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Expedited Site Assessment Tools For Underground Storage Tank Sites

A Guide For Regulators

United States Environmental Protection Agency
Office of Underground Storage Tanks, OSWER

March 1997

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Robert Hitzig
Office of Underground Storage Tanks
March 1997

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Introduction

Introduction

The U.S. Environmental Protection Agency's Office of Underground Storage Tanks (OUST) encourages the use of expedited site assessments (ESAs) as a way to streamline the corrective action process, improve data collection, and reduce the overall cost of remediation. The implementation of ESAs is especially important as many owners and operators of underground storage tanks (UST) facilities comply with the December 22, 1998 regulatory deadline for upgrading, replacing, or closing their USTs. As of March 1997, OUST has estimated that of the 1.1 million federally regulated USTs, between 400,000 and 500,000 meet the 1998 regulatory standards. The process of complying with these standards may result in the closure of about 300,000 USTs and the identification of 100,000 additional releases. Each of these sites will require an assessment. Furthermore, of the 317,000 releases confirmed since December 1988, about 64,000 still need to initiate cleanup activities. As a result, at least 360,000 sites are likely to require site assessments in the next few years.

As the first step in the overall corrective action process, the site assessment process is critical to making appropriate corrective action decisions. When site assessments are complete, they provide accurate information about the presence and distribution of contaminants, thereby facilitating cost-effective and efficient remediation. When they are incomplete, they can provide inaccurate or misleading information which can delay effective remediation, increase overall corrective action costs, and, result in an increased risk to human health and the environment. By nature, there are always gaps in the information provided in site assessments. It is, therefore, not always obvious when a site assessment is complete and when the information has been accurately interpreted. As a result, a tremendous amount of data is needed to determine where contaminants are located and how best to remediate them.

Site assessments can also contribute directly to a large percentage of the overall corrective action costs. Sampling equipment, sample analysis, and labor hours may cost between 10 and 50 percent of the total remediation costs at petroleum-contaminated sites. When investigators and regulators have determined that remediation by natural attenuation is appropriate, the site assessment may encompass an even higher percentage of remediation costs.

In many cases, regulators do not directly oversee site assessments and do not select specific site assessment equipment. Regulators do, however, have tremendous influence over the site assessment process in their jurisdictions through their issuance of regulations and guidance and by their acceptance of certain kinds of data for regulatory decisions.

With the emergence of an enormous number of new site assessment tools recently, regulators are often hard pressed to keep current with the latest technologies and maintain their other duties of reviewing site assessments, evaluating corrective action plans, and/or issuing regulations. There is, therefore, a need for a document that evaluates site assessment methods and tools for regulators. This *guide* addresses the overall ESA process as well as specific site assessment tools and methods. Topics include:

- The ESA process;
- Surface geophysical methods;
- Soil-gas surveys;
- Direct push technologies; and
- Field methods for the analysis of petroleum hydrocarbons.

Purpose

The purpose of this *guide* is to provide federal, state, and local regulators with information that will help them to evaluate new as well as conventional site assessment technologies, develop their own guidance documents, and promote the use of ESAs. The *guide* does not advocate the use of one technology over another; rather it focuses on appropriate technology use, taking into consideration site-specific conditions.

The *guide* is designed to enable the reader to answer the following basic questions about expedited site assessments at UST facilities:

- What is an ESA?
- How is an ESA conducted?
- What equipment can be used in an ESA?
- Under what site conditions are specific site assessment tools appropriate?

Scope And Limitation

This *guide* does not represent the issuance of formal policy or in any way affect the interpretation of federal regulations. The text focuses on scientific and practical considerations for evaluating various types of technologies used to assess UST sites. It does not provide instructions on the use of any specific tool and does not supersede or replace equipment manufacturer instructions. Although, this *guide* may be used by state and local agencies in the development of guidance documents, it should not be interpreted as providing guidance on securing permits, health and safety regulations, or state-specific requirements.

The material presented is based on available technical data and information as well as the knowledge and experience of the authors and peer reviewers.

How To Use This Guide

EPA's OUST encourages you to use this *guide* at your desk or in the field as you review, oversee, or manage site assessments. We have designed the *guide* so that you can tailor it to meet your own needs. The three-hole punch format allows you to place the *guide* in a binder with additional material (*e.g.*, state-specific information, guidance documents, journal articles, equipment literature) and remove certain tools (*e.g.*, summary tables) for photocopying. The wide margins were provided to enable you to add your own notes to the text.

In addition to this chapter, the *guide* contains five chapters--each addresses a major consideration necessary for promoting and conducting expedited site assessments.

Chapter II	*The Expedited Site Assessment Process*. This chapter presents an overview of the steps involved in an expedited site assessment, explains how site assessment equipment can be used to expedite the process, and makes comparisons with conventional site assessments.
Chapter III	*Surface Geophysical Methods*. This chapter describes the six surface geophysical methods that are most often appropriate at UST facilities and discusses their effectiveness as compared with other methods.
Chapter IV	*Soil-Gas Surveys*. This chapter provides a comparison of active and passive soil-gas surveying methods and discusses their applicability.
Chapter V	*Direct Push Technologies*. This chapter discusses direct push rod systems, sampling equipment, specialized probes, methods for advancing rods, and methods for sealing direct push holes. Each section explains the applications of all the discribed equipment.
Chapter VI	*Field Methods For The Analysis Of Petroleum Hydrocarbons*. This chapter discusses the eight most appropriate field analytical methods, including the applicability and limitations of each method.

The discussion in each chapter contains illustrations, comparative tables, and references. For the readers convenience, a list of manufactures are presented at the end of relevant chapters. At the end of each chapter are lists of references and peer reviews. At the end of the *guide* are two appendices. Appendix A covers data requirements for corrective action evaluations, and Appendix B is a table of U.S. EPA test methods for petroleum hydrocarbons. The appendices are followed by a list of abbreviations, and a glossary of relevant terms. Throughout this *guide*, discussions of specific equipment are presented in generic terms so as to not advocate any product of any specific manufacturer.

Chapter II

Expedited Site Assessment Process

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Chapter II
Expedited Site Assessment Process

The expedited site assessment (ESA) process is a framework for rapidly characterizing underground storage tank (UST) site conditions for input into corrective action decisions. This framework has been described with other names including accelerated site characterization, rapid site characterization, and expedited site investigation. An ESA is conducted in a single mobilization that typically covers several days and is made up of the following features:

- Field-generated data and on-site interpretation;
- A flexible sampling and analytical program; and
- Senior staff in the field who are authorized to make sampling and analytical decisions.

The ESA process contrasts with conventional site assessments (CSAs) in which a significant amount of analysis and data interpretation is completed off-site at a later date. As a result, CSAs can:

- Take weeks or months to generate a preliminary report;
- Require several phases of investigation; and
- Delay corrective action decisions for months and sometimes years.

ESAs have been made possible in recent years by the development of improved, cost-effective methods for rapid collection and field analysis of soil, soil-gas, and groundwater samples. When appropriate, conventional sampling and analytical methods can also be used in the ESA process. For example, an air rotary drilling rig may be used in consolidated material, or off-site certified laboratory analysis may be used on a limited basis to verify field analytical methods. The ESA process emphasizes the appropriate use of technologies in a way that minimizes the time required for complete characterization and maximizes the data available for making corrective action decisions.

Exhibit II-1 presents a comparison of CSAs and ESAs. The focus for a CSA is usually on installing groundwater monitoring wells that are sited with limited subsurface information. The sampling and analysis plan is typically rigid and defines the number of wells and their location. Most data analysis and synthesis are performed off-site and may take weeks or months to complete. The results of the assessment are usually focused on mapping the boundaries of the groundwater plume rather than the source areas or locating the most significant contaminant mass. In addition, the approach to mapping generally ignores the 3-dimensional nature of contaminant migration. Consequently, the CSA process

Exhibit II-1
Comparison Of Conventional And Expedited Site Assessments

Process Component	Conventional Site Assessments	Expedited Site Assessments
Number of phases of investigation	Multiple	Single
Field management	Manager typically in office; junior staff in field.	Manager in field with experienced staff.
Technical strategy	Focus on plan view map; sampling location based on limited information. Sampling locations are pre-determined.	Use of multiple, complementary technologies; sampling locations depend on existing data; minimal well installation; locating most significant contaminant mass in 3-dimensions.
Work plan	Rigid plan	Flexible plan
Data analysis	Interpretation of data is weeks or months later.	Regular (hourly/daily) interpretation of data.
Innovative technologies (*i.e.*, direct push and field analytical methods)	May or may not be used; not integrated into process.	Standard practice, allows on-site iterative process.

Source: Modified from Burton, 1995

tends to be time consuming, the total costs tend to be relatively high, and the site conditions reported are often incomplete or incorrect.

In contrast, the ESA process uses senior scientists as field managers to conduct the entire assessment. Both types of assessments evaluate existing data to develop an initial conceptual model of site conditions, however, with ESAs the sampling and analysis plan is dynamic. As new site information is generated, it is used to direct the assessment. The field-generated data are used to update and refine the conceptual model as the assessment proceeds. In this way, data gaps are filled, and anomalies are resolved, prior to demobilization. The ESA is complete when the data being obtained and the 3-dimensional characterization of the site are in agreement.

In recent years, Risk-Based Corrective Action (RBCA) has been recognized by regulators and industry as a valid approach to dealing with the enormous number of petroleum-contaminated sites. RBCA is a process that utilizes risk and exposure assessment methodology to help UST implementing agencies make determinations about the extent and urgency of corrective action and about the scope and intensity of their oversight of corrective action by UST owners and operators (EPA, 1995). The American Society for Testing and Materials (ASTM) RBCA standard (ASTM, 1995b) describes a three-tiered approach to site evaluations in which each tier requires more extensive site-specific data.

ESAs can be integrated with RBCA evaluations because the ESA process is a method of obtaining accurate site information that is necessary for making an appropriate corrective action decision. The first two RBCA tiers can be evaluated in a single mobilization as part of a standard ESA, provided the investigator has the cooperation of the appropriate regulatory agency. The data needs for a Tier 3 evaluation can also be acquired in the same mobilization; however, because of the complexity and cost of the data needed for this level of evaluation, investigators must be prepared for this tier level prior to mobilization and there should be a method for rapidly acquiring authorization from the implementating agency. A list of the data requirements for corrective action evaluations is provided in Appendix A which is located at the end of the manual. This information can be collected during an ESA and used in the RBCA process.

This chapter is divided into two major sections. The first section walks the reader through the steps in the ESA process and discusses how this process compares with conventional site assessments. The second section presents an example of an actual ESA and compares it with a CSA that occurred at the same site. This section illustrates how innovative data collection techniques and field analysis methods can be used with the ESA process to complete a site assessment quickly, while providing enough information to make remediation decisions. The ESA process described in this chapter and referenced throughout the manual is based on the provisional Accelerated Site Characterization standard by ASTM (ASTM, 1995c) and State of Texas guidance (TNRCC, 1995).

The flowchart in Exhibit II-2 depicts the ESA process in seven steps. While many of the steps are similar to those in a CSA, the activities within the highlighted box labeled "Implement On-Site Iterative Process" are unique to an ESA. These activities include:

- Collect and analyze field data;
- Refine the conceptual model as new data are produced; and
- Modify the sampling and analysis program when necessary.

In an ESA, a field manager is responsible for this entire process. Information about regional and site-specific geology/hydrogeology as well as knowledge of petroleum fate and transport are necessary for making and revising sampling and analysis decisions on-site. An ESA field manager must, therefore, have extensive site assessment experience and knowledge about all aspects of the ESA.

Step 1: Establish Site Assessment Objectives

The general objectives for any site assessment are to understand the:

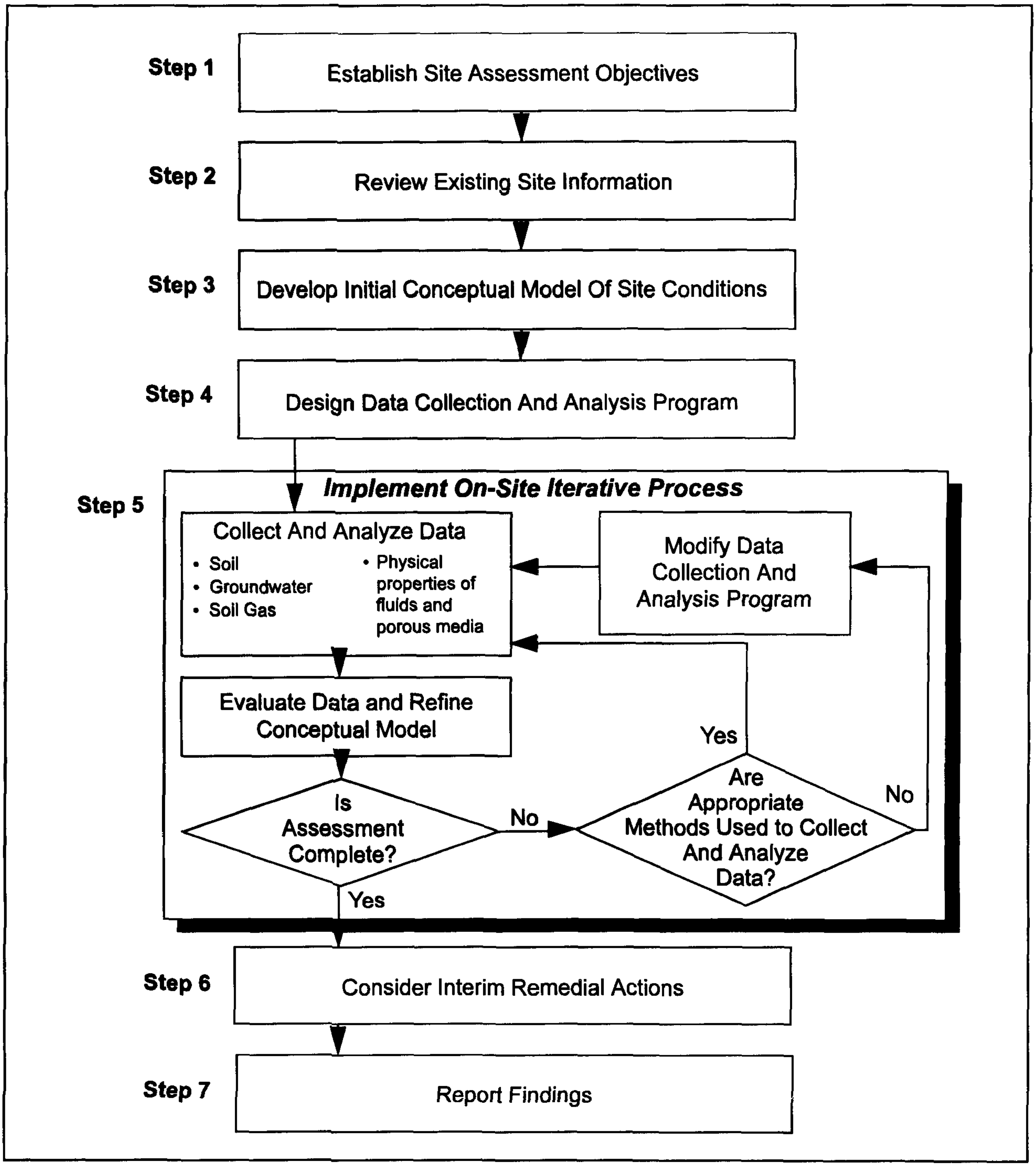
- Geology/hydrogeology of the site;
- Nature and extent of contamination; and
- Migration pathways and points of exposure.

The site-specific objectives may be to determine the existence of contamination, investigate suspected contamination, or evaluate known contamination. The objectives selected will dictate the priority of the type of samples to be collected and analyzed. For example, an ESA for an initial response action will focus on defining immediate hazards, while an assessment for a specific corrective action technology will focus on the parameters that affect the system design and performance.

Step 2: Review Existing Site Information

Both CSAs and ESAs require a review of existing site information before mobilization. However, existing site information is especially important in an

Exhibit II-2
Expedited Site Assessment Process



Source: Modified from ASTM, 1995c.

ESA because this information is required for the selection of sampling equipment, analytical methods, and strategies for the initial round of sampling. A list of potential sources of historical site information is provided in Exhibit II-3. The review of existing information should include past and current land use, potential sources of contamination, potential migration pathways and receptors, and likely geologic and hydrogeologic conditions. If the investigation includes a RBCA evaluation, potential future land uses would generally also be investigated.

Step 3: Develop Initial Conceptual Model Of Site Conditions

Based on existing site information, a field manager develops an initial conceptual model before any field work is begun. This model is a basic compilation of the field manager's understanding of existing conditions. A site map is used for developing the initial sampling and analysis program. An example of an initial conceptual model represented on plan view maps and a cross-section are provided in Exhibit II-4 on page II-15. The graphics can be drawn by hand or generated on a computer to be revised as the assessment progresses. On these maps, the field manager should include suspected geologic and hydrogeologic conditions; suspected contaminant source areas; and potential migration pathways, receptors, and sampling constraints (*e.g.*, utilities, depth to bedrock).

Step 4: Design Data Collection And Analysis Program

Prior to mobilization, the field manager makes use of the conceptual model to design a data collection and analysis program. This program, which is also referred to as the work plan, should be flexible so that the field manager can adjust the location, quantity, depth, and type of samples based on the developing conceptual model.

The data collection and analysis program is a general work plan which may be informally written or simply discussed by the field manager with the appropriate individuals, such as regulators or the responsible party. For example, the plan may seek to identify appropriate sampling tools and analytical methods, define the contaminant source area, and assess the property boundaries for potential off-site or on-site migration. The field manager may need to make minor adjustments in the program and the scope of work, within a specified funding level. The need for changes in the program is clarified as the understanding of the site conditions evolves.

Exhibit II-3
Sources And Types Of Site History Information

Sources	**Records/Documents**	**Types Of Available Information**
Owner/ operator records	Inventory records, deeds, detailed site maps, spill and release incident reports, historic photographs, and environmental consulting reports	Details regarding the storage, use, accidental release, and disposal of petroleum products in USTs, site features
Municipal and/or county offices	Records at the following departments: Tax assessor, fire, public works, building, utility, sewer, sanitation, and public health	Information on current and past owners, site history, UST permits, maps of drainage features, and investigation and incident reports
State government	State environmental agency; regional water quality board; health department; and fire marshal	Information on active and inactive UST sites, enforcement documents, and reports on LUSTs
Federal government	U.S. EPA	Site investigation and incident reports, UST and RCRA records
	U.S. Geological Survey	Topographic and geologic maps, geologic/hydrogeologic reports, aerial photographs
	Natural Resources Conservation Service (NRCS) and Agricultural Stabilization and Conservation Service (ASCS)	Aerial photographs and detailed information about soil properties available locally
Universities, libraries	Theses, archives, and historical information	Information on-site development, land use, site activities, geology, and hydrogeology
Key personnel (*e.g.*, owner, employees)	Interviews	Information regarding all aspects of site history, especially spills, overfills, and leaks
Miscellaneous	Aerial photographs: Listings of available public and private aerial photographs for given locations and periods are available from the National Cartographic Information Center in Reston, Virginia	Information regarding site development, land use, manufacturing activities, pipeline and UST locations
	Fire insurance maps dating back to the 1800s which depict the location of manufacturing facilities and potential fire hazards (*e.g.*, USTs) locations are available for all regions of the U.S. from the Sanborn Map Company in Pelham, New York	Information regarding site development, land use, waste disposal locations, manufacturing activities, UST locations

Source: Modified from Cohen and Mercer, 1993

In some instances, the first data are collected with surface geophysical measurements. Depending on the site conditions, surface geophysical methods may be able to provide initial information about the location of buried objects, the geologic and hydrogeologic conditions, and the location of floating and residual product. This information will influence the selection of sampling tools, sampling locations, and the analytical program. The applicability of surface geophysical methods, such as ground penetrating radar, electromagnetics, and magnetometry, is discussed in Chapter III of this manual.

Soil-gas surveys are also a useful method for obtaining a large amount of site data quickly. They can play a role in ESAs by providing information on the presence, type, and general location of contamination which can help focus more precise sampling activities. Moreover, at some sites the health risk posed by the upward migration of hydrocarbon vapors through the vadose zone is greater than the risk posed by groundwater contamination. Vapor-phase pathways of contaminant migration are especially important where there are thick unsaturated zones and subsurface structures (*e.g.*, basements, parking garages). Information obtained in these surveys can also help in the design of remediation technologies such as soil vapor extraction. A complete discussion of the types of soil-gas surveys and their applicability to UST sites is presented in Chapter IV.

For all site assessments, at least one type of media--soil, soil gas, or groundwater--must be sampled. Selection of the appropriate sampling tools depends primarily on site conditions, sample depth, local geology, availability, and cost. Direct push (DP) tools (steel rods that are pushed or driven into the ground) can be used in unconsolidated materials to collect these samples or to take *in situ* measurements using specialized DP probes. At other locations, an air rotary or hollow stem auger (HSA) drilling rig may be required. A complete discussion of DP applicability and associated sampling equipment appears in Chapter V.

As mentioned earlier, an ESA requires the use of field analysis. Selection of the appropriate method(s) for a particular site will depend on a variety of factors including the analyte to be measured, the quality of the data, the ease of its use, as well as cost, availability, and the speed with which it provides the data. Typically, an ESA utilizes several analytical methods of varying quality on a large number of samples in order to increase resolution of the contaminant plume. Examples of commonly used methods include immunoassay test kits, colorimetric test kits, and portable gas chromatographs (GC). These methods and selection criteria are discussed in Chapter VI.

Acquiring access to properties neighboring a leaking underground storage tank (LUST) site is an issue of concern in many site assessments, whether expedited or conventional. Often, property owners will deny access to site investigators, and legal methods must be pursued in order to collect soil, soil-gas, and/or groundwater samples. When conducting an ESA, it is best to acquire permission to sample neighboring properties, and any necessary permits, prior to mobilization. Although, acquiring access prior to mobilization may not always be possible, ESAs will continue to have at least two advantages over CSAs. First, it is often easier to convince a property owner to allow investigators to collect samples over a short period of time (*i.e.*, hours or days) as opposed to allowing access for several mobilizations over a period of weeks or months. Second, by conducting an ESA, investigators will know within days whether they will require off-site access. When conducting a CSA, this information may not be known until much later.

Step 5: Implement On-Site Iterative Process

The on-site iterative process depicted as Step 5 in Exhibit II-2 is unique to ESAs. As more data are obtained, the field manager refines the conceptual model. Although CSAs contain iterative processes, it is the ESA process that requires this work to be completed on-site during a single mobilization. The on-site iterative process is made up of two substeps: Collecting and analyzing the data, and evaluating the data to refine the conceptual model. If, during the course of the investigation, the field manager discovers that the sampling tools and/or analytical methods are inappropriate for the site conditions, he/she can amend the data collection and analysis program. Several iterations of this process can be completed in a day and, when this method is applied with the appropriate tools, a typical gasoline station site can usually be completely assessed in two to four days.

Substep 1: Collect And Analyze Data

The data collection and analysis program is an intensive, short-term, field investigation. The program and conceptual model are refined based on on-site measurements and observations. In order to ensure that these measurements are accurate, the field manager checks the field-generated data, usually by developing a quality control (QC) plan for the methods used. Examples of QC include instrument calibration, blank results, and control samples. In addition, field managers should check data by comparing results from different analytical methods (*e.g.*, field GC with immunoassay test kit) or by comparing results from other media. The validation process is important for the development of the conceptual model because it helps to resolve anomalous data.

Substep 2: Evaluate Data And Refine Conceptual Model

A key aspect of an ESA is the regular evaluation and refinement of the conceptual model. As the initial sample collection and analysis is conducted, certain conditions are anticipated based on the initial conceptual model. These conditions may include the concentrations and locations of contaminants, soil type, or depth to groundwater. As measurements are taken, variances become apparent between anticipated conditions and actual measurements. The conceptual model is then refined to include the current measurements and minimize the variances.

Modify The Data Collection And Analysis Program

If, after refining the conceptual model, the field manager determines that the methods used to collect and analyze data are not appropriate, then he/she must modify the collection and analysis program. Modification may involve selecting different sample collection technologies or different analytical methods. For example, a DP rig may be unable to penetrate semi-consolidated material located on the site and a HSA rig may be needed, or a contaminant that was not expected (*e.g.*, a solvent) may be discovered, necessitating the use of new field analytical methods. Because all the analysis is completed on site in an ESA, timely modification of procedures is possible. Various analytical methods should, therefore, be readily available so that procedures can be quickly changed if necessary.

Complete Expedited Site Assessment

An ESA is complete when the conceptual model:

- Fits the regional geological/hydrogeological setting;
- Is consistent with data collected; and
- Can be used to predict subsurface conditions.

Sometimes a technical reviewer who has not been part of the field team can provide an objective evaluation of how well the conceptual model correlates with the site data.

Step 6: Consider Interim Remedial Actions

One of the major advantages of an ESA is that it makes rapid and accurate interim remedial actions possible. These actions should follow state guidance (*e.g.*, preapproval may be required), however, many times remedial measures can take place immediately after the field work of an ESA is completed and before a formal report is submitted. For instance, an ESA may define the location of a significant quantity of free product or it may indicate that a contaminant plume is approaching a public drinking well. Because a formal report may take two weeks to write and review of the report may take longer, an interim remedial action can prevent a significant quantity of contaminants from spreading. If appropriate actions are undertaken in a timely manner, potential adverse affects to human health and the environment can be avoided, and the long-term cost of remediation can be minimized.

Step 7: Report The Findings

As with any site assessment, a report is written when the field work is completed. Because a greater quantity of data will be collected with a ESA than is possible with a CSA, an ESA should provide a more comprehensive representation of the site conditions. An ESA report will demonstrate an understanding of the 3-dimensional distribution of contamination, define the geological/hydrogeological site conditions, and identify migration pathways and points of exposure. As a result, ESAs provide a better basis for selection of appropriate corrective action options in significantly less time than is required with CSAs.

Conventional And Expedited Site Assessment Examples

The following is an example of how a well planned CSA and an ESA would proceed at the same site. The scenario is based on two actual assessments at one site, however, the details have been modified in order to provide the reader with a comparison. The CSA focused on installing a limited number of groundwater monitoring wells as part of a multiple-phase assessment. The ESA focused on a 3-dimensional definition of site conditions to develop and refine the conceptual model.

Release Scenario

In 1995 an UST system was being replaced at a service station in order to meet the 1998 tank upgrade requirements. The system consisted of two 10,000-gallon steel tanks and piping that had been installed in 1965. When they were removed, both tanks and their associated piping showed signs of significant corrosion, and the soils were stained with gasoline. The pit and the piping trench were over-excavated to remove some contamination, but stained soils remained. The release was reported to the state environmental department (SED), which then ordered that a site assessment be conducted.

Step 1: Establish Site Assessment Objectives (ESA And CSA)

The objectives for this assessment are the same for both an ESA and a CSA: Define the source area, characterize the site geology/hydrogeology, and delineate the extent of contamination in soil and groundwater. In addition, the major migration pathways and points of exposure also need to be determined in order for the state and the owner to make corrective action decisions.

Step 2: Review Existing Site Information (ESA And CSA)

In both the ESA and the CSA for this site, a review of background information was completed, however, the focus differed. In the CSA, information was reviewed in order to select the best location of three monitoring wells. In the ESA, the background information was reviewed in order to develop a 3-dimensional conceptual model of site conditions which were then plotted on maps and used to guide the investigation.

Site Interviews

The current owner stated that he bought the facility in 1984 and did not have any information about the use of the site prior to 1965. He knew that the tanks and piping were in need of upgrading but had no indication that they were leaking. Five tank and line tightness tests had been performed between 1988 and 1994, and none indicated a problem. The owner was not aware of any noticeable inventory losses. He was also not able to locate any site plans that would indicate migration pathways.

Employees stated that they did not notice any obvious inventory losses. However, after the tank and piping were removed, the employees did notice significant corrosion on the north side of the tank and on some of the pipes. The employees also stated that all product lines were removed.

Site Geology

Since two 10,000-gallon tanks had just been excavated, the geologist had a clear view of the site stratigraphy. The excavation was 20 feet deep, 30 feet long, and 25 feet wide. The soil was composed of silt and clay, and it appeared to have a low hydraulic conductivity. The pit did not intercept groundwater.

Inventory Records Search

Inventory records were analyzed but did not prove helpful because of incomplete and inconsistent information.

Receptor Survey

A survey of potential downgradient receptors indicated no wells within 0.5 mile, but several industrial buildings with basements were located nearby.

Other Environmental Investigations

The site assessment personnel reviewed state corrective action reports for possible upgradient sources and for regional geological information. They found a report from a LUST site 0.5 mile upgradient. In reviewing the report, the site assessment personnel noted that buried stream channels existed in the region.

Geologic Reports

Site assessment personnel reviewed USGS maps and reports, State Geologic Survey, Soil Conservation Service, and the local Water Service and found:

- Regional depth to groundwater is 20 to 30 feet below ground surface (bgs);
- Regional groundwater flow is to the north;
- Silts and clays are the predominant regional soil type; and
- Buried stream channels occur within the silts and clays and have a northwest regional orientation.

