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 **Environmental Technology  
Verification Report**

## Soil Gas Sampling Technology

Quadrel Services, Inc.  
EMFLUX Soil Gas System



# **Environmental Technology Verification Report**

## **Soil Gas Sampler**

### **Quadrel Services, Inc. EMFLUX<sup>®</sup> Soil Gas Investigation System**

Prepared by

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## **Notice**

This document was prepared for the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation Program under contract 68-C5-0037. The work detailed in this document was administered by the National Exposure Research Laboratory—Environmental Sciences Division in Las Vegas, Nevada. The document has been subjected to EPA's peer and administrative reviews, and has been approved for publication as an EPA document. Mention of corporation names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products.



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Office of Research and Development  
Washington, D.C. 20460



ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM  
VERIFICATION STATEMENT

TECHNOLOGY TYPE: PASSIVE SOIL GAS SAMPLER  
APPLICATION: SUBSURFACE SOIL GAS SAMPLING  
TECHNOLOGY NAME: EMFLUX® SOIL GAS INVESTIGATION SYSTEM  
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**ETV PROGRAM DESCRIPTION**

The U.S. Environmental Protection Agency (EPA) created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. The ETV Program is intended to assist and inform those involved in the design, distribution, permitting, and purchase of environmental technologies. This document summarizes the results of a demonstration of the Quadrel Services, Inc., EMFLUX® Soil Gas Investigation System.

**PROGRAM OPERATION**

Under the ETV Program and with the full participation of the technology developer, the EPA evaluates the performance of innovative technologies by developing demonstration plans, conducting field tests, collecting and analyzing demonstration data, and preparing reports. The technologies are evaluated under rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the demonstration results are defensible. The EPA's National Exposure Research Laboratory, which demonstrates field characterization and monitoring technologies, selected Tetra Tech EM Inc. as the verification organization to assist in field testing various soil and soil gas sampling technologies. This demonstration was conducted under EPA's Superfund Innovative Technology Evaluation Program.

**DEMONSTRATION DESCRIPTION**

In May and June 1997, the EPA conducted a field test of the EMFLUX® system along with one other soil gas and four soil sampling technologies. This verification statement focuses on the EMFLUX® system; similar statements have been prepared for each of the other technologies. The performance of the EMFLUX® system was compared to the reference sampling method, active soil gas sampling, which provides a snapshot of the soil gas environment at the time the sample is collected. The comparison addressed three parameters: (1) volatile organic compound (VOC) detection and quantitation, (2) sample retrieval time, and (3) cost. Data quality indicators for precision, accuracy, representativeness, completeness, and comparability were also assessed against project-specific QA objectives to ensure the usefulness of the data.

The EMFLUX® system was demonstrated at two sites: the Small Business Administration (SBA) site in Albert City, Iowa, and the Chemical Sales Company (CSC) site in Denver, Colorado. These sites were chosen because each site exhibited a wide range of VOC concentrations and a distinct soil type. The VOCs detected at the sites include vinyl

chloride; cis-1,2-dichloroethene (cis-1,2-DCE); 1,1-dichloroethane (1,1-DCA); 1,1,1-trichloroethane (1,1,1-TCA); trichloroethene (TCE); and tetrachloroethene (PCE). The SBA site is composed primarily of clay soil, and the CSC site is composed primarily of medium- to fine-grained sandy soil. A complete description of the demonstration, including a data summary and discussion of results, is available in the report titled Environmental Technology Verification Report: Passive Soil Gas Sampler, Quadrel Services, Inc. (Quadrel), EMFLUX<sup>®</sup>, EPA/600/R-98/096).

## TECHNOLOGY DESCRIPTION

The EMFLUX<sup>®</sup> system is a passive soil gas sampling technology designed for use in shallow deployment to identify and quantify a broad range of VOCs and semivolatile organic compounds (SVOC), including halogenated compounds, petroleum hydrocarbons, polynuclear aromatic hydrocarbons, and other compounds present at depths to more than 200 feet. For this ETV demonstration, the EMFLUX<sup>®</sup> system consisted of the EMFLUX<sup>®</sup> sample cartridge, sample insertion tools, and developer-provided sample analysis. The EMFLUX<sup>®</sup> cartridge consists of 100 milligrams of sorbent sealed in a fine-mesh screen, which is placed in a glass vial; the vial and cartridge make up the EMFLUX<sup>®</sup> field collector. This assembly is inserted into the soil, but only the cartridge is thermally desorbed and analyzed in the laboratory. The EMFLUX<sup>®</sup> field collector is installed by creating a three to four-inch deep pilot hole using a manual hammer and a stake, and inserting the sampler manually. The sampler is then covered to reduce the potential for sorption of airborne contaminants. The cartridge is retrieved by hand and, for this demonstration, was analyzed by the developer. The EMFLUX<sup>®</sup> system also includes computer modeling by Quadrel using a proprietary model to predict periods of maximum soil gas emission for geographic locations and optimize sampling efficiency. However, the performance of the model was not evaluated during the demonstration.

## VERIFICATION OF PERFORMANCE

The demonstration data indicate the following performance characteristics for the EMFLUX<sup>®</sup> system:

**VOC Detection and Quantitation:** Soil gas samples collected using the EMFLUX<sup>®</sup> system and the reference soil gas sampling method at nine grids at both the sites were analyzed for six target VOCs. Analysis of EMFLUX<sup>®</sup> samples yielded results in total nanograms per sample, which Quadrel converted to mass per unit volume of air (nanograms per liter [ng/L]). The reference method also produced results in mass per unit volume of air (ng/L). A comparison of the mean VOC concentrations calculated for each sampling method at each grid indicates that the EMFLUX<sup>®</sup> system identified the presence of all of the VOC compounds detected by the reference soil gas sampling method in 24 of 25 cases. In addition, in 7 of 31 cases, the EMFLUX<sup>®</sup> system also reported VOCs that the reference method did not detect but were identified as present during previous soil and groundwater investigations at the demonstration sites. This performance characteristic suggests that the EMFLUX<sup>®</sup> system can detect the presence of lower concentrations of VOCs in soil gas than the reference soil gas sampling method. In addition, the sample locations where the EMFLUX<sup>®</sup> system reported high VOC concentrations generally corresponded to the sample locations where the reference method also reported high VOC concentrations. However, the values in the two data sets do not appear to exhibit any direct or consistent proportional relationship, and the mean concentrations of VOCs calculated using the reference method data were typically one to four orders of magnitude higher than those calculated using the EMFLUX<sup>®</sup> system for samples from the same grid. Because the EMFLUX<sup>®</sup> system relies on diffusion of soil gas from subsurface sources such as contaminated soil or groundwater, the performance range for the EMFLUX<sup>®</sup> system may be controlled by factors such as depth to the contaminant source, contaminant concentrations and diffusion rates, soil type and organic content, the detection limits of the methods used to analyze the samples, and possibly other factors. However, during the demonstration, the system was evaluated at locations with relatively shallow subsurface contamination, and was only evaluated with regard to its ability to detect certain targeted VOCs. For these reasons, the performance range of the EMFLUX<sup>®</sup> system was not fully established by the demonstration data. It should be noted that the EMFLUX<sup>®</sup> system and reference method are field screening techniques that provide only an estimate of the actual concentration of contaminants in soil gas. Because the EMFLUX<sup>®</sup> system and reference method use different techniques to collect soil gas samples, it is not expected that the two methods will provide the same response and that the data will be directly comparable. Because the mean VOC concentrations for the data sets differ by several orders of magnitude in most instances, a statistical analysis of the data was not performed and interpretation of the chemical concentration data for this demonstration is limited to qualitative observations.

**Sample Retrieval Time:** Installation of the EMFLUX<sup>®</sup> system averaged 3.0 minutes per sample at the SBA site and 4.0 minutes per sample at the CSC site. For the demonstration, the samplers were left in place for approximately 4 days at each site. Collection of the samplers required an average of 2.3 minutes per sample at the SBA site and 3.2 minutes at the CSC site. Overall, installation and collection of 35 samples at the SBA site required 187 minutes, an average of 5.3 minutes per sample, and installation and collection of 28 samples at the CSC site required 201 minutes, an average of 7.2 minutes per sample. The analysis and reporting by the technology developer required an additional 12 days for the SBA site data and 16 days for the CSC site data from the time samples were collected until the laboratory report was delivered. The reference soil gas method required 458 minutes to collect 35 samples at the SBA site, an average of 13.1 minutes per sample, and 183 minutes to collect 28 samples at the CSC site, an average of 6.5 minutes per sample. One day was required per site to analyze the samples and report the results. Based on the demonstration results, the average sample retrieval times for the EMFLUX<sup>®</sup> system were quicker than those of the reference soil gas sampling method in the clay soils at the SBA site and slower than those of the reference sampling method in the sandy soils at the CSC site. During sample collection using the reference soil gas sampler, the clay soil at the SBA site caused the system to hold its vacuum at several sampling locations; therefore, soil gas was not completely drawn into the system for sampling. In these cases, the rod was withdrawn in additional 6-inch increments until the vacuum was broken and the system's pressure reached equilibrium with atmospheric pressure. The vacuum problem was not encountered in the sandy soil at the CSC site. At both sites, one person collected soil gas samples with the EMFLUX<sup>®</sup> system, and a three-person sampling crew collected and analyzed soil samples using the reference sampling method.

**Cost** Based on the demonstration results, the EMFLUX<sup>®</sup> system costs \$85 to \$195 per sample plus equipment costs of \$25 to \$90 per day and mobilization/demobilization costs of \$200 to \$600 per day. Operating costs for the EMFLUX<sup>®</sup> system ranged from \$660 to \$1,390 at the clay soil site and \$710 and \$1,440 at the sandy soil site. For this demonstration, the active soil gas sampling method was procured at a lump sum of \$4,700 for each site. The oversight costs for the active soil gas sampling method ranged from \$680 to \$1,260 at the clay soil site and \$480 to \$910 at the sandy soil site. A site-specific cost and performance analysis is recommended when selecting a subsurface soil gas sampling method.

A qualitative performance assessment of the EMFLUX<sup>®</sup> system indicated that (1) the samplers are reliable in that 100 percent of the required samples were collected without sample losses; (2) the samplers are easy to use and require minimal training (a 16-minute training video is available from the developer); (3) logistical requirements for the EMFLUX<sup>®</sup> system differ from those of the reference sampling method because the EMFLUX<sup>®</sup> field collectors are installed using a hammer-driven, 6-inch steel rod, left in place for several days, retrieved by hand, and sent to the developer for analysis; and (4) sample handling in the field was easier than the reference method because the only requirements are that the recovered cartridges be properly packed and shipped to the developer for analysis.

The demonstration results indicate that the EMFLUX<sup>®</sup> system can provide useful, cost-effective data for environmental problem-solving. The EMFLUX<sup>®</sup> system successfully collected soil gas samples in clay and sandy soils. The sampler provided positive identification of target VOCs and may be able to detect lower concentrations of VOCs in the soil gas than the reference method. The results of the demonstration did not indicate consistent proportional comparability between the EMFLUX<sup>®</sup> data and the reference method's data. As with any technology selected, the user must determine what is appropriate for the application and the project data quality objectives.

Gary J. Foley, Ph.D.  
Director  
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Office of Research and Development

**NOTICE:** EPA verifications are based on an evaluation of technology performance under specific, predetermined criteria and appropriate quality assurance procedures. EPA makes no expressed or implied warranties as to the performance of the technology and does not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements.

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## Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's natural resources. Under the 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, the EPA's Office of Research and Development (ORD) provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The National Exposure Research Laboratory (NERL) is the Agency's center for the investigation of technical and management approaches for identifying and quantifying risks to human health and the environment. Goals of the Laboratory's research program are to (1) develop and evaluate methods and technologies for characterizing and monitoring air, soil, and water; (2) support regulatory and policy decisions; and (3) provide the science support needed to ensure effective implementation of environmental regulations and strategies.

The EPA's Superfund Innovative Technology Evaluation (SITE) Program evaluates technologies for the characterization and remediation of contaminated Superfund and Resource Conservation and Recovery Act sites. The SITE Program was created to provide reliable cost and performance data to speed the acceptance and use of innovative remediation, characterization, and monitoring technologies by the regulatory and user communities.

Effective measurement and monitoring technologies are needed to assess the degree of contamination at a site, to provide data that can be used to determine the risk to public health or the environment, to supply the necessary cost and performance data to select the most appropriate technology, and to monitor the success or failure of a remediation process. One component of the EPA SITE Program, the Monitoring and Measurement Technologies Program, demonstrates and evaluates innovative technologies to meet these needs.

Candidate technologies can originate from within the federal government or from the private sector. Through the SITE Program, developers are given the opportunity to conduct a rigorous demonstration of their technology under actual field conditions. By completing the evaluation and distributing the results, the Agency establishes a baseline for acceptance and use of these technologies. The Monitoring and Measurement Technology Program is managed by the ORD's Environmental Sciences Division in Las Vegas, Nevada.

Gary Foley, Ph.D.  
Director  
National Exposure Research Laboratory  
Office of Research and Development

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## Contents

Notice . . . . .	ii
Verification Statement . . . . .	iii
Foreword . . . . .	vi
Figures . . . . .	ix
Tables . . . . .	x
Acronyms and Abbreviations . . . . .	xi
Acknowledgments . . . . .	xii
Executive Summary . . . . .	xiii
Chapter 1 Introduction . . . . .	1
Technology Verification Process . . . . .	3
Needs Identification and Technology Selection . . . . .	3
Demonstration Planning and Implementation . . . . .	3
Report Preparation . . . . .	4
Information Distribution . . . . .	4
Demonstration Purpose . . . . .	4
Chapter 2 Technology Description . . . . .	5
Background . . . . .	5
Components and Accessories . . . . .	7
General Operating Procedures . . . . .	7
Developer Contact . . . . .	9
Chapter 3 Site Descriptions and Demonstration Design . . . . .	10
Site Selection and Description . . . . .	10
SBA Site Description . . . . .	10
CSC Site Description . . . . .	12
Predemonstration Sampling and Analysis . . . . .	14
Demonstration Design . . . . .	14
VOC Detection and Quantitation . . . . .	15
Sample Retrieval Time . . . . .	17
Cost . . . . .	17
Deviations from the Demonstration Plan . . . . .	17
Chapter 4 Description and Performance of the Reference Method . . . . .	18
Background . . . . .	18
Components and Accessories . . . . .	18
Description of Platform . . . . .	19
Demonstration Operating Procedures . . . . .	19
Qualitative Performance Factors . . . . .	20
Reliability and Ruggedness . . . . .	20
Training Requirements and Ease of Operation . . . . .	21
Logistical Requirements . . . . .	21
Sample Handling . . . . .	21



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## Contents (Continued)

Performance Range . . . . .	21
Quantitative Performance Factors . . . . .	21
VOC Detection and Quantitation . . . . .	22
Sample Retrieval Time . . . . .	22
Data Quality . . . . .	22
Chapter 5 Technology Performance . . . . .	25
Qualitative Performance Factors . . . . .	25
Reliability and Ruggedness . . . . .	25
Training Requirements and Ease of Operation . . . . .	25
Logistical Requirements . . . . .	25
Sample Handling . . . . .	26
Performance Range . . . . .	26
Quantitative Performance Assessment . . . . .	26
VOC Detection and Quantitation . . . . .	26
Sample Retrieval Time . . . . .	32
Data Quality . . . . .	33
Chapter 6 Economic Analysis . . . . .	34
Assumptions . . . . .	34
EMFLUX <sup>®</sup> System . . . . .	34
Reference Sampling Method . . . . .	37
Chapter 7 Summary of Demonstration Results . . . . .	39
Chapter 8 Technology Update . . . . .	42
Empirical and Theoretical Bases for EMFLUX <sup>®</sup> System . . . . .	42
The ETV Demonstrations . . . . .	43
Expanding Applications . . . . .	44
Chapter 9 Previous Deployment . . . . .	45
References . . . . .	48
Appendix	
A Data Summary Tables . . . . .	A-1

---

## Figures

2-1.	EMFLUX <sup>®</sup> Collector Parts and Deployment Options . . . . .	8
3-1.	Small Business Administration Site . . . . .	11
3-2.	Chemical Sales Company Site . . . . .	13
3-3.	Typical Sampling Locations and Random Sampling Grid . . . . .	16
5-1.	Comparison of Mean 1,2-Dichloroethene Concentration in Samples Collected Using the EMFLUX <sup>®</sup> System and the Reference Soil Gas Sampling Method . . . . .	30
5-2.	Comparison of Mean 1,1,1-Trichloroethane Concentration in Samples Collected Using the EMFLUX <sup>®</sup> System and the Reference Soil Gas Sampling Method . . . . .	30
5-3.	Comparison of Mean Trichloroethene Concentration in Samples Collected Using the EMFLUX <sup>®</sup> System and the Reference Soil Gas Sampling Method . . . . .	31
5-4.	Comparison of Mean Tetrachloroethene Concentration in Samples Collected Using the EMFLUX <sup>®</sup> System and the Reference Soil Gas Sampling Method . . . . .	31

---

## Tables

4-1.	Volatile Organic Compound Concentrations in Samples Collected Using the Reference Soil Gas Sampling Method . . . . .	23
5-1.	Volatile Organic Compound Concentrations in Samples Collected Using the EMFLUX <sup>®</sup> System . . . . .	28
5-2.	Mean Chemical Concentrations of EMFLUX <sup>®</sup> and Reference Soil Gas Sampling Method Data . . . . .	29
5-3.	Average Sample Retrieval Times for the EMFLUX <sup>®</sup> System and the Reference Soil Gas Sampling Method . . . . .	32
6-1.	Estimated Subsurface Soil Gas Sampling Costs for the EMFLUX <sup>®</sup> System . . . . .	35
6-2.	Estimated Subsurface Soil Gas Sampling Costs for the Reference Sampling Method . . . . .	37

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## Acronyms and Abbreviations

bgs	below ground surface
cc	cubic centimeter
cis-1,2-DCE	cis-1,2-dichloroethene
CLP	contract laboratory program
CSC	Chemical Sales Company
CSCT	Consortium for Site Characterization Technology
1,1-DCA	1,1-dichloroethane
1,2-DCE	1,2-dichloroethene (total)
E&E	Ecology & Environment
ELCD	electrolytic conductivity detector
EMFLUX <sup>®</sup>	EMFLUX <sup>®</sup> Soil Gas Investigation System
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
ETVR	Environmental Technology Verification Report
GC	gas chromatography
GC/MS	gas chromatograph/mass spectrometer
mg	milligrams
mg/kg	milligrams per kilogram
ml	milliliters
Fg/kg	micrograms per kilogram
NERL	National Exposure Research Laboratory
ng/L	nanograms per liter
OU	operable unit
PAH	polynuclear aromatic hydrocarbon
PCE	tetrachloroethene
QA	quality assurance
QC	quality control
QA/QC	quality assurance/quality control
Quadrel	Quadrel Services, Inc.
RI/FS	remedial investigation/feasibility study
SBA	Small Business Administration
SITE	Superfund Innovative Technology Evaluation
SMC	Superior Manufacturing Company
SVOC	semivolatile organic compound
1,1,1-TCA	1,1,1-trichloroethane
TCE	trichloroethene
VOC	volatile organic compound

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## **Acknowledgments**

This report was prepared for the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification Program under the direction of Stephen Billets, Brian Schumacher, and Eric Koglin of the EPA's National Exposure Research Laboratory—Environmental Sciences Division in Las Vegas, Nevada. The project was also supported by the EPA's Superfund Innovative Technology Evaluation (SITE) Program. The EPA wishes to acknowledge the support of Janice Kroone (EPA Region 7), Joe Vranka (Colorado Department of Public Health and the Environment), Armando Saenz (EPA Region 8), Sam Goforth (independent consultant), Alan Hewitt (Cold Regions Research Engineering Laboratory), Bob Siegrist (Colorado School of Mines), and Ann Kern (EPA SITE Program). In addition, we gratefully acknowledge the collection of the passive soil gas samples using the EMFLUX<sup>®</sup> system by Bruce Tucker (Quadrel); implementation of this demonstration by Eric Hess, John Parks, and Willis Wilcoxon (Tetra Tech); editorial and publication support by Butch Fries, Jennifer Brainerd, and Stephanie Anderson (Tetra Tech); and technical report preparation by Ron Ohta, Roger Argus, and Ben Hough (Tetra Tech).

