&EPA

Environmental Technology Verification Report

Soil Sampling Technology

Simulprobe Technologies, Inc. Core Barrel Sampler

SITE

Environmental Technology Verification Report

Soil Sampler

Simulprobe® Technologies, Inc. Core Barrel Sampler

Prepared by

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Contract No. 68-C5-0037

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Office of Research and Development
U.S. Environmental Protection

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Notice

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, D.C. 20460

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ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM
VERIFICATION STATEMENT

TECHNOLOGY TYPE:	**SOIL SAMPLER**
APPLICATION:	**SUBSURFACE SOIL SAMPLING**
TECHNOLOGY NAME:	**SIMULPROBE® CORE BARREL SAMPLER**
COMPANY:	**SIMULPROBE® TECHNOLOGIES, INC.**
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ETV PROGRAM DESCRIPTION

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

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 SimulProbe® Core Barrel Sampler along with three other soil and two soil gas sampling technologies. This verification statement focuses on the SimulProbe® Core Barrel Sampler; similar statements have been prepared for each of the other technologies. The performance of the Core Barrel Sampler 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 Core Barrel Sampler 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, SimulProbe®Technologies, Inc., SimulProbe®Core Barrel Sampler*, EPA 600/R-98/094.

TECHNOLOGY DESCRIPTION

The Core Barrel Sampler was designed to collect subsurface soil samples and may be advanced by using direct-push or drilling platforms. The sampler is constructed of steel and consists of a split core barrel (similar to a split-spoon sampler), a drive shoe at the bottom of the unit, and a core barrel head at the top of the unit. The sampler has a uniform 2-inch outer diameter and is 27 inches long. It is capable of recovering a discrete sample in the form of a 1.25-inch-diameter and 27-inch-long soil core. Multiple 5.25-inch-long stainless-steel liners or a single full-length plastic liner can be used inside the sampler to contain the soil core. The drive shoe component of the sampler is equipped with a slide mechanism and has an optional drive tip for direct-push, discrete sampling applications. The drive tip (called SPLAT™—SimulProbe® Latch Activated Tip) seals the sample chamber until the target depth is reached. The SPLAT™ is released at the target depth to collect a discrete sample. Direct-push advancement platforms were used with an unlined Core Barrel Sampler for this evaluation.

VERIFICATION OF PERFORMANCE

The demonstration data indicate the following performance characteristics for the Core Barrel Sampler:

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 42 samples collected at the SBA site ranged from 63 to 100 percent, with an average sample recovery of 95 percent. Sample recoveries from 40 samples collected at the CSC site ranged from 31 to 100 percent, with an average sample recovery of 68 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 Core Barrel Sampler and the reference sampler indicates that the Core Barrel Sampler achieved higher sample recoveries in the clay soil at the SBA site and lower sample recoveries 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 Core Barrel Sampler and the reference sampling method at six sampling depths in nine grids (five at the SBA site and four at the CSC site) were analyzed for VOCs. For 22 of the 24 Core Barrel Sampler and reference sampling method pairs (12 at the SBA site and 12 at the CSC site), a statistical analysis using the Mann-Whitney test indicated no significant statistical difference at the 95 percent level between the VOC concentrations in samples collected with the Core Barrel Sampler and those collected with the reference sampling method. A statistically significant difference was identified for two sample pairs collected at the CSC site. Analysis of the SBA site data, using the sign test, indicated no statistical difference between the data obtained by the Core Barrel Sampler and by the reference sampling method. However, at the CSC site, the sign test indicated that data obtained by the Core Barrel Sampler 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 coarse-grained soils than does the Core Barrel Sampler.

Sample Integrity: Seven integrity samples were collected with the Core Barrel Sampler at each site to determine if potting soil in an unlined sampler became contaminated after it was advanced through a zone of high VOC concentrations. Seven integrity samples were collected with the reference sampling method at the SBA site and five integrity samples were collected at the CSC site. For the Core Barrel Sampler, VOCs were detected in eight of the 14 integrity samples: six at the SBA site and two at the CSC site. The range of VOC concentrations detected above the analytical detection limit in the potting soil at the SBA site was: cis-1,2-DCE (2.10 to 4,410 micrograms per kilogram [μg/kg]); TCE (5.28 to 1,960 μg/kg); and PCE (less than 1 to 7.05 μg/kg). The range of VOC concentrations in the potting soil at the CSC site was: cis-1,2-DCE (8.04 to 9.33 μg/kg); 1,1,1-TCA (108 to 218 μg/kg); TCE (21.5 to 39.4 μg/kg); and PCE (286 to 602 μg/kg). These results indicate that the integrity of the unlined chamber in the Core Barrel Sampler may not be preserved when the sampler is advanced through highly

contaminated soils. Results of sample integrity tests for the reference sampling 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. Additionally, the developer claims that use of liners will reduce the potential for cross-contamination.

Reliability and Throughput: At the SBA site (clay soil), the Core Barrel Sampler collected a sample from the desired depth on the initial attempt 60 percent of the time. Sample collection in the initial push was achieved 76 percent of the time at the CSC site (sandy soil). The initial push success rate was less than 100 percent because of sampler malfunction and breakage. By conducting multiple pushes using a solid point drive to create a pilot hole, the Core Barrel Sampler collected all samples required for this demonstration. The pilot hole greatly reduced the amount of hammering required to advance the sampler and subsequent wear on the sampler. During the performance test in Grid 5 at the CSC site, all attempts to collect a sample in saturated sand at a 40-foot depth were unsuccessful. 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 the Core Barrel Sampler to set up on a sampling point, collect the specified sample, grout the hole, decontaminate the sampler, and move to a new sampling location was 21.4 minutes per sample at the SBA site and 11.8 minutes per sample at the CSC site. 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 two-person sampling crew collected soil samples with the Core Barrel Sampler at the SBA and CSC sites, and a three-person sampling crew collected soil samples using the reference sampling method at both sites. Additional personnel were present at both sites to observe and assist with demonstration sampling, as necessary.

Cost: Based on the demonstration results and information provided by the vendor, the Core Barrel Sampler can be purchased for $2,700; the direct push platform can be rented for $750 per day plus $900 mobilization/ demobilization per site. Operating costs for the Core Barrel Sampler ranged from $2,880 to $4,860 at the clay soil site and $1,830 to $3,060 at the sandy soil site. For this demonstration, reference sampling was procured at a lump sum of $13,400 for the clay soil site and $7,700 for the sandy soil site. Oversight costs for the reference sampling 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 subsurface soil sampling method.

A qualitative performance assessment of the Core Barrel Sampler indicated that (1) reliability of the sampler can be affected by improper activation of the SPLAT™; (2) the sampler is easy to use and requires approximately 1 hour of training to operate; (3) logistical requirements are similar to those of the reference sampling method; (4) sample handling is similar to the reference method; (5) performance range is primarily a function of the advancement platform; and (6) no drill cuttings are generated when using the Core Barrel Sampler with a push platform.

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

Gary J. Foley, Ph.D.
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Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's natural resources. Under the mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development (ORD) provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

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

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

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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
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
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
RPD	relative percent difference
SBA	Small Business Administration
SITE	Superfund Innovative Technology Evaluation
SMC	Superior Manufacturing Company
SOP	standard operating procedure
SPLAT™	SimulProbe® Latch Activated Tip
1,1,1-TCA	1,1,1-trichloroethane
TCE	trichloroethene
Fg/kg	micrograms per kilogram
VOC	volatile organic compound

Acknowledgments

Executive Summary

In May and June 1997, the U.S. Environmental Protection Agency sponsored a demonstration of the SimulProbe® Core Barrel Sampler, three other soil sampling technologies, and two soil gas sampling technologies. This Environmental Technology Verification Report presents the results of the Core Barrel Sampler demonstration; similar reports have been published for each of the other soil and soil gas sampling technologies.

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

The Core Barrel Sampler 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; 1,1,1-trichloroethane; trichloroethene; 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 Core Barrel Sampler 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 Core Barrel Sampler:

- C   Compared to the reference method, average sample recoveries for the Core Barrel Sampler were higher in clay soil and lower in sandy soil.

- C   At the SBA site, no statistically significant difference was detected between VOC concentrations in soil collected using the Core Barrel Sampler and the reference sampling method. A significant statistical difference between VOC concentrations was detected for two of the 12 Core Barrel Sampler and reference sample method pairs collected at the CSC site. The data also suggest that the reference sampler tends to yield higher results than the Core Barrel Sampler in sampling coarse-grained soils.

- C   In eight of the 14 integrity test samples, the integrity of an unlined chamber of the Core Barrel Sampler was not preserved when the sampler was advanced through contaminated soils.

- C   The reliability of the Core Barrel Sampler to collect a sample in the first attempt was lower than that of the reference sampling method in both clay and sandy soils. The average sample retrieval time for the Core Barrel Sampler was 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 using the Core Barrel Sampler was lower than the reference 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.

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 Core Barrel Sampler performance.

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 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 SimulProbe® Core Barrel Sampler. Separate ETVRs have been published for the remaining soil and soil gas sampling technologies.

Technology Verification Process

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

Needs Identification and Technology Selection

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

C Designed for use in the field or in a mobile laboratory

C Applicable to a variety of environmentally contaminated sites

C Has potential for resolving problems for which current methods are unsatisfactory

C Has costs that are competitive with current methods

C Performs better than current methods in areas such as data quality, sample preparation, or analytical turnaround time

C Uses techniques that are easier and safer than current methods

C Is commercially available

Demonstration Planning and Implementation

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

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

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 SimulProbe® Core Barrel Sampler relative to the hollow-stem auger drilling and split-spoon sampling reference method.

This document summarizes the results of an evaluation of the SimulProbe® Core Barrel Sampler 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.

Chapter 2
Technology Description

This chapter describes the SimulProbe® Technologies, Inc., Core Barrel Sampler, 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 Core Barrel Sampler was developed by SimulProbe® Technologies, Inc. solely for collection of soil samples. The physical limitations on the operation of the Core Barrel Sampler depend on the method of sampler advancement and the nature of the subsurface matrix. The technology is primarily restricted to unconsolidated soil free of large cobbles or boulders. Sediments containing pebbles supported by a finer-grained matrix can also be sampled. The developer claims that the Core Barrel Sampler can be used to sample soil for VOCs, semivolatile organic compounds, metals, general minerals, and pesticides. Additional developer claims for the performance of the Core Barrel Sampler are that it:

- C   Prevents cross-contamination and preserve sample integrity

- C   Collects samples that are chemically representative of the target interval

- C   Can be used to collect either discrete or continuous soil samples

- C   Works in unconsolidated materials

- C   Requires no specialized training to operate

During the demonstration, the developer's claims regarding the ability of the Core Barrel Sampler to be used to sample for VOCs, preserve sample integrity, and collect representative discrete soil samples in consolidated and unconsolidated materials were evaluated.

Components and Accessories

The Core Barrel Sampler (Figure 2-1) has the appearance of a split-spoon sampler in that it has two core barrel halves, a drive shoe at the bottom, and a core barrel head at the top of the unit. The sampler has a uniform 2-inch outer diameter and is 27 inches long. It is capable of recovering a discrete sample that measures 1.25 inches in diameter and 27 inches long. Multiple 5.25-inch stainless-steel liners or one full-length plastic liner can be used to contain the core. The drive

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STANDARD AW PIN OR AW TO GEOPROBE
CUSTOM THREAD DESIGN AVAILABLE

CORE BARREL HEAD

REED VALVE (OPTIONAL FOR SATURATED ZONE)
(NON-ESSENTIAL FOR VADOSE ZONE)

CORE BARREL
BASE

CORE BARREL
COVER

RUBBER
WIPE SEAL

COVER SLEEVE

SPLAT TIP
ASSEMBLY

SHOE SLEEVE

DRIVE SHOE
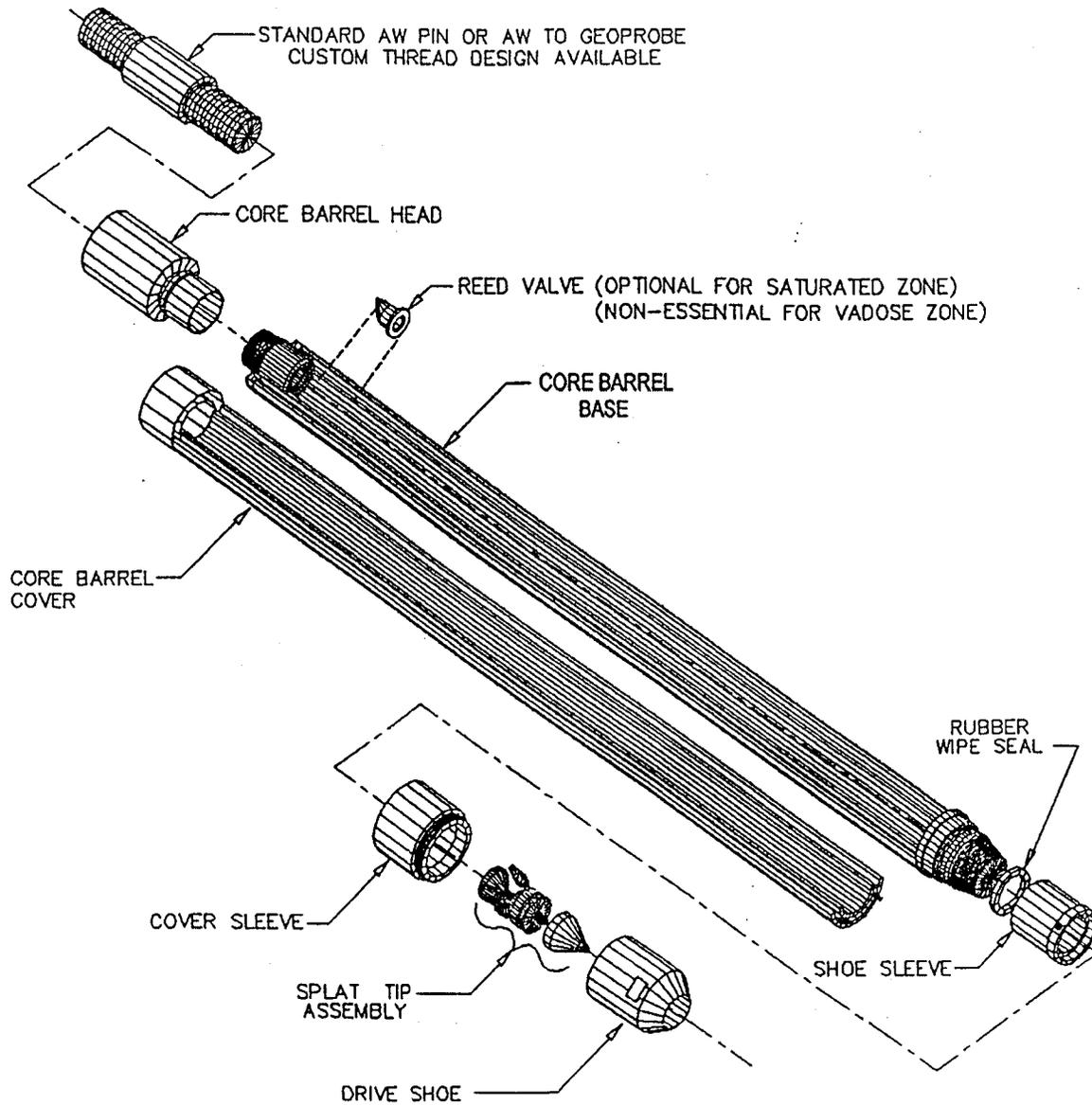
Figure 2-1. Core Barrel Assembly (Simulprobe®, 1997)

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shoe is equipped with a slide mechanism and has an optional drive tip for direct-push applications. The drive tip (called SPLAT™—SimulProbe® Latch Activated Tip) is recoverable after each sampling event, since the core sample pushes the SPLAT™ to the top of the core barrel. The SPLAT™ (Figure 2-2) is composed of a drive tip, a point base, point set, retractors, two O-rings, and a retractor band. Each of the SPLAT™ components can be purchased individually. The SPLAT™ uses collapsible retractors that hold it in place as the sampler is advanced. These retractors can be collapsed at the target sampling depth by pulling the sampler back 2 to 3 inches, allowing the SPLAT™ to move and the sampler to fill as it is advanced.

