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Tri-Service Site Characterization and Analysis Penetrometer System (SCAPS) Validation of the Thermal Desorption Sampler for Volatile Organic Compounds

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Preface

The work reported herein was funded by the Environmental Security Technology Certification Program. Mr. George Robataille was the technical monitor for the U.S. Army Environmental Center, and Dr. M. John Cullinane, U.S. Army Engineer Research and Development Center (ERDC), was the program manager.

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This report was prepared under the general supervision of Ms. Strong, Chief, ECB; Mr. Norman Fancingues, Jr., Acting Chief, EED; Dr. Richard E. Price, Chief, EPED; Dr. John Keeley, Acting Director, EL; Mr. Dan Y. Eng, Acting Chief, JD; Dr. Charles Robert Welch, Chief, ISDD; and Mr. Timothy D. Ables, Acting Director, ITL.

At the time of publication of this report, Dr. Lewis E. Link was Acting Director of ERDC, and COL Robin R. Cababa, EN, was Commander.

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Abbreviations and Acronyms

μm	Micrometer
μg/kg	Microgram per kilogram
μg/g	Microgram per gram
μg/L	Microgram per liter
AEC	U.S. Army Environmental Center
AFB	Air Force Base
AOC	Areas of concern
AMCCOM	U.S. Army Armament, Munitions, and Chemical Command
ASTM	American Society for Testing and Materials
BETX	Benzene, ethylbenzene, toluene, xylene
BGS	Below ground surface
BRSA	Bush River Study Area, U.S. Army Aberdeen Proving Ground
EC	Degree(s) Celsius
Cal EPA-DTSC	California Environmental Protection Agency, Department of Toxic Substance Control
CI	Chemical impact ionization
cm	Centimeter
CPT	Cone penetrometer test

CRREL	U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory
CSCT	Consortium for site characterization technology
DCE	Dichloroethene
DGCS	Davis Global Communications Site, McClellan Air Force Base
DoD	Department of Defense
DQO	Data quality objective
DSITMS	Direct sampling ion trap mass spectrometer
ECB	Environmental Chemistry Branch
EI	Electron impact ionization
EPA	U.S. Environmental Protection Agency
EQT	Environmental quality technology
ft	Feet
ft ²	Square feet
ft ³	Cubic feet
g	Gram
GC	Gas chromatograph
GC/FID	Gas chromatograph/flame ionization detector
GC/MS	Gas chromatograph/mass spectrometer
HS/GC	Head space/gas chromatograph
ITMS	Ion trap mass spectrometer
ITRC	Interstate Technology Regulatory Cooperation
LAP	Load and pack
LCAAP	Lake City Army Ammunition Plant

LHAAP	Longhorn Army Ammunition Plant
LIF	Laser induced fluorescence
m	Slope of a regression line
MDL	Method detection limit
MeOH	Methanol
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
ml	Milliliter
ml/min	Milliliters per minute
MNT	Monitored natural attenuation
mm	Millimeter
m/z	Mass to charge ratio of an ion
ng/g	Nanogram per gram
ORNL	Oak Ridge National Laboratory
OSHW	EPA Office of Solid and Hazardous Waste
PCE	Tetrachloroethene
PE	Performance evaluation
PEP	Propellant, explosive, and pyrotechnics
ppb	Parts per billion; equivalent to ng/g, µg/kg and µg/L
ppm	Parts per million; equivalent to µg/g, mg/kg and mg/L
P&T	Purge and trap sample concentrator
PV	<i>ex situ</i> TDS prove verification sample by ITMS
QA	Quality assurance
QAPP	Quality Assurance Project Plan

QC	Quality control
r^2	Correlation coefficient
SCAPS	Site Characterization and Analysis Penetrometer System
SCN	Soil class number
SWMU	Solid waste management units
SERDP	Strategic Environmental Research and Development Program
SOP	Standard operating procedure
TCE	Trichloroethene
TDS	Thermal desorption VOC sampler
TIC	Total ion chromatogram
TRP	Technology Reinvestment Program
U.S.	United States
USACE	United States Army Corps of Engineers
UST	Underground storage tank
VOC	Volatile organic compound
WES	Waterways Experiment Station

1 Introduction

Background Information

Chlorinated solvents and fuel related volatile organic compounds (VOCs), the by-products of day-to-day operations of motor pools, machine shops, and cleaning facilities, present significant problems at many Department of Defense (DoD) sites. Conventional technology for site characterization involves laboratory analysis of soil samples taken from multiple borings across a site, operations that are time-consuming, expensive, and often yield an incomplete representation of contaminant concentrations existing in the subsurface. Traditional sampling techniques often disrupt the integrity of the soil, causing it to fracture and expose an uncontrolled amount of surface area from which volatilization losses occur. In addition, typical turnaround times of 2 to 4 weeks for laboratory analyses can hinder remediation activities. Currently, rapid, onsite methods to investigate the extent of subsurface soil contamination for VOCs do not exist.

To address these problems, the Tri-Services cooperated in the development, testing, and field demonstration of the Site Characterization and Analysis Penetrometer System (SCAPS). The SCAPS consists of a hydraulically operated cone penetrometer test unit mounted in a custom-engineered 18.2-MT (20-ton) truck with onboard computers that provide real-time sensor data acquisition/processing. The truck is capable of pushing instrumented cones to depths greater than 50 meters, as well as providing subsurface soil stratigraphy. The SCAPS truck has also been designed to accommodate sensors and samplers for use in collecting data on specific classes of subsurface contaminants.

Funded by the Environmental Quality Technology (EQT) Program and Strategic Environmental Research and Development Program (SERDP), researchers at the U.S. Army Engineer Research and Development Center (ERDC), Waterways Experiment Station (WES), developed a thermal desorption sampler (TDS) for the SCAPS program for onsite detection of low concentrations of volatile compounds in the vadose and capillary zones. The sampler design is based on thermal desorption principles. Approximately 5 g of soil is desorbed *in situ*, and the volatilized compounds are transferred to the surface where they are trapped and analyzed on a field portable ion trap mass

spectrometer (ITMS). After desorption, the spent sample is ejected and the TDS is pushed to successive depths where additional samples may be taken.

Combined with the ITMS, the TDS system provides near real-time, onsite analysis for VOCs to assist site managers in selecting sampling locations. Initial TDS sampling locations are selected based on historical knowledge of potential contaminant source and site geology. Additional geologic and contaminant data are collected during subsequent SCAPS stratigraphic and TDS penetrations. Using the SCAPS TDS, areas of soil contamination can be rapidly delineated. Significant time and cost savings are realized as a result of the rapid analytical turnover. Additional cost savings are realized because of the significant reduction in investigation derived waste produced by direct push techniques compared with conventional drilling and sampling techniques.

Official DoD Requirement Statement

There exists a critical need to demonstrate rapid cost-effective technologies to characterize soil and groundwater contaminated by volatile organic compounds. It is expected that the successful completion of this project will provide DoD with demonstrated capabilities for characterizing VOCs in soil at contaminated sites. This project will provide a technical capabilities database for the pursuit of regulatory acceptance and detailed cost analysis for assistance in technology transfer.

Objectives of Demonstration

The purpose of the SCAPS TDS demonstrations was to generate field data appropriate for verifying the performance of the technology. This technology verification facilitated the technology's acceptance and use by the regulator and user communities for field screening of VOCs in the vadose and capillary zones. To obtain the data required to verify the performance of the SCAPS TDS for field screening of VOCs in the subsurface, both primary and secondary demonstration objectives have been identified.

The primary objectives of this demonstration were to evaluate the *in situ* SCAPS TDS technology in the following areas: (a) its performance compared to conventional sampling and analytical methods; (b) the logistical and economic resources necessary to operate the technologies; (c) data quality; and (d) the range of usefulness in which the technology can be operated (limitations). Secondary objectives for this demonstration were to evaluate the SCAPS TDS technology for reliability, ruggedness, and ease of operation.

The demonstration was designed to evaluate the SCAPS VOC technology as a field screening method by comparing TDS data to data produced by conventional sampling and analytical methods. Two different methods were used to evaluate the TDS system during the course of this demonstration. *In situ* TDS data were compared to soil samples taken from a verification core at the same depth below ground surface (BGS) but approximately 0.3 meter (1-ft) away horizontally. These soil samples were preserved with methanol according to U.S. Environmental Protection Agency (USEPA) SW-846, Method 5035, for offsite analysis by EPA SW-846, Method 8260B (USEPA 1995). A second verification sample was taken from the core and desorbed *ex situ* in the TDS probe. Data from this verification sample was then compared to the *in situ* TDS data as well as the offsite methanol verification sample data. Data were collected at five geologically distinct sites to evaluate the TDS under a variety of geologic conditions.

Regulatory Issues

A major obstacle to implementation of innovative site characterization techniques on DoD sites is acceptance of new technologies by both Federal and state regulatory agencies. The Tri-Service SCAPS program has experience with pursuit of regulator acceptance of the Laser Induced Fluorescence (LIF) petroleum, oil, and lubricant sensor. The significant lesson learned during the LIF sensor regulatory acceptance experience was that there is no clear path to regulatory acceptance of innovative technology, either at the Federal or state agency levels. Therefore, the approach adopted during this demonstration project was to interact with these agencies simultaneously. Early in the project, the State of California Environmental Protection Agency Department of Toxic Substance Control (Cal EPA-DTSC) was approached to evaluate the TDS for acceptance into its respective technology evaluation and certification program. Concurrently, the USEPA, Office of Solid and Hazardous Waste (OSHW), was involved in review of a proposed VOC analytical method using the direct sampling ion trap mass spectrometer (draft EPA SW-846, Method 8265 (Wise et al. 1997a)). This method included the TDS system, in addition to procedures for VOC analyses of air, groundwater, and additional procedures for soil. Visitors days at all three demonstration field sites included hands-on observation of the TDS technology by state and/or Federal regulators from four regions of the country. Primary points of contact for the TDS technology demonstrations are given in Appendix A.

Previous Testing of the Technology

Field tests for the TDS were undertaken at three sites prior to the Environmental Security Technology Certification Program (ESTCP) demonstration. Proof of concept for the TDS was conducted at the initial field

test in May 1995 at the SERDP National Test Site, Dover Air Force Base, Dover, DE (Myers et al. 1998a). The analytical device during this test was a field portable gas chromatograph (GC). TDS samples taken above and below the water table clearly demonstrated changes in chlorinated solvent and benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations with depth. Verification samples analyzed offsite by Method 8260B (USEPA 1995) confirmed a correlation between the TDS method and conventional analyses. A second field test of the TDS system was conducted in August 1995 at Aberdeen Proving Ground, Maryland (Brannon 1995). The site chosen had been partially characterized by conventional monitoring wells and offsite analyses. Fourteen samples from five TDS penetrations were taken from the vadose and capillary zones during the 4-day field test. Comparisons of trichloroethene (TCE) concentrations from the TDS taken in the vadose zone to validation samples by Method 8260B had a linear fit correlation (r^2) of 0.98 and a slope (m) of 0.96. A third field trial held May 1996, Eglin Air Force Base, Florida, was used to transition the analytical system from a field portable GC to a field portable ITMS (Myers et al. 1996).

2 Technology Description

This section describes the SCAPS VOC sampling technology demonstrated by ERDC, WES, and U.S. Army Environmental Center (AEC) and includes background information and a description of the equipment, general operating procedures, training, and maintenance requirements. Some preliminary information regarding the costs associated with the technologies are also discussed.

Description

The SCAPS 18.2-MT (20-ton) cone penetrometer truck is the platform for a planned family of new rapid field screening technologies for determination of the spatial distribution of surficial and subsurface contaminants. The VOC sampling technology demonstrated during this project was the TDS technology developed and provided by ERDC, WES.

Cone penetrometer platform

Cone penetrometry test (CPT) results have been widely used in the geotechnical sciences for determining soil strength and soil type from measurements of tip resistance and sleeve friction on an instrumented probe. The SCAPS uses a truck-mounted hydraulic ram to advance its chemical and geotechnical sensing probes. The SCAPS CPT platform provides a 18.2-MT (20-ton) static reaction force associated with the weight of the truck. The forward portion of the truck-mounted laboratory is the push room. It contains the rods, hydraulic rams, and associated system controllers. Underneath the SCAPS truck push room is a pressure manifold system for rod and probe decontamination. The rear portion of the truck-mounted laboratory is the data collection room in which components of the SCAPS technologies systems, onboard computers, and analytical instrumentation are located. The combination of reaction mass and hydraulics can advance a 1-meter-long by 3.57-cm-diam threaded-end rod into the ground at a rate of 1 meter per min in accordance with American Society for Testing and Materials (ASTM) Method D3441 (ASTM 1995), the standard for CPT soil classification. The rods, various sensing probes, and sampling tools can be advanced to depths in excess of 50 meters in naturally occurring soils. As the rods are withdrawn,

some CPT technology probes have the ability to inject grout through 0.6-cm- (1/4-in.-) diam tubing within the interior of the CPT probe umbilical, to hydraulically seal the push hole. Because of its design, the TDS probe cannot grout as it is removed from the push hole. SCAPS CPT probes used during this demonstration were the TDS probe, the soil classification or stratigraphy probe, and a CPT platform soil sampler that takes 3- to 4-cm (1-1/4- to 1-1/2-in.-) diam cores that are 45 to 51 cm (18 to 20 in.) long. The soil classification sensor used during the demonstration was a separate sensor designed for soil classification data collection only and was used to investigate subsurface soil stratigraphy at each cluster of TDS pushes to determine the types of soil associated with each TDS sample.

Thermal desorption sampler

The TDS principle of operation is based on capturing a known volume of subsurface soil *in situ* and purging the VOC contaminants with helium carrier gas while heating the soil. The TDS probe design is a series of steel cylinders with gas channels and piston chambers made tight by o-rings (Figure 1). A central actuator rod is held in place by locking lugs in the closed position while the probe is being pushed into the ground. Once the probe reaches sampling depth, the locking lugs are pneumatically released and the piston is retracted to reveal the sample chamber. At sampling depth, the probe is pushed an additional 4 to 5 cm (1.75 to 2.0 in.) to sample a plug of soil of a known diameter and an estimated volume. Depending upon soil density, the plug weight ranges from 3.5 to 5.0 g. Helium is introduced through a stainless steel tube located along the inner wall of the outer housing at a rate of 50 ml/min. The gas enters the sample chamber area from behind and below. It is preheated to temperatures between 170 and 200 °C as it moves across the surface of the heater before sweeping upward over the soil plug to purge the VOCs as they are volatilized into the chamber. The gas carries the volatilized sample up through the analyte line and into the sample collection device at the surface. Once the soil has been desorbed, the plug is ejected by forcing a burst of high-pressure gas down the line while lowering the actuator rod. A sensor in the probe indicates the rod position to the operator at the surface. After the spent soil is ejected and the actuator rod is locked in the closed position, the TDS is pushed to a new depth and the sampling process is repeated.

TDS VOC system

Figure 2 is a schematic of the TDS VOC system. The TDS probe is linked to a manifold housed in the SCAPS truck at the surface by a 61-meter (200-ft) umbilical cable threaded through 1-meter sections of pipe which are used to advance the TDS probe through the soil. The umbilical cable contains the unheated 1.6-mm (1/16-in.) deactivated fused silica lined stainless steel analyte transfer line, three 3-mm (1/8-in.) lines supplying carrier gas to support mechanical and sampling functions, and the heater, thermocouple, and position indicator wires bundled together with heat-shrink plastic tubing. Gas flows,

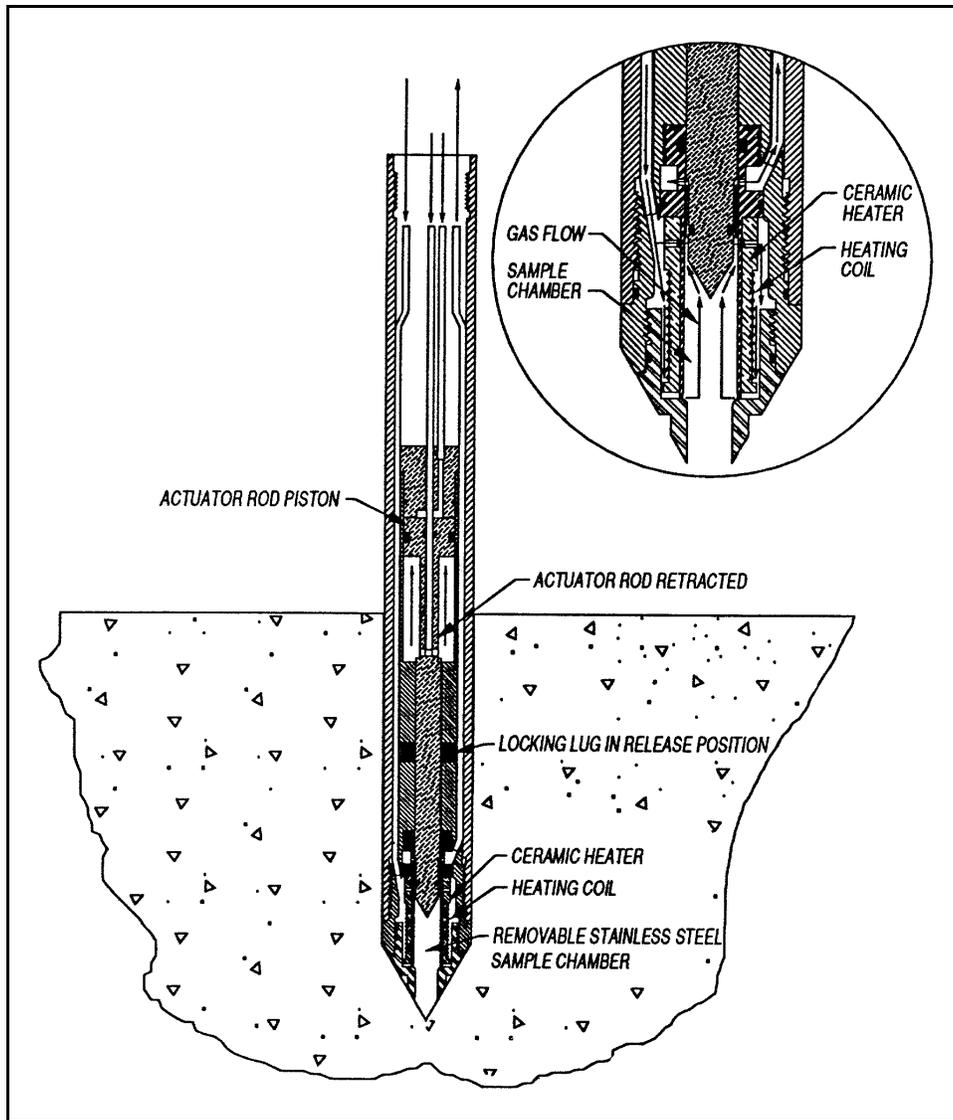


Figure 1. Schematic of TDS probe in ready-to-sample position

temperature, and position of the actuator rod are controlled and monitored at the surface through the manifold. Desorbed VOCs were collected on a sorbent trap attached directly to the manifold. Samples may be collected under vacuum, if needed, to maintain constant flow up through the TDS and analyte transfer line in balance with the flow going down through the umbilical transfer lines.

ITMS analytical system

The ITMS analytical system was a field portable ITMS with an OI Analytical purge and trap (P&T) sample concentrator as the sample introduction device. Once TDS sampling was completed, the sample was analyzed in one of two ways. If low-level concentrations were expected (less than 50 ppb of analyte on

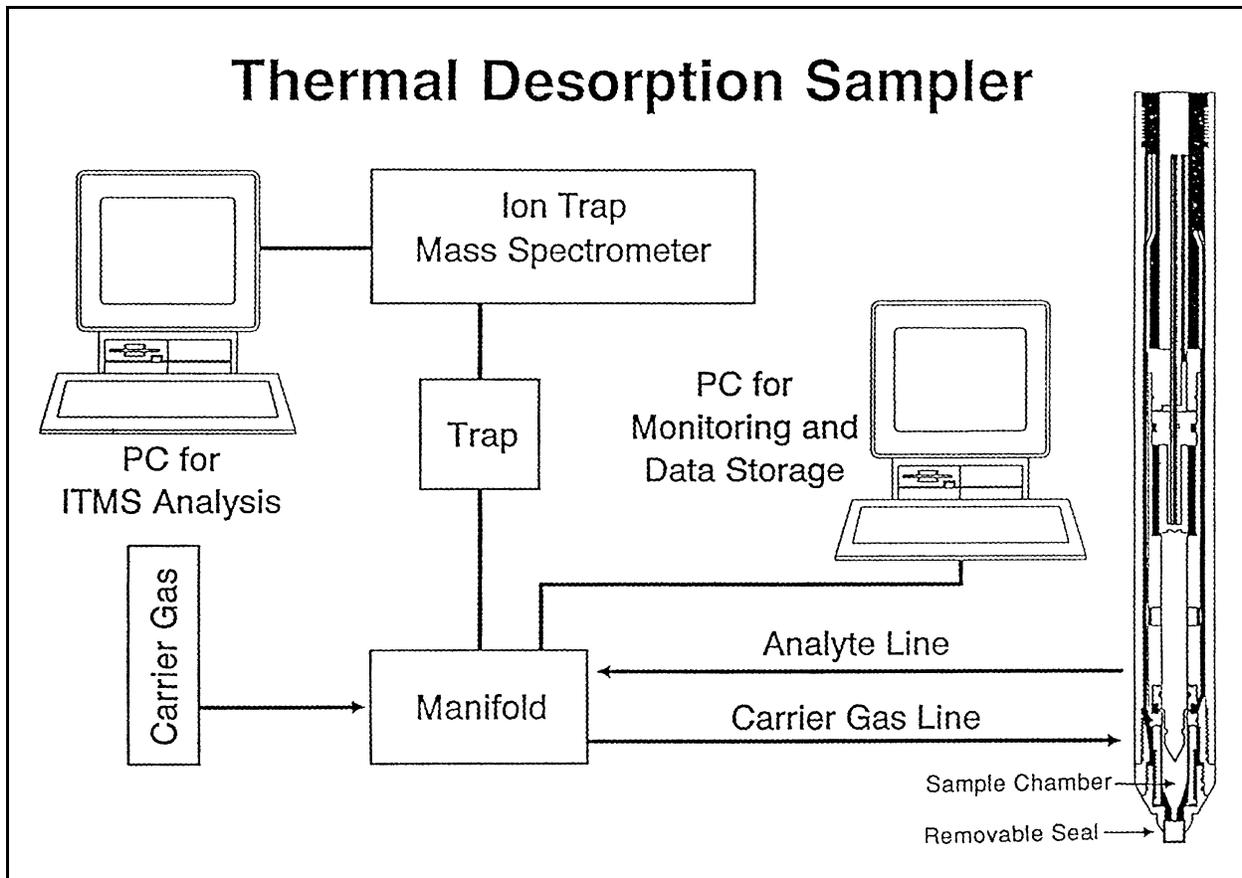


Figure 2. Schematic of TDS VOC system

a mass of 5 g of soil), the trap could be inserted into the P&T and desorbed directly into the ITMS. If higher concentrations were suspected, the trap was desorbed with methanol and an aliquot of the methanol was placed in water in the P&T vessel then desorbed in to the ITMS for analysis and quantitation.

Strengths, Advantages, and Weaknesses

Strengths of the TDS

The TDS probe was developed in response to the need for near real-time *in situ* measurements of subsurface VOC contamination. The TDS takes discrete soil samples of an estimated mass and volume at successive depths without removing the sampler from the push hole, desorbs the VOC contaminants, and carries them to the surface where they are analyzed and quantitated. The TDS provides semiquantitative field screening to determine either the presence or absence of VOCs in the vadose and capillary zones. Based on data collected using the TDS, conventional soil borings can be placed more effectively. In addition, remediation efforts can be directed on an expedited basis as a result of

the immediate availability of the TDS generated data. The TDS system has demonstrated its ability to sample sites contaminated with BTEX and chlorinated solvent, including vinyl chloride.

Advantages of the technology

The TDS is an *in situ* field screening technique for characterizing the subsurface distribution of VOC contamination before installing bore holes. The method is not intended to be a complete replacement for traditional soil bores but as a means of more accurately placing a reduced number of bores to achieve site characterization. Using a CPT platform, the TDS provides near real-time field screening of the distribution of VOC contamination. The system is configured to quickly and cost-effectively distinguish VOC contaminated areas from uncontaminated areas and provide semiquantitative estimates of soil VOC contaminant concentration, including vinyl chloride. This capability allows further investigation and remediation decisions to be made more efficiently and reduces the number of samples that must be submitted to laboratories for costly analysis. In addition, the SCAPS CPT platform allows for the characterization of contaminated sites with minimal exposure of site personnel and the community to toxic contaminants and minimizes the volume of investigation derived waste generated during typical site characterization activities.

Limits of the technology

This section discusses the limits of the SCAPS TDS technology, as they are currently understood.