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## Executive Summary

In May and June 1997, the U.S. Environmental Protection Agency (EPA) sponsored a demonstration of the EMFLUX<sup>®</sup> passive soil gas sampling technology, one other soil gas sampling technology, and four soil sampling technologies. This Environmental Technology Verification Report (ETVR) presents the results of the EMFLUX<sup>®</sup> Soil Gas Investigation System demonstration; similar reports have been prepared for each of the other technologies.

The EMFLUX<sup>®</sup> system is a passive soil gas sampling system distinguishable by its use of a model to predict periods of maximum soil gas emission for geographic locations to select optimal sampling times. The EMFLUX<sup>®</sup> system allows simultaneous sample collection by multiple field collectors, thereby eliminating movement of equipment from point to point. The EMFLUX<sup>®</sup> system consists of the EMFLUX<sup>®</sup> sample cartridge, sample insertion tools, and developer-provided sample analysis and computer modeling. The EMFLUX<sup>®</sup> cartridge consists of 100 milligrams of sorbent sealed in a fine mesh screen, which is placed in a glass vial for sample collection and shipped for laboratory analysis.

The EMFLUX<sup>®</sup> system was demonstrated at two sites: the Small Business Administration (SBA) site in Albert City, Iowa, and the Chemical Sales Company (CSC) site in Denver, Colorado. These sites were chosen because each has a wide range of volatile organic compound (VOC) concentrations and because each has a distinct soil type. The VOCs detected at the sites include vinyl chloride; 1,2-dichloroethene; 1,1-dichloroethane; 1,1,1-trichloroethane; trichloroethene; and tetrachloroethene. The SBA site is composed primarily of clay soil and the CSC site is composed primarily of sandy soil.

The EMFLUX<sup>®</sup> system was compared to the reference sampling method, active soil gas sampling, in terms of the following parameters: (1) VOC detection and quantitation, (2) sample retrieval time, and (3) cost. The demonstration data indicated the following performance characteristics:

- C The EMFLUX<sup>®</sup> system consistently detected all of the compounds identified by the reference sampling method and in several instances detected VOCs that the reference sampling method did not detect. However, VOC concentrations detected using the EMFLUX<sup>®</sup> system were typically one to four orders of magnitude lower than those reported by the reference method.
- C The average sample retrieval times for the EMFLUX<sup>®</sup> system were quicker than the reference soil gas sampling method in the clay soils at the SBA site and slower than the reference method in the sandy soils at the CSC site. For this demonstration, the EMFLUX<sup>®</sup> field collectors were left in place for 4 days at each site and required 12 days at the SBA site and 16 days at the CSC site for cartridge analysis and reporting by the developer. The reference sampling method required one day per site to analyze the samples and report the analytical results.
- C Based on the demonstration results, the EMFLUX<sup>®</sup> system cost \$85 to \$195 per sample plus equipment costs of \$25 to \$90 per day and mobilization/demobilization costs of \$200 to \$600 per site. Operating costs for the EMFLUX<sup>®</sup> system ranged from \$660 to \$1,390 at the clay soil site and \$710 and \$1,440 at the sandy soil site.

In general, results for the data quality indicators selected for this demonstration met the established quality assurance objectives and support the usefulness of the demonstration results in verifying the performance of the EMFLUX<sup>®</sup> system.

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## **Chapter 1**

### **Introduction**

Performance verification of innovative and alternative environmental technologies is an integral part of the U.S. Environmental Protection Agency's (EPA) regulatory and research mission. Early efforts focused on evaluating technologies that supported implementation of the Clean Air and Clean Water Acts. To meet the needs of the hazardous waste program, the Superfund Innovative Technology Evaluation (SITE) Program was established by the EPA Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) as part of the Superfund Amendments and Reauthorization Act of 1986. The primary purpose of the SITE Program is to promote the acceptance and use of innovative characterization, monitoring, and treatment technologies.

The overall goal of the SITE Program is to conduct research and performance verification studies of alternative or innovative technologies that may be used to achieve long-term protection of human health and the environment. The various components of the SITE Program are designed to encourage the development, demonstration, acceptance, and use of new or innovative treatment and monitoring technologies. The program is designed to meet four primary objectives: (1) identify and remove obstacles to the development and commercial use of alternative technologies, (2) support a development program that identifies and nurtures emerging technologies, (3) demonstrate promising innovative technologies to establish reliable performance and cost information for site characterization and cleanup decision-making, and (4) develop procedures and policies that encourage the selection of alternative technologies at Superfund sites, as well as other waste sites and commercial facilities.

The intent of a SITE demonstration is to obtain representative, high quality, performance and cost data on innovative technologies so that potential users can assess a given technology's suitability for a specific application. The SITE Program includes the following elements:

- C Monitoring and Measurement Technology (MMT) Program** — Evaluates technologies that detect, monitor, sample, and measure hazardous and toxic substances. These technologies are expected to provide better, faster, and more cost-effective methods for producing real-time data during site characterization and remediation studies
  
- C Remediation Technologies** — Conducts demonstrations of innovative treatment technologies to provide reliable performance, cost, and applicability data for site cleanup
  
- C Technology Transfer Program** — Provides and disseminates technical information in the form of updates, brochures, and other publications that promote the program and the technology. Provides technical assistance, training, and workshops to support the technology

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The MMT Program provides developers of innovative hazardous waste measurement, monitoring, and sampling technologies with an opportunity to demonstrate a technology's performance under actual field conditions. These technologies may be used to detect, monitor, sample, and measure hazardous and toxic substances in soil, sediment, waste materials, and groundwater. Technologies include chemical sensors for *in situ* (in place) measurements, groundwater sampling devices, soil and core sampling devices, soil gas samplers, laboratory and field-portable analytical equipment, and other systems that support field sampling or data acquisition and analysis.

The MMT Program promotes the acceptance of technologies that can be used to accurately assess the degree of contamination at a site, provide data to evaluate potential effects on human health and the environment, apply data to assist in selecting the most appropriate cleanup action, and monitor the effectiveness of a remediation process. Acceptance into the program places high priority on innovative technologies that provide more cost-effective, faster, and safer methods than conventional technologies for producing real-time or near-real-time data. These technologies are demonstrated under field conditions and results are compiled, evaluated, published, and disseminated by ORD. The primary objectives of the MMT Program are the following:

- C Test field analytical technologies that enhance monitoring and site characterization capabilities
- C Identify the performance attributes of new technologies to address field characterization and monitoring problems in a more cost-effective and efficient manner
- C Prepare protocols, guidelines, methods, and other technical publications that enhance the acceptance of these technologies for routine use

The SITE MMT Program is administered by ORD's National Exposure Research Laboratory (NERL-LV) at the Environmental Sciences Division in Las Vegas, Nevada.

In 1994, the EPA created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative technologies in other areas of environmental concern through performance verification and information dissemination. As in the SITE Program, the goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. The ETV Program is intended to assist and inform those involved in the design, distribution, permitting, and purchase of various environmental technologies. The ETV Program capitalizes on and applies the lessons learned in implementing the SITE Program.

For each demonstration, the EPA draws on the expertise of partner "verification organizations" to design efficient procedures for conducting performance tests of environmental technologies. The EPA selects its partners from both the public and private sectors, including federal laboratories, states, universities, and private sector entities. Verification organizations oversee and report verification activities based on testing and quality assurance (QA) protocols developed with input from all major stakeholder and customer groups associated with the technology area. For this demonstration, the EPA selected Tetra Tech EM Inc. (Tetra Tech; formerly PRC Environmental Management, Inc.) as the verification organization.

In May and June 1997, the EPA conducted a demonstration, funded by the SITE Program, to verify the performance of four soil and two soil gas sampling technologies: SimulProbe<sup>®</sup> Technologies, Inc., Core Barrel Sampler; Geoprobe<sup>®</sup> Systems, Inc., Large-Bore Soil Sampler; AMS<sup>™</sup> Dual Tube Liner



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Sampler; Clements Associates, Inc., Environmentalist's Subsoil Probe; Quadrel Services, Inc. (Quadrel), EMFLUX<sup>®</sup> Soil Gas Investigation System; and W.L. Gore & Associates GORE-SORBER<sup>®</sup> Screening Survey passive soil gas sampling system. This environmental technology verification report (ETVR) presents the results of the demonstration for one soil gas sampling technology, the Quadrel EMFLUX<sup>®</sup> Soil Gas Investigation System. Separate ETVRs have been published for the remaining soil and soil gas sampling technologies.

### **Technology Verification Process**

The technology verification process is designed to conduct demonstrations that will generate high-quality data that the EPA and others can use to verify technology performance and cost. Four key steps are inherent in the process: (1) needs identification and technology selection, (2) demonstration planning and implementation, (3) report preparation, and (4) information distribution.

#### ***Needs Identification and Technology Selection***

The first aspect of the technology verification process is to identify technology needs of the EPA and the regulated community. The EPA, the U.S. Department of Energy, the U.S. Department of Defense, industry, and state agencies are asked to identify technology needs for characterization, sampling, and monitoring. Once a technology area is chosen, a search is conducted to identify suitable technologies that will address that need. The technology search and identification process consists of reviewing responses to *Commerce Business Daily* announcements, searches of industry and trade publications, attendance at related conferences, and leads from technology developers. Selection of characterization and monitoring technologies for field testing includes an evaluation of the candidate technology against the following criteria:

- C Designed for use in the field or in a mobile laboratory
- C Applicable to a variety of environmentally contaminated sites
- C Has potential for resolving problems for which current methods are unsatisfactory
- C Has costs that are competitive with current methods
- C Performs better than current methods in areas such as data quality, sample preparation, or analytical turnaround time
- C Uses techniques that are easier and safer than current methods
- C Is commercially available

#### ***Demonstration Planning and Implementation***

After a technology has been selected, the EPA, the verification organization, and the developer agree to a strategy for conducting the demonstration and evaluating the technology. The following issues are addressed at this time:

- C Identifying and defining the roles of demonstration participants, observers, and reviewers

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- C Identifying demonstration sites that provide the appropriate physical or chemical attributes in the desired environmental media
  - C Determining logistical and support requirements (for example, field equipment, power and water sources, mobile laboratory, or communications network)
  - C Arranging analytical and sampling support
  - C Preparing and implementing a demonstration plan that addresses the experimental design, the sampling design, quality assurance/quality control (QA/QC), health and safety, field and laboratory operations scheduling, data analysis procedures, and reporting requirements

### ***Report Preparation***

Each of the innovative technologies is evaluated independently and, when possible, against a reference technology. The technologies are usually operated in the field by the developers in the presence of independent observers. These individuals are selected by the EPA or the verification organization and work to ensure that the technology is operated in accordance with the demonstration plan. Demonstration data are used to evaluate the capabilities, performance, limitations, and field applications of each technology. After the demonstration, all raw and reduced data used to evaluate each technology are compiled into a technology evaluation report as a record of the demonstration. A verification statement and detailed evaluation narrative of each technology are published in an ETVR. This document receives a thorough technical and editorial review prior to publication.

### ***Information Distribution***

The goal of the information distribution strategy is to ensure that ETVRs are readily available to interested parties through traditional data distribution pathways, such as printed documents. Related documents and technology updates are also available on the World Wide Web through the ETV Web site (<http://www.epa.gov/etv>) and through the Hazardous Waste Clean-Up Information Web site supported by the EPA OSWER Technology Innovation Office (<http://clu-in.org>). Additional information on the SITE Program can be found on ORD's web site (<http://www.epa.gov/ORD/SITE>).

### ***Demonstration Purpose***

The purpose of this demonstration of the EMFLUX<sup>®</sup> system was to evaluate how the sampler performed relative to the reference sampling method, active soil gas sampling. Specifically, this demonstration evaluated the EMFLUX<sup>®</sup> system in comparison to the reference soil gas sampling method in terms of the following parameters: (1) volatile organic compound (VOC) detection and quantitation, (2) sample retrieval time, and (3) cost. Data quality indicators for precision, accuracy, representativeness, completeness, and comparability were also assessed against established QA objectives to ensure the usefulness of the data for the purpose of this verification.

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## **Chapter 2**

### **Technology Description**

This chapter describes the EMFLUX<sup>®</sup> system, including its background, components and accessories, sampling platform, and general operating procedures. The text in this chapter was provided by the developer and was edited for format and relevance.

#### **Background**

Soil gas sampling techniques can be broadly divided into two categories: active and passive. The active soil gas sampling method uses vacuum methods to collect soil gas samples at discrete depth intervals and provides a “snapshot” of the soil gas environment at a particular moment and at a specific depth. This approach requires detectable vapor-phase compound concentrations, relatively porous subsurface soil, and experienced on-site personnel. Because the soil gas samples are usually analyzed immediately, an on-site or nearby laboratory is typically required. Active soil gas sampling is generally used for rapid screening of VOCs in the subsurface in moderately permeable soils and is generally not applicable to detecting semivolatile organic compounds (SVOC).

Passive sampling techniques rely on diffusion and adsorption and can be used to sample for VOCs and SVOCs, depending on the adsorbent selected and the diffusion membrane used. The developers of passive soil gas samplers claim that the passive samplers allow for equilibrium to develop between the soil gases and the sorbent over a period of several days to weeks. Further, the developers claim that exposure of the passive samplers to the soil gas over extended periods concentrates the mass of VOCs and SVOCs absorbed to the sampler; thereby enhancing contaminant detection sensitivity.

The EMFLUX<sup>®</sup> system is a passive soil gas sampling system developed by Quadrel. According to Quadrel, the EMFLUX<sup>®</sup> system is based on technology developed over the past 35 years, and was originally used in the minerals exploration industry to detect radon gas and locate uranium deposits.

The EMFLUX<sup>®</sup> system components consist of a sample cartridge and installation tools. The “system” also incorporates computer modeling to predict optimal sampling times for a specific geographic location and sample analyses, both provided by the developer. The EMFLUX<sup>®</sup> system uses a proprietary software package to predict periods of maximum soil gas emission for any location. This software package models the relationship between the gravitational phenomenon known as “earth tides” and orders-of-magnitude changes in the vertical velocities of gases moving through the earth’s crust. The modeling of this relationship allows Quadrel to theoretically predict favorable (relatively high-vertical-velocity) periods for soil gas sampling. Knowing when these favorable periods occur may decrease the period of time the samplers must be left installed at a site; however, EMFLUX<sup>®</sup> surveys may be conducted at virtually any time.

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The EMFLUX<sup>®</sup> data are reported in units of mass per sample, which Quadrel can convert to mass per unit volume of air. For this demonstration, the EMFLUX<sup>®</sup> data were reported in units of mass per unit volume of air (nanograms per liter [ng/L]). The conversion from mass of contaminant detected to mass of contaminant detected per volume of air was accomplished by the developer using equation 2-1.

$$C = 10^3 \frac{KW}{TR} \quad (2-1)$$

where:

- C = the soil gas concentration (nanograms per liter)
- K = the cartridge collection constant (1.0 second/cubic centimeter [cc])
- W = the detected contaminant mass (nanograms)
- T = the collection period (seconds)
- R = the adsorbent recovery factor (unitless). Adsorbent recovery factors are unique to each combination of sorbent and contaminant. The developer provided these recovery factors and converted all the data for this demonstration.

The EMFLUX<sup>®</sup> Soil Gas Investigation System is designed to identify and quantify a broad spectrum of VOCs and SVOCs, including halogenated compounds, petroleum hydrocarbons, polynuclear aromatic hydrocarbons (PAH), and other compounds. The developer lists a broad range of target analytes the EMFLUX<sup>®</sup> system can potentially detect:

- Common VOCs and SVOCs quantifiable by standard EPA techniques such as methods 8021, 8081, 8260, and 8270.
- Explosives such as nitrobenzene, 2-nitrotoluene, 3-nitrotoluene, 4-nitrotoluene, 1,3-dinitrobenzene, 2,4-dinitrotoluene, 2,6-dinitrotoluene, 1,3,5-trinitrobenzene, 2,4,6-trinitrotoluene, 2-amino-4,6-dinitrotoluene, 4-amino-2,6-dinitrotoluene, and others.
- Chemical agents and breakdown products such as 1,4-dithiane, 1,4-oxathiane, benzothiazole, p-chlorophenylmethylsulfide, p-chlorophenylmethylsulfoxide, p-chlorophenylmethylsulfone, dimethyldisulfide, diisopropyl methylphosphonate, thiodiglycol, and others.

Other developer claims regarding system performance include the following:

- The system detects VOCs and SVOCs in soil gas at concentrations proportional to the actual soil or groundwater contaminant concentrations and can trace the distribution of VOCs and SVOCs in subsurface soil and groundwater with a comparability rate of 90 percent with reference soil and groundwater sampling methods.
- EMFLUX<sup>®</sup> can detect contaminant masses per sample ranging from 25 to 1,000,000 nanograms, and can allow a reporting limit of less than 1 ng/L of air.
- EMFLUX<sup>®</sup> can collect samples under artificial surfaces and in fine-grained soils such as clays.

- 
- C The system can detect contaminants from depths over 200 feet below ground surface (bgs).
  - C The system employs accurate analytical techniques and relatively low detection limits to reduce the potential for false positive or negative results.
  - C No special training is required to install or collect samples using the technology.

During the demonstration, only Quadrel's claims regarding sample retrieval time, cost, and the ability of the EMFLUX<sup>®</sup> system to be used to sample for VOCs were evaluated.

### **Components and Accessories**

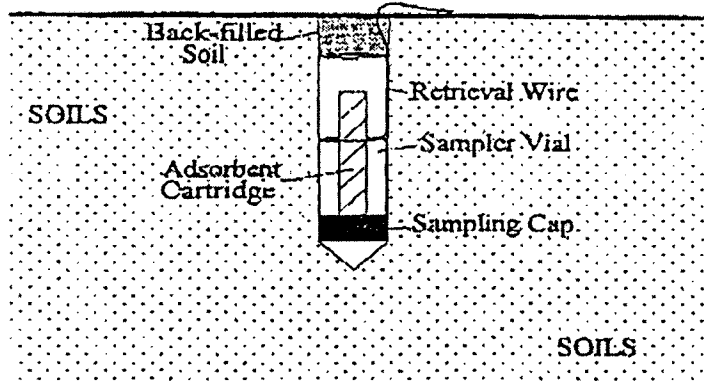
The EMFLUX<sup>®</sup> system consists of a sample cartridge and installation tools. The EMFLUX<sup>®</sup> cartridge consists of 100 milligrams (mg) of sorbent sealed in a fine-mesh screen, which is placed in a glass vial; the vial and cartridge make up the EMFLUX<sup>®</sup> field collector. Given the target VOCs present at the SBA and CSC sites, carboxen was selected by the developer as the absorbent material for this demonstration. Other absorbent materials are available for use with the EMFLUX<sup>®</sup> system. The sorbent is contained in a cartridge suspended in a 7-milliliter (ml) screw-top glass vial. The cartridge and tools are provided in an EMFLUX<sup>®</sup> field kit. The standard field kit is designed for sampling in areas where the EMFLUX<sup>®</sup> cartridges can be placed 3 to 4 inches bgs, and contains all supplies required to collect 30 samples. The standard field kit is 3 inches high, 9 inches long, 9 inches wide, and weighs about 5 pounds. A modified EMFLUX<sup>®</sup> field kit for surface-based (non-intrusive) sampling is 9 inches high by 9 inches wide by 19 inches long, and weighs about 25 pounds. The modified kit contains all tools and supplies needed to collect 60 samples.