The top of the sampler assembly consists of the core barrel head and an adapter that conforms to the appropriate thread required for the use of particular extension rods. SimulProbe® manufactures an adapter to Geoprobe® B thread, Quick Rod, or cone penetrometer rods. The bottom end of the assembly consists of a shoe sleeve, a rubber wipe seal, the cover sleeve, the SPLAT™, the drive shoe, and a gooch tube (a rubber sleeve that is stretched over the Core Barrel Sampler cover sleeve interface to prevent premature activation of the SPLAT™ prior to down-hole advancement).

Tools offered by SimulProbe® include two sizes of Spanner wrenches to remove the drive shoe and shoe sleeve from the core barrel. Pipe wrenches are strongly discouraged for these tasks because they will distort the shape of the cover sleeve.

Description of Platforms

The Core Barrel Sampler is designed to be advanced by direct-push, cased-hole, and mud rotary platforms. During the demonstration, two different direct-push platforms were used. At the Small Business Administration (SBA) site, a hydraulic-powered SK58 hammer was mast-mounted on a three-quarter-ton pickup truck. The mast had a 5-foot total stroke and a maximum height of approximately 10 feet. The 800-pound platform was built by the operator and is unique. The platform is powered by an 18-horsepower motor and uses 3-foot-long Geoprobe® push rods and Geoprobe® drive and pull caps during standard operation. The foot of the platform was not designed for vertical movement; as a result, the downward push of the mast often required constant application of the hammer to advance to the desired depth. This platform capably advanced the sampler to the required target sampling depths at the SBA site.

At the Chemical Sales Company (CSC) site, a Hurricane Dual-Rig, outfitted with both a hollow-stem auger and a direct-push platform with a hydraulic force-powered MBH 175 percussion hammer, was used to advance the Core Barrel Sampler. The mast had a 5.5-foot total stroke and a maximum height of approximately 15 feet when fully extended. The estimated 1,750-pound platform is manufactured by MagnaLine and was mounted on a 1-ton pickup truck. The direct-push platform used a 4-foot-long Magna Rod. A Geoprobe® to Magna adapter and the SimulProbe®-manufactured Geoprobe® adapter were used to enable the operation of the Magna Rod 1.5-inch push/pull cap. The MBH 175 percussion hammer and the Hurricane Dual-Rig capably advanced the Core Barrel Sampler to the target sampling depths at the CSC site.

General Operating Procedures

Before use and between each sample collected during the demonstration, the Core Barrel Sampler and any supporting equipment that may come in contact with the sample were decontaminated.

The sampler was then assembled according to the following protocol: (1) the core barrel cover was laid on top of the core barrel base and the two halves were slid snugly together, (2) the guide pins
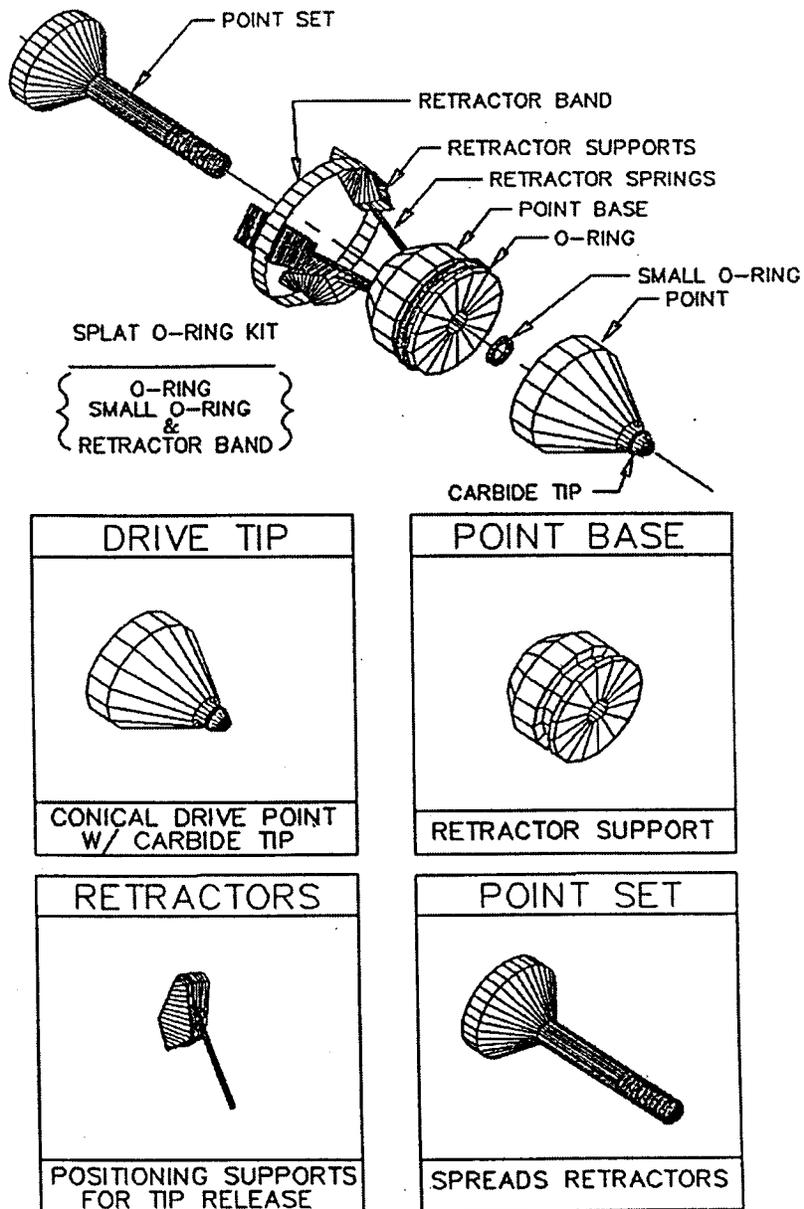
Figure 2-2. SPLAT™ Assembly Discrete Sampling Mode (SimulProbe®, 1997)

were aligned with their corresponding holes as the split halves were slid together, (3) the core barrel head was screwed into the top of the Core Barrel Sampler, (4) a rubber wipe seal was pulled onto the bottom end of the core barrel base half, (5) the cover sleeve was slid over the rubber wipe seal; (6) the shoe sleeve was screwed over the rubber wipe seal, and (7) the drive shoe containing the SPLAT™ assembly was screwed onto the shoe sleeve and attached to the push rod.

The sampler was pushed to the beginning of the sampling interval and pulled back 2 to 3 inches. Withdrawing the sampler closed the SPLAT™, allowing it to move upward in the core barrel as the sampler was filled. The sampler was then pushed forward 24 inches and pulled back to the surface to retrieve the core barrel and soil sample.

The following procedure was followed when disassembling the sampler: (1) the Core Barrel Sampler was unscrewed from the push rod, (2) the core barrel head was unscrewed from the core barrel assembly, (3) the drive shoe and cover sleeve were unscrewed from the bottom end of the core barrel assembly, and (4) a large flathead screw driver blade was inserted into the slot near the top of the core barrel assembly and the blade was rotated to separate the two core barrel halves and obtain access to the collected soil sample.

The Core Barrel Sampler was decontaminated according to the procedures specified in the demonstration plan (PRC, 1997). At a minimum, the SPLAT™, the inside of the Core Barrel Sampler, the cover sleeve, drive shoe, and shoe sleeve were decontaminated with an Alconox® wash and potable water rinse. One person was able to decontaminate all components of one sampler in 3 to 5 minutes. A new consumables kit was used for each sample to eliminate the risk of cross-contamination through incomplete decontamination or from leakage through damaged O-rings.

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.

Developer Contact

For more developer information on the Core Barrel Sampler, please refer to Chapters 8 and 9 of this ETVR or contact the developer at:

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> Novato, California 94949
> Telephone: (714) 374-9969
> Facsimile: (714) 374-9979
> E-mail: sprobe@simulprobe.com

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 [μg/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
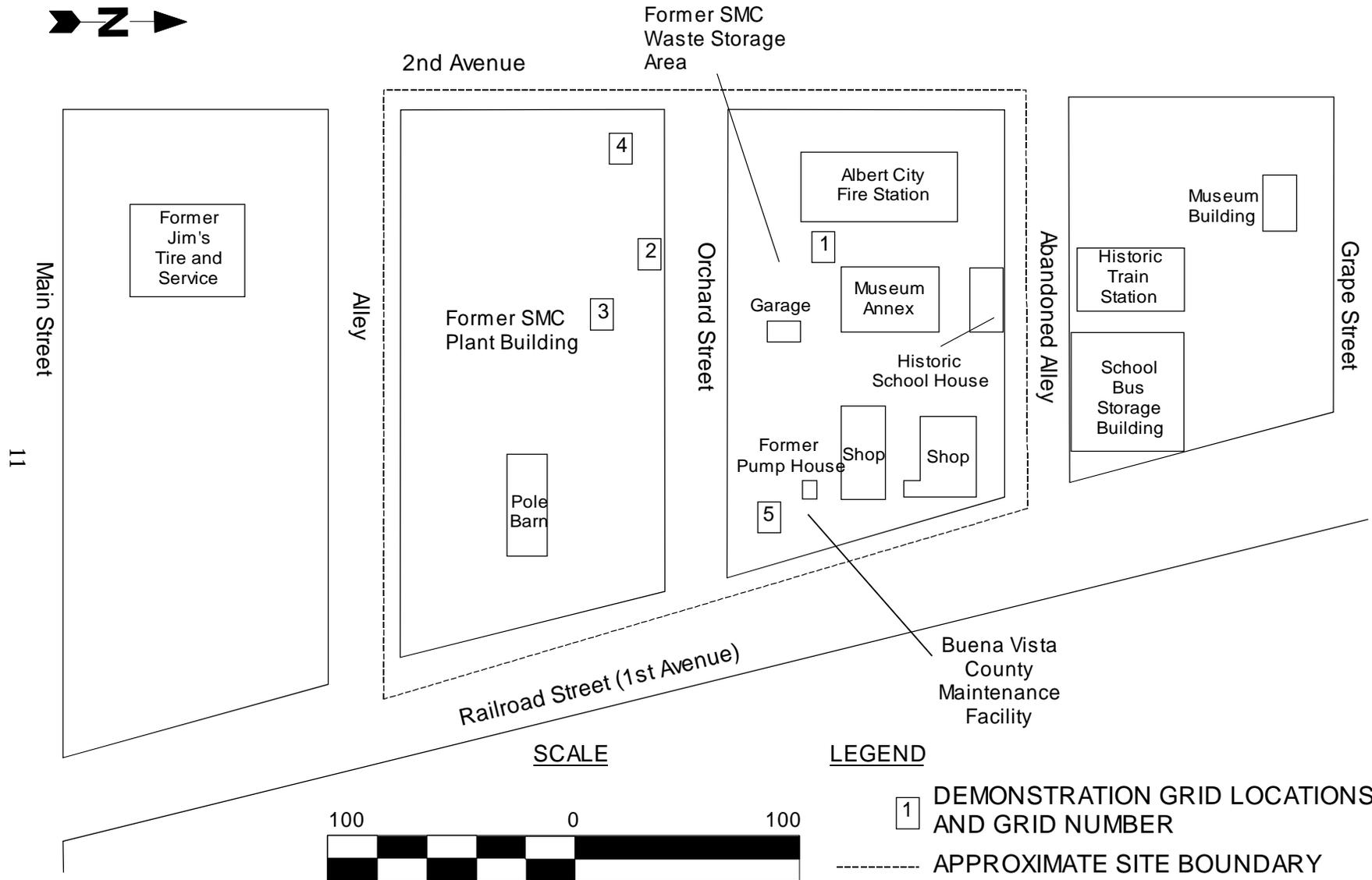
Figure 3-1. Small Business Administration Site

N

2nd Avenue

Former SMC
Waste Storage
Area

Former
Jim's
Tire and
Service

Main Street

Alley

4

2

3

Former SMC
Plant Building

Pole
Barn

Orchard Street

Garage

1

Albert City
Fire Station

Museum
Annex

Historic
School House

Former
Pump House

Shop

Shop

5

Abandoned Alley

Historic
Train
Station

School
Bus
Storage
Building

Museum
Building

Grape Street

Railroad Street (1st Avenue)

Buena Vista
County
Maintenance
Facility

11

SCALE

100   0   100

FEET

LEGEND

1 DEMONSTRATION GRID LOCATIONS
   AND GRID NUMBER

--------- APPROXIMATE SITE BOUNDARY

been razed. A pole barn is the only building currently on the former 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 below ground surface (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, which is 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
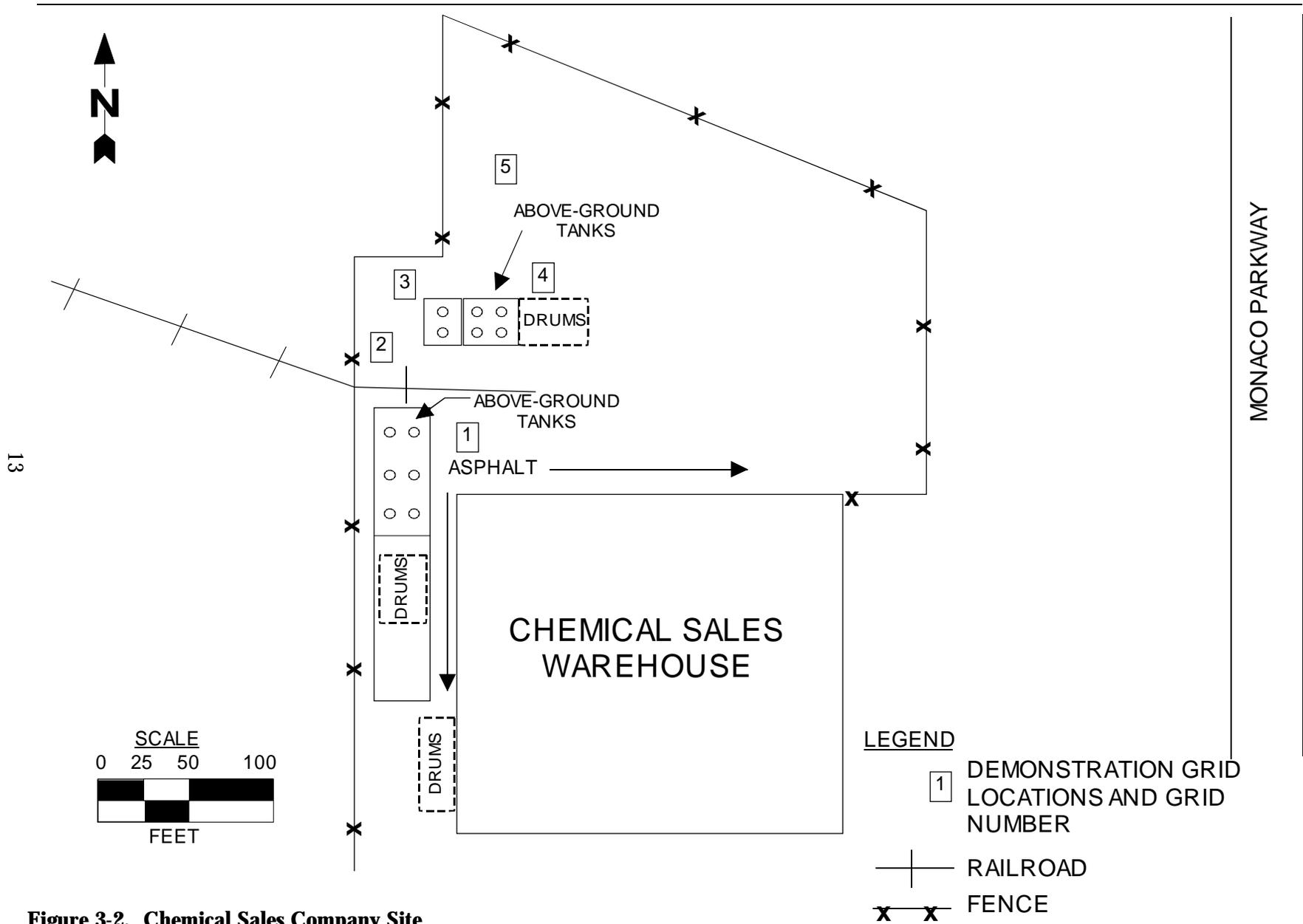
Figure 3-2. Chemical Sales Company Site

MONACO PARKWAY

N

5

ABOVE-GROUND TANKS

3

4

DRUMS

2

ABOVE-GROUND TANKS

1

ASPHALT

DRUMS

CHEMICAL SALES WAREHOUSE

DRUMS

SCALE

0   25   50   100

FEET

LEGEND

1   DEMONSTRATION GRID LOCATIONS AND GRID NUMBER

RAILROAD

X — X   FENCE

silts and clays. The alluvial aquifer also contains some poorly sorted gravel zones. The depth to water is about 30 to 40 feet bgs near the CSC warehouse.

