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 **Environmental Technology  
Verification Report**

## Soil Sampling Technology

Clements Associates, Inc.  
JMC Environmentalist's Subsoil Probe



# **Environmental Technology Verification Report**

## **Soil Sampler**

### **Clements Associates, Inc. JMC Environmentalist's Subsoil Probe**

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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 No. 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: SOIL SAMPLER  
APPLICATION: SUBSURFACE SOIL SAMPLING  
TECHNOLOGY NAME: JMC ENVIRONMENTALIST'S SUBSOIL PROBE  
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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 results of a demonstration of the Clements Associates, Inc. JMC Environmentalist's Subsoil Probe (ESP).

**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 the EPA's Superfund Innovative Technology Evaluation Program.

**DEMONSTRATION DESCRIPTION**

In May and June 1997, the EPA conducted a field test of the ESP along with three other soil and two soil gas sampling technologies. This verification statement focuses on the ESP; similar statements have been prepared for each of the other technologies. The performance of the ESP was compared to a reference subsurface soil sampling method (hollow-stem auger drilling and split-spoon sampling) in terms of the following parameters: (1) sample recovery, (2) volatile organic compound (VOC) concentrations in recovered samples, (3) sample integrity, (4) reliability and throughput, and (5) 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 ESP 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 of the wide range of VOC concentrations detected at the sites and because each has a distinct soil type. The VOCs detected at the sites include

cis-1,2-dichloroethene (cis-1,2-DCE); 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: Soil Sampler, Clements Associates, Inc., JMC Environmentalist's Subsoil Probe*, EPA/600/R-98/091.

## TECHNOLOGY DESCRIPTION

The ESP sampler is designed to collect subsurface soil samples and may be advanced by using manual or powered percussive techniques. The ESP can collect continuous or discrete samples. The ESP consists of a sampling tube, a body that guides the sampler as it is driven, and a foot-pedal-operated jack that retrieves the sampler. The sampler is a 36-inch long, solid barrel, open tube with an outside diameter of 1.125 inches. The sample tube is fitted with an inner sample liner and one of three interchangeable tips: a solid drive point, a standard cutting tip, or a wet cutting tip. The sampler is constructed of heat-treated 4130 alloy steel with nickel plating; the cutting tips and drive point are stainless steel. Liners facilitate retrieval of the sample and may be used for storage when applicable. The liner used for the demonstration was a 36-inch long by 0.90-inch inside diameter, thin-walled clear plastic tube that fits inside the sampler. It is capable of recovering a sample 36 inches long in the form of a soil core. Stainless steel liners are also available to meet the sample collection requirements and data quality objectives of a specific project.

## VERIFICATION OF PERFORMANCE

The demonstration data indicate the following performance characteristics for the ESP:

**Sample Recovery:** For the purposes of this demonstration, sample recovery was defined as the ratio of the length of recovered sample to the length of sampler advancement. Sample recoveries from 28 samples collected at the SBA site ranged from 42 to 100 percent, with an average sample recovery of 96 percent. Sample recoveries from 42 samples collected at the CSC site ranged from 72 to 100 percent, with an average sample recovery of 95 percent. Using the reference method, sample recoveries from 42 samples collected at the SBA site ranged from 40 to 100 percent, with an average recovery of 88 percent. Sample recoveries from the 41 samples collected at the CSC site ranged from 53 to 100 percent, with an average recovery of 87 percent. A comparison of recovery data from the ESP sampler and the reference sampler indicates that the ESP achieved higher sample recoveries in both the clay soil at the SBA site and in the sandy soil at the CSC site relative to the sample recoveries achieved by the reference sampling method.

**Volatile Organic Compound Concentrations:** Soil samples collected using the ESP and the reference sampling method at five sampling depths in eight grids (four at the SBA site and four at the CSC site) were analyzed for VOCs. For 16 of the 18 ESP and reference sampling method pairs (seven at the SBA site and 11 at the CSC site), a statistical analysis using the Mann-Whitney test indicated no significant statistical difference at the 95 percent level between VOC concentrations in samples collected with the ESP and those collected with the reference sampling method. A statistically significant difference was identified for one sample pair collected at the SBA site and one sample pair at the CSC site. Analysis of the CSC site data, using the sign test, indicated no statistical difference between the data obtained by the ESP and the reference sampling method. However, at the SBA site, the sign test indicated that the data obtained by the ESP are statistically significantly different than the data obtained by the reference sampling method, suggesting that the reference method tends to yield higher concentrations in sampling fine-grained soils than does the ESP.

**Sample Integrity:** Seven integrity samples were collected with each sampling method at the SBA site, and five integrity samples were collected with each sampling method at the CSC site to determine if potting soil in a lined sampler became contaminated after it was advanced through a zone of high VOC concentrations. For the ESP, VOCs were detected in two of the 12 integrity samples: both at the SBA site. One of the integrity samples collected at the SBA site contained cis-1,2-DCE at 5,700 micrograms per kilogram (Fg/kg), TCE at 4,070 Fg/kg, and PCE at 212 Fg/kg; the other sample contained cis-1,2-DCE at 114 Fg/kg and TCE at 3.17 Fg/kg. These results indicate that the integrity of a lined chamber of the ESP may not be preserved when the sampler is advanced through highly contaminated soils. Results of sample integrity tests for the reference sampling method indicated no contamination in the potting soil after it was advanced through a zone of high VOC concentrations. Because potting soil has an

organic carbon content many times greater than typical soils, the integrity tests represent a worst-case scenario for VOC absorbance and may not be representative of cross-contamination under normal field conditions.

**Reliability and Throughput:** At both the SBA and CSC sites, the ESP collected a sample from the desired depth on the initial attempt 100 percent of the time. Two target zones were not sampled at the SBA site due to the technology developer's absence on several days during the demonstration; however, no planned samples were omitted due to equipment failure. Collection of saturated soil samples using the ESP at 40 feet below ground surface (bgs) in Grid 5 at the CSC site was not attempted because the sample depth was beyond the ESP's performance range. For the reference sampling method, the initial sampling success rates at the SBA and CSC sites were 90 and 95 percent, respectively. Success rates for the reference sampling method were less than 100 percent due to (1) drilling beyond the target sampling depth, (2) insufficient sample recovery, or (3) auger refusal. The average sample retrieval time for a single operator to set up the ESP on a sampling point, collect the specified sample, backfill the hole with granular bentonite, decontaminate the sampler, and move to a new sampling location at the SBA site was 36.9 minutes per sample. The average sample retrieval time at the SBA site was 22.5 minutes per sample when two operators were used. Two operators were used for all grids sampled at the CSC site, resulting in an average sample retrieval time of 13.4 minutes per sample. For the reference sampling method, the average sample retrieval times at the SBA and CSC sites were 26 and 8.4 minutes per sample, respectively. A three-person sampling crew collected soil samples using the reference sampling method at both sites. One additional person was present at the CSC site to oversee and assist with sample collection using the reference method.

**Cost:** Based on the demonstration results and information provided by the vendor, the ESP can be purchased for \$2,780 or rented for \$250 per day. The optional electric hammer and generator can be rented for \$150 to \$300 per day. Operating costs for the ESP ranged from \$2,480 to \$4,210 at the clay soil site and \$1,880 to \$3,110 at the sandy soil site. For this demonstration, the reference sampling was procured at a lump sum rate of \$13,700 for the clay soil site and \$7,700 for the sandy soil site. Oversight costs for the reference method ranged from \$4,230 to \$6,510 at the clay soil site and \$1,230 to \$2,060 at the sandy soil site. A site-specific cost and performance analysis is recommended before selecting a soil sampling method.

A qualitative performance assessment of the ESP indicated that (1) the sampler is easy to use and requires no specialized training to operate; (2) logistical requirements are generally less than those of the reference sampling method; (3) sample handling is similar to the reference method; (4) the performance range is limited by the advancement platform, although the ESP successfully retrieved a sample on one of two sampling attempts at depths greater than 25 feet; and (5) no drill cuttings are generated when using the ESP.

The demonstration results indicate that the ESP can provide useful, cost-effective samples for environmental problem-solving. However, in some cases, VOC data collected using the ESP may be statistically different from VOC data collected using the reference sampling method. Also, the integrity of a lined sample chamber may not be preserved when the sampler is advanced through highly contaminated clay soils. As with any technology selection, the user must determine what is appropriate for the application and project data quality objectives.

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**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 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 community.

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 Technology 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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## Acronyms and Abbreviations

bgs	below ground surface
cc	cubic centimeter
cis-1,2-DCE	cis-1,2-dichloroethene
CME	Central Mine Equipment
CSC	Chemical Sales Company
1,1-DCA	1,1-dichloroethane
E&E	Ecology & Environment
EPA	U.S. Environmental Protection Agency
ESP	Environmentalist's Subsoil Probe
ETV	Environmental Technology Verification
ETVR	Environmental Technology Verification Report
g	gram
GC	gas chromatography
IDW	investigation-derived waste
LCS	laboratory control sample
mg/kg	milligrams per kilogram
mL	milliliter
MS/MSD	matrix spike/matrix spike duplicate
Fg/kg	micrograms per kilogram
NERL	National Exposure Research Laboratory
OU	operable unit
PCE	tetrachloroethene
QA	quality assurance
QA/QC	quality assurance/quality control
RI/FS	remedial investigation/feasibility study
SOP	standard operating procedures
SBA	Small Business Administration
SITE	Superfund Innovative Technology Evaluation
SMC	Superior Manufacturing Company
1,1,1-TCA	1,1,1-trichloroethane
TCE	trichloroethene
VOC	volatile organic compound

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## Executive Summary

In May and June 1997, the U.S. Environmental Protection Agency (EPA) sponsored a demonstration of the Clements Associates, Inc. JMC Environmentalist's Subsoil Probe (ESP), three other soil sampling technologies, and two soil gas sampling technologies. This Environmental Technology Verification Report presents the results of the ESP demonstration; similar reports have been published for each of the other soil and soil gas sampling technologies.

The ESP is a sampling tool capable of collecting unconsolidated subsurface material at depths that depend on the capability of the advancement platform. The ESP can be advanced into the subsurface with direct-push platforms, drill rigs, or manual methods.

The ESP 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 cis-1,2-dichloroethene; trichloroethene; 1,1,1-trichloroethane; and tetrachloroethene. The SBA site is composed primarily of clay soil, and the CSC site is composed primarily of medium- to fine-grained sandy soil.

The ESP was compared to a reference subsurface soil sampling method (hollow-stem auger drilling and split-spoon sampling) in terms of the following parameters: (1) sample recovery, (2) VOC concentrations in recovered samples, (3) sample integrity, (4) reliability and throughput, and (5) cost. The demonstration data indicate the following performance and cost characteristics for the ESP:

- C Compared to the reference method, average sample recoveries for the ESP were higher for both clay and sandy soils.
- C A significant statistical difference between the VOC concentrations measured was detected for one of the seven ESP and reference sampling method pairs collected at the SBA site and for one of the 11 sampling pairs collected at the CSC site. The data also suggest that the reference sampling method tends to yield higher results than the ESP in sampling fine-grained soils.
- C In two of the 12 integrity test samples, the integrity of a lined chamber of the ESP was not preserved when the sampler was advanced through highly contaminated clay soils.
- C The reliability of the ESP to collect a sample in the first attempt was higher than that of the reference sampling method in both clay and sandy soils. The average sample retrieval time for the ESP using two operators was slightly quicker than the retrieval time for the reference method in clay soil but slower in sandy soil.
- C For both clay soil and sandy soil sites, the range of costs for collecting soil samples using the ESP was lower than the reference sampling method. The actual cost depends on the number of samples required, the sample retrieval time, soil type, sample depth, and the cost for disposal of drill cuttings. A site-specific cost and performance analysis is recommended before selecting a subsurface soil sampling method.

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 Clements Associates, Inc. JMC ESP's performance.

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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

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

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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® Technologies, Inc., Core Barrel Sampler; Geoprobe® Systems, Inc., Large-Bore Soil Sampler; AMS™ Dual Tube Liner Sampler; Clements Associates, Inc., Environmentalist's Subsoil Probe; Quadrel Services, Inc., EMFLUX® Soil Gas Investigation System; and W.L. Gore & Associates GORE-SORBER® Soil Gas Sampler. This environmental technology verification report (ETVR) presents the results of the demonstration for one soil sampling technology, the JMC Environmentalist's Subsoil Probe (ESP). Separate ETVRs have been published for the remaining soil and soil gas sampling technologies.



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## **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
- 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 primary purpose of a soil sampling technology is to collect a sample from a specified depth and return it to the surface with minimal changes to the chemical concentration or physical properties of the sample. This report documents the performance of the ESP relative to the hollow-stem auger drilling and split-spoon sampling reference method.

This document summarizes the results of an evaluation of the ESP in comparison to the reference sampling method in terms of the following parameters: (1) sample recovery, (2) volatile organic compound (VOC) concentrations in recovered samples, (3) sample integrity, (4) reliability and throughput, and (5) cost. Data quality measures of 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 ESP, 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**

The ESP was developed by Clements Associates, Inc., as a hand-operated soil sampler designed to collect discrete or continuous subsurface soil samples for chemical analysis. The ESP was designed for sampling to depths of 4 feet below ground surface (bgs); however, through the use of extensions, samples may be obtained from depths as great as 20 feet bgs in some soil types. The physical limitations on the operation of the ESP depend on the method of sampler advancement (manual or electric hammer) and the nature of the subsurface matrix. The technology is primarily restricted to unconsolidated soil free of large cobbles or boulders. Sediments containing gravel-sized material supported by a finer-grained matrix can also be sampled. Additional developer claims for the performance of the ESP are that it:

- C Is simple to operate and requires no special training
- C Is unaffected by variable field conditions
- C Can be used to collect either discrete or continuous soil samples
- C Can be used to characterize subsurface soil contamination
- C Is easily transportable

However, during the demonstration only the developer's claims regarding collection of representative discrete soil samples in the subsurface, operation of the ESP, and the ability of the ESP to be used to sample for VOCs were evaluated.

#### **Components and Accessories**

The major components of the ESP sampling system (Figure 2-1) are a sampling tube assembly, the ESP body, and a jack that is used to assist in sample retrieval. The primary component of the ESP sample tube assembly is a heat-treated 4130 alloy steel sample tube with nickel plating. The tube has a uniform 1.125-inch outer diameter and is 36 inches long. The sampling tube assembly also includes

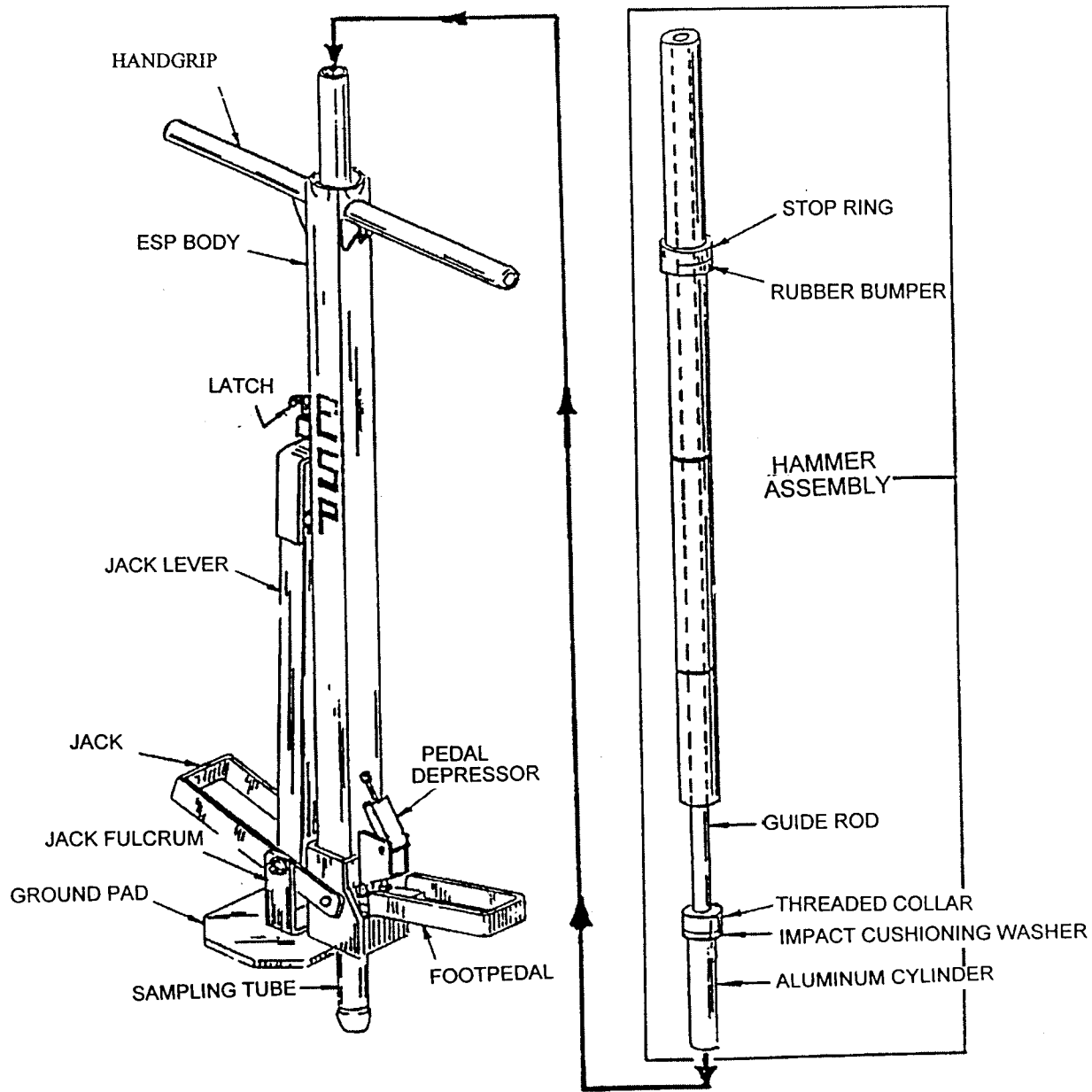


Figure 2-1. JMC Environmentalist's Subsoil Probe Components (modified from Clements Associates, Inc., 1997)

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one of three interchangeable stainless steel tips (a solid drive point, standard cutting tip, or wet cutting tip) and an inner sample liner. Several types of sample liners are available; they include a 36-inch-long plastic liner and stainless steel liners. A 36-inch-long plastic liner with an inside diameter of 0.90 inch was used for this demonstration.

The ESP body serves as a base and guide for the sampling tube as it is driven into or retrieved from the borehole. The jack is used to retrieve the sampling tube. The jack also allows operators to smoothly lower the sampler and tool string into the hole at a controlled rate, minimizing disturbance to the borehole as the sampling tube is returned to the bottom of the hole for each new sample.

A 2-inch diameter, 6-inch long stainless steel concentric sampler tube is also available for use with the ESP. The concentric tube may be used to temporarily case off the uppermost 6 inches of soil, reducing the risk of cross-contaminating subsurface soil samples when using the ESP in areas with significant surface contamination. However, this accessory was not used during the demonstration.

### **Description of Platforms**

The ESP is designed to be advanced using either a manual slide hammer or an optional hand-held electric hammer. A 42-inch master extension and the appropriate number of 36-inch regular extensions are required to advance the sampler to the target depth. Extensions are connected using cross pins, which are held in place with ball plungers. Common hand tools such as pliers may be used for inserting and extracting cross pins, or a pin ejection tool (consisting of a modified vise grip plier) is offered as an option.

The components for the manual slide hammer are shown in Figure 2-2. The 12.5-pound manual slide hammer connects either directly into the open female end of the sampling tube assembly, or to the master extension tube. The hammer cannot be connected directly to the regular extensions. As a result, the master extension must remain at the top of the tool string as the ESP is advanced, which requires the user to partially remove the tool string and disconnect the string at the bottom of the master extension each time a regular extension is added.

The electric hammer offered as an option with the ESP system is a Bosch™ model 11311 EVS, weighing 22.4 pounds and providing from 900 to 1,890 blows per minute. The hammer operates on 110-volt alternating current only, requiring 1,450 watts of power. An 1,850-watt portable generator supplied power to the hammer during the demonstration. The electric hammer can be fitted with two different drive caps, one that fits the master extension, or a second cap that fits all of the regular extensions, eliminating the need to disassemble the tool string as regular extensions are added.

The ESP is lightweight and mobile, and may be used in areas where space would prohibit use of a powered platform. The ESP is about 36 inches long and weighs about 20 pounds. The slide hammer, ESP, and extension pieces to reach 20 feet bgs weigh under 50 pounds, and may be carried by hand into locations inaccessible to vehicles. Use of the electric hammer and generator increases the combined weight of the sampling system components, reducing portability.

### **General Operating Procedures**

Before use and between each sample collected during the demonstration, the ESP and any supporting equipment that could contact the sample were decontaminated. The ESP was then assembled and operated according to standard operating procedures (SOP) recommended by the ESP manufacturer.

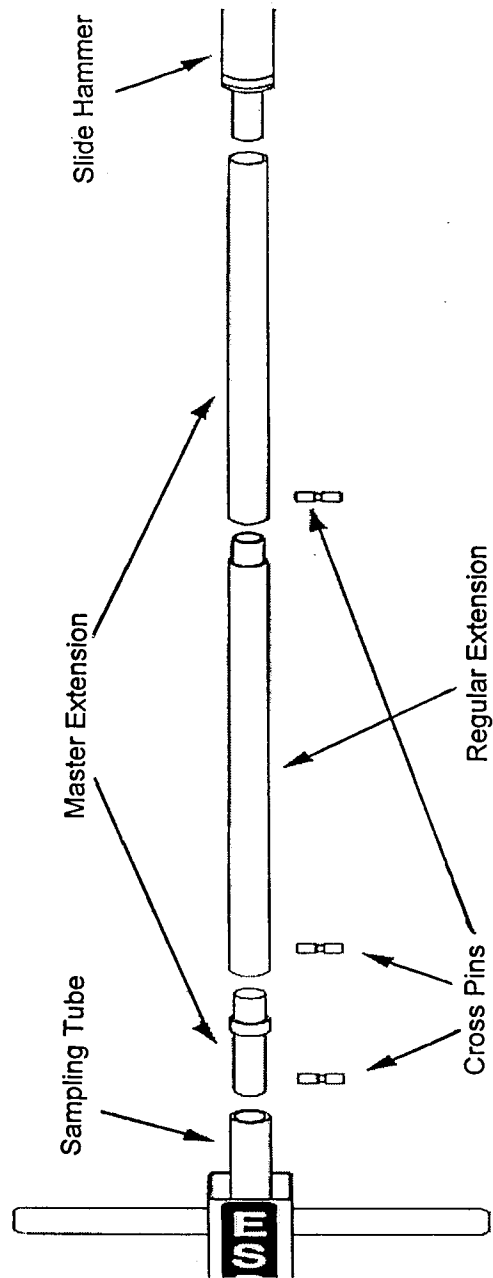


Figure 2-2. JMC Environmentalist's Subsoil Probe Hammer Assembly and Extensions (modified from Clements Associates, Inc., 1997)

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For continuous sampling, the ESP sampling tube was assembled by (1) sliding a core guide onto the end of the sample liner, (2) placing the core liner into a cutting tip, and (3) screwing the cutting tip onto the sampler tube. Following is the developer's SOP for continuous sampling (see Figures 2-3, 2-4 and 2-5 [and Figures 2-1 and 2-2 for referenced sampler parts]):

1. Lay the ESP (body and jack) on the ground and insert an assembled sampler tube.
2. Insert hammer assembly into sampling tube.
3. Put pedal depressor into drive-mode position.
4. Tip ESP with hammer assembly to vertical position.
5. Drive sampling tube into the ground.
6. Move pedal depressor to jacking mode position.
7. Release jack lever.
8. Jack sampling tube up.
9. Remove hammer assembly and continue jacking until sampling tube is out of the ground.
10. Lay the jack on ground. Unload liner and soil core.
11. Insert new liner.
12. Attach master extension assembly. Check ball plungers, and insert and tape pins.
13. Place the jack vertically over the hole and push sampling tube into the hole.
14. Depress pedal slightly with foot pressure and lift jack 6 to 8 inches.
15. Step down on pedal, forcing the sampling tube downward.
16. Repeat up and down movement until the sampling tube is at the bottom of hole.
17. Insert hammer assembly into the top of master extension.
18. Drive sampling tube into the ground.
19. Repeat steps 6 through 18.