Step 3: Develop Initial Conceptual Model Of Site Conditions (ESA And CSA)

Based on the review of existing regional and site data, investigators developed an initial conceptual model of the site geology, hydrogeology, nature and extent of contamination, contaminant migration pathways, and points of exposure. This initial conceptual model is presented in Exhibit II-4. For the CSA, site assessment personnel used this information to locate monitoring wells, to determine the approximate depth to be drilled, and to analyze data when available. For the ESA, the field manager incorporated the information onto site maps in the field as the assessment proceeded. These maps served as a basis for the working hypothesis of the site geology, hydrogeology, and extent of contamination. Sample locations were selected to test these hypotheses and resolve anomalies while on site.

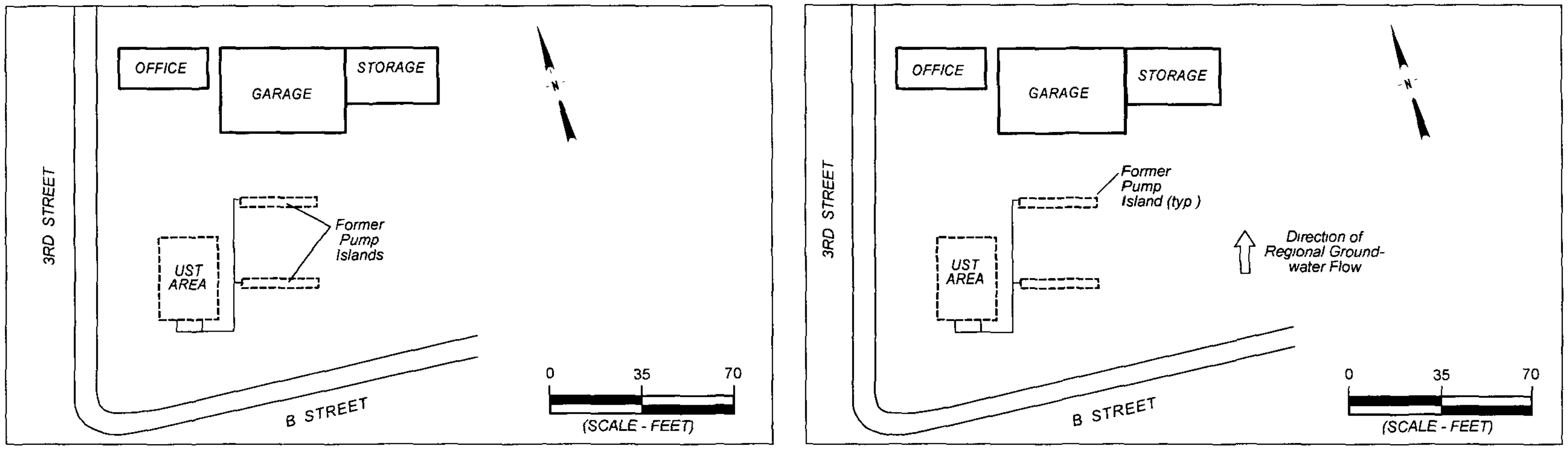
Geology

Regional fluvial deposits are oriented NW. Sands in these units are typically 2 to 15 feet thick and are surrounded by silt and clay. Granitic bedrock occurs at a depth of approximately 500 feet bgs.

Hydrogeology

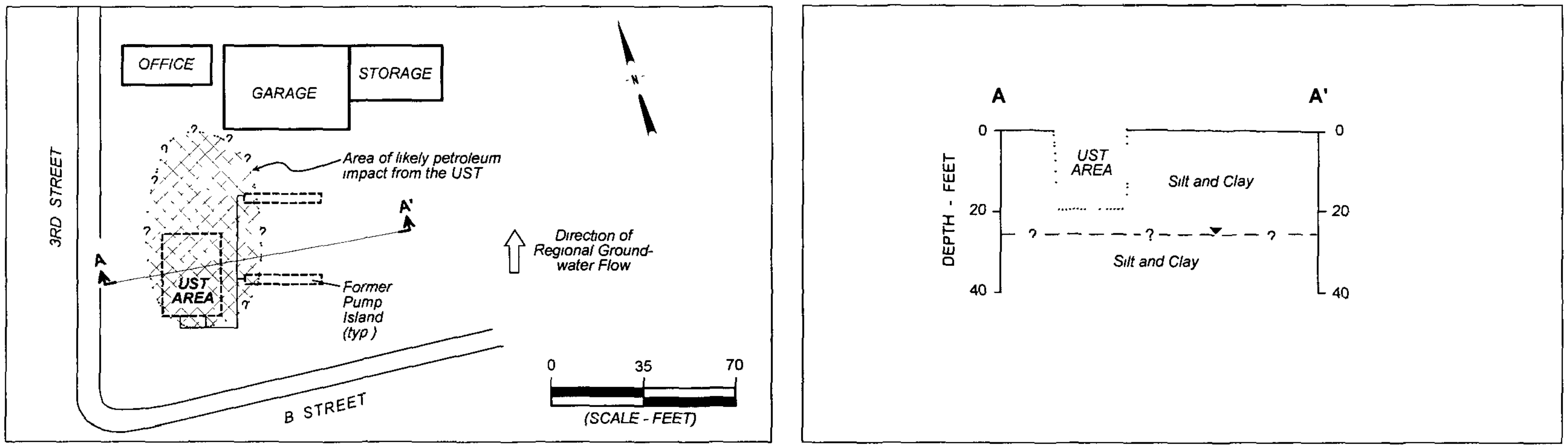
Unconfined groundwater occurs regionally within the unconsolidated sediments at depths ranging from 20 to 30 feet bgs. Regional groundwater flows

Exhibit II-4
Initial Conceptual Model (Both CSA and ESA)



a SITE PLAN

b. REGIONAL GROUNDWATER FLOW DIRECTION



c. AREA OF LIKELY PETROLEUM IMPACT FROM THE UST

d. CROSS SECTION A-A'

to the north, however, localized groundwater flow patterns occur through more permeable buried stream channels.

Source Area And Extent Of Contamination

Locations of the tanks, subsurface piping, on-site utility lines, and areas of artificial fill were compiled onto the site map. The relative magnitude of the petroleum release was estimated to be small (perhaps 300 gallons) because no significant loss of product was noticed, and field observations indicated a slow leak. The extent of contamination was believed to be contained on-site if the plume had not reached a buried stream channel. If a preferential pathway had been intercepted by the plume, contamination may have migrated off-site.

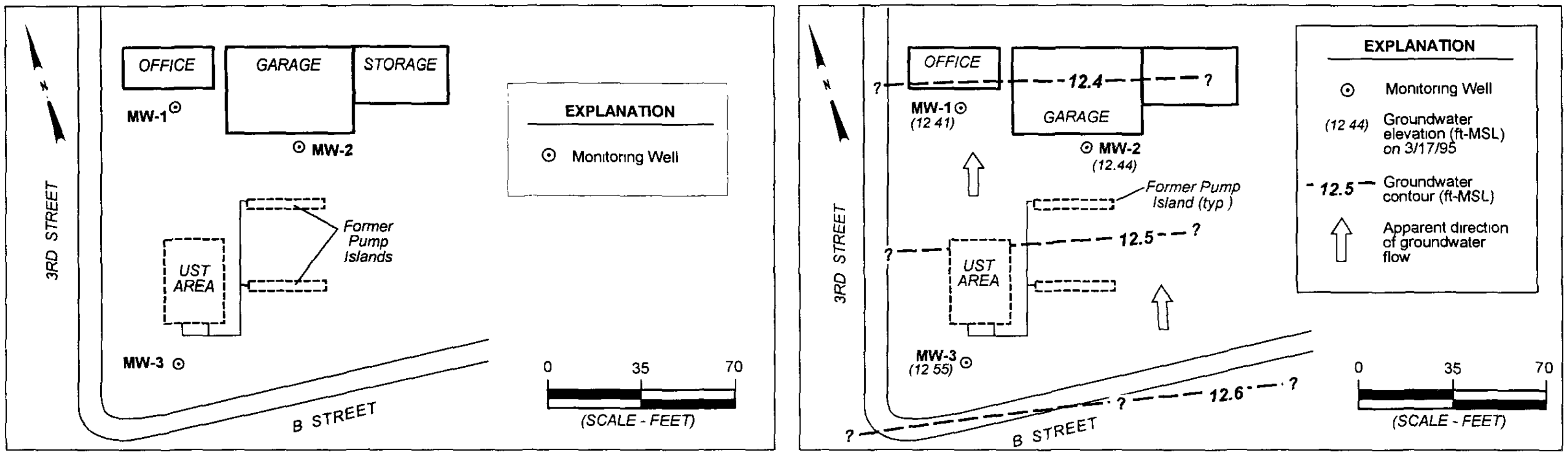
Step 4: Design Data Collection And Analysis Program (CSA)

Before beginning the field investigation, the site assessment managers must develop a data collection and analysis program for the field work. This program is also referred to as the initial work plan. From this point, the two site assessments begin to differ. The remainder of the CSA is presented first. The results are compared with the summary of the ESA that follows.

Conventional Site Assessment Work Plan

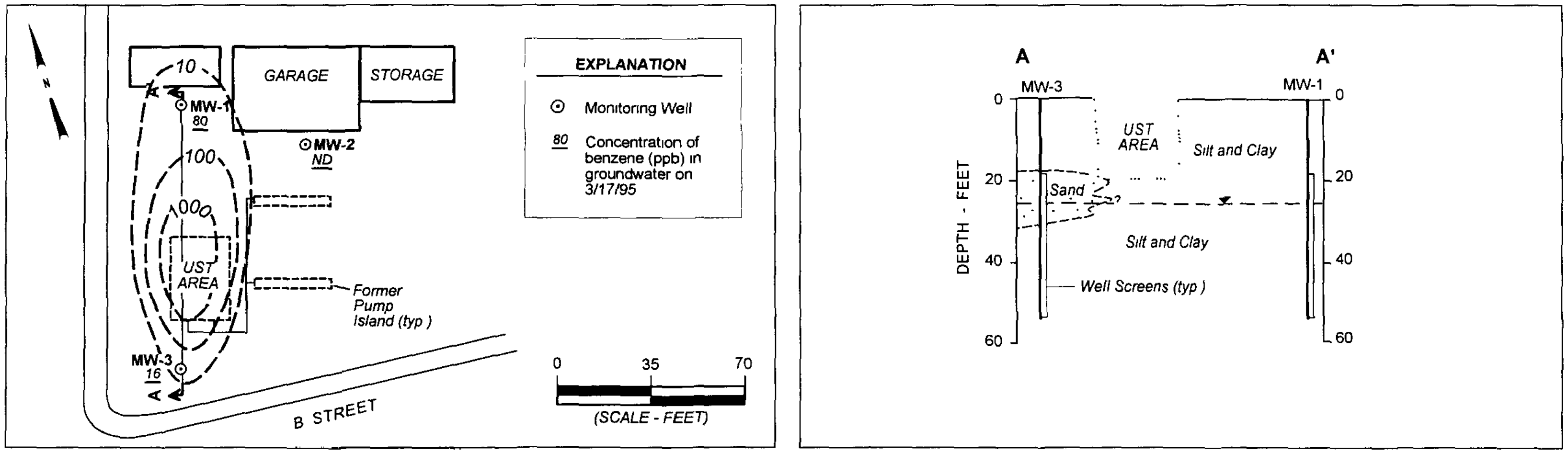
A hollow stem auger (HSA) drill rig was selected to collect soil samples and install 4-inch monitoring wells. Two wells would be installed downgradient from the USTs and pump islands, and a third would be installed upgradient from the tank excavation. Because the direction of regional groundwater flow is to the north, the wells would be placed in the locations designated on the map in Exhibit II-5a. A split-spoon sampler would be used to collect soil every 5 feet and, if screening analysis with a portable flame ionization detector (FID) indicated contamination, samples would be sent off-site for laboratory analysis. If no contamination was indicated through FID screening, a soil sample close to the water table would be sent to a laboratory. All soil samples would be logged with information about the vadose zone (*e.g.*, thickness, soil type, porosity, structure, stratigraphy, heterogeneities, moisture content, and location of contaminants). Groundwater samples from the three wells would also be analyzed off-site. Soil samples would be analyzed for both BTEX and TPH, while groundwater samples would be analyzed for BTEX.

Exhibit II-5
Final CSA Conceptual Model (First Phase)



a. SITE PLAN

b. GROUNDWATER CONTOURS



c. ISOCONCENTRATION CONTOURS - BENZENE IN GROUNDWATER (ppb)

d. CROSS SECTION A-A'

Step 5: Field Work (CSA)

During days one and two, the three monitoring wells (MW) were installed. Soil profiles from the two downgradient monitoring wells indicated only silt and clay sediments. The soil profile from the upgradient monitoring well (MW-3) indicated 10 feet of sand starting at 20 feet bgs. No soil contamination was detected at any of the locations; therefore, only three soil samples (one from each boring) were collected and sent off-site for further analysis.

On the third day, the geologist returned with an assistant to develop the wells. On the fourth day the groundwater level in MW-3 had fully recovered (because it was screened in sand) and was sampled. The two downgradient wells screened in silt and clay took a week to recover. All wells were then sampled, including MW-3 for a second time. The geologist received the laboratory analytical results four weeks after samples were collected (standard turnaround time) and then spent another week preparing a report for the SED and facility owner.

Step 6: Consider Interim Remedial Actions (CSA)

Prior to the assessment, the SED requested that the tank pit and piping trenches be over-excavated in order to remove contaminants from the source area. Because so little information was obtained from the CSA, the site assessment manager could not recommend additional interim remedial actions.

Step 7: Report The Findings (CSA)

The geologist submitted the report eight weeks after the assessment was requested. The maps in Exhibit II-5 show the findings. The major conclusions of the report are as follows:

- Groundwater depth is 26 feet bgs, and the flow appears to be north.
- The extent and quantity of contamination at this site is unknown.
- Additional investigation is needed in neighboring properties to better delineate the contaminant plume.
- The extent of the sand lens penetrated by MW-3 should be further investigated.

Step 4: Design Data Collection and Analysis Program (ESA)

The ESA used a very different process from the CSA; as a result, the findings of the ESA were more complete. The scope of work of the ESA included the following equipment and activities.

Direct Push Sampling

The field manager selected a DP rig for sampling of soil and groundwater because the subsurface materials were unconsolidated and the depth of investigation was relatively shallow. A cased system (Chapter V, Direct Push Technologies) was selected because of its capability to quickly collect continuous core samples. In unconsolidated material, this equipment can generate up to 200 feet of continuous cores per day.

Field Analysis

After obtaining permission from the state environmental department, the field manager contracted the services of a certified mobile laboratory to perform the analytical testing using state approved methods. Soil samples would be analyzed for both BTEX (by the mobile laboratory using EPA Method 8021 (GC/PID)) and total petroleum hydrocarbons as gasoline (TPH-g) (using Modified EPA Method 8015 (GC/FID)), while groundwater samples would be analyzed for BTEX only. The mobile laboratory selected could process up to 25 samples/day.

Soil Screening

All soil samples would be screened in the field for total organic volatiles (TOVs) via ambient air measurements using an FID. An FID was used because of its high sensitivity to gasoline vapors (0.1 ppm_v). Soil samples would be analyzed by the mobile laboratory either whenever soil screening indicated contamination or just above the water table if soil screening did not indicate contamination.

Groundwater Sampling

Groundwater samples would be collected and analyzed by the mobile laboratory at every probe location. Between six and eight temporary monitoring points would also be installed with DP equipment in order to determine hydraulic gradient and obtain groundwater samples over time.

Physical Properties

Continuous cores would be collected at each probe location. Every core would be logged and recorded by a geologist. Logs would include the vadose zone thickness; soil type and estimate of porosity; structure; stratigraphy; heterogeneities; moisture content; and location of constituents of concern. In addition, soil samples would be collected for off-site analysis of total organic carbon (TOC), bulk density, and moisture content to make more accurate estimates of contaminant migration potential. The aquifer flow direction and gradient would be determined from water level measurements, and hydraulic conductivity would be determined from slug tests conducted with 1.5 inch temporary monitoring points. Groundwater quality indicators (*e.g.*, pH, total dissolved solids, electrical conductivity) would be measured using portable meters. Dissolved oxygen would also be measured, using a flow-through cell, to provide information about biodegradation of petroleum compounds. Groundwater samples would also be sent to an off-site laboratory for analysis of biodegradation indicators (NO_3, SO_4, Fe, Mn^{2+}, CH_4, and CO_2). These parameters would help evaluate the potential for contaminant migration and biodegradation.

Communicating Project Status

The field manager agreed to update the owner and SED with the status of the ESA at the end of each field day. The field manager had a pager and portable telephone to communicate with all project participants whenever necessary.

Permits

The field manager obtained the necessary permits for drilling borings with DP probes and installing monitoring points. The field manager also obtained an encroachment permit from the city and filed a traffic plan with the county public works department in order to collect samples off-site under 3rd Street and B Street, if necessary.

Utility Clearance

Delineating the location of on-site utilities had already been completed for the tank excavation, however, the field manager suspected that a few off-site samples would be needed. A utility service was contacted and returned to the site to delineate the surrounding off-site utilities. This activity was supervised by the field manager so that the areas to be sampled would be well marked.

Step 5: *Implement On-Site Iterative Process (ESA)*

The field investigation was completed in 3 days by using the iterative process depicted in Exhibit II-2. Soil and groundwater samples were collected and analyzed; the conceptual model was refined on-site; and subsequent sampling and analysis helped to finalize the assessment.

Day 1: Conduct Initial Investigation

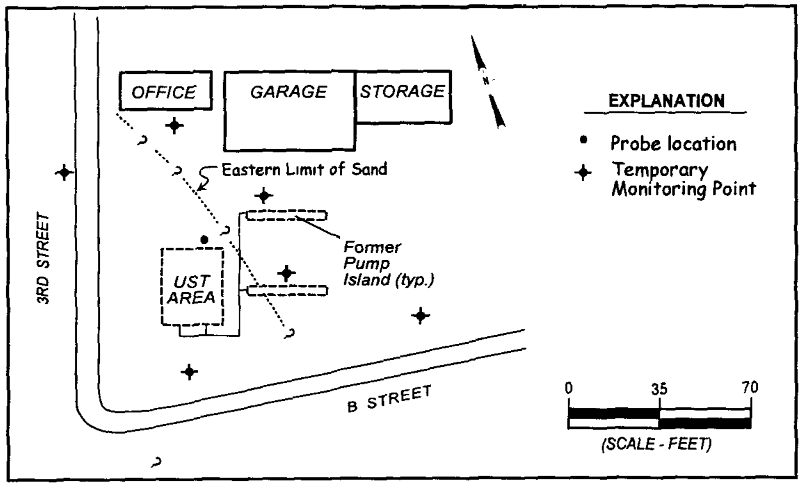
On the first day of the field investigation, the following activities were conducted:

- Continuous soil cores were collected and logged at seven locations to a depth of 20 to 40 feet.
- Six 1.5-inch-diameter temporary monitoring points were installed to measure the groundwater elevation and to define groundwater flow direction.
- Twenty soil samples were analyzed for BTEX and TPH by the mobile laboratory.
- Seven groundwater samples were collected and analyzed for BTEX by the mobile laboratory.
- Three soil samples were collected and preserved for off-site analysis of total organic carbon (TOC), bulk density, and moisture content to evaluate the potential for contaminant migration.
- Two groundwater samples were collected and preserved for off-site analysis of water quality to evaluate *in situ* biodegradation of contaminants. Dissolved oxygen was measured in the field.

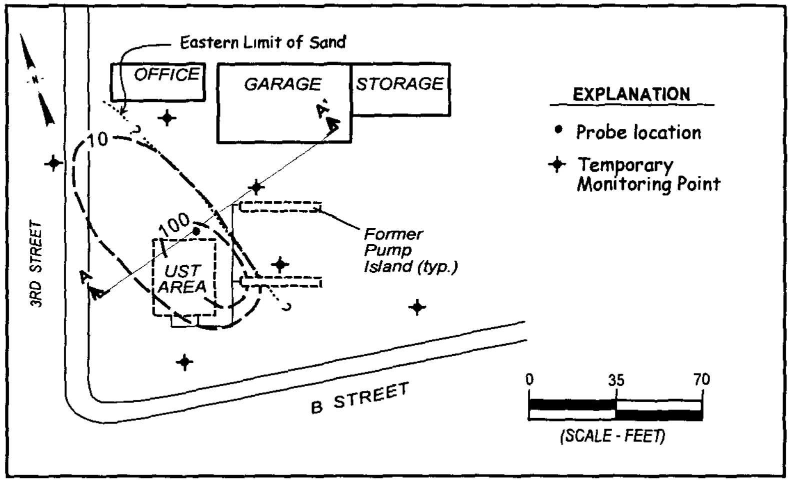
Information obtained on Day 1 was compiled on field drawings shown in Exhibit II-6. The key findings included the following:

- The UST area was the major source of contamination. Soil below the tanks was contaminated with gasoline, and an inch of free product was discovered above the water table.

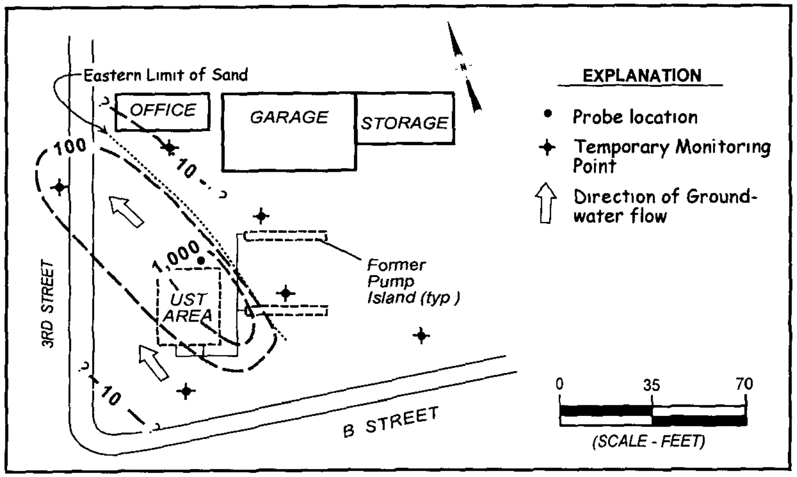
Exhibit II-6
ESA Conceptual Model After Day 1



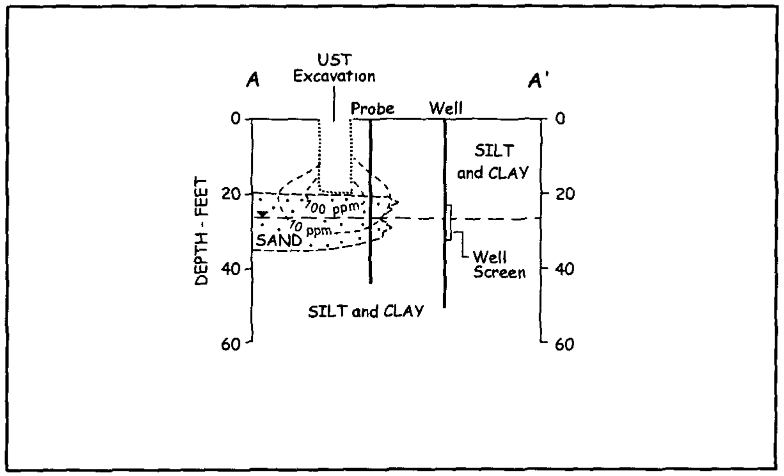
a. SITE PLAN



b. BTEX IN SOIL @ 20' (ppm)



c. ISOCONCENTRATION CONTOURS - BENZENE IN GROUNDWATER (ppb)



d. CROSS SECTION A-A' WITH BTEX IN SOIL

- Although there was significant contamination around the dispensers and piping, petroleum had not migrated to the water table in this area because of the low hydraulic conductivity of the surrounding soils.

- A buried stream channel was defined at depths between 20 and 33 feet bgs in four locations.

- Isoconcentration contours of benzene in the groundwater samples clearly indicated a northwest orientation and probable migration of dissolved contaminants within the sand unit.

Indications of a possible off-site source were also discovered. Benzene concentrations in groundwater upgradient from the former UST area were anomalously high, and the chromatograms indicated a higher ratio of toluene to benzene than from the sample downgradient from the UST area.

Days 2 And 3: Refine Conceptual Model

Characterization of the site continued on Days 2 and 3 to refine the conceptual model. The information was compiled on-site maps presented in Exhibit II-7. By the end of Day 3:

- Seventeen additional continuous core samples were collected.

- Two additional temporary monitoring points were installed.

- Fourteen groundwater samples were analyzed by the mobile laboratory.

- Twenty-five soil samples were analyzed by the mobile laboratory.

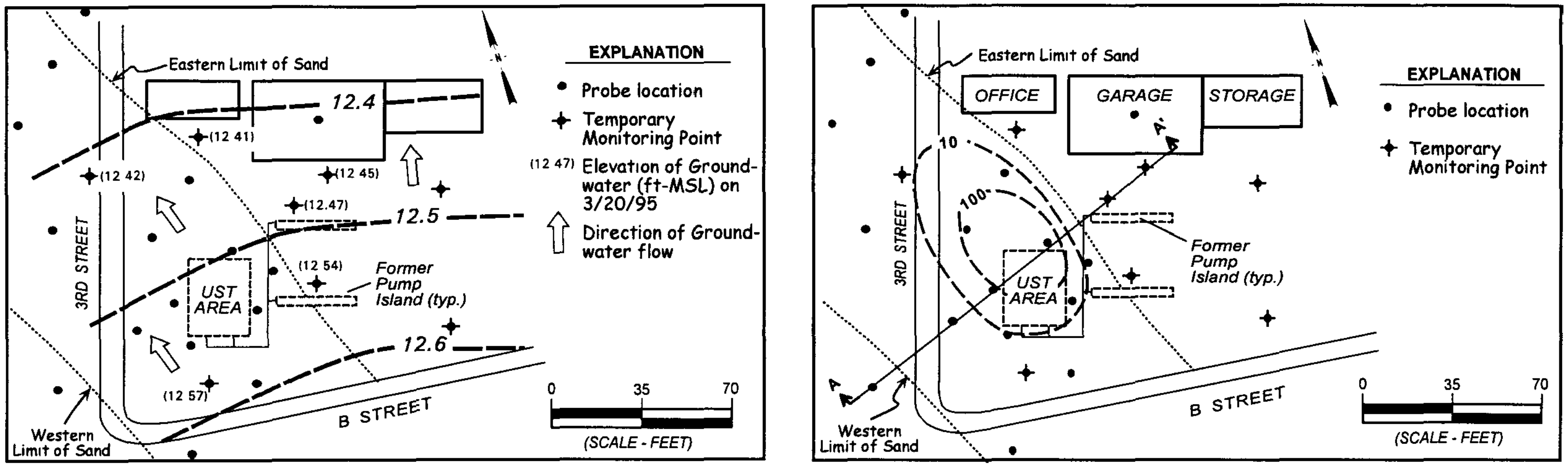
By the end of Day 3, the following information was determined:

- The eastern and western limits of the buried stream channel were defined.

- The eastern and northern portions of the site were shown to be underlain entirely by silt and clay. Groundwater was not contaminated in these locations.

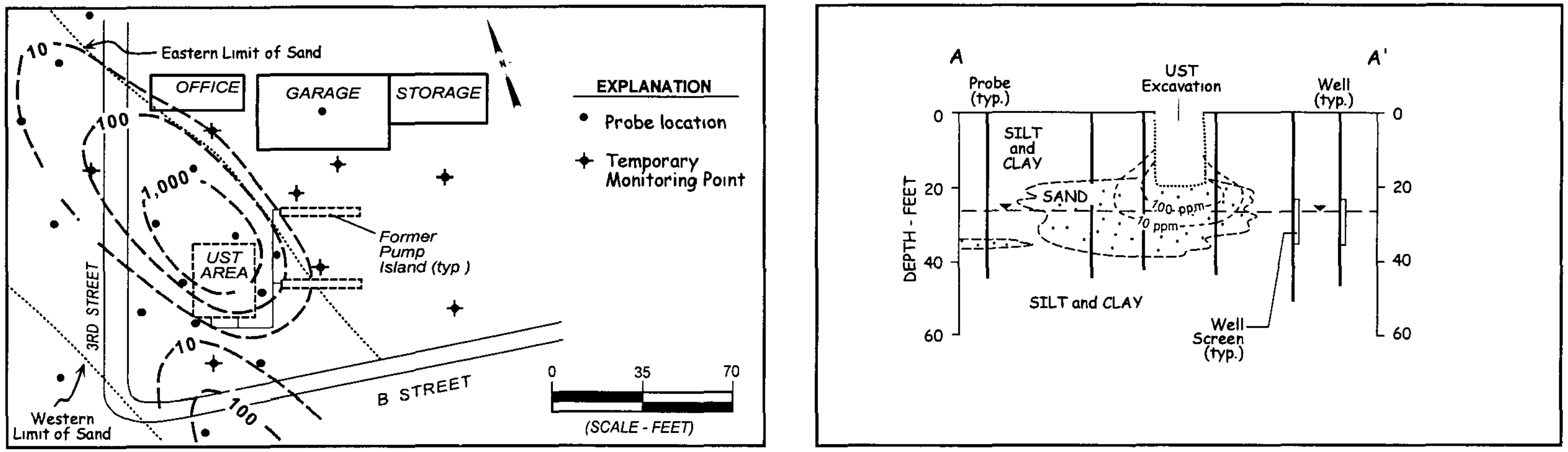
- Contours of BTEX in soil showed that the highest levels of contamination were directly beneath the former UST excavation. Analysis of groundwater samples showed that the dissolved plume of benzene extended off-site toward the north-northwest, beneath 3rd Street.