### **General Operating Procedures**

Prior to the survey, the developer can use a proprietary computer model to predict the optimal sampling time. The field sampling program is then implemented by the technology user. The following field procedures are routinely used during EMFLUX<sup>®</sup> soil gas surveys. Modifications can be incorporated from time to time in response to individual project requirements.

1. Surface debris or vegetation, if present, are removed by the field technician, exposing the ground surface. Using a hammer and a 0.75-inch diameter metal stake, the technician creates a hole approximately 3 to 4 inches deep (Figure 2-1). For locations covered with asphalt or concrete, the technician drills a 1-inch-diameter hole through the cover to the soils beneath. If necessary, the EMFLUX<sup>®</sup> sample cartridge can be sleeved with a 0.75-inch inner diameter copper pipe. This procedure is used at locations where asphalt surfaces may be possible sources of PAH contamination.
2. The technician removes the solid plastic cap from an EMFLUX<sup>®</sup> sampling cartridge and replaces it with a sampling cap (a plastic cap with a hole covered by screen mesh). The sampling cartridge has a metal retrieval wire secured around it. The technician inserts the collector, with the sampling cap end facing down, into the hole (Figure 2-1). The collector is then covered with either local soils or with aluminum foil and concrete or asphalt patching material. The collector's location, time and date of emplacement, and other relevant information are recorded.

**DEPLOYMENT THROUGH SOILS**



**DEPLOYMENT THROUGH AN ASPHALT/CONCRETE CAP**

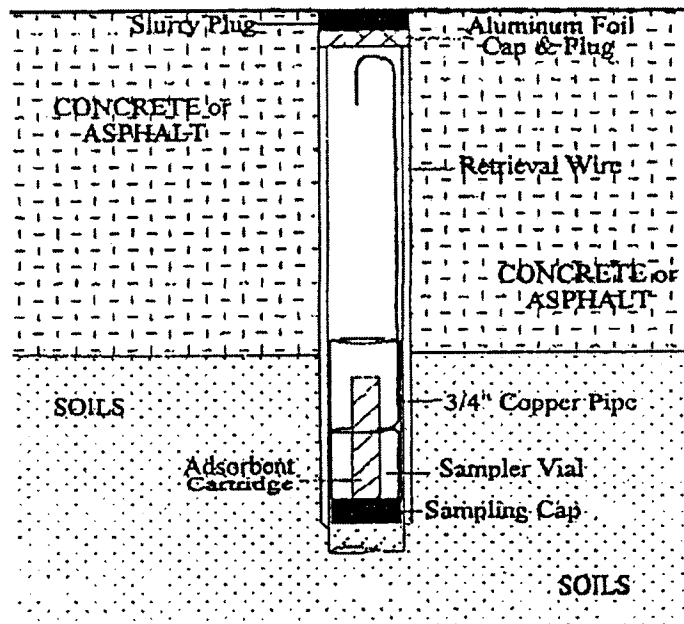


Figure 2-1. EMFLUX® Collector Parts and Deployment Options (Modified from Quadrel Services, Inc., 1997)

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3. As a quality control (QC) check during cartridge emplacement, and also during retrieval, the technician takes periodic ambient air control samples and records the date, time, and location of each. One or more trip blanks are also included as part of the QC procedures.
  4. After all EMFLUX<sup>®</sup> sampling cartridges have been deployed and appropriate control samples collected, personnel depart, leaving the cartridges in place.
  5. Field personnel retrieve the collectors at the end of the exposure period, typically 72 hours or more. At each location, a technician withdraws the collector from its hole and wipes the outside of the vial clean using gauze cloth; following removal of the sampling cap, the threads of the vial are also cleaned. A solid plastic cap is screwed onto the vial and the sampling location number is written on the vial's label. The technician then records sampling point location, date, time, and other relevant information on the field deployment form and on a chain-of-custody form.

Sample analysis is provided by the developer, either through its internal or contracted laboratory facilities. The developer can also provide mobile laboratories equipped with field gas chromatography (GC) equipment for on-site analysis, if required.

#### **Developer Contact**

For more developer information on the EMFLUX<sup>®</sup> Soil Gas Investigation System, please refer to Chapters 8 and 9 of this ETVR or contact the developer at:

Bruce Tucker  
Quadrel Services, Inc.  
1896 Urbana Pike, Suite 20  
Clarksburg, Maryland 20871  
Telephone: (800) 878-5510  
Facsimile: (301) 874-5567  
E-mail: [quadrel@erols.com](mailto:quadrel@erols.com)  
Web Site: <http://www.emflux.com>

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## **Chapter 3**

### **Site Descriptions and Demonstration Design**

This chapter describes the demonstration sites, predemonstration sampling and analysis, and the demonstration design. The demonstration was conducted in accordance with the “Final Demonstration Plan for the Evaluation of Soil Sampling and Soil Gas Sampling Technologies” (PRC, 1997).

#### **Site Selection and Description**

The following criteria were used to select the demonstration sites:

- C Unimpeded access for the demonstration
- C A range (micrograms per kilogram [Fg/kg] to milligrams per kilogram [mg/kg]) of chlorinated or aromatic VOC contamination in soil
- C Well-characterized contamination
- C Different soil textures
- C Minimal underground utilities
- C Situated in different climates

Based on a review of 48 candidate sites, the Small Business Administration (SBA) site in Albert City, Iowa, and the Chemical Sales Company (CSC) site in Denver, Colorado, were selected for the demonstration of the EMFLUX<sup>®</sup> system.

#### ***SBA Site Description***

The SBA site is located on Orchard Street between 1st and 2nd Avenues in east-central Albert City, Iowa (Figure 3-1). The site is the location of the former Superior Manufacturing Company (SMC) facility and is now owned by SBA and B&B Chlorination, Inc. SMC manufactured grease guns at the site from 1935 until 1967. Metal working, assembling, polishing, degreasing, painting, and other operations were carried out at the site during this period. The EPA files indicate that various solvents were used in manufacturing grease guns and that waste metal shavings coated with oil and solvents were placed in a waste storage area. The oil and solvents were allowed to drain onto the ground, and the metal waste was hauled off site by truck (Ecology & Environment [E&E], 1996).



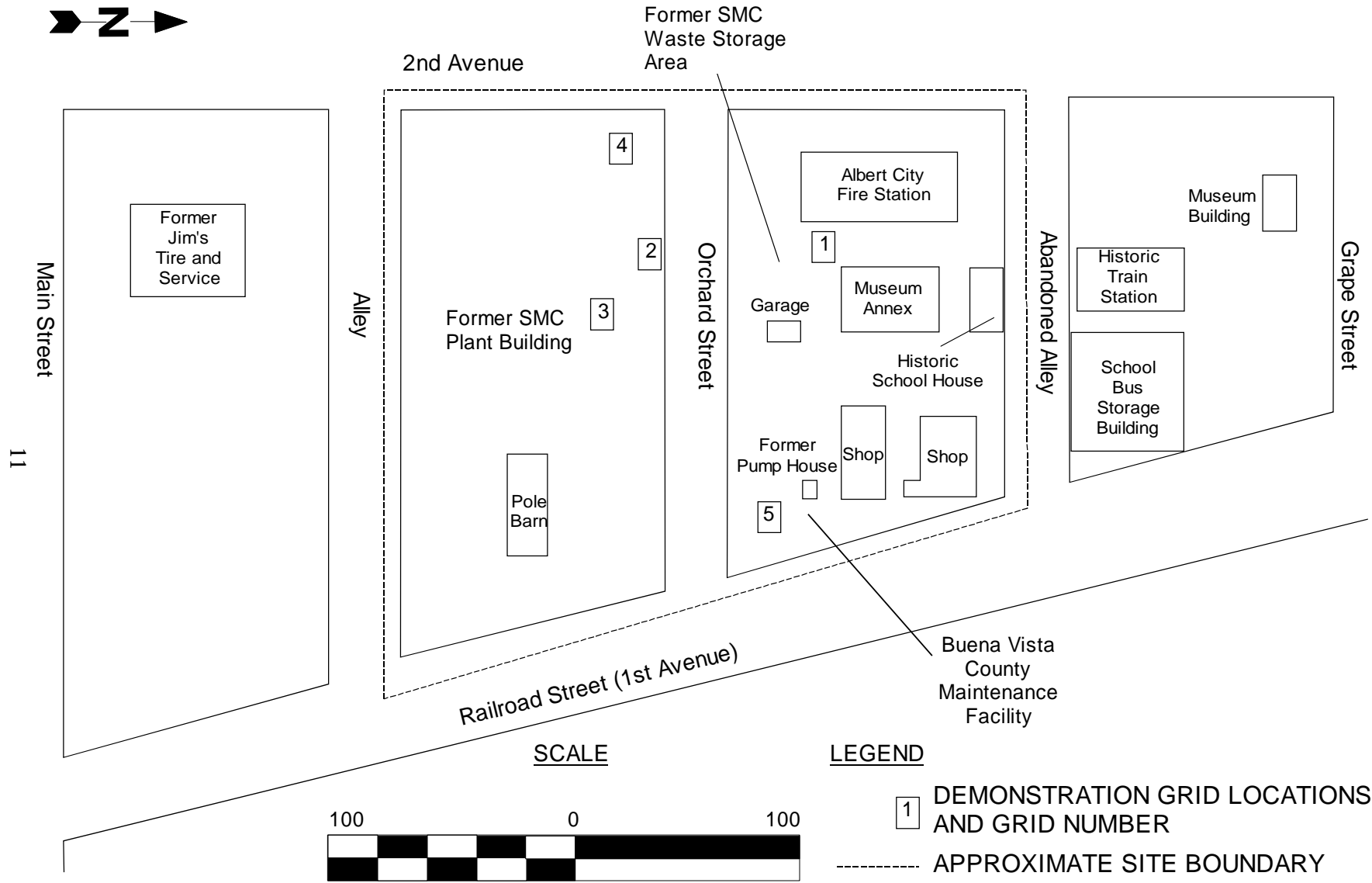


Figure 3-1. Small Business Administration Site

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The site consists of the former SMC plant property and a waste storage yard. The SMC plant property is currently a grass-covered, relatively flat, unfenced open lot. The plant buildings have been razed. A pole barn is the only building currently on the SMC plant property. Several buildings are present in the waste storage yard, including three historic buildings: a garage, a museum, and a school house.

Poorly drained, loamy soils of the Nicollet series are present throughout the site area. The upper layer of these soils is a black loam grading to a dark-gray loam. Below this layer, the soils grade to a friable, light clay loam extending to a depth of 60 inches. Underlying these soils is a thick sequence (400 feet or more) of glacial drift. The lithology of this glacial drift is generally a light yellowish-gray, sandy clay with some gravel, pebbles, or boulders. The sand-to-clay ratio is probably variable throughout the drift. Groundwater is encountered at about 6 to 7 feet bgs at the SBA site (E&E, 1996).

Tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride are the primary contaminants detected in soil at the site. These chlorinated VOCs have been detected in both surface (0 to 2 feet deep) and subsurface (3 to 5 feet deep) soil samples. TCE and cis-1,2-DCE are the VOCs usually detected at the highest concentrations in both soil and groundwater. In past site investigations, TCE and cis-1,2-DCE have been detected in soils at 17 and 40 mg/kg, respectively, with vinyl chloride present at 1.4 mg/kg. The areas of highest contamination have been found near the center of the former SMC plant property and near the south end of the former SMC waste storage area (E&E, 1996).

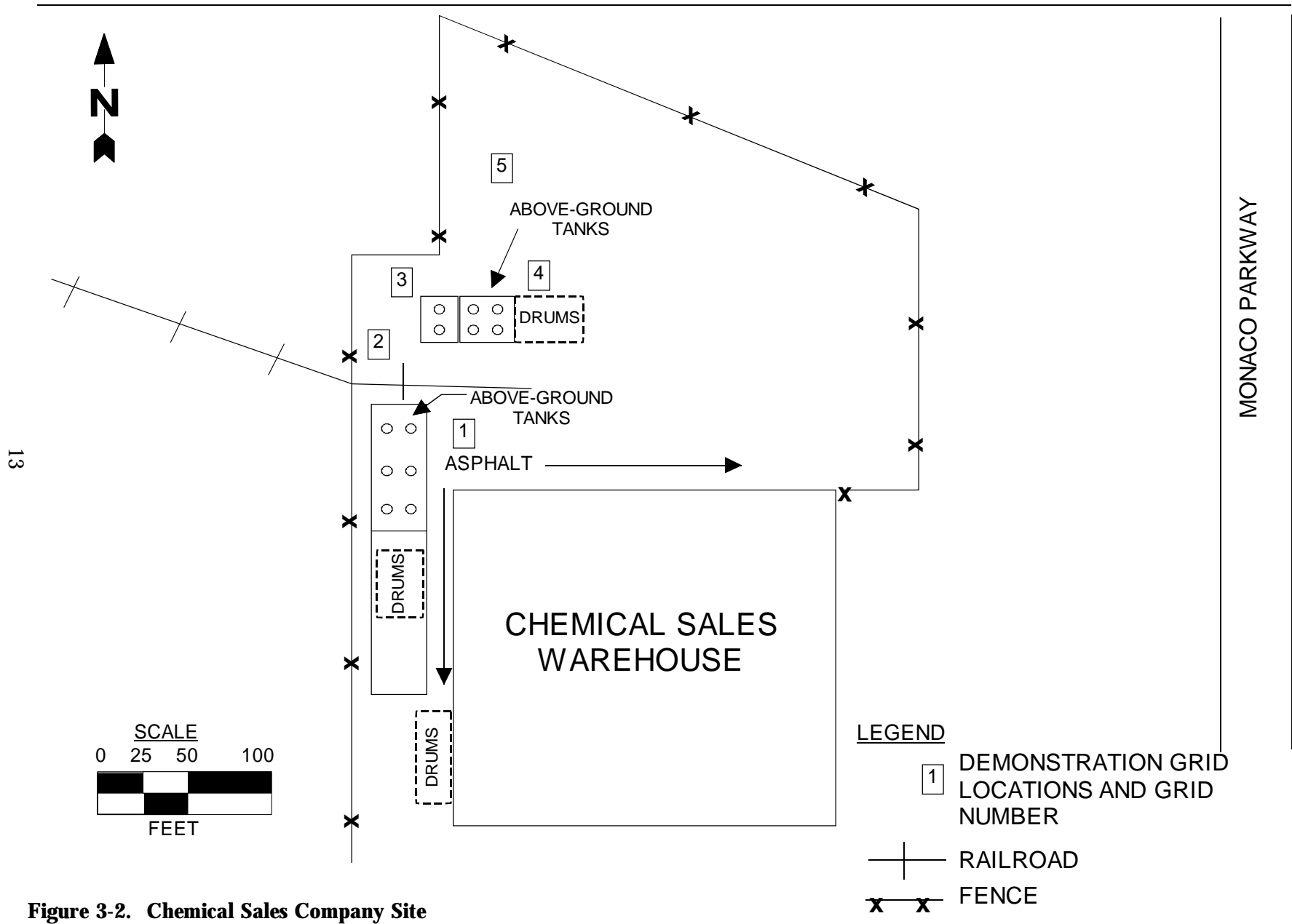
### ***CSC Site Description***

The CSC site is located in Denver, Colorado, approximately 5 miles northeast of downtown Denver. From 1962 to 1976, a warehouse at the site was used to store chemicals. The CSC purchased and first occupied the facility in 1976. The CSC installed aboveground and underground storage tanks and pipelines at the site between October 1976 and February 1977. From 1976 to 1992, the facility received, blended, stored, and distributed various chemicals and acids. Chemicals were transported in bulk to the CSC facility by train and were unloaded along railroad spurs located north and south of the CSC facility. These operations ceased at the CSC site in 1992.

The EPA conducted several investigations of the site from 1981 through 1991. Results of these investigations indicated a release of organic chemicals into the soil and groundwater at the site. As a result of this finding, the CSC site was placed on the National Priorities List in 1990. The site is divided into three operable units (OU). This demonstration was conducted at OU1, located at 4661 Monaco Parkway in Denver (Figure 3-2). In September 1989, EPA and CSC entered into an Administrative Order on Consent requiring CSC to conduct a remedial investigation/feasibility study (RI/FS) for CSC OU1. The RI/FS was completed at OU1 in 1991 (Engineering-Science, Inc., 1991).

The current site features of OU1 consist of the warehouse, a concrete containment pad with a few remaining tanks from the aboveground tank farm, another smaller containment pad with aboveground tanks north of a railroad spur, and multiple areas in which drums are stored on the west side of the warehouse and in the northwest corner of the property. The warehouse is currently in use and is occupied by Steel Works Corporation.

The topography, distribution of surficial deposits, and materials encountered during predemonstration sampling suggest that the portion of OU1 near the CSC warehouse is a terrace deposit composed of Slocum Alluvium beneath aeolian sand, silt, and clay. The terrace was likely formed by renewed



**Figure 3-2. Chemical Sales Company Site**

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downcutting of a tributary to Sand Creek. Borings at the CSC property indicate that soils in the vadose zone and saturated zone are primarily fine- to coarse-grained, poorly sorted sands with some silts and clays. The alluvial aquifer also contains some poorly sorted gravel zones. The depth to water is about 30 to 40 feet bgs near the CSC warehouse.

During previous soil investigations at the CSC property, chlorinated VOC contamination was detected extending from near the surface (less than 5 feet bgs) to the water table depth. The predominant chlorinated VOCs detected in site soils are PCE, TCE, 1,1,1-trichloroethane (1,1,1-TCA), and 1,1-dichloroethane (1,1-DCA). The area of highest VOC contamination is north of the CSC tank farm, near the northern railroad spur. The PCE concentrations detected in this area measure as high as 80 mg/kg, with TCE and 1,1,1-TCA concentrations measuring as high as 1 mg/kg. In addition, results from field analysis of soil headspace samples using GC indicated TCE, PCE, 1,1,1-TCA, and 1,1-DCA concentrations as high as 5,000 parts per million by volume.

### **Predemonstration Sampling and Analysis**

Predemonstration sampling and analysis were conducted to establish the geographic location of sampling grids, identify target sampling depths, and estimate the variability of contaminant concentrations exhibited at each grid location and target sampling depth. Predemonstration sampling was conducted at the SBA site between April 1 and 11, 1997, and at the CSC site between April 20 and 25, 1997. Eleven sampling grids, six at the SBA site and five at the CSC site, were investigated to confirm that each grid exhibited chemical concentrations and soil texture characteristics that met the criteria set forth in the predemonstration sampling plan (PRC, 1997) and to confirm that passive and active soil gas sampling could be used at the two sites.

At each of the grids sampled during the predemonstration, five borings were advanced from which soil samples were collected for VOC and soil texture analysis. As expected, the primary VOCs detected in the soil samples at the SBA site were vinyl chloride, cis-1,2-DCE, TCE, and PCE. The primary VOCs detected at the CSC site were 1,1,1-TCA, TCE, and PCE. TCE and cis-1,2-DCE were detected at the highest concentrations.

An active soil gas sampling method sample was collected from an area adjacent to each of the soil sampling grids at each site. Analyses of samples from these locations confirmed that (1) the active soil gas sampling method could be used at the two sites, and (2) soil gas contamination was detectable by the reference method. Of the eleven grids investigated, nine were selected for demonstration sampling, five grids at the SBA site and four grids at the CSC site.

