250]	ND [250]	ND [250]	ND [250]	ND [500]	ND [1000]	ND [1000]	ND [1000]	ND [1000]
Total VOCs		42,520	38,210	40,890	43,830	32,920	88,900	123,340	71,000	87,830
Ethylene	NL	-	-	-	-	1,800	-	-	-	-
Methane	NL	-	-	-	-	9,900	-	-	-	-

Notes: MCL = Maximum Contaminant Level. L = Listed for regulation. NL = Not Listed for Regulation.
ND [ ] = Analyte not detected above method detection limits shown in brackets. J = Estimated Value. B = Analyte also detected in QA blank.
R = Data validation qualifier is unusable. - = Sample not analyzed for this constituent. Shading indicates an exceeding of the MCL.

As shown in Table A-1, the total VOC concentrations decreased with depth and distance from the source area (MW-306S location) as would be expected. The range of VOC concentrations over time for each monitoring well varied by as much as an order of magnitude over the eight-week baseline sampling period. This variability was consistent with VOC concentrations observed during previous sampling events. This is believed to be attributable to the naturally occurring biodegradation and varying recharge rates from precipitation. In addition, the elevated detection limits caused by elevated acetone and isopropanol concentration in several monitoring wells occasionally masked the presence of chlorinated hydrocarbons that were present at concentrations below those detection limits.

When comparing the Earth Tech baseline data to the SITE program baseline data, it is important to remember the time between these sampling events (weekly sampling versus daily sampling), but more importantly, the change in precipitation conditions between sampling events. The SITE program baseline sampling event was performed following and during three months of nearly twice normal precipitation, which created anomalously elevated groundwater levels. These conditions could have created a short-term dilution affect on the observed groundwater VOC baseline concentrations. Thus, based on the ITT NV baseline data, the SITE program baseline can be considered truly conservative and any observed reductions would therefore be significant.

Split Samples

Groundwater samples were split with the SITE program following the air-only and air/nutrient injection phases to evaluate the comparability of the SITE program and Earth Tech data sets for selected monitoring wells. For the majority of the compounds and monitoring wells, the laboratory results were comparable, as shown on **Table-A-2**.

Full Scale Results

The SITE program focused on four critical VOCs (1,1-dichloroethane, chloroethane, cis-1,2 dichloroethene, and vinyl chloride) based upon acceptable statistics derived from the SITE program baseline sampling event. Several more biodegradable compounds are present in the groundwater at this site as indicated in Table A-1. The presence of these additional VOCs could have an effect on the rate of reduction of the critical VOCs since several alternative carbon sources are available. The heterogeneous nature of the fractured rock system allowed for preferential airflow pathways and a nonuniform delivery of the amendments. This led to VOC reductions occurring at different rates and at varying locations and distances from the injection well during the pilot test. VOC reductions were initially apparent in MW-401, MW-403, and MW-401S. Based on field monitoring data, these wells were the most connected to the airflow pathways from the injection well; and therefore, received amendments at a higher rate as compared to other locations in the pilot test area. As the pilot test and the injection phases progressed, VOC reductions were observed in other pilot test monitoring wells (MW-1) and hydraulically down gradient locations (MW-404S, MW-404, MW-405S, and MW-405).

The furthest hydraulically downgradient location to manifest VOC reductions thus far is the monitoring well couplet MW-405 and MW-405S located 75 feet down gradient from IW-400. Based on helium tracer test and methane monitoring, this well couplet was not directly affected by the injection system. The average total VOC concentration for the Earth Tech baseline sample for MW-405 is 53,940 ppb with the minimum total VOC concentration observed for the baseline being 25,600 ppb. Since the operation of the bioremediation system, the average total VOC concentration at MW-405 is 68 ppb. Likewise, significant VOC reduction was observed in MW-405S; the baseline total VOC concentration was 71,000 ppb and the most recent sampling event result was 86.1 ppb. Greater than 99% total VOC reduction was observed for both MW-405 and MW-405S.