The SOP may be modified for collection of discrete interval samples. To collect discrete interval samples during the demonstration, the ESP sample tube was fitted with the solid drive point and advanced to the target depth. The ESP sample tube was then retrieved, fitted with the appropriate cutting tip (for either wet or dry soil), returned to the hole, and driven through the desired sample interval. Also, at some locations, the SOP was modified by using the Bosch™ electric hammer rather than the manual slide hammer.

The ESP was decontaminated according to the procedures specified in the demonstration plan (PRC Environmental Management, Inc. [PRC], 1997). The sample liner protects the sample from contacting the sampling tube, eliminating the need for extensive decontamination of these components in most instances. At sampling locations where there was no visible free product in the soil, the sampling tube and extension rods were dry-decontaminated using brushes and steel wool. The cutting shoe and core guide, which directly contacted the sample, were scrubbed in a small bucket with a solution of Alconox® and water. A small-bore bristle brush was used to clean the inside of the cutting shoe and the core guide. The parts were then rinsed with clean water from a hand-held manual sprayer. At the Small Business Administration (SBA) site, where an oily product was present in soils in Grid 1, the sampling tubes and extension rods also were run through a similar wet decontamination procedure, using a shallow tub to contain the wash water.

Health and safety considerations for operating the sampler and the sampling platforms included complying with all applicable Occupational Safety and Health Administration hazardous waste operation training as well as eye, ear, head, hand, and foot protection.

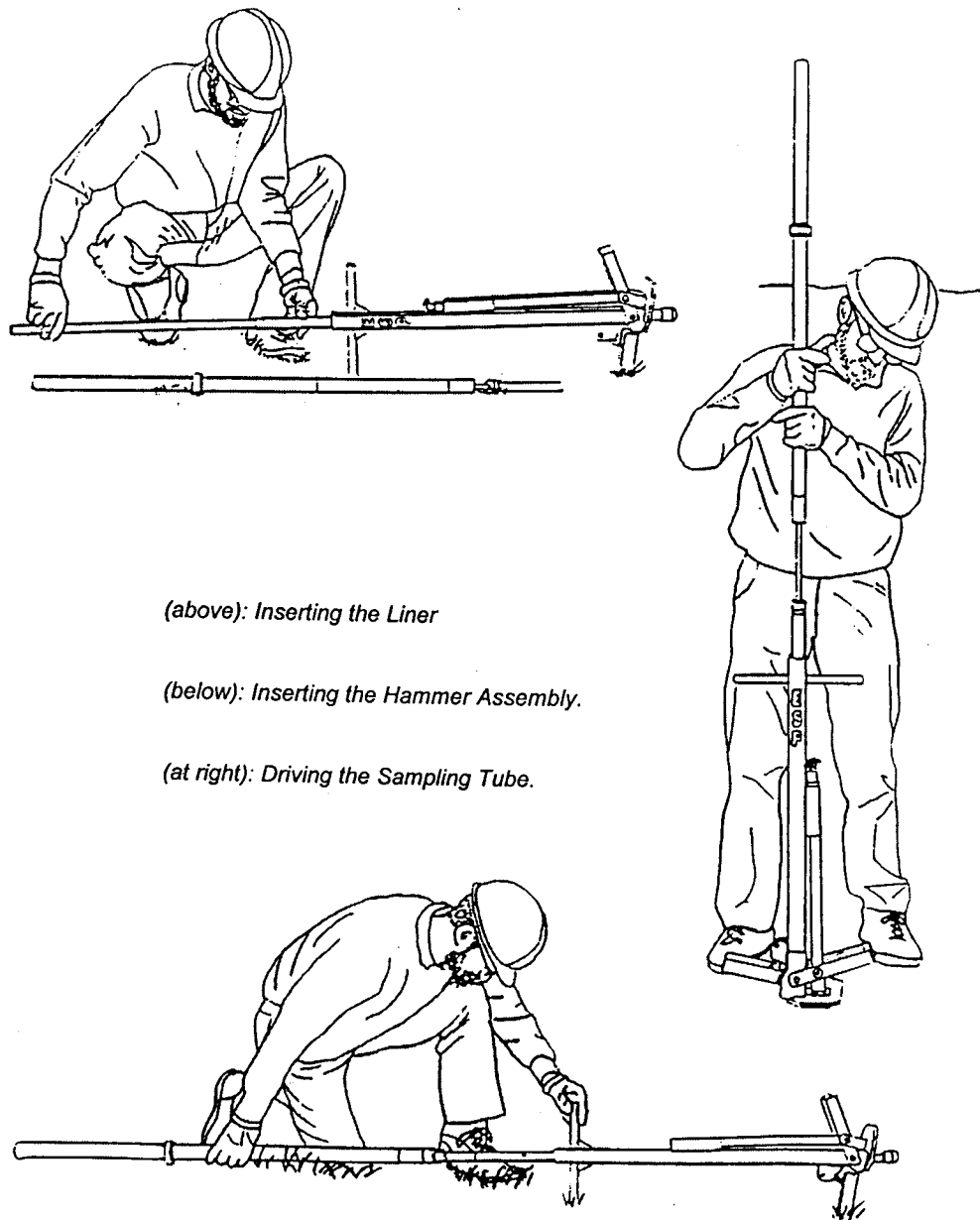
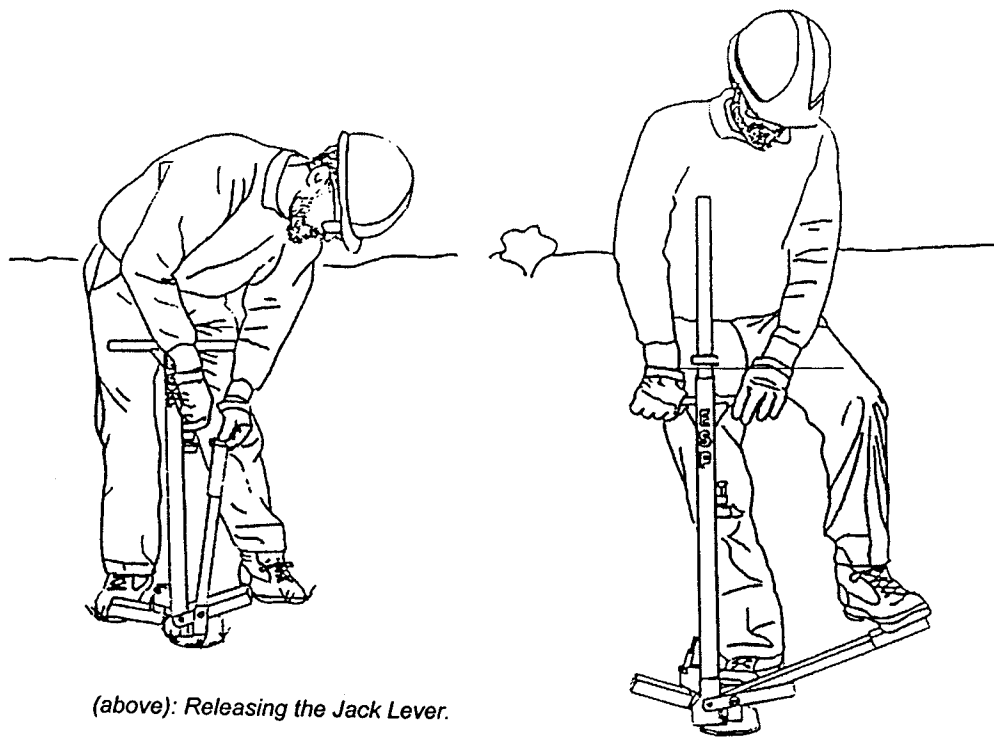


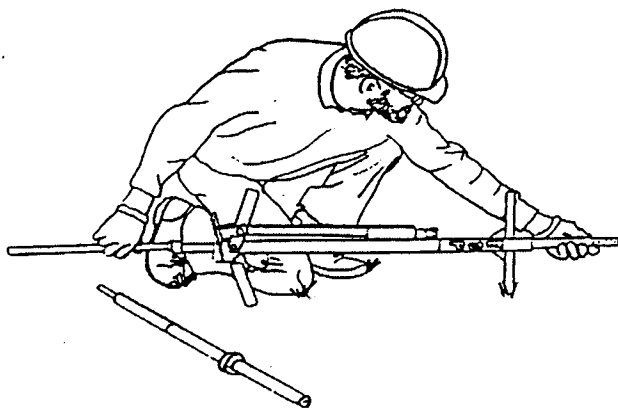
Figure 2-3. Operation of JMC Environmentalist's Subsoil Probe: Sampler Loading and Advancement (modified from Clements Associates, Inc., 1997)





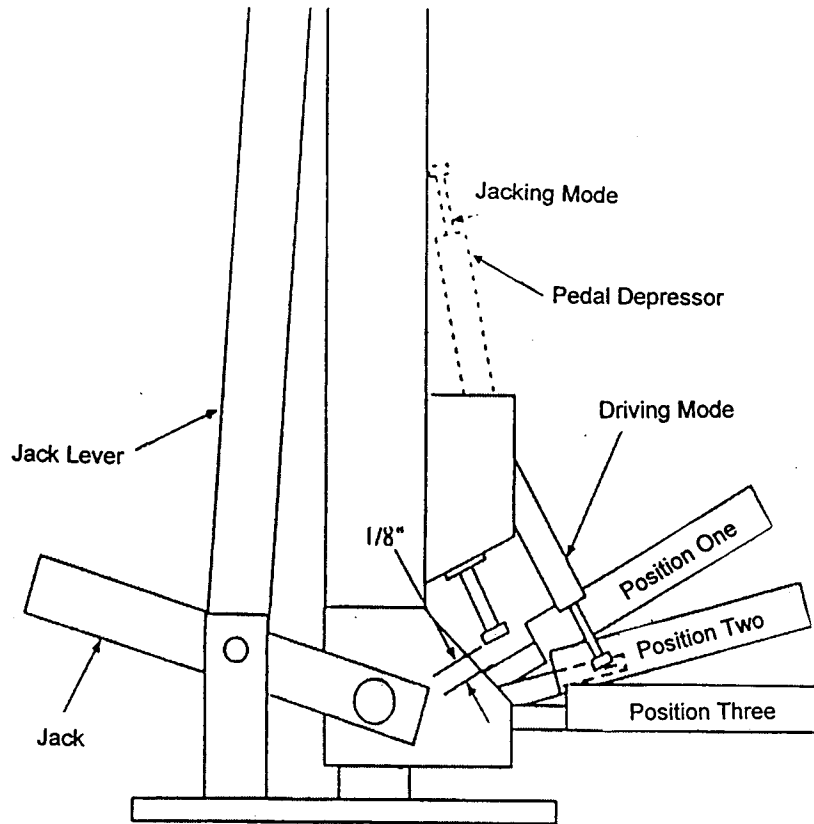
*(above): Releasing the Jack Lever.*

*(above): Retrieving the Sampling Tube.*



*(at left): Extracting the Liner and Soil Sample*

**Figure 2-4. Operation of JMC Environmentalist's Subsoil Probe: Sample Retrieval (modified from Clements Associates, Inc., 1997)**



Notes: The drawing shows the area surrounding the footpedal of the JMC Environmentalist's Subsoil Probe. The footpedal has three positions. In position one (jacking mode), the footpedal allows the sampling tube to be retracted, but prevents the tube from sliding back out. In position two (driving mode), the tube moves freely in either direction. And in position three, the footpedal immobilizes the tube.

Figure 2-5. Operation of the JMC Environmentalist's Subsoil Probe Footpedal (modified from Clements Associates, Inc., 1997)

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## **Developer Contact**

For more developer information on the ESP, please refer to Chapter 8 of this ETVR or contact Clements Associates, Inc. at:

Jim Clements  
Clements Associates, Inc.  
1992 Hunter Avenue  
Newton, Iowa 50208  
Telephone: (515) 792-8285  
Facsimile: (515) 792-1361  
E-mail: [jmcsoil@netins.net](mailto:jmcsoil@netins.net)

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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 SBA site in Albert City, Iowa, and the CSC site in Denver, Colorado, were selected for the demonstration.

#### ***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).

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

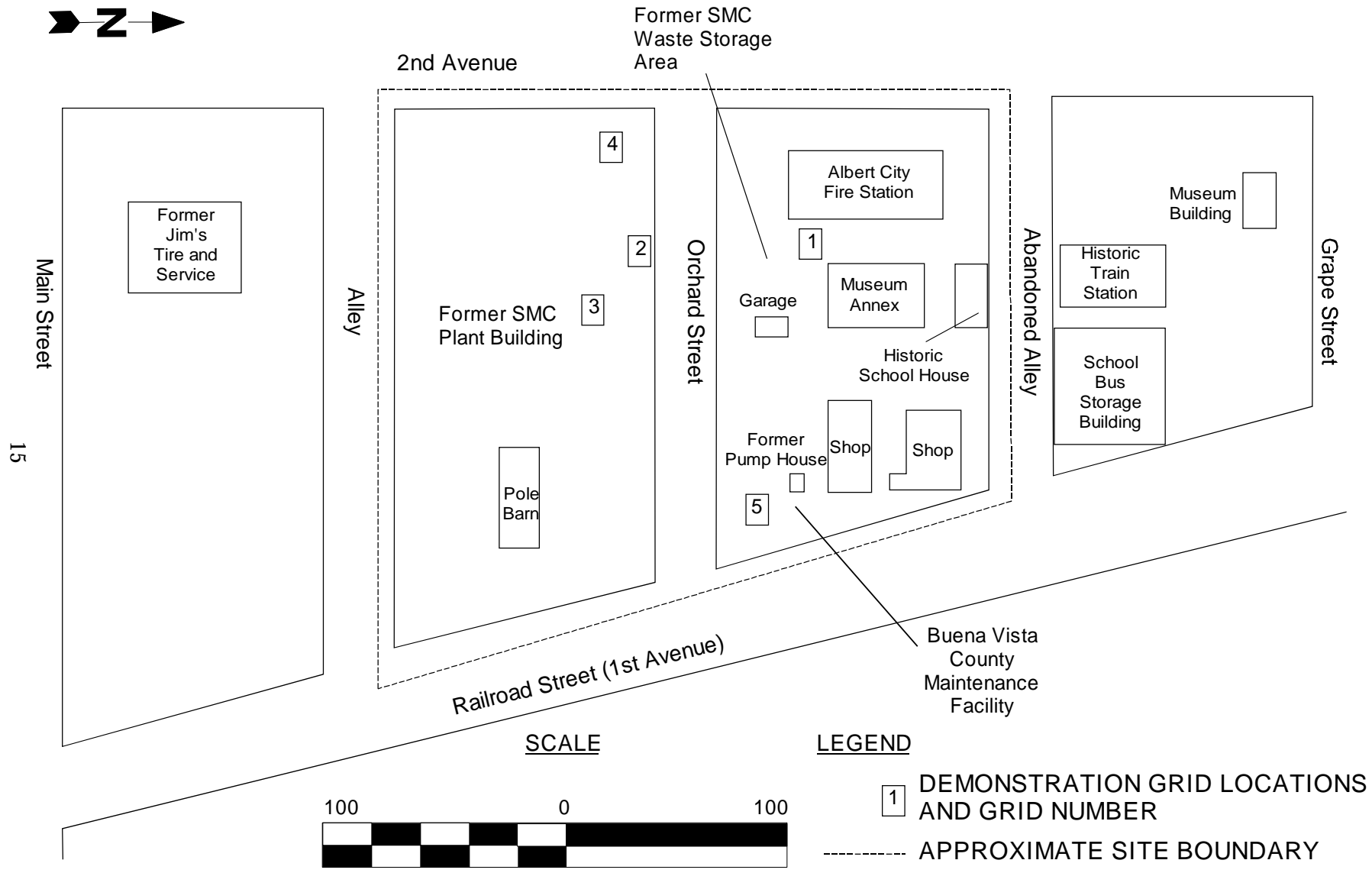


Figure 3-1. Small Business Administration Site

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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).

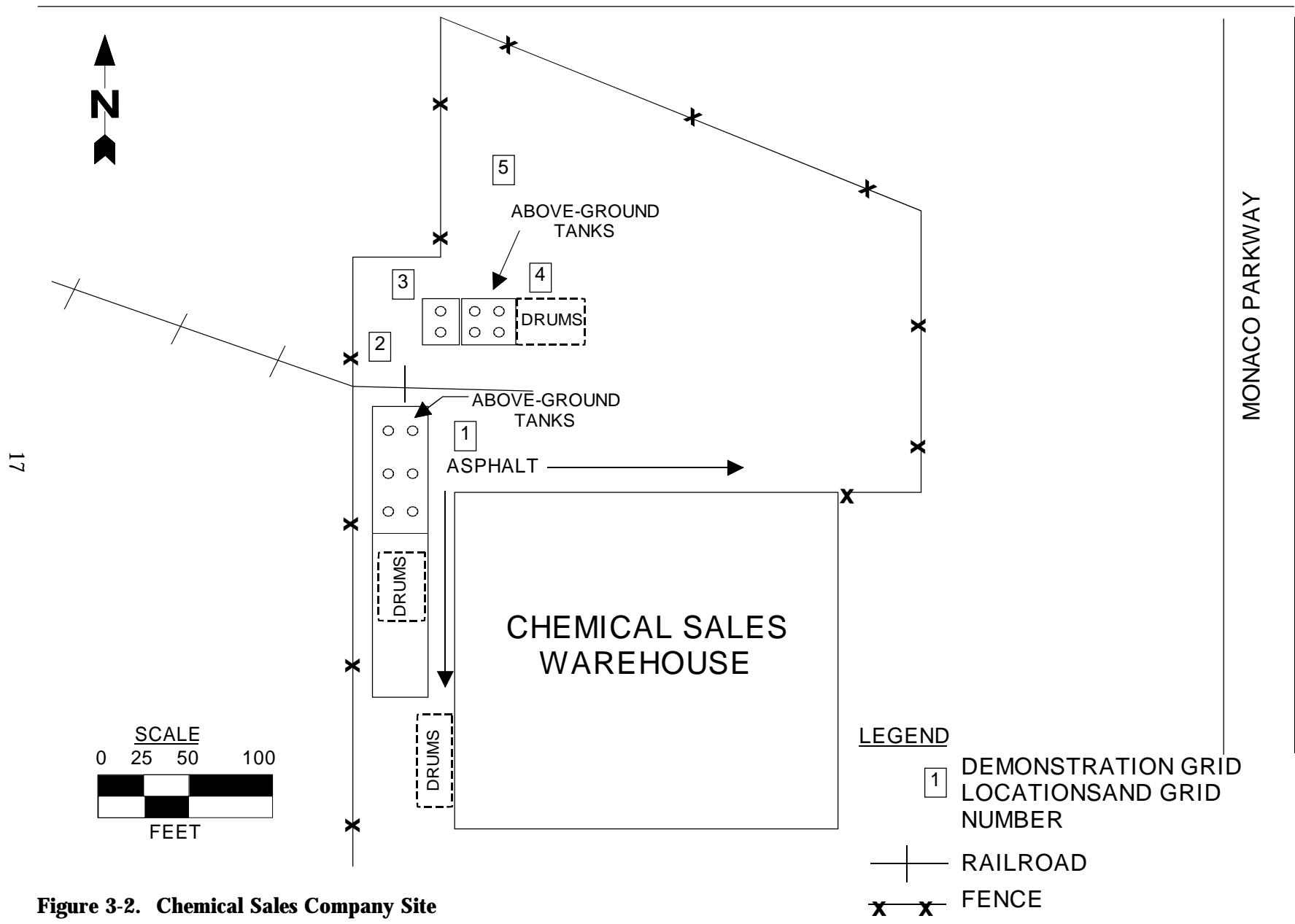
### ***CSC Site Description***

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 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.



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

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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.

### **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. Ten sampling grids, five at the SBA site and five at the CSC site, were investigated to identify sampling depths within each grid that exhibited chemical concentration and soil texture characteristics that met the criteria set forth in the predemonstration sampling plan (PRC, 1997) and would, therefore, be acceptable for the ESP demonstration.

At each of the grids sampled during the predemonstration, a single continuous core was collected at the center of the 10.5- by 10.5-foot sampling area. This continuous core was collected to a maximum depth of 20 feet bgs at the SBA site and 28 feet bgs at the CSC site. Analytical results for this core sample were used to identify target sampling depths and confirm that the target depths exhibited the desired contaminant concentrations and soil type. After the center of each grid was sampled, four additional boreholes were advanced and sampled in each of the outer four corners of the 10.5- by 10.5-foot grid area. These corner locations were sampled at depth intervals determined from the initial coring location in the center of the grid, and were analyzed for VOCs and soil texture.

During predemonstration sampling, ten distinct target depths were sampled at five grids at the SBA site: three depths at Grid 1, two depths at Grid 2, one depth at Grid 3, two depths at Grid 4, and two depths at Grid 5. Five of the target depths represented intervals with contaminant concentrations in the tens of mg/kg, and five of the target depths represented intervals with contaminant concentrations in the tens of Fg/kg. As expected, the primary VOCs detected in soil samples were vinyl chloride, cis-1,2-DCE, TCE, and PCE. TCE and cis-1,2-DCE were detected at the highest concentrations. Because the soil texture was relatively homogeneous for each target sampling depth, soil sampling locations for the demonstration were selected based on TCE and cis-1,2-DCE concentration variability within each grid. A depth was deemed acceptable for the demonstration if (1) individual TCE and cis-1,2-DCE concentrations were within a factor of 5, (2) the relative standard deviations for TCE and cis-1,2-DCE concentrations were less than 50 percent, and (3) the soil texture did not change in dominant grain size.

During predemonstration sampling, 12 distinct target depths were sampled at the five grids at the CSC site: two depths at Grid 1, three depths at Grid 2, three depths at Grid 3, two depths at Grid 4, and two depths at Grid 5. Two of the target depths represented intervals with contaminant concentrations greater than 200 Fg/kg, and ten of the target depths represented intervals with contaminant concentrations less than 200 Fg/kg. The primary VOCs detected in soil at the CSC site were 1,1,1-TCA, TCE, and PCE.

Of the 22 distinct target depths sampled during predemonstration activities at the SBA and CSC sites, seven sampling depths in 10 grids were selected for the demonstration. Six sampling depths within nine grids at the SBA and CSC sites (a total of 12 grid-depth combinations) were chosen to meet the contaminant concentration and soil texture requirements stated above. In addition, one sampling depth at one grid (40 feet bgs at Grid 5) at the CSC site was selected to evaluate the reliability and sample



recovery of the ESP in saturated sandy soil. The sampling depths and grids selected for the ESP demonstration at the SBA and CSC sites are listed in Table 3-1. The locations of the sampling grids are shown in Figures 3-1 and 3-2.

**Table 3-1. Sampling Depths Selected for the ESP Demonstration**

<b>Site</b>	<b>Grid</b>	<b>Concentration Zone</b>	<b>Depth (feet)</b>
SBA (Clay Soil)	1	High	9.5
		High	13.5
	2	Low	3.5
	3	High	9.5
	4	Low	9.5
CSC (Sandy Soil)	1	High	3.0
		Low	6.5
	2	High	3.0
	3	High	3.0
		Low	7.5
	4	Low	6.5
	5 <sup>a</sup>	Low	40.0 <sup>a</sup>

<sup>a</sup> Performance test sampling location only; samples collected but not analyzed. Sampling location selected to evaluate the reliability and sample recovery of the ESP in saturated sandy soil.

**Demonstration Design**

The demonstration was designed to evaluate the ESP in comparison to the reference sampling method in terms of the following parameters: (1) sample recovery, (2) VOC concentration in recovered samples, (3) sample integrity, (4) reliability and throughput, and (5) cost. These parameters were assessed in two different soil textures (clay soil at the SBA site and sandy soil at the CSC site), and in high- and low-concentration areas at each site. The demonstration design is described in detail in the demonstration plan (PRC, 1997) and is summarized below.

Predemonstration sampling identified 12 grid-depth combinations (See Table 3-1) for the demonstration that exhibited consistent soil texture, acceptable VOC concentrations, and acceptable variability in VOC concentrations. One additional grid-depth combination was selected for the demonstration to evaluate the performance of the ESP in saturated sandy soil. Each grid was 10.5 feet by 10.5 feet in area and was divided into seven rows and seven columns, producing 49, 18- by 18-inch sampling cells

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(Figure 3-3). Each target depth was sampled in each of the seven columns (labeled A through G) using the ESP and the reference sampling method. The cell that was sampled in each column was selected randomly. The procedure used to collect samples using the ESP is described in Chapter 2, and the procedure used to collect samples using the reference method is described in Chapter 4. In addition, Chapters 4 and 5 summarize the data collected at each grid for the reference method and ESP.