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

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 which met the criteria set forth in the predemonstration sampling plan (PRC, 1997) and would, therefore, be acceptable for the Core Barrel Sampler 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, 10 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 10 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.

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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 Core Barrel Sampler in saturated sandy soil. The sampling depths and grids selected for the Core Barrel Sampler 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 Core Barrel Sampler Demonstration

Site	Grid	Concentration Zone	Depth (feet)
SBA (Clay Soil)	1	High	9.5
		High	13.5
	2	Low	3.5
	3	High	9.5
	4	Low	9.5
	5	Low	13.5
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[a]	Low	40.0[a]

[a] Performance test sampling location only; samples collected but not analyzed. Sampling location selected to evaluate the reliability and sample recovery of the Core Barrel Sampler in saturated sandy soil.

Demonstration Design

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

Sample Recovery

Sample recoveries for each Core Barrel Sampler 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 Core Barrel Sampler 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 Core Barrel Sampler 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 were 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™-lined septum screw cap. Each vial contained 10 mL of pesticide-grade methanol. The 40-mL

	A	B	C	D	E	F	G
1			CBS			CBS	
2		Ref.				Ref.	
3	Ref.		Ref.	CBS			CBS
4	CBS			Ref.	Ref.		
5							
6					CBS		
7		CBS					Ref.

10.5 feet (vertical)

10.5 feet (horizontal)
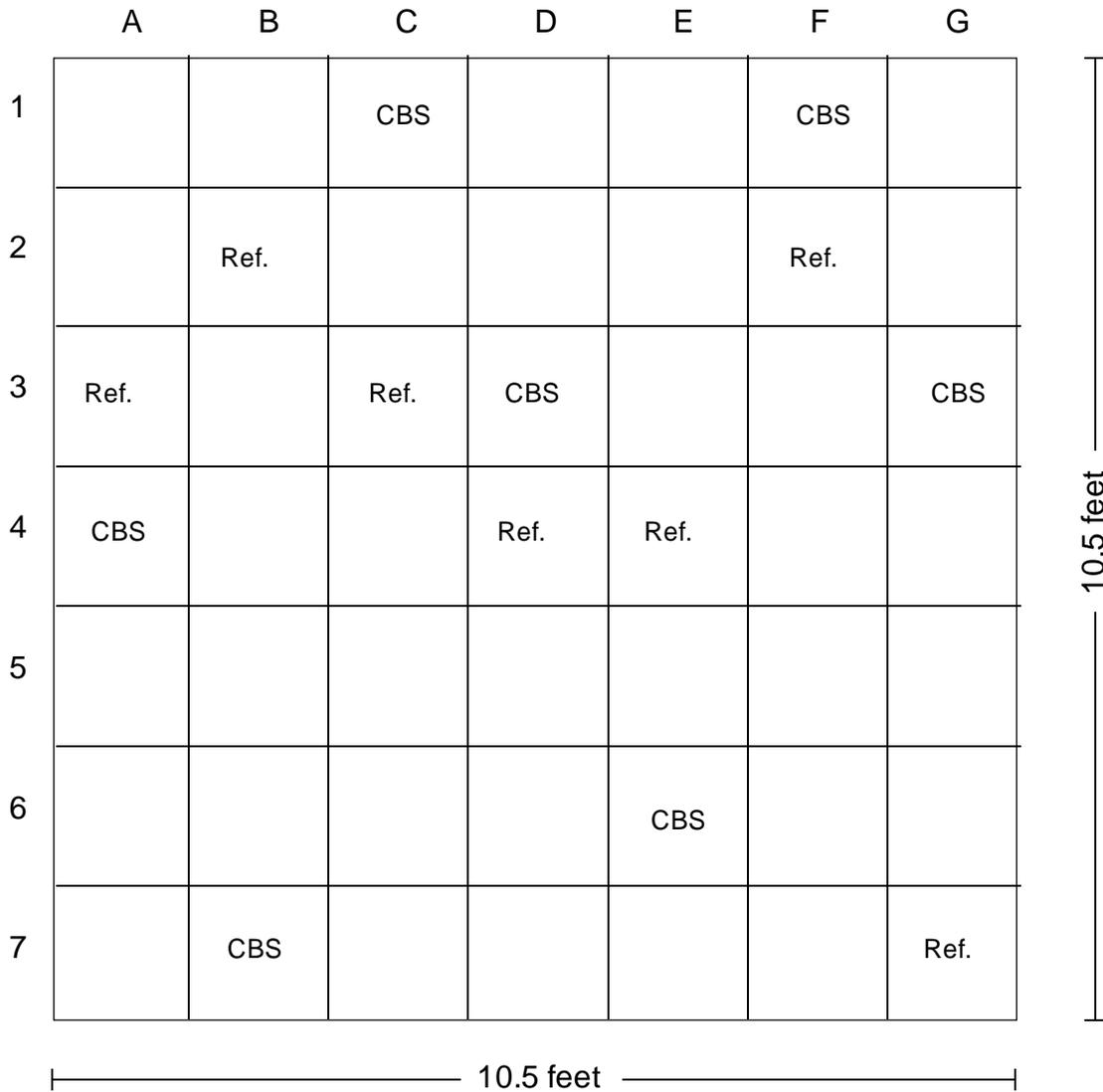
CBS   Core Barrel Sampler Location

Ref.   Reference Sampling Method Location

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

vials were labeled in the same manner as 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.

Samples were analyzed for VOCs by combining automated headspace sampling with gas chromatography (GC) analysis according to the standard operating guideline 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 its 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.

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_o) that there is no difference between the median contaminant concentrations obtained by the Core Barrel Sampler 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 # 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 Core Barrel Sampler). If, in fact, the sampling universe is uniform and there is no sampling bias, the median

	A	B	C	D	E	F	G
1	80,100						217,000
2		70,200	251,000			276,000	
3	52,800						
4				419,000	291,000		
5							
6							
7	57,900						258,000

10.5 feet (vertical)

10.5 feet (horizontal)
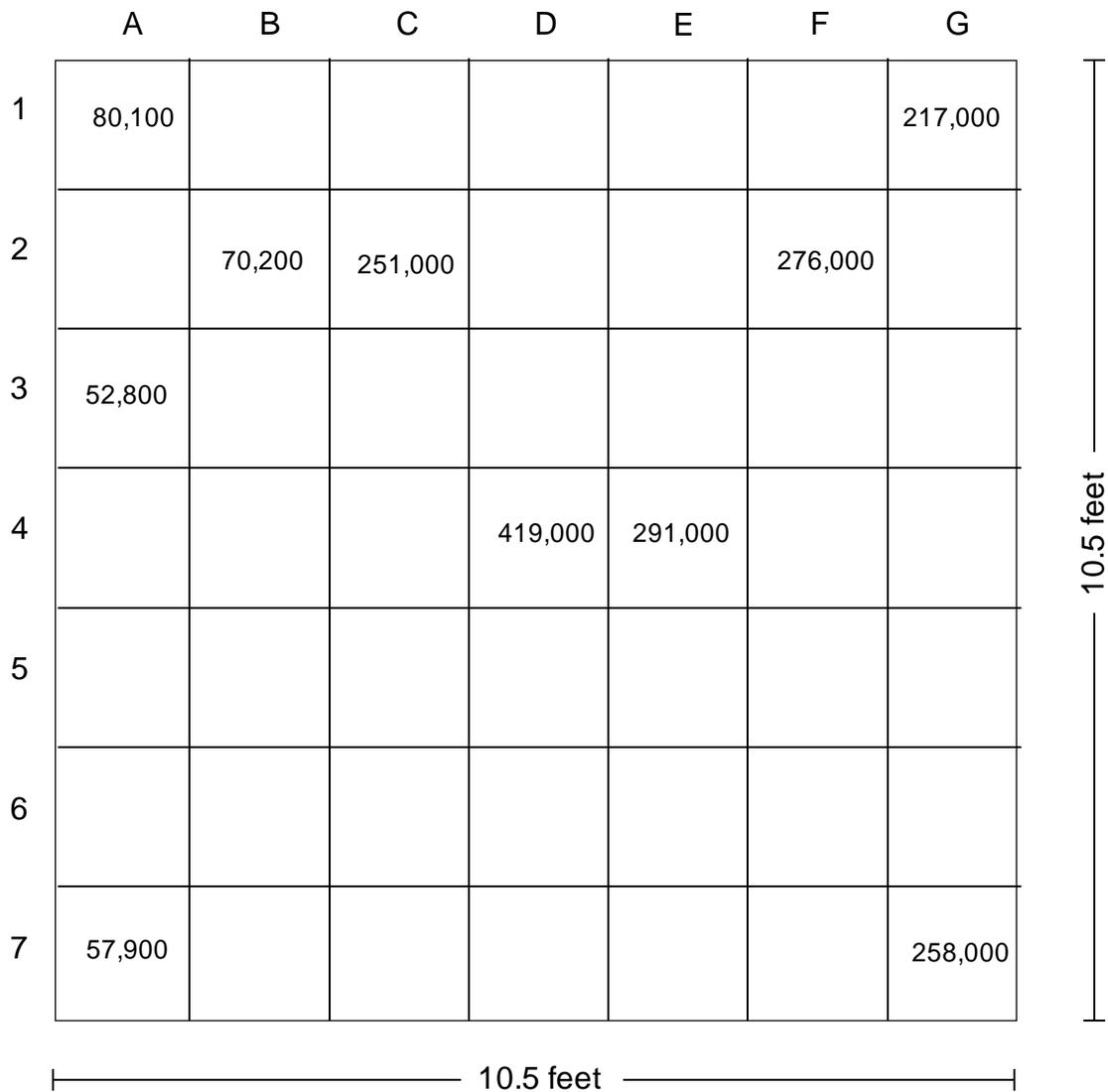
Units - micrograms per kilogram

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

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	A	B	C	D	E	F	G
1	32,600						32,600
2		40,500	48,700			26,700	
3	33,700						
4				33,900	41,000		
5							
6							
7	92,200						45,800

10.5 feet

10.5 feet
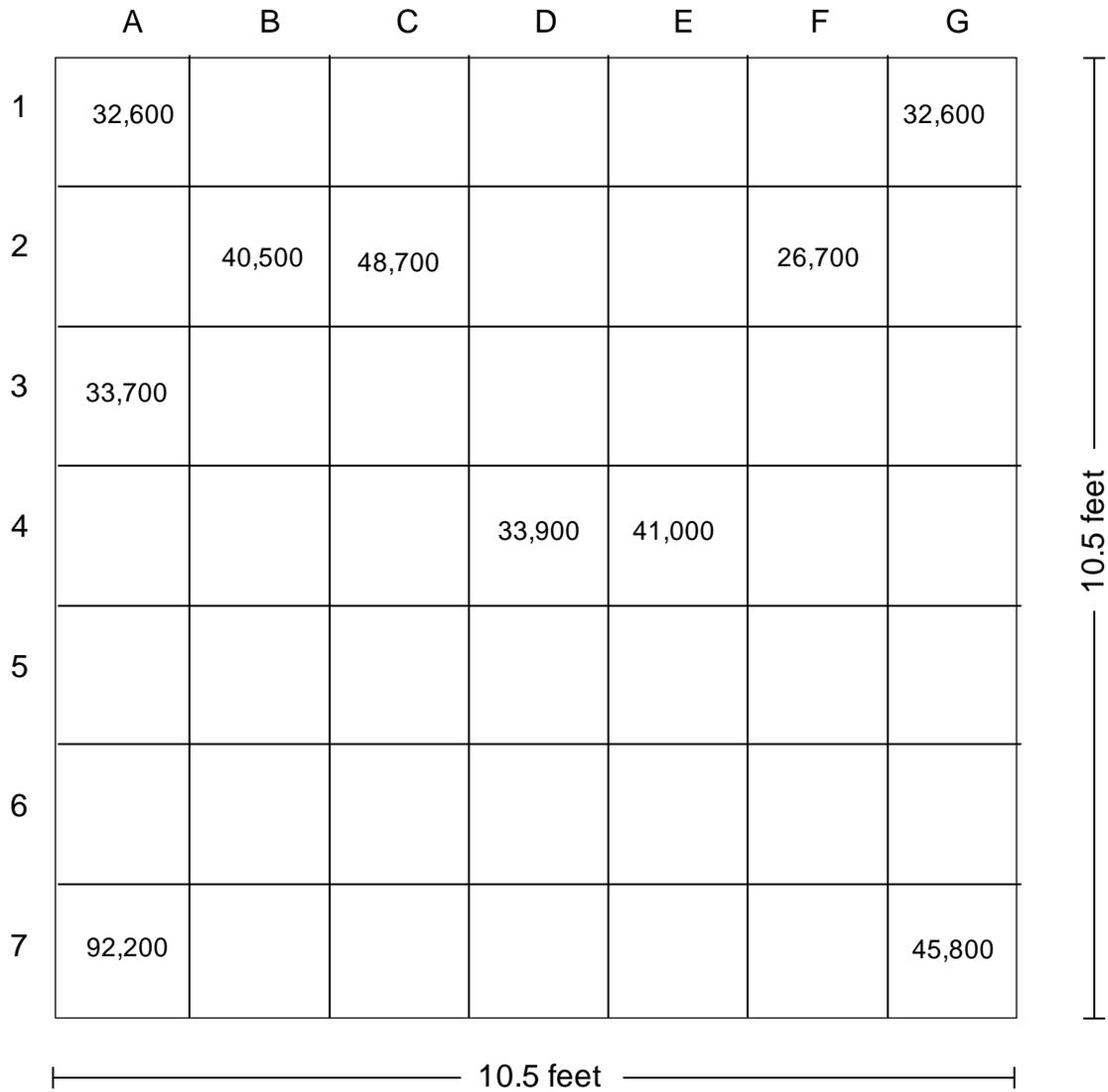
Units - micrograms per kilogram

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

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 Core Barrel Sampler 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 reference sampling method median concentrations were higher than the Core Barrel Sampler median concentrations and (2) the number of pairs in which the Core Barrel Sampler median concentrations were higher than the reference sampling method median concentrations. The total number of pairs in which the median concentrations were higher in the Core Barrel Sampler was then compared to the total number of pairs in which the median concentrations were higher in 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 Core Barrel Sampler 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 Core Barrel Sampler 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 Core Barrel Sampler and reference 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. Therefore, and for the 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 above the method detection limit 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.