### **Demonstration Design**

The demonstration was designed to evaluate the EMFLUX<sup>®</sup> system in comparison to the reference sampling method, active soil gas sampling, in terms of the following parameters: (1) VOC detection and quantitation, (2) sample retrieval rate, and (3) cost. These parameters were assessed in two different soil textures (clay soil at the SBA site and sandy soil at the CSC site). The demonstration design is described in detail in the demonstration plan (PRC, 1997) and is summarized below.

Predemonstration sampling identified nine grids (Grids 1, 2, 4, 5, and 6 at the SBA site and Grids 1, 2, 4, and 5 at the CSC site) that exhibited consistent soil texture and acceptable VOC concentrations for the demonstration. Each grid was 10.5 by 10.5 feet in area and was divided into seven rows and seven

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columns producing 49, 18- by 18-inch sampling cells (Figure 3-3). Each grid was sampled at a depth of approximately 3 feet in each of the seven columns (labeled A through G) using the reference soil gas sampling method; the EMFLUX<sup>®</sup> cartridges were emplaced at a depth of about 3 to 4 inches for passive sampling. For each grid, seven soil gas samples were collected using the EMFLUX<sup>®</sup> system and the reference soil gas sampling method. The seven cells that were sampled using each method were selected randomly. The procedure used to collect samples using the EMFLUX<sup>®</sup> system is described in Chapter 2 and the procedure used to collect samples using the reference soil gas sampling method is described in Chapter 4.

### ***VOC Detection and Quantitation***

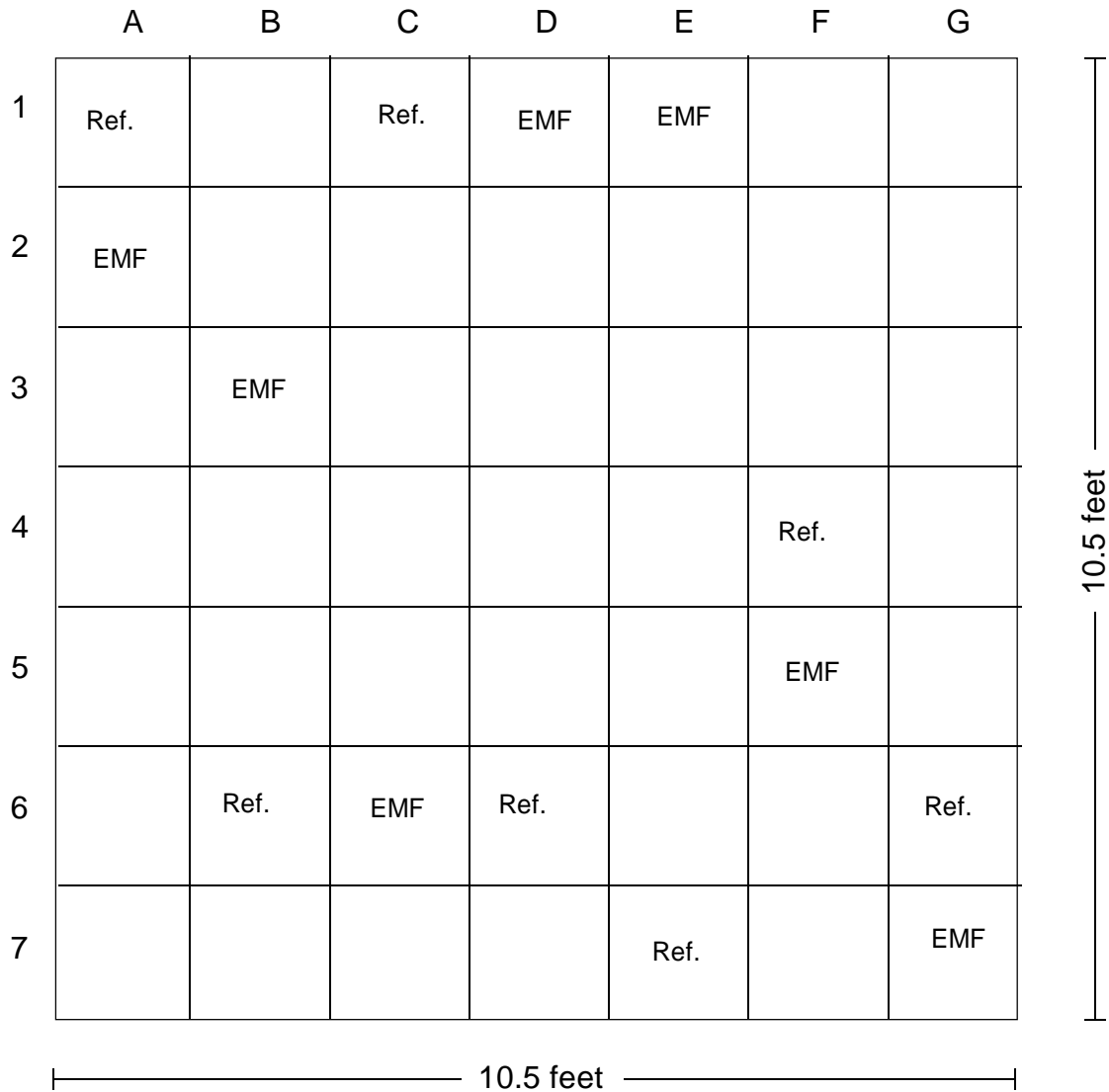
A Quadrel representative installed and collected the EMFLUX<sup>®</sup> samples and shipped them to Quadrel's team laboratory, Maryland Spectral Services, Inc., in Baltimore Maryland, where the samples were desorbed and analyzed. The samples were analyzed using gas chromatography/mass spectrometry (GC/MS) techniques according to EPA SW-846 modified Method 8260 for detection of VOCs, as described in EPA Office of Solid Waste and Emergency Response "Test Methods for Evaluating Solid Waste" (EPA, 1986).

The reference soil gas samples were analyzed using an on-site laboratory following the guidelines discussed in the quality assurance project plan (PRC, 1997). The guidelines used for on-site analysis were similar to SW-846 Method 5021 (Volatile Organic Compounds in Soils and Other Solid Matrices Using Equilibrium Headspace Analysis), modified to include high- and low-concentration procedures similar to those described in SW-846 Method 5035 (Closed-System Purge-and-Trap and Extraction for Volatile Organics in Soil and Waste Samples) (EPA, 1986). The target compounds were vinyl chloride, 1,2-DCE, TCE, and PCE at the SBA site, and 1,2-DCE, 1,1-DCA, 1,1,1-TCA, TCE, and PCE at the CSC site. Soil gas samples collected from the CSC site were not analyzed for vinyl chloride because it was not detected in soil during site characterization activities.

The reference soil gas samples were collected in 40-milliliter (ml) glass volatile organic analysis vials. The standard injection volume used for soil gas analysis was 2 ml. A gas-tight glass syringe was used to directly inject the soil gas samples onto the GC column. An electrolytic conductivity detector was used for compound identification and quantitation. The GC was a Hewlett-Packard Series II equipped with a packed injection port and a DB-624 column.

The demonstration plan (PRC, 1997) stated that data for the EMFLUX<sup>®</sup> and reference soil gas sampling methods would undergo a statistical analysis. However, comparison of the EMFLUX<sup>®</sup> and reference method data indicated significant differences between the two data sets, with mean VOC concentrations for the data sets differing by several orders of magnitude in most instances. For this reason, a statistical analysis of the data was not performed.

In addition, there appears to be no consistent proportional relationship between contaminant concentrations detected using the EMFLUX<sup>®</sup> system and those detected using the reference sampling method. Therefore, interpretation of the chemical concentration data for this demonstration is limited to qualitative observations.



EMF EMFLUX® System Sampling Location

Ref. Reference Sampling Method Location

**Figure 3-3. Typical Sampling Locations and Random Sampling Grid**

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### ***Sample Retrieval Time***

Sample retrieval time was measured as the time required to set up on a sampling grid, install and collect the seven EMFLUX<sup>®</sup> field collectors from each grid, decontaminate the sampler installation and collection equipment, and move to a new sampling grid. The time required to install the samplers was added to the time required to collect the samplers to obtain the sample retrieval time.

### ***Cost***

The cost estimate focused on the range of costs for using the EMFLUX<sup>®</sup> system and reference soil gas sampling method to collect 40 subsurface soil gas samples at a clay soil site (similar to the SBA site) and a sandy soil site (similar to the CSC site). The cost analysis is based on the results and experience gained from the demonstration and cost information provided by Quadrel. Factors that could affect the cost of operating the EMFLUX<sup>®</sup> system and the reference soil gas sampler include:

- C Equipment costs
- C Labor costs
- C Sample analysis and reporting costs
- C Decontamination costs
- C Site restoration costs

### ***Deviations from the Demonstration Plan***

Three project-wide deviations from the approved demonstration plan were identified: (1) vinyl chloride was eliminated from the target compound list at the CSC site because vinyl chloride was not present in the soil gas at the site; (2) a statistical comparison of the EMFLUX<sup>®</sup> system data to the reference sampling method data was not performed because, in most cases, the data sets differed by several orders of magnitude; and (3) reference soil gas sampling method results were not available from Grid 6 at the SBA site because of laboratory error. Cases where the performance of an individual sampling technology caused it to deviate from the demonstration plan are discussed on a technology-specific basis in Chapters 4 (reference method) and 5 (EMFLUX<sup>®</sup> system) of this ETVR.

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## **Chapter 4**

### **Description and Performance of the Reference Method**

This chapter describes the active soil gas sampling system used during the demonstration as the reference soil gas sampling method, and includes its associated background information, components and accessories, platform description, demonstration operating procedures, qualitative performance factors, quantitative performance factors, and data quality measures.

#### **Background**

Soil gas screening technology was used as early as 1929 as a surface geochemical technique in oil and gas exploration. In the early 1980s, active soil gas sampling became widely used as an environmental investigative tool for aiding in the delineation of subsurface organic contamination. The intent of active soil gas sampling is to reduce site characterization costs by identifying areas with suspected contamination, thereby minimizing the number of soil borings and monitoring wells required to delineate the extent of contamination.

Active soil gas sampling produces a discrete sample that provides a “snapshot” of the soil gas environment at the time the sample is collected. The sampling technique used in this demonstration requires the presence of vapor-phase compounds at detectable concentrations, relatively porous subsurface soil, experienced analytical instrument operators at the site, and portable analytical equipment for on-site analysis of samples.

#### **Components and Accessories**

Two active soil gas sampling systems were used during this demonstration: an AMS™ active sampling system at the SBA site, and a Geoprobe® sampling system at the CSC site. The systems are similar, and this description of system components and accessories applies to both technologies. The components of the reference sampling method consist of an expendable drive point, a drive-point holder, drive rods, expendable plastic tubing, a tubing connector, and a vacuum pump. The 2-inch-long, expendable drive point is a solid steel or aluminum component that has a cone-shaped drive end and a cylindrical shank on the other end that fits into the point holder. The drive-point holder is a hollow tube, 4 inches long by 1-inch outside-diameter. One end of the point holder holds the expendable point; the other has female threads for attaching the tubing connector. The 2-inch-long, hollow metal tubing connector has a nipple for the plastic tubing on one end and male threads with a rubber gasket on the other end, which attaches to the drive-point holder. The 36- to 48-inch-long by 1-inch outside-diameter drive rod is a hollow metal tube with male threads on one end and female threads on the other. The vacuum pump is capable of drawing a vacuum of 20 to 30 inches of mercury, is constructed of metal, and has pressure gauges on the sampling line and vacuum tank.



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Other components of the reference soil gas sampling system include a drive cap, pull cap, ancillary tools, and expendable sampling supplies. The drive and pull caps are metal and have female threads on one end for attaching to the top drive rod. Ancillary tools required include drill bits, vise grips, pipe wrenches, crescent wrenches, knives, hemostats, and screwdrivers. Expendable sampling supplies required include the plastic tubing (tygon, Teflon™, or polyethylene), silicone tubing, 40-ml volatile organic analysis vials, syringe with needle, double-ended needles, and a container for waste.

Because the soil gas samples are usually analyzed immediately, an on-site or nearby laboratory is typically required. A GC in an on-site, mobile laboratory was used to analyze the samples during this demonstration.

### **Description of Platform**

The AMS™ and Geoprobe® soil gas sampling systems use similar platforms to place the samplers. The platform consists of a hydraulically powered hammer mounted in the bed of a three-quarter-ton pickup truck. Additional equipment required includes an oil reservoir, a pump, a hammer support structure, hydraulic control levers, and three hydraulic cylinders: one to fold the hammer for transport, one to adjust the hammer height, and one to adjust the foot height.

The mobility and performance of the platform were adequate for the conditions at both demonstration sites. The size of the truck and the ability of the hammer to pivot in multiple directions allowed for smooth transition from one sampling location to another. The platform easily pushed or hammered the soil gas samplers to the 4.5-foot sampling depth at each demonstration site, and the platform easily extracted the soil gas samplers. The clay soil at the SBA site required less hammering to place the soil gas samplers than did the sandy soil at the CSC site.

### **Demonstration Operating Procedures**

The reference soil gas sampling method involved assembling and installing the sampling system and collecting the soil gas sample. Initially, a 1-inch outside-diameter hollow rod was driven to the target sampling depth within the selected grid cell. The rod was fitted with an expendable drive point. Once the rod reached the target depth of 4.5 feet bgs, it was withdrawn approximately 6 inches. The expendable drive point remained in place, producing a 6-inch void space that allowed a soil gas sample to be collected. Once the rod was retracted 6 inches, a 0.25-inch inside-diameter, high-density polyethylene or Teflon™ tube was lowered into the drive rod. The end of the tubing was fitted with a reverse threaded, barbed fitting. The barb was inserted into the tubing and the reverse threaded end was screwed into the expendable drive point holder at the end of the drive rod when the tubing reached the end of the drive rod. A butyl rubber O-ring around the threaded end of the barb fitting ensured an airtight seal between the tubing and the end of the drive rod.

Once the tubing was in place, the soil gas sample was collected by attaching an evacuated 40-ml sampling vial with a double-ended needle to the top end of the system tubing as follows.

1. The sampling vial was evacuated using a 60 cc plastic syringe. The syringe pulled a vacuum on the closed sampling vial for 10 seconds. This vacuum was applied by attempting to draw 60 cc of air out of the vial.

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2. A volume-calibrated vacuum system was attached to the end of the polyethylene tube connected to the end of the hollow rod. The vacuum system removed a volume of air equal to one tubing volume that was calculated to be 16.4 cc in this demonstration.
  3. The vacuum system was shut off and the sampling string was allowed to equilibrate with ambient air pressure. The system was closed so that equilibration occurred only by drawing soil gas into the sample tubing. (A vacuum line integrity test was successfully completed before each sampling event to ensure that there were no leaks in the soil gas system.)
  4. When no vacuum was left in the tubing, a double-end hypodermic needle was inserted into the tygon tubing that connected the polyethylene tubing with the vacuum pump. The exposed end of the needle was sealed with a soft rubber sheath. The evacuated sampling vial was pushed onto the exposed needle. The needle penetrated the vial's septum and exposed the soil gas in the tubing to the vacuum in the vial, causing the vial to fill with soil gas. The sampling vial was allowed to collect a sample for 40 seconds at the CSC site and 2 minutes at the SBA site. These times were selected after several tests on refilling evacuated vials were conducted by observing (1) septa "spring back" to their original positions, and (2) lack of an air hiss upon opening the vial.

Each sampling vial containing a soil gas sample was numbered according to the sample grid and cell where it was collected. After the samples were properly labeled, they were analyzed within 24 hours of collection. Prior to analysis, the active soil gas samples were stored at ambient temperatures.

All reusable soil gas sampling equipment was decontaminated by heating with a portable propane heater for approximately 30 seconds. The sampling vials and needles were not reused, and the sample tubing was discarded after a single use.

### **Qualitative Performance Factors**

The following qualitative performance factors were assessed for the reference soil gas sampling method: (1) reliability and ruggedness under the test conditions, (2) training requirements and ease of operation, (3) logistical requirements, (4) sample handling, and (5) performance range.

#### ***Reliability and Ruggedness***

The reliability and ruggedness of the reference soil gas sampling method was adequate for conditions at both demonstration sites. The sampler was pushed or hammered to the 4.5-foot sampling depth at each site without incident. During the demonstration, operators noted that attaching the tubing adapter to the point holder was easier when the tubing was precut to the required length (per the sampling depth); otherwise, the tubing tended to unwind when released, which would either loosen or unscrew the tubing adapter from the point holder. The clay soil at the SBA site caused the system to hold its vacuum at several sampling locations; hence, soil gas was not completely drawn into the system for sampling. In these cases, the rod was withdrawn in additional 6-inch increments until the vacuum was broken and the system's pressure reached equilibrium with atmospheric pressure. The vacuum problem was not encountered in the sandy soil at the CSC site. The reference soil gas sampling method operated without any equipment failure or mechanical breakdown during the demonstration.

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### ***Training Requirements and Ease of Operation***

The active soil gas sampling technology requires minimal training due to the ease of operating the system. Special certifications, advanced degrees, or other specialized training are not required to operate the sampling platform and use the system. However, health and safety training is required by the Occupational Safety and Health Administration when operating at hazardous waste sites. A novice would require 3 to 6 hours of hands-on training to become proficient at using the sampling platform and the soil gas sampling system. A crew of two is recommended for sampling and operation of the system and platform, but one person may safely operate the system.

### ***Logistical Requirements***

Logistical requirements for the reference soil gas sampling method include obtaining utility clearances and grouting the sampling holes. Permits to operate the system were not required by the states of Iowa and Colorado, but may be required in other states. The system, platform, and ancillary equipment are mounted on or contained in the platform vehicle.

The physical disruption caused by the sampling platform was minimal during the demonstration. No soil cuttings were generated and a 1-inch diameter hole was left at each sampling location after the reference soil gas sampling system was extracted. These holes were grouted with bentonite after samples were collected.

### ***Sample Handling***

The reference soil gas samples were easily collected and handled. When no vacuum was left in the sampling tubing, one end of a double-end hypodermic needle was inserted into the polyethylene tubing and the other end was inserted through the septum of the evacuated sampling vial. Soil gas in the tubing was drawn into the sampling vial until the pressure reached equilibrium. This took about 40 to 120 seconds. The sampling vial containing the soil gas sample was numbered according to the sample grid and cell where it was collected. The samples were properly labeled and were then stored at ambient temperature until analysis. The samples were analyzed within 24 hours of collection.

### ***Performance Range***

The performance range of the reference sampling method is limited by soil texture, permeability, soil moisture content, contaminant type, and depth to groundwater. During the demonstration, reference soil gas samples were collected from a depth of 4.5 feet; however, the system is capable of collecting samples at depths of 30 to 60 feet. Soil such as glacial till with cobbles or fill with pieces of concrete can cause refusal of the reference sampling method before it reaches the desired depth. Clay soil may also impede sample collection because the vacuum is not readily released. The active soil gas sampling must be conducted above the water table to avoid drawing water into the sampling tube.

### ***Quantitative Performance Factors***

Three quantitative performance indicators were measured for the reference soil gas sampling method: (1) VOC detection and quantitation, (2) sample retrieval time, and (3) cost. The following sections discuss the first two performance factors; a cost analysis of the reference soil gas sampling method is provided in Chapter 6.