Figure II-7
Final ESA Conceptual Model After Day 3



a. GROUNDWATER CONTOURS

b. BTEX IN SOIL @20' (ppm)



c. ISOCONCENTRATION CONTOURS - BENZENE IN GROUNDWATER (ppb)

d. CROSS SECTION A-A' WITH BTEX IN SOIL

- The tank backfill material was found to be in direct contact with a buried stream channel.

- Two more soil and groundwater samples were collected upgradient from the site to investigate the anomalous analytical data collected during Day 1. Although the soil samples were clean, the groundwater samples confirmed the initial suspicion of an off-site source.

- Water elevations measured in the temporary monitoring points indicated that groundwater within the silt and clay flows toward the north, consistent with the regional groundwater flow direction. As expected, groundwater in the buried stream channel flowed toward the northwest.

- Low dissolved oxygen levels were found in the core of the plume. There was also a significant reduction in dissolved BTEX concentrations in groundwater downgradient from the USTs.

Finalize Conceptual Model

By the end of the third day, the conceptual model had been developed in sufficient detail to meet the objectives of the project. No anomalies remained, and new DP probes yielded expected geologic information and analytical results. Moreover, the site data, including the geologic units, groundwater depth and flow direction, and upgradient impacts, were consistent with the regional setting.

Decommission Site

Before de-mobilizing, two of the eight temporary monitoring points were removed, and the resulting holes were filled with bentonite grout. The remaining six temporary monitoring points were left in place for one year (to provide additional groundwater elevation and analytical data) before they were removed.

Step 6: Consider Interim Remedial Actions (ESA)

After evaluating the data obtained in the three-day ESA, the field manager consulted with the SED to determine if any interim remedial actions should be taken. Since the contaminant plume did not pose an immediate threat to human health or the environment, and free product was not likely to spread significantly before a permanent corrective action technology was selected and implemented, they decided that there was no need to take additional interim remedial actions beyond the over-excavation of the contaminated soil in the tank pit and piping trenches that had occurred prior to the assessment. Because of the limited volume of gasoline discovered at the site, the SED determined that free product recovery was not appropriate to implement.

Step 7: Report The Findings (ESA)

Two weeks after the field work was complete, the field manager submitted a report to the SED and the site owner. The main findings for this investigation were:

- The USTs were the primary source of contamination. Contamination around associated piping was not continuous to groundwater.
- Approximately 600 gallons of petroleum had been released. An inch of free product was on the water table, and a dissolved plume had migrated off-site. The areal and vertical extent of BTEX concentrations in soil and groundwater was defined.
- A buried stream channel was the primary migration pathway for the petroleum release.
- A potential upgradient source of dissolved hydrocarbons was identified.
- *In situ* biodegradation of petroleum hydrocarbons is occurring beneath the site.

Analysis Of Conventional And Expedited Site Assessments

The ESA presented in this example cost significantly more than the CSA; however, the CSA is only an initial investigation and would require at least one more mobilization (probably two or three) for the site to be adequately characterized. In contrast, the ESA is complete. The one report would be enough for a regulator and facility owner to make effective corrective action decisions. A direct comparison of the costs is, therefore, not possible with the data provided. However, if the CSA was completed to provide enough information to make an accurate corrective action decision, the number of wells and the analyses would have probably cost significantly more than the ESA.

The primary advantage of an ESA is that it provides the user with rapid, accurate information about the extent of contamination and migration pathway so that effective remedial decisions can be made after only one mobilization. Although the initial cost of an ESA is often higher than the first phase of a CSA, the final cost is often much less. These savings are the result of:

- Characterization of a site in a single mobilization;
- Optimal placement of permanent monitoring wells;
- Effective corrective action measures being undertaken and optimized (*e.g.*, improved location of air sparging points and soil vapor extraction wells);
- Reduction in the administrative costs of writing and reviewing reports; and
- Reduced sampling and analysis of unnecessary and poorly placed monitoring wells.

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Chapter III

Surface Geophysical Methods

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Exhibits

Chapter III
Surface Geophysical Methods

Geophysical methods provide information about the physical properties of the earth's subsurface. There are two general types of methods: Active, which measure the subsurface response to electromagnetic, electrical, and seismic energy; and passive, which measure the earth's ambient magnetic, electrical, and gravitational fields. Information provided by these tools can be applied to UST sites by helping to locate buried objects, to determine geologic and hydrogeologic conditions, and, occasionally, to locate residual or floating product.

Geophysical methods can also be subdivided into either surface or borehole methods. Surface geophysical methods are generally non-intrusive and can be employed quickly to collect subsurface data. Borehole geophysical methods require that wells or borings be drilled in order for geophysical tools to be lowered through them into the subsurface. This process allows for the measurement of *in situ* conditions of the subsurface. In the past, using borehole geophysical methods had not been cost-effective for most UST site investigations; however, in recent years, direct push (DP) technology probe rods have been fitted with geophysical sensors that can provide geophysical information rapidly. Although many geophysical methods are not available with DP technologies, the methods that are available can often provide information more cost effectively than traditional borehole geophysical methods. As a result, borehole geophysics will be mentioned only briefly in this chapter. Geophysical sensors available with DP equipment are discussed in Chapter V, Direct Push Technologies.

Data collected with geophysical tools are often difficult to interprete because a given data set may not indicate specific subsurface conditions (*i.e.*, solutions are not unique). Instead, data provided by these tools indicate anomalies which can often be caused by numerous features. As a result, geophysical methods are most effectively used in combination with other site information (*e.g.*, data from different geophysical methods, sampling and analytical tools, geological and historic records, anecdotal information). A combination of these sources is often necessary to resolve ambiguities in geophysical plots (*i.e.*, the graphical representation of data produced by a specific method).

Geophysical methods can be important tools both in the implementation of cost-effective expedited site assessments (ESAs) and in the remediation design and monitoring phases. When they are used as part of an ESA, geophysical methods are, typically, best used in the initial phase of an investigation to help focus resources for the remainder of the assessment.

Exhibit III-1 provides a general guide to the applicability of the most appropriate geophysical methods for UST site investigations. The six technologies are ground penetrating radar, electromagnetic methods, electrical resistivity, metal detection, seismic methods, and magnetometry. All geophysical methods have limitations that will affect their applicability at specific sites. This chapter is designed to provide the reader with a basic understanding of when to consider using geophysical methods and which methods are applicable for specific conditions. It is beyond the scope of this chapter to discuss all geophysical methods that are potentially useful for the applications discussed below. There are numerous geophysical methods that are only marginally applicable for UST site investigations because of the interferences from cultural objects (*e.g.*, buildings, pipes) or because of the cost. In addition, there are numerous configurations for applying geophysical methods that can be used to minimize interferences and improve resolution. These specific configurations are also beyond the scope of this chapter and are best resolved by discussing specific site assessment objectives with an expert geophysicist. The reader may also refer to Dobecki (1985) and Daily (1995) for more information on these configurations.

In addition to this chapter, there are several documents developed by the U.S. EPA that provide useful information for the lay reader. A complete overview of available geophysical methods is provided in *Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites* (EPA, 1993b). The *Geophysical Advisor Expert System* (Olhoeft, 1992) is a software program that can help the user determine the most applicable geophysical methods for specific site conditions. Information about a specific site is entered in response to questions asked by the program. *Geophysical Techniques for Sensing Buried Wastes and Waste Migration* (Benson, *et al.*, 1984) is also a useful resource that provides a more complete discussion of the most applicable geophysical methods for environmental site assessment purposes.

The remainder of this chapter is divided into two sections. First, a methodology section provides general information about the applicability, operating principles, advantages and limitations of the geophysical methods listed in Exhibit III-1. Because many of these methods have multiple applications at UST sites, application sections have been developed to make comparisons between methods for specific tasks. The applications fall into three categories also presented in Exhibit III-1: Locating buried objects, assessing geologic and hydrogeologic conditions, and delineating residual and floating product. For the convenience of the reader a list of equipment manufacturers and a matrix of their products are included at the end of the chapter.

Exhibit III-1
Summary Of Surface Geophysical Method Applicability

Applications	**Ground Penetrating Radar**	**Electro-magnetic Methods**	**Electrical Resistivity**	**Metal Detection**	**Seismic Methods**	**Magnetometry**
Locating Buried Objects						
USTs	1	1	3	1	N/A	1a
Utilities	1	1	3	1	N/A	1a
Trench and backfill	1	2	2	N/A	3	3
Assessing Geologic And Hydrogeologic Condition						
Depth and thickness of soil and rock layers	2	2	1	N/A	1	N/A
Mapping lateral variation such as joints, karst, faults	2	2	2	N/A	2	3
Depth to groundwater	2	2	2	N/A	2	N/A
Delineating Residual And Floating Product	R[1]	R	R[1]	N/A	R	N/A

1=Primary choice -- Most effective method(s)
2=Secondary choice -- Alternate approach
3=Limited application under most field conditions
R=Methods currently being researched and developed
[1] Research methods that are well documented

a=ferrous objects only
N/A=Not Applicable

The following section provides overviews of the geophysical methods that are most likely to be useful at UST sites. The discussions summarize the uses of the method, its operating principles, and its advantages and limitations. Schematic drawings of the operating principles of these methods are also provided.

Ground Penetrating Radar

Ground penetrating radar (GPR) can be a very useful geophysical method for UST sites because it is appropriate for a broad range of investigations and is only rarely affected by cultural interferences (*e.g.*, buildings, fences, power lines). GPR can be helpful in:

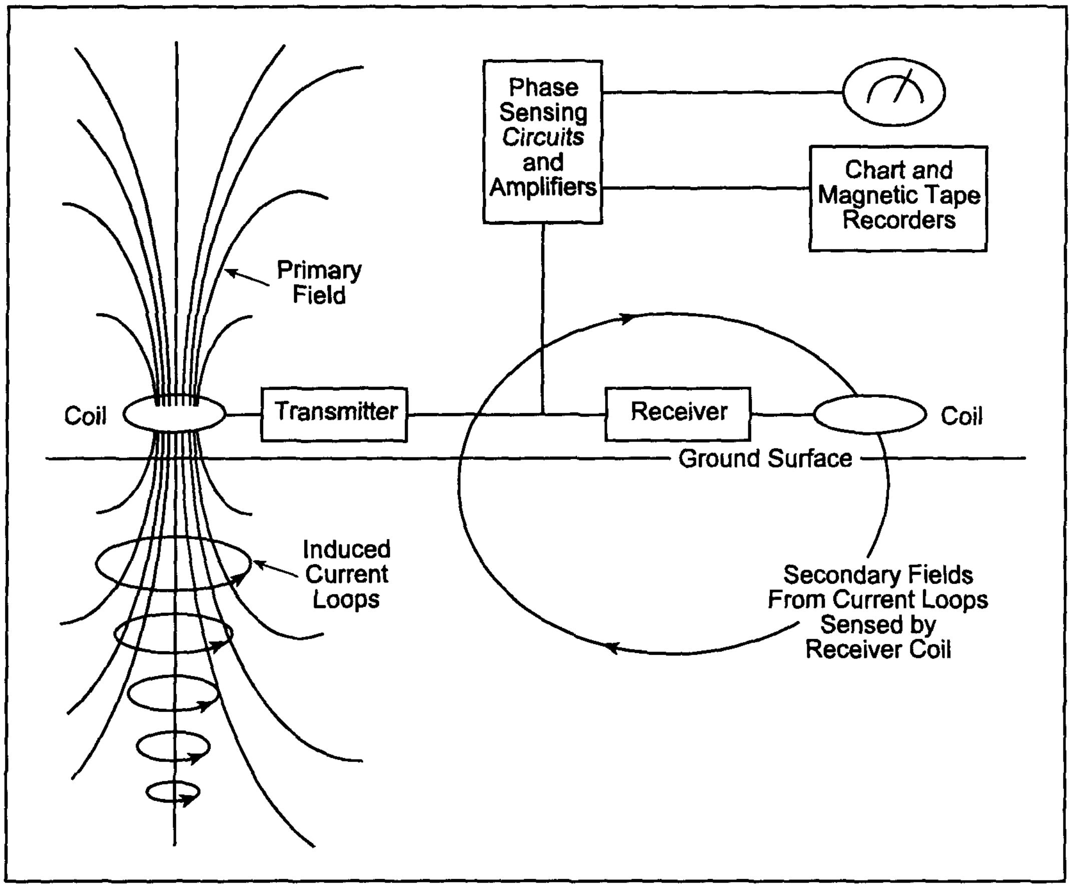
- Locating USTs, utilities, and backfilled areas;
- Determining geologic and hydrogeologic conditions; and
- Occasionally, delineating floating product.

GPR uses high frequency electromagnetic waves (*i.e.*, radar) to acquire subsurface information. The waves are radiated into the subsurface by an emitting antenna. When a wave strikes a suitable object, a portion of the wave is reflected back to a receiving antenna. Measurements are continuously recorded with a resolution that is significantly higher than most other surface geophysical methods, providing a profile (*i.e.*, cross-section) of subsurface conditions. Exhibit III-2 provides a schematic drawing of the GPR operating principles.

The GPR method utilizes antennas that emit a single frequency between 10 and 3000 MHz. Higher frequencies within this range provide better subsurface resolution at the expense of depth of penetration. Lower frequencies in this range allow for greater penetration depths but sacrifice subsurface target resolution. In UST investigations, the working frequency range is generally 100 to 900 MHz. Frequencies above 900 MHz are typically used for investigations less than 2 feet below ground surface (bgs).

In addition to the antenna frequency, the depth of wave penetration is controlled by the electrical properties of the media being investigated. In general, the higher the conductivity of the media, the more the induced radar wave is attenuated (absorbed), lessening the return wave. Electrically conductive materials (*e.g.*, many mineral clays and soil moisture rich in salts and other free ions) rapidly attenuate the radar signal and can significantly limit the usefulness

Exhibit III-3
Schematic Drawing Of Electromagnetic Operating Principles



Source: U.S. EPA, 1993a

of ions. Sands and gravels typically have fewer free ions in a saturated environment and, therefore, have lower conductivities. Metal objects, such as steel USTs, display very high conductivity measurements which provide an indication of their presence.

There are two basic types of EM methods--frequency domain (FD) and time domain (TD). FDEM measures the electrical response of the subsurface at several frequencies (different separation distances between the transmitter and receiver can also be used) to obtain information about variations of conductivity (or its reciprocal, resistivity) with depth. TDEM achieves the same results by measuring the electrical response of the subsurface to a pulsed wave at several time intervals after transmission, longer time intervals measure greater depths. Both methods have overlapping applicabilities.

The EM receiver and transmitter coils can be configured in many different ways, depending on the objectives of the survey. One common configuration for shallow environmental investigations utilizes transmitter and receiver coils that are attached to the ends of a rigid fiberglass rod at a fixed distance (*i.e.*, fixed-coil separation). The equipment is then moved across the area of investigation. This configuration is particularly suitable for detection of USTs and metal pipes.

The limitations of EM methods are primarily a result of the interferences, typically caused when this method is applied within 5 to 20 feet of power lines, buried metal objects (including rebar), radio transmitters, fences, vehicles, or buildings. In addition, its success depends upon subsurface conductivity contrasts. For example, the difference in conductivity between an UST and surrounding natural or fill material is typically adequate for detection. However, mapping more subtle targets, such as fine versus coarse material or contamination, is less predictable. Consequently, pilot studies can be conducted to determine if an adequate conductivity contrast exists for the objective of the study.

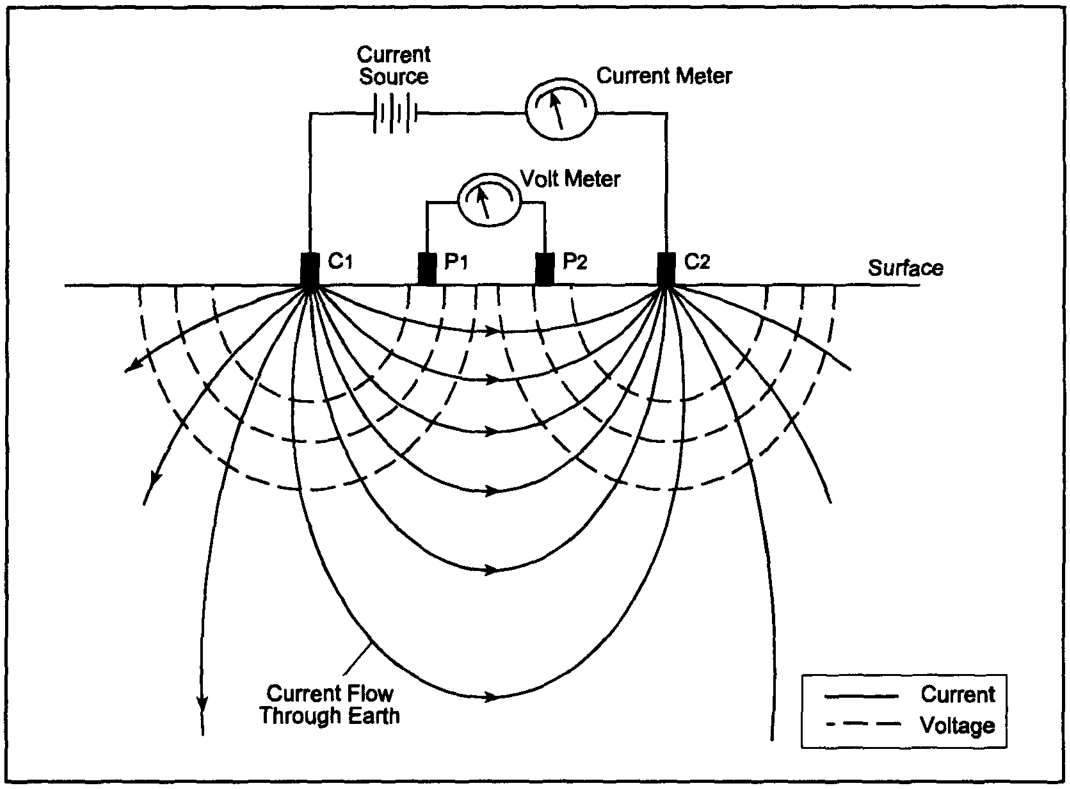
Electrical Resistivity

Electrical resistivity, also referred to as galvanic electrical methods, is occasionally useful at UST sites for determining shallow and deep geologic and hydrogeologic conditions. By measuring the electrical resistance to a direct current applied at the surface, this geophysical method can be used to:

- Locate fracture zones, faults, karst, and other preferred groundwater/contaminant pathways;
- Locate clay lenses and sand channels;
- Locate perched water zones and depth to groundwater; and
- Occasionally, locate large quantities of residual and floating product.

A variety of electrode configurations or arrays (*e.g.*, Wenner, Schlumberger, dipole-dipole) can be used depending on the application and the resolution desired. Typically, an electrical current is applied to the ground through a pair of electrodes. A second pair of electrodes is then used to measure the resulting voltage. The greater the distance between electrodes, the deeper the investigation. Because various subsurface materials have different, and generally understood, resistivity values, measurements at the surface can be used to determine the vertical and lateral variation of underlying materials. As with EM, success depends upon subsurface resistivity contrasts. Exhibit III-4 presents a schematic drawing of electrical resistivity operating principles using the Wenner array.

Exhibit III-4
Schematic Drawing Of Electrical Resistivity Operating Principles



Source: Benson et al., 1984

Although resistivity is subject to interferences from the same objects as EM, it is less affected by them. In addition, if the location of metal pipes and utilities is known, electrode arrays can often be arranged to minimize interferences. Furthermore, resistivity resolution is comparable to, and sometimes better than, EM.

Electrical resistivity, however, has a number of limitations. The following is a list of the most significant issues that should be considered when selecting this method:

- Electrodes must be in direct contact with soil; if concrete or asphalt are present, holes must be drilled for inserting the electrodes and then refilled when the survey is complete.

- For deep investigations, electrode arrays can be quite long. The distance between outside electrodes must be 4 to 5 times the depth of investigation.

- Measurements may be limited by both highly conductive or highly resistive surface soils. If shallow clays and extremely shallow groundwater are present, most of the current may concentrate at the surface. Although the condition is very rare, the presence of thick, dry, gravelly material (or massive dry material) at the surface may prevent the current from entering the ground.

Metal Detection

Metal detectors, also referred to as pipeline and cable detectors, are widely used at UST sites for the specific application of locating buried metal objects, both ferrous and non-ferrous in a process called metal detection (MD). MD can be used at UST sites to locate:

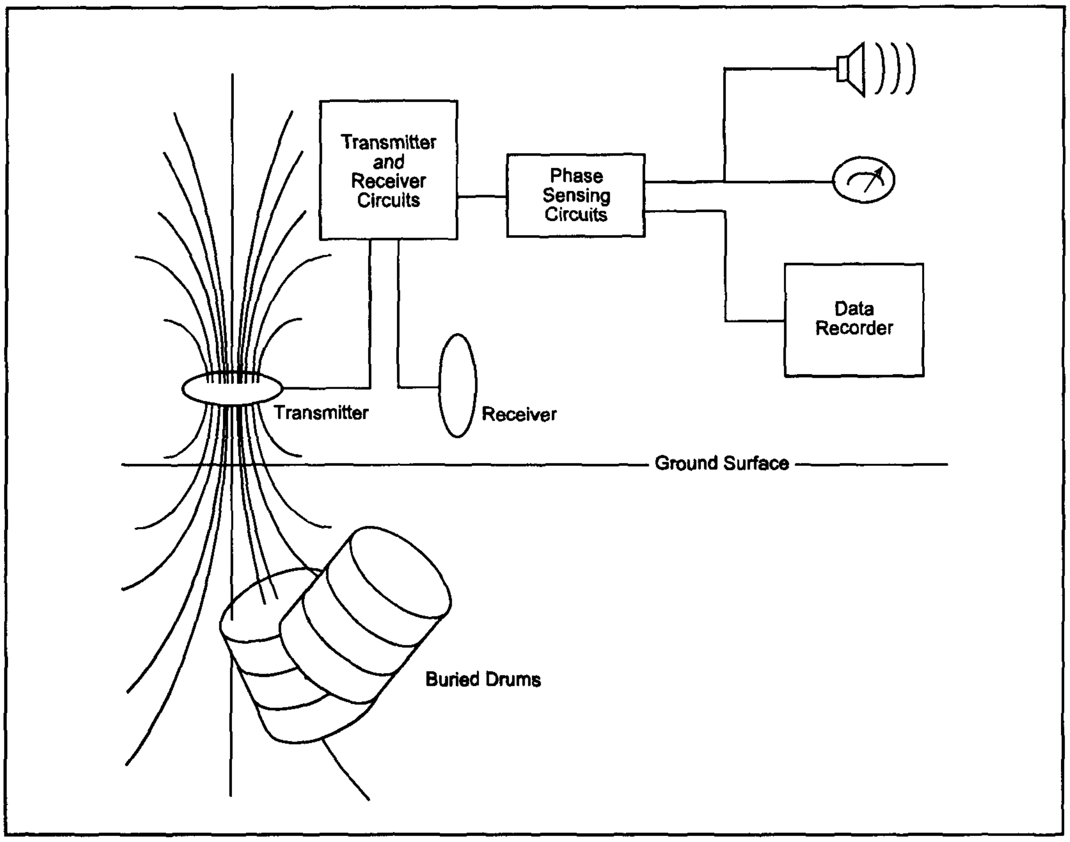
- Steel and composite (*i.e.*, fiberglass-coated steel) tanks;
- Metal piping; and
- Utilities.

There are two types of MD--frequency domain and time domain. Frequency-domain metal detectors are typically used for locating shallow metals (less than 2 feet) and for tracing piping and cables at UST sites. Time-domain metal detection is useful for investigations from 0 to 15 feet and for locating USTs or buried drums. Both types provide good response to all metal objects.

Metal detectors operate by the same principles as EM methods, but they are adapted to the specific purpose of locating metal objects. When the subsurface current is measured at a specific level, the presence of metal is indicated with a meter reading, with a sound, or with both. Commercial metal detectors used for locating USTs also have data recording capabilities although stakes or paint marks are typically placed over targets as the survey proceeds. Exhibit III-5 presents a schematic drawing of MD operating principles.

The depth of investigation with MD surveys is dependent primarily on the surface area and the depth of the object. The response of MD decreases dramatically with depth. As a target depth is doubled, the response decreases by a factor of as much as 64 (the response to small objects decreases more rapidly than the response to large objects). However, metal detectors are very appropriate for UST sites because they are capable of detecting metal utilities up to 3 feet bgs, a 55-gallon metal drum up to 10 feet bgs, or a 10,000-gallon steel tank up to 20 feet bgs.

Exhibit III-5
Schematic Drawing Of Metal Detection Operating Principles



Source: Benson et al., 1984

MD is less sensitive to surface and subsurface interferences than EM methods, but care must be taken to minimize noise from metal fences, vehicles, buildings, and buried pipes. Rebar in concrete is perhaps the most common problem for this method at UST sites. The electrical conductivity of the soil does not cause significant interferences for MD methods; however, mineralized soils and iron-bearing minerals can provide significant natural interference with surveys.

Seismic Methods

Seismic methods provide stratigraphic information by measuring how acoustic waves travel through the subsurface. They can be used at UST sites to:

- Determine depth and thickness of geologic strata;

- Determine depth to groundwater;
- Estimate soil and rock composition; and
- Help resolve fracture location and orientation.

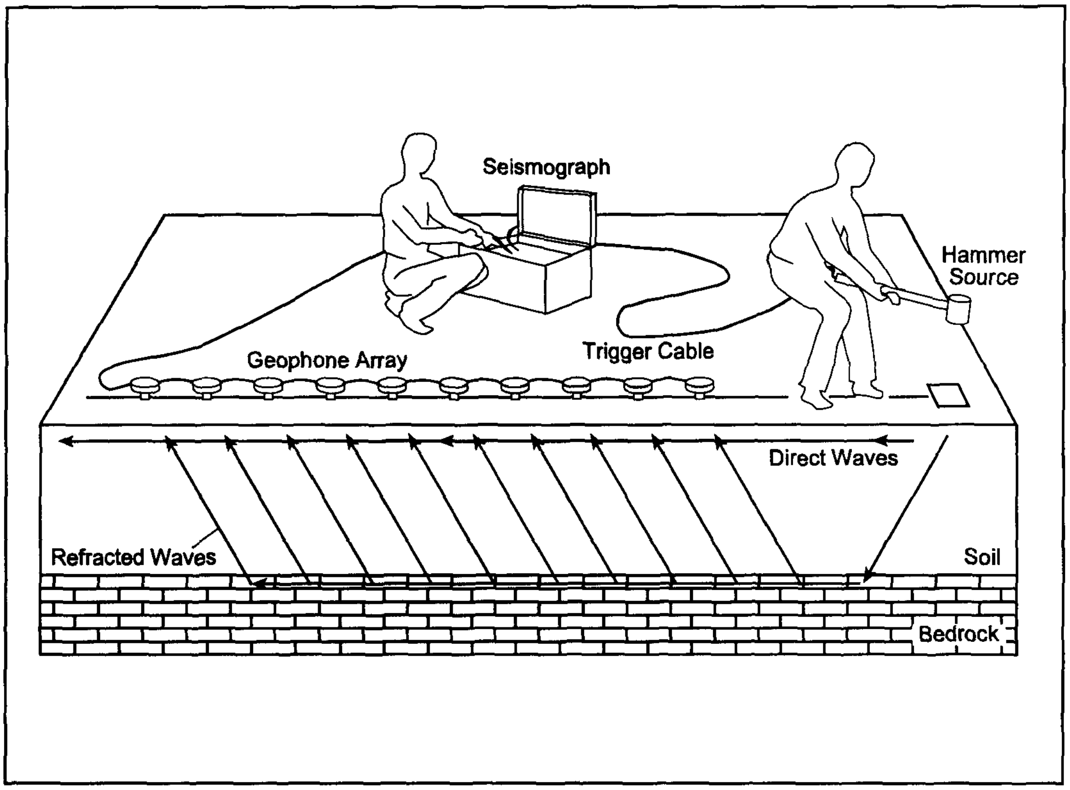
There are primarily two types of seismic method applications--refraction and reflection. Seismic refraction measures the travel times of multiple sound (*i.e.*, acoustic) waves as they travels along the interface of two layers having different acoustic velocities. Seismic reflection, on the other hand, measures the travel time of acoustic waves in the subsurface as they reflect off of these interfaces. Traditionally, seismic reflection has been used for deep geological investigations (up to 3000 feet), and seismic refraction has been used for shallow investigations (up to 100 feet). Although recent developments have blurred the applications of the two methods, seismic refraction remains more commonly used for shallow investigations because it is less expensive and easier to use for resolving stratigraphy less than 50 feet bgs. This chapter will focus on seismic refraction.