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Seven integrity samples were collected with the Core Barrel Sampler at each site to determine if potting soil in an unlined sampler interior became contaminated after it was advanced through a zone of high VOC concentrations. Additionally, seven integrity samples were collected with the reference sampling method at the SBA site and five integrity samples at the CSC site. All 14 integrity samples using the Core Barrel Sampler were collected without sample liners. However, sample liners were used during the collection of all the integrity samples when the reference sampling method was used. All integrity samples were collected from Grid 1 at both 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. The unlined Core Barrel Sampler was used because representative sample aliquots could not be collected as specified in the demonstration plan from samples lined with stainless steel Core Barrel Sampler liners.

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 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 Core Barrel Sampler 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 SimulProbe®. Factors that could affect the cost of operating the Core Barrel Sampler 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 Core Barrel Sampler and the reference sampling method; (2) the nonparametric sign test was used to assess potential bias between VOC concentrations determined from the Core Barrel Sampler 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 (Core Barrel Sampler) of this ETVR.

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 geological conditions anticipated (EPA, 1987).

Head Assembly

Split Barrel

Liner

Spacer

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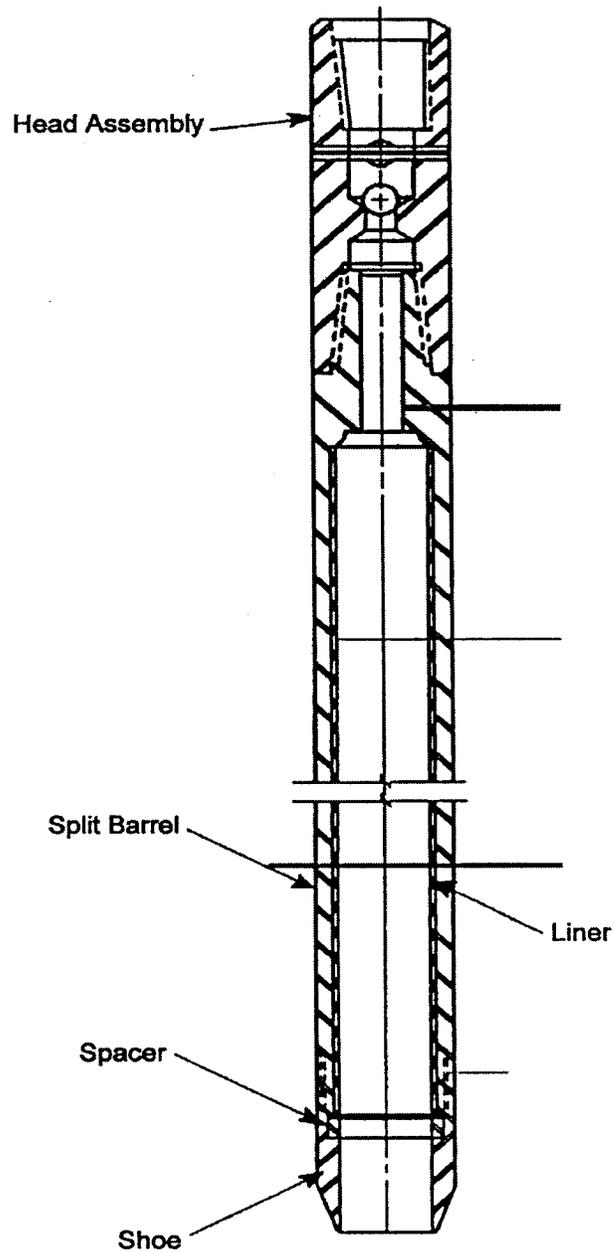
Figure 4-1. Split-Spoon Soil Sampler (modified from Central Mine Equipment Co., 1994)

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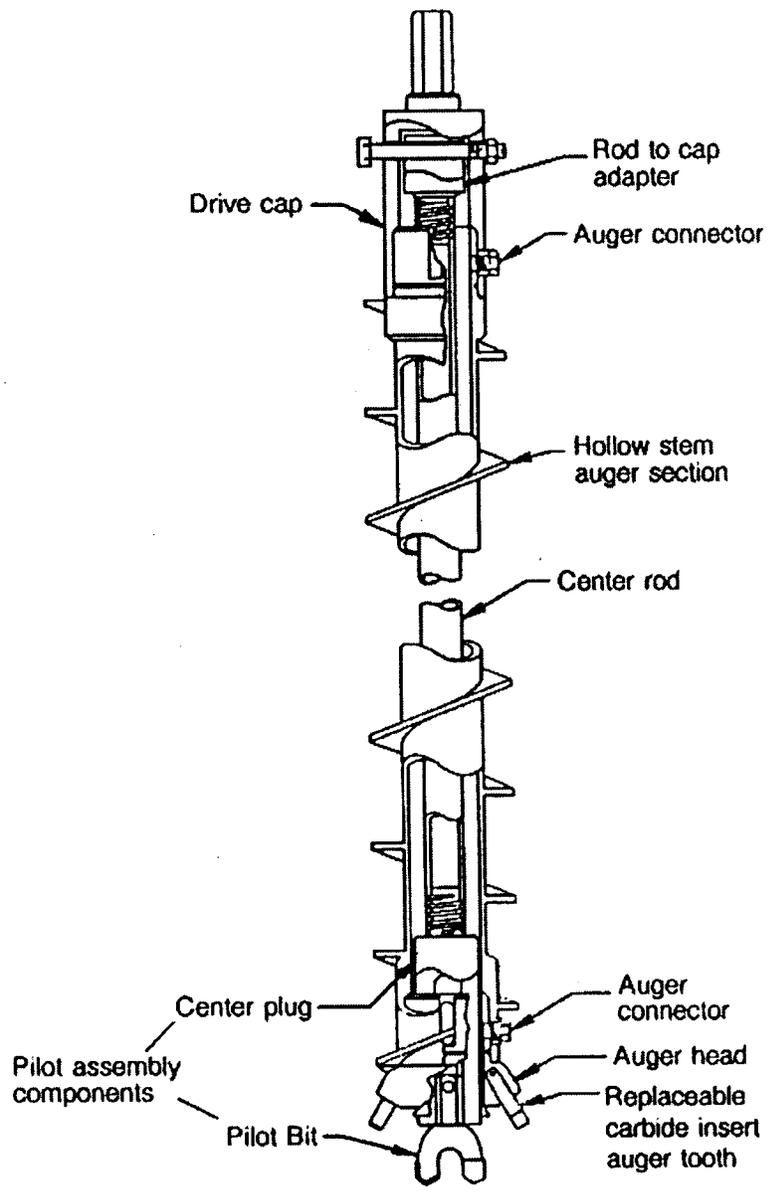
Figure 4-2. Typical Components of a Hollow-Stem Auger (Central Mine Equipment Co., 1994)

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. Generally, 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; the three events are 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.

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 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. 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 remaining sample data.

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

		Concentration (Ϝg/kg)									
		cis-1,2-DCE		1,1,1-TCA		TCE		PCE			
Site	Grid - Depth	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	22.5 - 88.9	56.9	< 1	NC		
SBA	3 - 9.5 feet[*]	796 - 1,450	905	< 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 - 658	NC	< 100	NC	1,880 - 6,220	2,540		
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	1,490		
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		

Ϝg/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 for only six samples are available
*	VOC data for only four 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.

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 Core Barrel Sampler.

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 sampling 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 rate was measured as the amount of time per sample required 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 Core Barrel Sampler 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 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 to 150 percent recovery for low-concentration samples.

Seventeen MS/MSD pairs, representing a 3.6 percent frequency, were analyzed to assess the precision of the analytical method. The relative percent differences (RPDs) 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).

Chapter 5
Technology Performance

This chapter describes the performance of the SimulProbe® Technologies, Inc., Core Barrel Sampler and assesses qualitative and quantitative performance factors. A description of the Core Barrel Sampler is provided in Chapter 2 of this ETVR.

Qualitative Performance Factors

The following qualitative performance factors were assessed for the Core Barrel Sampler: (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 Core Barrel Sampler, 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 68 percent. At the SBA site, the Core Barrel Sampler did not collect a sample in the initial push in 17 of 42 attempts, resulting in an initial sampling success rate of 60 percent. Two of the 17 instances were attributable to refusal from cobbles. Of the remaining 15 instances, three were the result of an improperly sized O-ring used in the assembly of the SPLAT™, which prevented activation of the SPLAT™; four were caused when a saturated zone or zone of oily product was encountered that may have prevented activation of the SPLAT™; and the remaining eight occurred when the SPLAT™ failed to properly activate for no apparent reason.

At the CSC site, the Core Barrel Sampler did not collect a sample in the initial push in 10 of 42 attempts, resulting in an initial sampling success rate of 76 percent. Seven of the 10 failures occurred when the weld broke on the top threads of the Core Barrel Sampler. The breakage caused the loss of the sampler into the hole. The remaining three instances occurred when the SPLAT™ did not properly activate for no apparent reason. Due to wear, the retractors on the SPLAT™ required replacement several times during sampling. All of the required samples were eventually collected by conducting multiple sampling pushes, resulting in 100 percent completeness.

The Core Barrel Sampler was subjected to an additional evaluation at Grid 5 at the CSC site to assess the efficiency of the sampler in collecting samples in saturated sand. However, when the Core Barrel Sampler was used to collect a saturated sample from 40 feet bgs, a weld broke and the sampler was lost. No further attempts were made to collect saturated samples at the 40 foot depth, resulting in zero percent sampling completeness in Grid 5 at the CSC site.

The developer theorized that sampler breakage was due to the power of the hammer on the Hurricane Rig. Therefore, to alleviate the stress on the sampler, the advancement procedure was changed at the CSC site. A solid point was piloted down the borehole until the subsurface material allowed for nonhammering, direct hydraulic push of the rods to 6 inches above the required sampling interval. The pilot point was then retracted from the borehole and the Core Barrel Sampler was pushed downhole to the depth of the desired sampling interval. The use of the pilot hole greatly reduced the amount of hammering required to advance the sampler and no subsequent breakage of the sampler resulted at the CSC site. New manufacturing procedures and redesign information that address the reliability issue discussed above are provided by the developer in Chapters 8 and 9 of this ETVR.

Training Requirements and Ease of Operation

Approximately 1 hour of hands-on training was required to become proficient in assembling and using the Core Barrel Sampler. To learn the assembly procedure, the sampling team should assemble the Core Barrel Sampler two to three times. The operation of an advancement platform to drive the Core Barrel Sampler requires training and experience. The many moving parts pose a risk of injury to the head, eyes, and feet, which can be protected with a hard hat, safety glasses, and steel-toed boots. Leather gloves facilitated assembly and disassembly of the Core Barrel 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 assess the applicability of any license or permit requirements. Additionally, underground utility clearances are needed before sampling with any intrusive subsurface equipment.

The physical impact of demonstration sampling on the site was minimal. The platforms used to push the Core Barrel Sampler during the demonstration were mounted on pickup trucks. With the exception of one portion of Grid 1 at the SBA site where an oily product was carried to the surface by the sampler, neither rig caused excessive wear to the ground in and around the grid. The Core Barrel Sampler left approximately 2-inch-diameter holes, which were grouted with neat-Portland cement at the SBA site and with dry granular bentonite at the CSC site. No drill cuttings were generated during use of the Core Barrel Sampler.

The push platform is powered by an on-board engine and needs no external power source (other than fuel). Only a limited amount of water (approximately 10 gallons per day) and a containment area were necessary for adequate sampler decontamination.

Sample Handling

Liners were not used in the Core Barrel Sampler during the demonstration. The sample was easily accessible by separating the Core Barrel Sampler's halves and exposing the sample. After a Core Barrel Sampler was retrieved from a borehole, it was immediately taken to the sample packaging area for processing. To minimize volatilization, the sampler remained closed until subsampling.

Performance Range

The performance range of the Core Barrel Sampler depends in part on the capability of the platform advancing the sampler. During the demonstration, the Core Barrel Sampler successfully collected samples at depths of up to 13.5 feet bgs. However, when the Core Barrel Sampler attempted to

collect a sample from 40 feet bgs in Grid 5 at the CSC site, the sampler was lost when a weld broke. This depth may define a lower performance limit for the sampler and push platform in sandy soil. Because the sampler was not depth-limited in the clay soils at the SBA site, no performance range can be postulated for clay soils. Additionally, based on the push refusals described above, this sampling method is likely inappropriate for unconsolidated formations containing large cobbles.

Investigation-Derived Waste

Minimal IDW was generated by the Core Barrel Sampler during the demonstration. The direct-push advancement platforms generated no soil cuttings, so the only soil waste created was that remaining in the sampler after the demonstration sample was collected for chemical analysis. Approximately 18 gallons of soil was generated at each site by the Core Barrel Sampler.

Decontamination of the Core Barrel Sampler generated approximately 10 gallons of wastewater per day. This quantity was sufficient to decontaminate all sampler components in both Alconox® mixture and rinse water for an 8-hour sampling period. At the SBA site, slightly more water was used when the sampler encountered a zone of saturated clay and oily product.

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

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

Sampler	Sampling Platform	Soil Generated	Wastewater Generated
Core Barrel Sampler	Push	18 gallons	50 gallons
Reference Sampler	Drilling	990 gallons	150 gallons

Quantitative Performance Assessment

Quantitative measures of the Core Barrel Sampler's performance consisted of (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 63 percent to 100 percent, with an average of 95 percent. At the CSC site, recoveries ranged from 31 percent to 100 percent with an average of 68 percent. Sample recovery data for each sample collected are summarized in Appendix A2, Table A2.

Average sample recoveries for the Core Barrel Sampler were greater than recoveries for those obtained using the reference method 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 was more difficult.

Table 5-2 presents a comparison of sample recoveries achieved by the Core Barrel Sampler and the reference sampling method during this demonstration.

Table 5-2. Sample Recoveries for the Core Barrel Sampler and the Reference Sampling Method

		Sample Recovery (percent)	
Sampler	**Site**	**Range**	**Average**
Core Barrel Sampler	SBA	63 to 100	95
Reference Sampler	SBA	40 to 100	88
Core Barrel Sampler	CSC	31 to 100	68
Reference Sampler	CSC	53 to 100	87

Two possible explanations for the different sample recoveries achieved by the Core Barrel Sampler and the reference sampler are the following: (1) due to problems encountered at the CSC site, the Core Barrel Sampler was advanced by pushing and not by hammering, which may have resulted in the reduced recoveries at this site, and (2) at both sites the Core Barrel Sampler was often retracted from the borehole at an accelerated rate, potentially causing the loss of material only loosely compacted in the Core Barrel Sampler.

Volatile Organic Compound Concentrations

Samples were collected with the Core Barrel Sampler at each sampling grid-depth combination as described in Chapter 3. Samples were analyzed for VOCs by combining headspace sampling with GC 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 Core Barrel Sampler. Data are reported on a dry-weight basis. For five of the 12 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 Core Barrel Sampler 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 were above the method detection limit for the grid, depth, and analyte combination.