The minimum VOC reductions in the pilot test area observed during the SITE Demonstration were in the samples collected from the MW-402 couplet. This lack of response to the bioremediation system was attributed to an insufficient volume of air, nutrients, and methane being delivered to this area. Following system expansion to full scale, significant VOC reductions were observed at this location. The average total VOC concentration during the baseline sampling event for MW-402 was 112,045 ppb. MW-402 has shown a steady decline in total VOCs since the system expansion with 30,730 ppb in April 1999 and 3,817 ppb in August 2000. Trichloroethene (TCE) and 1,1,1-trichloroethane (1,1,1-TCA) reductions at this location were significant. The TCE baseline average was 2,644 ppb while the most recent sampling result was 230 ppb. The 1,1,1 TCA baseline average was 6,733 ppb while the most recent sampling result was 270 ppb. This represents a greater than 90% reduction in the chlorinated hydrocarbon source contaminants. MW-402S had an average total VOC concentration of 1,617,000 ppb prior to the system expansion. The most recent sampling event for MW-402S indicated 2,320 ppb total VOCs. Vinyl chloride reductions were observed ranging from 24,000 ppb to less than 10 ppb in well MW-402S. Cis 1,2 dichloroethene reductions on the same order of magnitude (12,000 ppb to 170 ppb) were observed at MW-402S. Greater than 99% total VOC reduction was observed for both MW-402 and MW-402S.

Table A-2. Summary of VOCs in Groundwater from Split Sampling Events, Interim Measure at Building 3, ITT Night Vision - Roanoke, VA.

MW-401

Event Date	4/29/98	4/27/98 to 5/1/98	7/16/98	7/13/98 to 7/17/98
Constituent (ug/L or ppb)	Post-Air	SAIC Post-Air	Post-Nutrient	SAIC Post-Nutrient
VOCs		Average		Average
Acetone	620	700	540	750
Isopropanol	1200	1230	1300	925
TCE	3500	70	100	91
Cis 1,2 DCE	310	302	310	252
1,1 DCE	<10	8	<10	11
VC	120	107	80	87
1,1,1 TCA	100	114	180	145
1,1 DCA	460	390	380	310
CA	69	70	110	100
Total VOCs	6379	2991	3000	2671

IW-400

Event Date	4/29/98	4/27/98 to 5/1/98	7/16/98	7/13/98 to 7/17/98
Constituent (ug/L or ppb)	Post-Air	SAIC Post-Air	Post-Nutrient	SAIC Post-Nutrient
VOCs		Average		Average
Acetone	760	833	150000	222000
Isopropanol	1800	1700	240000	163000
TCE	15	40	<2500	10
Cis 1,2 DCE	290	360	<2500	1390
1,1 DCE	<10	8	<2500	14
VC	120	130	<2500	130
1,1,1 TCA	15	98	<2500	210
1,1 DCA	370	415	<2500	1540
CA	<10	70	<2500	217
Total VOCs	3370	3654	390000	388511

MW-403

Event Date	4/29/98	4/27/98 to 5/1/98	7/16/98	7/13/98 to 7/17/98
Constituent (ug/L or ppb)	Post-Air	SAIC Post-Air	Post-Nutrient	SAICPost-Nutrient
VOCs		Average		Average
Acetone	3800	3000	710	3000
Isopropanol	4600	1900	1300	3325
TCE	<50	6	<10	5
Cis 1,2 DCE	100	117	62	109
1,1 DCE	<50	2.4	<10	2.1
VC	<50	47	25	46
1,1,1 TCA	<50	33	22	14
1,1 DCA	210	190	120	122
CA	<50	84	55	68
Total VOCs	8710	5379.4	2294	6691.1

MW-402

Event Date	4/29/98	4/27/98 to 5/1/98	7/16/98	7/13/98 to 7/17/98
Constituent (ug/L or ppb)	Post-Air	SAIC Post-Air	Post-Nutrient	SAIC Post-Nutrient
VOCs		Average		Average
Acetone	<25000	18000	11000	17,500
Isopropanol	59000	47666	37000	36500
TCE	1100	1950	1400	1450
Cis 1,2 DCE	4900	5975	4700	5225
1,1 DCE	<500	144	<500	150
VC	<500	815	<500	867
1,1,1 TCA	3800	4400	3600	3300
1,1 DCA	1300	1273	1500	1500
CA	<500	247	<500	322
Total VOCs	70100	80470	59200	66814

Table A-2. Summary of VOCs in Groundwater from Split Sampling Events, Interim Measure at Building 3, ITT Night Vision - Roanoke, VA (Cont'd).