### ***Sample Recovery***

Sample recoveries for each ESP and reference method sample were calculated by comparing the length of sampler advancement to the length of sample core obtained for each attempt. Sample recovery is defined as the length of recovered sample core divided by the length of sampler advancement and is expressed as a percentage. In some instances, the length of recovered sample was reported as greater than the length of sampler advancement. In these cases, sample recovery was reported as 100 percent. Sample recoveries were calculated to assess the recovery range and mean for both the ESP and the reference sampling method.

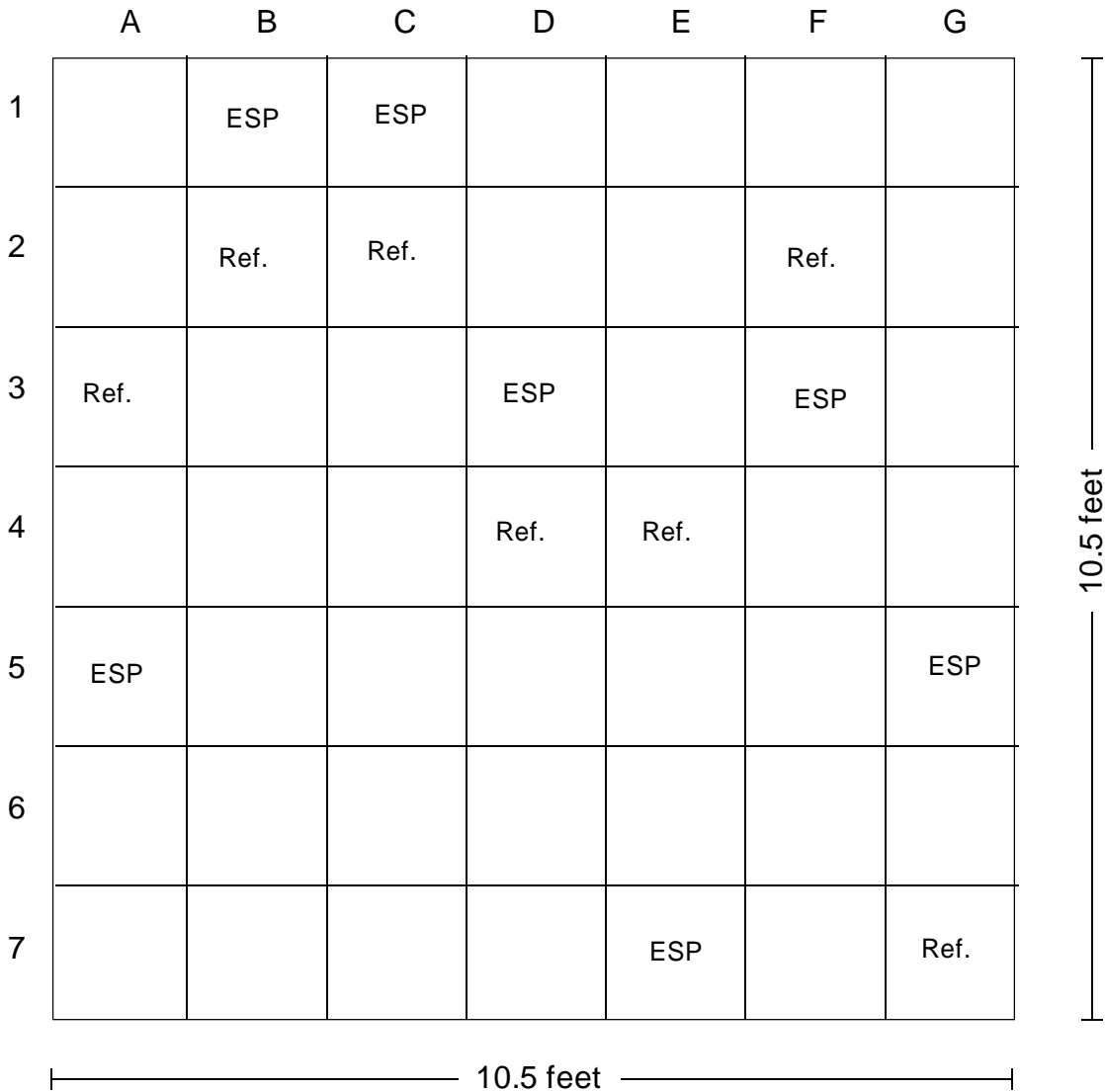
### ***Volatile Organic Compound Concentrations***

Once a sample was collected, the soil core was exposed and a subsample was collected at the designated sampling depth. The subsample was used for on-site analysis according to either a low-concentration or a high-concentration method using modified SW-846 methods. The low-concentration method was used for sampling depths believed to exhibit VOC concentrations of less than 200 Fg/kg. The high-concentration method was used for sampling depths believed to exhibit concentrations greater than 200 Fg/kg. The method detection limits for the low- and high-concentration methods were 1 Fg/kg and 100 Fg/kg, respectively. Predemonstration sampling results were used to classify target sampling depths as low or high concentration. Samples for VOC analysis were collected by a single sampling team using the same procedures for both the ESP and reference sampling method.

Samples from low-concentration sampling depths were collected as two 5-gram (g) aliquots. These aliquots were collected using a disposable 5-cubic centimeter (cc) syringe with the tip cut off and the rubber plunger tip removed. The syringe was pushed into the sample to the point that 3 to 3.5 cc of soil was contained in the syringe. The soil core in the syringe was extruded directly into a 22-milliliter (mL) headspace vial, and 5.0 mL of distilled water was added immediately. The headspace vial was sealed with a crimp-top septum cap within 5 seconds of adding the organic-free water. The headspace vial was labeled according to the technology, the sample grid and cell from which the sample was collected, and the sampling depth. These data, along with the U.S. Department of Agriculture soil texture, were recorded on field data sheets. For each subsurface soil sample, two collocated samples were collected for analysis. The second sample was intended as a backup sample for reanalysis or in case a sample was accidentally opened or destroyed prior to analysis.

Samples from high-concentration sampling depths were also collected with disposable syringes as described above. Each 3 to 3.5 cc of soil was extruded directly into a 40-mL vial and capped with a Teflon<sup>TM</sup>-lined septum screw cap. Each vial contained 10 mL of pesticide-grade methanol. The 40-mL vials were labeled in the same manner as the low-concentration samples, and the sample number and the U.S. Department of Agriculture soil texture were recorded on field data sheets. For each soil sample, two collocated samples were collected.

To minimize VOC loss, samples were handled as efficiently and consistently as possible. Throughout the demonstration, sample handling was timed from the moment the soil sample was exposed to the atmosphere to the moment the sample vials were sealed. Sample handling times ranged from 40 to 60 seconds for headspace sampling and from 30 to 47 seconds for methanol flood sampling.



ESP JMC Environmentalist's Subsoil Probe Sampling Location

Ref. Reference Sampling Method Location

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

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Samples were analyzed for VOCs by combining automated headspace sampling with gas chromatography (GC) analysis according to the standard operating guidelines provided in the demonstration plan (PRC, 1997). The standard operating guideline incorporates the protocols presented in SW-846 Methods 5021, 8000, 8010, 8015, and 8021 from the EPA Office of Solid Waste and Emergency Response, "Test Methods for Evaluating Solid Waste" (EPA, 1986). The target VOCs for this demonstration were vinyl chloride, cis-1,2-DCE, 1,1,1-TCA, TCE, and PCE. However, during the demonstration, vinyl chloride was removed from the target compound list because of resolution problems caused by coelution of methanol.

To report the VOC data on a dry weight basis, samples were collected to measure soil moisture content. For each sampling depth, a sample weighing approximately 100 g was collected from one of the reference method subsurface soil samples. The moisture samples were collected from the soil core within 1 inch of the VOC sampling location using a disposable steel teaspoon.

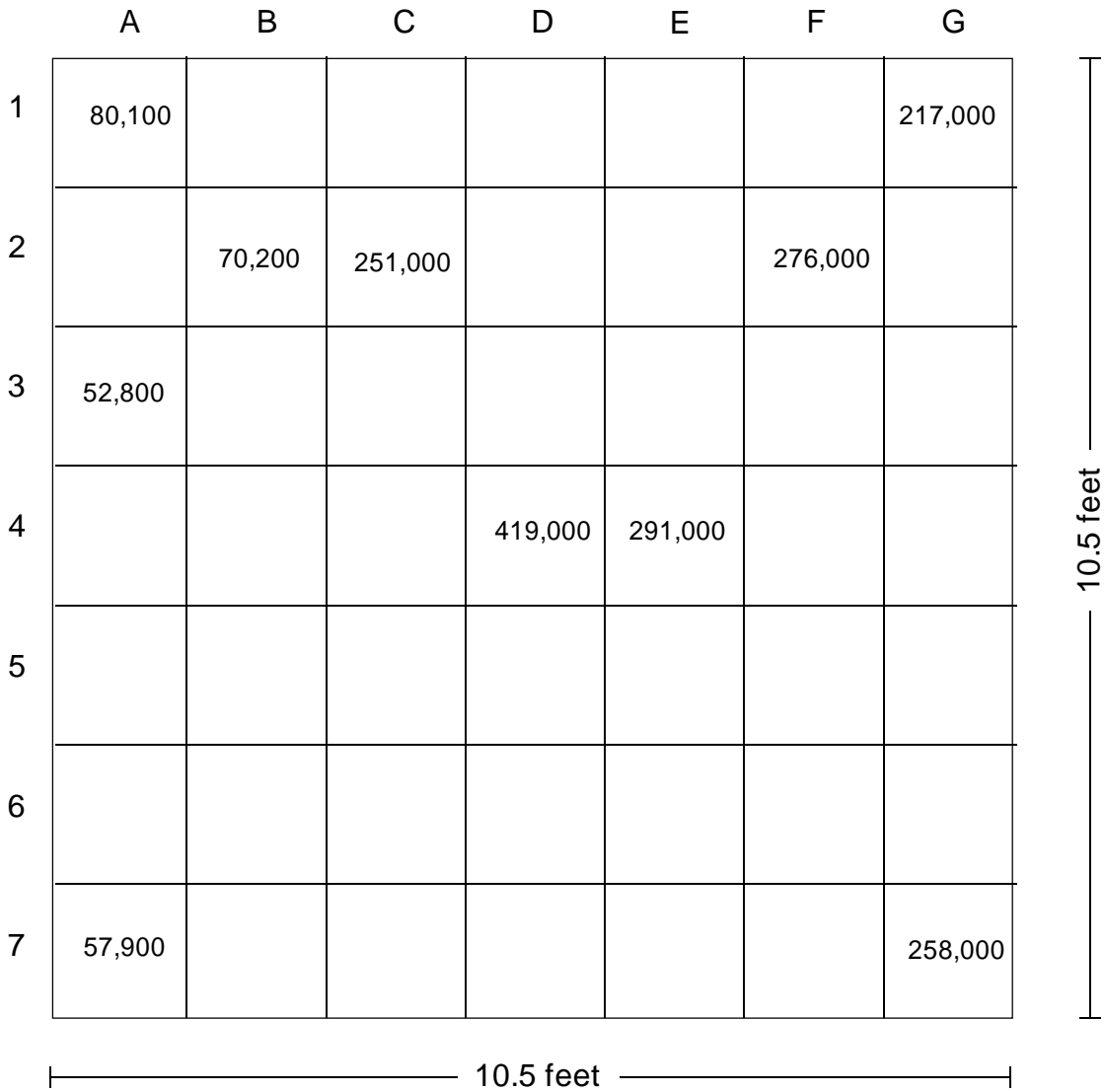
An F test for variance homogeneity was run on the VOC data to assess their suitability for parametric analysis. The data set variances failed the F test, indicating that parametric analysis was inappropriate for hypothesis testing. To illustrate this variability and heterogeneity of contaminant concentrations in soil, predemonstration and demonstration soil sample results (obtained using the reference sampling method for a grid depth combination with high variability and a grid depth combination with low variability) are provided as Figures 3-4 and 3-5, respectively.

Because the data set variance failed the F test, a nonparametric method, the Mann-Whitney test, was used for the statistical analysis. The Mann-Whitney statistic was chosen because (1) it is historically acceptable, (2) it is easy to apply to small data sets, (3) it requires no assumptions regarding normality, and (4) it assumes only that differences between two reported data values, in this case the reported chemical concentrations, can be determined. A description of the application of the Mann-Whitney test and the conditions under which it was used is presented in Appendix A1. A statistician should be consulted before applying the Mann-Whitney test to other data sets.

The Mann-Whitney statistical evaluation of the VOC concentration data was conducted based on the null hypothesis ( $H_0$ ) that there is no difference between the median contaminant concentrations obtained by the ESP and the reference sampling method. A two-tailed 95 percent confidence limit was used. The calculated two-tailed significance level for the null hypothesis thus becomes 5 percent ( $p \neq 0.05$ ). A two-tailed test was used because there is no reason to suspect *a priori* that one method would result in greater concentrations than the other.

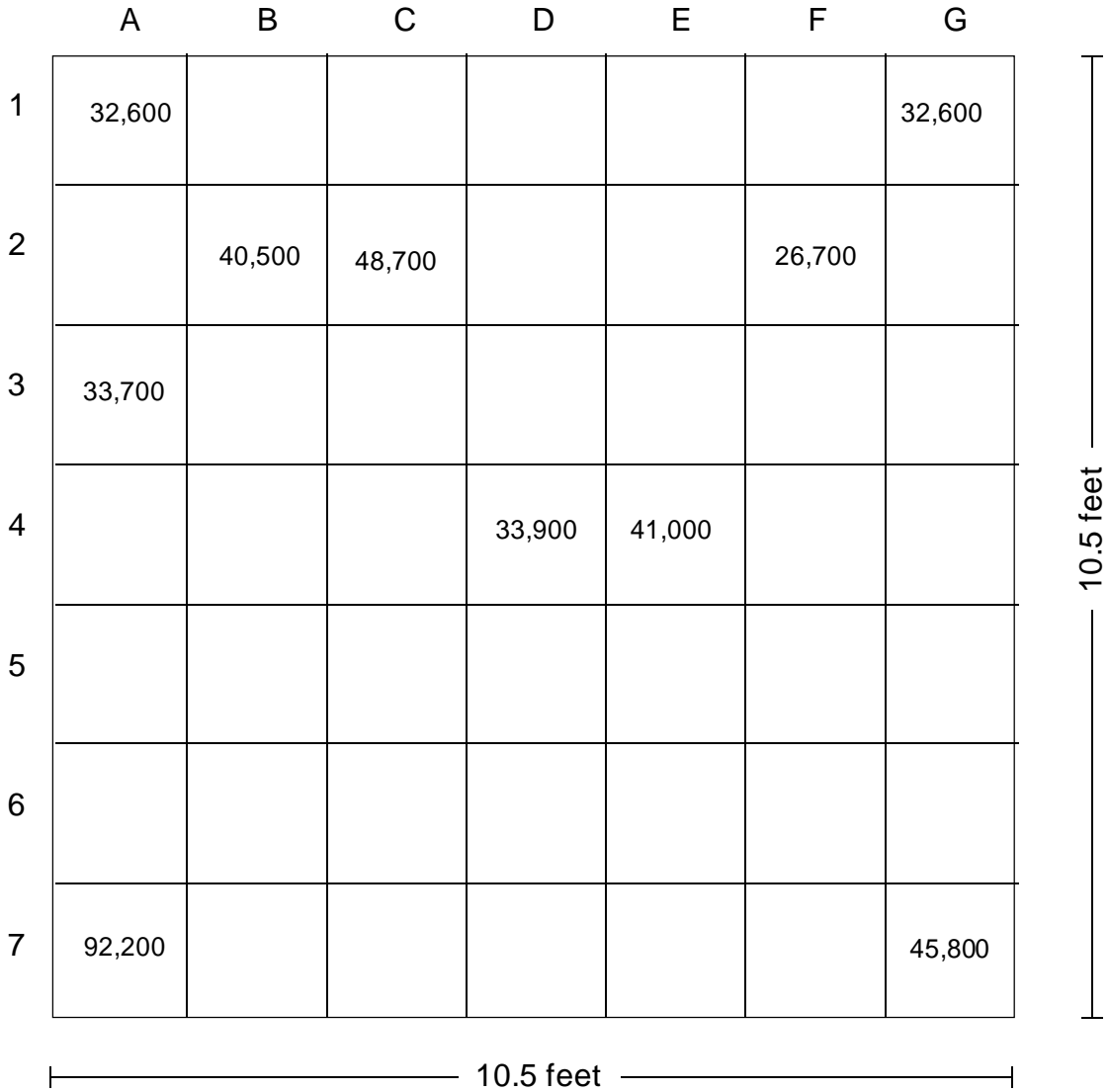
Specifically, the test evaluates the scenario wherein samples (soil samples, in this instance) would be drawn from a common universe with different sampling methods (reference versus ESP). If, in fact, the sampling universe is uniform and there is no sampling bias, the median value (median VOC concentration) for each data set should be statistically equivalent. Sampling, however, is random; therefore, the probability also exists that dissimilar values (particularly in small data sets) may be "withdrawn" even from an identical sampling universe. The 95 percent confidence limit used in this test was selected such that differences, should they be inferred statistically, should occur no more than 5 percent of the time.

Additionally, the sign test was used to examine the potential for sampling and analytical bias between the ESP and the reference sampling method. The sign test is nonparametric and counts the number of positive and negative signs among the differences. The differences tested, in this instance, were the differences in the median concentrations of paired data sets (within a site, within a grid, at a depth, and for each analyte). From the data sets, counts were taken of (1) the number of pairs in which the



Units - micrograms per kilogram

**Figure 3-4. Sampling Grid with High Contaminant Concentration Variability**



Units - micrograms per kilogram

**Figure 3-5. Sampling Grid with Low Contaminant Concentration Variability**

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reference sampling method median concentrations were higher than the ESP median concentrations and (2) the number of pairs in which the ESP median concentrations were higher than the reference sampling method median concentrations. The total number of pairs in which the median concentrations were higher for the ESP was then compared to the total number of pairs in which the median concentrations in the reference sampling method were higher. If no bias is present in the data sets, the probability of the total number of pairs for one or the other test method being higher is equivalent; that is, the probability of the number of pairs in which the median concentrations in the ESP are higher is equal to the probability of the number of pairs in which the median concentrations in the reference sampling method are higher. To determine the exact probability of the number of data sets in which the median concentrations in the ESP and reference sampling method were higher, a binomial expansion was used. If the calculated probability is less than 5 percent ( $p < 0.05$ ), then a significant difference is present between the ESP and reference sampling method.

The sign test was chosen because it (1) reduces sensitivity to random analysis error and matrix variabilities by using the median VOC concentration across each grid depth, (2) enlarges the sample sizes as compared to the Mann-Whitney test, and (3) is easy to use. A description of the application of the sign test and the conditions under which it was used is presented in Appendix A1.

For the demonstration data, certain VOCs were not detected in some, or all, of the samples in many data sets. There is no strict guidance regarding the appropriate number of values that must be reported within a data set to yield statistically valid results. For purposes of this demonstration, the maximum number of “nondetects” allowed within any given data set was arbitrarily set at three. That is, there must be at least four reported values within each data set to use the Mann-Whitney and sign tests.

### ***Sample Integrity***

The integrity tests were conducted by advancing a sampler filled with uncontaminated potting soil into a zone of grossly contaminated soil. The potting soil was analyzed prior to use and no target VOCs were detected. Potting soil has an organic carbon content many times greater than typical soils, 0.5 to 5 percent by weight (Bohn and George, 1979), representing a worst-case scenario for VOC absorbance. The integrity samples were advanced through a contaminated zone that was a minimum of 2 feet thick and exhibited VOC contamination in the tens of thousands of mg/kg. All of the integrity samples were packed to approximately the same density. The samplers filled with the uncontaminated potting soil were advanced 2 feet into the contaminated zone and left in place for approximately 2 minutes. The samplers were then withdrawn and the potting soil was sampled and analyzed for VOCs. In each case, the sampling team collected the potting soil samples for analysis from approximately the center of the potting soil core.

Seven integrity samples were collected with each sampling method at the SBA site, and five integrity samples were collected with each sampling method at the CSC site to determine if potting soil in a lined sampler became contaminated after it was advanced through a zone of high VOC concentrations. Sample liners were used for both the ESP and reference sampling method during collection of all the integrity samples. The integrity samples were collected from Grid 1 at both of the sites, because Grid 1 was the most contaminated grid at each site. The sample integrity data were used to directly indicate the potential for cross-contamination of the soil sample during sample collection.

### ***Reliability and Throughput***

Reliability was assessed by documenting the initial sampling success rate and the number of sampling attempts necessary to obtain an adequate sample from that depth. The cause of any failure of initial or subsequent sampling attempts was also documented. Throughput was assessed by examining sample

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retrieval time, which was measured as the time required to set up on a sampling point, collect the specified sample, grout the hole, decontaminate the sampler, and move to a new sampling location. In addition, a performance test was conducted in Grid 5 at the CSC site to evaluate the ability of the sampling methods to collect samples in saturated sandy material at a depth of 40 feet bgs.

### ***Cost***

The cost estimate focused on the range of costs for using the ESP and reference split-spoon sampler to collect 42 subsurface soil 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 results and experience gained from the demonstration and on cost information provided by Clements Associates, Inc. Factors that could affect the cost of operating the ESP and the reference split-spoon sampler include:

- C Equipment costs
- C Operating costs
- C Oversight costs
- C Disposal costs
- C Site restoration costs

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

Six project-wide deviations from the approved demonstration plan are described below: (1) the nonparametric Mann-Whitney test was used instead of ANOVA to determine whether there is a statistical difference between the VOC concentrations from the ESP and the reference sampling method; (2) the nonparametric sign test was used to assess potential bias between VOC concentrations determined from the ESP and the reference sampling method; (3) vinyl chloride was eliminated from the target compound list because of a coelution problem with methanol; (4) the drill rig, large tools, and augers were decontaminated between each grid instead of between each boring; (5) 24-inch split spoon samplers instead of 18-inch samplers were used and were driven 15 to 20 inches during sample collection; and (6) the split-spoon sampler was used with and without acetate liners. 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 (ESP) of this ETVR.



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## **Chapter 4**

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

This chapter describes the reference soil sampling method, including background information, components and accessories, platform description, demonstration operating procedures, qualitative performance factors, quantitative performance factors, and data quality. The reference method chosen for this demonstration was hollow-stem auger drilling and split-spoon sampling.