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### ***VOC Detection and Quantitation***

Seven samples were collected using the reference soil gas sampling method within each grid as described in Chapter 3 and specified in the demonstration plan (PRC, 1997). Samples were analyzed for VOCs by GC analysis according to the standard operating guideline provided in the demonstration plan (PRC, 1997). Table 4-1 presents the range and mean VOC concentrations for samples collected using the reference method. The VOC results for each sample collected are presented in Appendix A. For Grid 6 at the SBA site, VOC data for the reference method were not available because of laboratory error. For one of the sampling grids, VOC data for all seven samples are not available due to laboratory error; in this case, the range and mean were calculated from the available data. Chapter 5 presents a graphical comparison of the analytical results obtained using the reference sampling method to those obtained using the EMFLUX<sup>®</sup> system.

### ***Sample Retrieval Time***

The reference soil gas method required 458 minutes to collect 35 samples at the SBA site, an average of 13.1 minutes per sample, and 183 minutes to collect 28 samples at the CSC site, an average of 6.5 minutes per sample. Sample retrieval time was measured as the amount of time per sample required to set up at a sampling grid, collect the required samples, grout the hole, decontaminate the sampling equipment, and move to a new sampling location. Analytical results were available from the on-site laboratory within one day; this time was not included in calculating the sample retrieval rate. A three-person sampling and analysis crew was used to collect and analyze soil gas samples using the reference soil gas sampling method at both sites. The difference in sample retrieval time between the SBA and CSC sites may be due in part to differences in soil type (clay versus sandy soil).

### ***Data Quality***

Data quality for the reference sampling method was assessed throughout this demonstration by implementing an approved quality assurance project plan (PRC, 1997). The QA/QC procedures included the consistent application of approved methods for sample collection, chemical analysis, and data reduction. Based on the intended use of the data, QA objectives for precision, accuracy, representativeness, comparability, and completeness were established, and QC samples were collected to assess whether the QA objectives were met. Based on the results of a field audit conducted by the EPA and a detailed validation of the demonstration data by Tetra Tech, the data have been deemed acceptable for use as described in the demonstration design (Chapter 3). The results of the QC indicators used for the reference soil gas sampling method are provided in the technology evaluation report for this demonstration (Tetra Tech, 1997) and are summarized below.

All reference method soil gas samples were analyzed within 24 hours of collection, as specified in the QAPP. Some initial calibrations of the Hewlett-Packard Series II GC had to be abbreviated to meet acceptance criteria, and either a five-point or a three-point calibration was utilized instead of the specified six-point calibration. However, all continuing calibrations met the acceptance criteria for percent difference, indicating that the calibration was reproducible.

Two method blanks were analyzed at the SBA site and one at the CSC site. In addition, one ambient air blank and one equipment blank were analyzed at each site. None of these blanks exhibited any target compounds above the quantitation limit, indicating that there were no apparent sample contamination problems at either site.

**Table 4-1. Volatile Organic Compound Concentrations in Samples Collected Using the Reference Soil Gas Sampling Method**

		Concentration (ng/L)											
Site	Grid	Vinyl Chloride		Total DCE		1,1-DCA		1,1,1-TCA		TCE		PCE	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
SBA	1	230,000 - 5,180,000	2,390,000	279,000 - 2,220,000	958,000	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50
SBA	2	< 100	< 100	< 50 - 151	65	< 50	< 50	< 50	< 50	183 - 5,380	1,250	< 50	< 50
SBA	4	< 100	< 100	< 50 - 261	101	< 50	< 50	< 50	< 50	744 - 33,600	9,390	< 50	< 50
SBA	5	< 100 - 8,270	1,980	3,180 - 21,000	9,980	< 50	< 50	< 50	< 50	132 - 6,250	2,010	< 50	< 50
SBA	6 *	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CSC	1	NA	NA	2,260 - 21,300	10,800	< 500	< 500	7,530 - 670,000	314,000	7,450 - 77,400	41,800	79,000 - 770,000	330,000
CSC	2	NA	NA	< 500 - 3,780	1,850	< 500	< 500	33,900 - 439,000	288,000	11,400 - 154,000	89,500	32,000 - 427,000	223,000
CSC	4	NA	NA	< 500 - 10,500	6,190	< 500	< 500	19,600 - 217,000	142,000	1,880 - 41,800	22,200	20,800 - 389,000	192,000
CSC	5 †	NA	NA	< 500 - 1,400	738	< 500	< 500	12,600 - 132,000	69,900	2,430 - 24,700	11,500	24,800 - 220,000	98,500

ng/L

NA

SBA

CSC

†

\*

Nanograms per liter

Not analyzed

Small Business Administration site

Chemical Sales Company site

VOC data for only five samples are available

VOC data were collected but are not available because of laboratory error

Total DCE

1,1-DCA

1,1,1-TCA

TCE

PCE

Total Dichloroethene

1,1-Dichloroethane

1,1,1-Trichloroethane

Trichloroethene

Tetrachloroethene

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Tetra Tech performed a data validation review of all data, and an EPA Region 8 QC chemist performed an audit of the laboratory during the predemonstration phase. Neither of these reviews noted any significant data quality issues. Thus, the data appear to be of sufficient quality for the intended use.

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## Chapter 5 Technology Performance

This chapter describes the performance of the EMFLUX<sup>®</sup> system in terms of qualitative and quantitative performance factors. A description of the EMFLUX<sup>®</sup> system is provided in Chapter 2.

### **Qualitative Performance Factors**

The following qualitative performance factors were assessed for the EMFLUX<sup>®</sup> system: (1) reliability and ruggedness under the test conditions, (2) training requirements and ease of operation, (3) logistical requirements, (4) sample handling, and (5) performance range.

#### *Reliability and Ruggedness*

The Quadrel representative collected 100 percent (63 of 63) of the EMFLUX<sup>®</sup> field collectors without sample loss or downtime. This accomplishment verifies the developer's claim that the EMFLUX<sup>®</sup> system can collect samples in clay or poorly drained soils and under artificial surfaces. The sample vials used with this technology are protected before deployment and after collection by custom-made packaging materials, minimizing any possible breakage of the vials.

#### *Training Requirements and Ease of Operation*

Complete written instructions for sample deployment and retrieval accompany all EMFLUX<sup>®</sup> field kits. At the client's request, the developer also furnishes a 16-minute training video. During the demonstration, the EMFLUX<sup>®</sup> sample cartridges were installed and retrieved by the developer, but the developer claims that no specialized training is required to install, collect, or ship the samples.

#### *Logistical Requirements*

No special licensing requirements are necessary to use the EMFLUX<sup>®</sup> system. The system requires two mobilizations: one trip to install the samplers, and a second trip to collect the samplers. Once the samples are collected, they are sent back to the developer or to another qualified laboratory for analysis.

Installation of the EMFLUX<sup>®</sup> system only requires drilling a 3- to 4-inch deep hole for each sample. No specific logistical support is required for surveys in unpaved areas. Shallow underground utilities such as cable, telephone, and electrical lines should be located and utility clearances should be obtained before the holes are drilled. Installation of samplers through paved surfaces requires the use of a roto-

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hammer or drill, and holes in the pavement are usually patched after sampling. The use of the roto-hammer requires an electrical power source.

The physical impact of demonstration sampling on the site was minimal, as no advancement platforms are required for the EMFLUX<sup>®</sup> system. The EMFLUX<sup>®</sup> samplers left 0.75-inch-diameter holes, which were grouted with granular bentonite after the samplers were collected.

### ***Sample Handling***

At each sampling location, a field technician withdraws the field collector from its hole and wipes the outside of the vial clean using gauze cloth; following removal of the sampling cap, the threads of the vial are also cleaned. A solid plastic cap is screwed onto the vial and the sampling location number is written on the label. The samples must be securely packaged for shipment, but do not require cooling. The technician records the sampling point location, date, time, and other relevant information on the field deployment form and on the chain-of-custody form. The samples are shipped to the developer or other qualified laboratory for analysis. Samples are usually analyzed using GC/MS techniques, although other analytical techniques are offered by Quadrel.

### ***Performance Range***

The EMFLUX<sup>®</sup> field collectors are typically inserted in to the soil to a depth of 3 to 4 inches and are capable of sampling soil gas beneath artificial surfaces, such as asphalt and concrete, as well as in soils with sandy to clay textures. The system's use of computer modeling to predict optimal sampling times and the relatively long sample collection period may enhance the sensitivity of the EMFLUX<sup>®</sup> system. During the demonstration, the system successfully detected VOCs in both the clay soil at the SBA site and the sandy soil at the CSC site, at detection limits ranging from 0.09 to 0.28 ng/L. According to the developer, the EMFLUX<sup>®</sup> system can detect VOCs and SVOCs from soil or groundwater at depths as great as 200 feet bgs or more. Because the system relies on diffusion of soil gas from subsurface sources such as contaminated soil or groundwater, the performance range for the EMFLUX<sup>®</sup> system may be controlled by factors such as depth to the source, contaminant concentrations and diffusion rates, soil type and organic content, the detection limits of the methods used to analyze the samples, and possibly other factors. However, during the demonstration, the system was evaluated at locations with relatively shallow subsurface contamination and was only evaluated with regard to its ability to detect certain targeted VOCs. For these reasons, the performance range of the EMFLUX<sup>®</sup> system was not fully established by the demonstration data.

### ***Quantitative Performance Assessment***

Quantitative measures of the performance of the EMFLUX<sup>®</sup> system consisted of (1) VOC detection and quantitation, (2) sample retrieval rate, and (3) cost. The following sections discuss the first two performance factors; a cost analysis of the EMFLUX<sup>®</sup> system is provided in Chapter 6.

#### ***VOC Detection and Quantitation***

Seven samples were collected with the EMFLUX<sup>®</sup> system within each sampling grid, as described in Chapter 3. Samples were analyzed for VOCs by the technology developer's subcontract laboratory using GC/MS techniques (EPA SW-846 modified Method 8260) in accordance with the demonstration plan (PRC, 1997). Quadrel converted the raw VOC data, initially reported as mass of each VOC



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detected in each cartridge, to mass per unit volume of air, using the conversion equation presented in Chapter 2. Table 5-1 presents the range and mean VOC concentrations calculated from soil gas samples collected using the EMFLUX<sup>®</sup> system. The VOC results for each sample collected are presented in Appendix A. For all of the sampling grids, VOC data for all seven samples were used to calculate range and mean concentrations for the EMFLUX<sup>®</sup> samples. Reporting limits for the target VOCs were less than 1 ng/L, typically ranging from 0.09 ng/L for 1,2-DCE to 0.28 ng/L for PCE.

Table 5-2 compares the mean VOC concentrations detected using the EMFLUX<sup>®</sup> system to those detected in the samples collected using the reference soil gas sampling method. Based on the mean VOC concentrations for each sampling method at both sites, the EMFLUX<sup>®</sup> system identified the presence of all of the VOC compounds detected by the reference soil gas sampling method in 24 of 25 cases. In addition, the EMFLUX<sup>®</sup> system reported VOCs that the reference method did not detect in seven of 31 cases. For example, the EMFLUX<sup>®</sup> system detected 1,1-DCA at all four grids sampled at the CSC site at concentrations ranging from 0.13 to 6.69 ng/L; however, the reference method did not detect 1,1-DCA in any of the samples. Previous analyses of soil samples and soil headspace samples has indicated the presence of 1,1-DCA in soils at the CSC site (ESI, 1991). This performance characteristic suggests that the EMFLUX<sup>®</sup> system can detect the presence of lower concentrations of VOCs in the soil gas than the reference soil gas sampling method.

Graphical presentations of the mean 1,2-DCE, 1,1,1-TCA, TCE, and PCE concentrations for samples collected using the EMFLUX<sup>®</sup> system and the reference sampling method are provided in Figures 5-1 through 5-4 (insufficient data are available to provide meaningful graphs of vinyl chloride and 1,1-DCA data). Based on a review of the data distribution presented in Figures 5-1 through 5-4, a significant difference between the EMFLUX<sup>®</sup> and reference method data is evident, with mean VOC concentrations for the data sets differing by several orders of magnitude in most instances. Because of this difference, a statistical analysis of the data was not performed. The sample locations where the EMFLUX<sup>®</sup> system detected high VOC concentrations generally corresponded to the sample locations where the reference method also detected high VOC concentrations; however, the values in the two data sets do not appear to exhibit any direct or consistent proportional relationship. According to the technology developer, it is possible that the differences between the VOC concentrations detected using the two technologies may be due to one or a combination of several factors. These factors include: (1) the longer sample collection period for the EMFLUX<sup>®</sup> samples, which causes the EMFLUX<sup>®</sup> data to be subject to factors such as diurnal temperature, barometric pressure, and “earth tide” variations, resulting in concentrations that may be more representative of long-term, average soil gas flux; (2) the aggressive sample collection technique used for the reference method, which may draw more soil gas from the surrounding area than the amount that passively infiltrates the EMFLUX<sup>®</sup> field collectors; and (3) the different sampling depths used for the two techniques.

It should be noted that the EMFLUX<sup>®</sup> system and reference method are field screening techniques that provide only an estimate of the actual concentration of contaminants in soil gas. Because the EMFLUX<sup>®</sup> system and reference method use different techniques to collect soil gas samples, it is not expected that the two methods will provide the same response and that the data will be directly comparable. Because the mean VOC concentrations for the data sets differ by several orders of magnitude in most instances, a statistical analysis of the data was not performed and interpretation of the chemical concentration data for this demonstration is limited to qualitative observations.

Table 5-1. Volatile Organic Compound Concentrations in Samples Collected Using the EMFLUX<sup>®</sup> System

Concentration (ng/L)													
Site	Grid	Vinyl Chloride		1,2-DCE		1,1-DCA		1,1,1-TCA		TCE		PCE	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
SBA	1	0.19 - 104	38.0	16.0 - 958	520	<0.10	<0.10	<0.11	<0.11	0.69 - 16.3	7.35	<0.28	<0.28
SBA	2	<0.17	<0.17	0.12 - 5.34	3.28	<0.10	<0.10	<0.11	<0.11	13.0 - 63.6	35.6	<0.28 - 3.53	1.79
SBA	4	<0.17	<0.17	<0.09 - 0.11	0.09	<0.10	<0.10	<0.11	<0.11	0.24 - 121	20.8	<0.28 - 0.80	0.35
SBA	5	<0.17	<0.17	<0.09 - 8.40	2.92	<0.10	<0.10	<0.11	<0.11	0.34 - 33.6	11.7	<0.28	<0.28
SBA	6	<0.17	<0.17	<0.09	<0.09	<0.10	<0.10	<0.11	<0.11	<0.12	<0.12	<0.28	<0.28
CSC	1	NA	NA	19.7 - 157	58.3	<0.11 - 6.69	4.09	350 - 918	619	65.7 - 1,960	857	2,360 - 54,800	29,200
CSC	2	NA	NA	0.78 - 9.91	3.32	0.15 - 1.17	0.55	118 - 259	203	36.0 - 224	156	338 - 2,630	1,370
CSC	4	NA	NA	0.47 - 6.52	2.58	0.13 - 1.34	0.52	24.9 - 261	115	2.55 - 46.0	14.0	142 - 863	403
CSC	5	NA	NA	<0.10 - 0.27	0.17	<0.11 - 0.30	0.17	11.1 - 65.6	34.4	0.28 - 5.82	3.79	57.8 - 362	249

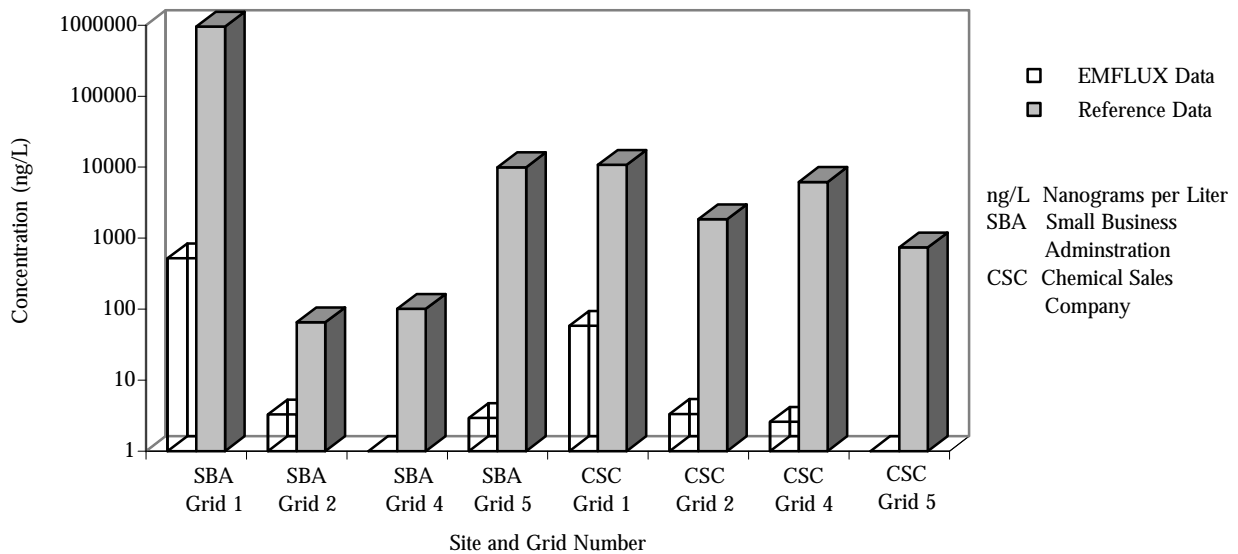
ng/L Nanograms per liter  
 SBA Small Business Administration site  
 CSC Chemical Sales Company site  
 NA Not analyzed  
 1,1-DCA 1,1-Dichloroethane  
 1,2-DCE Cis-1,2-Dichloroethene  
 1,1,1-TCA 1,1,1-Trichloroethane  
 PCE Tetrachloroethene  
 TCE Trichloroethene

Table 5-2. Mean Chemical Concentrations of EMFLUX® and Reference Soil Gas Sampling Method Data

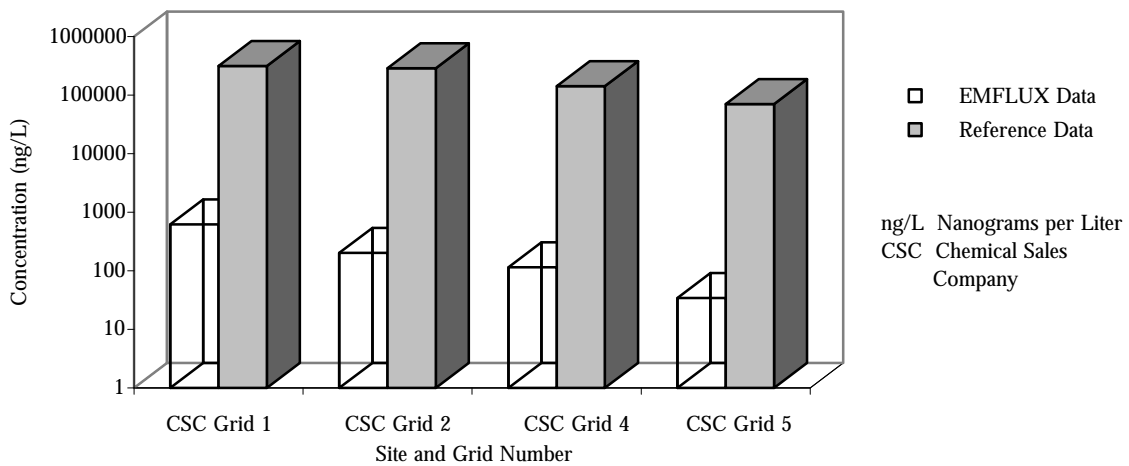
Mean Concentration (ng/L)													
Site	Grid	Vinyl Chloride		1,2-DCE		1,1-DCA		1,1,1-TCA		TCE		PCE	
		EMFLUX®	Ref.	EMFLUX®	Ref.	EMFLUX®	Ref.	EMFLUX®	Ref.	EMFLUX®	Ref.	EMFLUX®	Ref.
SBA	1	38.0	2,390,000	520	958,000	<0.10	<50	<0.11	<50	7.35	<50	<0.28	<50
SBA	2	<0.17	<100	3.28	65	<0.10	<50	<0.11	<50	35.6	1,250	1.79	<50
SBA	4	<0.17	<100	0.09	101	<0.10	<50	<0.11	<50	20.8	9,390	0.35	<50
SBA	5	<0.17	1,980	2.92	9,980	<0.10	<50	<0.11	<50	11.7	2,010	<0.28	<50
SBA	6	<0.17	NA	<0.09	NA	<0.10	NA	<0.11	NA	<0.12	NA	<0.28	NA
CSC	1	NA	NA	58.3	10,800	4.09	<500	619	314,000	857	41,800	29,200	330,000
CSC	2	NA	NA	3.32	1,850	0.55	<500	203	288,000	156	89,500	1,370	223,000
CSC	4	NA	NA	2.58	6,190	0.52	<500	115	142,000	14.0	22,200	403	192,000
CSC	5	NA	NA	0.17	738	0.17	<500	34.4	69,900	3.79	11,500	249	98,500