Truck-mounted cone penetrometer access limits. The SCAPS CPT vehicle is a 18.2-MT (20-ton) push platform built on a commercially available diesel powered truck chassis. The truck requires a minimum access width of 3 meters (10 ft) and a height clearance of 5 meters (15 ft). Some sites, or certain areas of sites, may not be accessible to a vehicle of this size and weight. The access limits for the SCAPS CPT vehicle are similar to those for conventional drill rigs and heavy excavation equipment.

Cone penetrometer advancement limits. The CPT sensors and sampling tools may be difficult to advance in subsurface lithologies containing cemented sands and clays, buried debris, gravel units, cobbles, boulders, and shallow bedrock. As with all intrusive site characterization methods, it is extremely important that all underground utilities and structures be located using reliable geophysical equipment operated by trained professionals before undertaking activities at a site. This should be done even if subsurface utility plans for the site are available for reference.

TDS limitations. Limitations for the TDS lie in three categories:
(a) maintenance and mechanical functioning; (b) the ability to take and expel a

physical soil sample; and (c) contaminant recovery from the soil sample. As with any device with moving parts deployed through subsurface strata, a certain amount of wear and maintenance is to be expected. The system should be checked for leaks and the seals and o-rings checked for wear on a daily basis. CPT advancement limitations in the previous paragraph apply. The elevated ram force required to push through densely packed strata, such as cemented sands, gravel, or cobbles, may cause the locking lugs to jam and prevent the TDS from opening. In areas of cobbles, a rock can be forced down the push hole ahead of the TDS, hereby preventing a sample from being taken into the sample chamber. Densely packed clays can swell after entering the sample chamber. After drying, the sample forms a hardened plug that can be difficult to eject without bringing the sampler to the surface.

The upper limit of detection for the TDS is determined by the system's ability to completely desorb analytes from the soil sample. Recovery is a function of the desorption efficiency and the completeness of the seal at the bottom of the sample chamber. TDS design assumes that the soil material will be densely packed enough to fill the sample chamber and plug the bottom opening to form a seal. Loosely packed soils may form an incomplete seal. The integrity of the seal is determined by monitoring the gas mass flow rates through the TDS system. Vacuum applied to the exit end of the sorbent trap is used to augment the gas flow by creating a gradient in favor of the gas returning up the analyte line and into the trap. During TDS development, soil type and moisture content were shown to affect analyte recoveries with wet clays having the lowest recoveries (Myers et al. 1995). A summary of these results is given in Table 1. By keeping temperatures above 170 °C during the desorption process and extending the sampling time to 20 min, analyte recovery can be maximized while keeping the sampling period down to a reasonable length of time.

Target Compound	Silt 10% M ² % R (SE) ³	Silt 20% M % R (SE)	Sand 10% M % R (SE)	Clay 10% M % R (SE)
Benzene	96.5 (2.0)	69.3 (0.8)	92.6 (2.1)	87.8 (2.0)
Trichloroethene	93.4 (1.2)	89.5 (2.5)	86.8 (1.6)	77.7 (7.3)
Toluene	102 (2.8)	94.1 (2.9)	95.9 (1.0)	88.3 (1.3)
Chlorobenzene	95.7 (1.0)	87.8 (3.2)	92.3 (0.1)	81.7 (0.3)
Ethylbenzene	92.9 (1.2)	93.9 (1.9)	91.2 (2.9)	81.7 (0.3)
m- & p-Xylenes	101 (1.3)	90.5 (4.2)	96.8 (0.7)	90.0 (1.0)
o-Xylene	100 (1.3)	89.0 (1.0)	96.3 (0.6)	86.8 (0.5)
m- & p-Dichlorobenzene	93.1 (2.1)	81.3 (3.8)	86.5 (0.7)	79.1 (2.9)
o- Dichlorobenzene	125 (8.2)	88.2 (1.8)	108 (10.3)	98.7 (7.4)

¹ Probe temperature was 100 °C with a flow rate of 40 ml/min.
² Percent moisture.
³ Percent recovery (standard error).

ITMS limitations. The ITMS methodology used to identify and quantitate desorbed VOC contaminants from the TDS follows draft Method 8265 (Wise et al. 1997a). This method is intended for field screening applications of ion trap mass spectrometry. Because a separation technique is not used, the ITMS cannot distinguish between analytes that yield identical mass fragments. For example, 1,1-dichloroethene, cis-1,2-dichloroethene, and trans-1,2-dichloroethene are identified by the same mass ion (96) and cannot be distinguished from each other. Results for this mass ion are reported as a total. Ethylbenzene and the xylenes are also identified with the same mass ion (106) and are reported as a total. The current laboratory method, Method 8260B (USEPA 1995), using gas chromatography separation with mass spectrometry detection (GC/MS) is also not able to differentiate some analyte pairs such as meta- and para-xylene. A second limitation is associated with high concentrations of contaminants whose mass ions fragment into smaller mass ions such as 96, the mass ion for total dichloroethene (DCE), and 62, the mass ion for vinyl chloride. When this type of fragmentation occurs, the analytical results can be biased on the high side. It may be necessary to raise the lower limit of detection for some analytes to reduce the probability of false positives. A third limitation associated with the ITMS instrumentation available for this demonstration was their low dynamic range. Essentially all analytical systems have upper limits of detection as well as lower limits of detection. The upper limit of detection for the ITMS is determined by the upper limit of the number of molecules that it can analyze before the detector is “saturated” with ions. Without an automatic gain control to adjust for high concentrations of analyte introduced into the system at any point in time, the ITMS detector can become saturated causing the analytical response to flatten out as the concentration of analyte increases. To compensate for this, the ITMS operator makes a series of dilutions to bring the analytes of interest into range of the calibration curve. Contaminants with lesser concentrations could be masked or diluted out during the analysis if the analyst was focusing on the contaminant with the highest concentration. This diluting out effect is not unique to ITMS analysis. However, when coupled with mass ion fragmentation and the lack of a chromatographic separation, it could have a significant impact on analyte reporting limits.

Extremely high-level contamination carryover. The effective dynamic range for the TDS is determined by three factors: the dynamic range of the ITMS, discussed in the previous section; the desorption efficiency from various soil types; and the potential for carryover or cross contamination between samples after desorption of a high concentration of contaminant (greater than 10 mg/kg). Extremely high levels of VOC contamination will cause carryover of analytes between successive samples. That is, after completion of a very high-level sample, residual VOC analytes may remain in the lower portion of the TDS analyte transfer line where they slowly desorb into successive samples over time. This is considered sample carryover between sampling events. While this residual carryover can have an additive effect on the reported concentration of a sample, it most impacts the lower limit of detection. This problem cannot be completely eliminated, but the effects of sample carryover can be minimized. A

system blank is analyzed after every TDS sampling event. Carryover is occurring if VOC analytes are detected above the system background response. When carryover is detected, the sample transfer lines are purged with inert gas until the background, measured by system blanks, returns to normal. This procedure requires approximately 30 min, equivalent to approximately two-thirds the time required for a normal TDS sampling event. After an extremely high-level sample has been analyzed, the TDS probe can be switched to allow sampling to continue while the contaminated system is purged.

Factors Influencing Cost and Performance

Labor and equipment are the primary costs incurred during a SCAPS deployment. Discounting the capital cost for the SCAPS CPT vehicle, equipment costs are made up of the cost for the TDS system, the ITMS, the P&T interface, consumable analytical supplies, and maintenance for the SCAPS vehicle including onboard equipment. Once the initial equipment purchase is made, the majority of the cost associated with TDS operation is for labor. Normal operation of the TDS requires four to five individuals: the CPT operator and helper; the TDS operator / electronics instrumentation operator; the ITMS analyst; and a crew chief to develop work plans, health, and safety plans and identify push locations if that function is not performed by a site manager. Costs are normally broken down into cost per sampling event based upon the amount of time required for each sample. The time required to push and retract a CPT probe is depth dependent, the deeper the push, the longer it takes to push and retract the sampler. Each sampling event averages approximately 40 min: a maximum of 20 min to desorb the soil sample; 5 to 10 min to eject the spent soil plug and flush the lines; and 5 to 10 min to push to the next sampling depth in the hole and/or take a blank sample, if required because of contaminant concentration found in the sample. Experience has shown that concentrations less than 1 mg/kg generally do not have excessive carryover after the initial 5- to 10-min flush. As mentioned in the paragraph on TDS limitations, performance can be affected by soil type. Densely packed soils, sand, or cobbles can prevent the TDS from taking a sample. Loosely packed soils may form an incomplete seal at the base of the sample chamber, lowering analyte recovery. This can be corrected with the use of vacuum, causing a gradient pulling the gas stream with the desorbed analyte up the analyte line and through the sorbent trap. Densely packed soils such as moist clays require the longest sampling time to avoid reduced analyte recovery. In addition, clay soils can be difficult to eject from the TDS probe. If a sample fails to eject below the surface, the TDS must be withdrawn from the push hole to remove the dried sample. This can affect performance by reducing the number of sampling events completed during the course of the day. A minor redesign of the sampling chamber has greatly reduced the frequency of failed ejections below the surface. As with any screening technology, a certain percentage of the samples should be confirmed by conventional methods. This is easily accomplished with a CPT platform soil sampler and should be figured into the cost.

3 Site/Facility Description

Background

Five sites were investigated during the field phase of this demonstration. Sites were selected in different geographic locations to facilitate wide exposure to user communities. Sites were selected based on the following criteria:

- a.* Known soil VOC contamination, from low ng/g to $\mu\text{g/g}$, in ranges detectable by the TDS;
- b.* Site topography that allows for SCAPS vehicle access and maneuvering;
- c.* Soil types, cataloged in previous soil bores, suitable for investigation using CPT technology with subsurface geology sufficiently complex to demonstrate the advantage of rapid onsite analysis compared to conventional site characterization practices.
- d.* Access to demonstration site and visitors' day by regulators from the EPA, Cal EPA-DTSC, and the Site Characterization subcommittee of the Interstate Technology Regulatory Cooperation (ITRC) consortium.

The sites selected were:

- a.* Bush River Study Area, U.S. Army Aberdeen Proving Ground, Edgewood, Maryland; June 1996.
- b.* Davis Global Communication Site, McClellan Air Force Base, Sacramento, California; December 1996 and February 1997.
- c.* U.S. Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire; June 1997.
- d.* Lake City Army Ammunition Plant, Independence, Missouri; June 1998.
- e.* Longhorn Army Ammunition Plant, Karnack, Texas; August 1998.

Bush River study area, Aberdeen Proving Ground site history

The Bush River Study Area (BRSA) is located in the northeast portion of the Edgewood Area (Figure 3), Aberdeen Proving Ground, Maryland. The BRSA covers (200 ha) 500 acres on a peninsula bounded north by Lauderick Creek, east and south by Bush River, and southwest by Kings Creek. As early as 1919, portions of the area were used for training, test activities, disposal, and chemical storage. The southern part of the peninsula was designated as “A-Field” and used for artillery firing, training, testing, and smoke and incendiary munitions testing facilities. The area has been used primarily as a storage location for chemical agents and materials used in research investigations and for production operations conducted in the Edgewood area. The BRSA predominantly consists of wooded areas with roads leading to open storage yards, warehouses, and igloos. During World Wars I and II, the area was a main storage and trans-shipment depot for chemical-filled munitions. The dock, on the southeast boundary, received foreign chemical munitions captured and shipped to Edgewood for testing and disposal. Chlorinated solvents associated with the chemical munitions were believed to be the source of VOC contamination in the area used for the TDS technology demonstration.

The southern two-thirds of the BRSA are fenced and patrolled; security clearance is required for access. Current activities involve storage of bulk chemical agents in “ton containers” and the accumulation and storage of hazardous materials and wastes in preparation for disposal. Waste management units include septic tanks, munitions burial sites, landfills, open burning sites, fill areas, and drum disposal sites. Although many of the sites historically relate to handling or disposal of chemical agents, potential contamination is usually from wastes generated during routine support activities. These contaminants may be expected to include heavy metals, chlorinated solvents, and petroleum hydrocarbon fuels.

The demonstration fieldwork conducted by the TDS SCAPS team at the BRSA was primarily in the area bounded by clusters 11 and 15. Work was conducted throughout cluster 11, primarily north and east of the fenced “ton container” yard and in the eastern portion of cluster 15. This area was known from previous monitoring well data to have subsurface VOC contamination at concentrations suitable for TDS analysis. Previous investigations of the site predicted a large contaminant groundwater plume with a minimum number of monitoring wells. Review of previous monitoring well logs indicated subsurface geology that was compatible with CPT equipment and was sufficiently complex to demonstrate the TDS system capabilities.

McClellan Air Force Base

Fieldwork for the TDS was originally set for McClellan Air Force Base (AFB) in Sacramento, CA. The site chosen was Site B-5 of Investigation Cluster (IC) 33 and IC 8. Attempts to push at each of these sites were

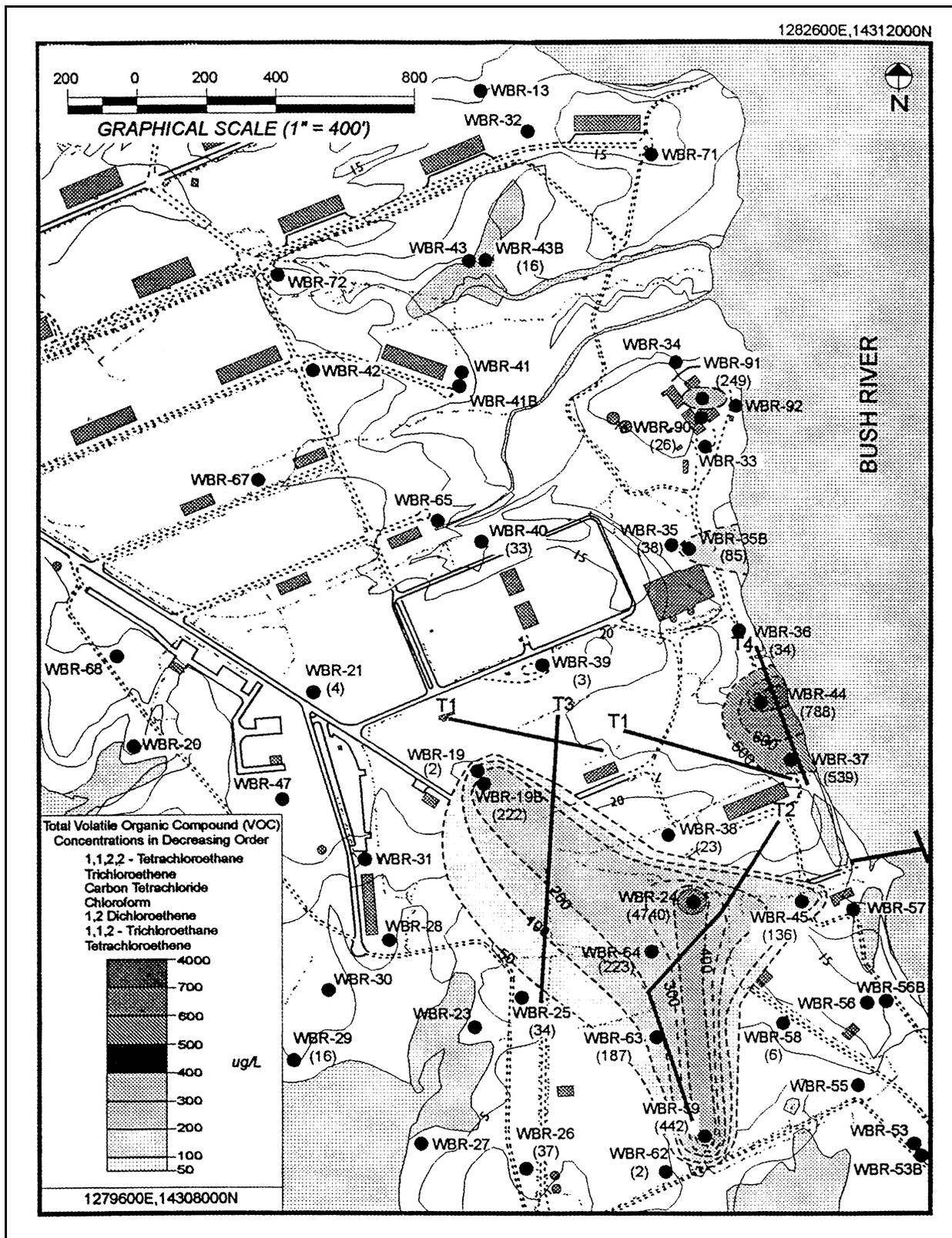


Figure 3. Site map for Bush River study area SCAPS TDS investigation (to obtain meters, multiply feet by 0.3048)

unsuccessful due to the presence of layers of hardpan at 4 and 2 meters (13 and 5 ft) BGS, respectively. The fieldwork was moved to Davis Global Communications Site (DGCS) where VOC contamination existed and where CPT equipment had been successfully deployed in the past.

Davis Global Communication site history. The Davis Global Communications Site is an annex of McClellan AFB, California, located 6.5 km (4 miles) south of the city of Davis. McClellan AFB is one of the Strategic Environmental Research and Development National Test Sites for demonstration and field evaluation of innovative environment restoration technologies. The DGCS was built in the 1950s and covers approximately 128 ha (316 acres) in Yolo County and is surrounded by farmland. The DGCS consists of the fenced, Main Compound Area (approximately 3 ha (8 acres)), communications antennas and undeveloped grasslands (CH2M Hill 1994). The site is operated by the 2049th Communication Squadron, McClellan AFB.

In 1985, three underground storage tanks containing diesel fuel were discovered to be leaking. In 1987, hydrocarbon contamination was confirmed in the vicinity of the underground storage tanks. The tanks were drained and removed in 1988. During the field investigation for hydrocarbon contamination, VOCs were discovered in groundwater samples. The source of the VOC contaminants is unknown but is likely the result of past disposal practices. Subsequent investigations indicated chlorinated VOC contamination in soil and groundwater. Previous investigations included 19 CPT soundings, 28 soil borings, 30 Hydropunch™ samplings, and 29 monitoring wells (Figure 4). Previous CPT penetrations at this site reached a maximum depth of 44 meters (145 ft) BGS with the majority of CPT penetrations reaching below 30 meters (100 ft) BGS.

Cold Regions Research and Engineering Laboratory site history

The U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) is located on 12 ha (30 acres) of land, west of and adjacent to State Highway 10, and 2.4 ha (1.5 miles) north of the town of Hanover in Grafton County, New Hampshire.

CRREL was established 1 February 1961 by the U.S. Army Corps of Engineers (USACE) to combine the work of two predecessor organizations: the Snow, Ice, and Permafrost Research Establishment and the Arctic Construction and Frost Effects Laboratory. CRREL performs basic and applied research in snow, ice, and frozen ground. CRREL also provides the U.S. Department of the Army (USDOA) with practical engineering research to develop equipment and procedures for applications in cold regions.

The CRREL site contains several locations where past spills, disposal practices, and operations have contaminated soils and groundwater. Past investigations (Authur D. Little, Inc. 1994) have identified and prioritized

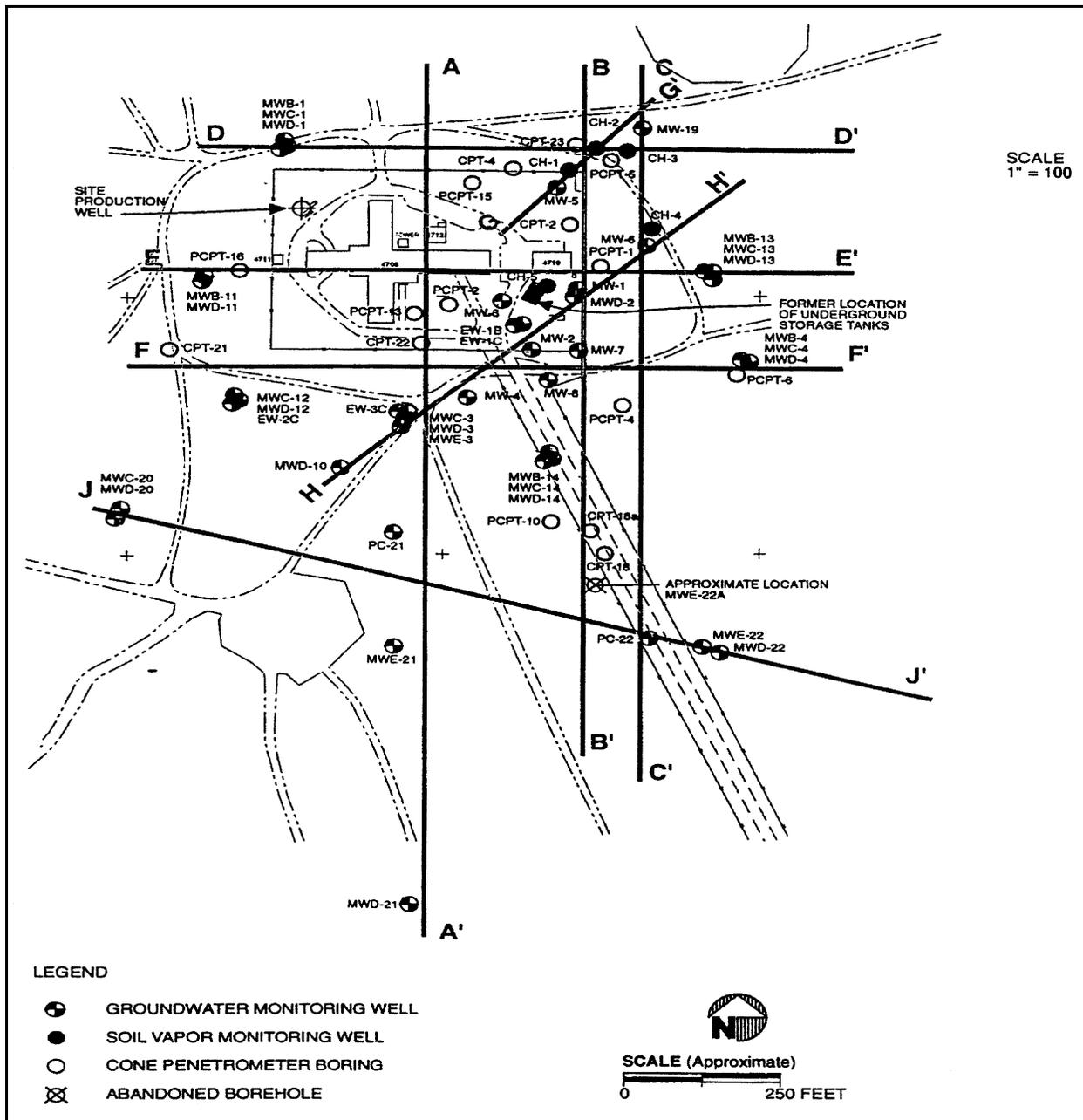


Figure 4. Site map for Davis Global Communications Site SCAPS TDS investigation (to obtain meters, multiply feet by 0.3048)

16 Areas of Concern (AOC) where contaminant sources may have been located. Two AOC met the requirements for testing with the TDS (Figure 5).