#### **Background**

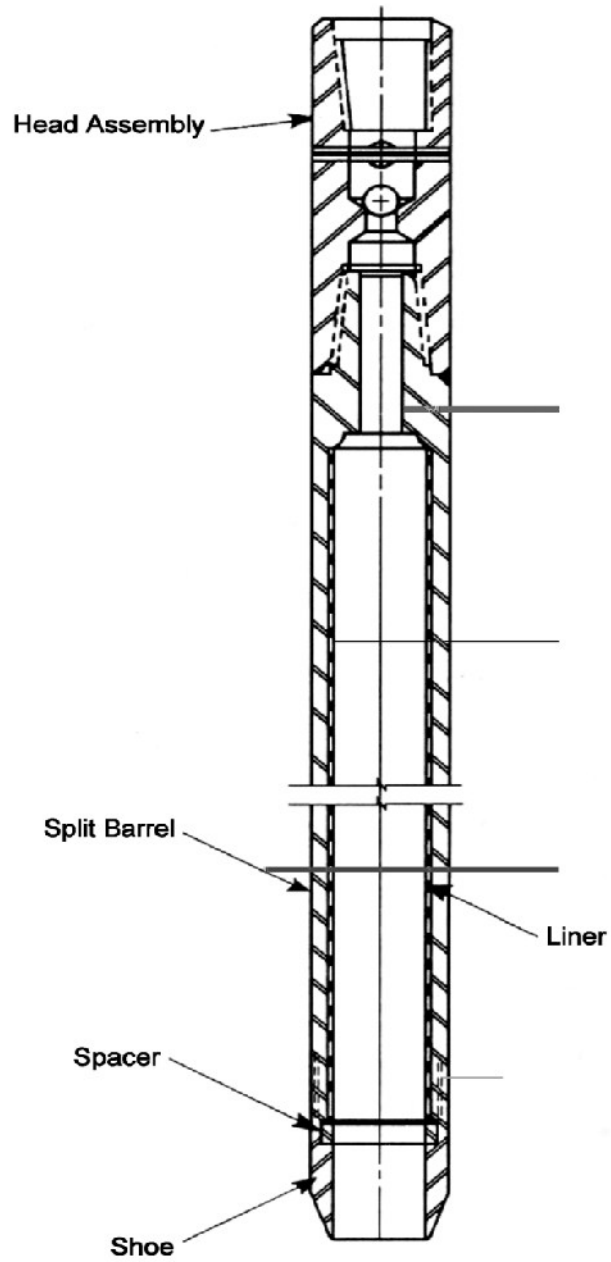
Several drilling methods have evolved to accommodate various stratigraphic conditions and the end use of the boring. Although there is no single preferred drilling method for all stratigraphic conditions and well installations, the hollow-stem auger method has become the most popular and widely used for environmental drilling and sampling. Hollow-stem augers have also been used extensively in the environmental field because soil samples can readily be collected and monitoring wells can easily be installed with this equipment (EPA, 1987). Use of hollow-stem augers as a method of drilling boreholes for soil investigations, installing groundwater monitoring wells, and completing other geotechnical work is widely accepted by federal, state, and local regulators. Because hollow-stem augers are the most commonly used drilling equipment for environmental applications, this method was selected as the reference drilling method for this demonstration.

#### **Components and Accessories**

The most common sampler used with hollow-stem augers for environmental applications is the split-spoon. The split-spoon sampler is a thick-walled steel tube that is split lengthwise (Figure 4-1). The split-spoon samplers used for this demonstration measured 24 inches long with an internal diameter of 2 inches and an external diameter of 2.5 inches. A cutting shoe is attached to the lower end, and the upper end contains a check valve and is connected to the drill rods. Split-spoon samplers are typically driven 18 to 24 inches beyond the auger head into the formation by a hammer drop system. The split-spoon sampler is used to collect a sample of material from the subsurface and to measure the resistance of the material to penetration by the sampler in the standard penetration test. The degree of soil compaction can be determined by counting the number of blows of the drop weight required to drive the split spoon a distance of 1 foot. A weight of 140 pounds and a height of fall of 30 inches are considered standard (Terzaghi and Peck, 1967).

#### **Description of Platform**

Hollow-stem augers are typically used with a truck- or trailer-mounted drill rig that is either mechanically or hydraulically powered. Trucks, vans, all-terrain vehicles, and crawler tractors are often used as the transport vehicle because of their easy mobilization. A variety of drill rig specifications are available based on the project-specific operation requirements and the anticipated geological conditions (EPA, 1987).



**Figure 4-1. Split-Spoon Soil Sampler (Central Mine Equipment Co., 1994)**

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Hollow-stem auger drilling is accomplished by using a series of interconnected auger sections with a cutting head at the lowest end. The hollow-stem auger consists of (1) a section of seamless steel tube with a spiral flight attached to a carbide-tooth auger head at the bottom and an adapter cap at the top, and (2) a center drill stem composed of drill rods attached to a center plug with a drag bit at the bottom and an adapter at the top. The center of the core of augers is open, but can be closed by the center plug attached to the bottom of the drill rods. As the hole is drilled, additional lengths of hollow-stem flights and center stem are added. The center stem and plug may be removed at any time during drilling to permit sampling below the bottom of the cutter head. Typical components of a hollow-stem auger are shown in Figure 4-2 (Central Mine Equipment Company [CME], 1994).

The dimensions of hollow-stem auger sections and the corresponding auger head used with each lead auger section are not standardized among the various auger manufacturers. Drilling at the SBA site was accomplished with a Mobile B-47 drill rig using 3.25-inch inside-diameter and 6.25-inch outside diameter CME hollow-stem augers. Drilling at the CSC site was accomplished with a Mobile D-5 and a Mobile B-47 drill rig using 3.25-inch inside-diameter and 6.25-inch outside-diameter CME hollow-stem augers. The Mobile B-47 used a pulley assembly to operate the hammer that drove the split-spoon samplers, and the Mobile D-5 used an automatic hydraulic hammer to drive the split-spoon samplers. The Mobile D-5 drill rig was used at the CSC site because the Mobile B-47 drill rig experienced mechanical problems en route to the CSC site, delaying its arrival at the site. The same drill crew operated both drill rigs; the use of the two drill rigs at the CSC site is not expected to affect the results of the demonstration.

### **Demonstration Operating Procedures**

To collect the samples for this demonstration, the hollow-stem augers were first rotated and advanced to 9 inches above the target sampling depth. As the augers were rotated and pressed downward, the cutting teeth on the auger head broke up the formation materials, and the cuttings were rotated up the continuous flights to the ground surface, where they were stored in drums as investigation-derived waste (IDW). At the point 9-inches above the sampling depth, the drill rods and the attached center plug were removed, and the split-spoon samplers were placed on the lower end of the drill rods and lowered through the hollow-stem augers to the bottom of the borehole. The split-spoon sampler was then driven approximately 18 inches to collect a soil sample, with the target sampling depth positioned in the center of the soil core. The loaded sampler and sampling rod were removed from the auger column. If a lower depth was to be sampled, the pilot assembly and center rod were reinserted.

During the demonstration, split-spoon samplers were used with and without acetate liners because formations that are weakly cohesive or hard commonly produce poor recovery with liners. Several boreholes were initially installed at each site to determine whether liners would be used, based on the driller's experience and the cohesiveness of the soil. Liners were used at SBA site Grid 1 and at half of the cells at Grid 3. Liners were also used for target sampling depths at half of the 3-foot depth intervals at CSC site Grid 1, and at the 7.5-foot sampling depth at Grid 3. Overall, sample liners were used during collection of about one-third of the reference method samples, including all samples collected to evaluate sample integrity.

Once a split-spoon sampler was retrieved from the borehole, the drive head and cutting shoe were loosened. If the sampler contained a liner, the liner was removed, capped, and taken directly to the sample preparation table for subsampling and sample packaging. If the split spoon did not contain a liner, the sampler was taken directly to the sample preparation table and opened for immediate subsampling and sample packaging.

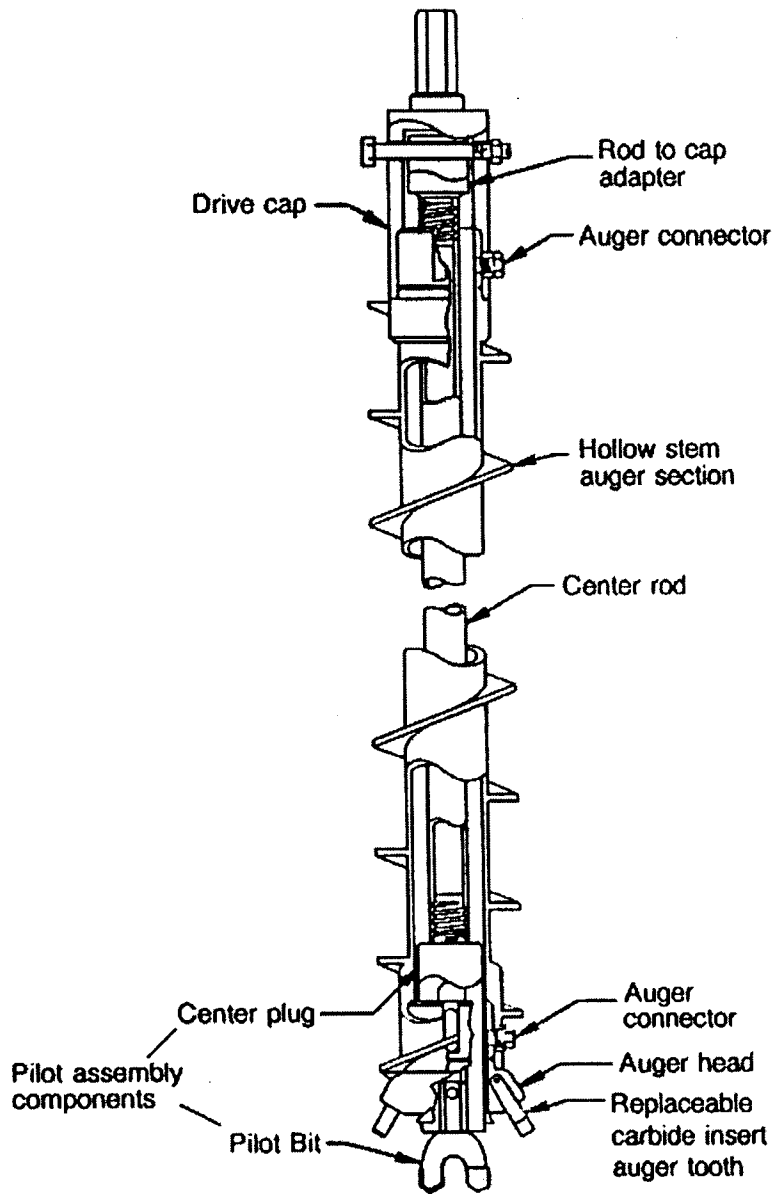


Figure 4-2. Typical Components of a Hollow-Stem Auger (Central Mine Equipment Co. 1994)

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Split-spoon samplers were decontaminated before each use by scrubbing the disassembled sampler parts with a stiff-bristle brush in a phosphate-free soap and water solution. This process was intended to remove the residual soil as well as chemical contaminants. After washing, the sampler parts were rinsed in potable water and reassembled for use at the next sampling point. Augers, larger tools, and the drill rig were decontaminated between each grid with a high-pressure hot water wash.

### **Qualitative Performance Factors**

The following qualitative performance factors were assessed for the reference sampling method: (1) reliability and ruggedness under the test conditions, (2) training requirements and ease of operation, (3) logistical requirements, (4) sample handling, (5) performance range, and (6) quantity of IDW generated during the demonstration.

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

Overall, the initial sampling success rate for the reference sampling method, defined as the rate of success in obtaining a sample on the initial attempt, was 93 percent. At the SBA site, the reference sampling method did not collect a sample on the initial drive in four of 42 attempts, resulting in an initial sampling success rate of 90 percent. At this site, two of the samples had insufficient recovery; one sample was not collected because drilling refusal was encountered above the target sampling depth, and one sample was not collected because the boring was drilled beyond the target sampling depth. At the CSC site, the reference sampling method did not collect a sample on the initial drive in two of 41 attempts, resulting in an initial sampling success rate of 95 percent. At this site, two samples were not collected because the borings were drilled beyond the target sampling depth. Drilling beyond the target depth is considered an operator error and was not caused by the sampling tool. Target sampling depths were determined by measuring the height of the auger above the ground surface, and subtracting the measured value from the total length of augers in use. During the saturated sand recovery test at Grid 5 at the CSC site, the reference method collected all seven samples on the initial try.

During the sampling at the SBA and CSC sites, the driller attempted sampling with and without sample liners to optimize soil sample recovery. In general, the greatest sample recovery was obtained without the use of liners.

Sampling downtime occurred three times during the demonstration. Each of these events occurred at the SBA site and are described as follows:

1. The main hydraulic cylinder on the drill rig began to leak at the start of drilling at Grid 5, resulting in the loss of less than 1 quart of hydraulic oil. The hose was repaired by a local farm implement dealer soon after it was removed from the rig. This breakdown resulted in approximately 2.5 hours of sampling downtime.
2. Drilling at Grid 5 was conducted with the mast down due to the proximity of overhead power lines. This arrangement prohibited the use of the drill rig winches to remove the augers and drill rod from the boring. While lifting out the center plug and attaching the drill rod, the rod fell back into the hole. The top of the fallen rod was well below the open end of the auger string. The drillers required approximately 10 minutes to retrieve the fallen drill rod.
3. During drilling at one sampling cell, material entered the auger bit and caused the center plug to jam. Drilling proceeded to the target depth, but the drillers required several minutes to free the center plug.

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As discussed above, the Mobile B-47 drill rig experienced mechanical problems en route to the CSC site, delaying its arrival at the site. Because of this delay, a Mobile D-5 drill rig was obtained from a local drilling company and was used to advance soil borings and collect soil samples until the Mobile B-47 arrived. Although drilling startup was delayed a half day because of the last-minute change in drill rigs, no sampling downtime occurred during drilling and no additional drilling costs were incurred.

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

Operation of the drill rig requires training and experience. The lead driller for this project had 17 years of environmental drilling experience and was a licensed driller in the states of Iowa and Colorado. Although the various drill rig manufacturers offer training in specific drilling techniques, much of a driller's training is obtained on the job, in a fashion similar to an apprenticeship. The state licenses require the driller to pass a written test and to renew the drilling license periodically.

The moving parts of a drill rig pose a risk of injury to the head, eyes, and feet, which can be protected with hard hat, safety glasses, and steel-toed boots. Leather gloves facilitate the safe assembly and disassembly of the split-spoon sampler. Additional personal protective equipment may be required in accordance with site-specific health and safety requirements.

### ***Logistical Requirements***

Some states require licenses for personnel conducting subsurface sampling. The sampler or equipment operator must contact appropriate state or local agencies to determine the applicability of any license or permit requirements. Additionally, underground utility clearances are usually needed before sampling with any intrusive subsurface equipment.

The augers created 6.25-inch-diameter boreholes, which were filled using neat-Portland cement grout at the SBA site and dry granular bentonite at the CSC site. Demonstration drilling generated 15 drums of soil cuttings at the SBA site and three drums of soil cuttings at the CSC site.

The drill rigs used in the demonstration were powered by an on-board engine and needed no external power source (other than fuel). Decontamination water can be carried on the truck, but a support truck with a 250-gallon tank was used to transport, store, and provide water for decontamination for the demonstration. Small tools and split-spoon samplers were decontaminated in a steel stock tank, while augers and drill rods were decontaminated in an on-site decontamination containment area with a high-pressure hot water washer.

### ***Sample Handling***

During the demonstration, liners were not used in the collection of approximately two-thirds of the split-spoon samples. This method allowed easy access to the sample by removing the drive head and cutting shoe and separating the two halves of the sampler. Liners were used in noncohesive soils because opening the split spoon without a liner would have allowed the sample core to collapse and disrupt sample integrity. After the liner was removed from the split spoon, it was capped and taken immediately to the sample packaging area for processing. Prior to sampling, the liner was split open to allow access to the soil for subsampling.

### ***Performance Range***

The depth limitations of the reference method are based on the torque provided by the drill rig, the strength of the augers, the diameter of the augers, and the textures of the formations penetrated.

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During the demonstration, samples were collected from a maximum depth of 40 feet bgs in Grid 5 at the CSC site. However, depths of 300 feet or more have been drilled with high-torque drill rigs using high-strength augers. This drilling and sampling method is inappropriate for unconsolidated formations containing large cobbles or boulders. In addition, the use of this method below the water table in sandy, noncohesive formations generally leads to sand heave into the augers, making borehole advancement and sampling difficult.

### ***Investigation-Derived Waste***

The IDW for the reference method primarily consisted of decontamination fluids and soil cuttings. Approximately 100 gallons of decontamination wastewater was generated at the SBA site, and approximately 50 gallons of decontamination wastewater was generated at the CSC site.

Soil cuttings were also generated during advancement of the boreholes. Eighteen 55-gallon drums of soil cuttings were generated during this demonstration: three at the CSC site and 15 at the SBA site. Fewer drums were generated at the CSC site due to the shallower sampling depths and the noncohesive nature of the soil. Reverse rotation during auger withdrawal allowed most of the sand to travel down the auger flights and back into the borehole at the CSC site. In addition to decontamination fluids and soil cuttings, sample liners and other materials were generated as IDW.

### **Quantitative Performance Factors**

The following quantitative performance indicators were measured for the reference sampling method: (1) sample recovery, (2) VOC concentrations in recovered samples, (3) sample integrity, and (4) sample throughput.

#### ***Sample Recovery***

Sample recoveries were calculated by comparing the length of sampler advancement to the length of sample core obtained for each attempt. Sample recovery is defined as the length of recovered sample core divided by the length of sampler advancement and is expressed as a percentage. At the SBA site, sample recoveries ranged from 40 percent to 100 percent, with an average of 88 percent. At the CSC site, recoveries ranged from 53 percent to 100 percent, with an average of 87 percent. Sample recovery data for each sample collected are summarized in Appendix A2, Table A2.

#### ***Volatile Organic Compound Concentrations***

Samples were collected using the reference sampling method at each sampling depth, as described in Chapter 3. Samples were analyzed for VOCs by combining headspace sampling with GC analysis according to the standard operating procedure (SOP) provided in the demonstration plan (PRC, 1997). Table 4-1 presents the range and median VOC concentrations for samples collected using the reference sampling method. The VOC results for each sample collected are summarized in Appendix A3, Table A3. For seven of the 12 sampling grid-depth combinations, VOC data for some samples collected are not available due to laboratory error; in these cases, the range and median were calculated from the remaining sample data.

Data are reported on a dry-weight basis. Chapter 5 presents a statistical comparison of the analytical results obtained using the reference sampling method to those obtained using the ESP.

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

		Concentration (F g/kg)							
Site	Grid - Depth	cis-1,2-DCE		1,1,1-TCA		TCE		PCE	
		Range	Median	Range	Median	Range	Median	Range	Median
SBA	1 - 9.5 feet	49,700 - 147,000	86,700	< 100	NC	52,800 - 419,000	276,000	< 100 - 4,510	1,630
SBA	1 - 13.5 feet	1,360 - 44,900	14,500	< 100	NC	26,700 - 433,000	40,500	< 100 - 2,400	NC
SBA	2 - 3.5 feet	< 1 - 2.18	NC	< 1	NC	22.6 - 88.8	56.9	< 1	NC
SBA	3 - 9.5 feet*	796 - 1,460	903	< 100	NC	34,100 - 63,700	38,500	< 100	NC
SBA	4 - 9.5 feet	6.68 - 22.1	13.2	< 1	NC	847 - 2,080	1,710	< 1	NC
SBA	5 - 13.5 feet†	33.7 - 147	93.6	< 1	NC	< 1 - 138	21.0	< 1	NC
CSC	1 - 3.0 feet†	< 100	NC	< 100 - 659	NC	< 100	NC	1,880 - 6,220	2,530
CSC	1 - 6.5 feet†	< 1 - 5.81	2.20	13.1 - 54.6	26.0	3.47 - 22.4	6.45	58.5 - 848	112
CSC	2 - 3.0 feet	< 100	NC	< 100 - 984	NC	< 100 - 435	126	1,560 - 2,910	2,000
CSC	3 - 3.0 feet†	< 100	NC	< 100 - 313	NC	< 100	NC	1,030 - 2,110	1,480
CSC	3 - 7.5 feet*	< 1 - 7.35	4.12	3.81 - 21.9	13.9	2.48 - 31.7	14.9	21.1 - 177	73.0
CSC	4 - 6.5 feet††	< 1 - 5.72	NC	< 1 - 51.4	8.09	< 1 - 43.3	2.37	5.55 - 749	50.3

Fg/kg Micrograms per kilogram  
 cis-1,2-DCE cis-1,2-Dichloroethene  
 1,1,1-TCA 1,1,1-Trichloroethane  
 CSC Chemical Sales Company site  
 \* VOC data for only four samples are available  
 † VOC data for only six samples are available  
 †† VOC data for only five samples are available  
 NC No median calculated because at least half the reported values were below the method detection limit.



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### ***Sample Integrity***

Seven integrity samples were collected using the reference sampling method in Grid 1 at the SBA site, and five integrity samples were collected using the reference sampling method in Grid 1 at the CSC site. No VOCs were detected in any of the integrity samples collected using the reference sampling method (the method detection limit for these analyses was 1 Fg/kg). Sample liners were used during collection of the integrity samples at both the SBA and CSC sites, but liners were not used in collecting approximately two-thirds of the soil samples collected during the demonstration. Because of this sampling deviation, the integrity of all samples collected using the reference method cannot be verified.

### ***Sample Throughput***

The average sample retrieval time for the reference sampling method was 26 minutes per sample for the SBA site and 8.4 minutes per sample for the CSC site. Sample retrieval time was measured as the amount of time required per sample to set up at a sampling point, collect the specified sample, grout the hole, decontaminate the sampling equipment, and move to a new sampling location. A three-person sampling crew collected soil samples using the reference sampling method at both sites. One additional person was present at the CSC site to direct drilling operations and assist with demonstration sampling, as necessary. The large discrepancy in the sample retrieval time between the SBA and CSC sites is due, in part, to the difference in average sampling depth (10 feet at the SBA site versus 5 feet at the CSC site) and soil type (clay versus sandy soil).

### ***Data Quality***

Data quality 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 this demonstration for both the reference sampling method and ESP are provided in the technology evaluation report for this demonstration (Tetra Tech, 1997) and are summarized here.

The VOC data quality was assessed through the incorporation of QC samples into the analytical process for each sample delivery group, and through a full data validation review on 20 percent of the samples. Specific QC samples that were processed to assess precision and accuracy included matrix spike/matrix spike duplicates (MS/MSDs), laboratory control samples (LCSs), and method blanks. Additionally, surrogate spikes were used in all samples.

The LCSs and matrix spikes were analyzed at frequencies of 8.3 percent and 3.9 percent, respectively. With few exceptions, the QA objective of 50 to 150 percent recovery was met for LCS and MS samples, indicating that acceptable accuracy was achieved. The few exceptions to meeting this objective were primarily for vinyl chloride; these exceptions are attributable to the high volatility of vinyl chloride and apparently result from its vaporization during the analytical process. Surrogate spike recoveries were also used to evaluate accuracy. Surrogate recoveries were problematic for the methanol flood method for high-concentration samples, indicating a reduced accuracy for these samples. Surrogate recoveries were consistently within the QA objective of 50 percent to 150 percent recovery for low-concentration samples.

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Seventeen MS/MSD pairs, representing a 3.6 percent frequency, were analyzed to assess the precision of the analytical method. The relative percent differences of the duplicate results were consistently less than the QA objective of 50 percent; only a few exceptions were noted. Thus, method precision appeared to be adequate for the intended use of the data.

Analysis of method blanks revealed only occasional contamination with low part-per-billion levels of chlorinated hydrocarbons. The frequency and levels of these contaminants were not judged to be sufficient to significantly affect data quality except for those results at or near the detection limit in the specific sample delivery group.

The data validation review noted chromatographic separation and coelution problems for vinyl chloride. As a result, all vinyl chloride data were rejected. Other analytes were flagged as having data quality problems in isolated instances and in response to specific exceptions to the QA objectives, as described generally above. Details of these and all other data quality issues can be found in the technology evaluation report for this demonstration (Tetra Tech, 1997).

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## **Chapter 5**

### **Technology Performance**

This chapter describes the performance of the Clements Associates, Inc. ESP and assesses qualitative and quantitative performance factors. A description of the ESP is provided in Chapter 2 of this ETVR.

#### **Qualitative Performance Factors**

The following qualitative performance factors were assessed for the ESP: (1) reliability and ruggedness under the test conditions, (2) training requirements and ease of operation, (3) logistical requirements, (4) sample handling, (5) performance range, and (6) quantity of IDW generated.

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

Overall, the initial sampling success rate for the ESP, defined as the ratio of the number of successful sampling attempts (sample obtained on the initial attempt) to the total number of sampling attempts, was 100 percent. All ESP parts assembled with ease, and no parts failed during the demonstration. The field observer noted that several features of the ESP were conducive to reliable operation, including (1) simple design, (2) capability for manual operation, (3) adaptability to varying field conditions, and (4) the relatively low stress exerted by the drive hammers on the ESP. All planned grids and target depth intervals were sampled at the CSC site. Collection of saturated soil samples using the ESP at 40 feet bgs in Grid 5 at the CSC site was not attempted because the sample depth was beyond the ESP's performance range. Two target zones (the 13.5-foot depth zones at Grids 1 and 5) were not sampled at the SBA site due to the ESP developer's absence on several days during the demonstration; however, there was no sampling downtime or omission of planned samples due to equipment failure.