29

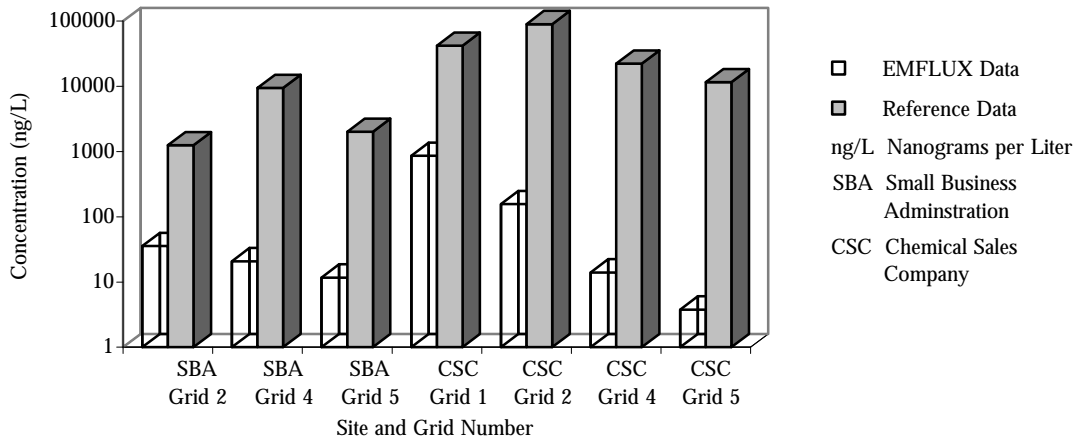
ng/L Nanograms per liter  
 1,2-DCE 1,2-Dichloroethene  
 1,1-DCA 1,1-Dichloroethane  
 1,1,1-TCA 1,1,1-Trichloroethane  
 TCE Trichloroethene  
 PCE Tetrachloroethene  
 Ref. Reference soil gas sampling method  
 SBA Small Business Administration site  
 CSC Chemical Sales Company site  
 NA Not analyzed



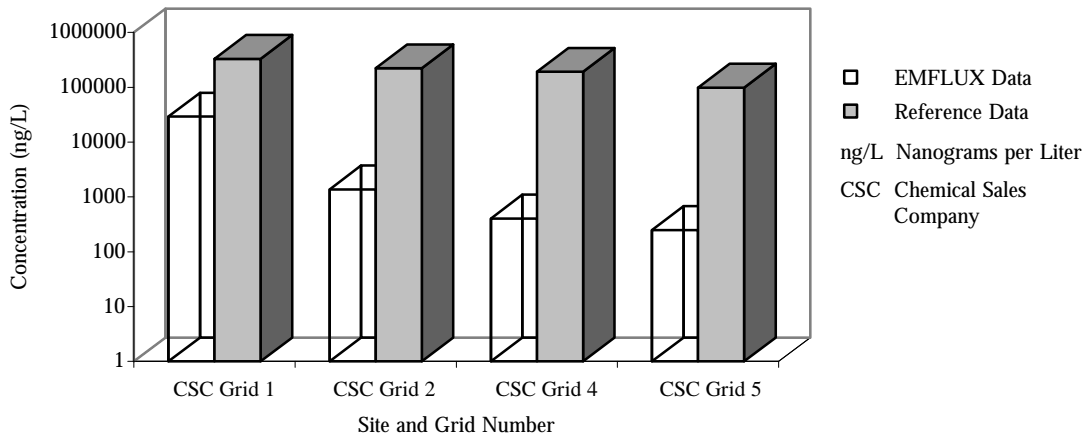
**Figure 5-1. Comparison of Mean 1,2-Dichloroethene Concentration in Samples Collected Using EMFLUX® System and the Reference Soil Gas Sampling Method**



**Figure 5-2. Comparison of Mean 1,1,1-Trichloroethane Concentration in Samples Collected Using EMFLUX® System and the Reference Soil Gas Sampling Method**



**Figure 5-3. Comparison of Mean Trichloroethene Concentration in Samples Collected Using EMFLUX® System and the Reference Soil Gas Sampling Method**



**Figure 5-4. Comparison of Mean Tetrachloroethene Concentration in Samples Collected Using EMFLUX® System and the Reference Soil Gas Sampling Method**

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### **Sample Retrieval Time**

During the demonstration, installation of the EMFLUX<sup>®</sup> system averaged 3.0 minutes per sample at the SBA site and 4.0 minutes per sample at the CSC site. For this demonstration, the samplers were left in place for approximately 4 days at each site. Collection of the samplers required an average of 2.3 minutes per sample at the SBA site and 3.2 minutes at the CSC site. Overall, installation and collection of 35 samples at the SBA site required 187 minutes, an average of 5.3 minutes per sample, and installation and collection of 28 samples at the CSC site required 201 minutes, an average of 7.2 minutes per sample. The analysis and reporting by the technology developer required an additional 12 days for the SBA site data and 16 days for the CSC site data from the time samples were collected until the laboratory report was delivered. The sample retrieval time for each site was determined based on the total length of time required to set up at a sampling grid, implant and collect the seven EMFLUX<sup>®</sup> field collectors, collect any necessary QA samples, grout the holes with bentonite, decontaminate any sampling equipment, and move to a new grid location. One person collected soil gas samples with the EMFLUX<sup>®</sup> system at the SBA and CSC sites.

Table 5-3 presents a comparison of the average sample collection rates for the EMFLUX<sup>®</sup> system and those for the reference soil gas sampling method. The average sample collection times for the EMFLUX<sup>®</sup> system were quicker than those of the reference sampling method in the clay soils at the SBA site and slightly slower than those of the reference sampling method in the sandy soils at the CSC site. The results also suggest that the sample collection rate for the EMFLUX<sup>®</sup> system may be less dependent on soil type than the collection rate for the reference method, possibly because the EMFLUX<sup>®</sup> samplers require only shallow placement and minimal equipment decontamination.

**Table 5-3. Average Sample Retrieval Times for the EMFLUX<sup>®</sup> System and the Reference Soil Gas Sampling Method**

<b>Sampler</b>	<b>Average Time (minutes per sample)</b>	
	<b>SBA Site</b>	<b>CSC Site</b>
<b>EMFLUX<sup>®</sup> Soil Gas Sampler</b>		
Average Sample Installation Time	3.0	4.0
Average Sample Collection Time	2.3	3.2
Average Sample Retrieval Time	5.3	7.2
<b>Reference Sampling Method</b>		
Average Sample Retrieval Time	13.1	6.5

Note: One person collected soil gas samples using the EMFLUX<sup>®</sup> system at the SBA and CSC sites, and a three-person sampling and analysis crew was used to collect and analyze the soil gas samples using the reference soil gas sampling method.

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## Data Quality

Data quality for the EMFLUX<sup>®</sup> system was assessed throughout this demonstration by implementing an approved quality assurance project plan (PRC, 1997). The QA/QC procedures included the consistent application of approved methods for sample collection, chemical analyses, and data reduction. Based on the intended use of the data, QA objectives for precision, accuracy, representativeness, comparability, and completeness were established and QC samples were collected to determine whether the QA objectives were met. Based on the results of a field audit conducted by EPA and a detailed validation of the demonstration data, the data have been deemed acceptable for use as described in the demonstration design (Chapter 3). The results of the QC indicators used for this demonstration for the EMFLUX<sup>®</sup> system are provided in the Technology Evaluation Report for this demonstration (Tetra Tech, 1997) and are summarized below.

As planned, adsorbent samples from the SBA site were sent to a laboratory (Maryland Spectral Services) that had been selected by the developer for analysis in accordance with the laboratory's Standard Operating Procedures. The QC samples included field blanks, trip blanks, method blanks, and surrogate spikes.

At both the SBA and the CSC site, the QC program incorporated the analysis of three field blanks, one trip blank, and at least three method blanks. One trip blank, from the CSC site, exhibited minor contamination (just above the quantitation limit) with methylene chloride, which is commonly used as a laboratory solvent. No other target VOCs were detected in any of the above-described blanks, indicating that contamination of samples in the field, in transport, or in the laboratory was not occurring to any significant degree.

Surrogate spike recovery data were not reported, but no deviations from acceptance criteria were reported by the laboratory.

In summary, although the QC program implemented by the developer laboratory was limited, the results of that QC program did not suggest that any significant data quality issues exist. Therefore, the data from the Quadrel laboratory appears to be of sufficient quality for use in this report as planned.

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## **Chapter 6**

### **Economic Analysis**

The Quadrel EMFLUX<sup>®</sup> Soil Gas Investigation System was demonstrated at two sites that varied geologically and were contaminated with VOCs at a range of concentrations. This chapter presents an economic analysis for applying the EMFLUX<sup>®</sup> system at sites similar to those used in this demonstration. The demonstration costs for the reference soil gas sampling method are also provided.

This economic analysis estimates the range of costs for using the EMFLUX<sup>®</sup> Soil Gas Investigation System to collect 40 subsurface soil gas samples at a clay soil site (similar to the SBA site) and a sandy soil site (similar to the CSC site). The analysis is based on the results and experience gained from this demonstration and costs provided by Quadrel. To account for variability in cost data and assumptions, the economic analysis is presented as a list of cost elements and a range of costs for collecting soil gas samples using the EMFLUX<sup>®</sup> system and reference sampling method.

#### **Assumptions**

Several factors affect the cost of subsurface soil gas sampling. Wherever possible, these factors are identified so that decision makers can independently complete a site-specific economic analysis. For example, this cost estimate is based on the soil types and average sample retrieval times calculated during the demonstrations of 5.3 minutes per sample for the clay soil site and 7.2 minutes per sample at the sandy soil site. This cost estimate assumes that a hammer-driven steel rod is used to install the EMFLUX<sup>®</sup> system 3- to 4-inches bgs, and a direct-push platform is used to advance the active soil gas sampling system to a depth of 4.5 feet bgs for sample collection. The cost estimate also assumes that a one-person sampling crew collects soil gas samples using the EMFLUX<sup>®</sup> system and that a two-person sampling and analysis crew collects and analyzes soil gas samples using the reference method.

#### **EMFLUX<sup>®</sup> System**

The costs for collecting soil gas samples using the EMFLUX<sup>®</sup> system are presented in two categories: (1) sampler, sample analysis, and equipment costs, which include mobilization/demobilization costs, equipment use costs, and sampler and sample analysis costs for the EMFLUX<sup>®</sup> system and (2) operating costs, which include labor costs for sampler installation and retrieval, and other direct costs such as supplies and site restoration.

The cost categories and associated cost elements are defined and discussed below and serve as the basis for the estimated cost ranges presented in Table 6-1.



**Table 6-1. Estimated Subsurface Soil Gas Sampling Costs for the EMFLUX<sup>®</sup> System**

<b>Sampler, Sample Analysis, and Equipment Costs</b>			
Mobilization/Demobilization = \$200 to \$600 per site			
Equipment = \$25 to \$90 per day			
EMFLUX <sup>®</sup> System and Sample Analysis = \$85 to \$195 per sample			
<b>Operating Costs</b>			
<b>Clay Soil Site</b>		<b>Sandy Soil Site</b>	
Sample Retrieval Time = 4 to 6 hours (1 day)		Sample Retrieval Time = 5 to 7 hours (1 day)	
Total Samples Collected = 40		Total Samples Collected = 40	
Total Sample Depth = 13 feet (4 inches/sample)		Total Sample Depth = 13 feet (4 inches/sample)	
Sampling Crew Size = 1 Person		Sampling Crew Size = 1 Person	
<b>Labor Costs</b>		<b>Labor Costs</b>	
Mobilization/Demobilization	\$400 - \$600	Mobilization/Demobilization	\$400 - \$600
Travel	\$12 - \$60	Travel	\$12 - \$60
Per Diem	0 - \$300	Per Diem	0 - \$300
Sample Retrieval	\$200 - \$300	Sample Retrieval	\$250 - \$350
<b>Other Direct Costs</b>		<b>Other Direct Costs</b>	
Supplies	\$25 - \$75	Supplies	\$25 - \$75
Site Restoration	\$25 - \$50	Site Restoration	\$25 - \$50
<b>Range of Operating Costs*</b>	<b>\$660 - \$1,390</b>		<b>\$710 - \$1,440</b>

\* The range of Operating Costs is rounded to the nearest tens of dollars and does not include Sampler, Sample Analysis, or Equipment Costs

*Sampler, Sample Analysis, and Equipment Costs.* These costs include the mobilization/demobilization costs, equipment costs, and sampler and sample analysis costs for the EMFLUX<sup>®</sup> system. Cost ranges were estimated as a daily equipment use fee and sampler and sample analysis charges. The costs include:

- C Mobilization/Demobilization Costs — These costs include preparing, delivering, and setting up the sampling equipment, as well as packing up and returning the equipment to the vendor’s yard. Equipment mobilization and demobilization costs are estimated to range from \$200 to \$600 for each site.
- C Equipment Costs — Based on the average sample retrieval times for the demonstration and on collecting 40 samples at each site, it is assumed that 1 day will be required to install the passive soil gas detectors at a clay soil site and 1 day at a sandy soil site. Equipment costs are estimated to range from \$25 to \$90 per day and include the cost of equipment to install the passive soil gas sampler (hammer-driven steel rod [\$25 per day]), rental of a roto-hammer (\$60 per day), and purchase of copper tubing (\$5 per day). A roto-hammer is only required if samplers must be installed below pavement. Copper tubing is required when installing the

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sampler through pavement. No equipment is needed during collection of the passive soil gas detectors.

- C Sampler and Sample Analysis Costs — Unit costs of the EMFLUX<sup>®</sup> samplers include passive soil gas detectors, laboratory analysis, data tables, maps, and a final report. The EMFLUX<sup>®</sup> field collector costs range from \$85 to \$195 per sample, depending on the selected target analytes. The EMFLUX<sup>®</sup> system costs include off-site laboratory analysis using a GC/MS.

*Operating Costs.* Operating costs are limited to mobilization/demobilization labor, travel, per diem, and sample collection labor. Operating costs for collecting samples with the EMFLUX<sup>®</sup> system are segregated into labor costs and other direct costs, as shown below.

Labor costs include mobilization/demobilization labor, travel costs, per diem, and sample retrieval.

- C Labor Mobilization/Demobilization Labor Costs — This cost element includes the time for one person to prepare for and travel to each site and includes 4 to 6 hours at a rate of \$50 per hour for two trips (one for sampler installation and one for sampler collection).
- C Travel costs — Travel costs for each site are limited to round-trip mileage costs and are estimated to be between 20 to 100 miles at a rate of \$0.30 per mile for 2 trips (one for sampler installation and one for sampler collection).
- C Per Diem Costs — This cost element includes food, lodging, and incidental expenses and is estimated to range from zero (for a local site) to \$150 per day per person for one person for 2 days at the clay soil site (½ day each for sampler installation and collection and 1 day for mobilization/demobilization and site restoration). Costs are estimated to be the same for the clay site and the sandy site.
- C Sample Retrieval Labor Costs — On-site labor costs include labor for sampler installation and sampler collection. Because installation and collection of the EMFLUX<sup>®</sup> system is relatively simple, additional oversight labor is not required. The total number of personnel required on site is one. Based on the average demonstration sample retrieval times, sample installation and collection labor times are estimated to be 4 to 6 hours for 1 person at each site (clay or sandy soil). Labor rates are estimated at \$50 per hour.

Other direct costs include supplies and site restoration costs.

- C Supplies — This cost element includes decontamination supplies, such as buckets, soap, high-purity rinse water, and brushes as well as personal protective equipment (Level D, the minimum level of protection, is assumed). Supplies are estimated to cost between \$25 and \$75.
- C Site Restoration — Site restoration costs include grouting the sample boreholes and site restoration labor. Grouting costs for each site are limited to grout and grouting tools (\$25 to \$50). Site restoration labor costs are included under sample collection labor costs.

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## Reference Sampling Method

The costs for implementing the reference method (active soil gas sampler) during the demonstration include categories for sampling and analysis and for oversight, as presented in Table 6-2 and discussed below.

**Table 6-2. Estimated Subsurface Soil Gas Sampling Costs for the Reference Sampling Method**

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### Sampling and Analysis Equipment Costs

Lump Sum = \$4,700 for each site

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### Oversight Costs

<b>Clay Soil Site</b>		<b>Sandy Soil Site</b>	
Total Sampling Time = 9 to 11 hours (2 days)		Total Sampling Time = 5 to 7 hours (1 day)	
Total Samples Collected = 40		Total Samples Collected = 40	
Total Sample Depth = 180 feet (4 feet/sample)		Total Sample Depth = 180 feet (4 feet/sample)	
Sampling Crew Size = 2 People		Sampling Crew Size = 2 People	
<b>Labor Costs</b>		<b>Labor Costs</b>	
Mobilization/Demobilization	\$200 - \$300	Mobilization/Demobilization	\$200 - \$300
Travel	\$6 - \$30	Travel	\$6 - \$30
Per Diem	0 - \$300	Per Diem	0 - \$150
Sampling Oversight	\$450 - \$550	Sampling Oversight	\$250 - \$350
<b>Other Direct Costs</b>		<b>Other Direct Costs</b>	
Supplies	\$25 - \$75	Supplies	\$25 - \$75
<b>Range of Oversight Costs*</b>	<b>\$680 - \$1,260</b>	<b>Range of Oversight Costs*</b>	<b>\$480 - \$910</b>

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\* The range of Oversight Costs is rounded to the nearest tens of dollars and does not include Sampling and Analysis Equipment Costs

*Sampling and Analysis Costs.* Total lump sum sampling and analysis equipment costs for the clay and sandy soil sites was \$4,700 for each site, and included:

- C Mobilization and demobilization
- C Drilling footage
- C Active soil gas sampling system
- C On-site laboratory analysis using a GC and an electrolytic conductivity detector (ELCD)
- C Active soil gas sampling and analysis crew labor costs (2 people)
- C Per diem for the crew (2 people)
- C Grouting boreholes
- C Site restoration
- C Decontamination supplies

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- C Waste collection and containerization
  - C Data tables

Additional mobilization/demobilization and per diem costs will apply if the site is more than 100 miles from the active soil gas service provider. The minimum active soil gas cost is \$2,500 per day for the collection and analysis of 20 samples for six or fewer VOCs. Up to 20 additional samples could be collected per day at an additional cost of \$90 per sample and \$5 per linear sample depth foot.

*Oversight Costs.* Oversight costs are presented as ranges to provide an estimate of oversight costs that may be incurred at other sites. Costs for overseeing the reference sampling are segregated into labor costs and other direct costs, as shown below.

Labor costs include mobilization/demobilization, travel, per diem, and sampling oversight costs.