MW-401S

Event Date	7/17/98	7/13/98 to 7/17/98
Constituent (ug/L or ppb)	Post-Nutrient	SAIC Post-Nutrient
VOCs		Average
Acetone	23000	40,000
Isopropanol	47000	54000
TCE	<500	17
Cis 1,2 DCE	1900	2200
1,1 DCE	<500	29
VC	<500	590
1,1,1 TCA	<500	410
1,1 DCA	510	520
CA	<500	170
Total VOCs	72410	97936

MW-404

Event Date	4/29/98	4/27/98 to 5/1/98	7/16/98	7/13/98 to 7/17/98
Constituent (ug/L or ppb)	Post-Air	SAIC Post-Air	Post-Nutrient	SAIC Post-Nutrient
VOCs		Average		
Acetone	<50	ND	<50	ND
Isopropanol	<50	ND	<50	ND
TCE	<1	0.6	1.2	0.7
Cis 1,2 DCE	<1	0.8	<1	0.6
1,1 DCE	<1	ND	<1	0.2
VC	<1	1.2	1.2	0.4
1,1,1 TCA	<1	0.2	<1	0.2
1,1 DCA	17	20	11	10
CA	<1	16.8	19	20.5
Total VOCs	17	39.6	32.4	32.6

MW402S

Event Date	7/16/98	7/13/98 to 7/17/98
Constituent (ug/L or ppb)	Post-Nutrient	SAIC Post-Nutrient
VOCs		
Acetone	410000	590,000
Isopropanol	1,200,000	920000
TCE	<10000	88
Cis 1,2 DCE	<10000	2700
1,1 DCE	<10000	85
VC	<10000	1300
1,1,1 TCA	<10000	640
1,1 DCA	<10000	700
CA	<10000	160
Total VOCs	1610000	1515673