AOC 9 is the location of an Ice Well, a cased boring fitted with a refrigeration coil for freezing water in the boring. It is 1 meter (3 ft) in diameter and approximately 61 meters (200 ft) deep. The Ice Well was formerly used for testing ice drilling technologies and was not constructed or used for injection or withdrawal of fluids from the ground. TCE was used in refrigeration lines and

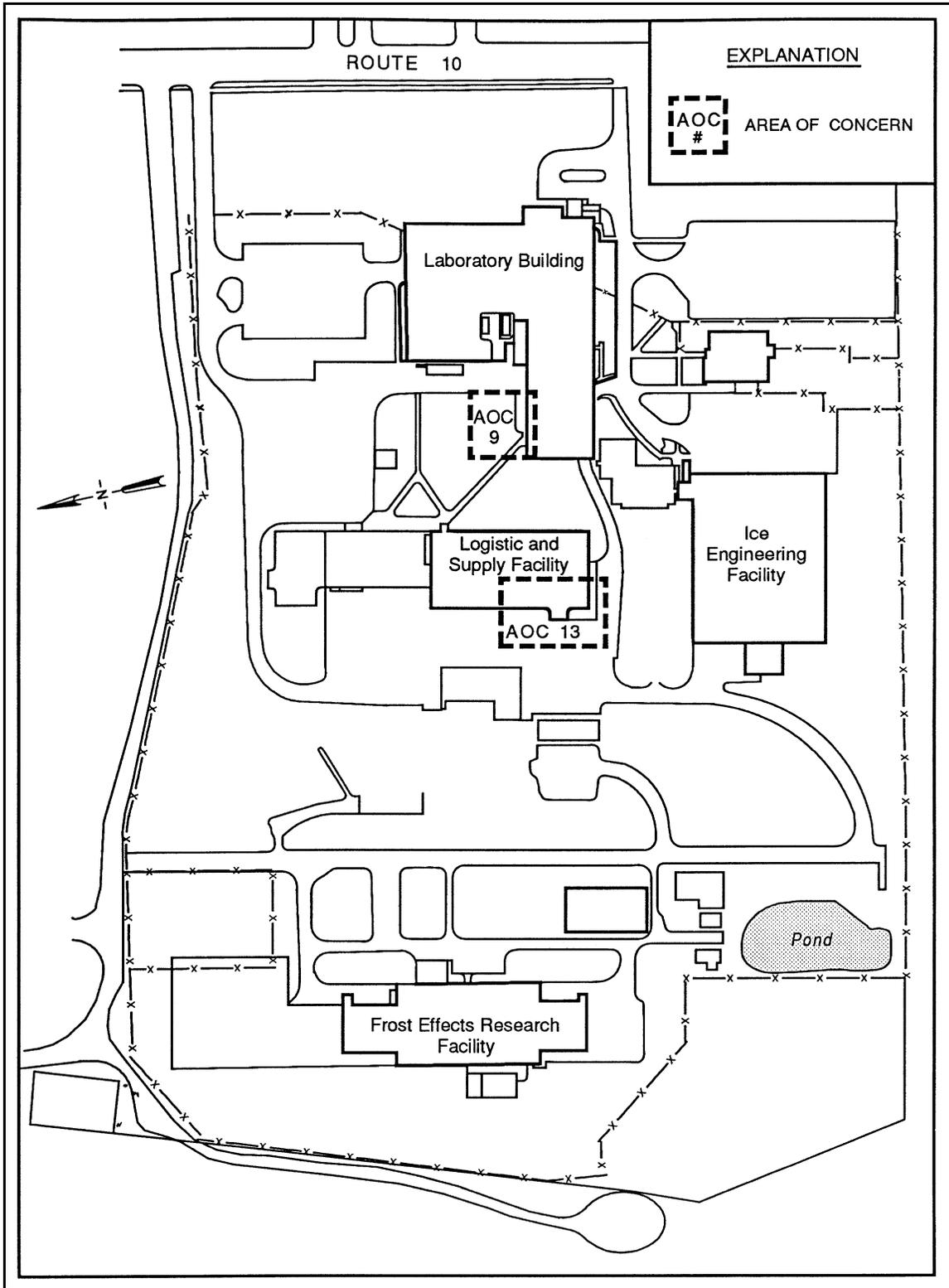


Figure 5. Site map for the TDS investigation at CRREL showing AOC 9 and AOC 13

drilling fluid mixtures. This area may also contain TCE-contaminated soils resulting from a 1970 explosion of the former TCE tank in AOC 1. This explosion released approximately 11.4 kl (3,000 gal) of TCE to the pavement and nearby unpaved area to the west of AOC 1. The refrigeration system for the Ice Well is no longer in operation; however, liquids and ice still exist within this well. AOC 9 is approximately 30 meters (100 ft) west of AOC 1.

AOC 13 is located between the Logistics and Supply Facility and the Storage Building. This was the location of a former gravel pad used for the disposal of spent TCE. A parking lot and road currently cover the site. A portion of the Logistics and Supply Facility footprint covers the site.

Previous investigations between 1990 and 1996 (Arthur D. Little, Inc. 1994 and McKay 1997) identified soil and groundwater contamination at AOC 9 and 13. These investigations have included hand auger borings, drilling and sampling shallow borings, and drilling and sampling deep soil borings to bedrock. In 1996, TCE was detected in soil samples taken in AOC 9 near the Ice Well. Concentrations were highest at 5 meters (18 ft) BGS. In 1996, the CRREL site was used to validate the SCAPS chlorinated solvent sensor. Concentrations of TCE detected at AOC 13 ranged from 0.05 to 24 mg/kg, with the highest concentrations found at 17 meters (56 ft) BGS. In addition to TCE, traces of DCE and vinyl chloride were detected during the 1996 investigation.

Lake City Army Ammunition Plant site history

Lake City Army Ammunition Plant (LCAAP) is located on approximately 1,600 ha (4,000 acres) in Jackson County, Missouri, mostly within the eastern corporate boundary of Independence, MO, and 37 km (23 miles) east of Kansas City, MO. LCAAP is a U.S. Army Armament, Munitions, and Chemical Command (AMCCOM) installation which manufactures small arms ammunition. Operations at LCAAP include manufacturing, storage, test firing, waste treatment, and waste disposal.

LCAAP consists of 33 “areas” that contain approximately 131 suspected or confirmed contaminated sites or solid waste management units (SWMUs). Each of the areas are designated by a numeric qualifier, 1 through 33. The TDS investigations took place in the Northeast Corner Operable Unit, Area 17.

Area 17 consists of four specific areas: the current sanitary landfill; the waste, glass, paint, and solvents area; the current pistol range; and the oil and solvent pits area. The oil and solvent pits area consists of three closed disposal pits located immediately adjacent to the current sanitary landfill. Two of the three pits were used for disposal of grease and oil, waste solvent, and waste oils. The easternmost pit was used for disposal of demolition waste and domestic refuse. The western and central pits were opened in the 1960s and closed in 1979. The pits occupied an estimated surface area of 0.23 ha (25,000 ft²) and reportedly received approximately 280 cubic meters (10,000 cu ft) of waste. The

easternmost pit was opened in 1977 and closed in 1979. Fill depths of up to 3 meters (10 ft) were indicated by soil boring drilled during the 1990 remedial investigation work. Closure of the three pits did not involve the use of an engineered cover system. Currently, the pits are heavily vegetated with a soil cover typically less than 0.3 meters (1 ft) thick. Stressed vegetation and small barren areas at the ground surface have been noted at this site. The TDS investigation took place at the oil and solvent pit area along the gravel road running beside the central pit (Figure 6).

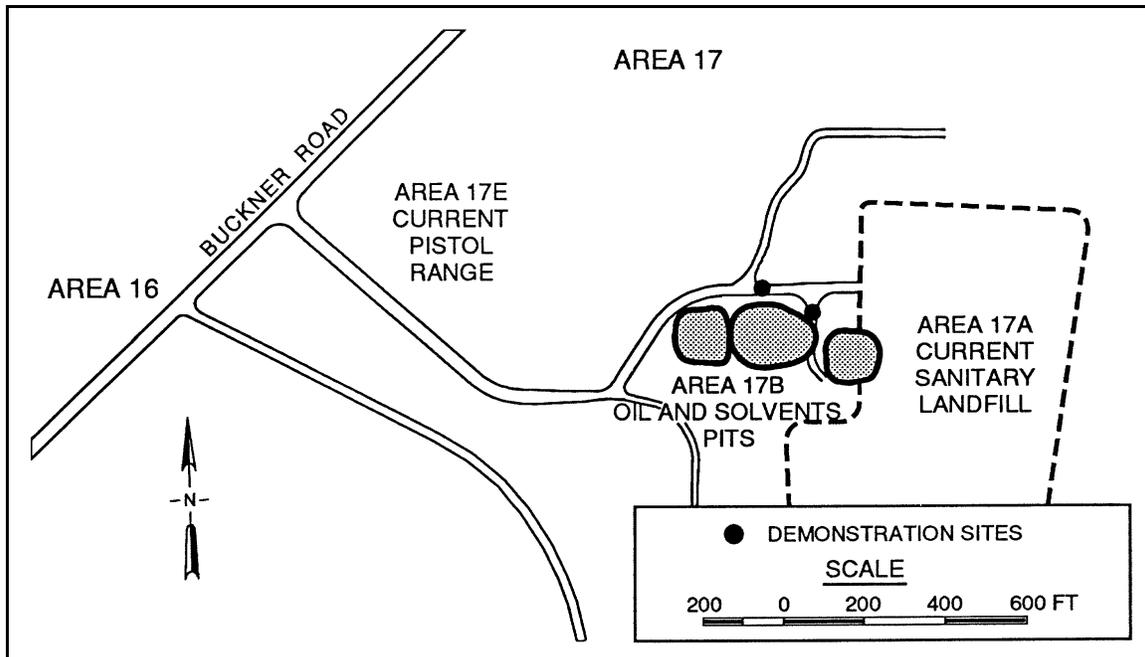


Figure 6. LCAAP Area 17. TDS investigation took place along the road adjacent to the oil and solvent pits (to obtain meters, multiply feet by 0.3048)

Longhorn Army Ammunition Plant site history

Longhorn Army Ammunition Plant (LHAAP) is located on 3,450 ha (8,523 acres) in the northeast corner of Harrison County near Karnack, TX, approximately 22 km (14 miles) northeast of Marshall, TX, and approximately 64 km (40 miles) west of Shreveport, LA. LHAAP is a government-owned, contractor-operated industrial facility operated under the jurisdiction of the U.S. Army Industrial Operations Command. Operations began in 1942 with the production of TNT flake by Monsanto Chemical Company. Production of TNT continued until August 1945. From 1952 until 1956, Universal Match Corporation produced pyrotechnic ammunition such as photoflash bombs, simulators, hand signals and 40-mm tracers. In 1955, Thiokol Corporation began operation of the Plant 3 area rocket motor facility. In 1965, production on pyrotechnic and illuminating ammunition was reestablished. These operations consisted of compounding pyrotechnic and propellant mixtures, load, assemble, and pack (LAP) activities, accommodating receipt and shipment of containerized cargo,

and the maintenance and lay away of standby facilities and equipment for mobilization planning. The installation has also been responsible for the static firing and elimination of Pershing I and II rocket motors in compliance with the Intermediate Range Nuclear Force Treaty in effect between the United States and the former Union of Soviet Socialist Republics. Currently there is no permanent operating contractor. The plant is now closed and is scheduled to be returned to state and/or private ownership.

Longhorn Army Ammunition Plant was placed on the national priority list in 1990. Fifty sites were included in the restoration effort: 4 open burning areas; 13 industrial areas; 5 burial pits; 5 sumps/tanks; 4 treatment plants; 16 storage areas; and 3 landfills. The current status of the areas ranges from site investigation to interim remedial action. Contaminants consist of explosives and volatiles in soil, groundwater, and surface water.

The TDS investigation took place in the sumps project area located in the Plant 3 area rocket motor facility (Figure 7). The sumps project area consists of 125 underground sumps and 20 waste rack sumps located throughout the LHAAP production area. Manufacturing areas at LHAAP were washed down with water to reduce propellant, explosive and pyrotechnic (PEP) dusts which would otherwise collect and pose a safety hazard. Water deactivates ignition sensitive compositions. To dissolve difficult chemical binders, chlorinated solvents were also used in the cleanup of manufacturing areas. These solvents and PEP compositions were washed into sumps with large volumes of water. Based upon previous investigations (Target Environmental Services 1994, USACE Tulsa 1996), VOC contaminants in the groundwater include TCE (0.010 to 5.0 mg/L), total DCE (0.020 to 2.0 mg/L) and, tetrachloroethene (PCE) (around 0.050 mg/L).

Site/Facility Characteristics

Site Characteristics, Bush River study area (BRSA), Aberdeen Proving Ground

Aberdeen Proving Ground is located in the Atlantic Coastal Plain physiographic province in the eastern part of Hartford County, Maryland. Unconsolidated sediments consisting of clay, silt, sand, and gravel underlie the Coastal Plain. Coastal Plain sediments in Hartford County were deposited on the southeastward-dipping surface of Piedmont basement rocks by the actions of seas, streams, or rivers and form a wedge-shaped body. These sediments comprise three units in the BRSA: from oldest to youngest they are the Potomac Group of Early Cretaceous age, the Talbot Formation of Pleistocene age, and recent alluvium. Alluvial deposits occur near drainage ways and topographic lows. The shallowest stratigraphic unit is the Talbot Formation. The lithology of the Talbot Formation is extremely variable because of the changing thicknesses of clay and sand facies, and presence of clay interbeds in gravelly sand facies. The deepest stratigraphic unit is the Potomac Group. The Potomac Group is

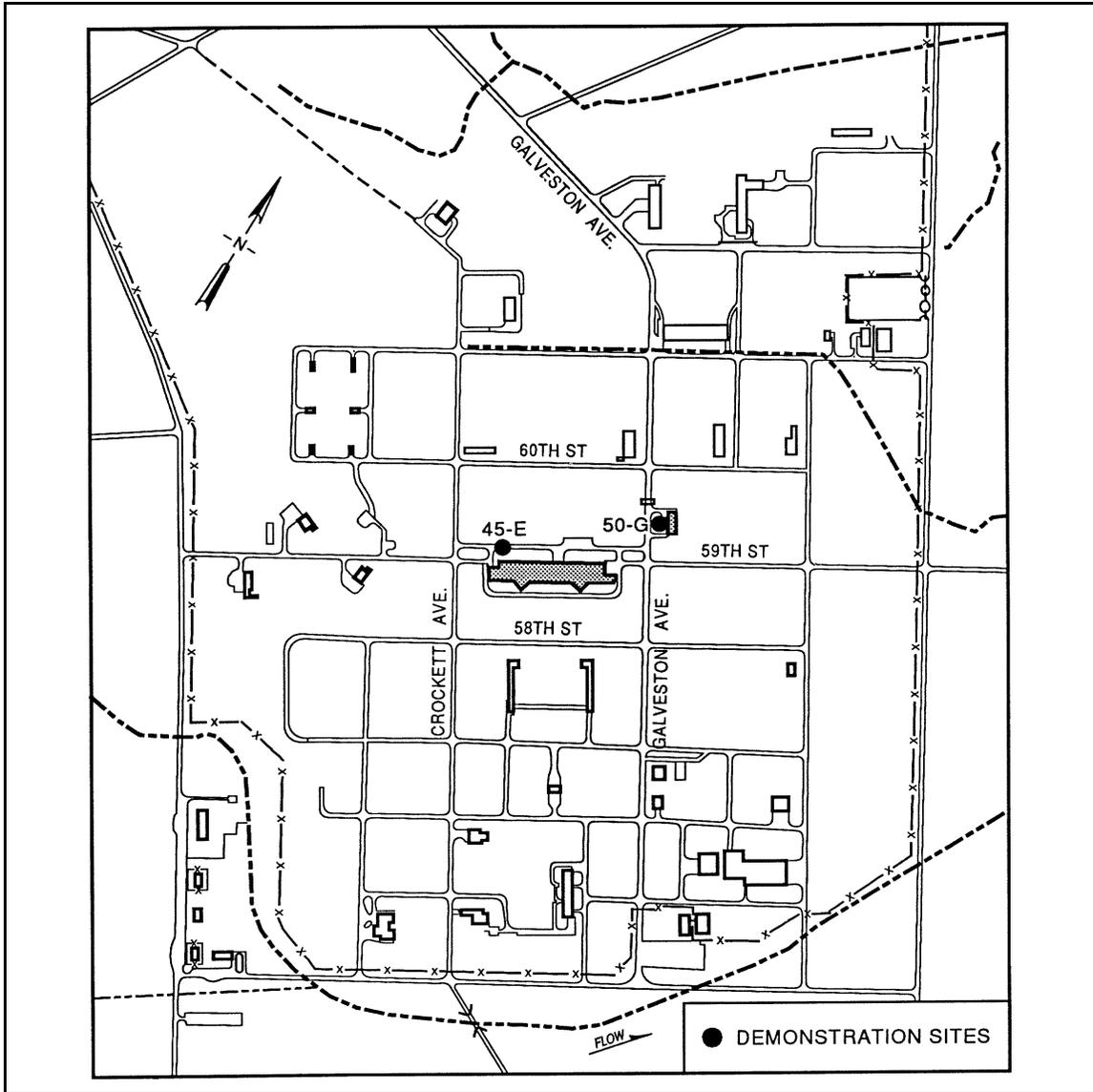


Figure 7. LHAAP sumps project area. TDS samples were taken at buildings 50-G and 45-E

undifferentiated in Hartford County and consists of sand and gravel units interbedded with multicolored clay units. The lithology encountered during the BRSA borehole drilling includes interbedded clay, silt, sand, and gravel facies. These sediments form confining units and aquifers. Silt and silty clay facies outcrop over the majority of the BRSA peninsula and form a discontinuous semiconfining (leaky) unit of varied thickness, averaging about 3 meters (10 ft).

In 40 of 44 boreholes (General Physics Corp. 1995), the first significant water-bearing unit encountered is the upper (water table) aquifer. The average depth to the upper aquifer in the extreme southern part of the BRSA peninsula is approximately 2.5 meters (8 ft). The upper aquifer ranges in thickness from 0.7 to 8.8 meters (2.3 to 28.8 ft), with an overall average thickness of 3.5 meters

(11.6 ft). The upper aquifer is thinnest in the northern part of the BRSA peninsula near cluster 35 and thickest in the south near cluster 18. The upper aquifer is unconfined by sand and sandy silt in places near some surface water bodies. As a result, the upper aquifer appears to be semiconfined in the BRSA. A tight, silty clay unit was encountered during drilling immediately below the upper aquifer and appears to be a confining unit. The deeper, confined “Canal Creek” aquifer is immediately below this confining unit. The Canal Creek aquifer was encountered in one borehole at a depth of approximately 13 meters (43 ft). The subsurface geology at the demonstration site was sufficiently complex to demonstrate the advantages of the combination of SCAPS geophysical data collection and near real-time soil VOC detection using the TDS system. Because of the shallowness of the vadose zone on the BRSA peninsula, TDS sampling activities took place in the silty clay confining unit immediately below the Upper aquifer.

Site characteristics, Davis Global Communications Site, Davis, California

The DGCS is situated in Yolo County, California, and is surrounded by irrigated farmland. Subsurface geology consists of three freshwater-bearing units listed from the surface to increasing depth and age: the younger alluvium, the older alluvium, and the Tehama Formation. The younger alluvium is up to 12 meters (40 ft) thick, consisting of primarily fine-grained floodplain and overbank deposits of silts and clays mixed with lesser amounts of stream channel deposits. A sand deposit typically 3 meters (10 ft) thick is found between 6 to 12 meters (20 to 40 ft) BGS in this unit. The older alluvium is 18 to 39 meters (60 to 130 ft) thick and consists of stream deposits of silt, silty clay, gravel, and sand deposited by Putah Creek. Fine-grained deposits predominate. Gravel and sand deposits comprise about one-fourth of the thickness and occur as discontinuous lenses rather than continuous sheets. The Tehama Formation occurs below about 49 meters (160 ft) BGS. Local groundwater levels fluctuate because of agricultural pumping during April to October. During late fall and winter, groundwater levels approach mean sea level. The groundwater is generally between 7 and 10 meters (25 and 35 ft) BGS during winter and 18 and 21 meters (60 to 70 ft) BGS during summer.

In 1987, hydrocarbon contamination was found in the vicinity of known underground storage tanks. Subsequent investigations indicated chlorinated VOC contamination in soil and groundwater. These investigations included 19 CPT soundings, 28 soil borings, 30 Hydropunch™ samplings, and 29 monitoring wells (CH2M Hill 1994). Previous CPT penetrations at this site have reached a maximum depth of 44 meters (145 ft) BGS with the majority of CPT penetrations conducted below 30 meters (100 ft) BGS. The previous use of CPT equipment at the site confirmed the suitability for the SCAPS TDS demonstration.

Contaminants of concern at the DGCS are PCE, TCE, DCEs, dichloroethane, vinyl chloride, and benzene. In 1994, CH2M Hill summarized the VOC

contaminants detected in eight monitoring wells at the DGCS site. The total VOC concentrations varied from a low of 8.3 µg/L to a high of 1.38 mg/L.

Site characteristics, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

CRREL is located in the upper Connecticut River Valley on terraced unconsolidated glacial deposits. Despite modification of the topography by development, CRREL has three main terraces at elevations ranging from 159 to 140 meters (520 ft to 460 ft) above mean sea level. The eastern third of CRREL, including AOC 9, is located on the upper terrace. The upper terrace slopes gently down to the west. The middle terrace is very narrow, generally less than 30 meters (100 ft), and is covered by asphalt. It contains AOC 13. The geology of CRREL consists of two main geological units: overburden sequence and bedrock. The overburden consists entirely of glaciofluvial and glaciolacustrine sediments. These soils are deep and well drained with silty and sandy textures. From east to west across the CRREL site, the soils consist primarily of Hitchcock silt loam and Windsor loamy fine sand. From previous soil borings, soil types that commonly occur are silt imbedded with layers of fine sandy silt. The sandy silt layers can range from less than 2.6 cm (1 in.) to several feet. Beneath the silt is a layer of fine silty sand that forms the basal lacustrine unit for the eastern two-thirds of CRREL. Moisture content of soil samples collected during previous investigations (McKay 1997) indicate a general trend of decreasing moisture with depth in the vadose zone. Soil moisture at AOC 9 varies from 20 percent near the surface to 5 percent at 36 meters (120 ft) BGS. The bedrock consists of poly-deformed metasedimentary rock. Water table depth ranges from 24 to 46 meters (80 to 150 ft) BGS. The maximum depth pushed during the TDS investigation was 18 meters (60 ft) BGS.

Site characteristics, Lake City Army Ammunition Plant, Independence, Missouri

The LCAAP lies within the Central Lowlands Physiographic Province near the boundary between the Osage Plains and the Dissected Till Plains. This section is characterized as a plain of low relief with gently rolling topography comprised of broad, shallow valleys and low-gradient meandering streams. The surface topography in the vicinity of LCAAP consists of rolling uplands traversed by broad steam valleys and floodplains of the Missouri River and Little Blue River. The former floodplain averages about 4.8 km (3 miles) in width in this area, with a surface elevation of approximately 224 meters (735 ft) above sea level. Elevations on the upland surface average between 244 to 274 meters (800 and 900 ft).

The north and west portions of LCAAP are flat, characteristic of an alluvial plain. The south and east portions of LCAAP are uplands created by headward erosion that exhibit moderate relief with narrow-crested ridges and 46 to

49 meters (150 to 160 ft) of relief from valley floor to ridge crest. Area 17, within the Northeast Corner Operable Unit, is typical of a ridged area underlain by uplands sedimentary rocks. Depth to bedrock at the oil and solvent pit area was approximately 12 meters (40 ft).

Site characteristics, Longhorn Army Ammunition Plant, Karnack, Texas

The LHAAP is characterized by mixed pine-hardwood forests that cover gently rolling to hilly terrain with an average slope of 3 percent toward the northeast. Most of the terrain at LHAAP slopes 3 percent or less, but slopes as steep as 12 percent are common in the western and northwestern portion of the installation and also along the Harrison Bayou floodplain. Pine-hardwood forests and agricultural land surround LHAAP. Caddo Lake and Goose Prairie Bayou form the northeastern border. Ground surface elevations on LHAAP vary from 52 to 102 meters (170 to 335 ft) above sea level. All surface water from LHAAP drains northeastwardly into Caddo Lake via four drainage systems: Saunder's Branch, Harrison Bayou, Central Creek, and Goose Prairie Creek.

LHAAP is situated on an outcrop of the Wilcox Group that crops out over a large part of the eastern half of Harrison County. The Wilcox Group is the bedrock unit beneath more than 99 percent of LHAAP. The Wilcox consists of interbedded sandstones, siltstones, and shales that are variously light gray, red, brown, and/or tan. Regionally, the Wilcox has a maximum thickness of 213 meters (700 ft).

Surficial soils across the facility predominately consist of medium plasticity sandy clays with some zones of higher plasticity to a depth of 1 to 3 meters (4 to 10 ft) BGS. Beneath this surficial layer, the soils typically consist of low plasticity clays and silty and clayey sands to a depth of at least 18 meters (59 ft) BGS. These deposits are typical of the Wilcox Group. Alluvial deposits also occur at LHAAP along the drainage systems featured across the facility. Typical deposits include interbedded fine-grained clays, silts, and sands.

Groundwater generally occurs under unconfined conditions, whether in the alluvial or Wilcox Group deposits. Perched and local confining conditions frequently occur within the Wilcox Group deposits due to the high clay content and highly variable stratigraphy. The base of the Wilcox water-bearing zone beneath LHAAP is defined by contact of the Wilcox Group with the underlying Midway Group. The Midway Group consists predominately of very low-permeability clay that yields little or no water. The Wilcox is considered as the base of fresh water in the area. The depth to groundwater across the facility ranges from 0.3 to 21 meters (1 to 70 ft) BGS, with depth to groundwater typically being 4 to 5 meters (12 to 16 ft). The regional groundwater flow direction beneath the facility is generally in the direction of Caddo Lake but varies by site location. At the TDS sampling site, groundwater was found in thin seams of sand and gravel above zones of clay.

4 Demonstration Approach

This section discusses developers' claims, demonstration objectives, factors that must be considered to meet the performance objectives, sampling design, and data analysis that will be used to evaluate the results of the demonstration.

Performance Objectives

The SCAPS TDS sampling technology demonstration plan had both primary and secondary objectives. Primary objectives are considered critical to verify and validate the technology. Secondary objectives provide additional information that is useful but not critical. The primary objectives of this demonstration were to evaluate the TDS sampling technology in the following areas: (a) performance compared to conventional sampling and analytical methods; (b) logistical and economic resources necessary to operate the technology; (c) data quality; and (d) range of usefulness in which the technology can be operated. Secondary objectives for this demonstration were to evaluate the SCAPS TDS technology for reliability, ruggedness, and ease of operation. To obtain the data required to meet the project objectives, samples and process measurements were collected as described in the text detailing sampling procedures.