The ESP advanced easily through surficial soils, and easily penetrated a hard-packed gravel surface on Grid 5 at the SBA site. The system's penetration is likely a result of the narrow diameter and resulting low surface area, which reduces friction on the tools. The ESP sampler was not advanced through the asphalt at Grid 1 of the CSC site. An opening was made in the surface by a powered direct-push technology. Typically, an electric rotary hammer with a carbide bit is used by the ESP operator to penetrate asphalt. The ESP advanced more easily when fitted with the cutting tips, as opposed to the solid drive point.

The only problems encountered with the ESP during the demonstration involved the extensions. At the SBA site, a loose cross pin made it difficult to retrieve the tool string from one hole, and nearly caused the loss of several rods down the hole. However, this problem was eliminated by using electrical tape to secure the pins on subsequent holes. A bulging cross pin also caused the tools to catch on the jack on several occasions, resulting in minor delays.

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

The ESP requires no specialized training. The instruction manual contains all information required to operate the ESP, and approximately 1 hour of hands-on training allows a user to become proficient in assembling and using the ESP. To learn the assembly procedure, the sampling team should assemble the ESP two to three times. Basic knowledge and understanding of the subsurface conditions prior to attempting sample collection is helpful, as knowledge of the depth to water will allow the operator to know when to select the wet cutting tip to retain the maximum sample volume. Removal of the sampling tube from an assembled tool string may be awkward until the operator gains experience.

If the electric hammer is used, the operator should be familiar with proper setup and operation of generators. The manual slide hammer is moderately labor intensive, requiring repeated lifting of the hammer; however, extra downward effort is not required to effectively drive the sampler. Driving the tool straight into the subsurface and keeping the foot plate level are critical to smooth advancement and retrieval of the ESP and require minor practice for a novice operator to develop proper techniques.

The ESP has relatively few moving parts, and therefore does not require extensive health and safety precautions. The operator's head, eyes, and feet should be protected with a hard hat, safety glasses, and steel-toed boots. Leather gloves facilitate assembly and disassembly of the ESP. Additional personal protective equipment may be required in accordance with site-specific health and safety requirements for each site.

### ***Logistical Requirements***

The ESP may be operated by one person. During the demonstration, the system was tested using a single operator at some grids and using an operator and assistant at others. When an assistant was used, this person assisted with jacking, assembling samplers and extensions, decontamination, and tending to the generator while the electric hammer was in use. Use of an assistant was found to improve sample throughput.

Some states require licenses for personnel conducting subsurface sampling. The sampler or equipment operator must contact the appropriate state or local agencies to assess the applicability of any license or permit requirements. Additionally, underground utility clearances are needed before sampling with any intrusive subsurface equipment.

When the manual slide hammer is used to advance the ESP, no external power source is necessary. The electric hammer requires a 1,450-watt-minimum on-site power supply or portable generator. Only a limited amount of water (typically less than 10 gallons per day) and a containment area were necessary for adequate sampler decontamination.

The ESP does not use an auxiliary powered platform; for this reason, the physical impact of demonstration sampling on the site was negligible. The ESP left approximately 1.25-inch-diameter holes, which were backfilled with dry granular bentonite. No drill cuttings were generated during advancement of the ESP.

### ***Sample Handling***

During the demonstration, the ESP sample liner was retrieved either by sliding it out of the sample tube assembly using gravity or by gently pushing the liner out with a clean liner or dowel rod. The gravity technique appeared to disturb the sample and was less preferable. After an ESP sample liner was retrieved, the ends were immediately capped to preserve VOCs and it was immediately taken to the

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sample packaging area for processing. To minimize volatilization, the sample liners were capped and were not opened until subsampling. Razor blades were used to open the liners when preparing subsamples; however, it is also possible to remove the entire sample from the tube by pushing it out with a dowel rod.

### ***Performance Range***

The ESP successfully advanced through and retained representative samples of the clay soils at the SBA site and the sandy soils at the CSC site, indicating that the sampler functions in a variety of subsurface materials. The ESP is not designed for use in soils containing coarse gravel, rock fragments, or cobbles, and will generally not sample particles with a diameter greater than 0.5-inch.

The maximum operating depth of the ESP sampling system is limited by the advancement platform, which allows only manual or electric-hammer drive techniques, and the soil type. The developer claims that the ESP is generally limited to a depth of 20 feet bgs. The greatest depth from which samples were collected at the SBA site was 9.5 feet bgs, and field observers noted no significant changes in the ESP's performance with regard to sample recovery and integrity over the range of depths sampled. For this reason, the lower depth performance limit for clay soils was not determined. The greatest depth of sample collection at the CSC site was 7.5 feet bgs. Although not required by the demonstration plan, at the CSC site the developer advanced the sampler (equipped with the solid drive point) to 27 feet bgs and 30 feet bgs in two consecutive borings to test the ESP's performance limits. The manual slide hammer was used to advance these borings as the Bosch™ electric hammer would not drive the ESP beyond 20 feet bgs. A sample was successfully retrieved from the 30-foot hole; however, the ESP was not fully driven past the bottom of the 27-foot hole due to excessive resistance, and a representative sample was not obtained. Based on these observations, the ESP's lower depth limit for sandy soils appears to be in the range of 20 to 30 feet. Because of the ESP's depth limitation, collection of saturated soil samples at the CSC site from Grid 5 at 40 feet bgs was not attempted.

### ***Investigation-Derived Waste***

Minimal IDW was generated by the ESP during the demonstration. The solid drive point used while advancing the ESP displaces soil outward, and does not transport cuttings to the ground surface. The only soil waste created was that remaining in the sampler after the demonstration sample was collected for chemical analysis. The total amount of this material generated during the demonstration at both sites was less than 6 gallons (less than 1 cubic foot), weighing about 35 pounds.

Approximately 5 gallons of wastewater was generated by the decontamination activities at the SBA site. Most of this water was generated during decontamination at Grid 1, where the sampler passed through a clay layer saturated with oily product. Decontamination at the CSC site generated less than 1 gallon of wastewater. The total quantities of water used at each site were sufficient to decontaminate all sampler components for an 8-hour sampling period.

Table 5-1 presents a comparison of the IDW generated by the ESP and by the reference sampling method during this demonstration.

### **Quantitative Performance Assessment**

Quantitative measures of the ESP's performance consisted of (1) sample recovery, (2) volatile organic compound concentrations in recovered samples, (3) sample integrity, and (4) sample throughput.

**Table 5-1. Investigation-Derived Waste Generated During the Demonstration**

<b>Sampler</b>	<b>Sampling Platform</b>	<b>Soil Generated</b>	<b>Wastewater Generated</b>
ESP	Push (hammer)	Less than 6 gallons	Less than 6 gallons
Reference Sampler	Drilling	990 gallons	150 gallons

**Sample Recovery**

Sample recoveries for the ESP were calculated by comparing the length of sampler advancement to the length of sample core obtained for each attempt. Sample recovery is defined as the length of recovered sample core divided by the length of sampler advancement and is expressed as a percentage. At the SBA site, sample recoveries ranged from 42 percent to 100 percent with an average of 96 percent. At the CSC site, the recoveries ranged from 72 percent to 100 percent with an average of 95 percent. Sample recovery data for each sample collected are summarized in Appendix A2, Table A2.

Average sample recoveries for the ESP were greater at the SBA site because the clay soils helped to hold the soil in the sampler. Filling the sampler and holding the less-cohesive, sandy soils at the CSC site were more difficult.

Table 5-2 presents a comparison of sample recoveries achieved by the ESP and the reference sampling method during this demonstration. The recovery data indicate that on average for both types of soil sampled (clay soil at the SBA site and sandy soil at the CSC site) the ESP retained a greater portion of the sampled material than the reference sampler.

**Table 5-2. Sample Recoveries for the ESP and the Reference Sampling Method**

<b>Sampler</b>	<b>Site</b>	<b>Sample Recovery (percent)</b>	
		<b>Range</b>	<b>Average</b>
ESP	SBA	42 to 100	96
Reference Sampler	SBA	40 to 100	88
ESP	CSC	72 to 100	95
Reference Sampler	CSC	53 to 100	87

It is possible that the greater sample recovery achieved by the ESP is due to the narrow core guide, the smaller diameter of the sample tube (in comparison to the split spoon), the relatively smooth, nonpercussive jacking technique used to remove the ESP, or a combination of these factors.

**Volatile Organic Compound Concentrations**

Samples were collected with the ESP at each sampling grid-depth combination as described in Chapter 3 with the exception of two grid-depth combinations at the SBA site (13.5-foot depth zones at Grids 1 and 5). Samples were analyzed for VOCs by combining headspace sampling with gas chromatography

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analysis according to the SOP provided in the demonstration plan (PRC, 1997). Table 5-3 presents the range and median VOC concentrations for samples collected using the ESP. Data are reported on a dry-weight basis. For five of the 10 sampling grid-depth combinations, VOC data for some samples collected are unavailable due to laboratory error; in these cases, the range and median were calculated from the remaining sample data. A summary of the number of samples collected and analyzed for each analyte at each site is presented in Table 5-4.

As described in Chapter 3, two statistical evaluations of the VOC concentration data were conducted: one using the Mann-Whitney test and the other using the sign test. Table 5-4 lists the number of analyte values used in the statistical evaluations. For the Mann-Whitney test, a statistical evaluation of the VOC concentration data was conducted based on the null hypothesis that there is no difference between the median contaminant concentrations obtained by the ESP and the reference sampling method described in Chapter 4. In addition, statistical evaluations using the Mann-Whitney and sign tests were conducted only when at least half of the reported values for the grid, depth, and analyte combination were above the method detection limit.

The two-tailed significance level for this null hypothesis was set at 5 percent (2.5 percent for one-tailed); that is, if a two-tailed statistical analysis indicates a probability of greater than 5 percent that there is no significant difference between data sets, then it is concluded that there is no significant difference between the data sets. Because the data are not normally distributed, the Mann-Whitney test, a nonparametric method, was used to test the statistical hypothesis for VOC concentrations. The Mann-Whitney test makes no assumptions regarding normality and assumes only that the differences between the medians of two independent random samples may be determined—in this case, the reported chemical concentrations of soils collected by two different sampling systems. The Mann-Whitney test was used because of its historical acceptability and ease of application to small data sets.

Table 5-5 lists the median VOC concentrations calculated from data for samples collected with the ESP and the reference sampling method. The table also indicates whether there is a significant difference ( $p \neq 0.05$ ) in VOC data sets for each sampling grid and depth for each analyte based on the Mann-Whitney test. A comparative summary of the Mann-Whitney statistics for the ESP and reference sampling method is presented in Appendix A4, Table A4. A total of 40 grid, depth, and analyte combination pairs were collected during the demonstration. Of the 40 pairs, only 18 data sets were obtained: seven from the SBA site and 11 from the CSC site. A statistical comparison could not be made for the remaining data sets because at least half of the reported values from the ESP or reference sampling method were below the method detection limit. According to the Mann-Whitney test, there is a statistically significant difference in the data sets collected using the ESP and the reference sampling method in two of 18 cases. One of the sampling pairs where the statistically significant difference was identified was at the SBA site; the other was at the CSC site. The statistically significant difference at the SBA site involved data collected from Grid 2 at the 3.5-foot sampling depth for the analyte TCE. The statistically significant difference at the CSC site involved data collected from Grid 2 at the 3.0-foot sampling depth for the analyte PCE. Figure 5-1 presents a graphic representation of the median VOC concentrations of the ESP versus the median VOC concentrations of the reference sampling method for each contaminant at each depth.

To test potential bias between the data sets, a statistical analysis using the sign test was conducted. As discussed in Chapter 3, the sign test is a nonparametric statistical method that counts the number of positive and negative signs among the differences. The differences tested, in this instance, were the differences in the medians of paired data sets (within a site, within a grid, at a depth, and for each analyte). From the data sets, counts were made of (1) the number of pairs in which the reference sampling method median concentrations were higher than the ESP median concentrations and (2) the number of pairs in which the ESP median concentrations were higher than the reference sampling

**Table 5-3. Volatile Organic Compound Concentrations in Samples Collected Using the ESP**

		Concentration (F g/kg)							
Site	Grid - Depth	cis-1,2-DCE		1,1,1-TCA		TCE		PCE	
		Range	Median	Range	Median	Range	Median	Range	Median
SBA	1 - 9.5 feet*	22,300 - 182,000	65,800	< 100	NC	53,800 - 551,000	78,900	< 100 - 3,620	570
SBA	2 - 3.5 feet	< 1 - 4.34	NC	< 1	NC	37.4 - 328	143	< 1	NC
SBA	3 - 9.5 feet	344 - 1,540	891	< 100	NC	13,200 - 49,200	26,300	< 100 - 138	NC
SBA	4 - 9.5 feet	7.44 - 16.4	9.63	< 1	NC	837 - 2,190	1,230	< 1	NC
CSC	1 - 3.0 feet†	< 100	NC	< 100 - 440	NC	< 100	NC	3,580 - 4,500	4,320
CSC	1 - 6.5 feet	< 1 - 7.70	5.29	20.2 - 80.1	38.8	< 1 - 23.5	11.7	113 - 840	294
CSC	2 - 3.0 feet**	< 100	NC	< 100	NC	< 100	NC	376 - 1,080	454
CSC	3 - 3.0 feet	< 100	NC	< 100	NC	< 100	NC	473 - 1,590	1,020
CSC	3 - 7.5 feet††	< 1 - 5.85	NC	6.44 - 43.0	9.77	4.59 - 32.8	7.97	33.6 - 191	73.9
CSC	4 - 6.5 feet**	< 1 - 4.11	NC	11.6 - 28.4	16.0	3.56 - 10.7	5.62	48.7 - 166	126

Fg/kg	Micrograms per kilogram	PCE	Tetrachloroethene
cis-1,2-DCE	cis-1,2-Dichloroethene	SBA	Small Business Administration site
1,1,1-TCA	1,1,1-Trichloroethane	TCE	Trichloroethene
CSC	Chemical Sales Company site	†	VOC data are available for only three samples
*	VOC data are available for only five samples	††	VOC data are available for only six samples
NC	No median calculated because at least half the reported values were below the method detection limit.		



**Table 5-4. Demonstration Data Summary for the ESP and Reference Sampling Method**

Site	Grid	Depth (feet)	Number of Samples Analyzed	Number of Data Points Above the Method Detection Limit				
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE	
<b>SBA</b>	<b>ESP</b>							
	1	9.5	5	5	0	5	3	
	2	3.5	7	3	0	7	0	
	3	9.5	7	7	0	7	1	
	4	9.5	7	7	0	7	0	
	<b>Reference Sampling Method</b>							
	1	9.5	7	7	0	7	6	
	1	13.5	7	7	0	7	1	
	2	3.5	7	1	0	7	0	
	3	9.5	4	4	0	4	0	
	4	9.5	7	7	0	7	0	
	5	13.5	6	6	0	5	0	
	<b>CSC</b>	<b>ESP</b>						
		1	3.0	3	0	1	0	3
1		6.5	7	5	7	6	7	
2		3.0	4	0	0	0	4	
3		3.0	7	0	0	0	7	
3		7.5	6	2	6	6	6	
4		6.5	4	1	4	4	4	
<b>Reference Sampling Method</b>								
1		3.0	6	0	3	0	6	
1		6.5	6	4	6	6	6	
2		3.0	7	0	3	4	7	
3		3.0	6	0	1	0	6	
3		7.5	4	3	4	4	4	
4		6.5	5	2	4	3	5	

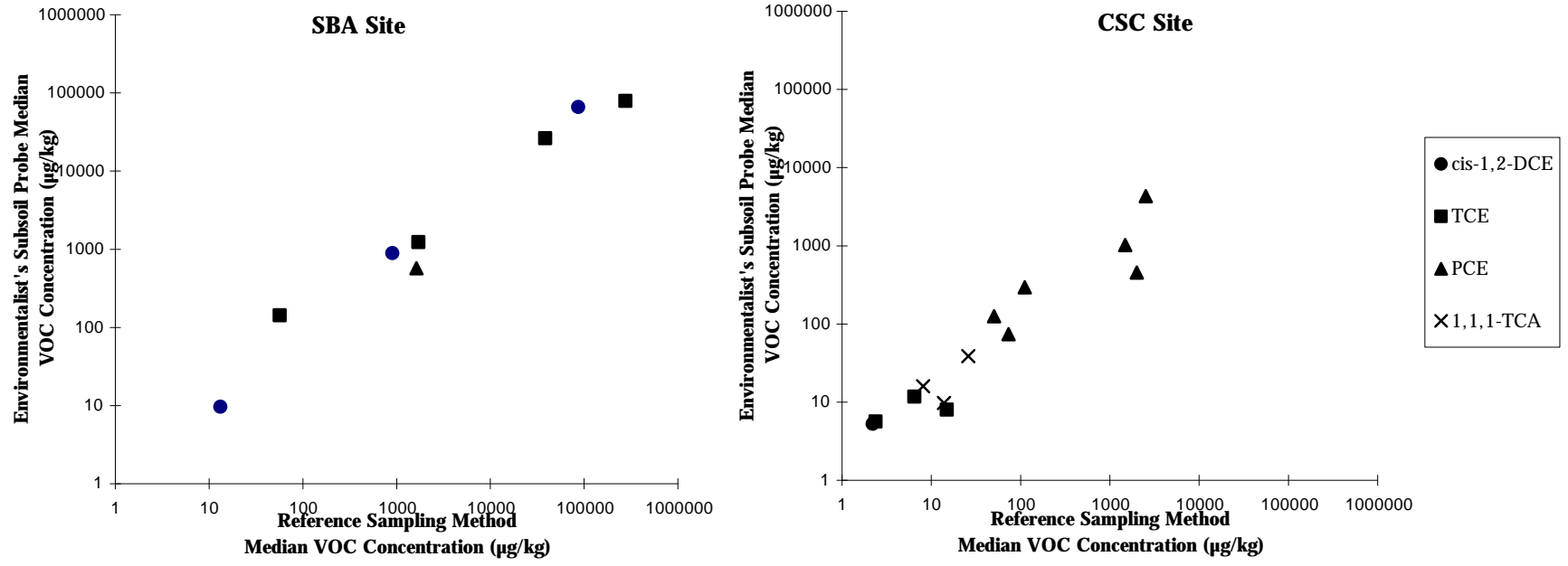
Note: Medians were not calculated for data sets when at least half of the reported values within the data set were below the method detection limit.

**Table 5-5. Comparison of Median Volatile Organic Compound Concentrations of ESP and Reference Sampler Data and Statistical Significance**

Median Concentration (F g/kg) and Significance													
Site	Grid & Depth	cis-1,2-DCE			1,1,1-TCA			TCE			PCE		
		ESP	Ref.	Sign.	ESP	Ref.	Sign.	ESP	Ref.	Sign.	ESP	Ref.	Sign.
SBA	1 - 9.5 feet	65,800	86,700	No	NC	NC	*	78,900	276,000	No	570	1,630	*
SBA	2 - 3.5 feet	NC	NC	*	NC	NC	*	143	56.9	Yes	NC	NC	*
SBA	3 - 9.5 feet	891	903	No	NC	NC	*	26,300	38,500	No	NC	NC	*
SBA	4 - 9.5 feet	9.63	13.2	No	NC	NC	*	1,230	1,710	No	NC	NC	*
CSC	1 - 3.0 feet	NC	NC	*	NC	NC	*	NC	NC	*	4,320	2,530	*
CSC	1 - 6.5 feet	5.29	2.20	No	38.8	26.0	No	11.7	6.45	No	294	112	No
CSC	2 - 3.0 feet	NC	NC	*	NC	NC	*	NC	126	*	454	2,000	Yes
CSC	3 - 3.0 feet	NC	NC	*	NC	NC	*	NC	NC	*	1,020	1,480	No
CSC	3 - 7.5 feet	NC	4.12	*	9.77	13.9	No	7.97	14.9	No	73.9	73.0	No
CSC	4 - 6.5 feet	NC	NC	*	16.0	8.09	No	5.62	2.37	*	126	50.3	No

Fg/kg Micrograms per kilogram  
 cis-1,2-DCE cis-1,2-Dichloroethene  
 1,1,1-TCA 1,1,1-Trichloroethane  
 TCE Trichloroethene  
 SBA Small Business Administration site  
 \* A statistical comparison could not be made because an insufficient number of VOC concentrations were detected

PCE Tetrachloroethene  
 ESP JMC Environmentalist's Subsoil Probe  
 Ref. Reference sampling method  
 Sign. Significance  
 CSC Chemical Sales Company site  
 NC No median calculated because at least half the reported values were below the method detection limit.



Note: µg/kg = micrograms per kilogram

**Figure 5-1. Comparative Plot of Median VOC Concentrations for the ESP and Reference Sampling Method at the SBA and CSC Sites**

method median concentrations. The total number of pairs in which the median concentrations were higher with the ESP were then compared with the total number of pairs in which the median concentrations were higher with the reference sampling method. If no bias is present in the data sets, the probability of the total number of pairs for one or the other test method being higher is equivalent; that is, the probability of the number of pairs in which the median concentrations in the ESP are higher is equal to the probability of the number of pairs in which the median concentrations in the reference sampling method are higher. A binomial expansion was used to determine the exact probability of the number of data sets in which the median concentrations for the ESP and reference sampling method were higher. If the calculated probability is less than 5 percent ( $p < 0.05$ ), then a significant difference is present between the ESP and reference sampling method.

The sign test data are provided in Table 5-6 and are summarized in Appendix A5, Table A5. At the CSC site, the calculated probability is greater than 0.05; therefore, the difference is not statistically significant. However, the calculated probability at the SBA site is less than 0.05 indicating that the ESP yielded results that, statistically, were significantly different than the results for the reference sampling method (probability of 3.1 percent). This result suggests that in sampling fine-grained soils, the reference sampling method tends to yield higher VOC concentrations than does the ESP.

**Table 5-6. Sign Test Results for the ESP and the Reference Sampling Method**

<b>Sampler</b>	<b>Number of Pairs in Which the Median Concentration is Higher than Other Method</b>	
	<b>SBA Site</b>	<b>CSC Site</b>
Reference Sampler	7	4
ESP	1	9
Total Comparisons	8	13
Calculated Probability	0.031	0.087

### ***Sample Integrity***

Seven integrity samples were collected with the ESP in Grid 1 at the SBA site and five integrity samples were collected in Grid 1 at the CSC site, as described in Chapter 3, to determine if potting soil in a lined sampler interior became contaminated after it was advanced through a zone of high VOC concentrations. For the ESP, VOCs were detected in two of the 12 integrity samples: two at the SBA site and none at the CSC site. One of the integrity samples collected at the SBA site contained cis-1,2-DCE at 5,700 Fg/kg, TCE at 4,070 Fg/kg, and PCE at 212 Fg/kg; the other sample contained cis-1,2-DCE at 114 Fg/kg and TCE at 3.17 Fg/kg. These results indicate that the integrity of a lined chamber of the ESP may not be preserved when the sampler is advanced through highly contaminated soils. Results of sample integrity tests for the reference method indicate no contamination in the potting soil after advancement through a zone of high VOC concentrations. Because potting soil has an organic carbon content many times greater than typical soils, the integrity tests represent a worst-case scenario for VOC absorbance and may not be representative of cross-contamination under normal field conditions.

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### **Sample Throughput**

Sample retrieval time was measured as the amount of time required to set up at a sampling point, collect the specified sample, backfill the hole with granular bentonite, decontaminate the sampling equipment, and move to a new sampling location. The average retrieval time for the ESP was 36.9 minutes per sample at the SBA site using a single operator and 22.5 minutes per sample when two operators were used. Two operators were used for all grids sampled at the CSC site, resulting in an average sample retrieval time of 13.4 minutes per sample. Table 5-7 presents a comparison of the average sample retrieval times for the ESP to those for the reference sampling method. The average sample retrieval times for the ESP (when two operators were used) were slightly quicker than the reference sampling method in the clay soils at the SBA site. However, the retrieval times for the ESP were based on samples collected at 3.5, 6.5, and 9.5 feet bgs, while the average sample retrieval times for the reference method were calculated based on the amount of time required to sample these same target depths and two additional target depths not sampled using the ESP: the 13.5-foot depths at Grids 1 and 5. For this reason, the sample retrieval times for the ESP and the reference method may not be directly comparable for the SBA site. The average sample retrieval times for the ESP were slower than the reference sampling method when collecting samples at depths of 3.0, 6.5, and 7.5 feet in the sandy soils at the CSC site.