- C Mobilization/Demobilization Labor Costs — This cost element includes the time for one person to prepare for and travel to each site, and includes 4 to 6 hours each at a rate of \$50 per hour.
- C Travel Costs — Travel costs for each site are limited to round-trip mileage costs for 20 to 100 miles at a rate of \$0.30 per mile.
- C Per Diem Costs — This cost element includes food, lodging, and incidental expenses and is estimated to range from zero (for a local site) to \$150 per day for one person for 2 days at the clay soil site (1 day for sample collection and ½ day for mobilization and demobilization and site restoration) and for one person for 1 day at the sandy soil site (½ day for sample collection and ½ day for mobilization/demobilization and site restoration). No per diem costs are presented for the sampling and analysis crew because these costs are included in the sampling and analysis equipment lump sum.
- C Sampling Oversight Labor Costs — On-site labor, often a registered geologist, is required to oversee sample collection. Active soil gas collection labor typically includes a platform operator and one helper to collect samples and decontaminate sampling equipment. Therefore, the total number of personnel on site would be three: one person to oversee sampling activities and two people to operate the direct-push equipment and collect samples. Based on the average sample retrieval rates determined during the demonstration, sampling oversight labor times are estimated to be 9 to 11 hours for one person at the clay soil site and 5 to 7 hours for one person at the sandy soil site. Labor rates are assumed to be \$50 per hour. Labor costs for the active soil gas sampler operators are included in the equipment costs.

Other direct costs include supplies. Decontamination and site restoration costs are included under the sampling and analysis equipment costs.

- C Supplies — This cost element includes personal protective equipment (Level D, the minimum level of protection, is assumed) and other miscellaneous field supplies. Supplies are estimated to cost between \$25 and \$75.

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## Chapter 7

### Summary of Demonstration Results

This chapter summarizes the technology performance results. The EMFLUX® system was compared to reference sampling methods (AMS™ and Geoprobe® active soil gas sampling systems) in terms of the following parameters: (1) VOC detection and quantitation, (2) sample retrieval time, and (3) cost. The demonstration data indicate the following performance characteristics for the EMFLUX® system:

- C VOC Detection and Quantitation** Soil gas samples collected using the EMFLUX® system and the reference soil gas sampling method at nine grids at both the sites were analyzed for six target VOCs. Analysis of EMFLUX® samples yielded results in total nanograms per sample, which Quadrel converted to mass per unit volume of air (ng/L). The reference method also produced results in mass per unit volume of air. A comparison of the mean VOC concentrations calculated for each sampling method at each grid indicates that the EMFLUX® system identified the presence of all of the VOC compounds detected by the reference soil gas sampling method in 24 of 25 cases. In addition, in 7 of 31 cases, the EMFLUX® system also reported VOCs that the reference method did not detect but were identified as present during previous soil and groundwater investigations at the demonstration sites. This performance characteristic suggests that the EMFLUX® system can detect the presence of lower concentrations of VOCs in soil gas than the reference soil gas sampling method. In addition, the sample locations where the EMFLUX® system reported high VOC concentrations generally corresponded to the sample locations where the reference method also reported high VOC concentrations. However, the values in the two data sets do not appear to exhibit any direct or consistent proportional relationship, and the mean concentrations of VOCs calculated using the reference method data were typically one to four orders of magnitude higher than those calculated using the EMFLUX® system for samples from the same grid. Because the EMFLUX® system relies on diffusion of soil gas from subsurface sources such as contaminated soil or groundwater, the performance range for the EMFLUX® system may be controlled by factors such as depth to the contaminant source, contaminant concentrations and diffusion rates, soil type and organic content, the detection limits of the methods used to analyze the samples, and possibly other factors. However, during the demonstration, the system was evaluated at locations with relatively shallow subsurface contamination, and was only evaluated with regard to its ability to detect certain targeted VOCs. For these reasons, the performance range of the EMFLUX® system was not fully established by the demonstration data. It should be noted that the EMFLUX® system and reference method are field screening techniques that provide only an estimate of the actual concentration of contaminants in soil gas. Because the EMFLUX® system and reference method use different techniques to collect soil gas samples, it is not expected that the two methods will provide the same response and that the data will be directly comparable. Because the mean VOC concentrations for the data sets differ by several orders of magnitude in most instances, a statistical analysis of the data was not

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performed and interpretation of the chemical concentration data for this demonstration is limited to qualitative observations.

- C **Sample Retrieval Time:** Installation of the EMFLUX® system averaged 3.0 minutes per sample at the SBA site and 4.0 minutes per sample at the CSC site. For the demonstration, the samplers were left in place for approximately 4 days at each site. Collection of the samplers required an average of 2.3 minutes per sample at the SBA site and 3.2 minutes at the CSC site. Overall, installation and collection of 35 samples at the SBA site required 187 minutes, an average of 5.3 minutes per sample and installation and collection of 28 samples at the CSC site required 201 minutes, an average of 7.2 minutes per sample. The analysis and reporting by the technology developer required an additional 12 days for the SBA site data and 16 days for the CSC site data from the time samples were collected until the laboratory report was delivered. The reference soil gas method required 458 minutes to collect 35 samples at the SBA site, an average of 13.1 minutes per sample, and 183 minutes to collect 28 samples at the CSC, an average of 6.5 minutes per sample. One day was required per site to analyze the samples and report the results. Based on the demonstration results, the average sample retrieval times for the EMFLUX® system were quicker than those of the reference soil gas sampling method in the clay soils at the SBA site and slower than those of the reference sampling method in the sandy soils at the CSC site. During sample collection using the reference soil gas sampler, the clay soil at the SBA site caused the system to hold its vacuum at several sampling locations; therefore, soil gas was not completely drawn into the system for sampling. In these cases, the rod was withdrawn in additional 6-inch increments until the vacuum was broken and the system's pressure reached equilibrium with atmospheric pressure. The vacuum problem was not encountered in the sandy soil at the CSC site. At both sites, one person collected soil gas samples with the EMFLUX® system, and a three-person sampling crew collected and analyzed soil samples using the reference sampling method.
- C **Cost:** Based on the demonstration results, the EMFLUX® system costs \$85 to \$195 per sample plus equipment costs of \$25 to \$90 per day and mobilization/demobilization costs of \$200 to \$600 per day. Operating costs for the EMFLUX® system ranged from \$660 to \$1,390 at the clay soil site and \$710 and \$1,440 at the sandy soil site. For this demonstration, the active soil gas sampling method was procured at a lump sum of \$4,700 for each site. The oversight costs for the active soil gas sampling method ranged from \$680 to \$1,260 at the clay soil site and \$480 to \$910 at the sandy soil site. A site-specific cost and performance analysis is recommended when selecting a subsurface soil gas sampling method.

In general, the data quality indicators met the established quality assurance objectives and support the usefulness of the demonstration results in verifying the performance of the EMFLUX® system.

A qualitative performance assessment of the EMFLUX® system indicated that (1) the samplers are reliable in that 100 percent of the required samples were collected with no sample losses; (2) the samplers are easy to use and require minimal training (a 16-minute training video is available from the developer); (3) logistical requirements for the EMFLUX® system differ from those of the reference sampling method because samplers are installed using a hammer-driven, 6-inch steel rod, left in place for several days, retrieved by hand, and sent to the developer for analysis; and (4) sample handling in the field was easier than the reference method because the only requirements are that the recovered cartridges be properly packed, and shipped to the developer for analysis.

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The demonstration results indicate that the EMFLUX® system can provide useful, cost-effective data for environmental problem-solving. The EMFLUX® system successfully collected soil gas samples in clay and sandy soils. The sampler provided positive identification of target compounds and may be able to detect lower concentrations of VOCs in the soil gas than the reference soil gas sampling method. The results of the demonstration did not indicate consistent proportional comparability between the EMFLUX® data and that of the reference method data. As with any technology selected, the user must determine what is appropriate for the application and the project data quality objectives.

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## **Chapter 8**

### **Technology Update**

#### **Empirical and Theoretical Bases for EMFLUX® System**

Quadrel's EMFLUX® technology is based on the existence of cyclical periods of favorable (high) and unfavorable (low) gas-migration velocities through the earth's crust and on the ability to predict the occurrence of those cycles consistently and reliably. The existence of order-of-magnitude cyclical changes in upward trace-gas velocity is predicated on empirical evidence; the utility of the EMFLUX® system rests on a theoretical connection between that empirical data and earth-tidal (gravitational) phenomena recorded by U.S. Geological Survey and National Aeronautics and Space Administration.

The relationship was developed in the early 1970s by Quadrel's Chief Scientist, George H. Milly, who holds doctorates in Geochemistry and Atmospheric Physics. Identification of this relationship grew out of Dr. Milly's search for the cause of observed cyclical variations in atmospheric concentrations of radon, which all but negated attempts to use atmospheric radon as an indicator in uranium exploration. Previously recognized factors influencing vertical trace-gas migration through soils (such as temperature, barometric pressure, and moisture changes) failed to correlate with the recorded cyclical variations, and this divergence ultimately led to the discovery of relationships between gravitational phenomena and soil-gas migration rates. Subsequent development includes computerization of the algorithms used to predict favorable soil-gas sampling periods. EMFLUX® was first used in the 1970s to support uranium exploration programs and located more than 34 million pounds of uranium reserves.

Quadrel was founded in the late 1980s to commercialize applications of this fundamental technology in the field of environmental testing. It is Quadrel's belief now—given available data, field verifications of soil-gas-velocity predictions, and successes in governmental, industrial, and private projects—that the company's predictive earth-tide model has established itself as a practical method for identifying favorable emission flux periods at any point on the earth's surface. This capability has, in turn, spurred development of an environmental field sampling system which can take advantage of the phenomenon: the passive, noninvasive EMFLUX® Soil-Gas Investigation System.

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In 1989, the EMFLUX® system was first formally evaluated on a (now closed) U.S. EPA test bed under the auspices of the National Environmental Technology Applications Center (NETAC). The objective of the test was to determine EMFLUX's® ability to detect and quantify the relative source strength of various contaminants in ground water. NETAC reported a 0.91 correlation coefficient between EMFLUX® soil-gas data and groundwater contaminant concentrations and that EMFLUX® correctly identified the dominant contaminant, chloroform. The most recent evaluation of the technology is the subject of the present ETVR.

### **The ETV Demonstrations**

The demonstrations described herein compared the passive EMFLUX® system with an active (reference method) soil gas system, rather than with data from soil or water samples. This procedure unfortunately leaves unresolved questions concerning the relative merits of the two systems, as no third source of reference data is available to serve as an independent standard for comparison. When discrepancies appear, it is impossible to determine which method is at fault. Nevertheless, the demonstration points out a number of EMFLUX® system advantages.

- EMFLUX® field samplers are small, lightweight, and easy to install (requiring a depth of no more than 3 inches).
- EMFLUX® field samplers can be rapidly deployed (demonstration results support a rate in excess of 100 per field person per day), making it possible to sample even large sites during favorable soil-gas emission periods with minimal personnel and consequent savings in time and cost.
- The technology's low detection thresholds permit EMFLUX® users to identify subsurface contamination at concentrations previously considered impossible, thus minimizing the risk of false negatives.
- Although the active (reference) soil-gas method collected higher mean concentrations of vapor-phase VOCs than EMFLUX®, the reference system failed, paradoxically, to pick up very low VOC concentrations that EMFLUX® did detect. Such paradoxes may stem from the fact that the vacuum system used in an active technique forcibly extracts gases from a larger area than that sampled by a passive device, but this characteristic does not denote superior sensitivity; on the contrary, it can actually distort survey data.
- Because *simultaneous* EMFLUX® samples were taken continuously over several days, while the reference system collected *sequential* samples, each during only a brief fraction of the total survey period, Quadrel contends that the EMFLUX® data much more consistently—and much more accurately—represent the degree and extent of subsurface contamination. Therefore,

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the demonstration's failure to show consistent proportional comparability between the EMFLUX® data and that collected by the reference method would not only be predictable, but also highly probable.

It is to be emphasized that, while the EMFLUX® demonstrations conducted under the ETV program involved sample analyses by an off-site laboratory affiliated with Quadrel, this is not an analytical requirement. Although most users have historically employed Quadrel laboratories for sample analysis, clients are free to contract with the qualified laboratory of their choice, provided that the facility has high-temperature thermal-desorption capabilities as well as GC and flame ionization detector, photoionization detector, ELCD, electron capture detector, or FPD detectors or GC/MS equipment. Specific analytical protocols (identical or very similar to standard EPA methods) are available from Quadrel for user organizations to determine whether in-house laboratories can successfully perform EMFLUX® sample analysis. Approximately one-third of the sampler and sample analysis cost component in Table 6-1 of the report is related to laboratory services.

### **Expanding Applications**

In its ongoing efforts to find useful new applications for the EMFLUX® Soil Gas detection system, Quadrel has recently completed successful projects involving:

- C Detection of elemental mercury in the subsurface soils of industrial sites
- C Identification of methane-producing landfill cells, and subsequent calculation of annual methane production levels
- C Detection of non-methane landfill gases (adsorptive and nonadsorptive)
- C Collection of target-gas emissions from soil to atmosphere as data for risk assessment studies
- C Extension of all-weather, all-terrain procedures.

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## **Chapter 9**

### **Previous Deployment**

The EMFLUX<sup>®</sup> Soil-Gas Investigation System has been employed successfully on nearly 450 projects by more than 190 user organizations on sites located in 47 U.S. states or territories and in several foreign countries. The following illustrates the range of typical projects. Specific references are available from the developer.

**Western U.S. Air Force Base.** More than 630 EMFLUX<sup>®</sup> collectors have been deployed at over 34 known or suspected release areas to date to determine hot spots and migration pathways of a full range of VOC and lighter SVOC contaminants. EMFLUX<sup>®</sup> results were later confirmed with follow-on intrusive sampling. Periodic reports under this ongoing program are issued within 3 weeks of each sampling event.

**Mid-Atlantic U.S. Landfill Site.** More than 150 EMFLUX<sup>®</sup> VOC samplers and 15 methane samplers were deployed across a 15-acre landfill reportedly used in the past for unpermitted dumping of liquid chemical solvents. The VOC samples were analyzed for a range of halogenated hydrocarbons, and methane locations were sampled periodically with hand-held infrared instrumentation to determine the methane generation rate from the landfill. EMFLUX<sup>®</sup> results were used to assist in landfill closure design and planning activities. The final report was received by the client 4 weeks after the start of field work.

**North Central U.S. Manufacturing Site.** Nearly 450 EMFLUX<sup>®</sup> samplers were deployed in a two-phase project at this site to determine potential emission rates of seven targeted halogenated compounds for the purpose of finding “hot spots” of contamination and determining the lateral extent of contaminant migration. Approximately half of the samplers were deployed through artificial caps. Data indicated several areas of potential concern consistent with previous, limited, invasive sampling values. The final reports, including extensive color isopleth mapping, were issued within 30 days of completion of each phase of field work.

**Southeastern U.S. Army Depot.** More than 300 EMFLUX<sup>®</sup> collectors were used in a series of investigations by the client of 16 subareas, including several chemical waste pits, equipment

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cleaning facilities, lagoons, and landfill areas, for the presence of various VOC and lighter SVOC contaminants. Subsequent invasive sampling results to date have closely correlated with the EMFLUX<sup>®</sup> data. Analytical data began flowing to the client within 48 hours of completion of field sampling, with the final reports delivered three weeks after the beginning of field work.

**Southeastern U.S. Air Force Base.** Approximately 2,000 EMFLUX<sup>®</sup> samplers were deployed to investigate nine different sites at this base for VOC contamination involving analysis of the entire EPA contract laboratory program (CLP) Target Compound List. The survey encompassed a series of sampling events over a 2-month period, with working draft reports delivered immediately following analysis of samples from each site. The final report was delivered within 10 working days of completion of the final sampling event.

**Western U.S. DOE National Laboratory.** More than 280 EMFLUX<sup>®</sup> samplers were deployed across 10 sites on three operable units as an initial screening survey to assist in planning a follow-on drilling program. Areas of study included landfills, burial pits, leach fields, drainage ditches, and trenches. Target compounds included halogenated and petroleum-related compounds. The client's QA program required full CLP data packages to be provided with 15 randomly chosen field samples to illustrate the quality of analytical data. The final report was received by the client within 5 weeks of the beginning of field work.

**Northeastern U.S. Air Force Base.** More than 180 EMFLUX<sup>®</sup> samplers were deployed on five survey areas, including landfills, drainage ditches, and suspected disposal areas. Survey data were used to assist in (1) the planning of a confirmatory drilling program, and (2) air contamination assessments. All samples were analyzed for CLP Target Compound List contaminants. The final report was received by the client 4 weeks after the beginning of field work.

**Northeastern Airport Annex Site.** Some 180 EMFLUX<sup>®</sup> samplers were deployed over 13 areas of concern to assess the nature and extent of VOC contamination at several disposal areas, two leach fields, several underground storage tank areas, and drainage ditches. All samples were analyzed for the presence of CLP Target Compound List contaminants. The final report was received by the client within 4 weeks of the beginning of field work.

**Eastern U.S. DOE National Laboratory.** More than 70 EMFLUX<sup>®</sup> samplers were deployed on and in the vicinity of a mixed waste landfill in an effort to determine the presence of halogenated and petroleum-related compounds through caliche soils. The final report was received by the client 4 weeks after the beginning of field work.

**North Central Abandoned Missile Site.** More than 125 EMFLUX<sup>®</sup> collectors were used to determine the presence and extent of soil and groundwater contamination at a former NIKE missile installation. EMFLUX<sup>®</sup> results identified the suspected contaminant locations. The final report was received by the client 3 weeks from the beginning of field work.

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**Southern U.S. Dry Cleaner Site.** Six EMFLUX<sup>®</sup> samplers were installed in and around a dry-cleaning establishment located in a strip mall to determine the presence and extent of subsurface PCE and TCE contamination. Because of the shallow groundwater depth and because the entire site was in the middle of a large asphalt cap (parking lot), valid results were obtained with only a 5-hour passive exposure. Analytical results were provided to the client within 48 hours of sample retrieval, with the formal report following 2 days later. Subsequent intrusive sampling confirmed the EMFLUX<sup>®</sup> findings.

**Southwestern U.S. Air Force Base.** More than 150 EMFLUX<sup>®</sup> collectors were used in two associated surveys to track soil and groundwater contamination comprising selected VOCs and lighter SVOCs from a suspected source facility at this base. The final report, including extensive color isopleth maps, was issued 4 weeks after the start of field work.

**North Central Manufacturing Site.** More than 100 EMFLUX<sup>®</sup> collectors were deployed at five discrete areas on this site, over 75 percent through asphalt and concrete, to determine the presence, identity, and relative strength of a suite of targeted solvent and fuel-related contaminants in soil and groundwater as part of the initial site characterization program. EMFLUX<sup>®</sup> data indicated the presence of a number of the targeted contaminants at several areas of concern on the site. The final report was issued 2 weeks following the completion of field work.

**Midwestern Abandoned Industrial Site.** Nearly 150 EMFLUX<sup>®</sup> collectors were used to survey this site for soil-gas emissions of a host of fuel and solvent-related contaminants. Survey results indicated the presence of soil gas emission of several of the targeted compounds, confirming suspicions based on a review of past practices at various subareas on the site. The report was issued to the client 14 days following completion of the field work.

**Mid-Atlantic U.S. Army Facility.** More than 300 EMFLUX<sup>®</sup> collectors were deployed at various areas of concern across a former disposal area, seeking to determine the presence of any of the full range of VOC contamination. Sampling was conducted in a series of events over an extensive range of terrain and weather conditions, including snow, ice, dry land, and marsh beds below several feet of water. Several key halogenated and petroleum-based compounds were identified and tracked, and their presence and locations were later confirmed with follow-on intrusive sampling. Reports were issued within 3 weeks of the start of each sampling event.