SCAPS TDS technology comparison to conventional methods

As part of the objectives outlined above, the TDS was evaluated to determine agreement between data produced using the TDS system and the results of the verification sample analyses by Method 8260B (USEPA 1995). The TDS data were compared on a sample-by-sample basis to data obtained from soil samples during verification sampling activities. During the first demonstration activity, comparisons were made between the *in situ* TDS data and verification samples taken approximately 0.3 meter (1 ft) away from a soil core sampler. These samples were analyzed offsite by Method 8260B. A second type of verification sample was added to the sampling scheme at the next four demonstration sites. This sample was taken from the soil core, between two verification samples analyzed offsite. This verification sample was analyzed *ex situ*, inside the TDS

probe. Comparisons were made between the two TDS results and the Method 8260B verification data.

The TDS data were reduced to concentrations of $\mu\text{g/g}$ in soil; the same concentration units used to report data from the verification method (Method 8260B). Therefore, direct comparison of the SCAPS TDS sampling technology data with that from the verification sample analyses is simple and straightforward. The strength of comparisons between the TDS data and the conventional method of analysis for verification samples was evaluated using least squares linear regression over the entire concentration range of data collected by each method at every site investigated. The TDS data and verification data were considered to strongly agree if the correlation coefficient of the linear regression was in the range of 0.8 to 1.0 and the slope (m) of the regression line was 1.0 ± 0.3 .

Economic considerations

The general logistics and economics associated with SCAPS CPT operation are known from previous work performed by the WES CPT system and from work performed over the last 4 years by the three USACE District SCAPS CPT vehicles that perform LIF and other site characterization investigations. Cost comparisons between the SCAPS deployed TDS technology and conventional methods of subsurface VOC detection (i.e., soil boring, sampling, and analysis) have been made based on actual TDS production rates at each of the technology demonstrations. Costs associated with conventional site characterization were obtained from site managers. The SCAPS TDS costs are a conservative estimate, since demonstration production rates are lower than operational production rates for site characterization. The reason for this rate difference is that 100 percent of the samples in a demonstration are verified by conventional offsite analysis. Verification sampling, including stratigraphy, doubles the amount of time required to complete a TDS sampling event. Generally speaking, 1 day is utilized for TDS sampling, and the following day is spent conducting the verification sampling. Labor costs were estimated for a four-person TDS crew, the minimum number required to operate the TDS system and SCAPS truck.

Data quality

Data quality was assured by strict adherence to the technology demonstration's Quality Assurance Plan (U.S. Army Engineer Waterways Experiment Station (USAWES) 1996a) for field analyses and to the USACEWES ECB Quality Assurance Manual (USAEWES 1996a) for verification sample analyses. The WES ECB data quality was also verified by splitting 5 percent of all TDS verification samples to an independent laboratory for analysis by Method 8260B (USEPA 1995).

Range of usefulness

The range of usefulness of the SCAPS TDS sampling technology was demonstrated at the five sites utilized in this demonstration. As discussed in the second chapter text detailing strength, advantages, and weaknesses, there are limits to the ability of the CPT truck to push in some soils, limits to the resolution of the ITMS detector, and limits to the ability of the TDS probe to function properly in some soil types.

Technical Performance Criteria

Technical performance criteria for the TDS system include the range of contaminants identified by the technique, reliability of each of the components, and ease of operation of the mechanical functions of the system and of the SCAPS technology itself in a site characterization environment.

Target compounds for TDS/ITMS analysis

As a field-screening tool, the TDS can be used to determine the location and relative extent of subsurface VOC contamination throughout the vadose, capillary fringe, and saturated zones. Analytical measurements are collected *in situ*, minimizing the need for physical sampling and offsite analysis. The ITMS, used as a detector, can detect the 34 VOC analytes included on the EPA Target Compound List found in Table 1 of Method 8265 (Wise et al. 1997a). While method sensitivity varies depending upon the analyte and upon daily changes in ITMS performance, lower limits of detection range from ng/g (ppb) to µg/g (ppm). Daily calibration curves and analysis of check standards document daily performance and ensure that samples are quantitated against correct system performance. The method yields both qualitative and quantitative results, making it appropriate for preliminary assessments of contaminant distribution during environmental field screening applications.

Reliability and ruggedness

The TDS sampling system consists of two components: the thermal desorption sampler system and the ITMS with the OI Analytical P&T sample introductory system. The complete system has been field demonstrated at three of the five demonstration sites. Reliability and ruggedness as discussed herein are associated with system mechanical functioning and with data comparability. The reliability and ruggedness of each component is discussed below.

Thermal desorption sampler. The TDS system can be broken down into its component parts: the TDS probe, the analyte transfer line, the control manifold, and the sample collection device (the sorbent trap).

The TDS is subject to the same physical limitations as all CPT direct push tools and sensors; its performance is affected by the materials it is pushed through. The TDS probe design facilitates quick maintenance of normal wear-and-tear components such as o-rings and seals. Periodical replacement of these items and routine daily maintenance can eliminate performance problems before they happen. If necessary, the TDS can be replaced with a replacement TDS with virtually no downtime. The original TDS can be repaired while sampling work continues.

The analyte transfer line consists of an unheated 1.5-mm (1/16-in.) deactivated fused silica lined stainless steel tube contained within the shrink wrapped umbilical cable that links the TDS probe to the manifold inside the SCAPS truck. Major problems associated with the analyte line were system leaks at the points of connection to the TDS probe and to the manifold and with analyte carryover from one sample to the next. Leak checks were conducted each morning before the system was placed in operation and again during the day if problems were suspected. Carryover from highly contaminated samples was discussed in the text detailing extremely high-level contamination carryover. Since the analyte line is unheated, contaminant residue can collect at the base of the analyte line. Analysis of blanks and extended purging times kept problems to a minimum. If problems persist, the TDS probe or the umbilical cable can be replaced with a backup, while the original is being purged of residual analyte.

The manifold, located inside the SCAPS truck, controls and monitors gas flows, temperature of the sample chamber heater, and position of the actuator rod inside the TDS probe. Besides operating the TDS, the TDS operator uses indicators on the manifold to determine if a sample is inside the sample chamber, the rate at which the sample is drying, and whether the sample has ejected from the sample chamber so that the next sample can be taken. Over the course of the five field demonstrations, the control manifold proved to be very rugged and reliable. Like the other system components, gas fittings were routinely checked for leaks.

The sorbent trap used to collect the desorbed VOCs can be filled with Tenax or a mixture of sorbents, depending upon the target analytes and the expected concentrations. These sorbent traps were off-the-shelf products, with documented adsorption efficiencies. The technique of eluting the analytes from the sorbent with methanol was evaluated by Myers et al. (1995). Traps utilized in this way can have a reduced working life of 20 to 25 samples, based upon field data. Before the onset of sampling work and on a case-by-case basis during the course of the project, each trap should be evaluated for analyte recovery.

The entire TDS system was evaluated each day for the target analytes. This was accomplished by injecting standards into a gas bag and injecting a known quantity of the volatilized standards into the TDS. Best success, measured on a scale of 100-percent analyte recovery, was found at the CRREL demonstration site where morning temperatures were approximately 18 EC. Lower recoveries were obtained when the temperature was above 24 EC.

Ion trap mass spectrometer. The ITMS technology has been commercially available for over a decade for laboratory use, as have purge and trap sample introduction systems. The ITMS, interfaced with the TDS, was developed under the Technology Reinvestment Program (TRP) for field portable use. The Teledyne™ ITMS used at the last three demonstrations sites, although still under final development, has proven in both laboratory and field studies to provide reliable detection of VOC analytes in the concentration ranges required for $\mu\text{g/L}$ and $\mu\text{g/kg}$ detection limits in water and soil, respectively (Myers et al. 1998b).

Ease of use

Typically, a five-person crew is employed to complete all aspects of field operation: the field site manager (who may be provided by the site); the TDS system operator; two push-room personnel; and an ITMS operator. SCAPS operation includes a large portion of the field activities associated with standard geotechnical CPT. The push-room personnel, a primary SCAPS operator and a helper, carry out these activities. The TDS system operator should have detailed training relating to the TDS system components and theory of operation to be able to maintain the system and make field repairs. The ITMS operator needs a background in science and ITMS theory.

Versatility

Operation of the TDS allows sampling throughout the soil column from the vadose zone through the capillary fringe and into the saturated zone. Use of sorbent traps, the OI Analytical P&T, and the ITMS provides quantification and identification of VOC contaminants in near real-time. When the SCAPS stratigraphy sensor is deployed with the TDS, both geotechnical data and contaminant data can be mapped at a site. This field screening data can be used to make remediation design decisions.

Off-the-shelf procurement

Standard CPT technology is commercially available. CPT platforms, soil classification probes, and soil samplers have been available for a number of years. Field portable ITMS has been commercially available for onsite analysis for the past 2 years. The purge and trap module used to interface with the ITMS is commercially available.

Maintenance

The SCAPS Operations Manual (Koester et al. 1994) details operation and maintenance items for the SCAPS CPT equipment. Briefly, maintenance falls into three categories: basic truck systems, CPT systems (hydraulic, grout

pumping, and ram systems), and VOC-sampling systems. The Operations Manual also covers the CPT, associated computers/electronics, and the LIF probe. The operation and maintenance of the TDS system deployed during this demonstration is not addressed by Koester et al. (1994).

The ITMS requires routine cleaning of the instrument. Based on laboratory experience, with constant field use, ion trap cleaning would be required about every 3 to 4 months and require 2 to 4 hr downtime. The ITMS filaments that produce ions and the electron multiplier that detects ions and produces the actual ITMS response require replacement at approximately the same interval. Maintenance should be performed by a trained ITMS operator.

Figure 1 is a schematic diagram of the TDS probe. The TDS requires periodic lubrication and/or replacement of inner o-rings that come in contact with soil. Periodic cleaning of the interior soil sampling chamber is required to remove excess grit that could prevent proper opening and closing.

The TDS VOC-sampling system includes computer and electronic instrumentation, the ITMS, and the probe assembly with umbilical. A systems operator trained for those specific tasks should perform maintenance.

Process waste

The TDS does not bring significant quantities of soil in the form of auger cuttings to the surface as do conventional drilling methods. Investigation-derived waste will, however, be generated during the pressure cleaning of the rods and probe during retraction. Pressure cleaning rinse water is placed in 208-R (55-gal) drums, and the drums are labeled and stored onsite for appropriate disposal by facility personnel. Often, this rinse water can be analyzed onsite using the ITMS P&T, determined to contain nondetectable levels of the target VOC analytes, then discharged to the site. To date, analysis of said rinse water for VOC contamination has consistently been at nondetectable levels. Data collected indicate that the wastewater production rate for rod decontamination is approximately 19 R (5 gal) per 15-meter (50-ft) penetration.

Sampling Procedures

Sampling procedures for the TDS demonstration were implemented to ensure the consistency and integrity of both the TDS data and the results of the verification sample analyses. The sections that follow detail the sample collection procedures necessary to meet demonstration objectives. Careful adherence to these procedures was necessary to ensure that sample data collected using the TDS were comparable to Method 8260B (USEPA 1995) as a screening technique for determining subsurface distribution of VOC contamination in soils. Sampling procedures are discussed in greater detail in Section 5.4 of the appropriate Technology Demonstration Plan (USACE WES 1996a,b,c; 1997, 1998).

Selection of sampling locations at the test site

The TDS sampling locations were selected at each site based upon knowledge of previous investigation results. Information unique to each demonstration site is found in the Technology Demonstration Plan, Section 4.3 (USAEWES 1996a,b,c; 1997, 1998). Before sampling in areas without historical data, the stratigraphy probe was used to obtain a vertical profile “snapshot” of the subsurface. In areas where depth to water table was known, layers of sand followed by clay often contained perched groundwater and possibly VOCs carried by the groundwater.

Soil classification procedures

The soil classification scheme used by the SCAPS CPT system was devised to identify the types of soils penetrated with the use of combinations of corrected values of sleeve friction and cone resistance (Olsen 1988). Computer algorithms convert this information into a soil class number (SCN) that corresponds to general soil types. For example, an SCN from 0.5 to 1 corresponds to typical clay while the SCNs ranging from 2 to 4 indicate sand. These parameters are mapped onto soil classification charts to produce a continuous vertical profile graphic representation of the stratigraphy push.

For validation purposes, standard TDS operational procedures required three penetrometer pushes, each a minimum of 23 cm (9 in.) from the other: one stratigraphy push to measure soil classification; one TDS push; and one soil core push to retrieve soil for verification samples. The simplest way to obtain all three types of samples was to move the truck forward or backward. Thus, the last sample of the set was at least 45 cm (18 in.) from the first. When a long run of TDS pushes was made in a row, a stratigraphy push was taken at either end to bracket the TDS and verification samples. Unless the stratigraphy was complex with interbedded sand and clay lenses, this bracketing method was sufficient.

TDS sampling procedures

Each morning prior to sampling, gas flows were established, the TDS system was checked for leaks, and the TDS was brought to temperature. As with other CPT platform sampler/sensors, the TDS was advanced into the soil at the end of successive lengths of 1-m-long push pipe. Once the TDS reached sampling depth, advancement stops, the sampler was retracted approximately 5 cm (2 in.) and actuator rod retracted to open the sample chamber. Temperature and gas flows were checked, and the TDS was returned to sampling depth. To sample, the TDS was advanced 4.5 to 5 cm (1.75 to 2 in.), while monitoring the temperature on the control manifold. When the sample chamber filled, the temperature on the ceramic heater dropped. If there was no temperature drop, the TDS was advanced slowly 1.3 cm (0.25 in.) more; however, the sample chamber is only 5 cm (2 in.) deep, and overfilling can damage the probe. If the

temperature did not drop after additional advancement, the TDS was brought to the surface and examined.

Sampling times varied from 15 to 30 min depending upon moisture and soil type. As the sample dried, the temperature in the sample chamber approached the preset temperature and stabilized. Normally for a site or conditions, a fixed sampling time such as 20 or 30 min was set. After sampling, the dried soil was ejected from the TDS sample chamber with a burst of high-pressure gas accompanied by pushing action of the actuator rod. A routine sampling scheme consisted of a TDS sampling event that was followed by a 10-min purge and by a 10-min blank to monitor system carryover.

TDS sample collection device procedures

Volatilized contaminants were collected on a sorbent trap attached to the control manifold. To capture the broadest range of VOCs, an OI Analytical style No. 9 trap filled with a mixture of Tenax, silica gel, and charcoal was used. For low-level analysis, the trap was directly inserted in the OI Analytical P&T. For high-level analysis, the trap was eluted with 1 ml of P&T grade methanol. Aliquots of the extracted sample were placed in the P&T sparge vessel for analysis. After the VOCs were eluted from the trap, any remaining methanol was flushed with inert gas. The trap was placed in a small 180 EC oven and baked for 5 min with continuous flushing to regenerate the sorbent material.

Verification sampling procedures

For demonstration purposes, each sampling event included 100-percent verification. These verification samples were taken from soil cores and processed according to the method developed by Hewitt (1994) and Method 5035 (USEPA 1995). Approximately 4 ml of soil were immediately subsampled from the core into a preweighed 20-ml VOC vial containing 5 ml of purge and trap grade methanol. The vial was sealed using a Teflon lined cap and the sample and vial were weighed to determine the soil sample weight. This sampling procedure ensured the integrity of the VOC analytes present in the soil and was essentially the first step of Method 8260B (USEPA 1995). Verification samples were taken at depths BGS corresponding to the depth of the TDS sample. This was accomplished by centering the length of the soil core around the TDS sampling depth. Table 2 shows a typical sampling profile.

The type and number of verification samples changed during the course of the demonstrations as our understanding of the distribution of VOC contaminants in the subsurface evolved. At the first demonstration at BRSA, one verification sample was taken for each *in situ* TDS sample. During the second demonstration at DGCS, two verification samples were taken to bracket the TDS sample. Starting with the third demonstration at CRREL, multiple verification samples were taken from preselected regions along the length of the soil core (Table 3) in

**Table 2
Typical Sampling Profile Showing Depths of TDS and Soil Core Verification Samples**

Depth feet (BGS)	Center of Sample inches (BGS)	Depth inches (BGS)	Action 1 TDS	Action 2 Soil Core
10	120	111		Start soil core
		119	Start TDS	
		121	End TDS	
		131		End soil core
12	144	135		Start soil core
		143	Start TDS	
		145	End TDS	
		155		End soil core

Note: To obtain meters, multiply feet by 0.3048; to obtain centimeters, multiply inches by 2.54.

**Table 3
Verification Sample Profile Along Soil Core**

	3 inches	MeOH verification sample
	6 inches	MeOH verification sample
	7 inches	Density sample
	8 inches	MeOH verification sample
	9 inches	<i>Ex situ</i> (PV) verification sample
	10 inches	MeOH verification sample
	11 inches	Density sample
	12 inches	MeOH verification sample
	15 inches	MeOH verification sample

Note: To obtain centimeters, multiply inches by 2.54; to obtain millimeters, multiply inches by 25.4.

order to have sufficient information to explain any data anomalies which might be the result of soil strata variability.

A second type of verification sample was introduced during the DGCS demonstration. This verification was an *ex situ* TDS probe verification (PV) sample taken 23 cm (9 in.) from the top of the soil core to correspond with the 5-cm (2-in.) *in situ* TDS sample taken from a push approximately 0.3 meter (1 ft) away. The PV sample was bracketed by two of the methanol (MeOH) extracted verification samples taken 2.5 cm (1 in.) away (Table 3). The *ex situ* PV sample was taken with a stainless steel syringe designed to fit into an adapter fitted on the end of the TDS (Figure 8). The syringe was preweighed, filled with sample, then reweighed, and the sample ejected into the heated TDS probe where it was desorbed and analyzed under the same conditions as the *in situ* TDS sample. The dried, desorbed soil sample was collected in methanol and analyzed offsite along with the verification samples to measure the amount of residual VOCs remaining after desorption.



Figure 8. Stainless steel soil sampling syringe and adapter attached to base of the TDS probe for *ex situ* (PV) verification

Results from the PV were compared to the two adjacent methanol-extracted verification samples and to the TDS sample. Validation samples were taken using this method to minimize the effects of VOC heterogeneity distribution in the soil and provide a direct comparison of sampler and verification results.

Analytical Procedures

The analytical procedures used during the demonstration include both the TDS/ITMS method for near real-time measurement and Method 8260B (USEPA 1995) used to analyze the verification samples.

TDS analytical procedures

The TDS system was evaluated each day by injecting 250 ng of a gas mixture consisting of trans-1,2-dichloroethene, TCE, and ethylbenzene or xylene through the system. This mixture was prepared each day from neat standards in an 8-R gas bag.

Ion trap mass spectrometer operation

Direct sampling ion trap mass spectrometry (DSITMS) is comprised of a quadrupole ITMS, a capillary retractor interface, and a variety of sample inlets for use with gas (air and soil gas), soil, and water. The ITMS used in these demonstrations was a Teledyne 3DQ ITMS or a Finnigan ITMS 40 fitted with a 20-cm-long, 100- μ m-internal-diameter capillary retractor heated interface operated at 105 EC. The capillary interface limits flow into the ITMS to 0.1 to 1.0 ml/min, approximately 4 percent of the gas flow entering the system, which is compatible with both electron impact (EI) and chemical ionization (CI) sources (Wise and Guerin 1997). The other 96 percent of the gas flow is vented through a port on the interface. When a second trap is attached to this port during sample desorption, the sample can be recollected for archival or reanalysis. Sample introduction into the ITMS is accomplished by way of an OI Analytical P&T attached to the capillary interface. During analysis, the ITMS acquires data from the P&T for 2 min.

For the TDS demonstration, chlorinated solvents and BTEX were analyzed using EI with the ITMS operated in the full-scan mode (40 to 270 daltons). The ITMS system does not include a technique to separate the contaminants before they enter the ITMS detector; rather, the resulting mass spectral data are in the form of a total ion chromatogram made up of a series of scans containing the mass ions that indicate the presence of VOC analytes. Individual compounds are identified and quantitated based on ions of specific masses (Figure 9) indicative of the individual compound (i.e., 132 m/z for TCE). Data acquired during calibration are reduced by integrating specific ions for a given analyte from 0.1 to 1.5 min. A discussion of ITMS calibration and detection limits is found in Myers et al. 1998b. Data acquired during the experiment are reduced in an analogous manner to the calibration standards and are quantitated based on the calibration curves. Daily calibration check standards and performance evaluation check standards are analyzed to ensure data quality.

Purge and trap operation

The OI Analytical Purge and Trap Sample Concentrator was connected to the ITMS and used to introduce samples into the ITMS. The P&T was operated according to the instrument instruction manual (OI Analytical 1992). Samples eluted with methanol were adjusted to 1.0 ml. An aliquot of the sample was

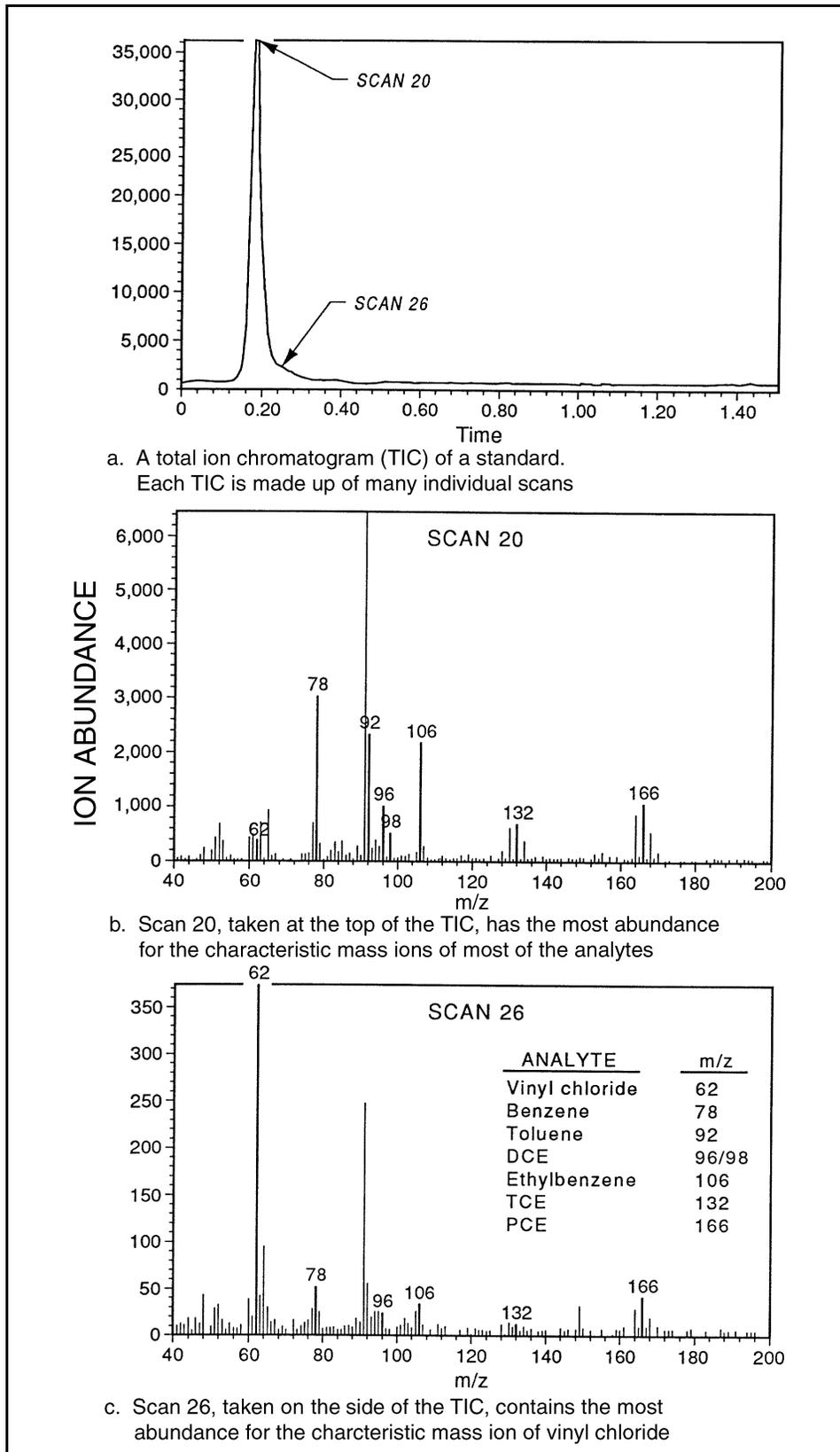


Figure 9. ITMS sample output

placed in 5.0 ml of ozonated distilled water inside the purge vessel. If sample concentration was low, the sorbent trap was not extracted but placed directly into the P&T, replacing the original trap. The sample on the trap was desorbed as usual.

Verification sample analytical procedures

The soil verification samples collected during demonstration activities were analyzed by the WES Environmental Chemistry Branch (ECB) analytical laboratory according to Method 8260B (USEPA 1995). All verification samples were analyzed in accordance with the WES ECB standard operating procedures, ECB laboratory Quality Assurance (QA) Manual and the project Quality Assurance Project Plan (QAPP) found in the Project Technology Demonstration Plan (USACEWES 1996a,b,c; 1997, 1998).