### **Data Quality**

Data quality 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 ESP and reference sampling method data have been deemed acceptable for use as described in the demonstration design (Chapter 3). The results of the QC indicators selected for this demonstration for both the ESP and reference sampling method are provided in the Technology Evaluation Report for this demonstration (Tetra Tech, 1997) and are summarized in the data quality section of Chapter 4.

**Table 5-7. Average Sample Retrieval Times for the ESP and the Reference Sampling Method**

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<b>Sampler</b>	<b>Average Sample Retrieval Time (minutes per sample)</b>	
	<b>SBA Site</b>	<b>CSC Site</b>
ESP	36.9 <sup>a</sup> /22.5 <sup>b</sup>	13.4 <sup>b</sup>
Reference Sampling Method	26	8.4

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Note: One- and two-person sampling crews collected soil samples using the ESP at the SBA and CSC sites, and a three-person sampling crew collected soil samples using the reference sampling method at both sites. One additional person was present at the CSC site to direct drilling operations and assist with demonstration sampling, as necessary.

<sup>a</sup> One-person sampling crew

<sup>b</sup> Two-person sampling crew

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## **Chapter 6**

### **Economic Analysis**

The ESP 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 ESP at sites similar to those used in this demonstration. The demonstration costs for the reference sampling method are also provided.

The purpose of this economic analysis is to estimate the range of costs for using a Clements Associates, Inc., ESP to collect 42 subsurface soil samples at a clay soil site (400 feet total depth, similar to the SBA site) and a sandy soil site (200 feet total depth, similar to the CSC site). The analysis is based on the results and experience gained from this demonstration and on costs provided by Clements Associates, Inc. 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 samples using the ESP.

#### **Assumptions**

Several factors affect the cost of subsurface soil 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 collecting soil samples from clay and sandy soil sites at sampling depths ranging from 3 feet bgs to 13.5 feet bgs and using the average sample retrieval times calculated during the demonstrations of 22.5 minutes per sample for the clay soil site and 13.4 minutes per sample at the sandy soil site. This cost estimate assumes that manual methods are used to advance the ESP and a hollow-stem auger drilling platform is used to advance the reference method. The cost estimate also assumes that minimal operator training is required for the ESP (less than one hour).

#### **JMC Environmentalist's Subsoil Probe**

Costs for implementing the ESP are presented in two categories: (1) sampling equipment costs, which may include sampler purchase or rental costs and daily equipment use costs, and (2) operating and oversight costs, which include labor costs for sampling and other direct costs such as equipment shipping, supplies, IDW disposal, and site restoration.

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

*Sampling Equipment Costs.* This cost category accounts for obtaining the ESP sampling equipment required to extract soil samples from the subsurface and for daily equipment use. The ESP can either be purchased or rented.

**Table 6-1. Estimated Subsurface Soil Sampling Costs for the JMC Environmentalist's Subsoil Probe**

<b>Sampling Equipment Costs</b>			
ESP Sampler Purchase = \$2,780			
ESP Sampler Rental = \$250 per day			
Daily Equipment Use (Optional) = \$150 to \$300 per day			
<b>Operating and Oversight Costs</b>			
<b>Clay Soil Site</b>		<b>Sandy Soil Site</b>	
Total Sampling Time = 15 to 19 hours (2 days)		Total Sampling Time = 9 to 11 hours (1 day)	
Total Samples Collected = 42		Total Samples Collected = 42	
Total Sample Depth = 400 feet		Total Sample Depth = 200 feet	
Sample Crew Size = 2 People		Sample Crew Size = 2 People	
<b>Labor Costs</b>		<b>Labor Costs</b>	
Mobilization/Demobilization	\$600 - \$1,000	Mobilization/Demobilization	\$600 - \$1,000
Travel	\$6 - \$30	Travel	\$6 - \$30
Per Diem	0 - \$600	Per Diem	0 - \$300
Sample Collection and Oversight	\$1,500 - \$1,900	Sample Collection and Oversight	\$900 - \$1,100
<b>Other Direct Costs</b>		<b>Other Direct Costs</b>	
Equipment Shipping	\$50 - \$100	Equipment Shipping	\$50 - \$100
Supplies	\$25 - \$75	Supplies	\$25 - \$75
IDW Disposal	\$200 - \$300	IDW Disposal	\$200 - \$300
Site Restoration	\$100 - \$200	Site Restoration	\$100 - \$200
<b>Range of Operating and Oversight Costs*</b>	<b>\$2,480 - \$4,210</b>		<b>\$1,880 - \$3,110</b>

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

- C Purchase Cost — The ESP purchase cost is estimated to be \$2,780, which includes the ESP sampler and 15 liners (\$1,826), one master extension rod (\$187), six 36-inch extension rods for collecting samples at 20 feet bgs (\$107 each), and 30 36-inch plastic liners (\$63.55 for 15 liners).
- C Rental Cost — The ESP rental cost from Clements Associates, Inc. is \$250 per day. Sampler rental includes the ESP, one master extension rod, and six 36-inch extension rods. However, plastic liners must be purchased at an additional cost of \$191 (\$63.55 for 15 liners).
- C Daily Equipment Use Costs — Daily equipment costs are estimated to range from \$150 to \$300 per day for the optional electric hammer and an 1,850-watt generator.

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*Operating and Oversight Costs.* Operating costs are segregated into labor costs and other direct costs, as follows:

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

- C Mobilization/Demobilization Labor Costs — This cost element includes the time for two personnel to prepare for and travel to each site, set up and pack up equipment, and return from the field and includes 6 to 10 hours for each person at a rate of \$50 per hour.
- 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.
- 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 two people for 2 days at the clay soil site (2 days for sample collection, mobilization/demobilization, and site restoration), and for 1 day at the sandy soil site (1 day for sample collection, mobilization/demobilization, and site restoration).
- C Sample Collection and Oversight Labor Costs — On-site labor may include a registered geologist and another environmental scientist to operate the sample probe, collect samples, and oversee sample collection. The total number of people on site is two. Based on the average demonstration sample retrieval times, sample collection and oversight labor is estimated to be 15 to 19 hours each for two people at the clay soil site, and 9 to 11 hours each for two people at the sandy soil site. Labor rates are estimated at \$50 per hour. This labor estimate includes time for decontamination and site restoration.

Other direct costs include equipment shipping, supplies, IDW disposal, and site restoration costs.

- C Equipment Shipping — These costs include the cost of shipping the ESP to and from the sampling site and are estimated to range from \$50 to \$100.
- 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.
- IDW Disposal — Disposal costs for each site are limited to the cost of disposing one 55-gallon drum of IDW for \$200 to \$300 (typically, the minimum IDW disposal unit is one 55-gallon drum). Limited volumes of IDW were generated during the demonstration using the ESP because of the direct-push nature of the sampler advancement unit. No costs are included for wastewater disposal.
- 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 and are estimated to range from \$100 to \$200.

### **Reference Sampling Method**

The costs for implementing the reference sampling method during the demonstration include driller's costs and oversight costs, as presented in Table 6-2 and discussed below.



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

<b>Driller's Costs</b>			
Lump Sum = \$21,100 (\$13,400 for the clay soil site and \$7,700 for the sandy soil site)			
<b>Oversight Costs</b>			
<b>Clay Soil Site</b>		<b>Sandy Soil Site</b>	
Total Sampling Time = 18 to 22 hours (2 days)		Total Sampling Time = 6 to 8 hours (1 day)	
Total Samples Collected = 42		Total Samples Collected = 42	
Total Sample Depth = 400 feet		Total Sample Depth = 200 feet	
Sample Crew Size = 3 People		Sample Crew Size = 3 People	
<b>Labor Costs</b>		<b>Labor Costs</b>	
Mobilization/Demobilization	\$300 - \$500	Mobilization/Demobilization	\$300 - \$500
Travel	\$6 - \$30	Travel	\$6 - \$30
Per Diem	0 - \$300	Per Diem	0 - \$150
Sampling Oversight	\$900 - \$1,100	Sampling Oversight	\$300 - \$400
<b>Other Direct Costs</b>		<b>Other Direct Costs</b>	
Supplies	\$25 - \$75	Supplies	\$25 - \$75
IDW Disposal	\$3,000 - \$4,500	IDW Disposal	\$600 - \$900
<b>Range of Oversight Costs*</b>	<b>\$4,230 - \$6,510</b>		<b>\$1,230 - \$2,060</b>

\* The range of Oversight Costs is rounded to the nearest tens of dollars and does not include Driller's Costs.

*Driller's Costs.* Total lump sum driller's cost was \$13,400 for the clay soil site and \$7,700 for the sandy soil site and included:

- C Mobilization and demobilization (\$2,700 per site)
- C Drilling footage (\$7 per linear foot)
- C Split-spoon sampling (\$45 per sample)
- C Grouting boreholes (\$3 per linear foot)
- C Waste collection and containerization (\$45 per drum)
- C Standby time (\$80 per hour)
- C Decontamination time (\$80 per hour)
- C Drum moving time (\$80 per hour)
- C Difficult move time (\$80 per hour)
- C Site restoration and cleanup (\$50 per hour)
- C Per diem for the drilling crew (3 people)
- C Drilling crew labor costs (3 people)

These rates are based on the demonstration data and vendor-supplied information for collecting soil samples at clay soil and sandy soil sites similar to the SBA and CSC sites.

*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 method are segregated into labor costs and other direct costs, as shown below.

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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, set up and pack up equipment, and return from the field and includes 6 to 10 hours at a rate of \$50 per hour.
- 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.
- 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 (2 days for sample collection, mobilization/demobilization and site restoration), and one person for 1 day at the sandy soil site (1 day for sample collection, mobilization/ demobilization, and site restoration).
- C Sampling Oversight Labor Costs — On-site labor, often a registered geologist, is required to oversee sample collection. This cost element does not include the drill crew, which is covered in the lump sum driller's cost. Based on the average demonstration sample retrieval times, oversight labor is estimated to be 18 to 22 hours for one person at the clay soil site, and 6 to 8 hours for one person at the sandy soil site. Labor rates are estimated at \$50 per hour.

Other direct costs include supplies and IDW disposal.

- 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.
- C IDW Disposal — Disposal costs for each site are limited to the cost of disposing of 15 55-gallon drums for the clay soil site and three 55-gallon drums for the sandy soil site at a cost of \$200 to \$300 per drum.

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## **Chapter 7**

### **Summary of Demonstration Results**

This chapter summarizes the technology performance results. The Clements Associates, Inc. ESP was compared to a reference subsurface soil sampling method (hollow-stem auger drilling and split-spoon sampling) in terms of the following parameters: (1) sample recovery, (2) VOC concentrations in recovered samples, (3) sample integrity, (4) reliability and throughput, and (5) cost.

The demonstration data indicate the following performance characteristics for the ESP:

- C **Sample Recovery:** For the purposes of this demonstration, sample recovery was defined as the ratio of the length of recovered sample to the length of sampler advancement. Sample recoveries from 28 samples collected at the SBA site ranged from 42 to 100 percent, with an average sample recovery of 96 percent. Sample recoveries from 42 samples collected at the CSC site ranged from 72 to 100 percent, with an average sample recovery of 95 percent. Using the reference method, sample recoveries from 42 samples collected at the SBA site ranged from 40 to 100 percent, with an average recovery of 88 percent. Sample recoveries from the 41 samples collected at the CSC site ranged from 53 to 100 percent, with an average recovery of 87 percent. A comparison of recovery data from the ESP sampler and the reference sampler indicates that the ESP achieved higher sample recoveries in both the clay soil at the SBA site and in the sandy soil at the CSC site relative to the sample recoveries achieved by the reference sampling method.
  
- C **Volatile Organic Compound Concentrations:** Soil samples collected using the ESP and the reference sampling method at five sampling depths in eight grids (four at the SBA site and four at the CSC site) were analyzed for VOCs. For 16 of the 18 ESP and reference sampling method pairs (seven at the SBA site and 11 at the CSC site), a statistical analysis using the Mann-Whitney test indicated no significant statistical difference at the 95 percent level between VOC concentrations in samples collected with the ESP and those collected with the reference sampling method. A statistically significant difference was identified for one sample pair collected at the SBA site and one sample pair at the CSC site. Analysis of the CSC site data, using the sign test, indicated no statistical difference between the data obtained by the ESP and the reference sampling method. However, at the SBA site, the sign test indicated that the data obtained by the ESP are statistically significantly different than the data obtained by the reference sampling method, suggesting that the reference method tends to yield higher concentrations in sampling fine-grained soils than does the ESP.
  
- C **Sample Integrity:** Seven integrity samples were collected with each sampling method at the SBA site, and five integrity samples were collected with each sampling method at the CSC site to determine if potting soil in a lined sampler became contaminated after it was advanced through a zone of high VOC concentrations. For the ESP, VOCs were detected in two of the

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12 integrity samples: both at the SBA site. One of the integrity samples collected at the SBA site contained cis-1,2-DCE at 5,700 Fg/kg, TCE at 4,070 Fg/kg, and PCE at 212 Fg/kg; the other sample contained cis-1,2-DCE at 114 Fg/kg and TCE at 3.17 Fg/kg. These results indicate that the integrity of a lined chamber of the ESP may not be preserved when the sampler is advanced through highly contaminated soils. Results of sample integrity tests for the reference method indicated no contamination in the potting soil after it was advanced through a zone of high VOC concentrations. Because potting soil has an organic carbon content many times greater than typical soils, the integrity tests represent a worst-case scenario for VOC absorbance, and may not be representative of cross-contamination under normal conditions.

- C **Reliability and Throughput:** At both the SBA and CSC sites, the ESP collected a sample from the desired depth on the initial attempt 100 percent of the time. Two target zones were not sampled at the SBA site due to the technology developer's absence on several days during the demonstration; however, no planned samples were omitted due to equipment failure. Collection of saturated soil samples using the ESP at 40 feet below ground surface (bgs) in Grid 5 at the CSC site was not attempted because the sample depth was beyond the ESP's performance range. For the reference sampling method, the initial sampling success rates at the SBA and CSC sites were 90 and 95 percent, respectively. Success rates for the reference sampling method were less than 100 percent due to (1) drilling beyond the target sampling depth, (2) insufficient sample recovery, or (3) auger refusal. The average sample retrieval time for a single operator to set up the ESP on a sampling point, collect the specified sample, backfill the hole with granular bentonite, decontaminate the sampler, and move to a new sampling location at the SBA site was 36.9 minutes per sample. The average sample retrieval time at the SBA site was 22.5 minutes per sample when two operators were used. Two operators were used for all grids sampled at the CSC site, resulting in an average sample retrieval time of 13.4 minutes per sample. For the reference sampling method, the average sample retrieval times at the SBA and CSC sites were 26 and 8.4 minutes per sample, respectively. A three-person sampling crew collected soil samples using the reference sampling method at both sites. One additional person was present at the CSC site to oversee and assist with sample collection using the reference method.
- C **Cost:** Based on the demonstration results and information provided by the vendor, the ESP can be purchased for \$2,780 or rented for \$250 per day. The optional electric hammer and generator can be rented for \$150 to \$300 per day. Operating costs for the ESP ranged from \$2,480 to \$4,210 at the clay soil site and \$1,880 to \$3,110 at the sandy soil site. For this demonstration, the reference sampling was procured at a lump sum rate of \$13,700 for the clay soil site and \$7,700 for the sandy soil site. Oversight costs for the reference method ranged from \$4,230 to \$6,510 at the clay soil site and \$1,230 to \$2,060 at the sandy soil site. A site-specific cost analysis is recommended before selecting a soil sampling method.

In general, the data quality indicators selected for this demonstration met the established QA objectives and support the usefulness of the demonstration results in verifying the ESP's performance.

A qualitative performance assessment of the ESP indicated that (1) the sampler is easy to use and requires no specialized training to operate; (2) logistical requirements are generally less than those for the reference sampling method; (3) sample handling is similar to the reference method; (4) the performance range is limited by the advancement platform, although the ESP successfully retrieved a sample on one of two sampling attempts at depths greater than 25 feet; and (5) no drill cuttings are generated when using the ESP.

The demonstration results indicate that the ESP can provide useful, cost-effective samples for environmental problem-solving. However, in some cases, VOC data collected using the ESP may be

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statistically different from VOC data collected using the reference sampling method. Also, the integrity of a lined sample chamber may not be preserved when the sampler is advanced through highly contaminated clay soils. As with any technology selection, the user must determine what is appropriate for the application and project data quality objectives.

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## **Chapter 8 Technology Update**

Clements Associates, Inc. has been in the business of manufacturing and selling hand-operated soil investigation equipment since 1972. The ESP system, used at the performance verification demonstration in June 1997, was developed initially to sample for agrichemical residues that contained radioactive trace elements.

The ESP has been used for a large range of environmental soil investigations. Its light weight and compact size mean that sampling personnel can carry it in the trunk of a passenger car or check it as airline baggage. This extreme portability and ease of use make the ESP a useful reconnaissance tool or, in many cases, the only subsurface investigation equipment of many consulting firms.

The ESP is being used in all of the United States, Canada, Mexico, Australia, Japan, Bolivia, England, and France. Units used in Bolivia were selected for use there by a large U.S.-based environmental consulting firm because of the simplicity, portability, and ease of operation. Much of the field work was done by local personnel having no previous sampling experience.

In addition to site assessment work, the ESP and the ESP Plus are used by agrichemical companies and agricultural research firms conducting soil dissipation or environmental fate studies as required by the EPA. The benefits are smaller plot sizes, the ability to sample regardless of surface ground conditions, ease of moving sampling equipment to remote locations or plots with limited access, and more efficient and more rapid sampling. Clements Associates, Inc. has developed a system of sampling tubes called Concentric Sampling Tubes for collecting the uppermost portion of the sample, which contains the highest amount of chemical contaminants.

The ESP Plus was developed to provide a larger volume of sample. It is of greater use in the soil dissipation arena.

Chapter 8 was written solely by Clements Associates, Inc. The statements presented in this chapter represent the vendor's point of view and summarize the claims made by the vendor regarding the ESP. Publication of this material does not represent the EPA's approval or endorsement of the statements made in this chapter; results of the performance evaluation of the ESP are discussed in other chapters of this report.

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## **Chapter 9**

### **Previous Deployment**

Although Clements Associates, Inc., claims that the ESP has been used widely throughout the United States and internationally, they chose not to provide additional information in this chapter on previous deployment of the ESP.

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**APPENDIX A**

**DATA SUMMARY TABLES AND STATISTICAL METHOD  
DESCRIPTIONS**

**FOR THE**

**CLEMENTS ASSOCIATES, INC.**  
**JMC ENVIRONMENTALIST'S SUBSOIL PROBE (ESP)**

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**APPENDIX A1**

**STATISTICAL METHOD DESCRIPTIONS**

**MANN-WHITNEY TEST AND SIGN TEST**

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## MANN-WHITNEY TEST

A statistical evaluation of the volatile organic compound (VOC) concentration data was conducted based on the null hypothesis that there is no difference between the median contaminant concentrations obtained by the Environmentalist's Subsoil Probe (ESP) and the reference sampling method. The two-tailed significance level for this null hypothesis was set at a probability of 5 percent ( $p \leq 0.05$ ) (2.5 percent for a one-tailed); that is, if a two-tailed statistical analysis indicates a probability of greater than 5 percent that there is no significant difference between data sets, then it will be concluded that there is no significant difference between the data sets. A two-tailed test was used because no information was available to indicate *a priori* that one method would result in greater concentrations than the other method. Because the F test for homogeneity of variances failed, a parametric analysis of variance could not be used to test the hypothesis. Therefore, a nonparametric method, the Mann-Whitney test, was used to test the statistical hypothesis for VOC concentrations. The Mann-Whitney statistic makes no assumptions regarding normality and assumes only that the differences between two values, in this case the reported chemical concentrations, can be determined. Other assumptions required for use of the Mann-Whitney test are that samples are independent of each other and that the populations from which the samples are taken differ only in location. The Mann-Whitney test was chosen because of its historical acceptability and ease of application to small data sets.

To use the Mann-Whitney test, all of the data within two data sets that are to be compared are ranked without regard to the population from which each sample was withdrawn. The cis-1,2-dichloroethene (DCE) data from the SBA site are provided as an example in Table A1. The combined data from both data sets are ranked from the lowest value to the highest. Next, the sum of ranks within a sample set is determined by adding the assigned rank values. In the example provided in Table A1, the sum of ranks is 26 for the ESP data and 52 for the reference sampling methods.

A Mann-Whitney statistic is then calculated for each data set as follows:

$$\text{Mann-Whitney}_1 = N_1N_2 + \frac{N_1(N_1 + 1)}{2} - \text{sum of ranks value for the first data set}$$

and

$$\text{Mann-Whitney}_2 = N_1N_2 + \frac{N_2(N_2 + 1)}{2} - \text{sum of ranks value for the second data set}$$

Where

$N_1$  is the number of values in data set 1

$N_2$  is the number of values in data set 2

**Table A1. Mann-Whitney Test Rank of cis-1,2-DCE Data from the 9.5 Foot Depth of Grid 1 at the SBA Site**

<b>Sampler</b>	<b>Sample Location</b>	<b>cis-1,2-DCE Concentration (mg/kg)</b>	<b>cis-1,2-DCE Concentration Rank</b>	<b>Median Value Rank</b>
ESP	A5	182	12	5
ESP	B1	22.3	1	1
ESP	E7	65.8	5	3
ESP	F3	66.1	6	4
ESP	G5	23.2	2	2
Reference	A3	49.7	3	1
Reference	B2	86.7	8	4
Reference	C2	109	10	6
Reference	D4	147	11	7
Reference	E4	67.1	7	3
Reference	F2	98.4	9	5
Reference	G7	50.2	4	2
Sum of ESP Ranks (12+ 1+ 5+ 6+ 2 = 26)			26	
Sum of Reference Sampler Ranks (3+ 8+ 10+ 11+ 7+ 9+ 4 = 52)			52	
Mann-Whitney <sub>1</sub> Statistic			24	
Mann-Whitney <sub>2</sub> Statistic			11	
Critical Mann-Whitney Value (for N <sub>1</sub> = 7, N <sub>2</sub> = 7, p= 0.05)			30	
Significance (Mann-Whitney Statistic > 30 ?)			no	

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For the example provided in Table A1, the equations become:

$$\text{Mann-Whitney}_2 = (7)(5) + \frac{5(5+1)}{2} - 26$$

$$\text{Mann-Whitney}_2 = 35 + 15 - 26$$

$$\text{Mann-Whitney}_2 = 24$$

and

$$\text{Mann-Whitney}_1 = (7)(5) + \frac{7(7+1)}{2} - 52$$

$$\text{Mann-Whitney}_1 = 35 + 28 - 52$$

$$\text{Mann-Whitney}_1 = 11$$

To determine the significance of the calculated Mann-Whitney value, a table of critical values for the Mann-Whitney statistic is consulted. For the case of 7 samples in each data set, the Mann-Whitney statistic value for  $N_1=7$  and  $N_2=5$  is of interest. For a two-tailed test with a significance level of 0.05, the Mann-Whitney statistic value is 30 (Rohlf and Sokal, 1969). Therefore, when the Mann-Whitney statistic value is greater than 30, a significance level of  $p < 0.05$  has been realized, and the null hypothesis is rejected; that is, the two data sets are statistically different. The example comparison provided in Table A1 yielded a maximum Mann-Whitney statistic of 24, which is less than 30; therefore, there is no statistically significant difference between the two data sets, and the null hypothesis is accepted.

The question of data points with equal values may be easily addressed with the Mann-Whitney statistic. When two values (contaminant concentrations in this instance) are equivalent, the median rank is assigned to each. For instance, if the initial two values in the rank series are equivalent (regardless of which data set they were derived from) they would be assigned a median rank of 1.5 ( $[1+2]/2 = 1.5$ ). For three equivalent ranks, the assigned rank for each value would be 2 ( $[1+2+3]/3 = 2$ ). This approach is also applied to data points where contaminant concentrations are reported as below the method detection limit.

For the demonstration data, certain VOCs were not detected in some, or all, of the samples for many data sets. There is no strict guidance regarding the appropriate number of values that must be reported within a data set to yield statistically valid results. Therefore, and for the purposes of this statistical analysis, the maximum number of nondetects allowed within any given data set has been set at three. That is, there must be at least four reported values above the method detection limit within each data set to perform the Mann-Whitney test.