Seismic refraction utilizes an energy source, such as a sledge hammer or small explosives, to create acoustic waves in the subsurface. When there is a change in the seismic velocity of the waves traveling from one layer to the next, refracted waves are created. These waves are recorded by geophone sensors (*i.e.*, seismic wave receivers) arranged in a direct line from the energy source. The time it takes the waves to refract is dependent on the composition, cementation, density, and degree of weathering and fracturing of the subsurface materials. Exhibit III-6 presents a schematic drawing of seismic refraction operating principles.

The advantage of seismic refraction is that it can resolve three to five layers of stratigraphy and provide good depth estimates. Furthermore, it is fairly easy to implement, and the energy source can be as simple as a 10-pound sledge hammer. Seismic refraction, however, has a number of limitations that should be considered:

- Geophone spreads may be as much as five times as long as the desired depth of investigation, therefore limiting its use in congested locations.
- If velocity contrasts do not exist between sediment layers they will not be resolved.
- Thin layers cannot be resolved.
- If numerous buried utilities are in the vicinity of the seismic profiles, they may interfere with the collection of usable data by creating a false layer near the surface.
- For surveys in paved areas, holes need to be drilled in order to provide a firm contact between the geophones and the soil.

Exhibit III-6
Schematic Drawing Of Seismic Refraction Operating Principles



Source: Benson et al., 1984

- Seismic velocities of geologic layers must increase with depth. Although this situation is typical, conditions such as frozen soil or buried pavement will prevent detection of underlying formations.
- Seismic methods are sensitive to acoustic noise and vibrations; however, there are a number of ways to minimize this noise, including using data filtering software or taking profiles (*i.e.*, geophysical subsurface cross-sections) when there is no traffic (*e.g.*, taking measurements during red lights or at night).

Although seismic refraction can be used for depths below 300 feet, it is usually used for depths less than 100 feet because of the very long geophone spreads required and the energy sources (*e.g.*, a 500 lb. drop weight, explosives) necessary to reach these depths.

Magnetic Methods

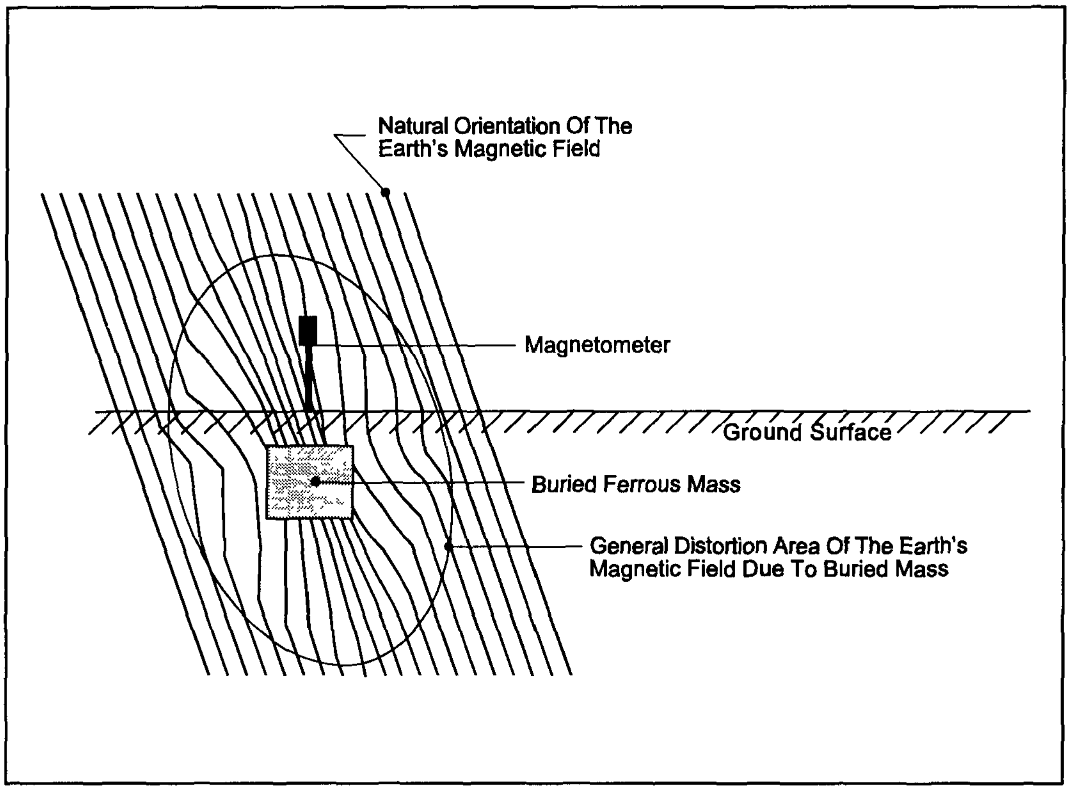
Magnetometers are useful at UST sites for locating tanks and piping made of ferrous materials. Although highly sensitive magnetometers have been developed that can detect the void space within large buried objects of any material (*e.g.*, fiberglass tanks), this technology is not often used in UST investigations because many cultural interferences present at UST sites will mask the affect.

Magnetometers that are commonly used at UST sites work by measuring the earth's total magnetic field at a particular location. Buried ferrous materials distort the magnetic field, creating a magnetic anomaly. There are two methods for measuring these anomalies--the total field method and the gradient method. The total field method utilizes one magnetic sensing device to record the value of the magnetic field at a specific location. The gradient method uses two sensors, one above the other. The difference in readings between the two sensors provides gradient information which helps to minimize lateral interferences. Total field magnetic methods are often used at sites with few cultural features. Gradiometer methods can be used in culturally complex areas. As a result, gradiometers are more applicable for UST sites. Exhibit III-7 presents a schematic drawing of magnetometry operating principles.

Magnetometers may be useful for reconnaissance surveys of UST sites because they are very fast and relatively inexpensive. Potential cultural interferences include steel fences, vehicles, buildings, iron debris, natural soil minerals, and underground utilities. Gradiometer methods are useful for minimizing these interferences. Power lines are an additional source of interference that can be neutralized with the use of very sophisticated equipment that synchronizes readings with the oscillating electrical current.

Some magnetometers are very simple and do not have a data recording or processing ability. They indicate the presence of iron with a sound or meter and can be used as a rapid screening tool. Magnetometers that record data can, with the aid of data processing software, be used to estimate the size and depth of ferrous targets.

Exhibit III-7
Schematic Drawing Of Magnetometry Operating Principles



Source: Modified from U.S. EPA, 1993a

There are three general applications for geophysical tools in the assessment of UST sites: Locating buried objects; assessing geological and hydrogeological conditions; and, to a lesser extent, delineating residual or floating product. The following text contains discussions of the geophysical methods that are most applicable for these activities. Specific information about each method and a comparison chart of all methods are provided to help the reader decide which method to use under various conditions.

Each of the following discussions includes a summary table highlighting the parameters that affect the applicability of the described methods. Only information that is relevant to the specific application is presented for each of the methods. Some of the parameters discussed in the previous section that affect the applicability of a method are presented in the tables but not repeated in the text.

The summary tables include cost estimates which are presented as low, moderate, or high. More accurate estimates are not possible because there are an enormous number of site-specific factors that affect cost (*e.g.*, survey objectives, survey size, spacing between traverse lines, mobilization costs). Furthermore, the expense of a survey will be greatly affected by who conducts the investigation (*e.g.*, a consultant or an individual renting equipment directly from the manufacturer), how much data processing will be required, and whether a written report is necessary.

Similar to cost estimates, time requirements for a geophysical survey are presented as fast, moderate, and slow. Geophysical methods can be ranked by how quickly they can be used, but the specific time that a survey will take varies considerably depending on the level of detail required and the size of the area to be investigated. In general, all of the methods presented in this chapter can be completed within one day at a typical UST site (*i.e.*, less than 2 acres); in some cases, a survey can be completed within half a day. Sometimes, no data processing will be necessary beyond what is immediately presented; or, additional data processing may be completed in the field; in other situations, extensive off-site data processing will be necessary.

Locating Buried Objects

Many times the initial step to a site assessment is to determine the location of USTs, associated piping, and/or utilities. This type of activity is ideally suited to geophysical tools. If the location of these structures has not been recorded, the use of geophysical methods can save an enormous amount of time and money.

There are four primary methods used for locating buried objects: Ground penetrating radar (GPR), time-domain metal detection (MD), magnetometry (MAG), and electromagnetic methods (EM). Exhibit III-8 provides a summary of the information presented in this discussion.

Ground Penetrating Radar

Ground penetrating radar is effective for locating buried objects, whether metal or non-metal. Targets of investigation include:

- Steel, fiberglass, composite, and steel-reinforced concrete USTs;
- Utilities;
- Rebar; and
- Backfill.

When site conditions are favorable, GPR provides the best resolution of any geophysical method for locating buried objects. Although the exact resolution depends on the frequency of the antenna used and the depth of penetration required, GPR can generally locate a tank to within a foot, both vertically and horizontally. However, because GPR is typically used at much slower rates and with more dense traverse lines than MAG, MD, and EM, it is often more cost-effective to use GPR for focused investigations. When the location of an object is only suspected or estimated, other (*i.e.*, reconnaissance) methods may be more appropriate. Exhibit III-9 is an example of a plot and interpretation of GPR being used to locate buried USTs. The hyperbolic shape of the radar wave reflections is a typical profile of a buried object.

Metal Detection

Metal detection (MD) surveys are useful for locating only metal objects, both ferrous and non-ferrous. Investigations at UST sites include:

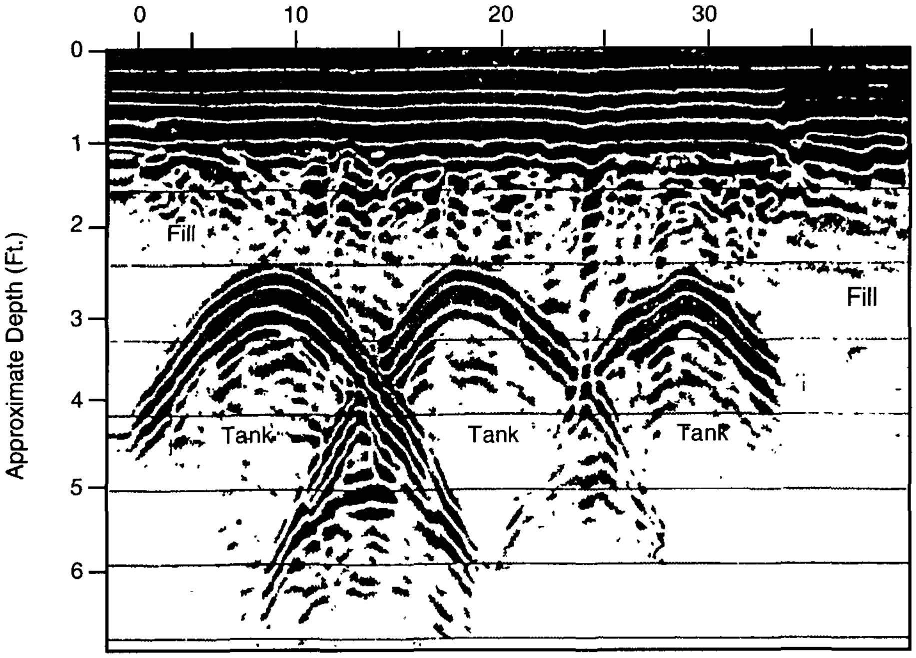
- Steel, composite, and steel-reinforced concrete USTs;
- Reinforced concrete covering fiberglass USTs; and
- Utilities composed of any metal.

Exhibit III-8
Summary Of Geophysical Methods For Locating Buried Objects

	Ground Penetrating Radar	Metal Detection	Magnetometry	Electromagnetic Methods
Purpose	Focused investigation	Reconnaissance survey	Reconnaissance survey	Reconnaissance survey
Typical Depth Of Penetration	3 to 15 ft	10 to 12 ft (55-gal. drum)	10 to 15 ft (55-gal. drum)	8 to 10 ft
Materials Detected	Metal and non-metal	Metal	Ferrous materials	Metal and non-metal
Cultural Interferences	Densely packed rebar, wire mesh	Metal surface structures, power lines	Metal surface structures, power lines	Metal surface structures, power lines
Natural Interferences	Conductive soils (*e.g.*, silts, clays)	Mineralized soils	Mineralized soils, iron deposits	Highly conductive saline soils
Resolution	0.1 to 4 ft	20% vertically and horizontally	10 to 15% vertically and horizontally	Vertical resolution is between 4 and 12 ft; 4 ft horizontally
Produces Usable Field Data	Yes	Yes	Yes	Yes
Time	Slow to Moderate	Moderate to Fast	Fast	Moderate to Fast
Cost	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate

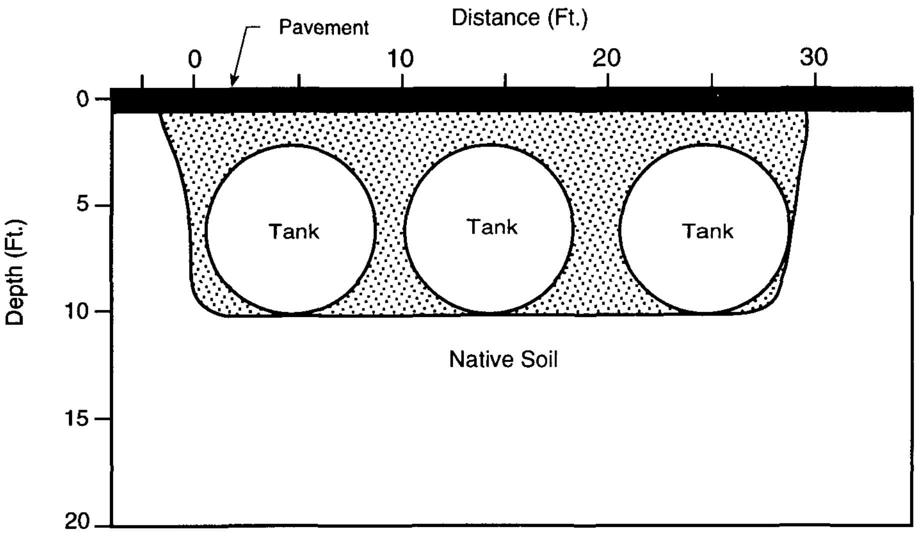
Exhibit III-9
Ground Penetrating Radar Survey And Interpretation Of Buried USTs

Survey



Radar Profile – 500 MHz Antenna

Interpretation



Source: NORCAL Geophysics Consultants, Inc.

MD provides excellent horizontal resolution. Utilities can be traced better than with magnetometry, however, resolution of depth can only be defined to within 20 percent of the actual depth. If better resolution is required, a follow-up survey with GPR may be appropriate. Exhibit III-10 presents an example of a survey plot and interpretation using a very sophisticated MD that was able to locate the UST and associated piping.

Magnetometry

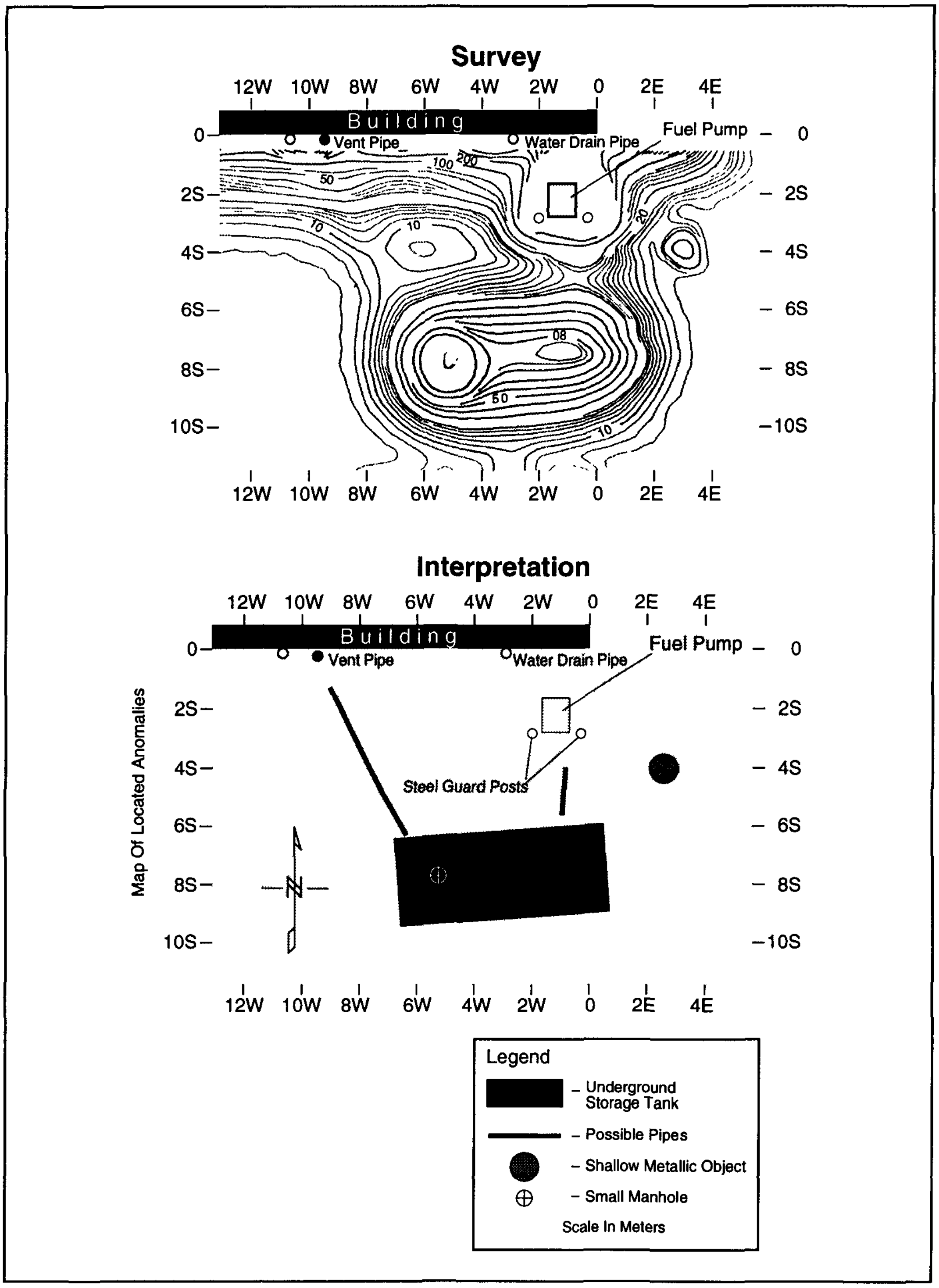
Magnetometry (MAG) methods are well suited for reconnaissance surveys because they collect data rapidly, they give large responses for buried ferrous objects, and they are cost-effective. As described in the method overviews, MAG surveys can be useful at UST sites for detecting:

- Steel, composite, and steel-reinforced concrete USTs;
- Utilities composed of ferrous materials; and
- Trenches.

In addition to being able to detect ferrous materials, very sensitive MAG equipment can also detect the void space in a large container of any material. However, because fiberglass tanks are typically covered with reinforced concrete, the magnetic response will be dominated by the presence of the reinforcing steel. Highly sensitive magnetometers can be more useful in detecting backfilled trenches because their iron content often contrasts with the surrounding soils. Depth of penetration is as deep as necessary for most UST sites. For example, a 55-gallon drum can be detected at 10 to 15 feet (depending on the sensitivity of the magnetometer), and a 10,000-gallon tank can be detected much deeper. The resolution of the data is also good when processed with the appropriate software, the vertical and horizontal location of an object can be determined to within 10 to 15 percent.

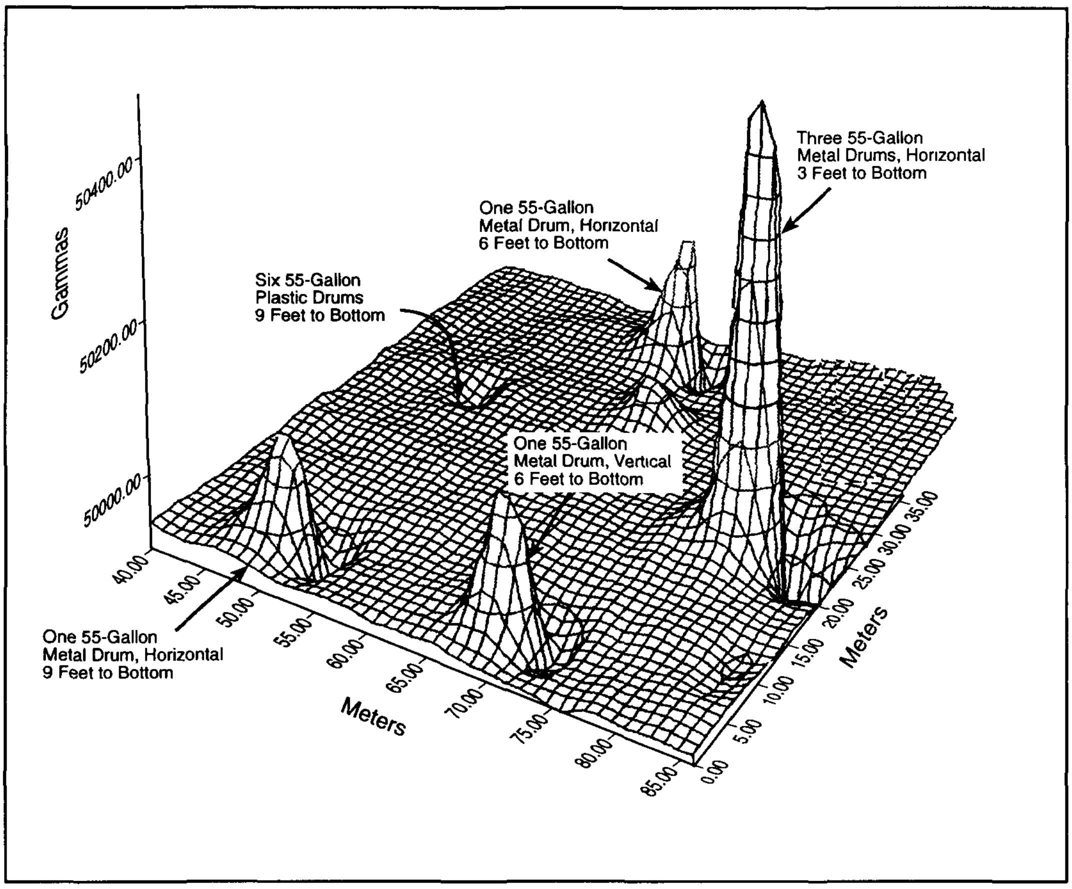
Exhibit III-11 provides an example of a MAG survey at a Stanford University test site. This section of the test site contained metal and non-metal objects, all of which were detected with the highly sensitive magnetometer. The large mounds indicate the location of metal drums buried at various depths and positions. Also of interest is the negative anomaly that is caused by six plastic drums buried 9 feet bgs.

Exhibit III-10
Metal Detection Survey And Interpretation At UST Site



Source: Geonics Limited

Exhibit III-11
Magnetometry Survey At Stanford University Test Site



Source: Geometrics, Inc.

Electromagnetic Methods

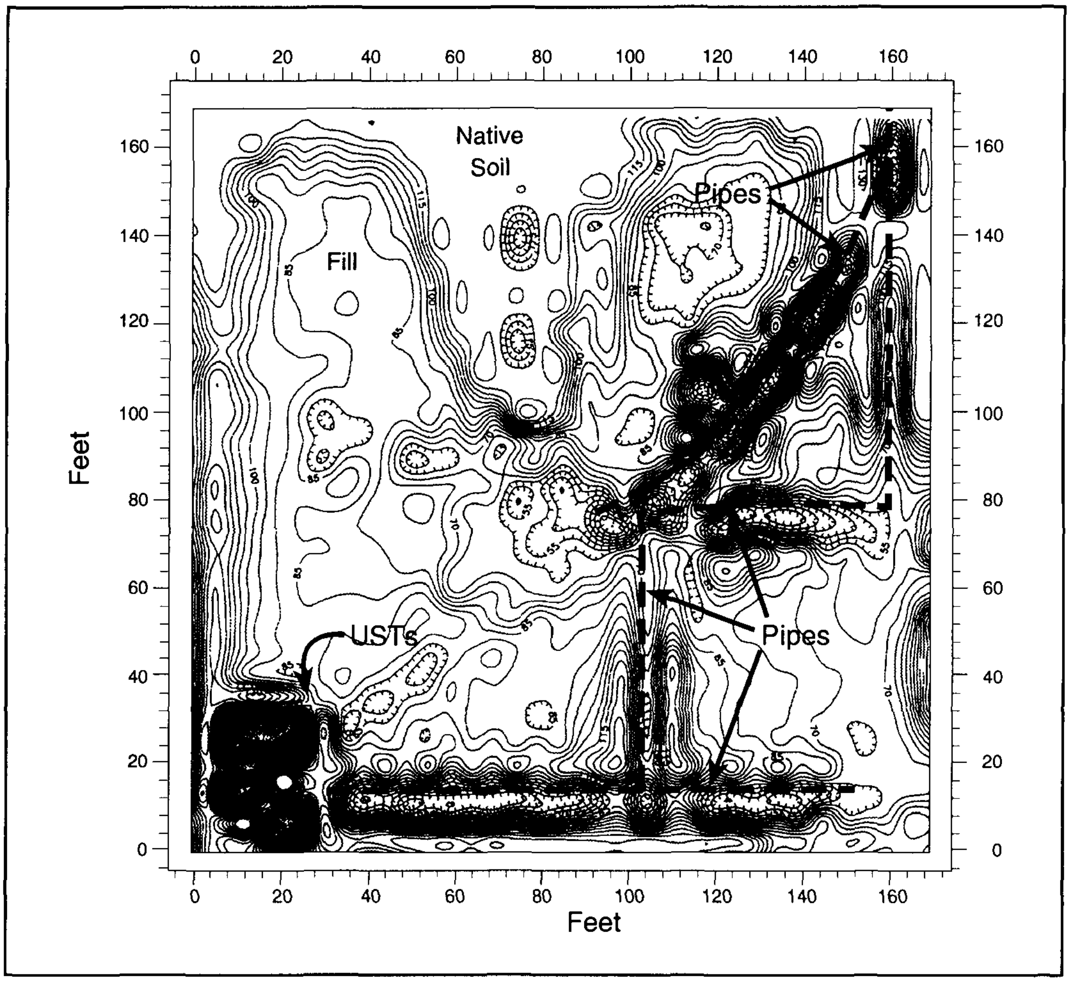
The most widely used EM method for UST investigations is frequency-domain fixed-coil EM (the distance between transmitter and receiver coils is fixed). It is useful for locating buried objects, whether metal or non-metal. This method can be used at UST sites to locate:

- Steel, composite, and steel-reinforced concrete USTs;
- Utilities; and
- Backfill soils.

EM methods are well suited for reconnaissance of large open areas because data collection is rapid, and a large variety of subsurface anomalies can be located, whether metal or non-metal, including the backfill of former USTs. Because EM methods can indicate the location of many types of buried objects, follow-up investigations with GPR are often applicable.

For EM instruments commonly used at UST sites for assessment of buried objects, the depth of investigation is limited to 12 feet or less, regardless of the size of the object detected. Horizonal resolution with EM is approximately 4 feet, and vertical resolution is between 4 and 12 feet. Exhibit III-12 is an example of contoured EM data and an interpretation map at an UST site. The survey was able to locate several USTs and associated piping as well as to delineate the area of backfill.

Exhibit III-12
Electromagnetic Survey And Interpretation At UST Site



Source: NORCAL Geophysical Consultants, Inc.

Assessing Geological And Hydrogeological Conditions

All geophysical methods are capable of providing information about geologic and/or hydrogeologic conditions. By assessing the subsurface, investigators can make judgements about where contamination is likely to be located and the direction it is likely to migrate. This information is also critical in the design of appropriate remediation technologies. Geophysical methods are, of course, not always necessary for determining the geologic and hydrogeological conditions of UST sites; however, when adequate background information does not exist and site geology is complicated, geophysical methods may be a cost-effective means of supplementing intrusive methods of characterization (*e.g.*, soil logging).

Geophysical methods can be helpful in resolving depth to groundwater; determining depth, thickness, and composition of soil and rock layers; and mapping local features such as permeable zones, joints, faults, karst, and buried stream channels. The following text summarizes the most useful methods for these tasks and explains their applicability. The geophysical methods most likely to be useful at UST sites include ground penetrating radar (GPR), seismic refraction (SR), electrical resistivity (ER), and electromagnetics (EM). Although all of these methods may on occasion be useful in determining the depth to the saturated zone, they all require sharp boundaries to be successful. As a result, when there is a large capillary fringe, they may not distinguish the saturated zone from the vadose zone.