5 TDS Performance Assessment

This section addresses the performance-based objectives relative to the quality of data produced by the TDS system, operation of the technology during each of the five field demonstrations, and TDS comparability to conventional sampling operations. Any variances from the procedures presented in Chapter 4 are discussed in the presentation of each demonstration’s results.

TDS Performance

Thermal Desorption VOC Sampler data were collected at five sites in different geographic locations: BRSA, Aberdeen Proving Ground, Maryland; DGCS, McClellan Air Force Base, California; USCE Cold Regions Research and Engineering Laboratory, New Hampshire; Lake City Army Ammunition Plant, Missouri; and Longhorn Army Ammunition Plant, Texas. These sites were amenable to CPT investigations and had known VOC contamination in the soil and groundwater. Table 4 contains a summary of the field work conducted at each site. Summary tables comparing the TDS data and the corresponding verification data are presented in Appendix B.

Table 4 Summary of Field Sampling at TDS Demonstrations Sites								
Site Name	Stratigraphy Penetrations	TDS Penetrations	TDS Samples	PV Samples	Verification Samples	VOCs Found	TDS Maximum Depth, ft	TDS Total Depth, ft
BRSA	18	18	64	NA	68	5	34	278
DGCS	5	11	28	24	39	2	52	400
CRREL	4	8	37	37	254	2	60	365
LCAAP	3	5	16	16	98	5	13	52
LHAAP	5	8	26	26	173	2	18	123

Note: To obtain meters, multiply feet by 0.3048.

Sample matrix effects on TDS performance

The TDS was deployed successfully in a wide variety of soil types and soil moisture contents at the five geographic sites selected for demonstration purposes. Data were collected from sands, silts, clays, and mixes of each at the various sites. Difficulties encountered due to the soil matrix were discussed in Chapter 2. During the demonstrations, CPT probes met refusal at two sites. The second demonstration was moved to DGCS when CPT probes could not penetrate shallow hardpan strata at McClellan AFB. At CRREL, excessive sleeve friction (i.e., push-rod sidewall friction) prevented the TDS from advancing deeper than 18 meters (60 ft) BGS. These types of limitations are not unique to the TDS probe. In instances when the sample chamber did not fill with soil, the probe was closed and pushed another 15 to 30 cm (6 to 12 in.), and the sampling process continued.

Samples were taken from saturated soils at three of the sites: BRSA, DGCS, and LHAAP. Laboratory studies indicate that clays and saturated soils should have the lowest recoveries. And, indeed, recovery differences were observed in natural soil samples. A desorbed soil sample taken at the DGCS was ejected from the TDS sample chamber above ground and collected in methanol for laboratory analysis. Results for the sample DVTD10-52 *in situ* TDS sample (clay, 21 percent moisture) and the residue after desorption were as follows: 0.079 $\mu\text{g/g}$ and 0.029 $\mu\text{g/g}$ of TCE, respectively, and 0.283 $\mu\text{g/g}$ and 0.150 $\mu\text{g/g}$ of PCE, respectively. A second sample taken at CRREL, CRTD01-40-2 (silt, 24 percent moisture) and analyzed similarly yielded the following results: 1.16 $\mu\text{g/g}$ and < 0.341 $\mu\text{g/g}$ of total DCE, respectively, and 31.4 $\mu\text{g/g}$ and 0.003 $\mu\text{g/g}$ of TCE, respectively. To improve analyte recovery and compensate for the reduced desorption efficiencies, temperatures and desorption times were increased as the demonstration progressed.

Carryover from high analyte concentrations was discussed in Chapter 2, paragraph intitled "Extremely high-level contamination carryover." Generally, at concentrations observed during the demonstration, carryover was eliminated by the 5- to 10-min purge after each sampling event and monitored by collection of a blank. At the CRREL site, a sample was taken to evaluate the effects of a highly contaminated sample on system carryover. Concentrations in the sample selected were measured at 406 $\mu\text{g/g}$ of TCE and 30.5 $\mu\text{g/g}$ of total DCE. Figure 10 shows TDS system recovery after analysis of a highly concentrated sample. After 50 min of purging, concentrations of TCE were reduced from 42 to 0.9 $\mu\text{g/g}$ and concentrations of total DCE were reduced from 3.2 to 0.6 $\mu\text{g/g}$. The TDS system would have to be purged overnight or removed from service and cleaned to achieve the 0.05 $\mu\text{g/g}$ detection limit typically used. However, screening at elevated detection limits could continue after 30 to 40 min of purging.

Soil type also affects maintenance and mechanical functioning. Gritty residue from sands can prevent the TDS actuator rod from closing, increase the wear

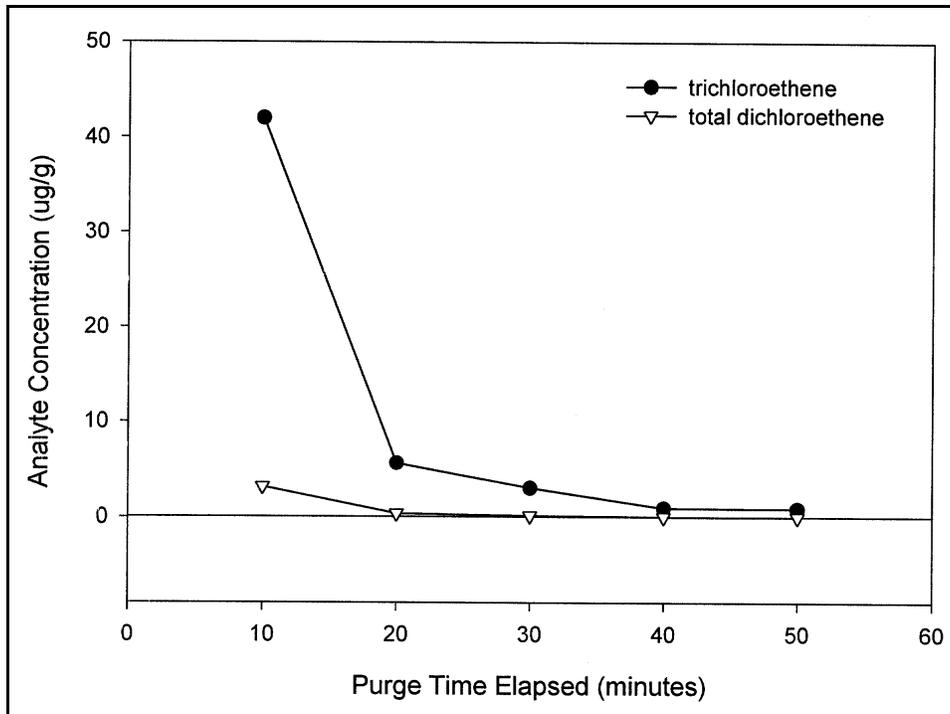


Figure 10. TDS system recovery after analysis of a highly concentrated sample

and tear on o-rings, and increase the frequency of system maintenance. Densely packed clays can swell after entering the sample chamber, drying into a hardened plug that can be difficult to eject. During the course of the five demonstrations, 20 percent of the 175 TDS samples either failed to eject below ground or the TDS failed to close. Most of these samples were taken in densely packed clays or coarse sand. A resizing of the stainless steel sleeve surrounding the sample chamber should eliminate most of these occurrences.

Bush River study area, Aberdeen Proving Ground

The analytical system used at the BRSA was a Finnigan ITMS 40 coupled with a thermal desorption module developed at the Oak Ridge National Laboratory (ORNL). The ITMS was operated as described in Chapter 4, paragraph entitled “ITMS operation,” with the exception of the OI Analytical P&T. After collecting the desorbed VOCs from the TDS, the ORNL traps were placed inside the thermal desorption module and desorbed directly into the ITMS. Soil stratigraphy data were used to locate the clay confining unit immediately below the upper aquifer. TDS samples were taken in the uppermost portion of this unit in saturated soil. For this demonstration, samples were desorbed at 100 to 110 EC for 5 min. One verification sample was taken for each TDS sample and analyzed as described in Chapter 4, paragraph entitled “Purge

and trap operation.” Quality assurance (QA) duplicates were taken at a rate of 5 percent.

A comparison of the TDS data and the verification data is found in Appendix B, Table B1. VOCs identified on site by the TDS were: methylene chloride; 1,1,2,2-tetrachloroethane; 1,1,2-trichloroethane; chlorobenzene; carbon tetrachloride; TCE; and PCE. Of the 92 TDS VOC detections, 27 were confirmed by EPA Method 8260B (USEPA 1995) and 46 were inconclusive because one of the detection limits was significantly higher than the corresponding value. There were also 19 false negatives and no false positives. Of the confirmed VOC detections, the 1,1,2,2-tetrachloroethane data had the best correlation with the verification sample ($r^2 = 0.9$). Generally, however, the correlation was biased low. This can be attributed, in part, to the short sampling time and to the saturated clay sample matrix.

Davis Global Communications Site, McClellan Air Force Base

The DGCS demonstration occurred during the winter rainy season. Sampling was restricted to the road bordering the northeast corner of the compound in an area surrounded by soil vapor extraction wells. Samples taken in December came from the capillary and saturated zone in sandy silt between 5 and 11 meters (15 and 36 ft) BGS. Samples taken in February came from an unsaturated clay layer between 14 and 15 meters (48 and 50 ft) BGS.

The Finnigan ITMS 40 and the ORNL thermal desorption module were also used as the analytical system during the DGCS demonstration. Sampling time was increased to 20 min, and TDS sample chamber initial temperature was increased to 150 °C. One verification sample for EPA Method 8260B (USEPA 1995) was taken for each TDS sample during December. Two verification samples per TDS sample were collected during February. Quality assurance duplicates were taken during each sampling trip. Use of the *ex situ* PV sample was initiated during this demonstration. A stainless steel plug with a single compression o-ring was used to seal the PV sample into the TDS sample chamber. This device proved to be difficult to tighten and did not always form a complete seal.

Table B2, Appendix B, has the comparisons of the DGCS data. Two VOCs, TCE and PCE, were identified at the site. Of the 33 TDS VOC detections, all but one was confirmed by EPA Method 8260B (USEPA 1995). Comparison results for that sample were inconclusive because the detection limit for the verification sample was higher than the concentration found in the TDS sample. There were no false positives or negatives. In general, results of the TDS samples and the PV samples were biased low with respect to the EPA Method 8260B verification samples.

Cold Regions Research and Engineering Laboratory

Three major changes were made at the CRREL demonstration in an attempt to eliminate extraneous factors that may have contributed to variances in the first two data sets. The ORNL thermal desorption module was replaced with the OI Analytical P&T system described in Chapter 4. The sorbent traps utilized by this system desorb quickly and efficiently, producing sharp total ion chromatograms that are easy to evaluate and quantitate. A stainless steel syringe and adapter designed to fit on the end of the TDS probe was used to take the *ex situ* PV samples (Figure 8). This device was easier to use and ensured that the TDS system was sealed. The third major change was an increase in the number of verification samples taken along the soil core. These samples became necessary to explain the differences in the concentrations of VOCs within a span of a few inches.

By screening aliquots of the methanol verification samples onsite and supplementing the data with soil samples analyzed at CRREL by head space (HS/GC) analysis, the SCAPS team was able to identify inconsistencies within the data set. Replicate samples, both *in situ* TDS and verification, were taken when the data disagreed by several orders of magnitude. Eleven repeat samples from three additional pushes were taken to fill gaps in the data. Total DCE and TCE were the primary analytes found at CRREL. At one location, the analyst screened the samples for vinyl chloride without finding it. Comparison tables for the CRREL data are found in Appendix B (Table B3). These tables show the *in situ* TDS results, the PV results, and the EPA Method 8260B (USEPA 1995) results. Because there was such variability, the main statistical comparison was made between the *ex situ* PV sample and one of the EPA Method 8260B samples taken adjacent to it. Because of the extreme variability, correlation of the TCE data was poorer than expected; however, there were no false positives or false negatives. Eleven samples were categorized as inconclusive because one of the lower detection limits was higher than the corresponding value. Twelve of the total DCE samples were also categorized as inconclusive because of high detection limits. Poor correlation was attributed to the extreme heterogeneity of the VOC distribution discovered at the site (Figure 11) and to the ITMS mass ion fragmentation phenomenon discussed in Chapter 2, paragraph entitled “ITMS limitations.”

Lake City Army Ammunition Plant

The analytical system used at LCAAP was identical to the analytical system used at CRREL, a Teledyne 3DQ ITMS coupled with the OI Analytical P&T. The sampling scheme followed is outlined in Tables 2 and 3. As with the CRREL demonstration, replicate samples were taken to fill in data gaps. Samples at LCAAP were taken in the vadose zone adjacent to an oil and solvent pit. Soil gases containing VOCs were the most probable source of contamination.

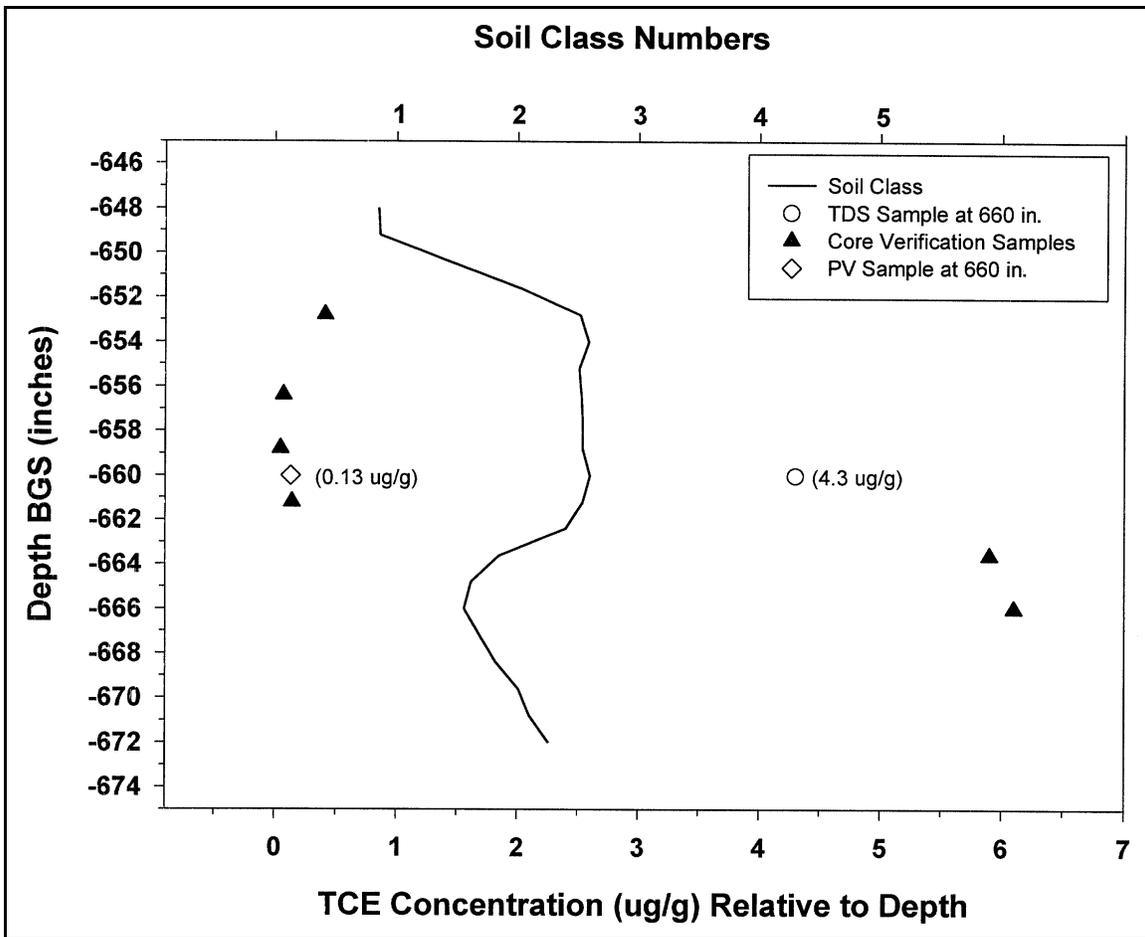


Figure 11. Changes in TCE concentration at CRREL relative to soil type and depth. Soil class changes from sand to silt between 1,687 and 1,701 cm (664 and 670 in.) BGS

Comparison tables for the LCAAP data are given in Appendix B (Table B4). Analytes found at LCAAP were vinyl chloride, total DCE, toluene, PCE, and ethylbenzene. Vinyl chloride and total DCE were the primary VOCs found at the site. Of the 16 samples taken, 11 were analyzed *in situ* by the TDS for vinyl chloride. The PV samples taken the second day for the first TDS push indicated that vinyl chloride was present in the samples from the first penetration. The analyst added vinyl chloride to the calibration but did not reanalyze the first five TDS samples. Correlation for the vinyl chloride data was poor; however, the TDS demonstrated its ability to detect this volatile gas *in situ* at levels that have been difficult to achieve previously by more traditional methods. The TDS detected total DCE in 12 of the 16 samples. Comparisons of the PV data to the co-located EPA Method 8260B (USEPA 1995) data show no false positives or negatives. Toluene was found in three samples in penetration number five. All three samples were confirmed. The detection of PCE was the poorest performer analytically. The presence of PCE was verified in the EPA Method 8260B samples from four of the penetrations but was not detected by the ITMS onsite in neither the *in situ* TDS nor the PV samples. Comparisons between the

PV samples and EPA Method 8260B samples identified three false negatives and one false positive. Background levels for ethylbenzene were elevated and the data biased high compared to the verification sample data. The lubricant used inside the TDS probe may have contributed to the elevated levels of mass ions in the 92 to 106 m/z range due to mass ion fragmentation.

Longhorn Army Ammunition Plant

The Teledyne 3DQ and OI Analytical P&T was the analytical system used at LHAAP. Samples were taken from saturated and unsaturated bedded layers of silty sands and clay. VOCs found at LHAAP were TCE and total DCE. Comparison data for these analytes are presented in Table B5 in Appendix B. There were no false positives or false negatives for TCE for the *ex situ* PV data relative to the Method 8260B verification sample data. Total DCE *ex situ* PV data versus Method 8260B (USEPA 1995) verification data showed one false positive. Samples with high TCE concentrations exhibited elevated ion abundance at 96 m/z, the range used to quantitate total DCE. The analyst switched the total DCE quant ion from 96 to 98 m/z to reduce the occurrence of false positives. The total DCE sample most affected by this enhancement was the PV sample for LHTD08-15. This sample was analyzed at two different dilutions to bring the concentration of TCE within range of the calibration curve. At the appropriate dilution for the TCE analysis, total DCE is undetected. At a lower dilution, the TCE concentration is above the highest standard in the calibration curve and its mass ion fragmentation contributes significantly to the concentration of total DCE reported. Enhancement of concentrations of VOCs with lower mass quantitation ions by other VOCs with higher mass ions was a continuing problem with the two ITMS systems used in this demonstration.

TDS Data Assessment

Data produced over the course of the TDS demonstration were assessed for usability following established QA procedures. Each analysis, whether performed onsite by ITMS or offsite in an analytical laboratory, is associated with standard quality control (QC) check samples that are evaluated to determine the quality and usefulness of the data. Quality control associated with onsite ITMS analysis includes: initial calibration curve of each target VOC, calibration checks at midday and at the end of the day, performance evaluation (PE) spikes for the target VOCs, and system blanks analyzed during the course of the day. Quality control associated with the EPA Method 8260B (USEPA 1995) verification samples includes an initial calibration, a daily continuing calibration check, method blanks, method spikes, method duplicates, PE checks, and surrogate spikes. In addition, 5 percent of the verification samples sent offsite were split and sent to a second laboratory for confirmation analysis. Field duplicates were taken at each site, but because of soil and VOC heterogeneity, they could not always be considered a true duplicate. Trip blanks accompanied each shipment of samples from the field. QC samples associated with the TDS and PV analyses include an

initial system blank each morning, a PE spike each morning, and system blanks following each sample.

More than 150 TDS samples, 100 PV samples, and 600 verification samples were taken from the five demonstration sites. The data tables presented in Appendix B are only summaries of the final data comparison. The raw data sets from each site are too massive to be presented in this document. However, the results and pertinent observations will be discussed.

Correlation coefficients for the ITMS daily calibration curves used to quantitate the TDS and PV data in the field were 0.97 or better. If the midday calibration checks fell above 20 percent, the calibration was repeated before sample analysis resumed. Samples with VOC concentrations outside the range of the standard curve were diluted and reanalyzed. Method blanks were within acceptable limits and PE spike recoveries for the target VOCs fell within a range of 70 to 130 percent. Based on the QC checks in place, the quality of the data produced by the ITMS was judged to be acceptable for field analysis.

Quality control associated with EPA Method 8260B (USEPA 1995) analysis were within laboratory prescribed limits. The GC/MS separates three VOCs that share the same mass quant ion on the ITMS: 1,1-DCE; cis-DCE; and trans-DCE. Results from EPA Method 8260B for these three VOCs were summed into a total DCE value for comparison purposes. Samples from LCAAP and LHAAP had low-level 1,1-dichloroethene in the blanks (reported as BJ). Method 8260B data were adjusted to subtract the blank before adding the 1,1-DCE to the total DCE value. Generally, these values were near or below the method detection limit and did not increase the summed total DCE values. The GC/MS method blanks from the BRSA and CRREL sites contained traces of methylene chloride, a common laboratory contaminant. BRSA had one TDS sample confirmed for methylene chloride. The concentration of methylene chloride in this sample was 10 times the concentration found in the method blank. All of the requested analyses were performed on the verification samples, therefore, the data set is considered to be 100 percent complete.

Quality control for the TDS system was not as straight forward to evaluate. Generally, system blanks between each TDS sample were significantly less than the reporting limit. During daily operation, time constraints did not allow the TDS to wait to ensure every blank was clean before proceeding. From past experience, if the calculated VOC concentration was less than 10 µg/g, the system was assumed to be clean and sampling continued. Longer purges and additional blanks were added on a sample-by-sample basis as needed. Recovery from daily QC spiked samples was dependent upon the ambient temperature during the field demonstration and upon the vapor pressure of the target VOC. This is because the spikes were made daily in a gas bag from pure VOC standards. Recoveries greater than 30 percent for DCE were rare at LCAAP or LHAAP where morning temperatures were near 27 EC. Spike recoveries at CRREL (morning temperatures near 18 EC) averaged 80 percent. Average

recoveries at LCAAP and LHAAP were 57 and 65 percent, respectively. Because spike recovery was a major portion of the laboratory evaluation during TDS development (Myers et al. 1995), it is unlikely that the daily spike recoveries reflect actual TDS performance. System performance can be controlled more accurately by adequate system maintenance, daily leak checks, and monitoring the gas flows during sampling.

Detection limits for the ITMS and the TDS system were established in the laboratory prior to the demonstration. Method detection limits (MDL) were determined according to Chapter 40 CFR, Part 136, Code of Federal Regulations, R1.11 (USEPA 1984).

Reporting limits are approximately 0.025 to 0.050 $\mu\text{g/g}$, depending on the number and concentrations of VOCs in the sample. Occasionally, when a TDS sample containing two or more VOCs at concentrations greater than an order of magnitude apart was diluted and reanalyzed to bring the major contaminant into calibration range, the lesser VOC was diluted out, leaving a gap in the data. An instance similar to this was described in the text detailing the Longhorn Army. Loss of analytical information due to elevated detection limits is not unique to ITMS analysis. This was a continuing problem with the offsite laboratory analysis, as well. An offsite analyst may not always repeat the analysis to get the best detection limit and most representative data. For comparison purposes, data with elevated detection limits were considered to be inconclusive and were omitted from the statistical comparison.

Comparison of TDS Technology with Conventional Technology

The TDS was designed to provide near real-time screening of VOC contamination at hazardous sites. During the five demonstrations, the TDS was used to detect chlorinated solvent and BTEX contamination at depths ranging from near-surface to 60 ft BGS in a wide range of soil types and soil moisture conditions. Over 170 TDS samples were taken from 50 TDS penetrations. More than 600 verification samples were taken for conventional analysis by Method 8260B (USEPA 1995) to evaluate the TDS results. Graphics of the comparisons made for these data are given in Figures 12 through 16. Statistical data presented in the figures are calculated from multiple VOCs found at each site. Statistics for the individual VOCs are given in each caption. Graphics of additional data comparisons are found in Appendix C. These data will not be discussed here.