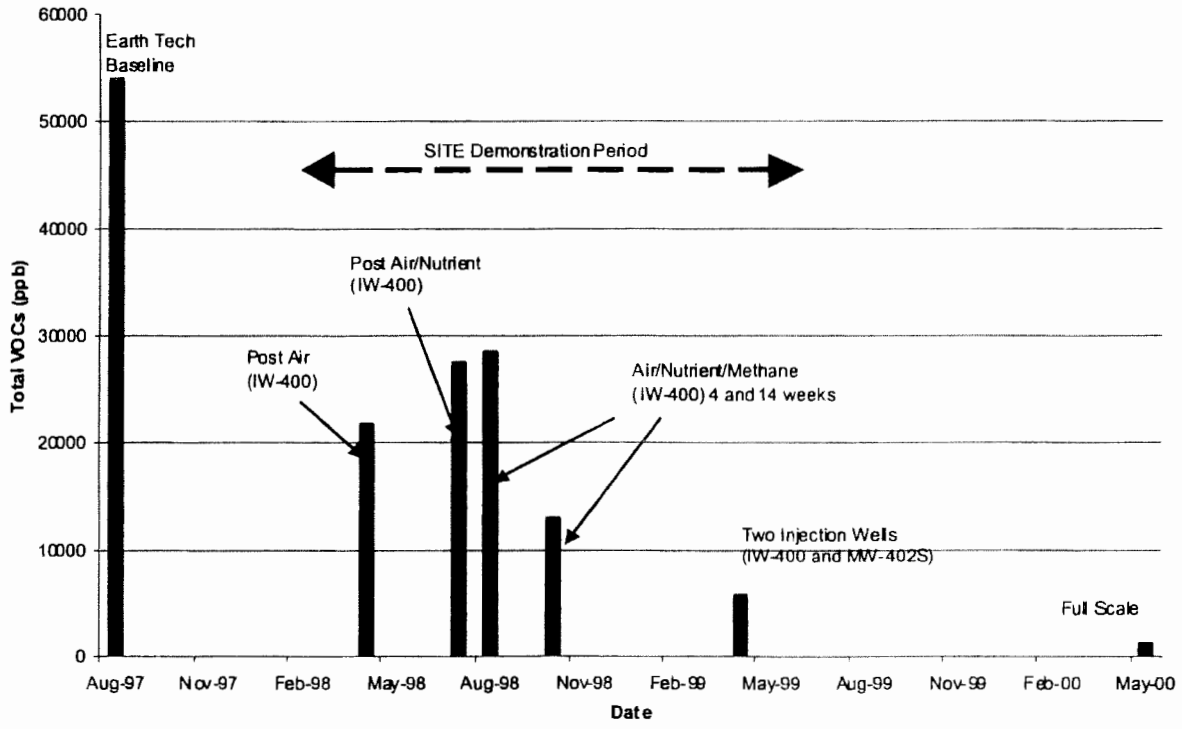
MW-404S

Event Date	7/16/98	7/13/98 to 7/17/98
Constituent (ug/L or ppb)	Post-Nutrient	SAIC Post-Nutrient
VOCs		Average
Acetone	<50	ND
Isopropanol	<50	ND
TCE	<1	0.8
Cis 1,2 DCE	4	4.5
1,1 DCE	<1	0.2
VC	<1	1.1
1,1,1 TCA	<1	0.3
1,1 DCA	1.6	1.6
CA	<1	0.4
Total VOCs	5.6	8.9

To summarize the overall VOC reductions at the site, average VOC concentrations in the pilot test monitoring wells were plotted over time on **Figure 2** which shows a steady overall decline in VOC concentrations at the site during the pilot test and following system expansion. Currently, VOC concentrations remain one to two orders of magnitude above the drinking water maximum contaminant levels (MCLs) in MW-306O, MW-306S, IW-400, MW-401, MW-40I, MW-402S, and MW-402. However, the bioremediation system has reduced the VOC concentrations in groundwater to drinking water MCLs in MW-1, IW-400S, MW-401S, MW-403, MW-404S, MW-404, MW-405S, and MW-405.

If these VOC reductions continue, long-term VOC removal will have been accomplished and the injection system operation will be discontinued in the very near future. Given the high initial VOC concentrations, recalcitrant VOCs present, and the complex hydrogeologic environment at the site, the observed VOC source removal has exceeded the expectations of Earth Tech and ITT Night Vision. Because of the successes at this and other sites, this enhanced cometabolic bioremediation technology is being successfully applied at other sites across the United States by Earth Tech and other approved Department of Energy licensees.

Figure 2
Average Total VOC Concentration in Pilot Test Area



Appendix B - PUMP TEST DATA and DISCUSSION OF ACOUSTIC BOREHOLE TELEVIEWER

Note: The excerpted information contained in this appendix was provided by Earth Tech, Inc. and has not been independently verified by the U.S. EPA SITE Program

B.1 Limited Pumping Test Results

During the development of IW-400, groundwater levels were monitored in selected surrounding monitoring wells. The monitoring well data is presented in **Table B-1**. Groundwater was pumped from IW-400 initially at 5.7 gpm; however, soon after pumping began it was apparent that the pumping rate was decreased to 2.6 gpm, the drawdown in the pumping well ceased and recovery began. Therefore, the well yield for IW-400 would be expected to be between 2 and 4 gpm.

As shown in Table B-1, drawdown was observed in the shallow bedrock as evidenced in MW-1. The shallowest zone monitored (SG-1D) showed a slight decrease in groundwater level during pumping. This apparent drawdown was minimal. Drawdown was most pronounced in the monitoring wells closest to the pumping well and decreased with distance from IW-400. Drawdown in the monitoring wells intercepting separate zones suggests that the shallow and deep upper bedrock fracture zones are hydraulically interconnected.