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, it will be 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

Table 5-3. Volatile Organic Compound Concentrations in Samples Collected Using the Core Barrel Sampler

		\#Fg/kg Concentration (F g/kg)							
		cis-1,2-DCE		**1,1,1-TCA**		**TCE**		**PCE**	
Site	**Grid - Depth**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**
SBA	1 - 9.5 feet	57,900 - 213,000	139,000	< 100	NC	133,000 - 759,000	247,000	< 100 - 4,670	2,440
SBA	1 - 13.5 feet†	2,060 - 55,000	18,700	< 100	NC	20,500 - 505,000	40,900	< 100 - 2,020	NC
SBA	2 - 3.5 feet	< 1	NC	< 1	NC	8.11 - 124	50.1	< 1	NC
SBA	3 - 9.5 feet	< 100 - 1,440	657	< 100	NC	12,300 - 59,100	22,300	< 100	NC
SBA	4 - 9.5 feet	6.95 - 28.8	16.6	< 1	NC	762 - 1,820	1,370	< 1	NC
SBA	5 - 13.5 feet*	92.0 - 327	213	< 1	NC	29.8 - 274	151	< 1	NC
CSC	1 - 3.0 feet†	< 100	NC	< 100 - 1,130	NC	< 100 - 342	NC	717 - 26,800	1480
CSC	1 - 6.5 feet*	< 1 - 3.35	2.33	< 1 - 100	17.2	< 1 - 21.1	5.48	17.7 - 907	68.9
CSC	2 - 3.0 feet†	< 100	NC	< 100	NC	< 100	NC	< 100 - 1,870	851
CSC	3 - 3.0 feet	< 100	NC	< 100	NC	< 100	NC	< 100 - 1,900	868
CSC	3 - 7.5 feet	< 1 - 12.7	NC	< 1 - 78.7	6.15	< 1 - 56.2	4.54	< 1 - 241	165
CSC	4 - 6.5 feet	< 1	NC	< 1 - 7.44	3.06	< 1 - 4.20	NC	10.0 - 126	32.6

F g/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	NC	No median calculated because at least half the reported
*	VOC data are available for only five samples		values were below the method detection limit.
†	VOC data are available for only six samples		

Table 5-4. Demonstration Data Summary for the Core Barrel Sampler 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
SBA				**Core Barrel Sampler**			
	1	9.5	7	7	0	7	6
	1	13.5	6	6	0	6	1
	2	3.5	7	0	0	7	0
	3	9.5	7	6	0	7	0
	4	9.5	7	7	0	7	0
	5	13.5	5	5	0	5	0
				Reference Sampling Method			
	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
CSC				**Core Barrel Sampler**			
	1	3.0	6	0	3	1	6
	1	6.5	5	4	4	4	5
	2	3.0	6	0	0	0	4
	3	3.0	7	0	0	0	5
	3	7.5	7	3	6	5	6
	4	6.5	7	0	6	3	7
				Reference Sampling Method			
	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: A statistical comparison was not conducted when at least half of the reported values within a data set were below the method detection limit.

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 Core Barrel Sampler and the reference sampling method. The table also indicates whether there is a significant difference (p # 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 Core Barrel Sampler and reference sampling method is presented in Appendix A4, Table A4. A total of 48 grid, depth, and analyte combination pairs were collected during the demonstration. Of the 48 pairs, only 24 data sets were obtained: 12 from the SBA site and 12 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 Core Barrel Sampler 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 Core Barrel Sampler and the reference sampling method in two of 24 cases. The statistically significant differences involve data collected from the CSC site: one from Grid 4 at the 6.5-foot sampling depth for the analyte 1,1,1-TCA, and one from Grid 2 at the 3-foot sampling depth for the analyte PCE. Figure 5-1 presents a graphic representation of median VOC concentrations of the Core Barrel Sampler 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 Core Barrel Sampler median concentrations and (2) the number of pairs in which the Core Barrel Sampler median concentrations were higher than the reference sampling method median concentrations. The total number of pairs in which the median concentrations were higher with the Core Barrel Sampler 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 Core Barrel Sampler 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 Core Barrel Sampler and reference sampling method were higher. If the calculated probability is less then 5 percent (p < 0.05), then a significant difference is present between the Core Barrel Sampler and reference sampling method.

The sign test data are provided in Table 5-6 and are summarized in Appendix A5, Table A5. At the SBA site, the calculated probability is greater than 0.05; therefore, the difference is not statistically significant. However, the calculated probability at the CSC site is less than 0.05, indicating that the Core Barrel Sampler yielded results that, statistically, were significantly different than the results yielded by the reference sampling method (probability of 1.6 percent). This result suggests that in sampling coarse-grained soils, the reference method tends to yield higher concentrations than does the Core Barrel Sampler.

Table 5-5. **Comparison of Median Chemical Concentrations of Core Barrel Sampler and Reference Sampler Data and Statistical Significance**

		Median Concentration (Fg/kg) and Significance											
		cis-1,2-DCE			1,1,1-TCA			TCE			PCE		
Site	Grid - Depth	CBS	Ref.	Sign.	CBS	Ref.	Sign.	CBS	Ref.	Sign.	CBS	Ref.	Sign.
SBA	1 - 9.5 feet	139,000	86,700	No	NC	NC	*	247,000	276,000	No	2,440	1,630	No
SBA	1 - 13.5 feet	18,700	14,500	No	NC	NC	*	40,900	40,500	No	NC	NC	*
SBA	2 - 3.5 feet	NC	NC	*	NC	NC	*	50.1	56.9	No	NC	NC	*
SBA	3 - 9.5 feet	657	905	No	NC	NC	*	22,300	38,500	No	NC	NC	*
SBA	4 - 9.5 feet	16.6	13.2	No	NC	NC	*	1,370	1,710	No	NC	NC	*
SBA	5 - 13.5 feet	213	93.6	No	NC	NC	*	151	21.0	No	NC	NC	*
CSC	1 - 3.0 feet	NC	NC	*	NC	NC	*	NC	NC	*	1,480	2,540	No
CSC	1 - 6.5 feet	2.33	2.20	No	17.2	26.0	No	5.48	6.45	No	68.9	112	No
CSC	2 - 3.0 feet	NC	NC	*	NC	NC	*	NC	126	*	851	2,000	Yes
CSC	3 - 3.0 feet	NC	NC	*	NC	NC	*	NC	NC	*	868	1,490	No
CSC	3 - 7.5 feet	NC	4.12	*	6.15	13.9	No	4.54	14.9	No	165	73.0	No
CSC	4 - 6.5 feet	NC	NC	*	3.06	8.09	Yes	NC	2.37	*	32.6	50.3	No

Fg/kg	Micrograms per kilogram	PCE	Tetrachloroethene
cis-1,2-DCE	cis-1,2-Dichloroethene	CBS	Core Barrel Sampler
1,1,1-TCA	1,1,1-Trichloroethane	Ref.	Reference sampling method
TCE	Trichloroethene	Sign.	Significance, P#0.05 two tailed Mann-Whitney test
SBA	Small Business Administration site	CSC	Chemical Sales Company site
*	A statistical comparison could not be made because an insufficient number of VOC concentrations were detected	NC	No median calculated because at least half the reported values were below the method detection limit

Figure 5-1. Comparative Plot of Median VOC Concentrations for the Core Barrel Sampler and Reference Sampling Method at the SBA and CSC Sites
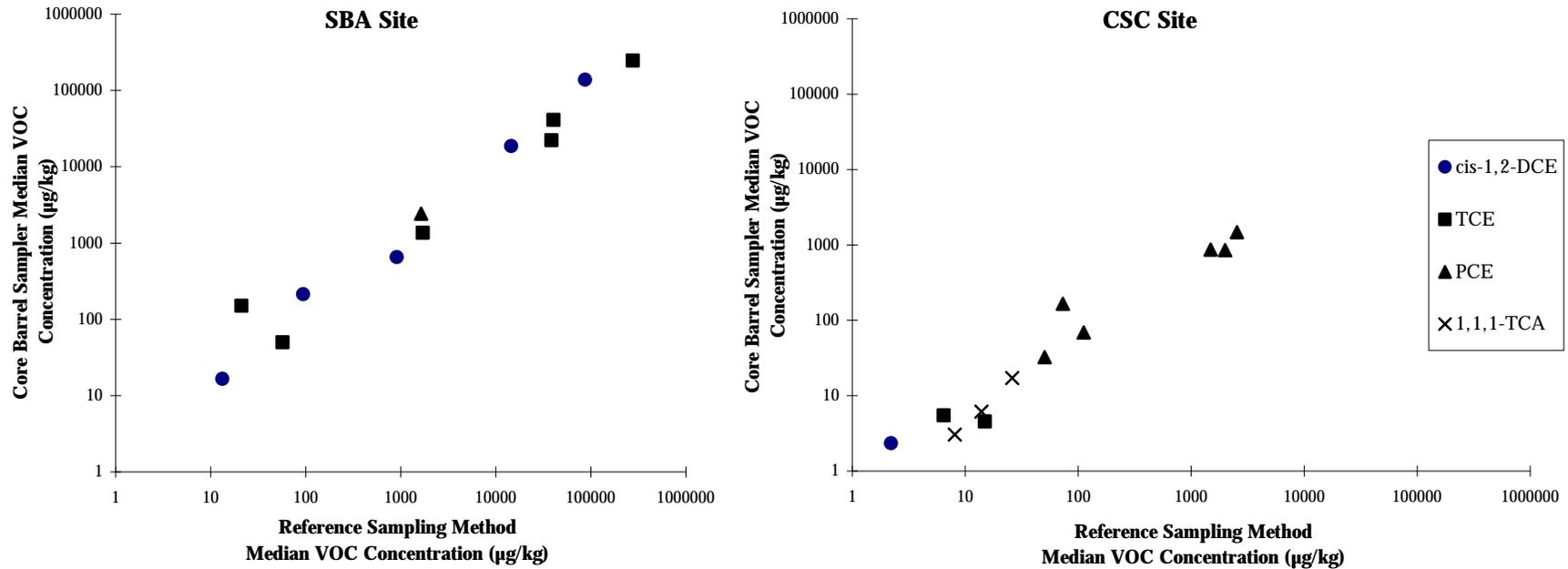
Note: µg/kg = microgram per kilogram

Table 5-6. Sign Test Results for the Core Barrel Sampler and the Reference Sampling Method

Sampler	Number of Pairs in Which the Median Concentration is Higher than Other Method	
	SBA Site	CSC Site
Reference Sampler	5	10
Core Barrel Sampler	7	2
Total Comparisons	12	12
Calculated Probability	0.193	0.016

Sample Integrity

Seven integrity test samples were collected with the Core Barrel Sampler in Grid 1 at each site, as described in Chapter 3, to determine if potting soil in an unlined sampler interior became contaminated after it was advanced through a zone of high VOC concentrations. For the Core Barrel Sampler, VOCs were detected in eight of the 14 integrity samples: six at the SBA site and two at the CSC site. The range of VOC concentrations detected above the analytical detection limit in potting soil at the SBA site was: cis-1,2-DCE (2.10 to 4,410 Fg/kg); TCE (5.28 to 1,960 Fg/kg); and PCE (less than 1 to 7.05 Fg/kg). The range of VOC concentrations detected above the analytical detection limit in potting soil at the CSC site was: cis-1,2-DCE (8.04 to 9.33 Fg/kg); 1,1,1-TCA (108 to 218 Fg/kg); TCE (21.5 to 39.4 Fg/kg); and PCE (286 to 602 Fg/kg). These results indicate that the integrity of an unlined chamber in the Core Barrel Sampler may not be preserved when the sampler is advanced through highly contaminated soils. Results of sample integrity tests for the reference sampling 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.

Sample Throughput

Sample retrieval time was measured as the amount of time required 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. The average sample retrieval time for the Core Barrel Sampler was 21.4 minutes per sample for the SBA site and 11.8 minutes per sample for the CSC sites. A two-person sampling crew collected soil samples with the Core Barrel Sampler at the SBA and CSC sites. Two additional personnel were present at both sites to observe and assist with demonstration sampling, as necessary. Table 5-7 presents a comparison of the average sample retrieval times for the Core Barrel Sampler and the reference sampling method. The average sample retrieval times for the Core Barrel Sampler were quicker than the reference sampling method when collecting samples at depths of 9.5 and 13.5 feet in the clay soils at the SBA site, and 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. New manufacturing procedures and redesign information that may increase sample throughput are provided in Chapters 8 and 9.

Table 5-7.   Average Sample Retrieval Times for the Core Barrel Sampler and the Reference Sampling Method

Sampler	Average Sample Retrieval Time (minutes per sample)	
	SBA Site	CSC Site
Core Barrel Sampler	21.4	11.8
Reference Sampling Method	26	8.4

Note: A two-person sampling crew collected soil samples using the Core Barrel Sampler at the SBA and CSC sites, and a three-person drilling and sampling crew collected soil samples using the reference sampling method at both sites. Additional personnel were present at both sites to observe and assist with demonstration sampling, as necessary.

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 Core Barrel Sampler 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 of this ETVR.

Chapter 6
Economic Analysis

The SimulProbe® Technologies, Inc., Core Barrel Sampler 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 Core Barrel Sampler at sites similar to those used in this demonstration. The demonstration costs for the reference sampling method are also provided.

This economic analysis estimates the range of costs for using a Core Barrel Sampler 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 SimulProbe® Technologies, 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 Core Barrel Sampler.

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 to suit their needs. 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 21.4 minutes per sample for the clay soil site and 11.8 minutes per sample at the sandy soil site. This cost estimate also assumes that a direct-push platform is used to advance the Core Barrel Sampler and that a hollow-stem auger drilling platform is used to advance the reference method sampler.

Core Barrel Sampler

The costs for collecting soil samples using the Core Barrel Sampler are presented in two categories: (1) equipment costs, which include purchase of the Core Barrel Sampler and rental costs for the push platform, and (2) sampler operating and oversight costs, which include labor costs for sampling and sampling oversight and other direct costs such as supplies, IDW disposal, and site restoration.

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

Equipment costs. Equipment costs include the direct-push platform and the Core Barrel Sampler. Direct-push platform costs are limited to mobilization and demobilization costs ($900 for each site) and daily equipment usage costs ($750 per day). Based on the average retrieval rate during the demonstration, and collecting 42 samples at each site, it is assumed that the direct-push platform will be required for 2 days at the clay soil site and 1 day at the sandy soil site. The Core Barrel Sampler is

Table 6-1. Estimated Subsurface Soil Sampling Costs for the Core Barrel Sampler

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Equipment Costs

Rental of Push Platform = $750 per day plus $900 mobilization/demobilization per site
Purchase of Core Barrel Sampler = $2,700

Operating and Oversight Costs

	Clay Soil Site		**Sandy Soil Site**	
	Total Sampling Time = 15 to 19 Hours (2 Days)		Total Sampling Time = 8 to 10 Hours (1 Day)	
	Total Samples Collected = 42		Total Samples Collected = 42	
	Total Sample Depth = 400 Feet		Total Sample Depth = 200 Feet	
	Sampling Crew Size = 2 People		Sampling Crew Size = 2 People	

Clay Soil Site		Sandy Soil Site	
Operating Costs		Operating Costs	
Sample Collection	$1,500 - $1,900	Sample Collection	$800 - $1,000
Per Diem	0 - $600	Per Diem	0 - $300
Oversight Costs		Oversight Costs	
Mobilization/Demobilization	$300 - $500	Mobilization/Demobilization	$300 - $500
Travel	$6 - $30	Travel	$6 - $30
Per Diem	0 - $300	Per Diem	0 - $150
Sampling Oversight	$750 - $950	Sampling Oversight	$400 - $500
Other Direct Costs		Other Direct Costs	
Supplies	$25 - $75	Supplies	$25 - $75
IDW Disposal	$200 - $300	IDW Disposal	$200 - $300
Site Restoration	$100 - $200	Site Restoration	$100 - $200
Range of Operating and Oversight Costs*	**$2,880 - $4,860**		**$1,830 - $3,060**

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

currently unavailable for rent from SimulProbe®, so only the Core Barrel Sampler purchase cost is presented. The purchase cost for the Core Barrel Sampler is estimated to be $2,700, which includes four core barrels ($375 each), four SPLAT™ assemblies ($160 each), the rod grip puller assembly ($110), additional drive caps ($110), sufficient probe rod to advance the sampler to 20 feet bgs ($110), two AW/Geoprobe® thread adapters ($110 each), and wipe seals (one per every 10 samples at a cost of $2 per seal). No costs have been included for liners. If liners are required, they are available from SimulProbe® at a cost of $4 per acetate liner and $11.50 per set of three 6-inch stainless steel sleeves.

Operating Costs. Operating costs are limited to sample collection labor and per diem. Site restoration and decontamination labor are included in sample collection labor.

 C Sample Collection Labor Costs — On-site labor includes two equipment operators to collect soil samples. Based on the average demonstration sample retrieval times, sample collection labor is

estimated to be 15 to 19 hours each for two people at the clay soil site and 8 to 10 hours each for two people at the sandy soil site. For this cost estimate, labor rates are estimated at $50 per hour. This labor estimate includes time for sampler decontamination and site restoration.