At the first two demonstrations, BRSA and DGCS, the data comparison was made between the *in situ* TDS data and the Method 8260B verification data. As evidenced by the collective correlation data (BRSA: $r^2 = 0.2$, $m = 4$; DGCS: $r^2 = 0.3$, $m = 0.8$), overall performance comparison was poor. Reasons were

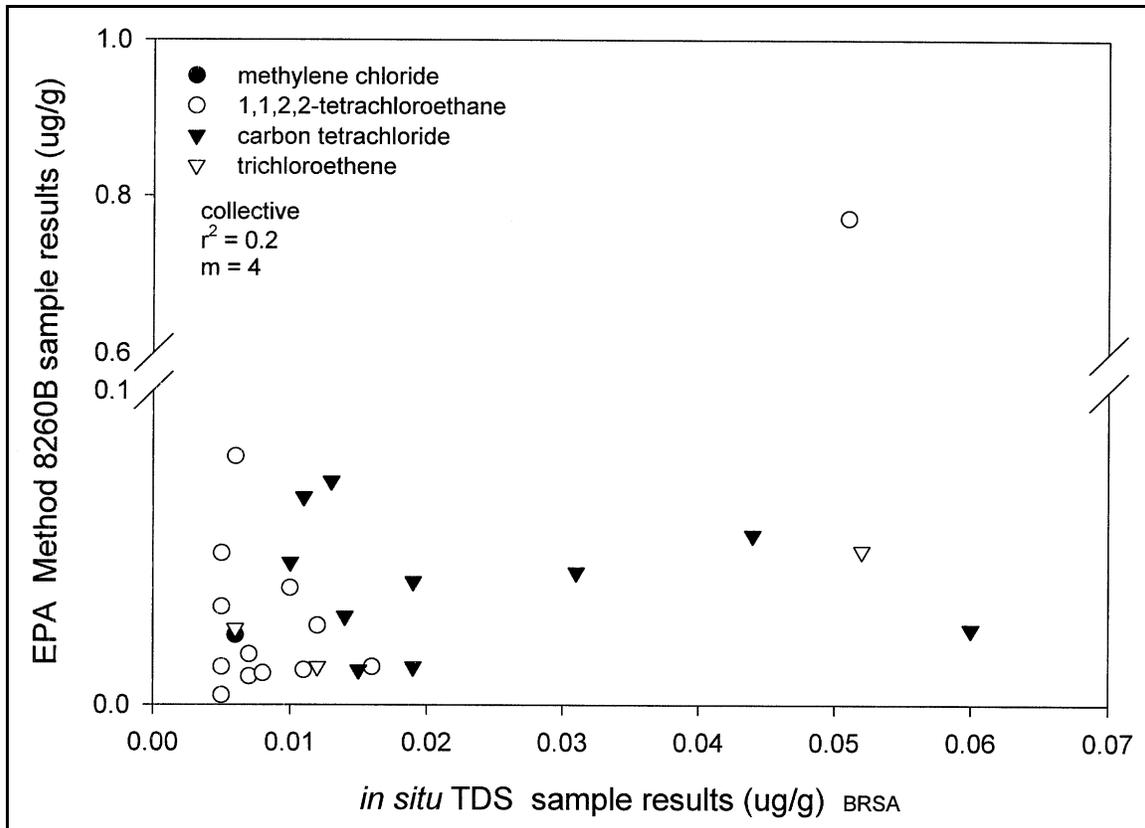


Figure 12. BRSA comparison between the collective *in situ* TDS and Method 8260B (USEPA 1995) data. Individual VOC statistics are: (a) methylene chloride, 1 point; (b) 1,1,2,2-trichloroethane, $r^2 = 0.9$, $m = 16$; (c) carbon tetrachloride, $r^2 = 0.03$, $m = -0.02$; (d) trichloroethene, $r^2 = 0.8$, $m = 0.7$

discussed in detail earlier in this chapter. After the DGCS demonstration, the TDS analytical system and verification test procedures were reevaluated to reduce as much non-TDS-specific sampling error as possible (paragraph on CRREL, this chapter). For this reason, the data obtained from the BRSA and the DGCS should not be considered representative of TDS system capabilities.

Due to the extreme variability of VOCs observed with depth at CRREL, the primary validation comparison for the remainder of the demonstration was between the co-located PV sample and the EPA Method 8260B (USEPA 1995) validation sample. This comparison eliminated error due to localized VOC heterogeneity within the soil.

As stated in Chapter 4, if the correlation coefficient of the linear regression is in the range of 0.8 to 1.0 and the slope of the regression line is 1.0 ± 0.3 , the data are said to strongly agree. Hence, the combined data comparisons for LCAAP and LHAAP strongly agree. The CRREL data set, even with its VOC heterogeneity, had a correlation coefficient of 0.7 and a regression slope of 1.0.

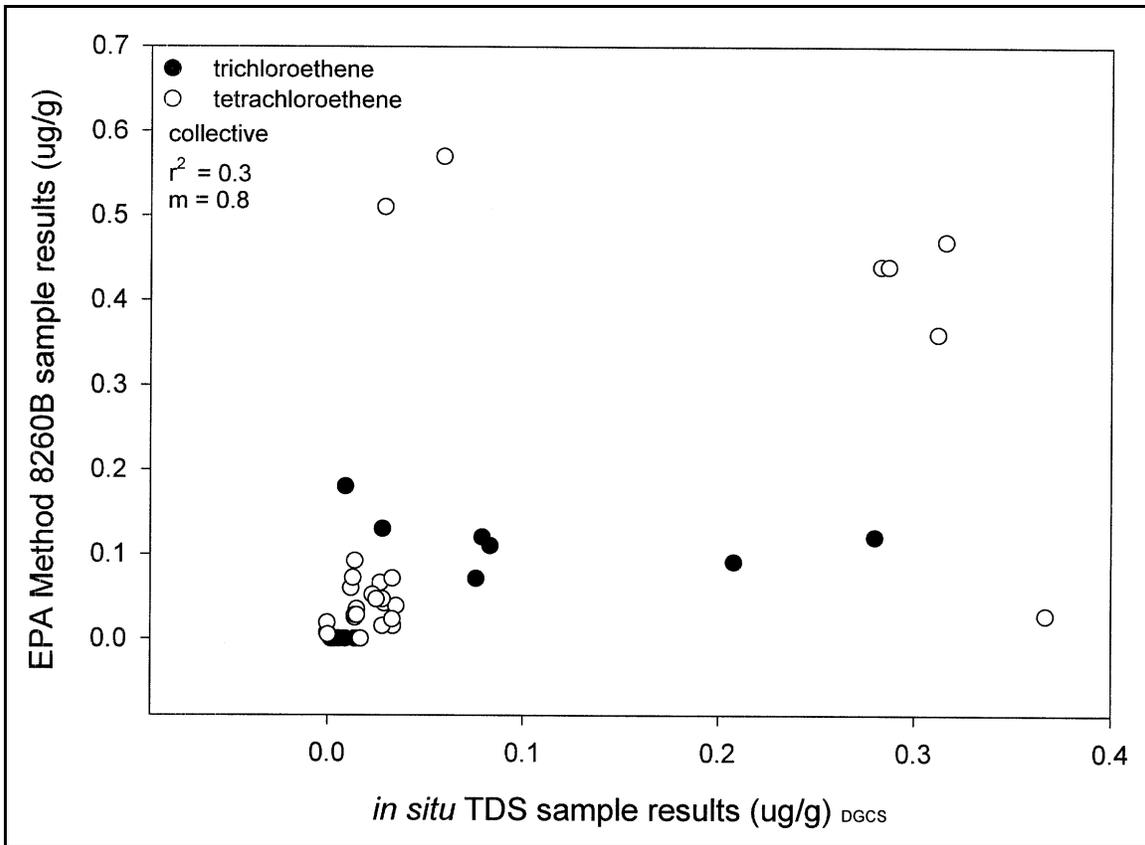


Figure 13. DGCS comparison between the collective *in situ* TDS and Method 8260B (USEPA 1995) data. Individual VOC statistics are: (a) trichloroethene, $r^2 = 0.3$, $m = 0.4$; (b) tetrachloroethene, $r^2 = 0.5$, $m = 1.1$

Closer inspection of the data (i.e., analyte by analyte) shows a distinct pattern with relation to analyte recovery and correlation to traditional laboratory analyses. Most of the VOCs found during the demonstrations were chlorinated solvents. At CRREL, the primary VOC contaminant was TCE ($r^2 = 0.7$, $m = 1.0$), the secondary contaminant was DCE ($r^2 = 0.2$, $m = 1.6$). At LCAAP, total DCE ($r^2 = 0.8$, $m = 0.8$) and vinyl chloride ($r^2 = 0.5$, $m = 1.1$) were the major contaminants. At LHAAP, TCE was the primary VOC ($r^2 = 1.0$, $m = 1.1$) and total DCE ($r^2 = 0.6$, $m = 0.5$) was secondary. In each case, the primary contaminant detected by the TDS system showed strongest agreement with the conventional analysis techniques. The primary contaminant also exhibited a higher mass quantitation ion than the secondary contaminant (i.e., TCE 132 m/z, DCE 96 m/z, vinyl chloride 62 m/z). The difficulties analyzing total DCE in the presence of TCE are associated with the ITMS analysis and are primarily due to the lack of chromatographic separation. Since individual VOCs are not separated from each other, the resulting high mass abundance in the single peak of the total ion chromatogram gives rise to the need for dilutions, while fragmentation to ions of lesser mass is difficult to identify. These two conditions contributed to lowering statistical correlation. However, new chromatographic

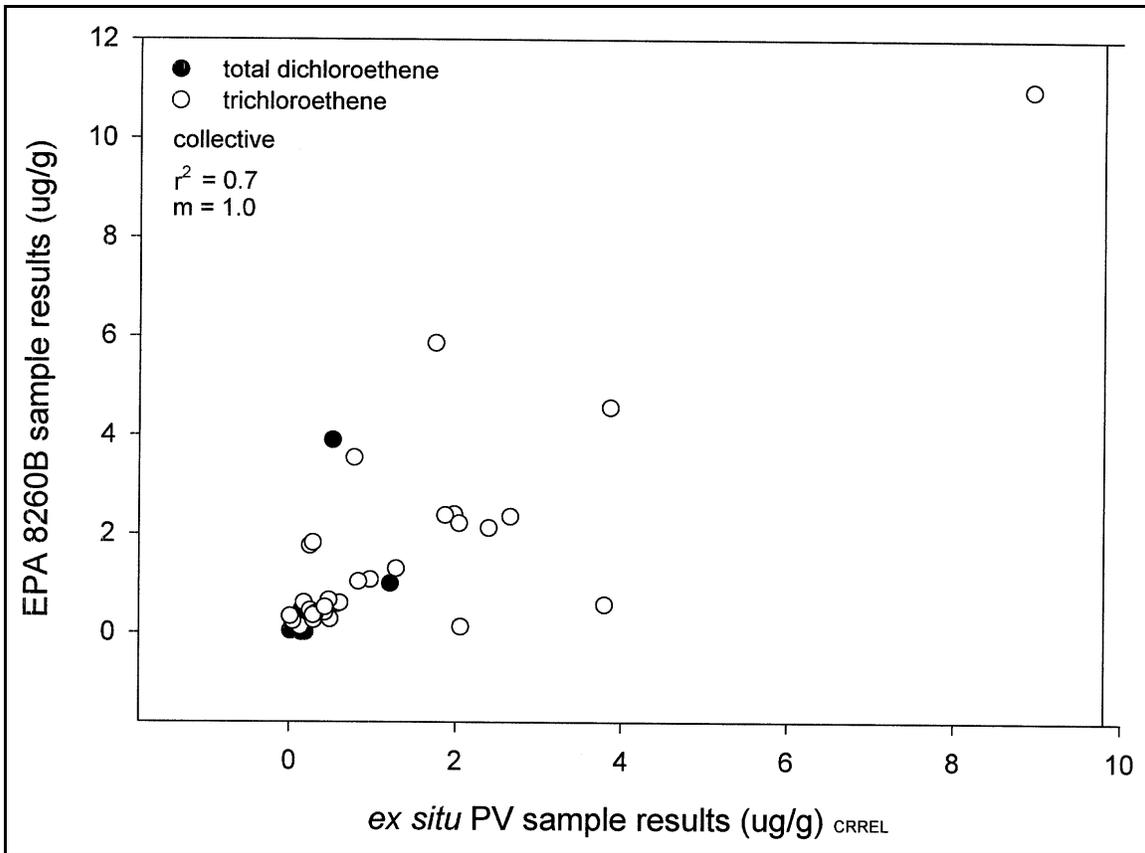


Figure 14. CRREL comparison between the collective *ex situ* PV and Method 8260B (USEPA 1995) data. Individual VOC statistics are: (a) total dichloroethene, $r^2 = 0.2$, $m = 1.6$; (b) trichloroethene, $r^2 = 0.7$, $m = 1.0$

techniques, such as “fast GC” coupled to the newer ITMS are expected to lessen this problem.

Based upon the results of the last three data sets, the TDS demonstrated good statistical comparison to the conventional soil analysis by Method 8260B (USEPA 1995). Identification of vinyl chloride soil gas at levels greater than $1 \mu\text{g/g}$ is a significant accomplishment. Because there were so few samples containing BTEX, the TDS was not adequately tested for those compounds.

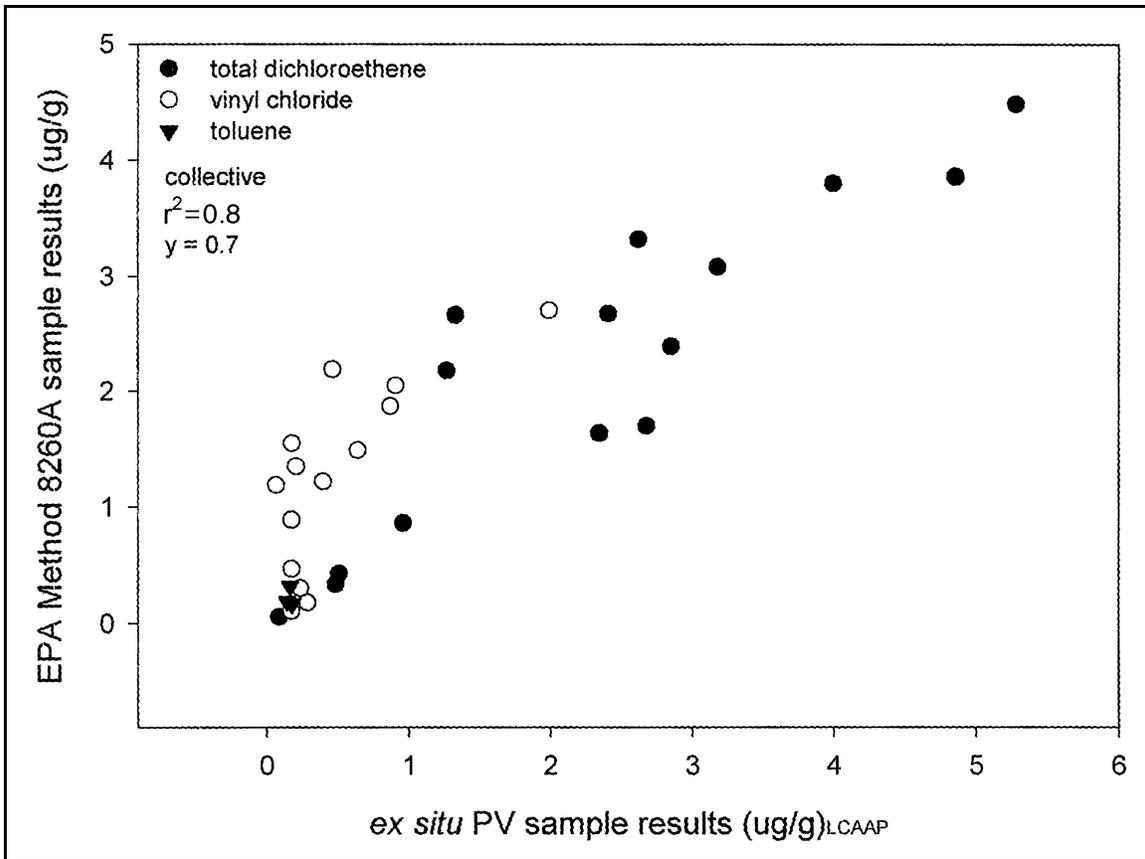


Figure 15. LCAAP comparison between the collective *ex situ* PV and Method 8260B (USEPA 1995) data. Individual VOC statistics are: (a) total dichloroethene, $r^2 = 0.8$, $m = 0.8$; (b) vinyl chloride, $r^2 = 0.5$, $m = 1.1$; (c) toluene, $r^2 = 0.004$, $m = -0.1$

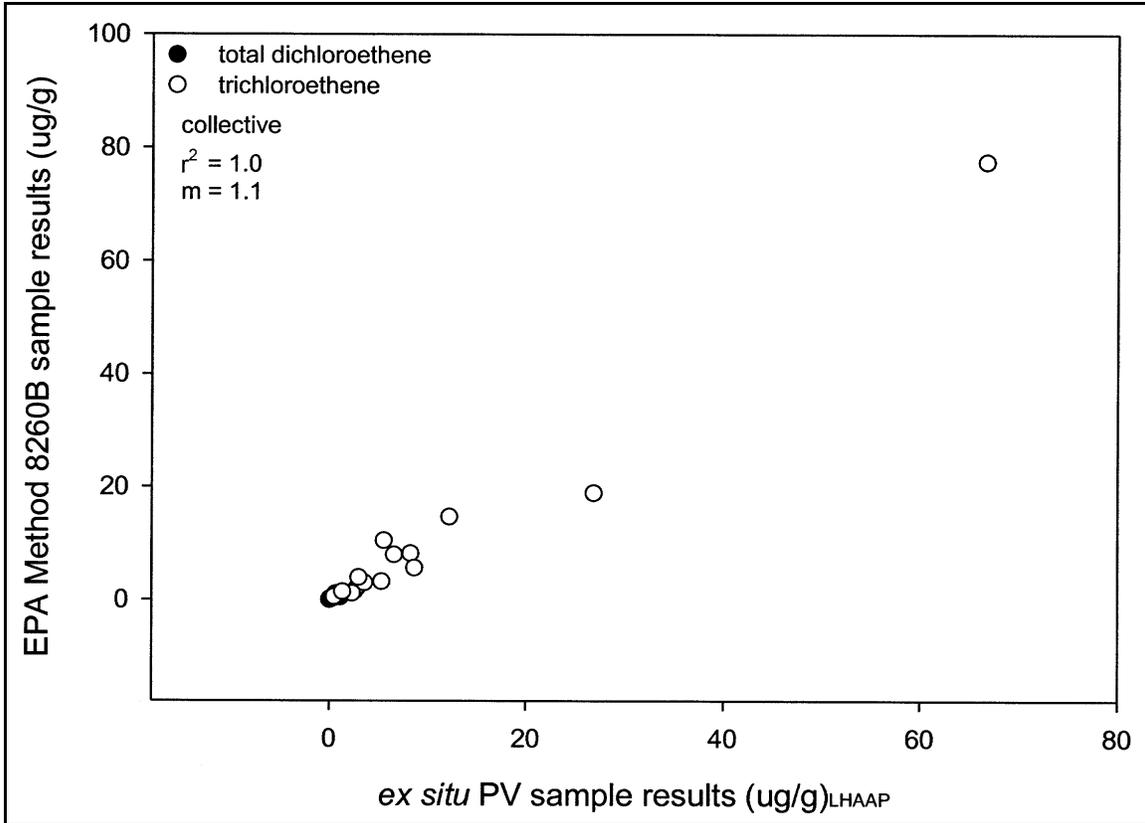


Figure 16. LHAAP comparison between the collective *ex situ* PV and Method 8260B (USEPA 1995) data. Individual VOC statistics are: (a) total dichloroethene, $r^2 = 0.6$, $m = 0.5$; (b) trichloroethene, $r^2 = 1.0$, $m = 1.1$

6 Cost Assessment

TDS Cost Performance

The costs associated with TDS operation include equipment costs for the SCAPS vehicle, expendable supplies, crew travel expenses, and labor. The cost for SCAPS field operations are well documented from previous work performed by the WES SCAPS and from work performed over the past 4 years by the three USACE District SCAPS vehicles. The average cost of operating a SCAPS truck and four-person crew in the field during production work, regardless of sensor type, is \$4,500 per day.

The cost per TDS data point (unit cost) depends on the number of TDS samples taken in a single day. The number of samples achievable in a single day depends upon several factors, some of which have already been discussed. The major factor is the depth of penetration and frequency of sampling along the descent as prescribed in the sampling plan. Secondly, normal CPT limitations such as onsite mobility and subsurface geology impact the amount of work achieved in 1 day. The majority of the time associated with a unit operation of the TDS is the time required to push the TDS to sampling depth, desorb the sample and purge the system (approximately 40 min per sample), and retract the push pipe after the TDS sampling event is completed. The deeper the penetration depth required at a particular site, the lower the production rate and the higher the unit cost. However, it should be noted the same unit cost relationship exists for conventional drilling and soil sampling techniques. Production rates obtained during this demonstration were lower than rates expected during actual production work, due in part, to the 100 percent verification of each TDS sample. The time required for verification sampling doubled the time required for each TDS sample.

Cost Comparison of the TDS System to Conventional and Other Technologies

Costs associated with conventional drill rig/soil sampling are site-dependent. The costs for conventional technology were obtained from managers at each demonstration site. These costs were not always broken out in ways that could

be directly comparable to the TDS sampling technology. For comparison purposes, costs associated with three technologies (SCAPS TDS onsite analysis, conventional drilling with offsite analysis, and direct push with offsite analysis) were itemized for a similar site characterization project consisting of ten 30-ft pushes and the analysis of 60 samples for VOCs. A comparison of each technology is summarized in Table 5.

Table 5 Comparison of Unit Costs for the TDS System and Conventional Technologies					
SCAPS TDS In Situ Measurement		Conventional Drilling (hollow stem auger, split spoon, and offsite analysis)		Direct Push and Offsite Analysis	
	Cost		Cost		Cost
10 Pushes to 30 ft		10 Borings to 30 ft (60 soil samples for TPH analysis)		10 Borings to 30 ft (60 soil samples for TPH analysis)	
6 Field Days @ \$4,500/day	\$27,000	Drilling for 300 ft @ \$50/ft	\$15,000	Drilling for 300 ft @ \$10/ft	\$3,000
Analysis for 60 samples	Included in Cost	TVOC Analysis for 60 samples @ \$200/sample	\$12,000	TVOC Analysis for 60 samples @ \$200/sample	\$12,000
Geotechnical Data for 1 sample/in.	Included in Cost	Geotechnical Analysis for 5 samples @ \$100/sample	\$500	Geotechnical Analysis for 5 samples @ \$100/sample	\$500
1 Waste Drum @ \$40/drum	\$40	28 Waste Drums @ \$40/drum	\$1,120	1 Waste Drum @ \$40/drum	\$40
Decon Water Testing	\$1,000	Decon Water Testing	\$1,000	Decon Water Testing	\$1,000
Waste Soil Testing	\$0	Waste Soil Testing	\$3,000	Waste Soil Testing	\$0
Waste Soil Disposal	\$0 (none produced)	Waste Soil Disposal for 20 Drums @ \$100/drum	\$2,000	Waste Soil Disposal	\$0 (none produced)
Decon Water Disposal for 1 Drums @ \$100/drum	\$100	Decon Water Disposal for 8 Drums @ \$100/drum	\$800	Decon Water Disposal for 1 Drum @ \$100/drum	\$100
4 Man Crew	Included in Cost	Geologist for 40 hr @ \$60/hr	\$2,400	Geologist for 24 hr @ \$60/hr	\$1,440
		Technician for 40 hr @ \$40/hr	\$1,600		
TOTAL		TOTAL		TOTAL	
Per Sample Cost for 60 Samples	\$28,140	Per Sample Cost for 60 Samples	\$39,420	Per Sample Cost for 60 Samples	\$18,080

Note: To obtain meters, multiply feet by 0.3048.

When compared on a unit cost basis, the SCAPS TDS system costs fall midway between direct push technologies with offsite analysis and conventional drilling with offsite analysis. The TDS system does have the advantage of near real-time turnaround, however. During several demonstrations, immediate sample turnaround enabled the SCAPS crew to take additional samples to fill in gaps in the data set. Using conventional technology, the drill rig and sampling crew would have had to be re-mobilized. This alone is a great cost savings that cannot be factored into costs on a per unit basis.

7 Regulatory Issues

One of the objectives of this demonstration was to gather data of a quality to be used in pursuing regulatory acceptance of the TDS system at state and Federal levels. Previous experience in the Tri-Service SCAPS Program with regulatory acceptance of the LIF sensor demonstrated that there is no clear path to regulatory acceptance of innovative environmental technologies (Lieberman 1996). Therefore, a multipathed approach to state and Federal regulatory acceptance was initiated early in the demonstration.

In cooperation with Dr. Marc Wise, ORNL, and Dr. William M. Davis, ERDC, the TDS was included with other sample inlet devices in a draft DSITMS method submitted to USEPA OSHW. The OSHW designated this document Draft Method 8265 (Wise et al. 1997a). It is currently under review for inclusion in the next revision of “Test Methods for Evaluating Solid Waste; Physical/Chemical Methods, SW-846” (USEPA 1995). Drs. Wise and Davis defended the method before the Organic Methods Working Group at the annual methods review meeting in July 1997.