Magnetometry, very low frequency electromagnetics (VLF-EM), self-potential (SP), and seismic reflection are other surface geophysical methods that may provide additional information; however, they are not discussed in detail because they are rarely useful at UST sites for assessing geologic and hydrogeologic conditions because of sensitivities to cultural interferences, cost, or applicability for rare conditions. Magnetometry and VLF-EM methods can be useful for delineating faults and large fracture zones. SP surveys, although sensitive to interferences, can be used to assess karst, fractures, and groundwater recharge. Borehole methods may also be useful for logging soil types and fracture characterization. Borehole methods that have been adapted to direct push technologies are discussed in the Chapter V. Exhibit III-13 summarizes the application of each of the major surface geophysical methods used for subsurface characterization of geologic and hydrogeologic conditions.

Exhibit III-13

Summary Of Geophysical Methods For Assessing Geologic And Hydrogeologic Conditions

	Seismic Refraction	**Electromagnetic Methods**	**Ground Penetrating Radar**	**Electrical Resistivity**
Depth Of Penetration	>100 ft	>100 ft	3 to 15 ft (up to 90 ft in clean sands and gravels)	>100 ft
Features Detected	Sediment thickness, bedrock, fractures, faults, groundwater	Distribution of sand and clays, bedrock, fractures, faults, groundwater	Sediment thickness, bedrock, fractures, faults, groundwater (rarely)	Distribution of sands and clays, bedrock, fractures, faults, groundwater
Cultural Interferences	Urban noise (*e.g.*, construction, traffic), buried concrete	Metal surface structures, radio transmitters, power lines, buried pipes and cables	Densely packed rebar	Concrete, metal surface structures
Natural Interferences	Frozen soil		Conductive soils	Highly conductive soils
Resolution	2 to 3 ft	Variable	<1 ft	Vertical: 5 ft Horizontal: 5 ft
Produces Usable Field Data	If required	Depends on the specific method	Yes	No
Time	Slow to Moderate	Moderate to Fast	Slow to Fast	Slow to Moderate
Cost	Moderate to High	Low to Moderate	Low to Moderate	Moderate to High

Seismic Refraction

Seismic refraction is typically the most applicable seismic method for assessing subsurface conditions at UST sites. It can be used to resolve:

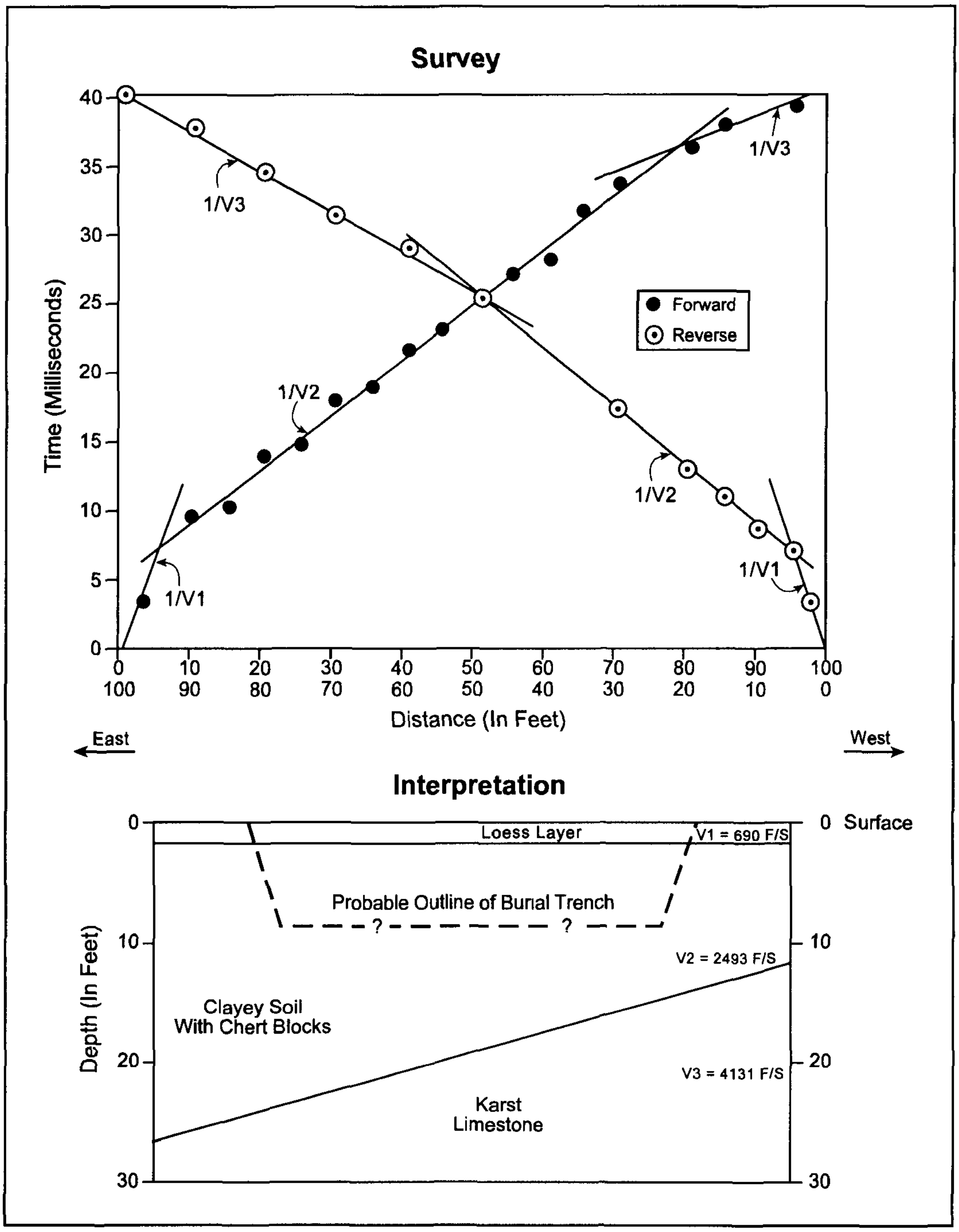
- Sediment depth and thickness;
- Karst, fractures, and faults;
- Depth to bedrock; and
- Occasionally, depth to groundwater.

Seismic refraction supplies semi-continuous data which, in combination with borings and other sampling techniques, can be extrapolated to resolve localized geologic features over the entire area of investigation. It is possible to resolve three to five distinct soil or rock layers and penetrate depths over 100 feet.

Occasionally, this method can be helpful in determining the depth to groundwater. In order to be successful, the velocity of the saturated zone must be significantly greater than the overlying formation. Because consolidated formations typically have very fast seismic velocities that are not significantly affected by groundwater, if the water table is located in a consolidated formation, it will not likely be discernable. Seismic velocities will typically increase significantly in unconsolidated formation; however, if the boundary is sharp (*e.g.*, as in course sands), a refraction survey will not be capable of determining if the layer is groundwater or another formation. Additional seismic tests, which are beyond the scope of this document, can be used to determine if the refraction is water or soil/rock.

Exhibit III-14 provides an example of a seismic refraction survey and interpretation used to resolve the depth to bedrock at a hazardous waste site. Each dot and circle represents the measured response of a geophone. Its placement on the graph is determined by the geophone location in the array and the time between energy release and the seismic wave arrival to the geophone. Measurements are taken in two directions (*e.g.*, forward and reverse) in order to resolve dipping (*i.e.*, inclined) stratigraphy. Because distance divided by time equals velocity, the inverse of the slope of the lines equals the seismic velocity of the subsurface material. Therefore, a change in the slope represents a change in the material. This survey was able to resolve three separate velocity layers (V_1, V_2, and V_3). The depth to bedrock throughout the area of investigation was resolved with V_3. The buried trench depicted in the interpretation was based on historical site information and was not resolved with seismic refraction.

Exhibit III-14
Seismic Refraction Survey And Interpretation



Source: Benson et al., 1984

Electromagnetic Methods

EM methods can be useful for assessing both the shallow subsurface and deep geological features. At some UST sites, it can provide information about:

- Stratigraphy;
- Preferred groundwater pathways;
- Fracture zones and faults; and
- Occasionally, depth to groundwater.

There are various EM methods that are useful for both shallow and deep geological and hydrogeological investigations. The frequency-domain fixed-coil separation EM method is the most practical EM approach for the shallow subsurface (less than 12 feet) at UST sites because its lateral resolution and speed of operation is superior to other EM methods. For collecting data from deeper than 12 feet, there are time-domain (TDEM) and other frequency-domain equipment available that can reach depths below 100 feet.

Exhibit III-15 is a schematic drawing of a TDEM survey. The black vertical lines are soundings (*i.e.*, vertical measurements) of subsurface electrical conductivity. The information between the lines is interpolated. By comparing information from the TDEM soundings with boring logs, it is possible to extrapolate the geology over a wide area. In this example, the approximate location of sediments is measured to a depth of 200 feet bgs.

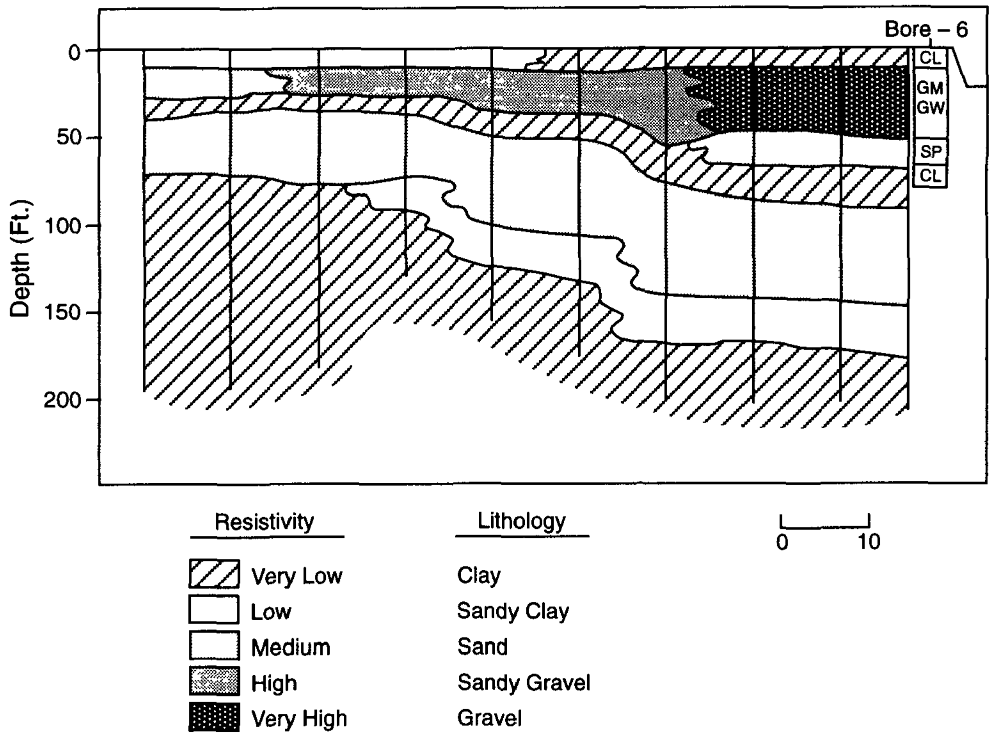
The resolution provided by EM methods is often not as good as other geophysical methods. Horizontal resolution may indicate the location of features to within 4 feet; vertical resolution can only be approximated. However, general indication of stratigraphy can be presented. The direction and general location of fractures and faults can also be presented.

Ground Penetrating Radar

When soil conditions are favorable, GPR can be very effective for assessing shallow, localized subsurface conditions. The geologic and hydrogeologic features that can be detected with GPR include:

- Karst, fractures, and faults;
- Depth and thickness of shallow sediments and bedrock; and
- Occasionally, depth to groundwater.

Exhibit III-15
Time-Domain Electromagnetic Survey Of Stratigraphy



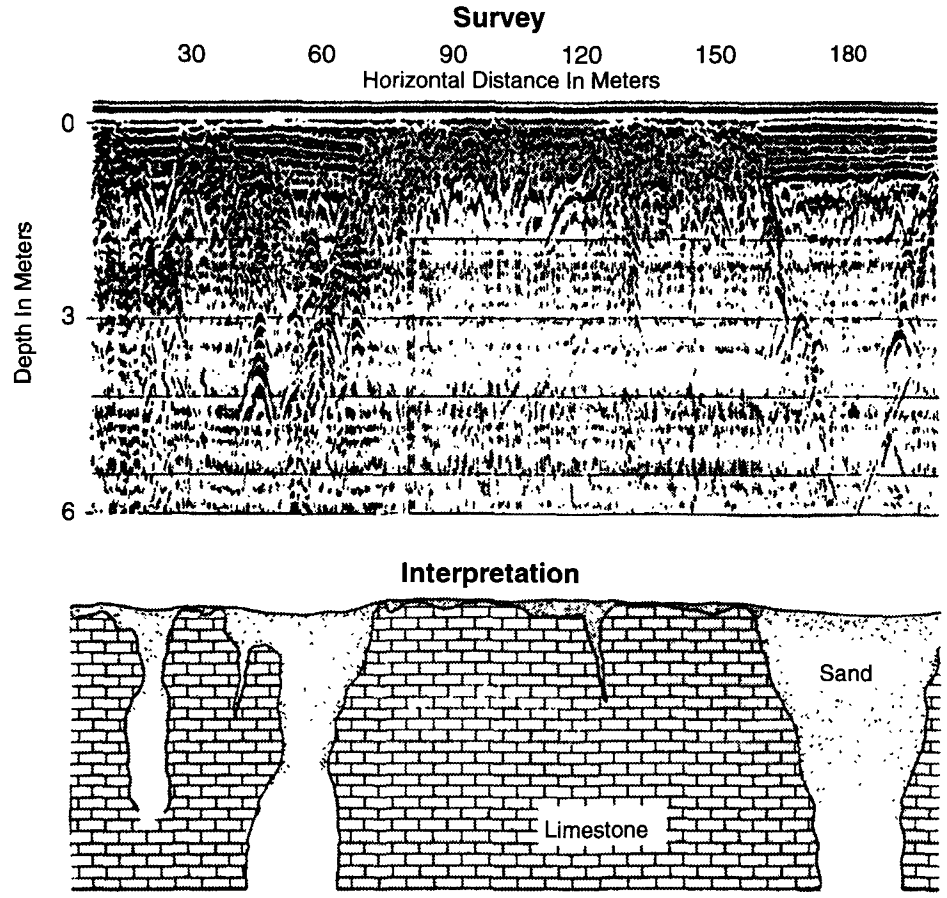
Source: NORCAL Geophysical Consultants, Inc.

GPR provides excellent resolution; however, interpretation of plots can be very difficult and require an experienced practitioner. Because it is not generally used as a reconnaissance tool, it is best used to clarify the existence and location of suspected features within a specific area. In addition, GPR is typically only useful for delineating shallow geological features because its depth of penetration can be significantly limited by site conditions. However, when soil conductivities are very low (*e.g.,* in sand, gravel), geologic features can be resolved up to 90 feet bgs.

GPR can be used to estimate the depth and thickness of soil and rock layers to within one foot. Occasionally, depth to groundwater can be determined, but the site must be above shallow, well-sorted sands that produce a water table with a small (less than 1 foot) capillary fringe.

Exhibit III-16 presents an example of a GPR survey and interpretation of karst. Although GPR did not provide good resolution in zones of solid limestone, the karst could be mapped because the radar signal is not attenuated as much in the sand that fills the karst.

Exhibit III-16
Ground Penetrating Radar Survey And Interpretation Of Karst



Source: Benson et al., 1984

Electrical Resistivity

Electrical resistivity can occasionally be used at UST sites to provide information about subsurface conditions. When used for this purpose, resistivity measurements can help resolve:

- Sediment depth and thickness;
- Karst, fractures, and faults;
- Depth to bedrock; and
- Depth to groundwater.

ER can easily collect data beyond 100 feet bgs, however, geologic features less than approximately 5 feet may not be resolved. Depths of these features can be estimated to within 5 feet if additional subsurface data (*e.g.*, boring logs) are available. The accuracy of depth estimates decreases with depth.

Delineating Residual Or Floating Product

One of the most difficult aspects of a site assessment is delineating the extent of contamination. Although geophysical tools are not helpful in mapping the extent of dissolved product at a site, in some situations they can play an important role in mapping the location of residual product in the vadose zone and floating product above groundwater. This is an area of active research and many issues involved with the uses of appropriate methods remain unresolved

In general, hydrocarbons are difficult to detect because they are resistive compounds that often cannot be distinguished from the surrounding soils and rock layers. However, among the hydrocarbons, light non-aqueous phase liquids (LNAPLs) (*e.g.*, gasoline, jet fuel, diesel fuel) are the most likely hydrocarbons to be detected because they float and form a distinct layer above the groundwater. For some geophysical methods, the LNAPL layer must be several feet thick for detection. Some detection methods may detect older spills more easily than newer spills because the natural rise and fall of a water table will "smear" the product over a greater area. In addition, the natural lateral geologic variations will interfere with the interpretation of geophysical plots for all methods because distinguishing between changes due to geology or LNAPLs may be difficult.

There are several surface geophysical methods that have the potential to detect LNAPLs in the subsurface. Ground penetrating radar (GPR) and electrical resistivity (ER) are currently the best documented methods and are discussed in the following text. A summary of the effectiveness of these two methods for delineating residual or floating product is presented in Exhibit III-17.

Exhibit III-17
Summary Of Geophysical Methods For Delineating Residual And Floating Product

	Ground Penetrating Radar	Electrical Resistivity
Depth Of Detection	3 to 15 ft	10 to 15 ft
Cultural Interferences	Densely packed rebar	Concrete, metal surface structures
Natural Interferences	Conductive soils (*e.g.*, clays), lateral geologic variations	Highly conductive soils (*e.g.*, wet dense clays), lateral geologic variations
Produces Usable Field Data	Yes	No
Detection Limit (Quantity Of Product)	Unknown	Unknown
Cost	Low to Moderate	Moderate to High

Other methods that are undergoing research but that are not yet appropriate for inclusion, include electromagnetic methods (EM), induced polarization (Olhoeft, 1986; also known as complex resistivity), and ultrasonic imaging (Geller, 1995; a type of seismic method). Borehole methods are extremely useful for the purpose of determining the thickness of floating product because they provide exact, *in situ* measurements that cannot be accomplished with any other means. These methods are discussed in detail in Direct Push Technologies, Chapter V.

Ground Penetrating Radar

Occasionally, GPR can provide an indication of the presence of hydrocarbons although success may be difficult to predict, and the reasons for its occurrence are not yet completely understood. There are several observations reported in scientific literature. In most cases, interpretation requires a boring log to compare reflection depths with actual soil types.

One study (Daniels, 1995) reports that in areas of petroleum hydrocarbon contamination, radar waves will not necessarily reflect back to the GPR receiver.

This effect causes a "halo" (*i.e.*, decrease in reflection) over the area of contamination which contrasts with neighboring areas of reflection. A similar result was observed in a controlled kerosene spill in Canada (DeRyck, 1993). However, in another controlled spill experiment (Campbell, 1996), a bright spot (*i.e.*, an increase in the reflected GPR signal) was observed. The reason for these contradictory results has not yet been adequately explained.

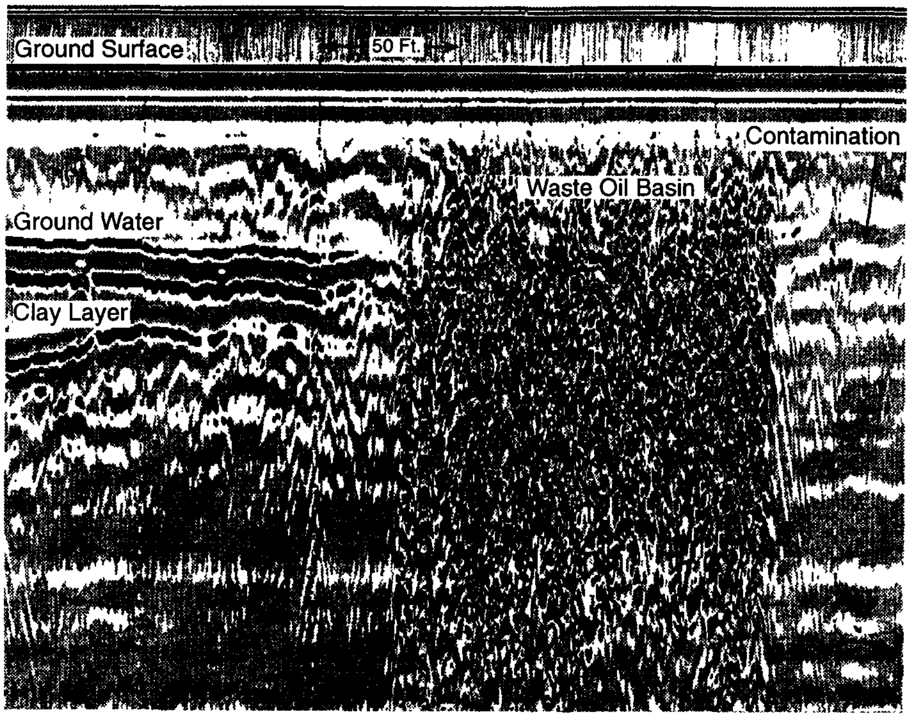
In addition (Benson, 1995) observed that, on occasion, a small amount of petroleum can cause the groundwater capillary fringe to collapse. If the water table is located in a zone of low permeability soils that create a large capillary fringe (*e.g.*, clays), then a drop in the location of the groundwater reflection compared with the surrounding area may be observed. Exhibit III-18 provides an example of this phenomenon.

The amount of floating product required for these observations, and the conditions that cause them requires further research. As a result, the use of GPR to detect contamination is still experimental.

Electrical Resistivity

Electrical resistivity surveys are primarily used for determining site stratigraphy. On occasion, as a secondary aspect of the survey, this method may present evidence of LNAPL contamination (DeRyck, 1993). In order for this method to be successful, a number of conditions must exist at a site. Groundwater must be no more than 15 feet deep, conductive soils must be present in the contaminated zone, and floating product must exist (although the minimum quantity is unknown). Because this method is relatively expensive and success in locating hydrocarbon contamination is not predictable, it is not typically used for the sole purpose of locating petroleum plumes.

Exhibit III-18
Petroleum Contamination Detected With Ground Penetrating Radar



Source: U.S. EPA, 1995

Geophysical Equipment Manufacturers

A list of geophysical equipment manufactures is included below in Exhibit III-19 and a matrix of their products is presented in Exhibit III-20. The equipment has not been evaluated by the EPA and inclusion in this manual in no way constitutes an endorsement. These vendors are listed solely for the convenience of the reader.

Exhibit III-19
Geophysical Equipment Manufacturers

Bison Instruments, Inc. 5708 West 36th Street Minneapolis, MN 55416-2595 Tel: (612) 931-0051 Fax: (612) 931-0997	Geometrics 395 Java Dr. Sunnyvale, CA 94089 Tel: (408) 734-4616 Fax: (408) 745-6131
Geonics Limited 8-1745 Meyerside Dr. Mississauga, Ontario Canada L5T 1C6 Tel: (905) 670-9580 Fax: (905) 670-9204	Geophysical Survey Systems, Inc. 13 Klein Dr. North Salem, NH 03073-0097 Tel: (603) 893-1109 Fax: (603) 889-3984
GeoRadar, Inc. 19623 Vis Escuela Dr. Saratoga, CA 95070 Tel: (408) 867-3792 Fax: (408) 867-4900	GeoStuff, Inc. 19623 Vis Escuela Dr. Saratoga, CA 95070 Tel: (408) 867-3792 Fax: (408) 867-4900
GISCO 900 Broadway Denver, CO 80203 Tel: (303) 863-8881 Fax: (303) 832-1461	Oyo-Geosciences, Inc. 7334 North Gessner Houston, TX 77040 Tel: (800) 824-2319 Fax: (713) 849-2595
Phoenix Geophysics, Ltd. 3871 Victoria Park Ave. Unit No.3 Scarborough, Ontario Canada M1W 3K5 Tel: (416) 491-7340	Scintrex, Ltd. 222 Snidecroft Rd. Concord, Ontario Canada L4K 1B5 Tel: (905) 669-2280 Fax: (905) 669-6403
Sensors and Software, Inc. 5566 Tomken Rd. Mississauga, Ontario Canada L4W 1P4 Tel: (905) 624-8909 Fax: (905) 624-9365	Zonge Engineering and Research Organization, Inc. 3322 East Fort Lowell Rd. Tucson, AZ 85716 Tel: (602) 327-5501 Fax: (602) 325-1588

Exhibit III-20
Matrix Of Manufacturers And Equipment[1]

	Borehole	Electro-magnetic Methods	Electrical Resistivity	Ground Penetrating Radar	Metal Detection	Magnetometry	Seismic Methods
Bison	✓		✓			✓	✓
Geometrics		✓				✓	✓
Geonics	✓	✓			✓		
GSSI				✓			
GeoRadar				✓			
GeoStuff	✓						✓
GISCO		✓	✓			✓	✓
Oyo	✓	✓	✓	✓	✓	✓	✓
Phoenix		✓					
Scintrex	✓		✓			✓	
SSI				✓			
Zonge		✓	✓		✓		

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[1] This matrix presents only a general list of the equipment manufactured that is discussed in this chapter. These manufactures *may manufacturer other geophysical equipment in addition to what is listed here. In addition, these manufacturers may only supply* specialized equipment for the listed methods, and not necessarily all the equipment that is needed.

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Chapter IV

Soil-Gas Surveys

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Chapter IV
Soil-Gas Surveys

Soil-gas surveys are defined as the collection, analysis, and interpretation of soil-gas data. As such, soil-gas surveys provide information on the soil atmosphere in the vadose zone that can aid in assessing the presence, composition, source, and distribution of contaminants. Soil-gas surveys can provide relatively rapid and cost-effective site data that can help direct more costly and invasive techniques. Although, they are typically performed early in the expedited site assessment (ESA) process, soil-gas surveys can also be used to monitor underground storage tanks (USTs) for releases, to evaluate remediation effectiveness, and to assess upward migration of vapors into buildings for risk assessments.

There are two basic types of soil-gas surveys commonly performed during UST site assessments. The first type is the active soil-gas survey in which a volume of soil gas is pumped out of the vadose zone into a sample collection device for analysis. The second type is the passive soil-gas survey in which a sorbent material is left in the ground so that contaminant vapors can be selectively adsorbed over time using the ambient flow of soil gas. Active soil-gas surveys can be completed in as little as one day and are most commonly used for sites with volatile organic compounds (VOCs). Passive soil-gas surveys take several days or weeks to complete and are most useful where semivolatile organic compounds (SVOCs) are suspected or when soils prevent sufficient air flow for active sampling.

This chapter provides a discussion of soil-gas principles affecting soil-gas surveys, the applicability and the essential elements of both active and passive soil-gas surveys, and case studies illustrating the effective use of both soil-gas surveying methods. Details on soil-gas sampling equipment are provided in Chapter V, Direct Push Technologies, and a discussion of soil-gas analytical methods is presented in Chapter VI, Field Methods For The Analysis Of Petroleum Hydrocarbons.

In order to understand the applicability and design of soil-gas surveys, it is important to first understand the parameters that control the migration of contaminants through the vadose zone. The primary controlling parameters are the physical and chemical properties of the contaminant, the site geology, and biological processes. This section contains brief descriptions of these parameters, how they affect various contaminants, and how they relate to the applicability of active and passive soil-gas sampling.

Physical And Chemical Properties Of Hydrocarbons

To assess whether soil-gas sampling is applicable to characterize subsurface contamination at an UST site, the potential for the contaminant to be present in the vapor phase first needs to be evaluated. Petroleum products stored in USTs, such as gasoline, diesel fuel, and kerosene, are complex mixtures with more than 100 different compounds, each with a different degree of volatility. Therefore, individual constituents must be assessed independently. The degree to which a chemical will partition into the vapor phase is primarily controlled by the compound's vapor pressure and its Henry's law constant.

Vapor Pressure

Vapor pressure is one of the most important constituent characteristics for determining if a particular hydrocarbon can be detected as a gas in the source area. The vapor pressure of a constituent is a measure of its tendency to evaporate. More precisely, it is the pressure that a vapor exerts when it is in equilibrium with its pure liquid or solid form. As a result, the higher the vapor pressure of a constituent, the more readily it evaporates into the vapor phase. As a general rule, vapor pressures higher than 0.5 mm Hg are considered to be detectable with active methods. Occasionally, constituents with lower vapor pressures can be detected, but the soil concentrations must be high and the geological formation should be permeable. If the contaminant is dissolved in groundwater or soil moisture, Henry's law constant must be considered along with the vapor pressure to determine the potential for detection (see below). Exhibit IV-1 lists the vapor pressures of selected petroleum constituents.

Gasoline contains a number of hydrocarbons that have sufficient vapor pressures to be easily sampled with active soil-gas surveying methods. Jet fuel,

Exhibit IV-1
Vapor Pressure And Henry's Law Constant Of Various Organic Compounds At 20° C

Compound	Vapor Pressure (mm Hg)	Compound	Henry's Law Constant (dimensionless)
n-Butane	1560	n-Hexane	36.61
Methyl *t*-butyl ether	245	n-Butane	25.22
n-Hexane	121	Ethylbenzene	0.322
Benzene	76	Xylenes	0.304
Toluene	22	Toluene	0.262
Ethylbenzene	7	Benzene	0.215
Xylenes	6	Methyl *t*-butyl ether	0.018
Naphthalene	0.5	Naphthalene	0.018

* Values above dotted line indicate active active soil-gas sampling methods are appropriate.

diesel fuel, and kerosene contain SVOCs that can be actively sampled only under optimal conditions. Lubricating and waste oils contain mainly low volatility compounds and cannot be directly sampled through active methods. Passive sampling methods, which are more successful in detecting SVOCs, may be successful in detecting some low volatility compounds.