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).

Additional mobilization/demobilization, travel, and per diem costs will apply if the site is greater than 100 miles from the push platform operator.

Oversight Costs. Oversight costs are presented as a range to provide an estimate of oversight costs that may be incurred. Costs for overseeing sampling using the Core Barrel Sampler are segregated into labor costs and other direct costs, as shown below.

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

C   Mobilization/Demobilization Labor Costs — This cost element includes the time for one person to prepare for and travel to each site, set up and pack up equipment, and return from the field, and includes 6 to 10 hours for one 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 one person for 2 days at the clay soil site (2 days for sample collection, mobilization/demobilization) 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. Based on the average demonstration sample retrieval times, sampling oversight labor times are estimated to be 15 to 19 hours for one person at the clay soil site and 8 to 10 hours for one person at the sandy soil site. Labor rates are estimated at $50 per hour.

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

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) and is estimated to range from $25 to $75.

C   IDW Disposal — Disposal costs for each site are limited to the cost of disposing of 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 Core Barrel Sampler 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.

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.

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 for one 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 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, sampling oversight labor times are estimated to be 18 to 22 hours for one person at the clay soil

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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.

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

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Driller's Costs

Lump Sum = $21,100 ($13,400 for the clay soil site and $7,700 for the sandy soil site)

Oversight Costs

Clay Soil Site		Sandy Soil Site	
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	
Sampling Crew Size = 3 People		Sampling Crew Size = 3 People	
Labor Costs		Labor Costs	
	$300 - $500	Mobilization/Demobilization	$300 - $500
Mobilization/Demobilization			
Travel	$6 - $30	Travel	$6 - $30
Per Diem	0 - $300	Per Diem	0 - $150
Sampling Oversight	$900 - $1,100	Sampling Oversight	$300 - $400
Other Direct Costs		Other Direct Costs	
Supplies	$25 - $75	Supplies	$25 - $75
IDW Disposal	$3,000 - $4,500	IDW Disposal	$600 - $900
Range of Oversight Costs*	**$4,230 - $6,510**		**$1,230 - $2,060**

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

Chapter 7
Summary of Demonstration Results

This chapter summarizes the technology performance results. The Core Barrel Sampler 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 SimulProbe® Technologies, Inc., Core Barrel Sampler:

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 42 samples collected at the SBA site ranged from 63 to 100 percent, with an average sample recovery of 95 percent. Sample recoveries from 40 samples collected at the CSC site ranged from 31 to 100 percent, with an average sample recovery of 68 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 Core Barrel Sampler and the reference sampler indicates that the Core Barrel Sampler achieved higher sample recoveries in the clay soil at the SBA site and lower sample recoveries 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 Core Barrel Sampler and the reference sampling method at six sampling depths in nine grids (five at the SBA site and four at the CSC site) were analyzed for VOCs. For 22 of the 24 Core Barrel Sampler and reference sampling method pairs (12 at the SBA site and 12 at the CSC site), a statistical analysis using the Mann-Whitney test indicated no significant statistical difference at the 95 percent level between the VOC concentrations in samples collected with the Core Barrel Sampler and those collected with the reference sampling method. A statistically significant difference was identified for two sample pairs collected at the CSC site. Analysis of the SBA site data, using the sign test, indicated no statistical difference between the data obtained by the Core Barrel Sampler and by the reference sampling method. However, at the CSC site, the sign test indicated that data obtained by the Core Barrel Sampler 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 coarse-grained soils than does the Core Barrel Sampler.

C **Sample Integrity**: Seven integrity samples were collected with the Core Barrel Sampler at each site to determine if potting soil in an unlined sampler became contaminated after it was advanced through a zone of high VOC concentrations. Seven integrity samples were collected with the reference sampling method at the SBA site and five integrity samples were collected at the CSC site. For the Core Barrel Sampler, VOCs were detected in eight of the 14 integrity samples: six at the SBA site and two at the CSC site. The range of VOC concentrations detected above the analytical detection limit in the potting soil at the SBA site were: cis-1,2-DCE (2.10 to 4,410 Fg/kg); TCE

(5.28 to 1,960 Fg/kg); and PCE (less than 1 to 7.05 Fg/kg). The range of VOC concentrations in the potting soil at the CSC site were: cis-1,2-DCE (8.04 to 9.33 Fg/kg); 1,1,1-TCA (108 to 218 Fg/kg); TCE (21.5 to 39.4 Fg/kg); and PCE (286 to 602 Fg/kg). These results indicate that the integrity of the unlined chamber in the Core Barrel Sampler may not be preserved when the sampler is advanced through highly contaminated soils. Results of sample integrity tests for the reference sampling 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. Additionally, the developer claims that use of liners will reduce the potential for cross-contamination.

C **Reliability and Throughput** : At the SBA site (clay soil), the Core Barrel Sampler collected a sample from the desired depth on the initial attempt 60 percent of the time. Sample collection in the initial push was achieved 76 percent of the time at the CSC site (sandy soil). The initial push success rate was less than 100 percent because of sampler malfunction and breakage. By conducting multiple pushes using a solid point drive to create a pilot hole, the Core Barrel Sampler collected all samples required for this demonstration. The pilot hole greatly reduced the amount of hammering required to advance the sampler and subsequent wear on the sampler. During the performance test in Grid 5 at the CSC site, all attempts to collect a sample in saturated sand at a 40-foot depth were unsuccessful. 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 the Core Barrel Sampler to set up on a sampling point, collect the specified sample, grout the hole, decontaminate the sampler, and move to a new sampling location was 21.4 minutes per sample at the SBA site and 11.8 minutes per sample at the CSC site. 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 two-person sampling crew collected soil samples with the Core Barrel Sampler at the SBA and CSC sites, and a three-person sampling crew collected soil samples using the reference sampling method at both sites. Additional personnel were present at both sites to observe and assist with demonstration sampling, as necessary.

C **Cost**: Based on the demonstration results and information provided by the vendor, the Core Barrel Sampler can be purchased for $2,700; the direct push platform can be rented for $750 per day plus $900 mobilization/demobilization per site. Operating costs for the Core Barrel Sampler ranged from $2,880 to $4,860 at the clay soil site and $1,830 to $3,060 at the sandy soil site. For this demonstration, reference sampling was procured at a lump sum of $13,400 for the clay soil site and $7,700 for the sandy soil site. Oversight costs for the reference sampling 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 subsurface soil sampling method.

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

A qualitative performance assessment of the Core Barrel Sampler indicated that (1) reliability of the sampler can be affected by improper activation of the SPLAT™; (2) the sampler is easy to use and requires approximately 1 hour of training to operate; (3) logistical requirements are similar to those for the reference sampling method; (4) sample handling is similar to the reference method; (5) performance range is primarily a function of the advancement platform; and (6) no drill cuttings are generated when using the Core Barrel Sampler with a push platform.

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

Chapter 8
Technology Update

Foreword

This chapter was written in response to, and as part of, SimulProbe's® requirements for participation in the SITE Program and EPA's *Environmental Technology Verification Report of the SimulProbe® Technologies, Inc. Core Barrel Sampler.*

Background

The Core Barrel Sampler was developed by SimulProbe® Technologies, Inc. solely for the collection of subsurface samples. The physical limitations of the Core Barrel Sampler's operation depend on the method of sampler advancement and the nature of the subsurface matrix. The technology is primarily restricted to unconsolidated soil free of large cobbles or boulders. Sediments containing pebbles supported by a finer-grained matrix can also be sampled. The Core Barrel Sampler may be used to sample for VOCs, semivolatile organic compounds, metals, general minerals, and pesticides. The Core Barrel Sampler can also:

C   Prevent cross-contamination and preserve sample integrity with the use of liners

C   Be used to collect either discrete or continuous soil samples

C   Work in unconsolidated materials

C   Collect samples that are chemically representative of the target interval

Finally, the Core Barrel Sampler requires no specialized training to operate.

Updated Components and Accessories

Based on our experiences and the results of the SITE Program in Albert City, Iowa, and Denver, Colorado, SimulProbe® Technologies, Inc., has reengineered a small number of Core Barrel Sampler

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components and has slightly revised the SOPs to improve the use and function of the Core Barrel Sampler as well as other tools SimulProbe® Technologies, Inc. provides.

As stated in Chapter 2, the Core Barrel Sampler is capable of recovering a discrete sample that measures 1.25 inches in diameter and 27 inches long. Multiple 5.25-inch stainless-steel liners or one full-length plastic liner can be used to contain the core. Although liners are not necessary to obtain a soil sample used for geology only, it *is* advised that liners be employed when obtaining samples that will be used for contaminant investigation.

For direct push or discrete sampling applications, a drive-tip (called the SPLAT™) can be employed and is recoverable after each sampling event. The reengineered SPLAT™ is composed of a carbide-tipped drive tip, a point-base, an *extended* point set, retractors, two O-rings, and a retractor band. In some soils, the original point set (Figure 2-2) tended to catch after it was released, rendering the SPLAT™ inoperable. The extended point set alleviates this problem by acting as a guide; as a result, the SPLAT™ can enter the core barrel unimpeded. The overall success rate of the reengineered SPLAT™ is in the range of 90 to 95 percent.

Also, the comment on page 33, 2nd paragraph under *Reliability and Ruggedness*, which states "…the retractors on the SPLAT™ required replacement several times during sampling" is false. This statement was the result of an on-site experiment that involved removable retractors. These were quickly done away with and were not used further on the SITE Program or any other project.

Unfortunately, the Core Barrel Samplers that SimulProbe® Technologies, Inc. used during the SITE Program were manufactured incorrectly. Only one of the three required welds was completed at the top of the core barrel (see Figure 2-1). This improper weld subsequently caused breakage and a failed sampling attempt. No pilot hole will be needed with a properly functioning Core Barrel Sampler. Henceforth, each completed Core Barrel Sampler must pass a thorough weld inspection before it can be released.

Sample Integrity

Although SimulProbe® Technologies, Inc., states that liners are not necessary to obtain a soil sample used for geology only, it *does* advise that liners be employed when obtaining samples that will be used for contaminant investigation. Tetra Tech could not sample through SimulProbe® Technologies, Inc.'s stainless-steel liners, so SimulProbe® Technologies, Inc. did not used them to obtain the required samples. Sample liners were used during the collection of all integrity samples collected using the reference sampling method. However, all 14 integrity samples collected by the Core Barrel Sampler were collected without liners. SimulProbe® Technologies, Inc. feels this is the reason for the high level of cross-contamination exhibited using the Core Barrel Sampler.

A soil sample can be obtained easily by using an aliquot to subsample from the top and the bottom of each 5.25-inch liner.

Sample Recovery

SITE Program data seem to suggest that sample recoveries using the Core Barrel Sampler are less than desirable. Each SimulProbe® Technologies, Inc. soil sample was obtained without the aid of a sand-catcher. As with the reference sampling method, when a sand-catcher is employed, the Core Barrel Sampler will retain any unconsolidated material in its sample chamber. The recovery remains the same regardless of whether liners are used with the Core Barrel Sampler.

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Chapter 9
Previous Deployment

Previously, the SimulProbe® Core Barrel Sampler had been successfully deployed on more reference, hollow-stem drilling rigs. The core barrel had little direct/vibratory rig usage prior to the SITE Program. The Core Barrel Sampler had been used successfully on a mud rotary drilling project at Lawrence Livermore National Laboratories to collect soil samples out in front of the mud infiltration zone.

Since the SITE demonstration was completed, SimulProbe® has taken an aggressive approach to working out the sampling protocols and internal QA/QC.

Chapter 9 was written solely by SimulProbe® Technologies, Inc. The statements presented in this chapter represent the vendor's point of view and summarize the claims made by the vendor regarding the Core Barrel Sampler. 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 Core Barrel Sampler are discussed in other chapters of this report.

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APPENDIX A

DATA SUMMARY TABLES AND STATISTICAL METHOD DESCRIPTIONS

FOR THE

SIMULPROBE® TECHNOLOGIES, INC. CORE BARREL SAMPLER

APPENDIX A1

STATISTICAL METHOD DESCRIPTIONS

MANN-WHITNEY TEST AND SIGN TEST

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 Core Barrel Sampler and the reference sampling method. The two-tailed significance level for this null hypothesis was set at a probability of 5 percent ($p\#0.05$) (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 65 for the Core Barrel Sampler data and 40 for the reference sampling method data.

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

$$\text{Mann-Whitney}_1 = N_1 N_2 + \frac{N_1(N_1 + 1)}{2} - \text{sum of ranks value for the first data set}$$

and

$$\text{Mann-Whitney}_2 = N_1 N_2 + \frac{N_2(N_2 + 1)}{2} - \text{sum of ranks value for the second data set}$$

Where

N_1 is the number of values in data set 1
N_2 is the number of values in data set 2

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

$$\text{Mann-Whitney}_1 = (7)(7) + \frac{7(7+1)}{2} - 65$$

$$\text{Mann-Whitney}_1 = 49 + 28 - 65$$

$$\text{Mann-Whitney}_1 = 12$$

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

Sampler	Sample Location	cis-1,2-DCE Concentration (mg/kg)	cis-1,2-DCE Concentration Rank	Median Value Rank
Core Barrel Sampler	A4	165	13	6
Core Barrel Sampler	B7	148	12	5
Core Barrel Sampler	C1	87.0	6	2
Core Barrel Sampler	D3	213	14	7
Core Barrel Sampler	E6	139	10	4
Core Barrel Sampler	F1	92.8	7	3
Core Barrel Sampler	G3	57.9	3	1
Reference	A3	49.7	1	1
Reference	B2	86.7	5	4
Reference	C2	109	9	6
Reference	D4	147	11	7
Reference	E4	67.1	4	3
Reference	F2	98.4	8	5
Reference	G7	50.2	2	2
Sum of Core Barrel Sampler Ranks (13+ 12+ 6+ 14+ 10+ 7+ 3 = 65)			65	
Sum of Reference Sampler Ranks (1+ 5+ 9+ 11+ 4+ 8+ 2 = 40)			40	
Mann-Whitney$_1$ Statistic			12	
Mann-Whitney$_2$ Statistic			37	
Critical Mann-Whitney Value (for N_1= 7, N_2= 7, p= 0.05)			41	
Significance (Mann-Whitney Statistic > 41 ?)			no	

and

Mann-Whitney$_2$ = $(7)(7)$ + $\frac{7(7+1)}{2}$ - 40

Mann-Whitney$_2$ = $49 + 28 - 40$

Mann-Whitney$_2$ = 37

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 $N_2 = 7$ is of interest. For a two-tailed test with a significance level of 0.05, the Mann-Whitney statistic value is 41 (Rohlf and Sokal, 1969). Therefore, when the Mann-Whitney statistic value is greater than 41, 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 37, which is less than 41; 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.