Hydraulic characteristic estimates were made using the groundwater measurement data from IW-400. The frequency of measurements from the surrounding monitoring wells was too limited for estimating the hydraulic characteristics. The Moench method was used to estimate the hydraulic characteristics of the water-bearing zone in this location. The hydraulic conductivity of the fissure (major fractures) system was estimated to be 8.1×10^{-4} ft/min, with the hydraulic conductivity of the matrix (minor discrete fractures) system estimated to be on the order of 1.2×10^{-5} ft/min. The specific storage estimates yielded a 10^{-6} ft^{-1} for the fissure system and 0.5 ft^{-1} for the specific storage of the matrix system. These estimates are consistent with the hydraulic characteristic estimates from the MW-1 extended pumping test (discussed in the Stage IIB Data Report). As would be expected, groundwater storage is primarily occurring in the matrix rock.

B.2 Acoustic Borehole Televiewer Discussion

Numerous open hole wells were selected for downhole logging using the acoustic borehole televiewer (ABT) tool. The ABT log is created when an acoustic pulse is reflected off the borehole wall as the transmitter and receiver rotate. The digital image is related to magnetic north and is presented as a continuous image on logs. The image can be displayed in color or black and white. The reproducibility of black and white was chosen over color for the purposes of Earth Tech's report[1]. Therefore, fractures and other borehole irregularities appear in the report as the darker features. If the fracture was tilted, relative to the borehole, the image will appear as a sine wave. The dip direction is the lowest point on the curve. The dip angle is calculated using the amplitude of the curve and borehole diameter. The trend of the fracture would be perpendicular (90 degrees relative) to the dip direction.

When viewing the ABT logs, the exact fracture curve is not always clear; therefore, interpretation plays an important role in the determination of the fracture orientation. Also, the ABT log data as presented in the Earth Tech's report has an estimated error range between 1 and 5 degrees. The potential error would be highest with low (<15 degrees) dip angle fractures.

The ABT tool provided the most data in boreholes with limited "wash out" zones. In some boreholes with large irregular openings (such as "mud seams"), the tool lodged in the hole because of the tool's centralizers and could not be advanced. In other boreholes, planer features were not apparent.

Table B-1. Data From Limited Pumping Tests, ITT Night Vision - RFI Supplemental Data Report.

Well ID	Time (min)	Depth to Water (ft BGS)	Drawdown (ft)	Conditions
IW-400	0	13.22	—	Static
	2	18.72	5.5	Pumping 5.7 gpm
	3	19.5	6.28	Pumping 5.7 gpm
	5	21.18	7.96	Pumping 5.7 gpm
	18	32.13	18.91	Pumping 5.7 gpm
	30	41.12	27.9	Pumping 5.0 gpm
	35	41.92	28.7	Pumping 2.6 gpm
	48	39.15	25.93	Pumping 2.6 gpm
	59	36.74	23.52	Pumping 2.6 gpm
MW-401	0	12.98	—	Static
	9	22.91	9.93	Pumping 5.7 gpm
	21	33.13	20.15	Pumping 5.0 gpm
	38	40.81	27.83	Pumping 2.6 gpm
	62	36.02	23.04	Pumping 2.6 gpm
MW-402	0	12.49	—	Static
	10	13.79	1.3	Pumping 5.7 gpm
	22	16.62	4.13	Pumping 5.0 gpm
	42	20.47	7.98	Pumping 2.6 gpm
	64	22.59	10.1	Pumping 2.6 gpm
MW-403	0	13.56	—	Static
	12	14.02	0.46	Pumping 5.7 gpm
	25	14.88	1.32	Pumping 5.0 gpm
	45	15.58	2.02	Pumping 2.6 gpm
	66	15.93	2.37	Pumping 2.6 gpm
MW-404	0	13.21	—	Static
	15	13.25	0.04	Pumping 5.7 gpm
	28	13.44	0.23	Pumping 5.0 gpm
	46	13.79	0.58	Pumping 2.6 gpm
	68	14.08	0.87	Pumping 2.6 gpm
MW-1	0	15.15	—	Static
	13	15.32	0.17	Pumping 5.7 gpm
	24	15.66	0.51	Pumping 5.0 gpm
	43	16.29	1.14	Pumping 2.6 gpm
SG-1 Deep	0	12.15	—	Static
	7	12.15	0	Pumping 5.7 gpm
	20	12.17	0.02	Pumping 5.0 gpm
	37	12.19	0.04	Pumping 2.6 gpm
	60	12.21	0.06	Pumping 2.6 gpm

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