Henry's Law Constant (Water To Vapor Partitioning)

Henry's law constant is a measure of a compound's tendency to partition between water and vapor. This constant can be used to estimate the likelihood of detecting a constituent in the vapor phase that had dissolved in soil moisture or groundwater. There are several ways to express this constant, but the most useful way is in the dimensionless form. Henry's law constant can be obtained by dividing the equilibrium concentration of a compound in air with the equilibrium concentration of the compound in water (at a given temperature and pressure). Because the units on both values are the same, the resulting constant is dimensionless.

Compounds with a greater tendency to exist in the vapor phase have a Henry's law constant greater than 1, compounds with a greater tendency to exist in water have a Henry's law constant less than 1. Henry's law constants for several common constituents found in petroleum products are shown in Exhibit IV-1.

Notice that alkanes (chained hydrocarbons [*e.g.*, butane, hexane] commonly found in gasoline) have Henry's law constant values two orders of magnitude greater than aromatics (ringed hydrocarbons [*e.g.*, benzene, toluene]). In a state of equilibrium, 36 molecules of hexane will exist in the vapor phase for every molecule of hexane dissolved in water. Whereas, for every five molecules of benzene dissolved in water, only one will be found in the vapor phase. Consequently, if equal volumes of alkanes and aromatics have been spilled on a site, in the source area alkanes will be found in much higher concentrations in the soil gas. However, because alkanes partition out of the dissolved phase to a greater extent, aromatics are more likely to provide an indication of dissolved contaminant plumes. In addition, vapor phase concentrations of compounds such as methyl *t*-butyl ether (MTBE) or naphthalene will not be useful indicators of contamination in soil gas outside the source area because they tend to remain dissolved in water.

In general, compounds with Henry's law constants greater than 0.1 are considered to be detectable with active soil-gas sampling if the vapor pressure is also sufficient and geologic conditions are favorable. Constituents with slightly lower values may also be detectable if initial concentrations are high. Passive soil gas techniques are able to detect compounds with lower Henry's law constants, however, a precise limit of detection cannot be estimated because site conditions, exposure times, and product sensitivities will vary.

Geologic Factors

The most important geologic factor in the movement of soil gas through the vadose zone is soil permeability, a measure of the relative ease with which rock, soil, or sediment will transmit a gas or liquid. Soil permeability is primarily related to grain size and soil moisture. Soils with smaller grain sizes, and hence smaller pore spaces, are less permeable. Clays, having the smallest grain size, significantly restrict soil vapor migration.

Soil moisture decreases permeability because moisture trapped in the pore space of sediments can inhibit or block vapor flow. Since soil moisture content varies seasonally and geographically, effective air permeabilities are often unknown prior to sampling. For active soil-gas surveys, soil-air permeability testing should be conducted in vertical profiles at select locations in order to optimize sampling depth. For passive soil-gas surveys, soil-air permeability is important but usually not determined because additional equipment is required.

In addition, there are several other soil factors that can create misleading information about the location of contamination. Preferential pathways (*e.g.*, tree roots, soil cracks, utilities, backfill) and vapor impervious layers (*e.g.*, clay layers, foundations, buried pavement, perched groundwater) are features that should be evaluated. Moreover, adsorption of hydrocarbons on soils with high percentages of clay or organic matter can limit partitioning of contaminants into the vapor phase.

Although active soil-gas sampling is applicable for all soil types except tight clays, it is generally ineffective when the soil moisture is above 80- to 90-percent saturation (Corey, 1986) because of the absence of connected air-filled pores. High soil moisture conditions can be overcome with sampling procedures (*e.g.*, minimizing sample volume, increasing the air volume around the tip, waiting for equilibrium to take place), but these procedures can often be very time consuming.

Passive soil-gas sampling is generally useful in all soil types and conditions, however, sediments with low intrinsic permeabilities and high degrees of saturation can affect both the quantity of contaminants coming into contact with the sampler and the quantity of contaminant that is adsorbed. For example, the presence of a dense moist clay lense will reduce the amount of vapor that contacts a sampler directly above it. In addition, Werner (1985) demonstrated that activated carbon, a common soil-gas adsorbent, will adsorb significantly less TCE with increasing relative humidity levels. Other contaminants may, therefore, also be adsorbed to a lesser degree under humid conditions. Although passive soil-gas sampling remains more sensitive to contaminant detection than active soil-gas sampling under low permeability and high humidity, geologic heterogeneities in the subsurface can also affect passive soil-gas results.

Biodegradation

Biodegradation of VOCs in the vadose zone can reduce the ability to detect the contaminants in soil gas. Petroleum hydrocarbons are readily degraded by microorganisms to produce increased levels of numerous gases (*e.g.*, carbon dioxide, hydrogen sulfide, methane) while decreasing the concentration of oxygen. The rate of biodegradation is controlled by several factors, including soil moisture content, concentration of electron acceptors (*e.g.*, oxygen) available nutrients in the soils, contaminant type, and soil temperatures.

Sampling for soil gases affected by biodegradation (*e.g.*, oxygen, carbon dioxide, methane, hydrogen sulfide) can provide useful information about the contaminant source area and plume, provided background samples are collected in a neighboring uncontaminated area. Measurement of these parameters is most useful when active soil-gas sampling is being employed and the contaminant is a semivolatile or non-volatile compound, or if a volatile contaminant is known to exist but has not been directly detected.

Summary

Detection of individual constituents by both active and passive soil-gas sampling methods is limited by the physical and chemical properties of hydrocarbons. General parameters for selecting active soil-gas sampling are presented in Exhibit IV-2. Passive soil-gas sampling methods are more sensitive than active soil-gas sampling, but individual manufacturers should be contacted for specific compounds that can be detected.

Vapor pressure and Henry's law constant are indicators of the potential of a method to detect a specific constituent. For active sampling, the vapor pressure should be above 0.5 mm Hg. If contamination is dissolved in soil moisture or groundwater, the Henry's law constant should also be above 0.1. Geologic factors (*e.g.*, clay layers, high soil moisture content) will affect both active and passive sampling capabilities, but passive sampling will generally provide more sensitive results under these conditions. In addition, the byproducts of biodegradation can provide valuable information in active soil-gas sampling for indirect detection of contaminants.

Exhibit IV-2
Summary Of General Active Soil-Gas Sampling Criteria*

Vapor Pressure > 0.5 mm Hg

Henry's Law Constant > 0.1

Degree Of Saturation < 80%

Sampling Zone Is Free Of Clay

* Active sampling may still be useful for the indirect detection of contaminants below these vapor pressure and Henry's law constant values.

Active Soil-Gas Sampling Methods

Of the two soil-gas sampling methods--active and passive--active soil-gas sampling is the method typically used for site investigations where VOCs are the primary constituents of concern. This method allows for rapid soil-gas collection from specific depths by analyzing soil gas that has been pumped from the ground through probe holes. The samples are typically analyzed on-site so that real-time data can be used to direct further sampling. VOCs can be detected directly with soil-gas sampling methods, while SVOCs and low volatility organic compounds may be detected indirectly through the measurement of gases (O_2, CO_2, H_2S, CH_4) influenced by biogenic processes.

Active soil-gas surveying was initially utilized by the oil industry in the 1960s to monitor gas control systems, track gas migration off-site, and evaluate resources. It was first applied to VOC site assessments in the early 1980s and rapidly gained popularity as a screening tool to detect and delineate subsurface contamination.

Samples are collected by inserting a sampling device into a borehole, usually with a slam bar, a direct push system, or a hollow stem auger. Most sampling devices consist of screens or ports that are pushed directly into the ground or inserted through the insides of drill rod or pipe. Soil gas is drawn through the port or screen through plastic (primarily polyethylene or Teflon™) or metal tubing and into a collection vessel using a vacuum device. The port or screen, tubing, sample vessel, and vacuum source are collectively referred to as the "sample train." For a more detailed discussion of soil-gas sampling equipment refer to Chapter V, Direct Push Technologies.

As active soil-gas sampling has evolved and become more cost effective through the application of direct push technology, on-site analysis of soil-gas samples by mobile laboratories utilizing transportable gas chromatographs has become more common. Mobile laboratories provide quantitative chemical data with rapid turnaround time and do not necessitate the packaging and shipping of samples. Other useful pieces of analytical equipment include total organic vapor detection instruments, such as photoionization detectors (PID) and flame ionization detectors (FID), field portable gas chromatographs, and detector tubes. Assessment objectives must be considered in the selection of analytical methods because capabilities and limitations are extremely variable. A detailed discussion of analytical methods for soil-gas analysis is provided in Chapter VI, Field Methods For The Analysis Of Petroleum Hydrocarbons.

Applications For Active Soil-Gas Sampling

Active soil-gas sampling can be an important aspect of an ESA because it provides the ability to assess many different aspects of a site in a short period of time, typically in 1 to 3 days. Active soil-gas sampling can help the investigator:

- Identify releases;
- Identify sources of contaminants;
- Identify the types of VOCs present in the vadose zone;
- Provide an indication of the magnitude of VOC and SVOC contamination;
- Infer contaminant distribution of SVOCs and low volatility organic hydrocarbons by measuring indicators of biodegradation;
- Optimize the placement of soil borings and monitoring wells;
- Monitor potential off-site sources;
- Collect data that could be useful in the design of soil vapor extraction (SVE) or bioventing systems;
- Assess the potential for upward migration of vapors in buildings; and
- Monitor the effectiveness of remedial systems.

One major advantage of active soil-gas sampling is that data can be collected from discrete depths for vertical profiling of contaminant concentrations and relative air permeabilities in the vadose zone. This information helps to provide a 3-dimensional conceptualization of the contaminant distribution and allows for calculation of upward and downward contaminant fluxes.

Active Soil-Gas Survey Design

Although active soil-gas surveys are a rapid and effective way to focus subsequent assessment methods, several procedures are needed to ensure that the data provided are valid. The following section describes some of the essential elements required for a successful active soil-gas survey.

Review Existing Site Information

Investigators should review and evaluate existing site information in order to make an initial determination of the applicability of active soil-gas sampling (refer to previous section). If active sampling is appropriate, this information will also help the investigator select sampling locations. Information to be reviewed may include:

- Type of contaminant and suspected release mechanism (*e.g.*, spills, leaks);

- Estimates of volume of contaminant discharged;
- Length of time contaminant has been present;
- Stratigraphy of the site;
- Depth of groundwater, direction and rate of flow;
- Map of site facility with subsurface structures (*e.g.*, tanks, sewers, piping, wells); and
- Reports of site inspections.

Preliminary Measurements For Soil-Gas Sampling

There are three conditions that should be assessed prior to sampling, to determine how soil-gas samples should be extracted and to ensure that the samples are representative of subsurface conditions: Relative soil-air permeability, purge volume and rates, and subsurface short circuiting.

Relative Soil-Air Permeability Testing

Relative soil-air permeability can help to assess the influence of geologic materials and the moisture content at the locations tested. An estimate can be calculated by comparing air flow data with the corresponding vacuum pressure or more accurately by using a pressure transducer. Low permeability zones should be identified to help interpret the data.

Purge Volume And Rates

Prior to initiating sampling at a site, tests should be conducted to optimize the purge volume and rates. Generally, these tests should be conducted in various soil types encountered at the site and in the areas of suspected elevated VOC concentrations. The tests are performed by varying the purge volume and rates at a single location while samples are being taken. Optimal sampling conditions occur when contaminant concentrations stabilize.

Subsurface Short Circuiting

Purge volume and rate tests should also be used to check for subsurface short circuiting with the above-ground atmosphere. This condition is indicated when contaminant levels decrease rapidly or when atmospheric gases (*e.g.*, atmospheric oxygen levels) are detected. Sometimes indicator VOCs (*e.g.*, pentane) are placed on a rag near the probe hole. In order to prevent short circuiting, it is important to seal the probe hole, typically with wet bentonite. In addition, the drive-point should not be larger than the diameter of the probe because the open space created by the drive-point would provide a conduit for atmospheric gases to travel.

Initial Sampling

Initial sampling points are usually located in potential source areas. The proposed sampling locations should be located on a facility map with subsurface structures noted. Additional sampling points need to be considered along possible conduits (*e.g.*, sewer lines, trenches, utility vaults, pipelines) where contaminants may preferentially migrate. Sampling may also be organized along a standard orthogonal grid.

Sampling Depth

The depth of sampling will vary depending on the depth to groundwater and the stratigraphy of the site. Active soil-gas sampling in a vertical profile is necessary to determine the permeable horizons and vertical contaminant distributions. Initial profiles should be completed in known or suspected source areas and in areas where elevated VOCs are detected. If liquid phase hydrocarbon delineation is the objective, soil-gas surveys should be collected just above the water table.

Sample Spacing

Sample spacing depends primarily on the objectives of the investigation, the size of the site, and the size of potential contaminant sources. At 1- or 2-acre USTs sites, initial spacing is generally between 10 and 50 feet. When trying to track down the source at a major industrial site, spacing may be as great as 400 or 500 feet. Sufficient soil-gas data from shallow and deeper vadose zone horizons should also be collected to provide a 3-dimensional distribution of the contaminants. The spacing between vertical samples depends primarily on the depth to groundwater and the objectives of the investigation. Data should be integrated into maps and contoured in the field to determine if additional sampling locations are necessary. As a general rule, if two sampling points have a 2 to 3 orders of magnitude change, samples should be collected in the area between the two points.

Sample Containers

There are four commonly used sample containers, each with different advantages and limitations. Stainless steel canisters are durable, but they can be difficult to decontaminate. Glass bulbs are easy to decontaminate, but they are breakable and may have leakage through the septa. Tedlar® bags are easy to handle and leakage is readily apparent, but some contaminants may sorb onto the bag (for the primary gasoline constituents, however, this is not a problem). Syringes are inexpensive and allow for easy collection of samples, but they have short holding times and are difficult to decontaminate. Although no sampling container is perfect, problems are minimized by analyzing samples as soon as possible after collection.

Quality Assurance/Quality Control Procedures

There are numerous QA/QC procedures that must be undertaken during an active soil-gas survey to ensure that the samples are representative of subsurface conditions. The following list is not comprehensive for all site conditions or equipment; rather, it contains the primary issues that regulators should check when they evaluate active soil-gas survey reports. QA/QC procedures include:

- All soil-gas surveys should be collected following the same procedures.
- Sampling should be completed in a relatively short period of time (*e.g.*, hours, days) because temporal variations such as temperature, humidity, barometric pressure, and rain can affect contaminant concentrations.
- Decontamination procedures should be practiced to prevent contaminant gain or loss that results from adsorption onto sampling equipment.
- The insides of the sample train components should be as dry as possible because water can raise or lower contamination values.
- Ambient air present in the sample train must be purged prior to sample collection.
- When sampling directly through probe rods, the sample train connections should be checked prior to collecting each sample to ensure they are air-tight.
- Annular space between the side of the borehole and the installation device (*e.g.*, probe rod) should be sealed at the ground surface with a bentonite paste or similar material.
- Blank samples should be tested regularly to ensure that decontamination procedures are adequate and to determine background VOC levels.
- Duplicate soil-gas samples should be collected each day (generally 1 for every 10 samples) to assess the reproducibility of the data.
- Sample containers should be monitored for leakage.

Interpretation Of Active Soil-Gas Data

A thorough understanding of the capabilities of the active soil-gas sampling methods and the site conditions is necessary for avoiding over-interpretation of the soil-gas survey results. Soil-gas concentrations must be compared with stratigraphic and cultural features in order to determine how soil-gas migrates and how contaminants are distributed. Subsurface barriers (*e.g.*, clay lenses, perched groundwater, infrastructure, buildings) and secondary pathways (*e.g.*, utility trenches, animal burrows) can cause soil-gas distribution to be significantly different than soil and groundwater contamination. As a result, stratigraphic cross-sectional maps should be used to evaluate vertical concentrations. Trends noted should be evaluated to assess whether they are associated with soil types, chemical migration, influence of diffusion from groundwater, potential preferential pathways, or obstructions.

Interpretation of the soil-gas data should begin in the field. Posting the data on a site map as the results are reported will help to direct and refine the sampling program. The final results of the soil-gas survey are usually presented in maps showing contours of gas concentrations at various subsurface depths. Sample depths should be corrected for site elevation changes so that the contour represents a horizontal layer. By creating several horizontal contours, data can be analyzed in 3-dimensions. Plotting total VOCs is often the easiest method, but it is important to evaluate if differing sources exist by examining the distribution of individual constituents.

An example of this type of analysis is the use of the ratio between pre-benzene hydrocarbons (*i.e.*, constituents that pass through a gas chromatograph column prior to benzene) to total VOCs to determine the relative length of time a contaminant has been present. Since the pre-benzene constituents of gasoline migrate more rapidly than other hydrocarbons, a relatively high ratio will indicate a more recent release while a low ratio will indicate an older release. Because there are many factors that affect the absolute ratio, the ratios can only be used to compare multiple releases at a single site.

An additional issue that is important for interpretation of results is analysis of the units of measurement. Commonly, two types of units are used for reporting soil-gas data: Volume per volume (*e.g.*, ppm_v or ppb_v) or mass per volume (*e.g.*, $\mu g/l$ or mg/m^3). Although for water, $\mu g/l$ is equivalent to ppb, this is not true for gases. If concentrations are reported in $\mu g/l$, a conversion may be required. For samples analyzed at 20° C and 1 atm pressure:

$$ppb_v = \mu g/l \quad \times \quad \frac{2.447 \times 10^4}{\text{molecular weight of the gas.}}$$

Costs Of Active Soil-Gas Surveys

Because the sampling and analytical equipment used in active soil-gas surveys varies considerably according to the site conditions, the survey objectives, and the investigator preferences, the cost will also vary considerably. Most soil-gas surveys are performed using direct push (DP) technology. The cost of collecting active soil-gas surveys with truck mounted DP ranges from $1,000 to $2,000 per day. In some cases, DP can be deployed manually, which may be less expensive. Typically, 10 to 30 samples can be collected per day depending primarily on soil type, sampling depths, and sampling method. Numerous field analytical methods are applicable for soil-gas surveys (listed in Chapter VI, Field Methods For The Analysis Of Petroleum Hydrocarbons), however, portable and transportable gas chromatographs are most common because of their high data quality level capabilities. Samples are rarely sent off-site to a fixed laboratory because on-site information is often used for determining subsequent sample locations and delays in analysis can affect data quality. Active soil-gas survey sampling can be completed in as little as 1 day at a 1-acre site and should rarely require more than 3 days. As a result, the cost of a complete soil-gas survey with a report will typically range from $3,000 to $15,000.

Active Soil-Gas Survey Case Study

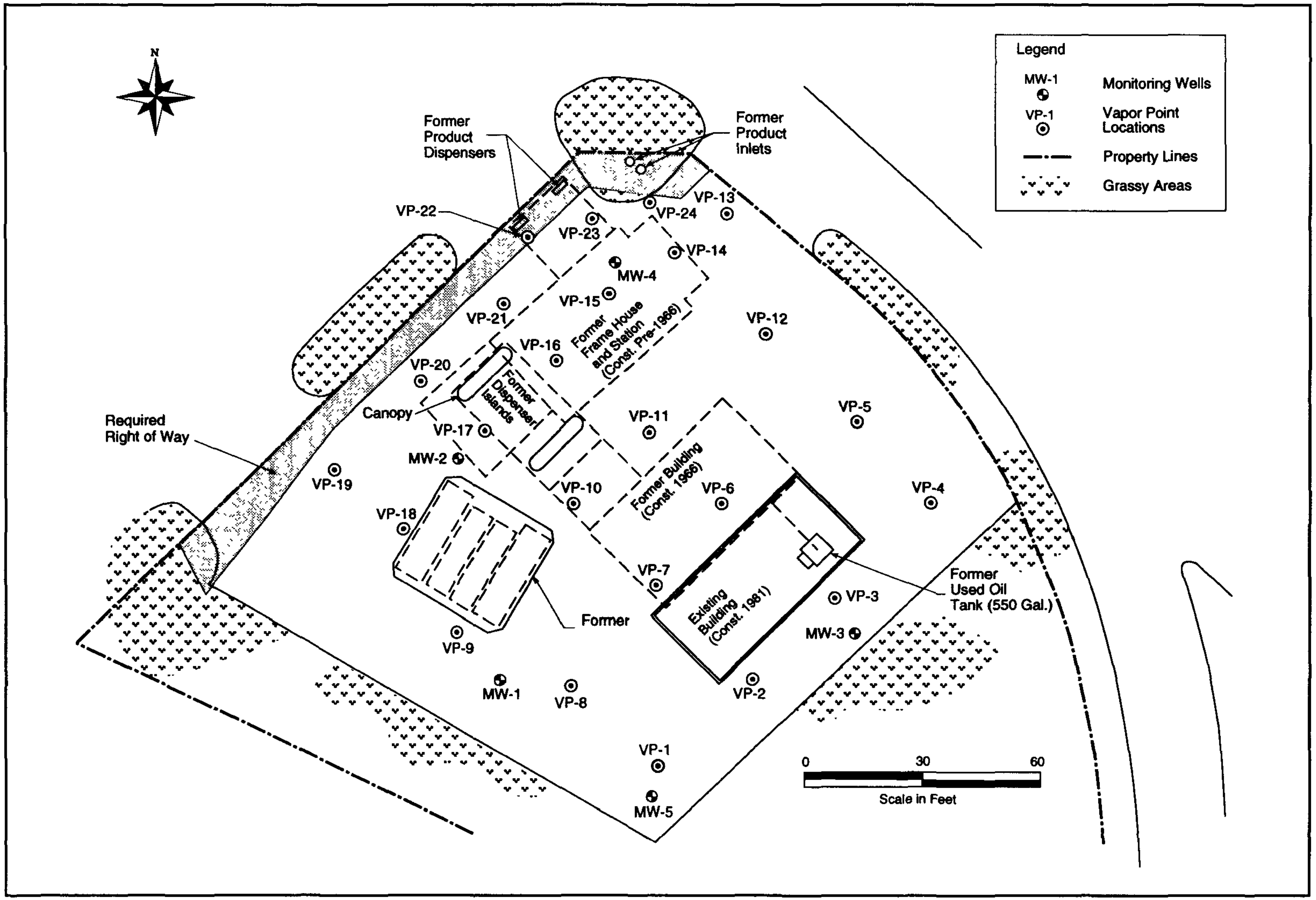
The following case study provides an example of the type of data that can be collected with an actual active soil-gas survey at an UST site and how it may be interpreted. A map of the site described in this case study, including the vapor point and monitoring well locations, is presented in Exhibit IV-3.

Site History

In 1966, a retail gasoline marketing company purchased an UST facility from an independent dealer. The facility had been operated as a gasoline station for an undetermined period of time; there were an unknown number of USTs on the property. The company reconstructed the facility shortly after the purchase date and remodeled in 1981. In 1991, the site was closed, and the tanks were removed. In order to remove petroleum-stained soil, the tank pit and piping trenches were over-excavated. Five monitoring wells were installed to determine if groundwater had been contaminated. The results indicated that groundwater remained uncontaminated; however, a high degree of soil contamination was discovered in MW-4, and significantly less contamination was discovered in MW-1. In addition, monitoring well data indicated that the water table was located at approximately 21 feet and the gradient flowed to the south.

Exhibit IV-3

Active Soil-Gas Survey Site Map With Vapor Point And Monitoring Well Locations



Source: Integrated Science and Technology, Inc.

Soil-Gas Survey Objective

The main objective of the survey was to determine the risk of contaminant migration. Emphasis was placed on source identification and delineation because of the multiple ownership history of the facility and the potential for multiple responsibilities for the contamination.

Sampling And Analytical Methods

The site was divided into a grid with spacing of 30 feet by 30 feet. Twenty-four sampling locations were established, providing comprehensive areal site coverage. A small-diameter steel probe sampler with a slotted terminal end was driven into the subsurface with a mechanical hand-held hammer. An electric vacuum pump was used to purge the system for 5 minutes prior to sampling. Samples were collected with a gas-tight glass syringe and immediately analyzed with a field portable GC/PID.

In order to assess the soil heterogeneities, vertical profiling was performed at all 24 locations. Sampling depths were at 3, 6, 9, 12, 15, and 18 feet. When no significant contamination was indicated, samples were only taken at the first two or three levels. A total of 87 samples was collected and analyzed over 3 days.

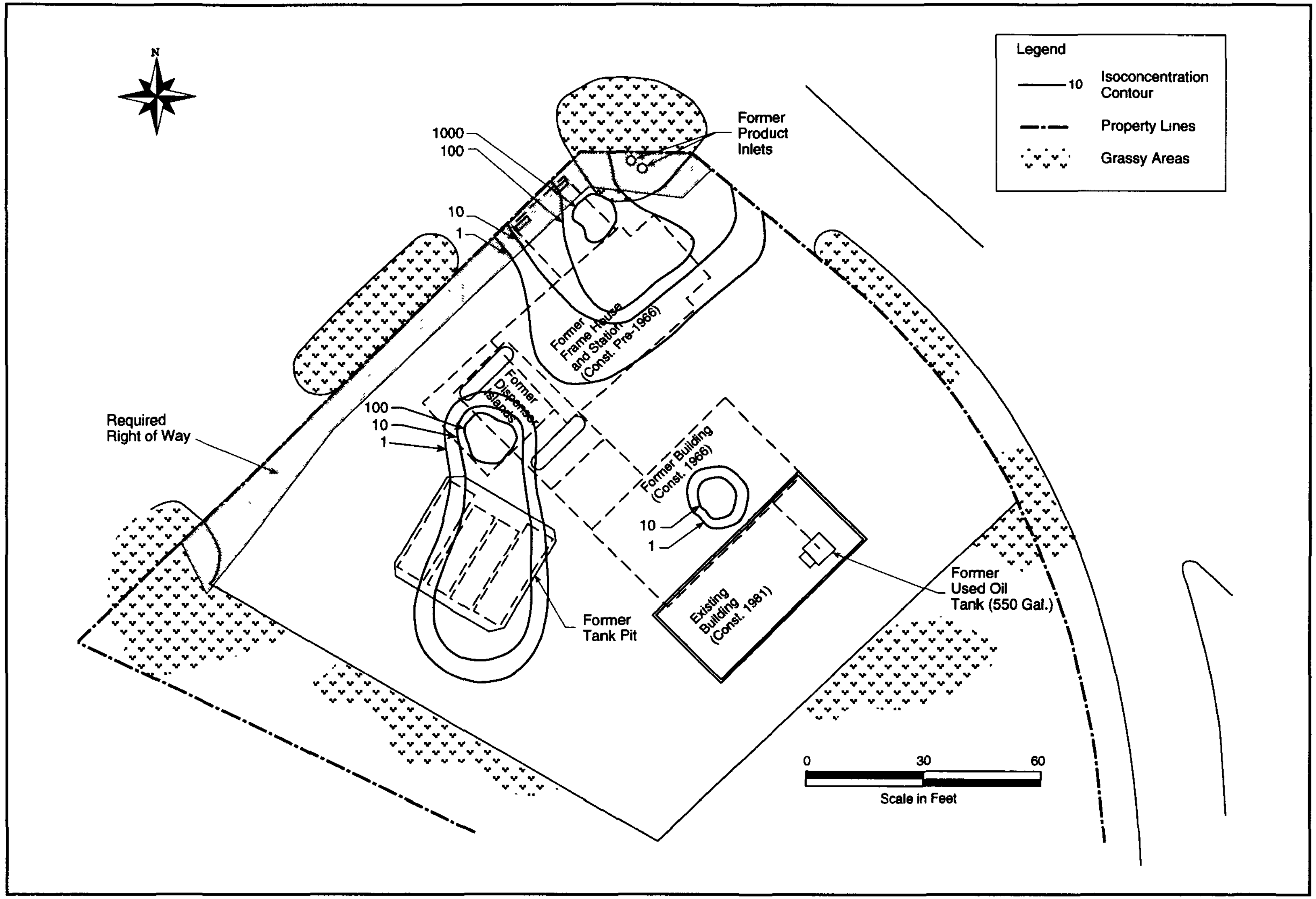
Results and Discussion

An evaluation of the vertical profiles indicated that the site geology was relatively homogenous, permeable, and appropriate for active soil-gas sampling. Short circuiting of the above-ground atmosphere was determined to not have affected the data. In total, all QA/QC procedures supported the validity of the data collected.

Exhibits IV-4 and IV-5 present the isoconcentration contours for total volatiles at 9 and 12 feet, respectively. The data indicated three separate areas of contamination. Most of the hydrocarbons were located at the north end of the station, directly under the former operation area (pre-1966). A smaller zone of contamination was located just north of the existing building and at the northwest side of the site, next to existing product line trenches. Multi-level sampling proved very useful at this site because if samples had been collected from only one level, only one release would likely have been identified.