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## **SIGN TEST**

The sign test was used to examine the potential for sampling and analytical bias between the ESP and the reference sampling method. The sign test is nonparametric and counts the number of positive and negative signs among the differences. The differences tested, in this instance, were the differences in the median concentrations of paired data sets (within a site, within a grid, within a depth, and within an analyte). From the data sets, counts were made of (1) the number of pairs in which the reference sampling method median concentrations were higher than the ESP median concentrations and (2) the number of pairs in which the ESP median concentrations were higher than the reference sampling method median concentrations. The total number of pairs in which the median concentrations were higher in ESP was then compared with the total number of pairs in which the median concentrations in the reference sampling method were higher. If no bias is present in the data sets, the probability that the total number of pairs for one or the other test method is higher is equivalent. That is, the probability of the number of pairs in which the median concentrations in the ESP are higher is equal to the probability of the number of pairs in which the median concentrations in the reference sampling method are higher. A binomial expansion was used to determine the exact probability of the number of data sets in which the median concentrations in the ESP and reference sampling method were higher. If the calculated probability is less than 5 percent ( $p < 0.05$ ), then a significant difference is present between the ESP and reference sampling method.

The sign test was chosen because it (1) reduces sensitivity to random analysis error and matrix variabilities by using the median VOC concentration across each grid depth, (2) enlarges the sample sizes as compared to the Mann-Whitney test, and (3) is easy to use.

For the demonstration data, certain VOCs were not detected in some, or all of the samples for many data sets. There is no strict guidance regarding the appropriate number of values that must be reported within a data set to yield statistically valid results. Therefore, and for the purposes of the statistical analysis, the maximum number of nondetects allowed within any given data set has been set at three. That is, there must be four reported values within each data set to perform the sign test.



**APPENDIX A2**  
**SAMPLE RECOVERY TEST DATA**

**TABLE A2a. ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER RECOVERY TEST DATA  
SBA SITE**

<b>Sample Number</b>	<b>Sample Location</b>	<b>Soil Type</b>	<b>Reported Length Pushed (in.)</b>	<b>Reported Length Recovered (in.)</b>	<b>Sample Recovery (%)</b>
CLEAC1G509.5	G5	Fine	12.0	12.0	100.0%
CLEAG1A509.5	A5	Fine	12.0	13.0	100.0% <sup>a</sup>
CLEAG1B109.5	B1	Fine	12.0	15.0	100.0% <sup>a</sup>
CLEAG1C309.5	C3	Fine	12.0	12.0	100.0%
CLEAG1D709.5	D7	Fine	12.0	18.0	100.0% <sup>a</sup>
CLEAG1E109.5	E1	Fine	12.0	15.0	100.0% <sup>a</sup>
CLEAG1F309.5	F3	Fine	12.0	15.0	100.0% <sup>a</sup>
CLEAG2A603.5	A6	Fine	36.0	36.0	100.0%
CLEAG2B103.5	B1	Fine	30.0	26.0	86.7%
CLEAG2C603.5	C6	Fine	36.0	34.0	94.4%
CLEAG2D403.5	D4	Fine	36.0	34.0	94.4%
CLEAG2E303.5	E3	Fine	36.0	31.0	86.1%
CLEAG2G103.5	G1	Fine	30.0	27.0	90.0%
CLEAG2F603.5	F6	Fine	36.0	36.0	100.0%
CLEAG3A509.5	A5	Fine	12.0	20.0	100.0% <sup>a</sup>
CLEAG3B309.5	B3	Fine	12.0	5.0	41.7%
CLEAG3C209.5	C2	Fine	12.0	14.0	100.0% <sup>a</sup>
CLEAG3D509.5	D5	Fine	12.0	18.0	100.0% <sup>a</sup>
CLEAG3E409.5	E4	Fine	12.0	18.0	100.0% <sup>a</sup>
CLEAG3F109.5	F1	Fine	12.0	16.0	100.0% <sup>a</sup>
CLEAG3G309.5	G3	Fine	12.0	12.0	100.0%
CLEAG4A709.5	A7	Fine	36.0	36.0	100.0%
CLEAG4B609.5	B6	Fine	12.0	15.0	100.0% <sup>a</sup>
CLEAG4C209.5	C2	Fine	12.0	18.0	100.0% <sup>a</sup>
CLEAG4D509.5	D5	Fine	36.0	36.0	100.0%
CLEAG4F709.5	F7	Fine	24.0	24.0	100.0%
CLEAG4E209.5	E2	Fine	36.0	36.0	100.0%
CLEAG4G509.5	G5	Fine	36.0	36.0	100.0%

<sup>a</sup> Sample recovery is reported as 100 percent when length recovered is greater than length pushed.

Average: 96.2%  
 Range: 41.7% - 100%  
 Total # Samples: 28



**TABLE A2b. ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER RECOVERY TEST DATA  
CSC SITE**

<b>Sample Number</b>	<b>Sample Location</b>	<b>Soil Type</b>	<b>Reported Length Pushed (in.)</b>	<b>Reported Length Recovered (in.)</b>	<b>Sample Recovery (%)</b>
CLECG1A103.0	A1	Coarse	36.0	32.0	88.9%
CLECG1B403.0	B4	Coarse	36.0	36.0	100.0%
CLECG1C103.0	C1	Coarse	36.0	36.0	100.0%
CLECG1D303.0	D3	Coarse	36.0	33.0	91.7%
CLECG1E703.0	E7	Coarse	36.0	36.0	100.0%
CLECG1F603.0	F6	Coarse	36.0	36.0	100.0%
CLECG1G103.0	G1	Coarse	36.0	35.0	97.2%
CLECG1A106.5	A1	Coarse	36.0	34.5	95.8%
CLECG1B406.5	B4	Coarse	36.0	31.5	87.5%
CLECG1C106.5	C1	Coarse	36.0	31.0	86.1%
CLECG1D306.5	D3	Coarse	36.0	32.0	88.9%
CLECG1E706.5	E7	Coarse	36.0	31.5	87.5%
CLECG1F606.5	F6	Coarse	36.0	32.0	88.9%
CLECG1G106.5	G1	Coarse	36.0	32.0	88.9%
CLECG2A503.0	A5	Coarse	36.0	33.0	91.7%
CLECG2C603.0	C6	Coarse	36.0	36.0	100.0%
CLECG2F403.0	F4	Coarse	36.0	36.0	100.0%
CLECG2E603.0	E6	Coarse	36.0	33.5	93.1%
CLECG2B203.0	B2	Coarse	36.0	36.0	100.0%
CLECG2D303.0	D3	Coarse	36.0	33.0	91.7%
CLECG2G603.0	G6	Coarse	36.0	36.0	100.0%
CLECG3A503.0	A5	Coarse	36.0	36.0	100.0%
CLECG3B403.0	B4	Coarse	36.0	34.0	94.4%
CLECG3C603.0	C6	Coarse	36.0	36.0	100.0%
CLECG3D503.0	D5	Coarse	36.0	36.0	100.0%
CLECG3E303.0	E3	Coarse	36.0	35.0	97.2%
CLECG3F403.0	F4	Coarse	36.0	32.0	88.9%
CLECG3G503.0	G5	Coarse	36.0	36.0	100.0%
CLECG3A507.5	A5	Coarse	36.0	31.5	87.5%
CLECG3B407.5	B4	Coarse	36.0	32.0	88.9%
CLECG3C607.5	C6	Coarse	36.0	29.0	80.6%
CLECG3D507.5	D5	Coarse	36.0	26.0	72.2%
CLECG3E307.5	E3	Coarse	36.0	36.0	100.0%
CLECG3F407.5	F4	Coarse	36.0	31.0	86.1%
CLECG3G507.5	G5	Coarse	36.0	34.0	94.4%
CLECG4A306.5	A3	Coarse	36.0	36.0	100.0%
CLECG4B506.5	B5	Coarse	36.0	36.0	100.0%
CLECG4C606.5	C6	Coarse	36.0	36.0	100.0%
CLECG4D706.5	D7	Coarse	36.0	36.0	100.0%
CLECG4E306.5	E3	Coarse	36.0	36.0	100.0%
CLECG4F506.5	F5	Coarse	36.0	36.0	100.0%
CLECG4G406.5	G4	Coarse	36.0	36.0	100.0%

Average: 94.5%  
Range: 72.2 - 100.0%  
Total # Samples: 42

**TABLE A2c. REFERENCE SAMPLING METHOD RECOVERY TEST DATA  
SBA SITE**

<b>Sample Number</b>	<b>Sample Location</b>	<b>Soil Type</b>	<b>Reported Length Pushed (in.)</b>	<b>Reported Length Recovered (in.)</b>	<b>Sample Recovery (%)</b>
REFAG1A309.5	A3	Fine	18.0	13.5	75.0%
REFAG1A313.5	A3	Fine	19.0	17.0	89.5%
REFAG1B209.5	B2	Fine	18.0	17.0	94.4%
REFAG1B213.5	B2	Fine	18.0	19.0	100.0% <sup>a</sup>
REFAG1C209.5	C2	Fine	18.0	16.0	88.9%
REFAG1C213.5	C2	Fine	18.0	11.0	61.1%
REFAG1D409.5	D4	Fine	18.0	16.0	88.9%
REFAG1D413.5	D4	Fine	18.0	17.5	97.2%
REFAG1E409.5	E4	Fine	18.0	17.0	94.4%
REFAG1E413.5	E4	Fine	18.0	17.0	94.4%
REFAG1F209.5	F2	Fine	18.0	16.0	88.9%
REFAG1F213.5	F2	Fine	18.0	17.0	94.4%
REFAG1G709.5	G7	Fine	18.0	18.0	100.0%
REFAG1G713.5	G7	Fine	18.0	16.0	88.9%
REFAG2A203.5	A2	Fine	18.0	18.0	100.0%
REFAG2B403.5	B4	Fine	18.0	14.0	77.8%
REFAG2C103.5	C1	Fine	18.0	12.0	66.7%
REFAG2D603.5	D6	Fine	18.0	9.0	50.0%
REFAG2E503.5	E5	Fine	18.0	16.0	88.9%
REFAG2F103.5	F1	Fine	18.0	18.0	100.0%
REFAG2G403.5	G4	Fine	18.0	17.0	94.4%
REFAG3A209.5	A2	Fine	15.0	20.0	100.0% <sup>a</sup>
REFAG3B609.5	B6	Fine	15.0	18.0	100.0% <sup>a</sup>
REFAG3C409.5	C4	Fine	15.0	6.0	40.0%
REFAG3D609.5	D6	Fine	15.0	13.0	86.7%
REFAG3E109.5	E1	Fine	15.0	16.5	100.0% <sup>a</sup>
REFAG3F309.5	F3	Fine	15.0	21.0	100.0% <sup>a</sup>
REFAG3G609.5	G6	Fine	18.0	24.0	100.0% <sup>a</sup>
REFAG4A109.5	A1	Fine	18.0	16.5	91.7%
REFAG4B309.5	B3	Fine	18.0	18.0	100.0%
REFAG4C309.5	C3	Fine	18.0	16.0	88.9%
REFAG4D609.5	D6	Fine	18.0	17.0	94.4%
REFAG4E709.5	E7	Fine	18.0	17.0	94.4%
REFAG4F209.5	F2	Fine	18.0	15.0	83.3%
REFAG4G209.5	G2	Fine	18.0	17.5	97.2%
REFAG5A213.5	A2	Fine	18.0	18.0	100.0%
REFAG3B113.5	B1	Fine	18.0	18.0	100.0%
REFAG5C213.5	C2	Fine	18.0	15.5	86.1%
REFAG5D613.5	D6	Fine	18.0	17.0	94.4%
REFAG5E313.5	E3	Fine	18.0	11.0	61.1%
REFAG5F313.5	F3	Fine	18.0	12.0	66.7%
REFAG5G413.5	G4	Fine	18.0	17.0	94.4%

<sup>a</sup> Sample recovery is reported as 100 percent when length recovered is greater than length pushed.

Average: 88.4%  
Range: 40.0-100.0%  
Total # Samples: 42

**TABLE A2d. REFERENCE SAMPLING METHOD RECOVERY TEST DATA  
CSC SITE**

<b>Sample Number</b>	<b>Sample Location</b>	<b>Soil Type</b>	<b>Reported Length Pushed (in.)</b>	<b>Reported Length Recovered (in.)</b>	<b>Sample Recovery (%)</b>
REFCG1A303.0	A3	Coarse	18.0	12.0	66.7%
REFCG1A306.5	A3	Coarse	18.0	16.0	88.9%
REFCG1B303.0	B3	Coarse	18.0	10.0	55.6%
REFCG1B306.5	B3	Coarse	18.0	14.0	77.8%
REFCG1C303.0	C3	Coarse	18.0	15.0	83.3%
REFCG1C306.5	C3	Coarse	18.0	13.0	72.2%
REFCG1D503.0	D5	Coarse	18.0	16.0	88.9%
REFCG1D506.5	D5	Coarse	18.0	14.0	77.8%
REFCG1E103.0	E1	Coarse	18.0	20.0	100.0% <sup>a</sup>
REFCG1E106.5	E1	Coarse	18.0	11.5	63.9%
REFCG1F103.0	F1	Coarse	18.0	14.5	80.6%
REFCG1F106.5	F1	Coarse	18.0	15.0	83.3%
REFCG1G703.0	G7	Coarse	18.0	14.0	77.8%
REFCG1G706.5	G7	Coarse	18.0	15.0	83.3%
REFCG2A103.0	A1	Coarse	18.0	13.0	72.2%
REFCG2B603.0	B6	Coarse	18.0	19.0	100.0% <sup>a</sup>
REFCG2C103.0	C1	Coarse	18.0	16.0	88.9%
REFCG2D603.0	D6	Coarse	18.0	18.0	100.0%
REFCG2E303.0	E3	Coarse	18.0	19.5	100.0% <sup>a</sup>
REFCG2F503.0	F5	Coarse	18.0	18.5	100.0% <sup>a</sup>
REFCG2G103.0	G1	Coarse	19.0	19.0	100.0%
REFCG3A203.0	A2	Coarse	18.0	17.5	97.2%
REFCG3A207.5	A2	Coarse	18.0	12.0	66.7%
REFCG3B103.0	B1	Coarse	18.0	17.0	94.4%
REFCG3B107.5	B1	Coarse	18.0	12.0	66.7%
REFCG3C203.0	C2	Coarse	18.0	18.0	100.0%
REFCG3C207.5	C2	Coarse	18.0	9.5	52.8%
REFCG3D603.0	D6	Coarse	19.0	18.0	94.7%
REFCG3D607.5	D6	Coarse	20.0	20.0	100.0%
REFCG3E603.0	E6	Coarse	18.0	18.0	100.0%
REFCG3E607.5	E6	Coarse	18.0	18.0	100.0%
REFCG3F603.0	F6	Coarse	18.0	18.0	100.0%
REFCG3F607.5	F6	Coarse	No data	No data	--
REFCG3G403.0	G4	Coarse	18.0	17.0	94.4%
REFCG3G407.5	G4	Coarse	18.0	18.0	100.0%
REFCG4A706.5	A7	Coarse	18.0	18.0	100.0%
REFCG4B606.5	B6	Coarse	18.0	13.0	72.2%
REFCG4C706.5	C7	Coarse	18.0	17.0	94.4%
REFCG4D306.5	D3	Coarse	18.0	17.0	94.4%
REFCG4E506.5	E5	Coarse	18.0	18.0	100.0%
REFCG4F306.5	F3	Coarse	18.0	18.0	100.0%
REFCG4G506.5	G5	Coarse	18.0	11.5	63.9%

<sup>a</sup> Sample recovery is reported as 100 percent when length recovered is greater than length pushed.

Average: 86.7%  
Range: 52.8-100.0%  
Total # Samples: 41



**APPENDIX A3**  
**VOLATILE ORGANIC COMPOUND CONCENTRATIONS**

**TABLE A3a. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
SBA SITE - GRID 1 - 9.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (mg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLEAG1A509.5	A5	Fine	High	182,441	100	63,996	570
CLEAG1B109.5	B1	Fine	High	22,319	100	53,779	100
CLEAG1E709.5	E7	Fine	High	65,819	100	454,575	3,622
CLEAG1F309.5	F3	Fine	High	66,130	100	551,013	2,357
CLEAG1G509.5	G5	Fine	High	23,237	100	78,916	100

Range:                    22,300 - 182,000      100      53,800 - 551,000      100 - 3,620

Median:                    65,800                    NC                    78,900                    570

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFAG1A309.5	A3	Fine	High	49,671	100	52,846	100
REFAG1B209.5	B2	Fine	High	86,749	100	70,217	669
REFAG1C209.5	C2	Fine	High	108,582	100	251,269	2,012
REFAG1D409.5	D4	Fine	High	147,042	100	418,733	4,511
REFAG1E409.5	E4	Fine	High	67,126	100	290,739	1,534
REFAG1F209.5	F2	Fine	High	98,437	100	276,149	1,720
REFAG1G709.5	G7	Fine	High	50,237	100	289,330	1,625

Range:                    49,700 - 147,000      100      52,800 - 419,000      100 - 4,510

Median:                    86,700                    NC                    276,000                    1,630

Note:                    Values reported as "100" are nondetects with a detection limit of 100.  
 NC =                    No medians calculated because at least half the reported values were below  
                               the method detection limit.  
 µg/kg =                Micrograms per kilogram.

**TABLE A3b. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
SBA SITE - GRID 1 - 13.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (mg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA NOT COLLECTED							

Range:

Median:

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFAG5A213.5	A2	Fine	High	6,762	100	33,736	100
REFAG5C213.5	C2	Fine	High	14,453	100	40,511	100
REFAG5C213.5D	C2	Fine	High	20,362	100	48,730	100
REFAG5D613.5	D6	Fine	High	44,929	100	432,508	2,405
REFAG5E313.5	E3	Fine	High	12,343	100	40,984	100
REFAG5F313.5	F3	Fine	High	15,415	100	26,652	100
REFAG5G413.5	G4	Fine	High	1,356	100	39,138	100

Range:                    1,360 - 44,900            100            26,700 - 433,000            100

Median:                    14,500                    NC                    40,500                    NC

Note:                    Values reported as "100" are nondetects with a detection limit of 100.  
 NC =                    No medians calculated because at least half the reported values were below  
                               the method detection limit.  
 µg/kg =                    Micrograms per kilogram.

**TABLE A3c. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
SBA SITE - GRID 2 - 3.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (mg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLEAG2A603.5	A6	Fine	Low	3.42	1	328	1
CLEAG2B103.5	B1	Fine	Low	1	1	37.4	1
CLEAG2C603.5	C6	Fine	Low	1	1	159	1
CLEAG2D403.5	D4	Fine	Low	1	1	71.0	1
CLEAG2E303.5	E3	Fine	Low	3.08	1	143	1
CLEAG2F603.5	F6	Fine	Low	1	1	109	1
CLEAG2G103.5	G1	Fine	Low	4.34	1	155	1

Range:                    1 - 4.34                    1                    37.4 - 328                    1

Median:                    NC                    NC                    143                    NC

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFAG2A203.5	A2	Fine	Low	1	1	22.6	1
REFAG2B403.5	B4	Fine	Low	1	1	58.2	1
REFAG2C103.5	C1	Fine	Low	1	1	29.3	1
REFAG2D603.5	D6	Fine	Low	1	1	43.5	1
REFAG2E503.5	E5	Fine	Low	1	1	56.9	1
REFAG2F103.5	F1	Fine	Low	1	1	78.6	1
REFAG2G403.5	G4	Fine	Low	2.18	1	88.8	1

Range:                    1 - 2.18                    1                    22.6 - 88.8                    1

Median:                    NC                    NC                    56.9                    NC

Note:                    Values reported as "1" are nondetects with a detection limit of 1.  
 NC =                    No medians calculated because at least half the reported values were below  
                               the method detection limit.  
 µg/kg =                    Micrograms per kilogram.

**TABLE A3d. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
SBA SITE - GRID 3 - 9.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (ng/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLEAG3A509.5	A5	Fine	High	1,363	100	36,955	100
CLEAG3B309.5	B3	Fine	High	891	100	49,180	138
CLEAG3C209.5	C2	Fine	High	662	100	13,215	100
CLEAG3D509.5	D5	Fine	High	1,538	100	26,253	100
CLEAG3E409.5	E4	Fine	High	1,378	100	24,162	100
CLEAG3F109.5	F1	Fine	High	344	100	20,796	100
CLEAG3G309.5	G3	Fine	High	366	100	31,494	100

Range:                    344 - 1,540            100            13,200 - 49,200    100 - 138

Median:                    891                    NC                    26,300                    NC

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFAG3A209.5	A2	Fine	High	796	100	34,069	100
REFAG3B609.5	B6	Fine	High	1,007	100	34,420	100
REFAG3C409.5	C4	Fine	High	1,455	100	63,740	100
REFAG3D609.5	D6	Fine	High	799	100	42,502	100

Range:                    796 - 1,460            100            34,100 - 63,700    100

Median:                    903                    NC                    38,500                    NC

Note:                    Values reported as "100" are nondetects with a detection limit of 100.  
 NC =                    No medians calculated because at least half the reported values were below  
                               the method detection limit.  
 µg/kg =                Micrograms per kilogram.



**TABLE A3e. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
SBA SITE - GRID 4 - 9.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (mg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLEAG4A709.5	A7	Fine	Low	8.06	1	837	1
CLEAG4B609.5	B6	Fine	Low	16.4	1	2,193	1
CLEAG4C209.5	C2	Fine	Low	7.44	1	1,007	1
CLEAG4D509.5	D5	Fine	Low	9.63	1	2,087	1
CLEAG4E209.5	E2	Fine	Low	8.81	1	1,237	1
CLEAG4F709.5	F7	Fine	Low	15.3	1	1,071	1
CLEAG4G509.5	G5	Fine	Low	10.7	1	1,229	1

Range:                    7.44 - 16.4                    1                    837 - 2,190                    1

Median:                    9.63                    NC                    1,230                    NC

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFAG4A109.5	A1	Fine	Low	7.15	1	847	1
REFAG4B309.5	B3	Fine	Low	6.68	1	966	1
REFAG4C309.5	C3	Fine	Low	21.2	1	1,709	1
REFAG4D609.5	D6	Fine	Low	13.2	1	1,834	1
REFAG4E709.5	E7	Fine	Low	12.1	1	1,306	1
REFAG4F209.5	F2	Fine	Low	22.1	1	2,084	1
REFAG4G209.5	G2	Fine	Low	19.2	1	1,870	1

Range:                    6.68 - 22.1                    1                    847 - 2,080                    1

Median:                    13.2                    NC                    1,710                    NC

Note:                    Values reported as "1" are nondetects with a detection limit of 1.  
 NC =                    No medians calculated because at least half the reported values were below  
                                  the method detection limit.  
 µg/kg =                    Micrograms per kilogram.

**TABLE A3f. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
SBA SITE - GRID 5 - 13.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (ng/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA NOT COLLECTED							

Range:

Median:

REFERENCE SAMPLING METHOD DATA							
REFAG5A213.5	A2	Fine	Low	81.2	1	23.3	1
REFAG5C213.5	C2	Fine	Low	118	1	58.0	1
REFAG5C213.5D	C2	Fine	Low	89	1	42	1
REFAG5D613.5	D6	Fine	Low	147	1	138	1
REFAG5E313.5	E3	Fine	Low	106	1	18.7	1
REFAG5F313.5	F3	Fine	Low	59.5	1	3.23	1
REFAG5G413.5	G4	Fine	Low	33.7	1	1	1

Range:                      33.7 - 147                      1                      1 - 138                      1

Median:                      93.6                      NC                      21.0                      NC

Note:                      Values reported as "1" are nondetects with a detection limit of 1.  
 NC =                      No medians calculated because at least half the reported values were below the method detection limit.  
 µg/kg =                      Micrograms per kilogram.

**TABLE A3g. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE - GRID 1 - 3.0 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (ng/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLECG1A103.0	A1	Coarse	High	100	100	100	4,318
CLECG1B403.0	B4	Coarse	High	100	100	100	4,500
CLECG1F603.0	F6	Coarse	High	100	440	100	3,584

Range:                    100            100 - 440            100            3,580 - 4,500

Median:                    NC            NC            NC            4,320

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFCG1B303.0	B3	Coarse	High	100	256	100	5,742
REFCG1C303.0	C3	Coarse	High	100	659	100	1,881
REFCG1D503.0	D5	Coarse	High	100	100	100	6,217
REFCG1E303.0	E3	Coarse	High	100	644	100	2,166
REFCG1F103.0	F1	Coarse	High	100	100	100	2,895
REFCG1G703.0	G7	Coarse	High	100	100	100	1,887

Range:                    100            100 - 659            100            1,880 - 6,220

Median:                    NC            NC            NC            2,530

Note:                    Values reported as "100" are nondetects with a detection limit of 100.  
 NC =                    No medians calculated because at least half the reported values were below the method detection limit.  
 µg/kg =                Micrograms per kilogram.