SIGN TEST

The sign test was used to examine the potential for sampling and analytical bias between the Core Barrel Sampler 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 Core Barrel Sampler median concentrations and (2) the number of pairs in which the Core Barrel Sampler median concentrations were higher than the reference sampling method median concentrations. The total number of pairs in which the median concentrations were higher in the Core Barrel Sampler was then compared with the total number of pairs in which the median concentrations were higher in the reference sampling method. 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 Core Barrel Sampler 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 Core Barrel Sampler and reference sampling method were higher. If the calculated probability is less then 5 percent ($p < 0.05$), then a significant difference is present between the Core Barrel Sampler 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. CORE BARREL SAMPLER RECOVERY TEST DATA
SBA SITE

Sample Number	Sample Location	Soil Type	Reported Length Pushed (in.)	Reported Length Recovered (in.)	Sample Recovery (%)
SIMAG1A409.5	A4	Fine	24.0	24.0	100.0%
SIMAG1A413.5	A4	Fine	24.0	24.0	100.0%
SIMAG1B709.5	B7	Fine	24.0	24.0	100.0%
SIMAG1B713.5	B7	Fine	24.0	24.0	100.0%
SIMAG1C609.5	C6	Fine	24.0	20.0	83.3%
SIMAG1C613.5	C6	Fine	24.0	24.0	100.0%
SIMAG1D309.5	D3	Fine	24.0	22.0	91.7%
SIMAG1D313.5	D3	Fine	24.0	24.0	100.0%
SIMAG1E609.5	E6	Fine	24.0	24.0	100.0%
SIMAG1E613.5	E6	Fine	24.0	24.0	100.0%
SIMAG1F109.5	F1	Fine	24.0	25.0	100.0%[a]
SIMAG1F113.5	F1	Fine	24.0	22.0	91.7%
SIMAG1G309.5	G3	Fine	24.0	24.0	100.0%
SIMAG1G313.5	G3	Fine	24.0	24.0	100.0%
SIMAG2A503.5	A5	Fine	24.0	19.0	79.2%
SIMAG2B703.5	B7	Fine	24.0	17.0	70.8%
SIMAG2C503.5	C5	Fine	24.0	20.5	85.4%
SIMAG2D103.5	D1	Fine	24.0	19.0	79.2%
SIMAG2E703.5	E7	Fine	24.0	19.0	79.2%
SIMAG2F403.5	F4	Fine	24.0	15.0	62.5%
SIMAG2G503.5	G5	Fine	24.0	17.0	70.8%
SIMAG3A409.5	A4	Fine	24.0	24.0	100.0%
SIMAG3B109.5	B1	Fine	24.0	24.0	100.0%
SIMAG3C309.5	C3	Fine	24.0	27.0	100.0%[a]
SIMAG3D309.5	D3	Fine	24.0	24.0	100.0%
SIMAG3E309.5	E3	Fine	24.0	24.0	100.0%
SIMAG3F709.5	F7	Fine	24.0	24.0	100.0%
SIMAG3G209.5	G2	Fine	24.0	24.0	100.0%
SIMAG4A609.5	A4	Fine	24.0	24.0	100.0%
SIMAG4B209.5	B2	Fine	24.0	24.0	100.0%
SIMAG4C409.5	C4	Fine	24.0	24.0	100.0%
SIMAG4D709.5	D7	Fine	24.0	24.0	100.0%
SIMAG4E609.5	E6	Fine	24.0	24.0	100.0%
SIMAG4F609.5	F6	Fine	24.0	24.0	100.0%
SIMAG4G309.5	G3	Fine	24.0	24.0	100.0%
SIMAG5A613.5	A6	Fine	24.0	24.0	100.0%
SIMAG5B313.5	B3	Fine	24.0	24.0	100.0%
SIMAG5C613.5	C6	Fine	24.0	27.0	100.0%[a]
SIMAG5D213.5	D2	Fine	24.0	24.0	100.0%
SIMAG5E713.5	E7	Fine	24.0	24.0	100.0%
SIMAG5F113.5	F1	Fine	24.0	27.0	100.0%[a]
SIMAG5G213.5	G2	Fine	24.0	18.0	75.0%

[a] Sample recovery is reported as 100 percent when length recovered is greater than length pushed.

Average:	94.5%
Range:	62.5-100.0%
Total # Samples:	42

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TABLE A2b. CORE BARREL SAMPLER RECOVERY TEST DATA
CSC SITE

Sample Number	Sample Location	Soil Type	Reported Length Pushed (in.)	Reported Length Recovered (in.)	Sample Recovery (%)
SIMCG1A203.0	A2	Coarse	24.0	13.0	54.2%
SIMCG1A206.5	A2	Coarse	24.0	15.0	62.5%
SIMCG1B103.0	B1	Coarse	24.0	12.5	52.1%
SIMCG1B106.5	B1	Coarse	24.0	10.5	43.8%
SIMCG1C603.0	C6	Coarse	24.0	19.0	79.2%
SIMCG1C606.5	C6	Coarse	24.0	20.0	83.3%
SIMCG1D103.0	D1	Coarse	24.0	19.0	79.2%
SIMCG1D106.5	D1	Coarse	24.0	13.0	54.2%
SIMCG1E603.0	E6	Coarse	24.0	15.0	62.5%
SIMCG1E606.5	E6	Coarse	24.0	10.0	41.7%
SIMCG1F203.0	F2	Coarse	24.0	19.5	81.3%
SIMCG1F206.5	F2	Coarse	24.0	17.0	70.8%
SIMCG1G203.0	G2	Coarse	24.0	18.0	75.0%
SIMCG1G206.5	G2	Coarse	24.0	17.0	70.8%
SIMCG2A203.0	A2	Coarse	24.0	12.0	50.0%
SIMCG2B703.0	B7	Coarse	24.0	20.0	83.3%
SIMCG2C303.0	C3	Coarse	24.0	10.0	41.7%
SIMCG2D103.0	D1	Coarse	24.0	17.0	70.8%
SIMCG2E703.0	E7	Coarse	24.0	20.0	83.3%
SIMCG2F103.0	F1	Coarse	24.0	18.0	75.0%
SIMCG2G203.0	G2	Coarse	No data	No data	-
SIMCG3A703.0	A7	Coarse	24.0	21.5	89.6%
SIMCG3A707.5	A7	Coarse	24.0	24.0	100.0%
SIMCG3B303.0	B3	Coarse	24.0	13.5	56.3%
SIMCG3B307.5	B3	Coarse	24.0	14.0	58.3%
SIMCG3C703.0	C7	Coarse	24.0	12.0	50.0%
SIMCG3C707.5	C7	Coarse	24.0	17.5	72.9%
SIMCG3D703.0	D7	Coarse	24.0	23.0	95.8%
SIMCG3D707.5	D7	Coarse	24.0	14.0	58.3%
SIMCG3E103.0	E1	Coarse	24.0	22.0	91.7%
SIMCG3E107.5	E1	Coarse	24.0	19.0	79.2%
SIMCG3F203.0	F2	Coarse	24.0	7.5	31.3%
SIMCG3F207.5	F2	Coarse	24.0	19.0	79.2%
SIMCG3G203.0	G2	Coarse	24.0	17.5	72.9%
SIMCG3G207.5	G2	Coarse	24.0	19.5	81.3%
SIMCG4A206.5	A2	Coarse	24.0	16.0	66.7%
SIMCG4B206.5	B2	Coarse	24.0	16.0	66.7%
SIMCG4C406.5	C4	Coarse	24.0	No data	-
SIMCG4D106.5	D1	Coarse	24.0	17.0	70.8%
SIMCG4E106.5	E1	Coarse	24.0	12.0	50.0%
SIMCG4F606.5	F6	Coarse	24.0	15.0	62.5%
SIMCG4G706.5	G7	Coarse	24.0	17.0	70.8%

Average: 68.0%
Range: 31.3-100.0%
Total # Samples: 40

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TABLE A2c. REFERENCE SAMPLING METHOD RECOVERY TEST DATA
SBA SITE

Sample Number	Sample Location	Soil Type	Reported Length Pushed (in.)	Reported Length Recovered (in.)	Sample Recovery (%)
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%[a]
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%[a]
REFAG3B609.5	B6	Fine	15.0	18.0	100.0%[a]
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%[a]
REFAG3F309.5	F3	Fine	15.0	21.0	100.0%[a]
REFAG3G609.5	G6	Fine	18.0	24.0	100.0%[a]
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%

[a] 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

Sample Number	Sample Location	Soil Type	Reported Length Pushed (in.)	Reported Length Recovered (in.)	Sample Recovery (%)
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%[a]
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%[a]
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%[a]
REFCG2F503.0	F5	Coarse	18.0	18.5	100.0%[a]
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%

[a] 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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 1 - 9.5 FEET

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMAG1A409.5	A4	Fine	High	165,000	100	759,000	4,670
SIMAG1B709.5	B7	Fine	High	148,000	100	407,000	2,440
SIMAG1C609.5	C6	Fine	High	87,000	100	133,000	100
SIMAG1D309.5	D3	Fine	High	213,000	100	247,000	2,740
SIMAG1E609.5	E6	Fine	High	139,000	100	631,000	4,550
SIMAG1F109.5	F1	Fine	High	92,800	100	241,000	1,890
SIMAG1G309.5	G3	Fine	High	57,900	100	154,000	772

Range: 57,900 - 213,000   100   133,000 - 759,000 100 - 4,670

Median: 139,000   NC   247,000   2,440

REFERENCE SAMPLING METHOD DATA							
REFAG1A309.5	A3	Fine	High	49,700	100	52,800	100
REFAG1B209.5	B2	Fine	High	86,700	100	70,200	669
REFAG1C209.5	C2	Fine	High	109,000	100	251,000	2,010
REFAG1D409.5	D4	Fine	High	147,000	100	419,000	4,510
REFAG1E409.5	E4	Fine	High	67,100	100	291,000	1,530
REFAG1F209.5	F2	Fine	High	98,400	100	276,000	1,720
REFAG1G709.5	G7	Fine	High	50,200	100	289,000	1,630

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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 1 - 13.5 FEET

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMAG1A413.5	A4	Fine	High	8,610	100	40,200	100
SIMAG1B713.5	B7	Fine	High	55,000	100	505,000	2,020
SIMAG1D313.5	D3	Fine	High	28,700	100	41,600	100
SIMAG1E613.5	E6	Fine	High	2,060	100	22,900	100
SIMAG1F113.5	F1	Fine	High	32,200	100	52,600	100
SIMAG1G313.5	G3	Fine	High	2,330	100	20,500	100
			Range:	2,060 - 55,000	100	20,500 - 505,000	100 - 2,020
			Median:	18,700	NC	40,900	NC
REFERENCE SAMPLING METHOD DATA							
REFAG1A313.5	A3	Fine	High	6,760	100	33,700	100
REFAG1B213.5	B2	Fine	High	14,500	100	40,500	100
REFAG1C213.5	C2	Fine	High	20,400	100	48,700	100
REFAG1D413.5	D4	Fine	High	44,900	100	433,000	2,400
REFAG1E413.5	E4	Fine	High	12,300	100	41,000	100
REFAG1F213.5	F2	Fine	High	15,400	100	26,700	100
REFAG1G713.5	G7	Fine	High	1,360	100	39,100	100
			Range:	1,360 - 44,900	100	26,700 - 433,000	100 - 2,410
			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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 2 - 3.5 FEET

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMAG2A503.5	A5	Fine	Low	1	1	57.9	1
SIMAG2B703.5	B7	Fine	Low	1	1	124	1
SIMAG2C503.5	C5	Fine	Low	1	1	50.1	1
SIMAG2D103.5	D1	Fine	Low	1	1	53.6	1
SIMAG2E703.5	E7	Fine	Low	1	1	32.4	1
SIMAG2F403.5	F4	Fine	Low	1	1	29.4	1
SIMAG2G503.5	G5	Fine	Low	1	1	8.11	1

			Range:	1	1	8.11 - 124	1
			Median:	NC	NC	50.1	NC

REFERENCE SAMPLING METHOD DATA							
REFAG2A203.5	A2	Fine	Low	1	1	22.5	1
REFAG2B403.5	B4	Fine	Low	1	1	58.1	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	88.9	1

			Range:	1 - 2.18	1	22.5 - 88.9	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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 3 - 9.5 FEET

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMAG3A409.5	A4	Fine	High	282	100	13,000	100
SIMAG3B109.5	B1	Fine	High	435	100	12,300	100
SIMAG3C309.5	C3	Fine	High	1,240	100	26,200	100
SIMAG3D309.5	D3	Fine	High	1,440	100	22,300	100
SIMAG3E309.5	E3	Fine	High	657	100	15,600	100
SIMAG3F709.5	F7	Fine	High	100	100	59,100	100
SIMAG3G209.5	G2	Fine	High	665	100	22,800	100
			Range:	100 - 1,440	100	12,300 - 59,100	100
			Median:	657	NC	22,300	NC

REFERENCE SAMPLING METHOD DATA							
REFAG3A209.5	A2	Fine	High	796	100	34,100	100
REFAG3B609.5	B6	Fine	High	1,010	100	34,400	100
REFAG3C409.5	C4	Fine	High	1,450	100	63,700	100
REFAG3D609.5	D6	Fine	High	799	100	42,500	100
			Range:	796 - 1,450	100	34,100 - 63,700	100
			Median:	905	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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 4 - 9.5 FEET

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMAG4A609.5	A6	Fine	Low	22.1	1	1,220	1
SIMAG4B209.5	B2	Fine	Low	25.4	1	1,820	1
SIMAG4C409.5	C4	Fine	Low	28.8	1	1,570	1
SIMAG4D709.5	D7	Fine	Low	6.95	1	762	1
SIMAG4E609.5	E6	Fine	Low	14.7	1	1,370	1
SIMAG4F609.5	F6	Fine	Low	9.68	1	1,110	1
SIMAG4G309.5	G3	Fine	Low	16.6	1	1,470	1

Range: 6.95 - 28.8   1   762 - 1,820   1

Median: 16.6   NC   1,370   NC

REFERENCE SAMPLING METHOD DATA							
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	1,710	1
REFAG4D609.5	D6	Fine	Low	13.2	1	1,830	1
REFAG4E709.5	E7	Fine	Low	12.1	1	1,310	1
REFAG4F209.5	F2	Fine	Low	22.1	1	2,080	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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 5 - 13.5 FEET

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMAG5A613.5	A6	Fine	Low	327	1	214	1
SIMAG5B313.5	B3	Fine	Low	213	1	151	1
SIMAG5E713.5	E7	Fine	Low	215	1	274	1
SIMAG5F113.5	F1	Fine	Low	96.7	1	29.8	1
SIMAG5G213.5	G2	Fine	Low	92.0	1	69.4	1
			Range:	92.0 - 327	1	29.8 - 274	1
			Median:	213	NC	151	NC
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
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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 1 - 3.0 FEET

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMCG1B103.0	B1	Coarse	High	100	144	100	3,010
SIMCG1C603.0	C6	Coarse	High	100	100	100	1,760
SIMCG1D103.0	D1	Coarse	High	100	528	100	1,190
SIMCG1E603.0	E6	Coarse	High	100	100	100	1,170
SIMCG1F203.0	F2	Coarse	High	100	100	100	717
SIMCG1G203.0	G2	Coarse	High	100	1,130	342	26,800

Range: 100 100 - 1,130 100 - 342 717 - 26,800

Median: NC NC NC 1,480

REFERENCE SAMPLING METHOD DATA							
REFCG1B303.0	B3	Coarse	High	100	256	100	5,740
REFCG1C303.0	C3	Coarse	High	100	659	100	1,880
REFCG1D503.0	D5	Coarse	High	100	100	100	6,220
REFCG1E303.0	E3	Coarse	High	100	644	100	2,170
REFCG1F103.0	F1	Coarse	High	100	100	100	2,900
REFCG1G703.0	G7	Coarse	High	100	100	100	1,890

Range: 100 100 - 658 100 1,880 - 6,220

Median: NC NC NC 2,540

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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 1 - 6.5 FEET

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMCG1B106.5	B1	Coarse	Low	2.33	10.3	4.00	68.9
SIMCG1C606.5	C6	Coarse	Low	2.29	32.6	9.60	254
SIMCG1D106.5	D1	Coarse	Low	1	1	1	17.7
SIMCG1E606.5	E6	Coarse	Low	2.68	100	21.1	907
SIMCG1F206.5	F2	Coarse	Low	3.35	17.2	5.48	60.3

			Range:	1 - 3.35	1 - 100	1 - 21.1	17.7 - 907
			Median:	2.33	17.2	5.48	68.9

REFERENCE SAMPLING METHOD DATA							
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 ORGANIC COMPOUND CONCENTRATIONS
FOR CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 2 - 3.0 FEET**