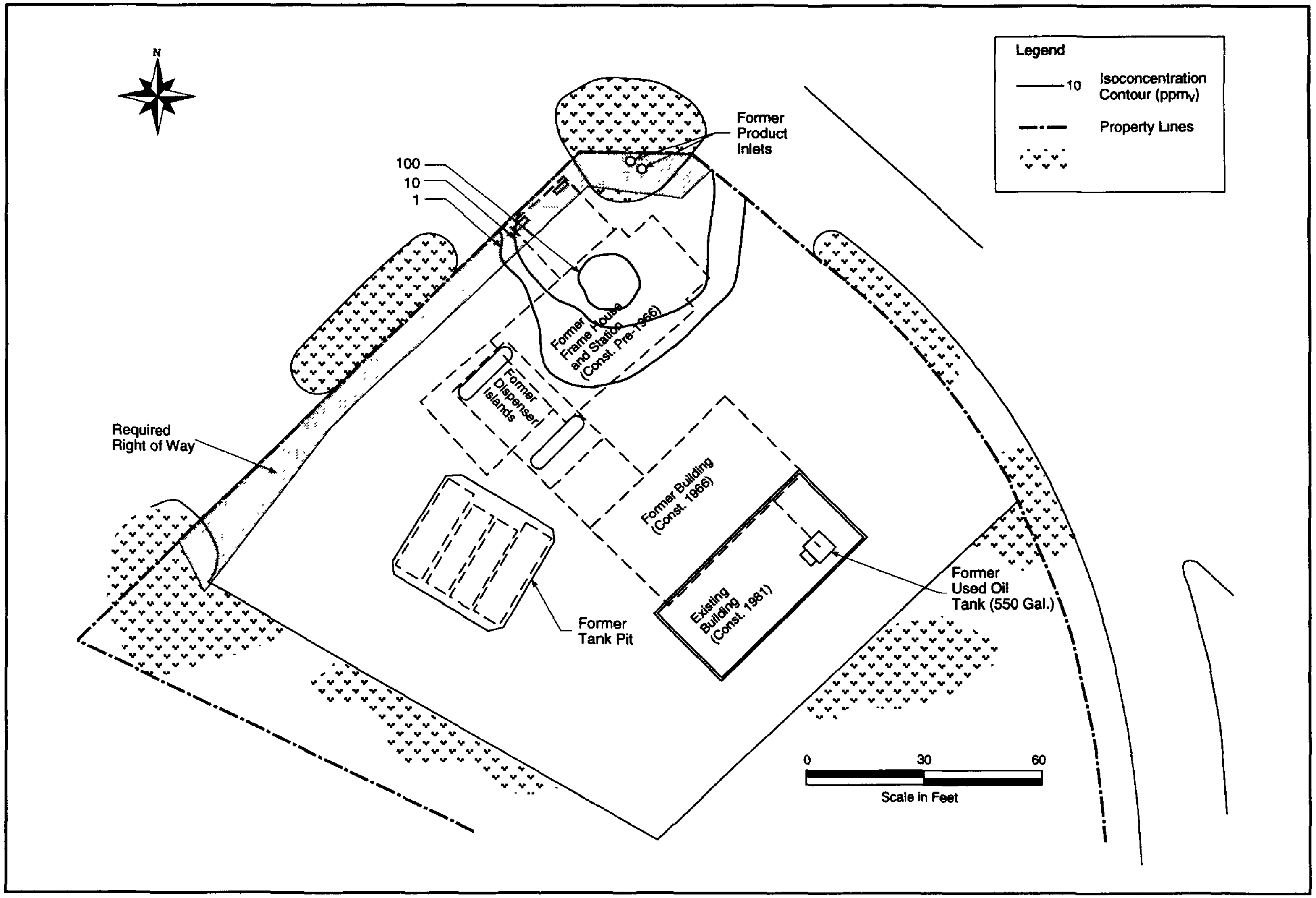
The absolute hydrocarbon vapor concentrations indicated the presence of moderately high levels of soil residual hydrocarbons, especially in the north

Exhibit IV-4
Active Soil-Gas Survey Plot Of Total Volatiles (ppm_v) Isoconcentrations At 9 Feet



Source: Integrated Science and Technology, Inc.

Exhibit IV-5
Active Soil-Gas Survey Plot Of Total Volatiles (ppm_v) Isoconcentrations At 12 Feet



Source: Integrated Science and Technology, Inc.

corner of the facility. The measurements at the 15 and 18 feet depth were lower than would be expected if floating product existed on the water table. In addition, the pre-benzene to total VOC ratio was examined for each sample to determine the relative age of the source areas. The data indicated that the source area in the north corner was significantly older than the other two areas. This evidence suggested that there were at least two--and possibly three--separate source areas.

Because the oldest and largest source area had been present for at least 25 years without contamination reaching the groundwater, and because there were no sensitive receptors in the vicinity, the state regulator determined that further remediation of this site was not necessary.

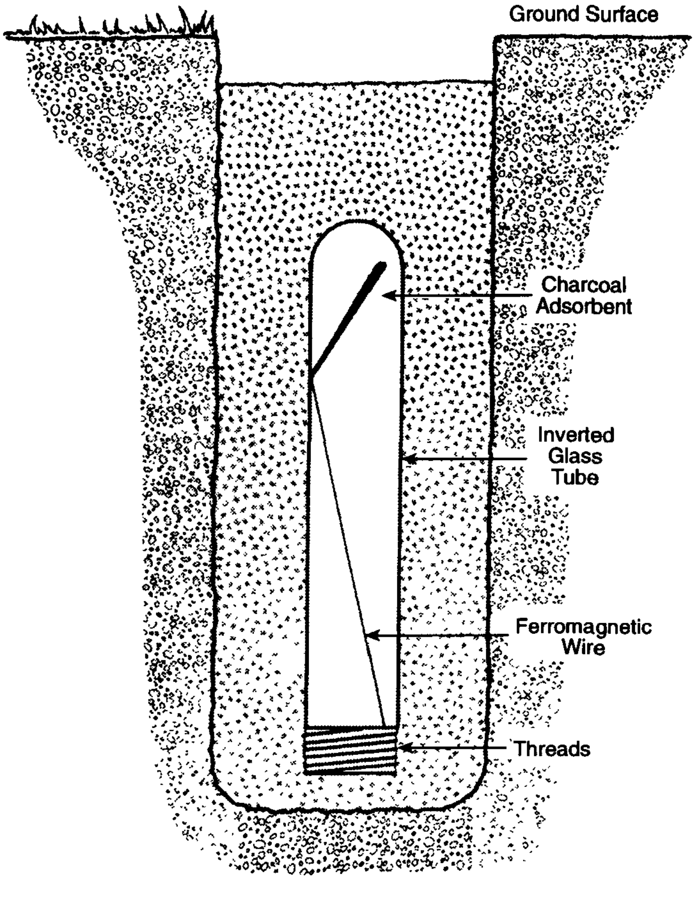
A summary of the advantages and limitations of active soil-gas surveys is presented in Exhibit IV-6.

Exhibit IV-6
Advantages And Limitations Of Active Soil-Gas Sampling

Advantages	Limitations
Samples can be analyzed on site for "real time" data reporting.	Not effective for identifying SVOCs or low volatility compounds.
From 10 to 30 samples can typically be collected and analyzed per day.	Extensive QA/QC must be followed.
Can delineate contaminant source area and plume of VOCs.	Cannot be easily conducted in very low permeability or saturated soils.
SVOCs and heavy petroleum product contamination can be inferred indirectly by measuring products of biodegradation.	Analytical equipment selected may not be capable of identifying all constituents present.

Of the two soil-gas sampling methods--active and passive--passive soil-gas sampling techniques are typically used when SVOCs or low volatility compounds are the primary constituents of concern. Passive soil-gas surveys utilize probes that are placed in the ground for days or weeks to adsorb soil-gas constituents on sorbent material using the ambient flow of vapors in the subsurface. After the probe is removed from the ground, it is sent to a laboratory where contaminants are desorbed and analyzed. An example of a passive soil-gas sampler is presented in Exhibit IV-7.

Exhibit IV-7
Example Of Passive Soil-Gas Sampler



Source: Kerfoot and Barrows, 1987

Applications For Passive Soil-Gas Sampling

Passive soil-gas surveys are not considered an expedited site assessment method because of the extended time required to collect and analyze the data. However, in certain applications, the passive devices may be used as a screening tool to help determine the soil and groundwater sampling location needed to complete a site assessment. Generally, passive sampling is most applicable when SVOCs are a primary concern, when numerous unknown compounds are suspected (*e.g.*, a Superfund site), or when subsurface conditions do not permit adequate penetration with DP methods for active soil-gas sampling. Capabilities of passive soil-gas surveys include:

- Providing an initial screening at very large sites;
- Screening the site for potential leakage from a UST or product line;
- Providing data on the types of contaminants present in the vadose zone, including a wide range of VOCs, SVOCs, and complex mixtures;
- Providing information on the lateral distribution of contaminants in the vadose zone;
- Identifying sources of contaminants; and
- Tracking a groundwater plume.

Passive Soil-Gas Survey Design

The specific survey design will vary between sites for a number of reasons including the size of the site, the survey objectives, and the capabilities of the sampler; however, some generalities can be presented. Sampling devices are placed just below the surface (between 3 inches and 4 feet) and can be quickly installed (between 2 and 15 minutes per device). A grid design is used because all sampling devices are analyzed at the same time (*i.e.*, analytical results do not affect sampling locations). The number of samples and their spacing vary but, in general, 15 to 30 samples are sufficient for a 1- to 2-acre gasoline station survey. Sampling devices are left in the ground for 3 to 21 days and then removed and typically shipped to the manufacturer's laboratory for analysis. Individuals installing the sampling devices must ensure that contamination does not occur prior to installation or after removal. Field blanks are, therefore, a necessary check on field procedures.

Interpretation Of Passive Soil-Gas Data

A report can usually be developed 2 to 3 weeks after removal of the sampling devices. The results are reported in the amount of contaminant detected per sorbent device. It is not possible to quantify the concentration of contaminants present in the soil gas using passive sorbent devices because the volume of gas contacting the sorbent material is unknown. The relative concentrations of analytes on the sorbent may be related more to differences in the affinity of individual VOCs for the sorbent (as well as sorbent capacity for that VOC) and vapor flow rates than to the relative VOC concentrations in soil gas. In addition, passive soil-gas surveys typically collect samples from a single depth which will provide only a 2-dimensional view of contaminant distribution. Usually there is not sufficient site-specific geologic information to make a judgement about the actual distribution of contaminants. For example, perched water tables may appear as clean zones, and changes in the data may be related to changes in the thickness of clay layers rather than changes in subsurface contaminant concentrations. As a result, although passive soil-gas surveys are an effective screening method, interpretation of the data is more limited than active soil-gas surveys.

Cost Of Passive Soil-Gas Surveys

The cost of passive soil-gas surveys varies among manufacturers of sampling devices, ranging from $75 to $225 per sample (including analysis). Because analytical costs for UST sites tend to be on the low end of this range and because sampling 15 to 30 locations is typical for a 1-acre site, most gasoline stations can be screened for between $1,200 and $3,000.

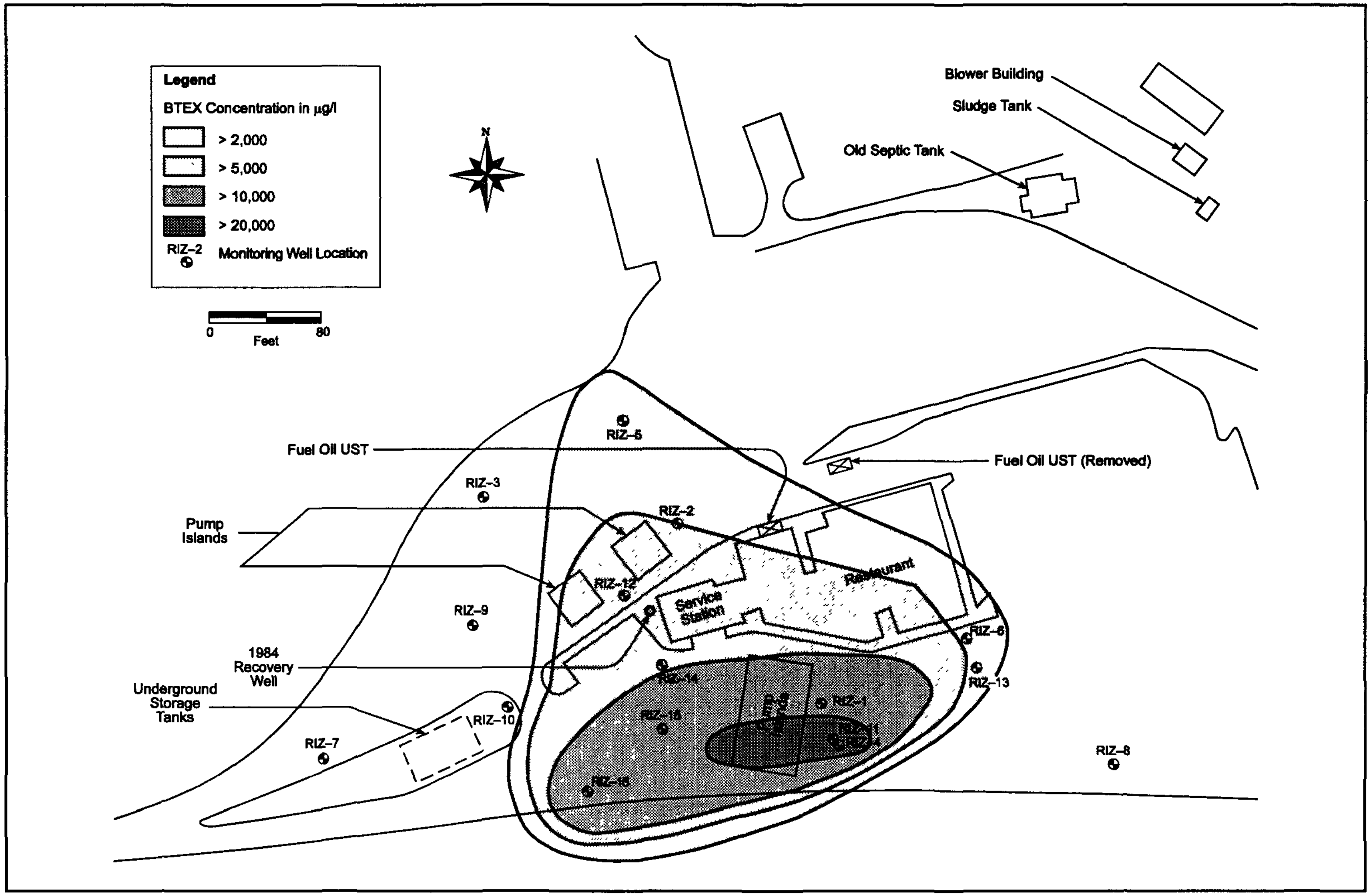
Passive Soil-Gas Survey Case Study

The following case study provides an example of the type of data that can be collected with an actual passive soil-gas survey at an UST site and how it may be interpreted. A site map is presented in Exhibit IV-8 with isoconcentration lines for BTEX in groundwater. Exhibits IV-9 and IV-10 present isoconcentration lines for diesel fuel and gasoline constituents in soil gas.

Site History

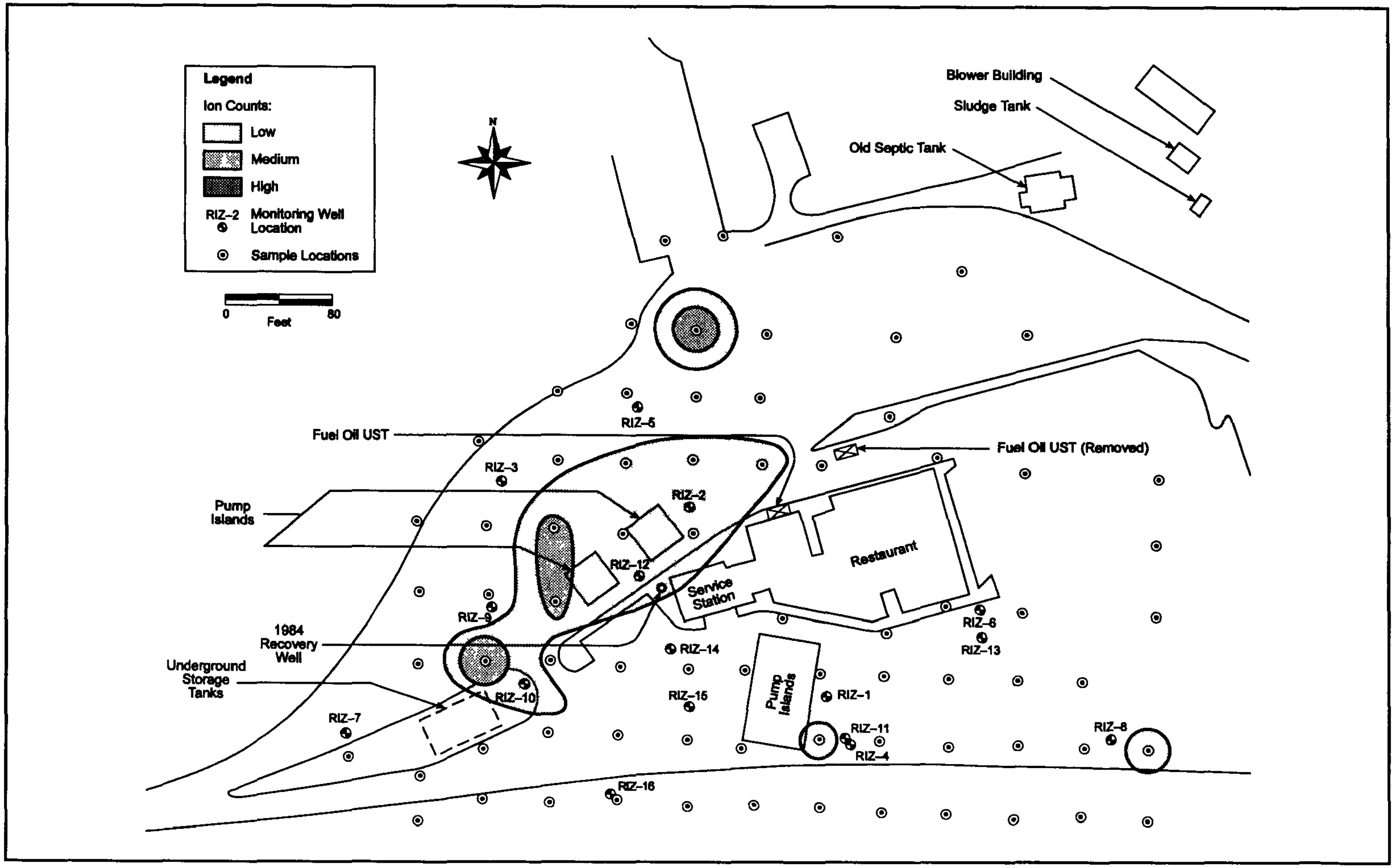
In 1990, a public highway agency began a systematic assessment of environmental site conditions at public refueling stations under its jurisdiction.

Exhibit IV-8
BTEX Distribution In Groundwater Based On Monitoring Well Data ($\mu g/l$)



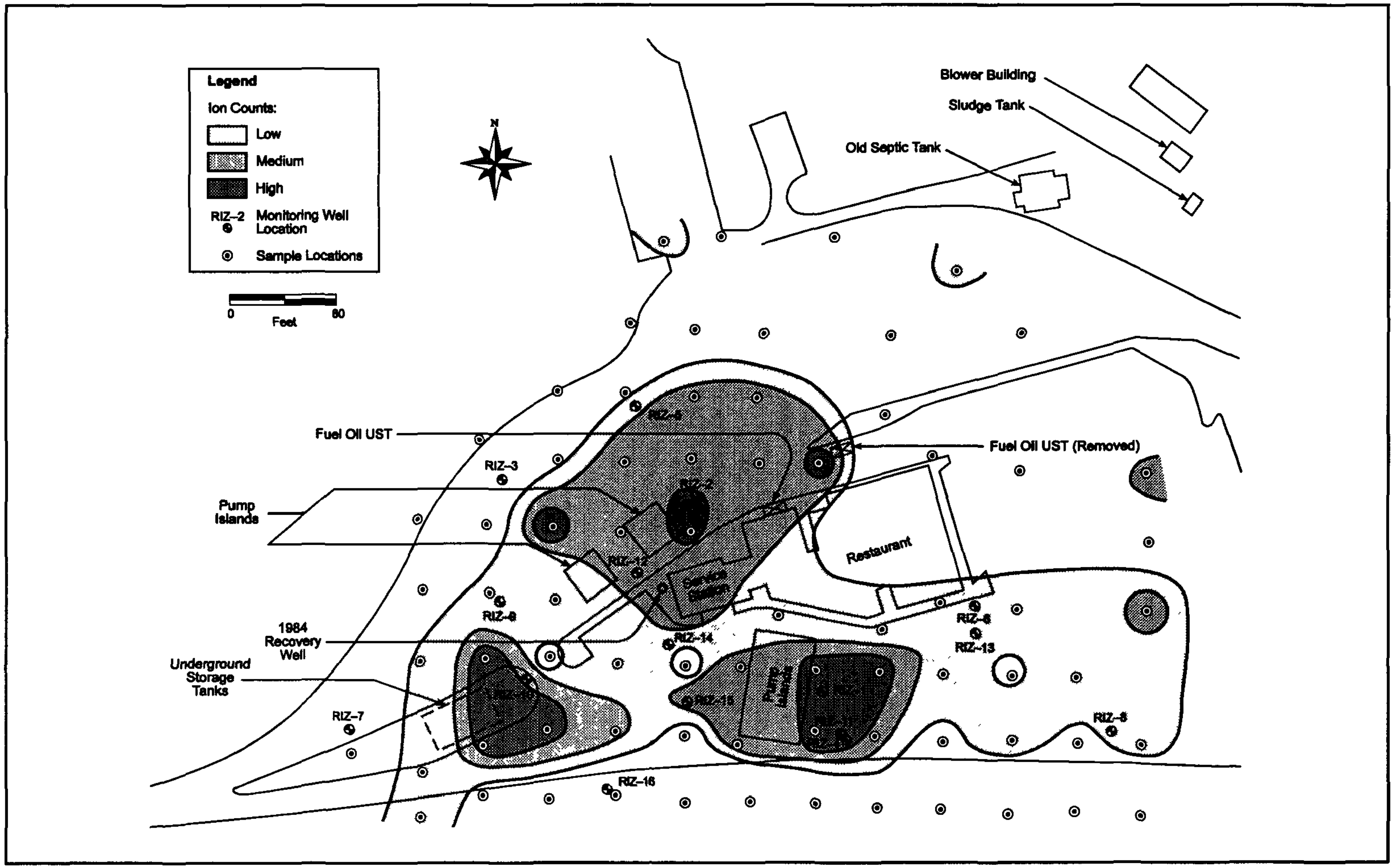
Source: Roberts et al., 1992 (Reprinted by permission of the National Ground Water Association, Westerville, Ohio. Copyright 1992. All rights reserved.)

Exhibit IV-9
Passive Soil-Gas Survey Results For Diesel Fuel Constituents (ion counts of naphthalene and alicyclic hydrocarbons)



Source: Roberts et al., 1992 (Reprinted by permission of the National Ground Water Association, Westerville, Ohio. Copyright 1992. All rights reserved.)

Exhibit IV-10
Passive Soil-Gas Survey Results For BTEX (ion counts)



Source: Roberts et al., 1992 (Reprinted by permission of the National Ground Water Association, Westerville, Ohio. Copyright 1992. All rights reserved.)

Records at one site indicated a significant degree of contamination and warranted further investigation. Diesel fuel and gasoline USTs were replaced in 1982 and 1990. Evidence of contamination was found at both tank removals. Records suggested the potential for substantial releases throughout the site history including a potential major release of about 8,000 gallons in 1983. Sixteen monitoring wells were initially installed, and free product was discovered in four of them (Exhibit IV-8). Because the site overlaid shallow bedrock at depths between 2 and 20 feet and because of the need to delineate the SVOCs found in diesel fuel, a passive soil-gas survey was conducted.

Soil-Gas Survey Objectives

The main objective of the survey was to determine the location of the contaminant source area to facilitate remediation. The direction of plume migration was also a concern, particularly in the underlying fractured bedrock, because several drinking water wells were located within 0.5 mile.

Sampling And Analytical Methods

Eighty canisters containing ferromagnetic wires coated with active carbon adsorbent were place in a grid pattern throughout the 3 acres of the site. The canisters were left in the ground for 11 days. After the canisters were retrieved, the samples were analyzed with a gas chromatograph/mass spectrometer. Data were reported as relative flux (ion counts) for both gasoline character (BTEX) and diesel fuel character (naphthalene and alicyclic hydrocarbons).

Results And Discussion

The passive soil-gas data provided useful information about the diesel fuel source area. Exhibit IV-9 indicates that the "hot spots" are between the pump islands and the diesel fuel UST. In addition, the passive soil-gas survey correlated well with monitoring well data. Exhibit IV-10 shows that the highest BTEX concentrations were located near wells that contained floating product. Both passive soil-gas maps indicated areas that warranted additional investigation. In particular, the gasoline source area at the south end of the site appears to be centered in two locations, suggesting that the undulating bedrock might partially control the migration pattern of the petroleum compounds. Subsequent investigations with seismic refraction and boring log data supported these findings.

A summary of the advantages and limitations of passive soil-gas surveys is presented in Exhibit IV-11.

Exhibit IV-11
Advantages And Limitations Of Passive Soil-Gas Sampling

Advantages	Limitations
A wide range of VOCs, SVOCs, and low volatile mixtures can be detected.	The data cannot be used to estimate contaminant mass.
More effective than active sampling in low permeability and high moisture soils.	The vertical distribution of contaminants is typically not assessed.
From 40 to 100 devices can be installed in a day.	The time required to collect and analyze samples is typically 3 to 6 weeks.
There is minimal disturbance to subsurface and site operations.	Sorbent desorption may destroy some compounds.
Easy to install.	Measurements are time weighted and are not directly comparable to soil and groundwater laboratory methods.
	Impervious layers and changes in the thickness of clay layers can create misleading information.

Comparison Of Soil-Gas Sampling Applications

Active soil-gas surveys are more appropriate than passive soil-gas surveys for most petroleum UST expedited site assessments because active soil-gas surveys provide more information, more rapidly, and often at a cost that is comparable to that of passive soil-gas surveys. Data collected with active soil-gas surveys can be used immediately to direct additional sampling and analysis so that the site assessment can be completed in a single mobilization. Active soil-gas surveys also provide 3-dimensional information about the distribution of contaminants and subsurface stratigraphy which allows for better interpretation of data than is possible with passive soil-gas surveys.

Passive soil-gas surveys are most useful as a screening tool when SVOCs and low volatility compounds are known or suspected to be present at a site. In addition, passive soil-gas surveys may also be useful in real estate transactions because passive soil-gas surveys provide valuable screening information which can be obtained during time-consuming negotiations without more expensive, intrusive techniques. Because of their high sensitivity to contaminant vapors, passive soil-gas surveys can provide accurate information about the specific compounds present and their relative concentration in 2-dimensions. A summary and comparison of the applications of these two soil-gas sampling methods are listed in Exhibit IV-12.

Exhibit IV-12
Applications For Active And Passive Soil-Gas Data

Application	Active	Passive
Detect presence of VOCs	✓	✓
Detect presence of SVOCs		✓
Infer assessment of hydrocarbon presence through the measurement of indicators of biodegradation	✓	
Identify specific compounds	✓	✓
Evaluate (indirectly) contaminant concentrations in soil	✓	
Evaluate 2-dimensional contaminant distribution	✓	✓
Evaluate 3-dimensional contaminant distribution	✓	
Evaluate remedial options	✓	
Monitor remedial system effectiveness	✓	✓

Passive Soil-Gas Sampling Equipment Manufacturers

A list of passive soil-gas sampling equipment manufactures is included below as Exhibit IV-13. The equipment has not been evaluated by the EPA and inclusion in this manual in no way constitutes an endorsement. These vendors are listed solely for the convenience of the reader.

Because active soil-gas surveys are performed by numerous contractors throughout the country, they have not been listed here. Because these surveys are typically performed with direct push technologies, a list of active soil-gas sampling equipment manufactures is presented in Chapter V, Direct Push Technologies.

Exhibit IV-13
Passive Soil-Gas Sampling Equipment Manufacturers

PCR Laboratories 1318 East Mission Road, Suite 133 San Marcos, CA 92069 (619) 630-5106	Quadrel Services, Inc. 1896 Urbana Pike, Suite 20 Clarksburg, MD 20871 (301) 874-5510
Transglobal Environmental Geochemistry (TEG) 13 locations across the country (800) 834-9888	W.L. Gore & Associates, Inc. 101 Lewisville Road P.O. Box 1100 Elkton, MD 21922-1100 (410) 392-3300

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Chapter V

Direct Push Technologies

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Exhibits

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Chapter V
Direct Push Technologies

Direct push (DP) technology (also known as "direct drive," "drive point," or "push" technology) refers to a growing family of tools used for performing subsurface investigations by driving, pushing, and/or vibrating small-diameter hollow steel rods into the ground. By attaching sampling tools to the end of the steel rods they can be used to collect soil, soil-gas, and groundwater samples. DP rods can also be equipped with probes that provide continuous *in situ* measurements of subsurface properties (*e.g.*, stratigraphy, contaminant distribution). DP equipment can be advanced with various methods ranging from 30 pound manual hammers to trucks weighing 60 tons.