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**APPENDIX A**

**DATA SUMMARY TABLES**

**FOR THE**

**QUADREL SERVICES, INC.**

**EMFLUX® SOIL GAS INVESTIGATORY SYSTEM**

**TABLE A1. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR QUADREL AND REFERENCE DATA  
SBA SITE - GRID 1**

Sample Name	Sample Location	Soil Type	Contaminant Concentration (ng/L)					
			Vinyl Chloride	1,2-DCE	1,1-DCA	1,1,1-TCA	TCE	PCE
<b>QUADREL SAMPLER DATA</b>								
1A2-QUADREL	A2	Fine	97.3	720	0.10	0.11	9.56	0.28
1B3-QUADREL	B3	Fine	104	958	0.10	0.11	16.2	0.28
1C6-QUADREL	C6	Fine	0.54	21.8	0.10	0.11	2.00	0.28
1D1-QUADREL	D1	Fine	1.72	533	0.10	0.11	5.19	0.28
1E1-QUADREL	E1	Fine	1.39	411	0.10	0.11	3.06	0.28
1F5-QUADREL	F5	Fine	23.7	475	0.10	0.11	8.09	0.28
1G7-QUADREL	G7	Fine	0.19	16.0	0.10	0.11	0.69	0.28
Quantitation Limit	-	-	0.17	0.09	0.10	0.11	0.12	0.28

Range:                    0.19 - 104                    16.0 - 958                    0.10                    0.11                    0.69 - 16.3                    0.28

Mean:                        38.0                        520                        0.10                    0.11                    7.35                    0.28

<b>REFERENCE SAMPLING METHOD DATA</b>								
ACTAG1A105.0	A1	Fine	230,224	343,072	50	50	50	50
ACTAG1B605.0	B6	Fine	3,830,535	2,223,217	50	50	50	50
ACTAG1C105.0	C1	Fine	2,808,445	1,705,212	50	50	50	50
ACTAG1D605.0	D6	Fine	1,059,056	640,633	50	50	50	50
ACTAG1E705.0	E7	Fine	3,102,754	1,218,334	50	50	50	50
ACTAG1F405.0	F4	Fine	517,255	297,770	50	50	50	50
ACTAG1G605.0	G6	Fine	5,178,313	279,336	50	50	50	50

Range:                    230,000 - 5,180,000                    279,000 - 2,220,000                    50                    50                    50                    50

Mean:                        2,390,000                        958,000                        50                    50                    50                    50

Notes:

Quadrel Data:            Quantitation limits are listed in the last row of the table.

Reference Data:        Values reported as "50" are actually non-detects with a detection limit of 50 ng/L.



**TABLE A2. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR QUADREL AND REFERENCE DATA  
SBA SITE - GRID 2**

Sample Name	Sample Location	Soil Type	Contaminant Concentration (ng/L)					
			Vinyl Chloride	1,2-DCE	1,1-DCA	1,1,1-TCA	TCE	PCE
<b>QUADREL SAMPLER DATA</b>								
2A3-QUADREL	A3	Fine	0.17	4.15	0.10	0.11	19.1	0.75
2B7-QUADREL	B7	Fine	0.17	2.33	0.10	0.11	29.7	0.75
2C6-QUADREL	C6	Fine	0.17	5.34	0.10	0.11	50.0	2.44
2D1-QUADREL	D1	Fine	0.17	2.80	0.10	0.11	36.9	1.88
2E3-QUADREL	E3	Fine	0.17	0.12	0.10	0.11	36.6	3.53
2F7-QUADREL	F7	Fine	0.17	2.91	0.10	0.11	13.0	0.28
2G5-QUADREL	G5	Fine	0.17	5.31	0.10	0.11	63.6	2.89
Quantitation Limit	-	-	0.17	0.09	0.10	0.11	0.12	0.28

Range:            0.17            0.12 - 5.34    0.10            0.11            13.0 - 63.6    0.28 - 3.53

Mean:             0.17            3.28            0.10            0.11            35.6            1.79

<b>REFERENCE SAMPLING METHOD DATA</b>								
ACTAG2A405.0	A4	Fine	100	50	50	50	491	50
ACTAG2B605.0	B6	Fine	100	50	50	50	560	50
ACTAG2C305.0	C3	Fine	100	50	50	50	508	50
ACTAG2D205.0	D2	Fine	100	151	50	50	5,378	50
ACTAG2E605.0	E6	Fine	100	50	50	50	323	50
ACTAG2F505.0	F5	Fine	100	58	50	50	1,283	50
ACTAG2G705.0	G7	Fine	100	50	50	50	183	50

Range:            100            50 - 151        50            50            183 - 5,380    50

Mean:             100            65            50            50            1,250            50

Notes:

Quadrel Data:    Quantitation limits are listed in the last row of the table.

Reference Data:    Values reported as "50" (or 100 for vinyl chloride) are actually non-detects with a detection limit of 50 ng/L (or 100 ng/L for vinyl chloride).

**TABLE A3. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR QUADREL AND REFERENCE DATA  
SBA SITE - GRID 4**

Sample Name	Sample Location	Soil Type	Contaminant Concentration (ng/L)					
			Vinyl Chloride	1,2-DCE	1,1-DCA	1,1,1-TCA	TCE	PCE
<b>QUADREL SAMPLER DATA</b>								
4A7-QUADREL	A7	Fine	0.17	0.11	0.10	0.11	121	0.80
4B6-QUADREL	B6	Fine	0.17	0.09	0.10	0.11	1.62	0.28
4C4-QUADREL	C4	Fine	0.17	0.09	0.10	0.11	9.11	0.28
4D3-QUADREL	D3	Fine	0.17	0.09	0.10	0.11	3.04	0.28
4E6-QUADREL	E6	Fine	0.17	0.09	0.10	0.11	0.24	0.28
4F4-QUADREL	F4	Fine	0.17	0.09	0.10	0.11	9.9	0.28
4G1-QUADREL	G1	Fine	0.17	0.09	0.10	0.11	0.85	0.28
Quantitation Limit	-	-	0.17	0.09	0.10	0.11	0.12	0.28

Range:            0.17            0.09 - 0.11    0.10            0.11            0.24 - 121    0.28 - 0.80

Mean:            0.17            0.09            0.10            0.11            20.8            0.35

<b>REFERENCE SAMPLING METHOD DATA</b>								
ACTAG4A305.0	A3	Fine	100	50	50	50	3,429	50
ACTAG4B505.0	B5	Fine	100	195	50	50	14,259	50
ACTAG4C105.0	C1	Fine	100	261	50	50	33,558	50
ACTAG4D205.0	D2	Fine	100	50	50	50	744	50
ACTAG4E405.0	E4	Fine	100	50	50	50	1,088	50
ACTAG4F305.0	F3	Fine	100	50	50	50	3,330	50
ACTAG4G105.0	G1	Fine	100	50	50	50	9,295	50

Range:            100            50 - 261            50            50            744 - 33,600    50

Mean:            100            101            50            50            9,390            50

Notes:

Quadrel Data:            Quantitation limits are listed in the last row of the table.

Reference Data:        Values reported as "50" (or 100 for vinyl chloride) are actually non-detects with a detection limit of 50 ng/L (or 100 ng/L for vinyl chloride).

**TABLE A4. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR QUADREL AND REFERENCE DATA  
SBA SITE - GRID 5**

Sample Name	Sample Location	Soil Type	Contaminant Concentration (ng/L)					
			Vinyl Chloride	1,2-DCE	1,1-DCA	1,1,1-TCA	TCE	PCE
<b>QUADREL SAMPLER DATA</b>								
5A7-QUADREL	A7	Fine	0.17	0.09	0.10	0.11	0.34	0.28
5B4-QUADREL	B4	Fine	0.17	4.11	0.10	0.11	8.89	0.28
5C4-QUADREL	C4	Fine	0.17	3.05	0.10	0.11	10.9	0.28
5D7-QUADREL	D7	Fine	0.17	0.09	0.10	0.11	8.69	0.28
5E3-QUADREL	E3	Fine	0.17	0.45	0.10	0.11	1.80	0.28
5F5-QUADREL	F5	Fine	0.17	4.23	0.10	0.11	33.6	0.28
5G1-QUADREL	G1	Fine	0.17	8.40	0.10	0.11	17.7	0.28
Quantitation Limit	-	-	0.17	0.09	0.10	0.11	0.12	0.28

Range:            0.17            0.09 - 8.40            0.10            0.11            0.34 - 33.6            0.28

Mean:             0.17             2.92             0.10             0.11             11.7             0.28

<b>REFERENCE SAMPLING METHOD DATA</b>								
ACTAG5A405.0	A4	Fine	100	5,544	50	50	355	50
ACTAG5B605.0	B6	Fine	275	4,773	50	50	1,222	50
ACTAG5C405.0	C4	Fine	100	8,745	50	50	545	50
ACTAG5D705.0	D7	Fine	8,265	17,865	50	50	6,253	50
ACTAG5E205.0	E2	Fine	100	3,175	50	50	132	50
ACTAG5F705.0	F7	Fine	4,889	21,028	50	50	2,710	50
ACTAG5G705.0	G7	Fine	100	8,734	50	50	2,867	50

Range:            100 - 8,270            3,180 - 21,000            50            50            132 - 6,250            50

Mean:             1,980             9,980             50             50             2,010             50

Notes:

Quadrel Data:            Quantitation limits are listed in the last row of the table.

Reference Data:        Values reported as "50" (or 100 for vinyl chloride) are actually non-detects with a detection limit of 50 ng/L (or 100 ng/L for vinyl chloride).

**TABLE A5. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR QUADREL AND REFERENCE DATA  
SBA SITE - GRID 6**

Sample Name	Sample Location	Soil Type	Contaminant Concentration (ng/L)					
			Vinyl Chloride	1,2-DCE	1,1-DCA	1,1,1-TCA	TCE	PCE
<b>QUADREL SAMPLER DATA</b>								
6A6-QUADREL	A6	Fine	0.17	0.09	0.10	0.11	0.12	0.28
6B4-QUADREL	B4	Fine	0.17	0.09	0.10	0.11	0.12	0.28
6C5-QUADREL	C5	Fine	0.17	0.09	0.10	0.11	0.12	0.28
6D2-QUADREL	D2	Fine	0.17	0.09	0.10	0.11	0.12	0.28
6E1-QUADREL	E1	Fine	0.17	0.09	0.10	0.11	0.12	0.28
6F2-QUADREL	F2	Fine	0.17	0.09	0.10	0.11	0.12	0.28
6G4-QUADREL	G4	Fine	0.17	0.09	0.10	0.11	0.12	0.28
Quantitation Limit	-	-	0.17	0.09	0.10	0.11	0.12	0.28

Range:            0.17            0.09            0.10            0.11            0.12            0.28

Mean:             0.17            0.09            0.10            0.11            0.12            0.28

<b>REFERENCE SAMPLING METHOD DATA</b>								
REFERENCE SAMPLES NOT ANALYZED IN THIS GRID								

Note:  
Quadrel Data:        Quantitation limits are listed in the last row of the table.

**TABLE A6. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR QUADREL AND REFERENCE DATA  
CSC SITE - GRID 1**

Sample Name	Sample Location	Soil Type	Contaminant Concentration (ng/L)				
			1,2-DCE	1,1-DCA	1,1,1-TCA	TCE	PCE
<b>QUADREL SAMPLER DATA</b>							
1A7-QUADREL	A7	Coarse	19.7	0.11	550	647	47,133
1B1-QUADREL	B1	Coarse	30.5	1.69	350	162	2,357
1C5-QUADREL	C5	Coarse	30.4	6.69	615	1,294	36,356
1D1-QUADREL	D1	Coarse	79.9	6.04	629	274	6,692
1E7-QUADREL	E7	Coarse	157	4.19	918	1,955	53,291
1F4-QUADREL	F4	Coarse	49.2	5.29	592	1,602	54,831
1G1-QUADREL	G1	Coarse	41.1	4.64	680	65.7	3,589
Quantitation Limit	-	-	0.10	0.11	0.12	0.12	0.30

Range:            19.7 - 157    0.11 - 6.69    350 - 918    65.7 - 1,960    2,360 - 54,800

Mean:             58.3            4.09            619            857            29,200

<b>REFERENCE SAMPLING METHOD DATA</b>							
ACTCG1A505.0	A5	Coarse	7,242	500	7,526	26,349	249,342
ACTCG1B605.0	B6	Coarse	2,255	500	170,724	7,450	79,017
ACTCG1C405.0	C4	Coarse	21,311	500	670,474	77,382	769,940
ACTCG1D405.0	D4	Coarse	12,637	500	411,390	44,031	438,473
ACTCG1E205.0	E2	Coarse	19,039	500	478,451	54,857	480,887
ACTCG1F305.0	F3	Coarse	6,246	500	225,933	14,739	117,979
ACTCG1G605.0	G6	Coarse	6,683	500	236,256	67,632	170,967

Range:            2,260 - 21,300    500    7,530 - 670,000    7,450 - 77,400    79,000 - 770,000

Mean:             10,800            500            314,000            41,800            330,000

Notes:

Quadrel Data:            Quantitation limits are listed in the last row of the table.

Reference Data:        Values reported as "500" are actually non-detects with a detection limit of 500 ng/L.

**TABLE A7. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR QUADREL AND REFERENCE DATA  
CSC SITE - GRID 2**

Sample Name	Sample Location	Soil Type	Contaminant Concentration (ng/L)				
			1,2-DCE	1,1-DCA	1,1,1-TCA	TCE	PCE
<b>QUADREL SAMPLER DATA</b>							
2A2-QUADREL	A2	Coarse	2.50	0.45	259	153	752
2B1-QUADREL	B1	Coarse	2.67	0.52	256	133	776
2C6-QUADREL	C6	Coarse	2.73	0.62	118	173	1,953
2D2-QUADREL	D2	Coarse	9.91	1.17	127	224	1,113
2E5-QUADREL	E5	Coarse	2.40	0.43	232	172	2,001
2F4-QUADREL	F4	Coarse	2.25	0.50	242	200	2,629
2G3-QUADREL	G3	Coarse	0.78	0.15	186	36.0	338
Quantitation Limit	-	-	0.10	0.11	0.12	0.12	0.30

Range: 0.78 - 9.91 0.15 - 1.17 118 - 259 36.0 - 224 338 - 2,630

Mean: 3.32 0.55 203 156 1,370

<b>REFERENCE SAMPLING METHOD DATA</b>							
ACTCG2A405.0	A4	Coarse	500	500	33,875	11,353	31,950
ACTCG2B405.0	B4	Coarse	500	500	138,681	42,596	101,902
ACTCG2C505.0	C5	Coarse	942	500	219,486	76,171	201,050
ACTCG2D405.0	D4	Coarse	1,708	500	353,483	99,223	222,623
ACTCG2E105.0	E1	Coarse	2,694	500	413,456	123,487	288,770
ACTCG2F205.0	F2	Coarse	2,827	500	415,093	119,787	287,739
ACTCG2G405.0	G4	Coarse	3,780	500	439,087	153,683	427,089

Range: 500 - 3,780 500 33,900 - 439,000 11,400 - 154,000 32,000 - 427,000

Mean: 1,850 500 288,000 89,500 223,000

Notes:

Quadrel Data: Quantitation limits are listed in the last row of the table.

Reference Data: Values reported as "500" are actually non-detects with a detection limit of 500 ng/L.

**TABLE A8. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR QUADREL AND REFERENCE DATA  
CSC SITE - GRID 4**

Sample Name	Sample Location	Soil Type	Contaminant Concentration (ng/L)				
			1,2-DCE	1,1-DCA	1,1,1-TCA	TCE	PCE
<b>QUADREL SAMPLER DATA</b>							
4A3-QUADREL	A3	Coarse	1.92	0.31	65.6	8.03	344
4B2-QUADREL	B2	Coarse	3.59	0.64	167	21.1	586
4C7-QUADREL	C7	Coarse	1.86	0.53	141	5.82	378
4D2-QUADREL	D2	Coarse	1.38	0.27	32.8	4.24	166
4E1-QUADREL	E1	Coarse	0.47	0.13	24.9	2.55	142
4F4-QUADREL	F4	Coarse	6.52	1.34	261	46.0	863
4G6-QUADREL	G6	Coarse	2.34	0.43	111	10.5	345
Quantitation Limit	-	-	0.10	0.11	0.12	0.12	0.30

Range:      0.47 - 6.52    0.13 - 1.34    24.9 - 261    2.55 - 46.0    142 - 863

Mean:        2.58            0.52            115            14.0            403

<b>REFERENCE SAMPLING METHOD DATA</b>							
ACTCG4A405.0	A4	Coarse	7,008	500	168,233	20,043	143,142
ACTCG4B305.0	B3	Coarse	500	500	19,627	1,881	20,753
ACTCG4C105.0	C1	Coarse	6,882	500	162,682	21,872	152,164
ACTCG4D605.0	D6	Coarse	3,964	500	115,537	15,855	129,093
ACTCG4E405.0	E4	Coarse	10,513	500	216,980	41,798	388,861
ACTCG4F105.0	F1	Coarse	6,650	500	123,393	21,178	194,826
ACTCG4G305.0	G3	Coarse	7,823	500	184,170	32,812	313,472

Range:      500 - 10,500    500    19,600 - 217,000    1,880 - 41,800    20,800 - 389,000

Mean:        6,190            500            142,000            22,200            192,000

Notes:

Quadrel Data:      Quantitation limits are listed in the last row of the table.

Reference Data:    Values reported as "500" are actually non-detects with a detection limit of 500 ng/L.

**TABLE A9. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR QUADREL AND REFERENCE DATA  
CSC SITE - GRID 5**

Sample Name	Sample Location	Soil Type	Contaminant Concentration (ng/L)				
			1,2-DCE	1,1-DCA	1,1,1-TCA	TCE	PCE
<b>QUADREL SAMPLER DATA</b>							
5A7-QUADREL	A7	Coarse	0.17	0.13	26.3	3.06	210
5B5-QUADREL	B5	Coarse	0.10	0.11	43.9	3.06	281
5C7-QUADREL	C7	Coarse	0.27	0.27	65.6	5.77	350
5D2-QUADREL	D2	Coarse	0.10	0.11	11.1	0.28	57.8
5E3-QUADREL	E3	Coarse	0.23	0.30	20.6	3.79	233
5F3-QUADREL	F3	Coarse	0.19	0.15	24.2	4.75	251
5G4-QUADREL	G4	Coarse	0.13	0.14	49.3	5.82	362
Quantitation Limit	-	-	0.10	0.11	0.12	0.12	0.30

Range:      0.10 - 0.27    0.11 - 0.30    11.1 - 65.6      0.28 - 5.82      57.8 - 362

Mean:            0.17            0.17            34.4            3.79            249

<b>REFERENCE SAMPLING METHOD DATA</b>							
ACTCG5A105.0	A1	Coarse	545	500	67,314	8,995	76,084
ACTCG5D505.0	D5	Coarse	744	500	78,631	12,097	99,169
ACTCG5E405.0	E4	Coarse	500	500	58,536	9,166	71,940
ACTCG5F105.0	F1	Coarse	500	500	12,571	2,429	24,812
ACTCG5G705.0	G7	Coarse	1,401	500	132,480	24,684	220,317

Range:      500 - 1,400      500      12,600 - 132,000    2,430 - 24,700    24,800 - 220,000

Mean:            738            500            69,900            11,500            98,500

Notes:

Quadrel Data:      Quantitation limits are listed in the last row of the table.

Reference Data:    Values reported as "500" are actually non-detects with a detection limit of 500 ng/L.