**TABLE A3h. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE - GRID 1 - 6.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (mg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLECG1A106.5	A1	Coarse	Low	1	65.4	1	840
CLECG1B406.5	B4	Coarse	Low	1	20.2	5.11	113
CLECG1C106.5	C1	Coarse	Low	7.33	49.9	15.5	173
CLECG1D306.5	D3	Coarse	Low	5.29	38.8	12.3	207
CLECG1E706.5	E7	Coarse	Low	6.03	33.0	11.7	340
CLECG1F606.5	F6	Coarse	Low	7.70	80.1	23.5	496
CLECG1G106.5	G1	Coarse	Low	3.84	20.2	10.5	294

Range:                    1 - 7.70      20.2 - 80.1      1 - 23.5      113 - 840

Median:                    5.29              38.8              11.7              294

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFCG1A306.5	A3	Coarse	Low	2.03	32.1	6.46	107
REFCG1B306.5	B3	Coarse	Low	1	14.0	3.47	58.5
REFCG1C306.5	C3	Coarse	Low	2.36	54.6	22.4	848
REFCG1D506.5	D5	Coarse	Low	1	13.1	4.18	109
REFCG1F106.5	F1	Coarse	Low	5.81	19.8	8.39	114
REFCG1G706.5	G7	Coarse	Low	3.08	36.3	6.44	256

Range:                    1 - 5.81      13.1 - 54.6      3.47 - 22.4      58.5 - 848

Median:                    2.20              26.0              6.45              112

Note:                    Values reported as "1" are nondetects with a detection limit of 1.  
 NC =                    No medians calculated because at least half the reported values were below  
                              the method detection limit.  
 µg/kg =                Micrograms per kilogram.

**TABLE A3i. VOLATILE COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE - GRID 2 - 3.0 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (mg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLECG2A503.0	A5	Coarse	High	100	100	100	376
CLECG2C603.0	C6	Coarse	High	100	100	100	377
CLECG2F403.0	F4	Coarse	High	100	100	100	532
CLECG2G603.0	G6	Coarse	High	100	100	100	1,078

Range:                    100            100            100            376 - 1,080

Median:                    NC            NC            NC            454

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFCG2A103.0	A1	Coarse	High	100	100	126	1,830
REFCG2B603.0	B6	Coarse	High	100	100	100	1,615
REFCG2C103.0	C1	Coarse	High	100	100	100	2,003
REFCG2D603.0	D6	Coarse	High	100	100	100	1,556
REFCG2E303.0	E3	Coarse	High	100	984	435	2,905
REFCG2F503.0	F5	Coarse	High	100	320	375	2,149
REFCG2G103.0	G1	Coarse	High	100	273	355	2,282

Range:                    100            100 - 984    100 - 435    1,560 - 2,910

Median:                    NC            NC            126            2,000

Note:                    Values reported as "100" are nondetects with a detection limit of 100.  
 NC =                    No medians calculated because at least half the reported values were below the method detection limit.  
 µg/kg =                Micrograms per kilogram.

**TABLE A3j. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE - GRID 3 - 3.0 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (mg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLECG3A503.0	A5	Coarse	High	100	100	100	944
CLECG3B403.0	B4	Coarse	High	100	100	100	1,022
CLECG3C603.0	C6	Coarse	High	100	100	100	1,259
CLECG3D503.0	D5	Coarse	High	100	100	100	473
CLECG3E303.0	E3	Coarse	High	100	100	100	843
CLECG3F403.0	F4	Coarse	High	100	100	100	1,161
CLECG3G503.0	G5	Coarse	High	100	100	100	1,587

Range:                    100            100            100            473 - 1,590

Median:                    NC            NC            NC            1,020

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFCG3A203.0	A2	Coarse	High	100	313	100	2,105
REFCG3B103.0	B1	Coarse	High	100	100	100	1,597
REFCG3C203.0	C2	Coarse	High	100	100	100	2,067
REFCG3D603.0	D6	Coarse	High	100	100	100	1,372
REFCG3E603.0	E6	Coarse	High	100	100	100	1,027
REFCG3F603.0	F6	Coarse	High	100	100	100	1,056

Range:                    100            100 - 313            100            1,030 - 2,110

Median:                    NC            NC            NC            1,480

Note:                    Values reported as "100" are nondetects with a detection limit of 100.  
 NC =                    No medians calculated because at least half the reported values were below  
                               the method detection limit.  
 µg/kg =                Micrograms per kilogram.

**TABLE A3k. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE - GRID 3 - 7.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (mg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLECG3B407.5	B4	Coarse	Low	1	6.44	4.59	33.6
CLECG3C607.5	C6	Coarse	Low	4.06	43.0	32.8	191
CLECG3D507.5	D5	Coarse	Low	1	7.92	8.21	76.6
CLECG3E307.5	E3	Coarse	Low	1	9.50	7.73	48.1
CLECG3F407.5	F4	Coarse	Low	1	10.0	7.57	71.1
CLECG3G507.5	G5	Coarse	Low	5.85	38.2	25.4	112

Range:                    1 - 5.85      6.44 - 43.0    4.59 - 32.8    33.6 - 191

Median:                    NC                    9.77                    7.97                    73.9

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFCG3A207.5	A2	Coarse	Low	1	3.81	2.48	21.1
REFCG3D607.5	D6	Coarse	Low	7.35	21.9	31.7	177
REFCG3E607.5	E6	Coarse	Low	5.69	13.5	19.6	98.7
REFCG3G407.5	G4	Coarse	Low	2.55	14.3	10.2	47.3

Range:                    1 - 7.35      3.81 - 21.9    2.48 - 31.7    21.1 - 177

Median:                    4.12                    13.9                    14.9                    73.0

Note:                    Values reported as "1" are nondetects with a detection limit of 1.  
 NC =                    No medians calculated because at least half the reported values were below  
                                  the method detection limit.  
 $\mu\text{g}/\text{kg}$  =                    Micrograms per kilogram.

**TABLE A3I. VOLATILE ORGANIC COMPOUND CONCENTRATIONS  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE - GRID 4 - 6.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (mg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLECG4C606.5	C6	Coarse	Low	1	17.2	6.28	166
CLECG4D706.5	D7	Coarse	Low	4.11	28.4	10.7	135
CLECG4F506.5	F5	Coarse	Low	1	14.8	4.96	116
CLECG4G406.5	G4	Coarse	Low	1	11.6	3.56	48.7

Range:                    1 - 4.11      11.6 - 28.4    3.56 - 10.7    48.7 - 166

Median:                    NC                    16.0            5.62            126

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFCG4B606.5	B6	Coarse	Low	5.72	51.4	43.3	749
REFCG4C706.5	C7	Coarse	Low	1	8.09	2.37	24.8
REFCG4D306.5	D3	Coarse	Low	1	3.54	1	50.3
REFCG4F306.5	F3	Coarse	Low	2.10	12.9	4.39	59.7
REFCG4G506.5	G5	Coarse	Low	1	1	1	5.55

Range:                    1 - 5.72      1 - 51.4      1 - 43.3      5.55 - 749

Median:                    NC                    8.09            2.37            50.3

Note:                    Values reported as "1" are nondetects with a detection limit of 1.  
 NC =                    No medians calculated because at least half the reported values were below the method detection limit.  
 µg/kg =                Micrograms per kilogram.



**TABLE A3m. VOLATILE ORGANIC COMPOUND CONCENTRATIONS IN INTEGRITY SAMPLES  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
SBA SITE**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (ng/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLEAG1A50INT	A5	Fine	Low	1	1	1	1
CLEAG1B10INT	B1	Fine	Low	1	1	1	1
CLEAG1C30INT	C3	Fine	Low	1	1	1	1
CLEAG1D70INT	D7	Fine	Low	1	1	1	1
CLEAG1E10INT	E1	Fine	Low	5,700	1	4,066	212
CLEAG1F30INT	F3	Fine	Low	1	1	1	1
CLEAG1G50INT (02R)	G5	Fine	Low	114	1	3.17	1

Range:                    1 - 5,700                    1                    1 - 4,070                    1 - 212

Median:                    NC                    NC                    NC                    NC

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFAG1A30INT	A3	Fine	Low	1	1	1	1
REFAG1B20INT	B2	Fine	Low	1	1	1	1
REFAG1C20INT	C2	Fine	Low	1	1	1	1
REFAG1D40INT	D4	Fine	Low	1	1	1	1
REFAG1E40INT	E4	Fine	Low	1	1	1	1
REFAG1F20INT	F2	Fine	Low	1	1	1	1
REFAG1G70INT	G7	Fine	Low	1	1	1	1

Range:                    1                    1                    1                    1

Median:                    NC                    NC                    NC                    NC

Note:                    Values reported as "1" are nondetects with a detection limit of 1.  
 NC =                    No medians calculated because at least half the reported values were below  
                               the method detection limit.  
 µg/kg =                    Micrograms per kilogram.

**TABLE A3n. VOLATILE ORGANIC COMPOUND CONCENTRATIONS IN INTEGRITY SAMPLES  
FOR ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (mg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
<b>ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER DATA</b>							
CLECG1A10INT	A1	Coarse	Low	1	1	1	1
CLECG1C10INT	C1	Coarse	Low	1	1	1	1
CLECG1D30INT	D3	Coarse	Low	1	1	1	1
CLECG1E70INT	E7	Coarse	Low	1	1	1	1
CLECG1F60INT	F6	Coarse	Low	1	1	1	1

Range:                    1                    1                    1                    1

Median:                    NC                    NC                    NC                    NC

<b>REFERENCE SAMPLING METHOD DATA</b>							
REFCG1A30INT	A3	Coarse	Low	1	1	1	1
REFCG1B30INT	B3	Coarse	Low	1	1	1	1
REFCG1D50INT	D5	Coarse	Low	1	1	1	1
REFCG1E10INT	E1	Coarse	Low	1	1	1	1
REFCG1G70INT	G7	Coarse	Low	1	1	1	1

Range:                    1                    1                    1                    1

Median:                    NC                    NC                    NC                    NC

Note:                    Values reported as "1" are nondetects with a detection limit of 1.  
 NC =                    No medians calculated because at least half the reported values were below  
                               the method detection limit.  
 $\mu\text{g}/\text{kg}$  =                    Micrograms per kilogram.



**APPENDIX A4**  
**STATISTICAL SUMMARY OF MANN-WHITNEY TEST**

**TABLE A4a. COMPARATIVE SUMMARY OF MANN-WHITNEY STATISTICS FOR THE ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD**

<b>Sampling Location</b>	<b>cis-1,2-DCE</b>	<b>1,1,1-TCA</b>	<b>TCE</b>	<b>PCE</b>
Site: <b>SBA</b> Grid: <b>1</b> Depth: <b>9.5 feet</b> Soil Type: <b>Fine</b> Concentration: <b>High</b>	NO	NC (ALL ND)	NO	NC (9)
Site: <b>SBA</b> Grid: <b>2</b> Depth: <b>3.5 feet</b> Soil Type: <b>Fine</b> Concentration: <b>Low</b>	NC (4)	NC (ALL ND)	<b>YES</b>	NC (ALL ND)
Site: <b>SBA</b> Grid: <b>3</b> Depth: <b>9.5 feet</b> Soil Type: <b>Fine</b> Concentration: <b>High</b>	NO	NC (ALL ND)	NO	NC (1)
Site: <b>SBA</b> Grid: <b>4</b> Depth: <b>9.5 feet</b> Soil Type: <b>Fine</b> Concentration: <b>Low</b>	NO	NC (ALL ND)	NO	NC (ALL ND)
Site: <b>CSC</b> Grid: <b>1</b> Depth: <b>3.0 feet</b> Soil Type: <b>Coarse</b> Concentration: <b>High</b>	NC (ALL ND)	NC (4)	NC (ALL ND)	NC (9)
Site: <b>CSC</b> Grid: <b>1</b> Depth: <b>6.5 feet</b> Soil Type: <b>Coarse</b> Concentration: <b>Low</b>	NO	NO	NO	NO
Site: <b>CSC</b> Grid: <b>2</b> Depth: <b>3.0 feet</b> Soil Type: <b>Coarse</b> Concentration: <b>High</b>	NC (ALL ND)	NC (3)	NC(4)	<b>YES</b>

**TABLE A4a. COMPARATIVE SUMMARY OF MANN-WHITNEY STATISTICS FOR THE ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD (continued)**

<b>Sampling Location</b>	<b>cis-1,2-DCE</b>	<b>1,1,1-TCA</b>	<b>TCE</b>	<b>PCE</b>
Site: <b>CSC</b> Grid: <b>3</b> Depth: <b>3.0 feet</b> Soil Type: <b>Coarse</b> Concentration: <b>High</b>	NC (ALL ND)	NC (1)	NC (ALL ND)	NO
Site: <b>CSC</b> Grid: <b>3</b> Depth: <b>7.5 feet</b> Soil Type: <b>Coarse</b> Concentration: <b>Low</b>	NC (5)	NO	NO	NO
Site: <b>CSC</b> Grid: <b>4</b> Depth: <b>6.5 feet</b> Soil Type: <b>Coarse</b> Concentration: <b>Low</b>	NC (3)	NO	NC (7)	NO

Notes:

- NC No medians calculated because at least half the reported values were below the method detection limit.
- (ALL ND) Level of contaminants in all samples tested were below the method detection limits.
- (X) Number of samples in which some level of contamination was detected. The number of samples containing some contaminants in the referenced test series was deemed too low for statistical analysis (that is, there were too many "0" values).
- NO Level of difference between tested populations was not statistically significant.
- YES Level of significance between tested populations was  $p \leq 0.10$ .

**TABLE A4b. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
SBA SITE**

Site: **SBA**  
 Grid: **1**  
 Depth: **9.5 feet**  
 Soil Type: **Fine**  
 Concentration: **High**

**Sum of Rank Statistics**

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
ESP (1)	5	26		33	
Reference (2)	7	52		45	
$N_1N_2 + [N_1(N_1 + 1)]/2$		50		50	
$N_1N_2 + [N_2(N_2 + 1)]/2$		63		63	
Mann-Whitney 1		24		17	
Mann-Whitney 2		11		18	
Mann-Whitney > 30?		NO		NO	

Site: **SBA**  
 Grid: **2**  
 Depth: **3.5 feet**  
 Soil Type: **Fine**  
 Concentration: **Low**

**Sum of Rank Statistics**

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
ESP (1)	7			70	
Reference (2)	7			35	
$N_1N_2 + [N_1(N_1 + 1)]/2$				77	
$N_1N_2 + [N_2(N_2 + 1)]/2$				77	
Mann-Whitney 1				7	
Mann-Whitney 2				42	
Mann-Whitney > 41?				<b>YES</b>	

**TABLE A4b. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
SBA SITE (continued)**

Site: **SBA**  
 Grid: **3**  
 Depth: **9.5 feet**  
 Soil Type: **Fine**  
 Concentration: **High**

**Sum of Rank Statistics**

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
ESP (1)	7	40		33	
Reference (2)	4	26		33	
$N_1N_2 + [N_1(N_1 + 1)]/2$		56		56	
$N_1N_2 + [N_2(N_2 + 1)]/2$		38		38	
Mann-Whitney 1		16		23	
Mann-Whitney 2		12		5	
Mann-Whitney > 25?		NO		NO	

Site: **SBA**  
 Grid: **4**  
 Depth: **9.5 feet**  
 Soil Type: **Fine**  
 Concentration: **Low**

**Sum of Rank Statistics**

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
ESP (1)	7	46		50	
Reference (2)	7	59		55	
$N_1N_2 + [N_1(N_1 + 1)]/2$		77		77	
$N_1N_2 + [N_2(N_2 + 1)]/2$		77		77	
Mann-Whitney 1		31		27	
Mann-Whitney 2		18		22	
Mann-Whitney > 41?		NO		NO	

**TABLE A4c. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE**

Site: **CSC**  
 Grid: **1**  
 Depth: **3.0 feet**  
 Soil Type: **Coarse**  
 Concentration: **Low**

**Sum of Rank Statistics**

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
ESP (1)	3				
Reference (2)	6				
$N1N2 + [N1(N1 + 1)]/2$					
$N1N2 + [N2(N2 + 1)]/2$					
Mann-Whitney 1					
Mann-Whitney 2					
Mann-Whitney > 17?					

Site: **CSC**  
 Grid: **1**  
 Depth: **6.5 feet**  
 Soil Type: **Coarse**  
 Concentration: **Low**

**Sum of Rank Statistics**

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
ESP (1)	7	56.5	60	56	59
Reference (2)	6	31.5	31	35	32
$N1N2 + [N1(N1 + 1)]/2$		70	70	70	70
$N1N2 + [N2(N2 + 1)]/2$		63	63	63	63
Mann-Whitney 1		13.5	10	14	11
Mann-Whitney 2		31.5	32	28	31
Mann-Whitney > 36?		NO	NO	NO	NO



**TABLE A4c. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE (continued)**

Site: **CSC**  
 Grid: **2**  
 Depth: **3.0 feet**  
 Soil Type: **Coarse**  
 Concentration: **High**

**Sum of Rank Statistics**

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
ESP (1)	4				10
Reference (2)	7				56
$N1N2 + [N1(N1 + 1)]/2$					38
$N1N2 + [N2(N2 + 1)]/2$					56
Mann-Whitney 1					28
Mann-Whitney 2					10
Mann-Whitney > 25?					<b>YES</b>

Site: **CSC**  
 Grid: **3**  
 Depth: **3.0 feet**  
 Soil Type: **Coarse**  
 Concentration: **High**

**Sum of Rank Statistics**

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
ESP (1)	7				35
Reference (2)	6				56
$N1N2 + [N1(N1 + 1)]/2$					70
$N1N2 + [N2(N2 + 1)]/2$					63
Mann-Whitney 1					35
Mann-Whitney 2					7
Mann-Whitney > 36?					NO

**TABLE A4c. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE ENVIRONMENTALIST'S SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE (continued)**

Site: **CSC**  
 Grid: **3**  
 Depth: **7.5 feet**  
 Soil Type: **Coarse**  
 Concentration: **Low**

**Sum of Rank Statistics**

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
ESP (1)	6		33	32	35
Reference (2)	4		22	23	20
$N1N2 + [N1(N1 + 1)]/2$			45	45	45
$N1N2 + [N2(N2 + 1)]/2$			34	34	34
Mann-Whitney 1			12	13	10
Mann-Whitney 2			12	11	14
Mann-Whitney > 22?			NO	NO	NO

Site: **CSC**  
 Grid: **4**  
 Depth: **6.5 feet**  
 Soil Type: **Coarse**  
 Concentration: **Low**

**Sum of Rank Statistics**

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
ESP (1)	4		25		24
Reference (2)	5		20		21
$N1N2 + [N1(N1 + 1)]/2$			30		30
$N1N2 + [N2(N2 + 1)]/2$			35		35
Mann-Whitney 1			5		6
Mann-Whitney 2			15		14
Mann-Whitney > 19?			NO		NO

Note: (N > xx) **Mann-Whitney** value must be greater than the given value to be significant at the 0.05 level of statistical significance. This is a two-tailed test.

**Statistical Source:**

Rohlf, F. James and Robert R. Sokal. 1969. *Statistical Tables*. W. H. Freeman and Company. Table CC. Critical values of the Mann-Whitney statistic, page 241.



**APPENDIX A5**  
**STATISTICAL SUMMARY OF SIGN TEST**

**TABLE A5a. SIGN TEST SUMMARY  
COMPARISON OF MEDIAN VOC CONCENTRATIONS FOR ENVIRONMENTALIST'S  
SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
SBA SITE**

<b>Site Description</b>	<b>Technology</b>	<b>Median cis-1,2-DCE</b>	<b>Median 1,1,1- TCA</b>	<b>Median TCE</b>	<b>Median PCE</b>
Site: <b>SBA</b> Grid: <b>1</b> Depth: <b>9.5 feet</b> Concentration: <b>High</b>	Reference Sampling Method	86,700	ALL ND	276,000	1,630
	Subsoil Probe Sampler	65,800	ALL ND	78,900	570
Site: <b>SBA</b> Grid: <b>2</b> Depth: <b>3.5 feet</b> Concentration: <b>Low</b>	Reference Sampling Method	NC(1)	ALL ND	56.9	ALL ND
	Subsoil Probe Sampler	NC(3)	ALL ND	143	ALL ND
Site: <b>SBA</b> Grid: <b>3</b> Depth: <b>9.5 feet</b> Concentration: <b>High</b>	Reference Sampling Method	903	ALL ND	38,500	ALL ND
	Subsoil Probe Sampler	891	ALL ND	26,300	NC(1)
Site: <b>SBA</b> Grid: <b>4</b> Depth: <b>9.5 feet</b> Concentration: <b>Low</b>	Reference Sampling Method	13.2	ALL ND	1,710	ALL ND
	Subsoil Probe Sampler	9.63	ALL ND	1,230	ALL ND
Number of pairs in which Reference Sampling Method median is higher		3	0	3	1
Number of pairs in which Subsoil Probe Sampler median is higher		0	0	1	0

Notes:

- NC No medians calculated because at least half the reported values were below the method detection limit.
- ALL ND Level of contaminants in all samples tested were below the method detection limits.
- (X) Number of samples in which some level of contamination was detected. The number of samples containing some contaminants in the referenced test series was deemed too low for statistical analysis (that is, there were too many "0" values).

**TABLE A5b. SIGN TEST SUMMARY  
COMPARISON OF MEDIAN VOC CONCENTRATIONS FOR ENVIRONMENTALIST'S  
SUBSOIL PROBE SAMPLER AND REFERENCE SAMPLING METHOD  
CSC SITE**

<b>Site Description</b>	<b>Technology</b>	<b>Median cis-1,2-DCE</b>	<b>Median 1,1,1- TCA</b>	<b>Median TCE</b>	<b>Median PCE</b>
Site: <b>CSC</b> Grid: <b>1</b> Depth: <b>3.0</b> Concentration: <b>High</b>	Reference Sampling Method	ALL ND	NC(3)	ALL ND	2,530
	Subsoil Probe Sampler	ALL ND	NC(1)	ALL ND	4,320
Site: <b>CSC</b> Grid: <b>1</b> Depth: <b>6.5 feet</b> Concentration: <b>Low</b>	Reference Sampling Method	2.20	25.9	6.45	111
	Subsoil Probe Sampler	5.29	38.8	11.7	294
Site: <b>CSC</b> Grid: <b>2</b> Depth: <b>3.0 feet</b> Concentration: <b>High</b>	Reference Sampling Method	ALL ND	NC(3)	126	2,000
	Subsoil Probe Sampler	ALL ND	ALL ND	ALL ND	454
Site: <b>CSC</b> Grid: <b>3</b> Depth: <b>3.0 feet</b> Concentration: <b>High</b>	Reference Sampling Method	ALL ND	NC(1)	ALL ND	1,490
	Subsoil Probe Sampler	ALL ND	ALL ND	ALL ND	1,020
Site: <b>CSC</b> Grid: <b>3</b> Depth: <b>7.5 feet</b> Concentration: <b>Low</b>	Reference Sampling Method	4.12	13.9	14.9	73.0
	Subsoil Probe Sampler	NC(2)	9.77	7.97	73.9
Site: <b>CSC</b> Grid: <b>4</b> Depth: <b>6.5 feet</b> Concentration: <b>Low</b>	Reference Sampling Method	NC(2)	8.09	2.37	50.3
	Subsoil Probe Sampler	NC (1)	16.0	5.62	126
Number of pairs in which Reference Sampling Method median is higher		0	1	1	2
Number of pairs in which Subsoil Probe Sampler median is higher		1	2	2	4

Notes:

- NC No medians calculated because at least half the reported values were below the method detection limit.
- ALL ND Level of contaminants in all samples tested were below the method detection limits.
- (X) Number of samples in which some level of contamination was detected. The number of samples containing some contaminants in the referenced test series was deemed too low for statistical analysis (that is, there were too many "0" values).