The TDS sampler is under review by the Cal EPA-DTSC under the state Hazardous Waste Environmental Technology Certification Program. The evaluation process includes high-level data validation of both the TDS data sets and laboratory validation data sets. In addition, representatives of the Cal EPA-DTSC reviewed the DGCS Demonstration Plan and provided comments before the demonstration took place. Cal EPA-DTSC personnel observed the field operation of the TDS system at the DGCS and at LHAAP. The agreement for evaluation was initiated in 1998 and TDS data sets are currently under review by that office.

8 Technology Implementation

DOD Requirements for VOC Site Characterization

A large number of sites at DoD installations are contaminated with VOCs including chlorinated solvents and BTEX. The EPA surveyed site remediation needs within Federal and state agencies and has published the results of this survey (Happel, Bechanbach, and Halden 1997). This survey reported 8,300 DoD sites requiring remediation at 2,000 installations. Of the reported sites, 65 percent contained VOCs.

The vadose zone is a particularly difficult region to characterize because VOC contaminants can exist in either vapor or liquid phase depending upon the makeup of the soil strata. In the past, traditional methods of site characterization, collecting a soil sample and sending it to an offsite laboratory for analysis, have underestimated the magnitude of the problem. Past protocols recommended by EPA SW-846 Method 5030 (USEPA 1995) often resulted in a 90 to 99 percent loss of VOCs from soil samples prior to laboratory analysis (Hewitt and Lukash 1997). While Method 5030 is being replaced with alternative methods for in-vial sample collection and analysis, such as EPA SW-846 Methods 5035 and 5021 (USEPA 1995), much of the site characterization data available was based upon the older, less reliable method. Hence, the extent of vadose zone VOC contamination may be much greater than currently believed.

Remediation is the desired follow-up to site characterization. Remediation of chlorinated solvents and fuel spills consists of removing the source of the contamination as much as is practical and containment, treatment, or removal of the dissolved or sorbed contamination from the groundwater or soil. Under the proper conditions at some sites, monitored natural attenuation (MNA) can contribute significantly to remediation of VOC contamination and may accomplish site remediation goals at a lower cost than conventional remediation technologies, within a similar time frame (USEPA 1999). Monitored natural attenuation is currently being used to clean up residual petroleum contamination from leaking underground storage tanks (UST) across the country. With acceptance by the EPA and many states, this remediation trend for UST sites with petroleum releases has increased significantly over the past few years. As

of 1995, MNA was the second most popular remediation option for soil sites. It is being used at roughly 29,000 sites (USEPA 1998).

The SCAPS TDS technology has proven to be fairly reliable at taking discrete snapshots of vadose zone chlorinated solvent contamination, including vinyl chloride. In a previous trial at Dover AFB, the technology was used to determine BTEX concentrations with depth using gas chromatographic separation with photo ionization detection (Myers et al. 1998a). Under the right scenario, this technology could be used to provide cost-effective, less-intrusive analytical snapshots of subsurface VOC concentration changes for MNA remediation.

TDS Technology Transition

Based on verified results of the last three TDS technology demonstrations, the TDS system is ready to be transitioned for onsite screening. The TDS technology was made available to the USACE Districts that operate SCAPS vehicles in 1998. To date there has been limited use of TDS technology by the user community. Currently, the user community utilizes a continuous screening tool for operational site characterization applications. Two TDS probes are available for Tri-Service use. No further testing is recommended.

9 Lessons Learned

The most significant lessons learned in these demonstrations relate to an increased understanding of subsurface heterogeneity and its relationship to VOC distribution within the vadose and capillary zones and to the complexity of attempting to statistically validate a technology associated with so many variables. The SCAPS TDS system, along with the more traditional technology utilized for validation, is only capable of taking a snapshot of the subsurface at localized points. Attempts to establish linear correlation between two samples taken 0.3 meters (12 in.) apart horizontally is not always possible. Researchers should collect as much data as possible during site investigations to obtain a good subsurface profile of both the geology and the extent of contamination. Sufficient verification data collected from multiple sites must be obtained before true statistical patterns can be recognized.

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Appendix A

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Appendix B

Data Tables

**Table B1
BRSA Data Comparison between ITMS and Methanol Verification Data (To obtain meters, multiply feet by 0.3048)**

Sample ID	Depth ft	Methylene Chloride µg/g		1,1,2,2- Tetrachloroethane µg/g		1,1,2- Trichloroethane µg/g		Chlorobenzene µg/g		Carbon Tetrachloride µg/g		Trichloroethene µg/g		Tetrachloroethene µg/g	
		ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH
SBRD	5	<0.005	<0.121	<0.005	<0.121	<0.005	<0.121	<0.005	<0.121	<0.005	<0.121	<0.005	<0.121	<0.005	<0.121
	7.5	<0.005	<0.043	<0.005	<0.043	<0.005	<0.043	<0.005	<0.043	<0.005	<0.043	<0.005	<0.043	<0.005	<0.043
	7.5 D		<0.038		<0.038		<0.038		<0.038		<0.038		<0.038		<0.038
	12	<0.005	<0.048	0.005	<0.048	<0.005	<0.048	<0.005	<0.048	0.011	<0.048	<0.005	<0.048	<0.005	<0.048
	15.5	<0.005	<0.057	<0.005	<0.057	<0.005	<0.057	<0.005	<0.057	<0.005	<0.057	<0.005	<0.057	<0.005	<0.057
SBRB	5	<0.005	<0.039	0.005	<0.039	<0.005	<0.039	<0.005	<0.039	<0.005	<0.039	<0.005	<0.039	<0.005	<0.039
	8	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033
	12	<0.005	<0.047	0.016	0.012	0.006	<0.047	<0.005	<0.047	0.019	0.012	<0.005	<0.047	<0.005	<0.047
	15	<0.005	<0.042	0.005	<0.042	<0.005	<0.042	<0.005	<0.042	<0.005	<0.042	<0.005	<0.042	<0.005	<0.042
SBRA	5	<0.005	0.004 B	0.005	<0.038	0.007	<0.038	<0.005	<0.038	0.005	<0.038	<0.005	<0.038	<0.005	<0.038
	8	<0.005	<0.029	<0.005	<0.029	0.005	<0.029	<0.005	<0.029	0.005	<0.029	<0.005	<0.029	<0.005	<0.029
	15	<0.005	<0.065	<0.005	<0.065	<0.005	<0.065	<0.005	<0.065	0.015	<0.065	<0.005	<0.065	<0.005	<0.065
	16.5	<0.005	<0.045	<0.005	<0.045	<0.005	<0.045	<0.005	<0.045	<0.005	<0.045	<0.005	<0.045	<0.005	<0.045
SBRF	7.5	<0.005	0.089 B	0.011	0.011	<0.005	<0.077	<0.005	<0.077	0.017	<0.077	<0.005	<0.077	<0.005	<0.077
	10	<0.005	0.050 B	<0.005	<0.083	<0.005	<0.083	<0.005	<0.083	<0.005	<0.083	<0.005	<0.083	<0.005	0.016
	15	0.006	0.022 B	0.005	0.003	<0.005	<0.038	<0.005	<0.038	<0.005	<0.038	<0.005	<0.038	<0.005	0.014
	16.5	<0.005	0.058 B	<0.005	<0.090	<0.005	<0.090	<0.005	<0.090	<0.005	<0.090	<0.005	0.011	<0.005	0.025
	18	<0.005	0.014 B	<0.005	<0.099	<0.005	<0.099	<0.005	<0.099	<0.005	<0.099	<0.005	<0.099	<0.005	<0.099

B Compound also found in blank.
D Duplicate sample.

Table B1 (Continued)															
Sample ID	Depth ft	Methylene Chloride µg/g		1,1,2,2- Tetrachlorethane µg/g		1,1,2- Trichloroethane µg/g		Chlorobenzene µg/g		Carbon Tetrachloride µg/g		Trichloroethene µg/g		Tetrachloroethene µg/g	
		ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH
SBRC	5	<0.005	<0.040	<0.005	<0.040	<0.005	<0.040	<0.005	<0.040	<0.005	<0.040	<0.005	<0.040	<0.005	<0.040
	8	<0.005	<0.067	<0.005	<0.067	<0.005	<0.067	<0.005	<0.067	<0.005	<0.067	<0.005	<0.067	<0.005	<0.067
	12	<0.005	<0.036	<0.005	<0.036	<0.005	<0.036	<0.005	<0.036	<0.005	<0.036	0.006	<0.036	<0.005	<0.036
	15	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034
SBRE	5	<0.005	<0.045	<0.005	<0.045	<0.005	<0.045	<0.005	0.012	0.006	<0.045	<0.005	<0.045	<0.005	<0.045
	8	<0.005	<0.067	<0.005	<0.067	<0.005	<0.067	<0.005	0.012	<0.005	<0.067	<0.005	<0.067	<0.005	<0.067
	15	<0.005	<0.038	<0.005	<0.038	<0.005	<0.038	<0.005	0.012	0.008	<0.038	<0.005	<0.038	<0.005	<0.038
	16.5	<0.005	<0.061	<0.005	<0.061	<0.005	<0.061	<0.005	0.012	<0.005	0.024	<0.005	<0.061	<0.005	<0.061
SBRM	5	<0.005	<0.050	<0.005	<0.050	<0.005	<0.050	<0.005	<0.050	<0.005	<0.050	<0.005	<0.050	<0.005	<0.050
	10	<0.005	<0.050	<0.005	<0.050	<0.005	<0.050	<0.005	<0.050	<0.005	<0.050	<0.005	<0.050	<0.005	<0.050
	17	<0.005	<0.037	<0.005	<0.037	<0.005	<0.037	<0.005	<0.037	<0.005	<0.037	<0.005	<0.037	<0.005	<0.037
	17 D		0.006		<0.034		<0.034		<0.034		<0.034		<0.034		<0.034
	34	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034
SBR21	4	0.005	<0.045	0.010	<0.045	<0.005	<0.045	<0.005	<0.045	<0.005	<0.045	<0.005	<0.045	<0.005	<0.045
	7	0.006	<0.032	0.010	<0.032	<0.005	<0.032	<0.005	<0.032	<0.005	<0.032	0.017	<0.032	<0.005	<0.032
	10	0.007	<0.044	<0.005	<0.044	<0.005	<0.044	<0.005	<0.044	0.006	<0.044	<0.005	<0.044	<0.005	<0.044
	12	<0.005	<0.036	<0.005	<0.036	<0.005	<0.036	<0.005	<0.036	<0.005	<0.036	<0.005	<0.036	<0.005	<0.036

(Sheet 2 of 4)

Table B1 (Continued)															
Sample ID	Depth ft	Methylene Chloride µg/g		1,1,2,2- Tetrachloroethane µg/g		1,1,2- Trichloroethane µg/g		Chlorobenzene µg/g		Carbon Tetrachloride µg/g		Trichloroethene µg/g		Tetrachloroethene µg/g	
		ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH
SBR13	5.5	0.005	<0.051	0.051	0.772	0.028	<0.051	<0.005	<0.051	<0.005	<0.051	0.052	0.049	<0.005	<0.051
	8.5	<0.005	<0.042	0.006	0.080	<0.005	<0.042	<0.005	<0.042	<0.005	<0.042	<0.005	0.007	<0.005	<0.042
	14	<0.005	<0.049	0.010	0.037	<0.005	<0.049	<0.005	<0.049	<0.005	<0.049	0.008	<0.049	<0.005	<0.049
	14 D		<0.034		0.035		<0.034		<0.034		<0.034		<0.034		<0.034
	17	<0.005	<0.044	0.007	0.009	<0.005	<0.044	<0.005	<0.044	<0.005	<0.044	<0.005	<0.044	<0.005	<0.044
SBR27	4.5	<0.005	<0.044	<0.005	<0.044	<0.005	<0.044	<0.005	<0.044	<0.005	<0.044	<0.005	<0.044	<0.005	<0.044
	9.5	<0.005	<0.036	0.005	0.012	<0.005	<0.036	<0.005	<0.036	0.014	0.028	<0.005	<0.036	<0.005	<0.036
	10.5	<0.005	<0.047	<0.005	0.010	<0.005	<0.047	<0.005	<0.047	0.031	0.042	<0.005	<0.047	<0.005	<0.047
	13	<0.005	<0.037	0.005	<0.037	<0.005	<0.037	<0.005	<0.037	0.015	0.010	<0.005	<0.037	<0.005	<0.037
SBR28	4.5	<0.005	<0.047	0.008	0.010	<0.005	<0.047	0.005	<0.047	<0.005	<0.047	<0.005	<0.047	<0.005	<0.047
	5	<0.005	<0.037	<0.005	0.010	<0.005	<0.037	<0.005	<0.037	<0.005	<0.037	<0.005	<0.037	<0.005	<0.037
	9.5	0.005	<0.051	0.005	0.048	<0.005	<0.051	<0.005	<0.051	0.044	0.054	0.012	0.012	<0.005	<0.051
SBR28-2	11	<0.005	<0.051	<0.005	0.011	<0.005	<0.051	<0.005	<0.051	0.010	<0.051	<0.005	<0.051	<0.005	<0.051
	13	<0.005	<0.072	<0.005	<0.072	<0.005	<0.072	<0.005	<0.072	<0.005	<0.072	<0.005	<0.072	<0.005	<0.072
SBR10	5	0.011	<0.033	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033
	6	<0.005	<0.062	<0.005	<0.062	<0.005	<0.062	<0.005	<0.062	<0.005	<0.062	<0.005	<0.062	<0.005	<0.062
	8	<0.005	<0.060	<0.005	<0.060	<0.005	<0.060	<0.005	<0.060	<0.005	<0.060	<0.005	<0.060	<0.005	<0.060
	10	<0.005	<0.032	<0.005	0.022	<0.005	<0.032	<0.005	<0.032	<0.005	<0.032	<0.005	0.004	<0.005	<0.032

(Sheet 3 of 4)

Table B1 (Concluded)															
Sample ID	Depth ft	Methylene Chloride µg/g		1,1,2,2- Tetrachlorethane µg/g		1,1,2- Trichloroethane µg/g		Chlorobenzene µg/g		Carbon Tetrachloride µg/g		Trichloroethene µg/g		Tetrachloroethene µg/g	
		ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH	ITMS	MeOH
SBRH	8	<0.005	<0.038	0.006	<0.038	<0.005	<0.038	<0.005	<0.038	<0.005	<0.038	<0.005	<0.038	<0.005	<0.038
	12	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034	<0.005	<0.034
	12 D		<0.046		<0.046		<0.046		<0.046		<0.046		<0.046		<0.046
SBRL	8	<0.005	<0.055	<0.005	<0.055	<0.005	<0.055	<0.005	<0.055	<0.005	<0.055	<0.005	<0.055	<0.005	<0.055
	13	<0.005	<0.042	<0.005	<0.042	<0.005	<0.042	<0.005	<0.042	<0.005	<0.042	<0.005	<0.042	<0.005	<0.042
	17.5	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033	<0.005	<0.033	<0.005	0.008	<0.005	<0.033	<0.005	<0.033
SBRK	6	<0.005	<0.032	<0.005	<0.032	<0.005	<0.032	<0.005	<0.032	<0.005	<0.032	<0.005	<0.032	<0.005	<0.032
	17.5	<0.005	<0.017	<0.005	0.004	<0.005	<0.017	<0.005	<0.017	<0.005	<0.017	<0.005	<0.017	<0.005	<0.017
SBR33	7	0.052	<0.046	0.007	0.016	<0.005	<0.046	<0.005	<0.046	0.060	0.024	<0.005	<0.046	<0.005	<0.046
	7 D		<0.042		0.014		<0.042		<0.042		0.022		<0.042		<0.042
	10.5	0.014	<0.038	0.012	0.025	<0.005	<0.038	<0.005	<0.038	0.019	0.039	<0.005	<0.038	<0.005	<0.038
	11.5	0.005	<0.052	0.005	0.031	<0.005	<0.052	<0.005	<0.052	0.011	0.066	<0.005	<0.052	<0.005	<0.052
SBR34	7	0.005	<0.036	<0.005	0.209	<0.005	<0.036	<0.005	<0.036	0.010	0.045	<0.005	0.048	<0.005	0.007
	13.5	<0.005	<0.030	<0.005	0.119	<0.005	<0.030	<0.005	<0.030	0.013	0.071	0.006	0.023	<0.005	<0.030
	23.5	<0.005	<0.039	<0.005	<0.039	<0.005	<0.039	<0.005	<0.039	<0.005	<0.039	<0.005	<0.039	<0.005	<0.039

(Sheet 4 of 4)

Table B2

DGCS Data Comparison between TDS ITMS, PV ITMS, and Methanol Verification Data (To obtain meters, multiply feet by 0.3048)

Sample ID	Depth, ft	Trichloroethene, µg/g				Tetrachloroethene, µg/g			
		TDS	PV	MeOH	MeOH QC	TDS	PV	MeOH	MeOH QC
DVTD01	5	<0.010		<0.050		<0.010		0.007	
	15	<0.010		<0.050		<0.010		0.019	
	20	<0.010		<0.050		0.003		0.005	
	25	<0.010	<0.010	<0.050		0.034	0.006	0.015	
	25 D			<0.050				0.020	
	36	<0.010		<0.050		0.028		0.015	
DVTD02	26	<0.010	<0.010	<0.050		0.017	0.024	<0.050	
DVTD03	26	<0.010	<0.010	<0.050		0.012	0.034	0.006	
DVTD04	30	<0.010	<0.010	<0.050	<0.050	0.029	0.051	0.042	0.047
	30 D			<0.050	<0.050			0.026	0.040
DVTD05	26	<0.010	<0.010	<0.050		0.015	0.048	0.035	
	28	<0.010	<0.010	<0.050		0.035	0.037	0.039	
	30	<0.010	<0.010	<0.050		0.028	0.048	0.047	
	30 D			<0.050				0.044	
	32	<0.010	<0.010	<0.050		0.027	0.078	0.066	
DVTD06	30	<0.010	<0.010	<0.050	<0.050	0.023	0.024	0.110	0.085
	30 D			<0.050	<0.050			0.052	0.110
	32	<0.010	<0.010	<0.050		0.014	0.062	0.092	
	34	<0.010	<0.010	<0.050		0.033	0.009	0.023	
D Duplicate sample.									
(Continued)									

Table B2 (Concluded)

Sample ID	Depth, ft	Trichloroethene, µg/g				Tetrachloroethene, µg/g			
		TDS	PV	MeOH	MeOH QC	TDS	PV	MeOH	MeOH QC
		DVTD07	26	<0.010	<0.010	<0.050		0.014	0.006
	28	<0.010	<0.010	<0.050		0.014	0.015	0.028	
	30	<0.010	<0.010	<0.050		0.033	0.017	0.071	
DVTD08	26	<0.010	<0.010	<0.050		0.015	0.039	0.028	
	26 D			<0.050				0.034	
	28	<0.010	<0.010	<0.050		0.013	0.042	0.072	
	28 D			<0.050				0.061	
	30	<0.010	<0.010	<0.050		0.025	0.030	0.047	
	30 D			<0.050				0.047	
DVTD09	50	0.009	0.023	0.180		0.029	0.057	0.510	
	50 D			0.083				0.380	
	52	0.028	0.044	0.130		0.059	0.127	0.570	
	52 D			0.012				0.500	
DVTD10	50	0.076	0.102	0.071		0.367	0.190	0.280	
	50 D			0.053				0.220	
	52	0.079	0.018	0.120		0.283	0.045	0.440	
	52 D			0.120				0.410	
DVTD11	48	0.208	0.006	0.091		0.312	0.011	0.360	
	48 D			0.072				0.310	
	50	0.280	0.033	0.120		0.316	0.038	0.470	
	50 D			0.110					
	52	0.083	0.014	0.110		0.287	0.019	0.440	
	52 D			0.113				0.460	

Table B3
CRREL Data Comparison between TDS ITMS, PV ITMS, and Methanol Verification Data (To obtain meters, multiply feet by 0.3048)

Sample ID	Depth, ft	Dichloroethene, µg/g			Trichloroethene, µg/g		
		TDS	PV	MeOH	TDS	PV	MeOH
CRTD01	10	<0.156	0.119	<0.441	3.24	0.773	3.54
	10 D			<0.384			4.01
	20	0.202	0.199	<0.394	1.92	3.86	4.57
	20 D			<0.385			1.06
	30	0.108	0.106	<0.440	1.95	3.80	0.387
	30 D			<0.493			0.572
CRTD02	40	<0.156	0.435	<0.366	<0.650	8.94	10.98
	40 D			<0.493			-
	50	<0.156	0.235	<0.520	0.228	0.487	0.270
	50 D						0.174
	30	<0.156	<0.094	<0.326	<0.156	<0.094	<0.326
	30 D			<0.341			<0.341
CRTD02	45	0.090	<0.095	<0.371	<0.156	<0.095	0.146
	45 D			<0.383			<0.383
	50	0.130	0.024	<0.350	1.29	0.303	0.350
	50 D			<0.343			0.329
	55	0.317	<0.156	<0.428	4.30	0.127	0.089
	55 D			<0.389			0.143
CRTD02	60	<0.781	0.145	<0.377	2.42	1.98	3.02
	60 D			<0.360			3.88

(Sheet 1 of 3)

Table B3 (Continued)

Sample ID	Depth, ft	Dichloroethene, µg/g				Trichloroethene, µg/g			
		TDS	PV	MeOH	MeOH QC	TDS	PV	MeOH	MeOH QC
CRTD03	5	0.479	0.174	<0.410		1.82	0.574	0.574	0.574
	5 D			<0.415					0.581
	10	0.404	0.160	0.116		1.11	0.424	0.400	0.400
	10 D			0.116				0.388	0.388
	15	<0.156	<0.094	<0.345		0.191	<0.094	<0.345	<0.345
	15 D			<0.331				<0.331	<0.331
	20	0.070	<0.147	<0.367		0.765	0.606	0.601	0.601
	20 D			<0.327				0.576	0.576
	25	<0.156	0.195	<0.375		0.158	2.06	0.990	0.990
	25 D			<0.399				2.39	2.39
	30	0.175	0.237	<0.358		2.16	2.66	1.86	1.86
	30 D			<0.346				2.35	2.35
	35	0.277	0.138	0.009		3.19	1.28	1.38	1.38
	35D			0.009				1.30	1.30
CRTD04	5	0.156	0.094	0.054		0.522	0.289	0.214	0.214
	5 D			0.034				0.254	0.254
	10	0.207	0.110	0.103		0.807	0.314	0.381	0.381
	10 D			0.115				0.401	0.401
	25	0.342	0.126	<0.331		4.07	1.87	2.38	2.38
	25 D			<0.331				2.78	2.78
	30	0.556	0.188	0.001		0.138	2.40	1.99	1.99
	30 D			0.004				2.12	2.12

(Sheet 2 of 3)

Table B3 (Concluded)												
Sample ID	Depth, ft	Dichloroethene, µg/g				Trichloroethene, µg/g				MeOH QC	MeOH	MeOH QC
		TDS	PV	MeOH	MeOH QC	TDS	PV	MeOH	MeOH QC			
CRTD04	35	0.134	<0.262	<0.379		1.65	0.971			1.08		
	35 D			<0.436						0.803		
	40	0.164	0.066	<0.384		2.26	0.831			1.44		
	40 D			<0.389						1.04		
	50	0.284	0.015	<0.361		3.37	0.477			0.707		
	50 D			<0.308						0.653		
CRTD05	60	0.246	0.035	<0.337		2.56	0.285			0.351		
	60 D			<0.233						0.279		
	5	0.008	<0.085	0.029		0.487	0.041			0.234		
	5 D			0.040						0.291		
	10	1.20	0.154	2.64		0.279	<0.108			0.515		0.492
	10 D			1.83						0.327		
	15	<0.156	0.013	0.320		<0.156	0.012			0.331		
	15 D									0.428		
	20	8.48	0.513	3.90		4.74	0.282			1.82		
	20 D			4.55						2.11		
25	1.05	<0.103	1.73		2.20	<0.103			2.49		2.74	
25 D			0.798						3.59			
25-2	1.05	1.21	1.44		2.20	2.04			2.21			
25-2 D			1.02						1.64			
30	0.100	0.109	0.226		0.319	0.427			0.655			
30 D			0.108						0.511			

(Sheet 3 of 3)

**Table B4
LCAAP Data Comparison between TDS ITMS, PV ITMS, and Methanol Verification Data (To obtain meters, multiply feet by 0.3048)**

Sample ID	Depth, ft	Analyte	TDS, µg/g	PV, µg/g	MeOH, µg/g	MeOH D, µg/g	MeOH QC, µg/g	MeOH QC D, µg/g
LCTD01	4	Vinyl chloride	NA	0.287	0.180	0.029		
		Dichloroethene	3.58	2.68	1.70	2.00		
		Toluene	<0.125	<0.268	<0.100	<0.100		
		Tetrachloroethene	0.205	<0.268	<0.100	<0.100		
		Ethyl Benzene	<0.125	<0.268	<0.100	<0.100		
LCTD01	6	Vinyl chloride	NA	0.175	0.890	0.970		
		Dichloroethene	4.18	2.58	2.39	2.38		
		Toluene	<0.200	<0.192	<0.200	<0.200		
		Tetrachloroethene	0.599	<0.192	<0.200	<0.200		
		Ethyl Benzene	<0.200	<0.192	<0.200	<0.200		
LCTD01	8	Vinyl chloride	NA	0.208	1.35	1.32		
		Dichloroethene	2.38	2.41	2.67	2.57		
		Toluene	<0.200	<0.187	<0.200	<0.200		
		Tetrachloroethene	0.500	<0.187	<0.200	<0.200		
		Ethyl Benzene	<0.200	<0.187	<0.200	<0.200		
LCTD01	10	Vinyl chloride	NA	0.640	1.49	0.383		
		Dichloroethene	9.15	3.18	3.08	2.92		
		Toluene	<0.333	<0.375	<0.200	<0.200		
		Tetrachloroethene	0.628	<0.375	<0.200	<0.200		
		Ethyl Benzene	<0.333	<0.375	<0.200	<0.200		

D Duplicate sample.
NA Sample was not analyzed for analyte.