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMCG2A203.0	A2	Coarse	High	100	100	100	1,280
SIMCG2B703.0	B7	Coarse	High	100	100	100	100
SIMCG2C303.0	C3	Coarse	High	100	100	100	100
SIMCG2D103.0	D1	Coarse	High	100	100	100	1,180
SIMCG2E703.0	E7	Coarse	High	100	100	100	522
SIMCG2F103.0	F1	Coarse	High	100	100	100	1,870
			Range:	100	100	100	100 - 1,870
			Median:	NC	NC	NC	851
REFERENCE SAMPLING METHOD DATA							
REFCG2A103.0	A1	Coarse	High	100	100	126	1,830
REFCG2B603.0	B6	Coarse	High	100	100	100	1,610
REFCG2C103.0	C1	Coarse	High	100	100	100	2,000
REFCG2D603.0	D6	Coarse	High	100	100	100	1,560
REFCG2E303.0	E3	Coarse	High	100	984	435	2,910
REFCG2F503.0	F5	Coarse	High	100	320	375	2,150
REFCG2G103.0	G1	Coarse	High	100	273	355	2,280
			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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 3 - 3.0 FEET**

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMCG3A703.0	A7	Coarse	High	100	100	100	100
SIMCG3B303.0	B3	Coarse	High	100	100	100	1,420
SIMCG3C703.0	C7	Coarse	High	100	100	100	908
SIMCG3D703.0	D7	Coarse	High	100	100	100	100
SIMCG3E103.0	E1	Coarse	High	100	100	100	743
SIMCG3F203.0	F2	Coarse	High	100	100	100	1,900
SIMCG3G203.0	G2	Coarse	High	100	100	100	868
			Range:	100	100	100	100 - 1,900
			Median:	NC	NC	NC	868

REFERENCE SAMPLING METHOD DATA							
REFCG3A203.0	A2	Coarse	High	100	313	100	2,110
REFCG3B103.0	B1	Coarse	High	100	100	100	1,600
REFCG3C203.0	C2	Coarse	High	100	100	100	2,070
REFCG3D603.0	D6	Coarse	High	100	100	100	1,370
REFCG3E603.0	E6	Coarse	High	100	100	100	1,030
REFCG3F603.0	F6	Coarse	High	100	100	100	1,060
			Range:	100	100 - 313	100	1,030 - 2,110
			Median:	NC	NC	NC	1,490

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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 3 - 7.5 FEET

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMCG3A707.5	A7	Coarse	Low	3.04	16.8	26.2	165
SIMCG3B307.5	B3	Coarse	Low	1	1	1	171
SIMCG3C707.5	C7	Coarse	Low	1	4.97	1	1
SIMCG3D707.5	D7	Coarse	Low	10.0	78.7	56.2	241
SIMCG3E107.5	E1	Coarse	Low	1	6.15	4.54	36.7
SIMCG3F207.5	F2	Coarse	Low	12.7	48.8	48.5	211
SIMCG3G207.5	G2	Coarse	Low	1	3.17	2.33	21.1

			Range:	1 - 12.7	1 - 78.7	1 - 56.2	1 - 241
			Median:	NC	6.15	4.54	165

REFERENCE SAMPLING METHOD DATA							
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	5.68	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.

µg/kg = Micrograms per kilogram.

TABLE A3l. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 4 - 6.5 FEET

Sample Number	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMCG4A206.5	A2	Coarse	Low	1	3.06	1	32.6
SIMCG4B206.5	B2	Coarse	Low	1	7.44	4.20	91.9
SIMCG4C406.5	C4	Coarse	Low	1	6.41	3.77	126
SIMCG4D106.5	D1	Coarse	Low	1	6.68	3.88	82.2
SIMCG4E106.5	E1	Coarse	Low	1	1	1	10.2
SIMCG4F606.5	F6	Coarse	Low	1	1.95	1	10.0
SIMCG4G706.5	G7	Coarse	Low	1	3.48	1	32.6

			Range:	1	1 - 7.44	1 - 4.20	10.0 - 126
			Median:	NC	3.06	NC	32.6

REFERENCE SAMPLING METHOD DATA							
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	13.0	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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMAG1A40INT	A4	Fine	Low	8.68	1	1	1
SIMAG1B70INT	B7	Fine	Low	191	1	5.28	1
SIMAG1C60INT	C6	Fine	Low	1	1	1	1
SIMAG1D30INT	D3	Fine	Low	4,410	1	1,960	7.05
SIMAG1E60INT	E6	Fine	Low	99.3	1	7.83	1
SIMAG1F10INT	F1	Fine	Low	2.10	1	1	1
SIMAG1G30INT	G3	Fine	Low	30.5	1	65.3	1

Range: 1 - 4,410 1 1 - 1,960 1 - 7.05

Median: 30.5 NC 5.28 NC

REFERENCE SAMPLING METHOD DATA							
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 CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
CORE BARREL SAMPLER DATA							
SIMCG1A20INT	A2	Coarse	Low	1	1	1	1
SIMCG1B10INT	B1	Coarse	Low	1	1	1	1
SIMCG1C60INT	C6	Coarse	Low	1	1	1	1
SIMCG1D10INT	D1	Coarse	Low	9.33	218	39.4	602
SIMCG1E60INT	E6	Coarse	Low	8.04	108	21.5	286
SIMCG1F20INT	F2	Coarse	Low	1	1	1	1
SIMCG1G20INT	G2	Coarse	Low	1	1	1	1

Range:		1 - 9.33	1 - 218	1 - 39.4	1 - 602
Median:		NC	NC	NC	NC

REFERENCE SAMPLING METHOD DATA							
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.
µg/kg =	Micrograms per kilogram.

APPENDIX A4

STATISTICAL SUMMARY OF MANN-WHITNEY TEST

TABLE A4a. COMPARATIVE SUMMARY OF MANN-WHITNEY STATISTICS FOR THE CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD

Site Description	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
Site: **SBA** Grid: **1** Depth: **9.5 feet** Soil Type: **Fine** Concentration: **High**	NO	NC (ALL ND)	NO	NO
Site: **SBA** Grid: **1** Depth: **13.5 feet** Soil Type: **Fine** Concentration: **High**	NO	NC (ALL ND)	NO	NC(2)
Site: **SBA** Grid: **2** Depth: **3.5 feet** Soil Type: **Fine** Concentration: **Low**	NC(1)	NC (ALL ND)	NO	NC (ALL ND)
Site: **SBA** Grid: **3** Depth: **9.5 feet** Soil Type: **Fine** Concentration: **High**	NO	NC (ALL ND)	NO	NC (ALL ND)
Site: **SBA** Grid: **4** Depth: **9.5 feet** Soil Type: **Fine** Concentration: **Low**	NO	NC (ALL ND)	NO	NC (ALL ND)
Site: **SBA** Grid: **5** Depth: **13.5 feet** Soil Type: **Fine** Concentration: **Low**	NO	NC (ALL ND)	NO	NC (ALL ND)
Site: **CSC** Grid: **1** Depth: **3.0 feet** Soil Type: **Coarse** Concentration: **High**	NC (ALL ND)	NC (6)	NC (1)	NO

TABLE A4a. COMPARATIVE SUMMARY OF MANN-WHITNEY STATISTICS FOR THE CORE BARREL SAMPLER AND REFERENCE SAMPLING METHODS (continued)

Site Description	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
Site: **CSC** Grid: **1** Depth: **6.5 feet** Soil Type: **Coarse** Concentration: **Low**	NO	NO	NO	NO
Site: **CSC** Grid: **2** Depth: **3.0 feet** Soil Type: **Coarse** Concentration: **High**	NC (ALL ND)	NC (3)	NC (4)	**YES**
Site: **CSC** Grid: **3** Depth: **3.0 feet** Soil Type: **Coarse** Concentration: **High**	NC (ALL ND)	NC(1)	NC (ALL ND)	NO
Site: **CSC** Grid: **3** Depth: **7.5 feet** Soil Type: **Coarse** Concentration: **Low**	NC (6)	NO	NO	NO
Site: **CSC** Grid: **4** Depth: **6.5 feet** Soil Type: **Coarse** Concentration: **Low**	NC (2)	**YES**	NC (6)	NO

Note:

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 # 0.10.

**TABLE A4b. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE CORE BARREL
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
Simulprobe (1)	7	65		56	61.5
Reference (2)	7	40		49	43.5
N1N2+ [N1(N1+1)]/2		77		77	77
N1N2+ [N2(N2+1)]/2		77		77	77
Mann-Whitney 1		12		21	15.5
Mann-Whitney 2		37		28	33.5
Mann-Whitney > 41?		NO		NO	NO

Site: **SBA**
Grid: **1**
Depth: **13.5 feet**
Soil Type: **Fine**
Concentration: **High**

Sum of Rank Statistics

	N	cis 1,2-DCE	1,1,1-TCA	TCE	PCE
Simulprobe (1)	6	45		42	
Reference (2)	7	46		49	
N1N2+ [N1(N1+1)]/2		63		63	
N1N2+ [N2(N2+1)]/2		70		70	
Mann-Whitney 1		18		21	
Mann-Whitney 2		24		21	
Mann-Whitney> 36?		NO		NO	

TABLE A4b. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD SBA SITE (continued)

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
Simulprobe (1)	7			49	
Reference (2)	7			56	
N1N2+ [N1(N1+1)]/2				77	
N1N2+ [N2(N2+1)]/2				77	
Mann-Whitney 1				28	
Mann-Whitney 2				21	
Mann-Whitney> 41?				NO	

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
Simulprobe (1)	7	34		31	
Reference (2)	4	32		35	
N1N2+ [N1(N1+1)]/2		56		56	
N1N2+ [N2(N2+1)]/2		38		38	
Mann-Whitney 1		22		25	
Mann-Whitney 2		6		3	
Mann-Whitney> 25?		NO		NO	

TABLE A4b. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD SBA SITE (continued)

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
Simulprobe (1)	7	59.5		45	
Reference (2)	7	45.5		60	
N1N2+ [N1(N1+1)]/2		77		77	
N1N2+ [N2(N2+1)]/2		77		77	
Mann-Whitney 1		17.5		32	
Mann-Whitney 2		31.5		17	
Mann-Whitney> 41?		NO		NO	

Site: **SBA**
Grid: **5**
Depth: **13.5 feet**
Soil Type: **Fine**
Concentration: **Low**

Sum of Rank Statistics

	N	cis 1,2-DCE	1,1,1-TCA	TCE	PCE
Simulprobe (1)	5	39		42	
Reference (2)	6	26		24	
N1N2+ [N1(N1+1)]/2		45		45	
N1N2+ [N2(N2+1)]/2		51		51	
Mann-Whitney 1		6		3	
Mann-Whitney 2		25		27	
Mann-Whitney> 27?		NO		NO	

TABLE A4c. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE CORE BARREL SAMPLER AND REFERENCE SAMPLING METHOD CSC SITE

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

Sum of Rank Statistics

	N	cis 1,2-DCE	1,1,1-TCA	TCE	PCE
Simulprobe (1)	6				31
Reference (2)	6				47
N1N2+ [N1(N1+1)]/2					57
N1N2+ [N2(N2+1)]/2					57
Mann-Whitney 1					26
Mann-Whitney 2					10
Mann-Whitney> 31?					NO

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
Simulprobe (1)	5	31	27	28	27
Reference (2)	6	35	39	38	39
N1N2+ [N1(N1+1)]/2		45	45	45	45
N1N2+ [N2(N2+1)]/2		51	51	51	51
Mann-Whitney 1		14	18	17	18
Mann-Whitney 2		16	12	13	12
Mann-Whitney> 27?		NO	NO	NO	NO

TABLE A4c. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE CORE BARREL 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
Simulprobe (1)	6				24
Reference (2)	7				67
N1N2+ [N1(N1+ 1)]/2					63
N1N2+ [N2(N2+ 1)]/2					70
Mann-Whitney 1					39
Mann-Whitney 2					3
Mann-Whitney> 36?					**YES**

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
Simulprobe (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 CORE BARREL 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
Simulprobe (1)	7		41	40	43.5
Reference (2)	4		25	26	22.5
N1N2+ [N1(N1+1)]/2			56	56	56
N1N2+ [N2(N2+1)]/2			38	38	38
Mann-Whitney 1			15	16	12.5
Mann-Whitney 2			13	12	15.5
Mann-Whitney> 25?			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
Simulprobe (1)	7		31.5		46
Reference (2)	5		36.5		32
N1N2+ [N1(N1+1)]/2			63		63
N1N2+ [N2(N2+1)]/2			50		50
Mann-Whitney 1			31.5		17
Mann-Whitney 2			13.5		18
Mann-Whitney> 30?			**YES**		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.

A-35

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 CORE BARREL SAMPLER AND
REFERENCE SAMPLING METHOD
SBA SITE

Site Description	Technology	Median cis 1,2-DCE	Median 1,1,1-TCA	Median TCE	Median PCE
Site: **SBA** Grid: **1** Depth: **9.5 feet** Concentration: **High**	Reference Sampling Method	86,700	ALL ND	276,000	1,630
	Core Barrel Sampler	139,000	ALL ND	247,000	2,440
Site: **SBA** Grid: **1** Depth: **13.5 feet** Concentration: **High**	Reference Sampling Method	14,500	ALL ND	40,500	NC(1)
	Core Barrel Sampler	18,700	ALL ND	40,900	NC(1)
Site: **SBA** Grid: **2** Depth: **3.5 feet** Concentration: **Low**	Reference Sampling Method	NC(1)	ALL ND	56.9	ALL ND
	Core Barrel Sampler	ALL ND	ALL ND	50.1	ALL ND
Site: **SBA** Grid: **3** Depth: **9.5 feet** Concentration: **High**	Reference Sampling Method	905	ALL ND	38,500	ALL ND
	Core Barrel Sampler	657	ALL ND	22,300	ALL ND
Site: **SBA** Grid: **4** Depth: **9.5 feet** Concentration: **Low**	Reference Sampling Method	13.2	ALL ND	1,710	ALL ND
	Core Barrel Sampler	16.6	ALL ND	1,370	ALL ND
Site: **SBA** Grid: **5** Depth**: 13.5 feet** Concentration: **Low**	Reference Sampling Method	93.6	ALL ND	21.0	ALL ND
	Core Barrel Sampler	213	ALL ND	151	ALL ND
Number of pairs in which Reference Sampling Method median is higher		1	0	4	0
Number of pairs in which Core Barrel Sampler median is higher		4	0	2	1

Note:

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 CORE BARREL SAMPLER AND
REFERENCE SAMPLING METHOD
CSC SITE

Site Description	Technology	Median cis 1,2-DCE	Median 1,1,1-TCA	MedianTCE	Median PCE
Site: **CSC** Grid: **1** Depth: **3.0** Concentration: **High**	Reference Sampling Method	ALL ND	NC(3)	ALL ND	2,540
	Core Barrel Sampler	ALL ND	NC(3)	NC(1)	1,480
Site: **CSC** Grid: **1** Depth: **6.5 feet** Concentration: **Low**	Reference Sampling Method	2.20	26.0	6.45	112
	Core Barrel Sampler	2.33	17.2	5.48	68.9
Site: **CSC** Grid: **2** Depth: **3.0 feet** Concentration: **High**	Reference Sampling Method	ALL ND	NC(3)	126	2,000
	Core Barrel Sampler	ALL ND	ALL ND	ALL ND	851
Site: **CSC** Grid: **3** Depth: **3.0 feet** Concentration: **High**	Reference Sampling Method	ALL ND	NC(1)	ALL ND	1,490
	Core Barrel Sampler	ALL ND	ALL ND	ALL ND	868
Site: **CSC** Grid: **3** Depth: **7.5 feet** Concentration: **Low**	Reference Sampling Method	4.12	13.9	14.9	73.0
	Core Barrel Sampler	NC(3)	6.15	4.54	165
Site: **CSC** Grid: **4** Depth: **6.5 feet** Concentration: **Low**	Reference Sampling Method	NC(2)	8.09	2.37	50.3
	Core Barrel Sampler	ALL ND	3.06	NC(3)	32.6
Number of pairs in which Reference Sampling Method median is higher		0	3	2	5
Number of pairs in which Core Barrel Sampler median is higher		1	0	0	1

Note:

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).