Table B4 (Continued)										
Sample ID	Depth, ft	Analyte	TDS, µg/g	PV, µg/g	MeOH, µg/g	MeOH D, µg/g	MeOH QC, µg/g	MeOH QC D, µg/g		
LCTD01	12	Vinyl chloride	NA	0.870	1.87	1.81	1.24	1.50		
		Dichloroethene	6.85	5.28	4.48	4.60	4.53	5.16		
		Toluene	<0.250	<0.240	<0.500	<0.500	<0.200	<0.200		
		Tetrachloroethene	0.574	<0.240	<0.500	<0.500	<0.200	<0.200		
		Ethyl Benzene	<0.250	<0.240	<0.500	<0.500	<0.200	<0.200		
LCTD02	4	Vinyl chloride	0.412	0.662	<0.100	0.102				
		Dichloroethene	2.50	0.958	0.861	1.10				
		Toluene	<0.125	<0.117	<0.100	<0.100				
		Tetrachloroethene	<0.125	<0.117	<0.100	<0.100				
		Ethyl Benzene	<0.125	<0.117	<0.100	<0.100				
LCTD02	6.5	Vinyl chloride	0.205	0.266	<0.200	1.21				
		Dichloroethene	2.47	2.35	1.64	2.05				
		Toluene	<0.143	<0.153	<0.200	<0.100				
		Tetrachloroethene	<0.143	0.158	<0.200	<0.100				
		Ethyl Benzene	<0.143	0.327	<0.200	<0.100				
LCTD02	9	Vinyl chloride	2.12	0.463	2.19	2.33				
		Dichloroethene	2.12	1.33	2.66	2.89				
		Toluene	<0.125	<0.116	<0.200	<0.200				
		Tetrachloroethene	<0.125	<0.116	<0.200	<0.200				
		Ethyl Benzene	<0.125	<0.116	<0.200	<0.200				
LCTD02	11	Vinyl chloride	1.67	0.906	2.05	1.87				
		Dichloroethene	1.84	3.99	2.80	3.92				
		Toluene	<0.143	<0.184	<0.200	<0.200				
		Tetrachloroethene	<0.143	<0.184	<0.200	<0.200				
		Ethyl Benzene	<0.143	<0.184	<0.200	<0.200				

Table B4 (Continued)

Sample ID	Depth, ft	Analyte	TDS, µg/g	PV, µg/g	MeOH, µg/g	MeOH D, µg/g	MeOH QC, µg/g	MeOH QC D, µg/g
LCTD02	13	Vinyl chloride	0.427	0.396	1.22	0.857		
		Dichloroethene	2.15	2.62	3.32	2.69		
		Toluene	<0.125	<0.126	<0.250	<0.250		
		Tetrachloroethene	0.150	<0.126	<0.250	<0.250		
		Ethyl Benzene	<0.125	<0.126	<0.250	<0.250		
LCTD03	6	Vinyl chloride	<0.125	0.173	0.105	0.118		
		Dichloroethene	1.46	1.27	2.18	2.05		
		Toluene	<0.125	<0.116	<0.100	<0.100		
		Tetrachloroethene	<0.125	<0.116	0.179	<0.100		
		Ethyl Benzene	<0.125	<0.116	<0.100	<0.100		
LCTD04	11	Vinyl chloride	0.414	1.99	2.70	2.53		
		Dichloroethene	0.841	4.86	3.86	3.55		
		Toluene	<0.050	<0.234	<0.250	<0.250		
		Tetrachloroethene	0.066	<0.234	<0.250	<0.250		
		Ethyl Benzene	0.102	<0.234	<0.250	<0.250		
LCTD05	4	Vinyl chloride	0.084	0.236	0.303	0.025		
		Dichloroethene	<0.050	0.087	0.055	0.222		
		Toluene	<0.050	<0.081	<0.100	<0.100		
		Tetrachloroethene	<0.050	<0.081	<0.100	<0.100		
		Ethyl Benzene	<0.050	0.142	<0.100	<0.100		

(Sheet 3 of 4)

Table B4 (Concluded)									
Sample ID	Depth, ft	Analyte	TDS, µg/g	PV, µg/g	MeOH, µg/g	MeOH D, µg/g	MeOH QC, µg/g	MeOH QC D, µg/g	
LCTD05	6	Vinyl chloride	0.645	0.179	1.55	0.321			
		Dichloroethene	<0.050	0.073	<0.250	0.040			
		Toluene	0.188	0.178	0.168	0.180			
		Tetrachloroethene	<0.050	<0.078	0.168	0.180			
		Ethyl Benzene	0.198	0.178	0.021	0.008			
LCTD05	8	Vinyl chloride	0.879	0.174	0.469	1.64			
		Dichloroethene	<0.100	0.484	0.336	0.361			
		Toluene	0.200	0.144	0.189	0.234			
		Tetrachloroethene	<0.050	<0.042	0.189	0.234			
		Ethyl Benzene	0.208	0.121	0.014	0.018			
LCTD05	10	Vinyl chloride	0.193	0.065	1.19	2.36			
		Dichloroethene	<0.050	0.507	0.427	0.499			
		Toluene	0.284	0.164	0.323	0.315			
		Tetrachloroethene	<0.050	<0.054	0.323	0.317			
		Ethyl Benzene	0.212	0.132	0.019	0.017			

(Sheet 4 of 4)

Table B5

LHAAP Data Comparison between TDX ITMS, PV ITMS, and Methanol Validation Data (To obtain meters, multiply feet by 0.3048)

Sample ID	Depth,ft	Dichloroethene, µg/g			Trichloroethene, µg/g				
		TDS	PV	MeOH	MeOH QC	TDS	PV	MeOH	MeOH QC
LHTD01	10	<0.025	0.016	0.006		0.134	0.101	0.064	
	10 D			0.006				0.069	
	12	<0.050	<0.038	<0.100		0.631	0.234	0.255	
	12 D			<0.100				0.288	
	15	<2.50	<0.450	<1.00	<0.050	16.8	5.50	10.5	11.4
	15 D			<1.00	<0.050			11.5	11.6
	18	<2.50	<0.700	<1.00		20.8	8.21	8.18	
	18 D			<1.00				9.03	
LHTD02	10	<0.025	0.035	0.012		0.110	0.067	0.100	
	10 D			0.011				0.086	
	12	0.044	0.031	0.011		0.972	0.227	0.211	
	12 D			0.010				0.193	
	15	<0.830	<0.100	<0.100		3.54	0.653	1.04	
	15 D			<0.100				0.894	
	18	<0.025	<0.042	<0.250		1.5	0.393	0.416	
	18 D			<0.250				0.475	

D Duplicate Sample.

B Second sample taken at sampling depth and location.

NS Sample lost or not taken.

(Sheet 1 of 3)

Table B5 (Continued)												
Sample ID	Depth,ft	Dichloroethene, µg/g				Trichloroethene, µg/g				MeOH QC	MeOH	MeOH QC
		TDS	PV	MeOH	MeOH QC	TDS	PV	MeOH	MeOH QC			
LHTD03	10	<0.025	<0.020	<0.100		0.072	0.043	0.041				
	10 D			<0.100				0.034				
	12	<0.050	<0.020	<0.100		0.074	0.031	0.032				
	12 D			<0.100				0.026				
	15	0.086	0.027	<0.100		1.31	0.150	0.208				
	15 D			<0.100				0.281				
	18	<1.25	<0.430	<0.100		12.1	2.58	1.56				
	18 D			NS				NS				
	18B	NS	<0.420	<0.250		NS	4.77	2.02				
	18B D			<0.250				2.22				
LHTD04	9	1.02	0.037	0.092		7.76	0.502	0.664				
	9 D			0.099				0.748				
	12	0.322	0.130	0.131		2.36	1.27	1.04				
	12 D			0.124				0.958				
	14	0.191	0.061	0.066		1.00	0.363	0.316				
	14 D			0.064				0.280				
LHTD05	5	0.865	0.645	0.597		1.18	0.672	0.454				
	5 D			0.614				0.528				
	9	0.805	0.488	0.300		7.63	3.54	2.94				
	9 D			0.311				2.32				

(Sheet 2 of 3)

Table B5 (Concluded)

Sample ID	Depth,ft	Dichloroethene, µg/g			Trichloroethene, µg/g		
		TDS	PV	MeOH	TDS	PV	MeOH
LHTD05	12	0.772	0.284	0.274	4.77	2.94	3.94
	12 D			0.261			3.79
	14	0.122	0.083	0.050	1.09	0.468	0.476
	14 D			0.054			0.477
LHTD06	5	2.37	0.557	0.620	4.07	2.28	1.10
	5 D			0.608			1.22
	9	3.51	1.08	0.422	46.8	8.58	5.58
	9 D			0.564			7.87
	12	1.81	0.425	0.465	21.3	6.54	7.97
	12 D			0.468			7.84
	14	0.448	0.116	0.085	5.25	1.30	1.38
	14 D			0.093			1.46
LHTD07	5	6.07	2.84	2.13	10.9	5.27	3.20
	5 D			2.15			3.68
	9	1.15	1.07	1.12	18.2	12.2	14.7
	9 D			1.06			13.5
	12	0.742	1.07	1.08	13.3	26.9	18.9
	12 D			1.36			22.1
	15	0.596	3.00	0.353	135	66.7	77.5
	15 D			0.279			80.1

(Sheet 3 of 3)

Appendix C

Additional Comparison Graphs

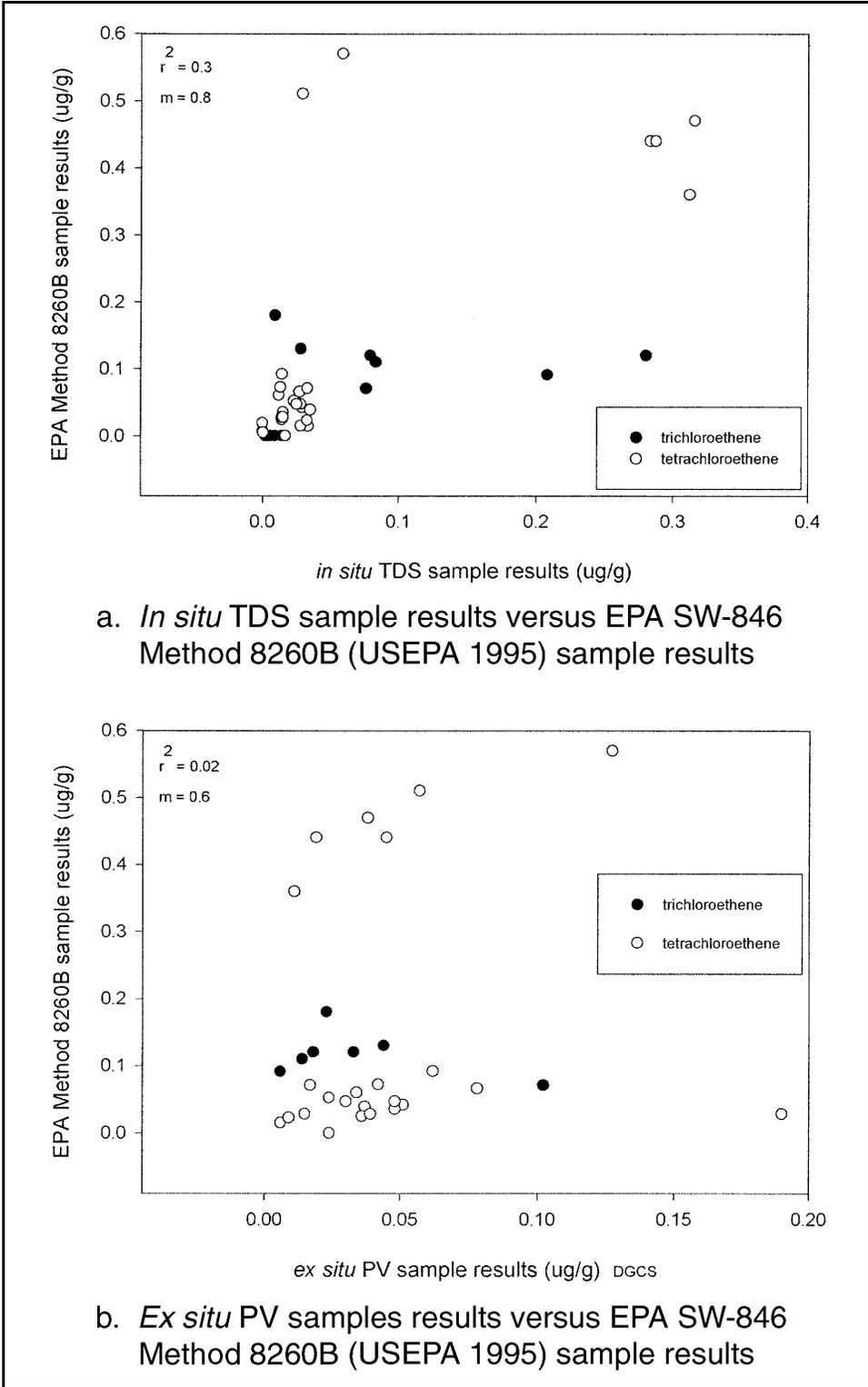


Figure C1. DGCS data comparisons. Correlation is for all analytes listed in legend

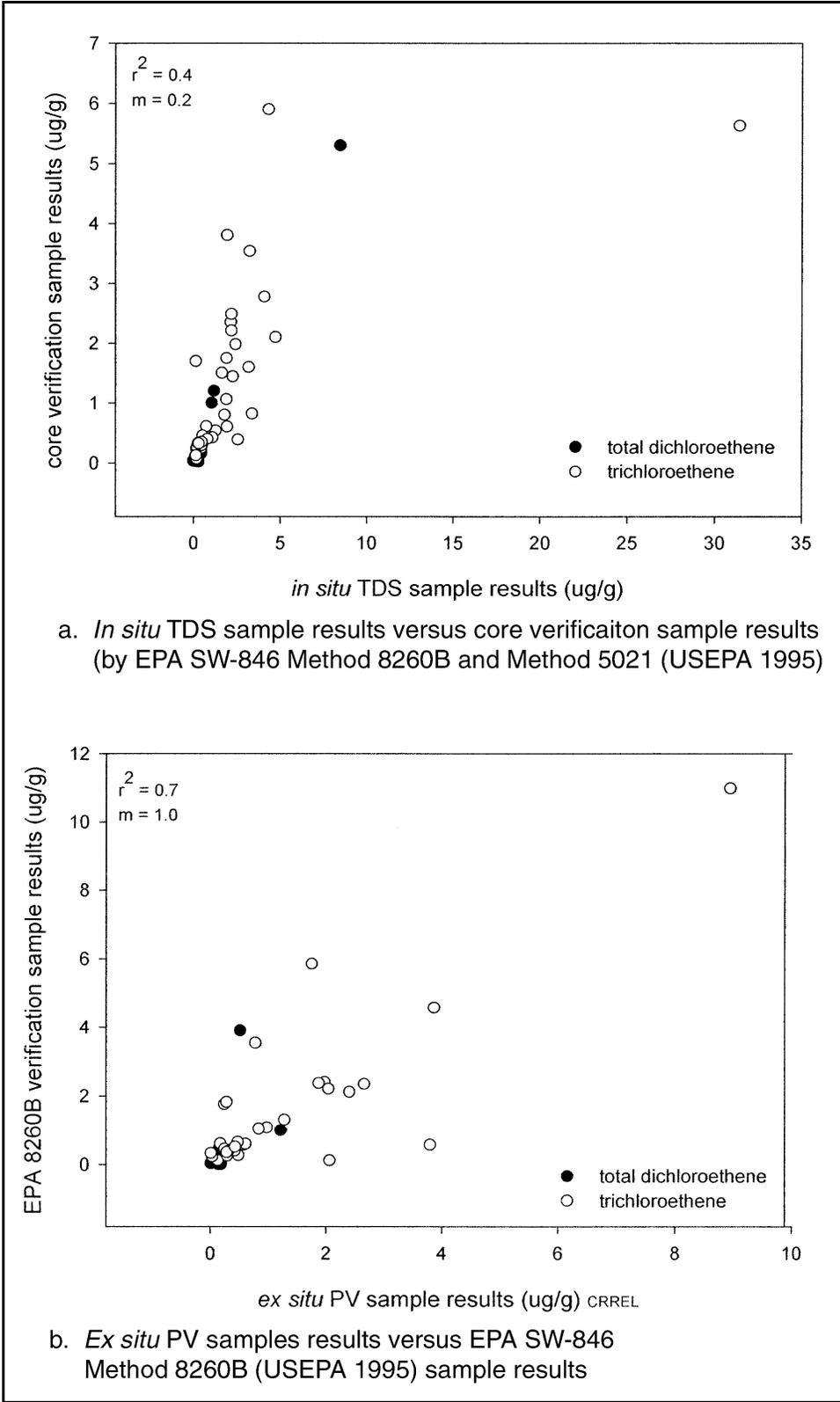
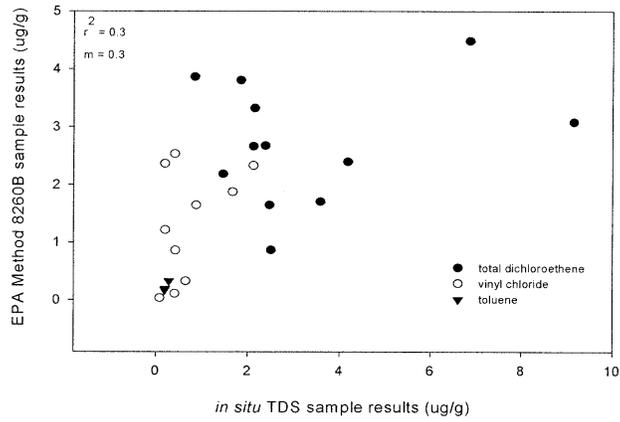
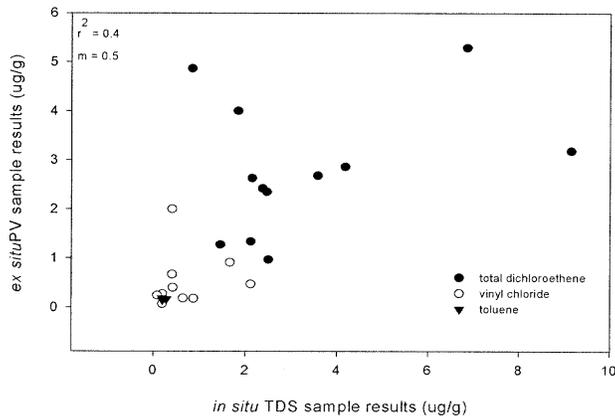


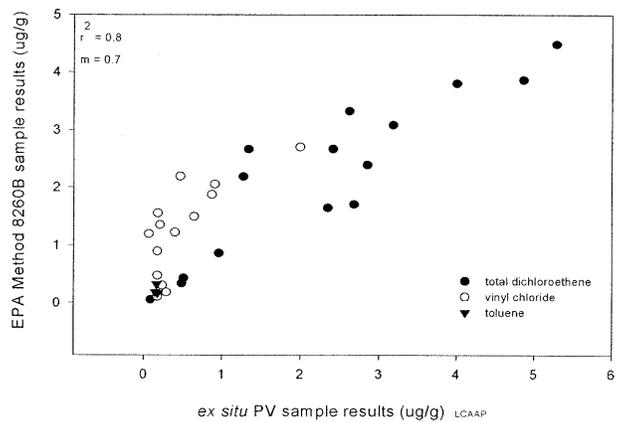
Figure C2. CRREL data comparisons. Correlation is for all analytes listed in legend



a. *In situ* TDS sample results versus EPA SW-846 Method 8260B (USEPA 1995) sample results

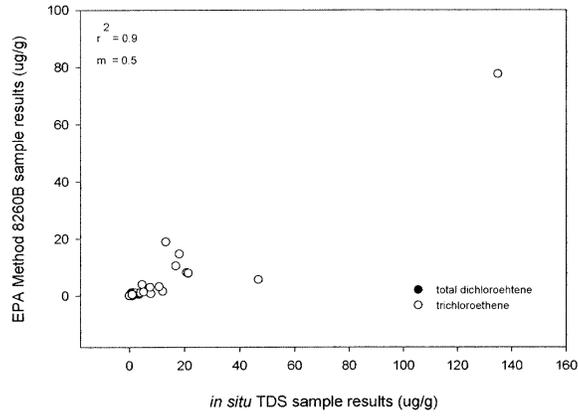


b. *In situ* TDS sample results versus *ex situ* PV sample results

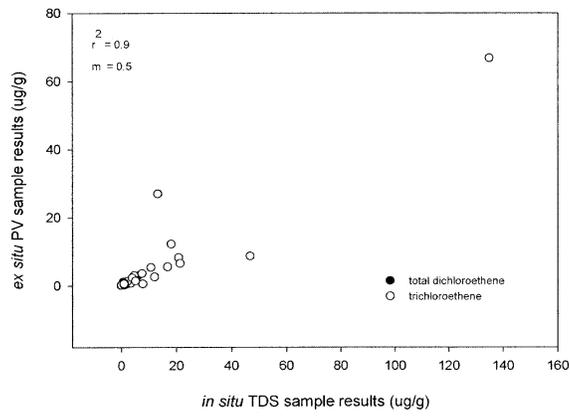


c. *Ex situ* PV samples results versus EPA SW-846 Method 8260B (USEPA 1995) sample results

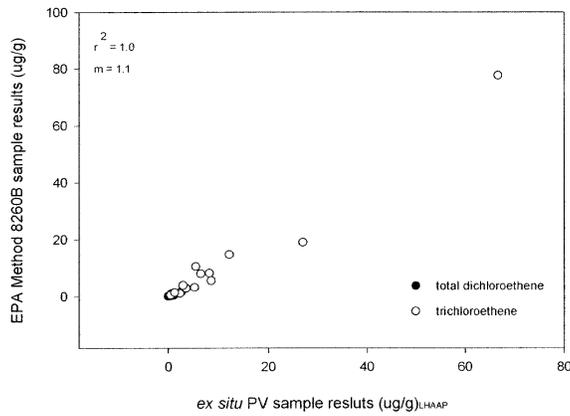
Figure C3. LCAAP data comparisons. Correlation is for all analytes listed in legend



a. *In situ* TDS sample results versus EPA SW-846 Method 8260B (USEPA 1995) sample results



b. *In situ* TDS sample results versus ex situ PV sample results



c. Ex situ PV samples results versus EPA SW-846 Method 8260B (USEPA 1995) sample results

Figure C4. LHAAP data comparisons. Correlation is for all analytes listed in legend

REPORT DOCUMENTATION PAGE

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13. SUPPLEMENTARY NOTES						
14. ABSTRACT Volatile organic compounds (VOCs) are among the most frequently identified contaminants in soil and groundwater samples obtained during investigation of hazardous waste sites. The thermal desorption sampler (TDS), was developed for the Site Characterization and Analysis Penetrometer System (SCAPS) program to provide in situ analysis of VOCs in vadose zone and saturated soils. In operation, the TDS captures an estimated quantity of soil below ground, thermally desorbs the VOCs, and transfers them to the surface where they are analyzed on a field portable ion trap mass spectrometer (ITMS). This analysis is sensitive to the low ppb range for chlorinated solvents and BETX compounds. The TDS was field tested at five geologically distinct sites across the country. Field data were compared to laboratory data (EPA SW-846 Method 8260B (USEPA 1995)) for validation of the technique. Data analysis indicated that the in situ analysis of the primary VOC contaminant at each site demonstrated good correlation with the validation method with a liner regression correlation coefficient between 0.8 and 1.0 and the slope of the regression line between 0.7 and 1.3. Secondary VOC contaminants of lesser concentration demonstrated poorer correlation that could be attributed to the lack of chromatographic separation prior to the ITMS analysis.						
15. SUBJECT TERMS In situ analysis, Ion trap mass spectrometer, SCAPS, Site characterization, TCE, TDS, Thermal desorption, Vinyl chloride, Volatile organic compounds						
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