DP technology has developed in response to a growing need to assess contaminated sites more completely and more quickly than is possible with conventional methods. As explained in Chapter II, The Expedited Site Assessment Process, conventional assessments have relied heavily on traditional drilling methods, primarily hollow stem augers (HSA), to collect soil and groundwater samples and install permanent monitoring wells. Because installing permanent monitoring wells with HSA is a relatively slow process that provides a limited number of samples for analysis, the most economical use for the equipment is to perform site assessments in phases with rigid work plans and off-site analysis of samples.

With the development of DP technologies, large, permanent monitoring wells are no longer the only method for collecting groundwater samples or characterizing a site. Multiple soil, soil-gas, and groundwater samples can now be collected rapidly, allowing high data quality analytical methods to be used on-site, economically. As a result, DP technologies have played a major role in the development of expedited site assessments (ESAs).

DP technologies are most applicable in unconsolidated sediments, typically to depths less than 100 feet. In addition to being used to collect samples from various media, they can also be used to install small-diameter (*i.e.*, less than 2 inches) temporary or permanent monitoring wells and small-diameter piezometers (used for measuring groundwater gradients). They have also been used in the installation of remediation equipment such as soil vapor extraction wells and air sparging injection points. Penetration is limited in semiconsolidated sediments and is generally not possible in consolidated formations, although highly weathered bedrock (*i.e.*, saprolite) is an exception for some equipment. DP equipment may also be limited in unconsolidated sediments with high percentages of gravels and cobbles. As a result, other drilling methods are necessary in site assessment and remediation activities where geological conditions are unfavorable for DP technologies or where larger diameter (*i.e.*, greater than 2 inches) wells are needed.

An additional benefit of DP technologies is that they produce a minimal amount of waste material because very little soil is removed as the probe rods advance and retract. Although this feature may result in some soil compaction that could reduce the hydraulic conductivity of silts and clays, methods exist for minimizing resulting problems.

In contrast, although most other drilling methods remove soil from the hole, resulting in less compaction, conventional drilling methods create a significant amount of contaminated cuttings and they also smear clay and silt across more permeable formations which can obscure their true nature. Moreover, these other drilling methods have the potential of causing a redistribution of contamination as residual and free product are brought to the surface.

Choosing a DP method (or combination of DP methods) appropriate for a specific site requires a clear understanding of data collection goals because many tools are designed for only one specific purpose (*e.g.*, collection of groundwater samples). This chapter contains descriptions of the operation of specific DP systems and tools, highlighting their main advantages and limitations; its purpose is to assist regulators in evaluating the appropriateness of these systems and tools.

This chapter does not contain discussions of specific tools manufactured by specific companies because equipment is evolving rapidly. Not only are unique tools being invented, but existing equipment is being used in creative ways to meet the needs of specific site conditions. As a result, the distinctions between types of DP equipment is becoming blurred and it is necessary to focus on component groups rather than entire DP systems. The four component groups discussed in this chapter include:

- Rod systems;
- Sampling tools;
- *In situ* measurements using specialized probes; and
- Equipment for advancing DP rods.

The chapter also includes a discussion of methods for sealing DP holes because of their importance in preventing the spread of contaminants and, therefore, in the selection of DP equipment. The cost of various DP equipment is not discussed in this chapter because cost estimates become quickly outdated due to rapid changes in the industry. An overview of the advantages and limitations of DP equipment and systems discussed in this chapter are presented in Exhibit V-1.

Exhibit V-1
Overview Of Direct Push Technologies

Direct Push Component	Example	Advantages	Limitations
Probing systems	Single-rod or cased	Minimizes the need for waste disposal or treatment	Compaction of sediments may decrease hydraulic conductivity
Soil, soil-gas, and groundwater sampling	Piston samplers, expendable tip samplers	Relatively rapid	Permanent monitoring wells are limited to 2 inch diameter or less
In situ measurement of subsurface conditions	Conductivity probes, laser induced fluorescence	Can be used to rapidly log site	Correlation with boring logs is necessary
Methods for advancing probe rods	Percussion hammers, hydraulic presses	Some methods are extremely portable	Very dense, consolidated formations are generally impenetrable
Sealing methods	Re-entry grouting, retraction *grouting*	Holes can be sealed so that contaminants *cannot* preferentially migrate through them	Appropriate sealing methods may limit sampling equipment options

DP systems use hollow steel rods to advance a probe or sampling tool. The rods are typically 3-feet long and have male threads on one end and female threads on the other. As the DP rods are pushed, hammered, and/or vibrated into the ground, new sections are added until the target depth has been reached, or until the equipment is unable to advance (*i.e.*, refusal). There are two types of rod systems, single-rod and cased. Both systems allow for the collection of soil, soil-gas, and groundwater samples. Exhibit V-2 presents a schematic drawing of single-rod and cased DP rod systems.

Single-Rod Systems

Single-rod systems are the most common types of rods used in DP equipment. They use only a single string (*i.e.*, sequence) of rods to connect the probe or sampling tool to the rig. Once a sample has been collected, the entire string of rods must usually be removed from the probe hole. Collection of samples at greater depths may require re-entering the probe hole with an empty sampler and repeating the process. The diameter of the rods is typically around 1 inch, but it can range from 0.5 to 2.125 inches.

Cased Systems

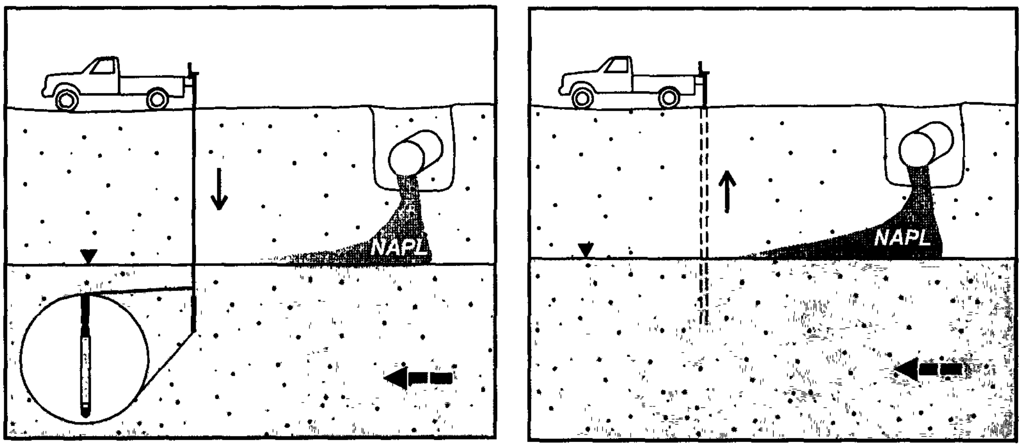
Cased systems, which are also called dual-tube systems, advance two sections--an outer tube, or casing, and a separate inner sampling rod. The outer casing can be advanced simultaneously with, or immediately after, the inner rods. Samples can, therefore, be collected without removing the entire string of rods from the ground. Because two tubes are advanced, outer tube diameters are relatively large, typically 2.4 inches, but they can range between 1.25 and 4.2 inches.

Discussion And Recommendations

Single-rod and cased systems have overlapping applications; they can be used in many of the same environments. However, when compared with cased systems, single-rod systems are easier to use and are capable of collecting soil, soil-gas, or groundwater samples more rapidly when only one sample is retrieved. They are particularly useful at sites where the stratigraphy is either relatively homogeneous or well delineated.

Exhibit V-2
Schematic Drawing Of Single And Cased Direct Push Rod Systems

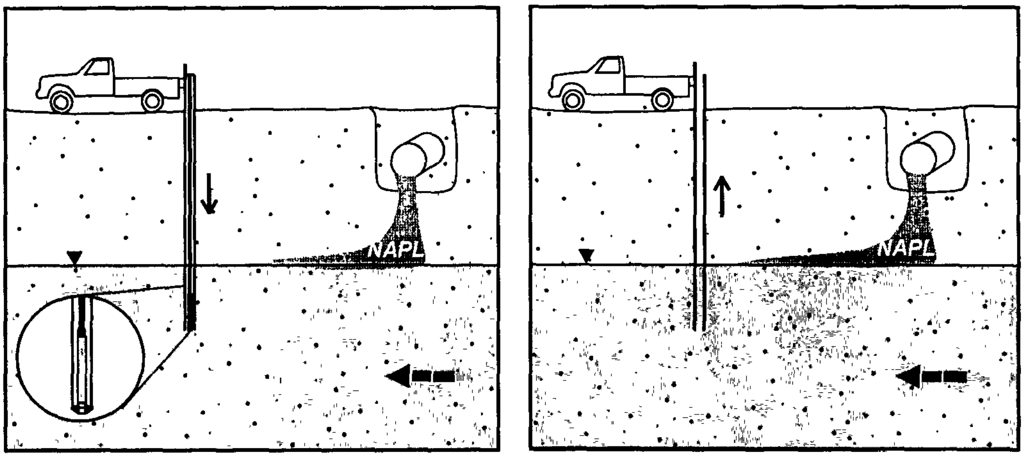
Single-Rod Direct Push System



1) DP sampling tool is advanced on the end of a single sequence of rods.

2) Once the sampling tool is full, tool and rods are withdrawn from the ground. To collect another sample, the tool must be re-inserted and pushed to the next sampling depth.

Cased Direct Push System



1) DP sampling tool is attached to inner rods. Sampling tool, inner rods, and outer drive casing are advanced simultaneously.

2) To collect the sample, only the sampling tool and inner rods are removed. The outer drive casing remains in the ground to prevent sloughing or hole collapse. To collect a deeper sample, the tool and inner rods are re-inserted to the bottom of probe hole and advanced along with the outer drive casing. The outer casing is removed only after the last sample has been collected.

The primary advantage of cased DP systems is that the outer casing prevents the probe hole from collapsing and sloughing during sampling. This feature allows for the collection of continuous soil samples that do not contain any slough, thereby preventing sample contamination. Because only the inner sample barrel is removed, and not the entire rod string, cased systems are faster than single-rod systems for continuous sampling at depths below 10 feet. The collection of continuous samples is especially important at geologically heterogeneous sites where direct visual observation of lithology is necessary to ensure that small-scale features such as sand stringers in aquitards or thin zones of non-aqueous-phase liquids (NAPLs) are not missed.

Another advantage of cased systems is that they allow sampling of groundwater after the zone of saturation has been identified. This feature allows investigators to identify soils with relatively high hydraulic conductivities from which to take groundwater samples. If only soils with low hydraulic conductivity are present, investigators may choose to take a soil sample and/or install a monitoring well. With most single-rod systems, groundwater samples must be taken without prior knowledge of the type of soil present. (Some exposed-screen samplers used with single-rod systems as described in the *Groundwater Sampling Tools* section are an exception.)

A major drawback of single-rod systems is that they can be slow when multiple entries into the probe hole are necessary, such as when collecting continuous soil samples. In addition, in non-cohesive formations (*i.e.*, loose sands), sections of the probe hole may collapse, particularly in the zone of saturation, enabling contaminated soil present to reach depths that may be otherwise uncontaminated. Sloughing soils may, therefore, contaminate the sample. This contamination can be minimized through the use of sealed soil sampling tools (*i.e.*, piston samplers, which are discussed in more detail in the *Soil Sampling Tools* section that follows).

Multiple entries made with single-rod systems into the same hole should be avoided when NAPLs are present because contaminants could flow through the open hole after the probe rods have been removed; particularly if dense-non-aqueous phase liquids (DNAPLs) are present. In addition, multiple entries into the probe hole may result in the ineffective sealing of holes. (These issues are discussed in more detail in *Methods For Sealing Direct Push Holes* at the end of the chapter.) If samples need to be taken at different depths in zones of significant NAPL contamination, single-rod systems can be used, but new entries into soil should be made next to previous holes.

The major drawback of cased systems is that they are more complex and difficult to use than single-rod systems. In addition, because they require larger-diameter probe rods, cased systems require heavier DP rigs, larger percussion hammers, and/or vibratory systems for advancing the probe rod. Furthermore, even with the additional equipment, penetration depths are often not as great as are possible with single-rod systems and sampling rates are slower when single, discrete samples are collected. Exhibit V-3 summarizes the comparison of single and cased systems.

Exhibit V-3
Comparison Of Single-Rod And Cased Systems

	Single-Rod	**Cased**
Allows collection of a single soil, soil-gas, or groundwater sample	✓ (faster)	✓
Allows collection of continuous soil samples	✓[1]	✓[2] (faster)
Allows collection of groundwater sampling after determining ideal sampling zone[3]		✓
Lighter carrier vehicles can be used to advance rods	✓	
Greater penetration depths	✓	
Multiple soil samples can be collected when NAPLs are present		✓

[1] Sloughed soil may also be collected.
[2] Faster at depths below approximately 10 feet.
[3] Some exposed-screen samplers, discussed in the groundwater sampling section, also have this ability.

A large number of DP tools have been developed for sampling soil, soil-gas, and groundwater. Each of these tools was designed to meet a specific purpose; however, many of these tools also have overlapping capabilities. This section describes the commonly used tools currently available and clarifies their applications. All of the tools described in this section can be advanced by rigs designed specifically for DP. In addition, many of these tools can also be used with conventional drilling rigs.

Soil Sampling Tools

There are two types of soil samplers: Nonsealed and sealed. Nonsealed soil sampling tools remain open as they are pushed to the target depth; sealed soil samplers remain closed until they reach the sampling depth.

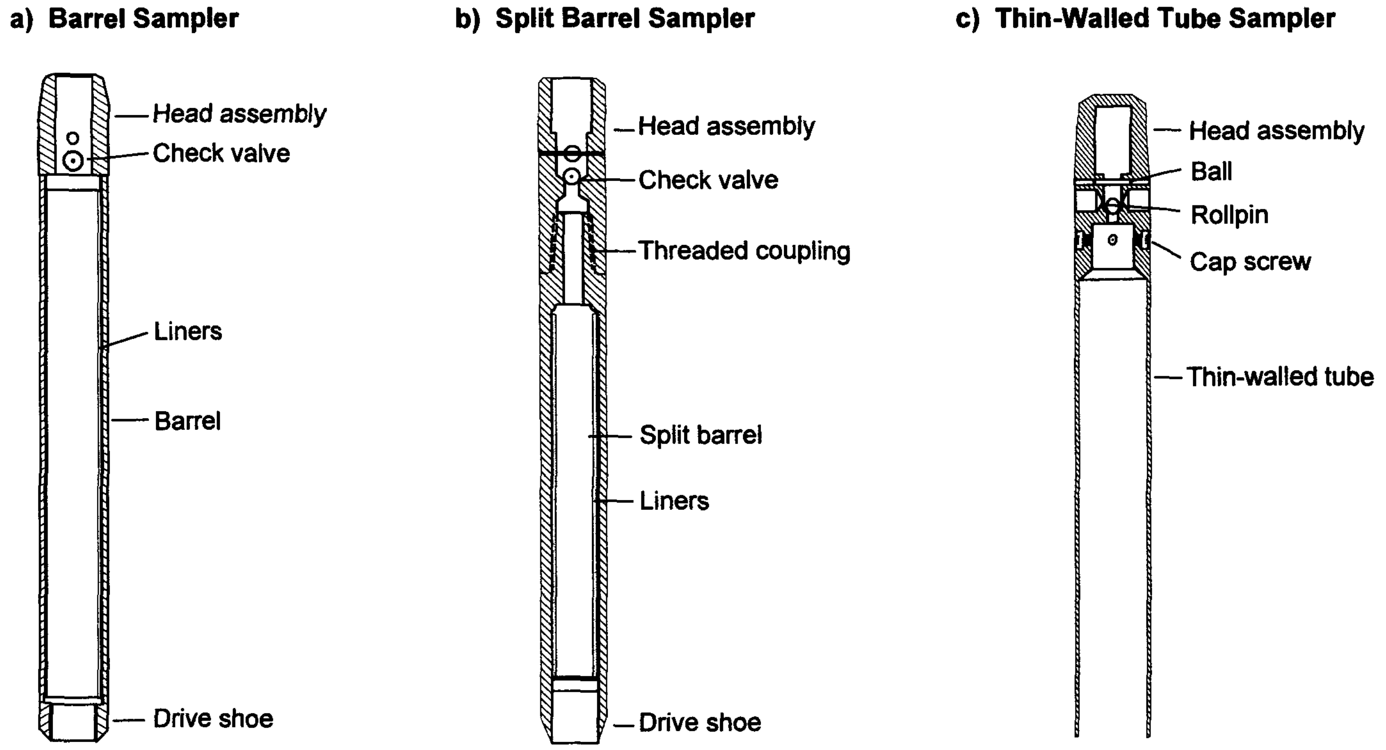
Nonsealed Soil Samplers

The three most commonly used nonsealed soil samplers are barrel, split-barrel, and thin-walled tube samplers. All three are modified from soil samplers used with conventional drilling rigs (*e.g.*, HSA). The primary difference is that DP soil samplers have smaller diameters. Nonsealed soil samplers should only be used in combination with single-rod systems when sampling in uncontaminated fine-grained, cohesive formations because multiple entries into the probe hole are required. When sloughing soils and cross-contamination are a significant concern, nonsealed soil samplers may be used with cased DP systems or more conventional sampling methods (*e.g.*, HSA). In addition, nonsealed samplers necessitate continuous soil coring because there is no other way to remove soil from the hole. All three types of nonsealed soil sampling tools are presented in Exhibit V-4.

Barrel Samplers

Barrel samplers, also referred to as solid-barrel or open-barrel samplers, consist of a head assembly, a barrel, and a drive shoe (Exhibit V-4a). The sampler is attached to the DP rods at the head assembly. A check valve, which allows air or water to escape as the barrel fills with soil, is located within the head assembly. The check valve improves the amount of soil recovered in each sample by allowing air to escape. With the use of liners, samples can be easily removed for volatile organic compound (VOC) analysis or for observation of soil structure.

Exhibit V-4
Types Of Nonsealed Direct Push Soil Sampling Tools



a) **Barrel Sampler**

b) **Split Barrel Sampler**

c) **Thin-Walled Tube Sampler**

Source: Christensen/Acker

Without the use of liners, soil cores must be physically extruded using a hydraulic ram which may damage fragile structures (*e.g.*, root holes, desiccation cracks).

Split-Barrel Samplers

Split-barrel samplers, also referred to as "split-spoon" samplers, are similar to barrel samplers except that the barrels are split longitudinally (Exhibit V-4b) so that the sampler can be easily opened. The primary advantage of split-barrel samplers is that they allow direct observation of soil cores without the use of liners and without physically extruding the soil core. As a result, split-barrel samplers are often used for geologic logging. Split-barrel samplers, however, may cause more soil compaction than barrel samplers because the tool wall thickness is often greater. In addition, although liners are not compatible with all split-barrel samplers, liners are necessary if samples are used for analysis of VOCs.

Thin-Wall Tube Samplers

Thin-wall tube samplers (larger diameter samplers are known as Shelby Tubes) are DP sampling tools used primarily for collecting undisturbed soil samples (Exhibit V-4c). The sampling tube is typically attached to the sampler head using recessed cap screws or rubber expanding bushings. The walls of the samplers are made of thin steel (*e.g.*, 1/16-inch thick). The thin walls of the sampler cause the least compaction of the soil, making it the DP tool of choice for geotechnical sample analysis (*e.g.*, laboratory measurement of hydraulic conductivity, moisture content, density, bearing strength).

Samples are typically preserved, inside the tube, for off-site geotechnical analysis. If the samples are intended for on-site chemical analysis, they can be extruded from the sampler using a hydraulic ram, or the tubes can be cut with a hacksaw or tubing cutter. Because of their fragile construction, thin-wall tube samplers can be used only in soft, fine-grained sediments. In addition, the sampler is usually pushed at a constant rate rather than driven with impact hammers. If samples are needed for off-site VOC analysis, the tube is used as the sample container which can be capped and preserved.

Sealed Soil (Piston) Samplers

Piston samplers are the only type of sealed soil sampler currently available. They are similar to barrel samplers, except that the opening of the sampler is sealed with a piston. Thus, while the sampler is re-inserted into an open probe hole, contaminated soil and water can be prevented from entering the sampler. The probe displaces the soil as it is advanced. When the sampler has been pushed to the desired sampling depth, the piston is unlocked by releasing a retaining device, and subsequent pushing or driving forces soil into the sampler (Exhibit V-5).

Several types of piston samplers are currently available. Most use a rigid, pointed piston that displaces soil as it is advanced. Piston samplers are typically air- and water-tight; however, if o-ring seals are not maintained, leakage may occur. Piston samplers also have the advantage of increasing the recovery of unconsolidated sediments as a result of the relative vacuum that is created by the movement of the piston.

Discussion And Recommendations

Issues affecting the selection of soil samplers include the ability of the sampler to provide samples for lithological description, geotechnical characterization, or chemical analysis. In addition, the potential of a sample contamination with a specific sampler must be considered.

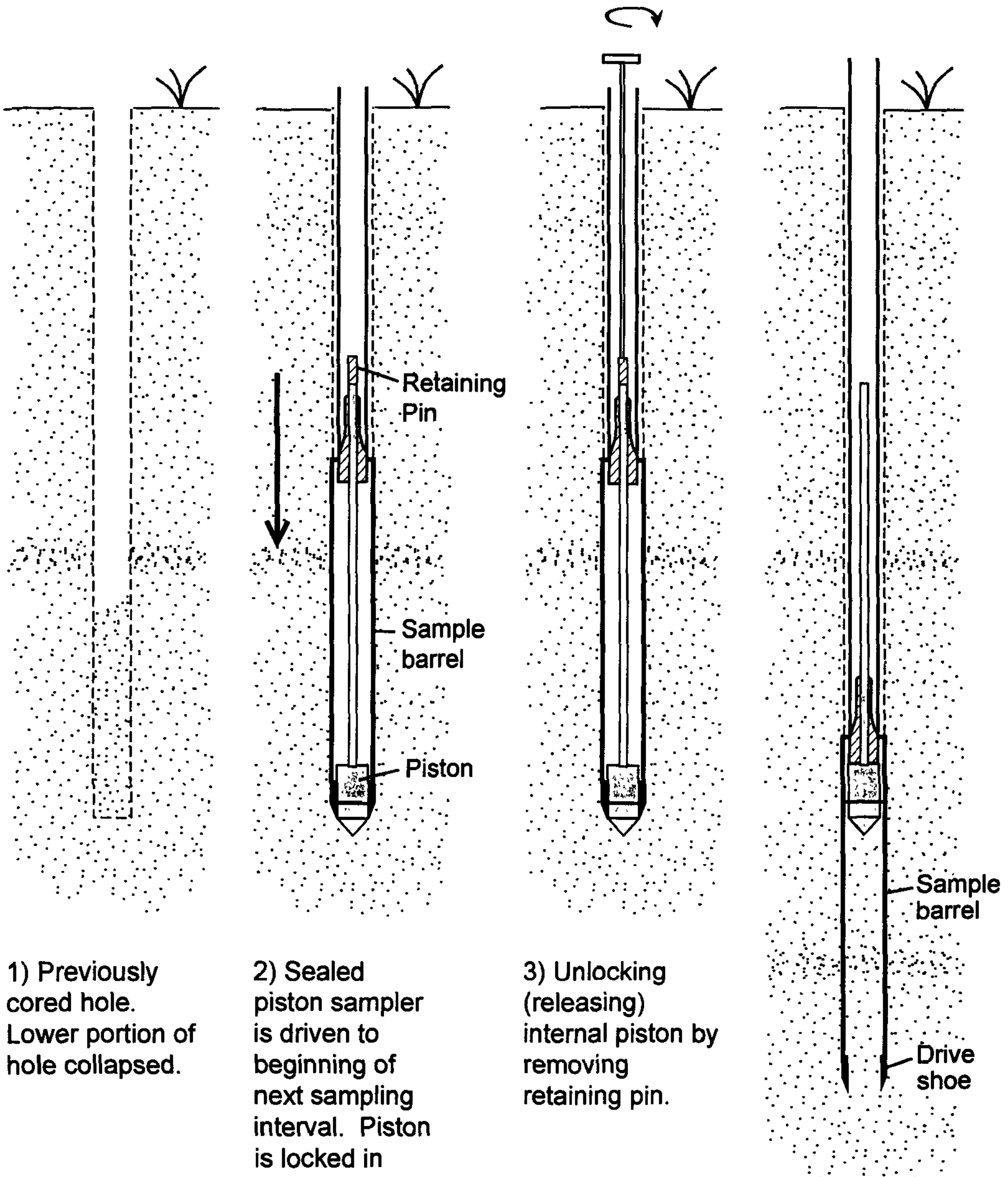
Lithologic Description/Geotechnical Characterization

All soil samplers can be used to some extent for lithologic description and geotechnical characterization but because the disturbance to the sample varies between tools, the preferred tool will vary depending on the application. Split-barrel samplers or barrel samplers used with split-liners are the best DP sampling methods for lithological description because they allow the investigator to directly inspect the soil without further disturbing the sample. Thin-walled tube samplers are best for collecting undisturbed samples needed for geotechnical analysis; barrel and piston samplers are the next best option. With single-rod systems, piston samplers are the only tools that can reliably be used for these same objectives because they produce discrete soil samples.

Chemical Analysis

All sealed or nonsealed soil samplers can be used for the collection of samples for VOC analysis. If samples are analyzed on-site, liners of various materials (*e.g.*, brass, stainless steel, clear acrylic, polyvinylchloride [PVC]) can be used as long as the soil is immediately subsampled and preserved. Soil samples intended for off-site analysis should be collected directly into brass or stainless steel liners within the DP soil sampling tool. Once the tool has been retrieved, the liners can be immediately capped, minimizing the loss of VOCs. Unfortunately, without extruding the soil core from the metal liners, detailed

Exhibit V-5
Using The Sealed Direct Push Soil Sampler (Piston Sampler)



1) Previously cored hole. Lower portion of hole collapsed.

2) Sealed piston sampler is driven to beginning of next sampling interval. Piston is locked in place to prevent soil and water from entering sample barrel.

3) Unlocking (releasing) internal piston by removing retaining pin.

4) Sampler driven to collect next soil core. Piston remains stationary while sample barrel is advanced. Soil core is retrieved by removing entire assembly from hole.

Source: Geoprobe® Systems

logging of the soil core is not possible. Short liners (4 to 6 inches long) may be useful for providing a minimal amount of lithological information. The soil lithology can be roughly discerned by inspecting the ends of the soil-filled liners; specific liners can then be sealed and submitted for chemical analysis. Extruding soil cores directly into glass jars for chemical analysis should be avoided since up to 90 percent of the VOCs may be lost from the sample (Siegrist, 1990).

Sample Contamination

The potential for sample contamination will depend on both the type of soil sampler and the type of DP rod system. The major concern with nonsealed samplers is that the open bottom may, when used with single-rod systems, allow them to collect soil that has sloughed from an upper section of the probe hole; they, therefore, may collect samples that are not representative of the sampling zone. If the sloughed soil contains contaminants, an incorrect conclusion could be made regarding the presence of contaminants at the target interval. Alternatively, if the overlying soil is less contaminated than the soil in the targeted interval, erroneously low concentrations could be indicated. As a result, nonsealed samplers should not be used with single-rod DP systems where contaminated soils are present. In such cases, piston samplers are the only appropriate soil samplers.

Nonsealed samplers can be safely used with cased DP systems above the water table. When sampling below the water table, particularly through geological formations with a high hydraulic conductivity, nonsealed samplers should not be used because contaminated water can enter the drive casing. In this situation, water-tight piston samplers must be used in combination with cased DP systems. In many low permeability formations, water does not immediately enter the outer drive casing of cased DP systems, even when the casing is driven to depths well below the water table. In these settings the potential for sample contamination is greatly reduced, and nonsealed soil samplers can be lowered through the outer casing. A summary of sealed and nonsealed soil samplers is presented in Exhibit V-6.

Active Soil-Gas Sampling Tools

Chapter IV, Soil-Gas Surveys, discusses the methods, capabilities, and applicabilities of both active and passive soil-gas surveys. Because active soil-gas sampling is performed with DP equipment, the various DP tools used in the collection of active soil-gas samples are covered in this section.

Exhibit V-6
Summary Of Sealed And Nonsealed Soil Sampler Applications

		Single-Rod System		**Cased System**	
		Nonsealed	Sealed	Nonsealed	Sealed
Sampling Above Watertable	NAPLs Not Present	✓[1]	✓	✓	✓
	NAPLs Present		✓	✓	✓
Sampling Below Watertable	NAPLs Not Present	✓[1]	✓	✓	✓
	NAPLs Present		✓	✓[2]	✓

[1] Fine-grained (cohesive) formations where probe hole does not collapse.
[2] In low permeability soil where groundwater does not enter drive casing.

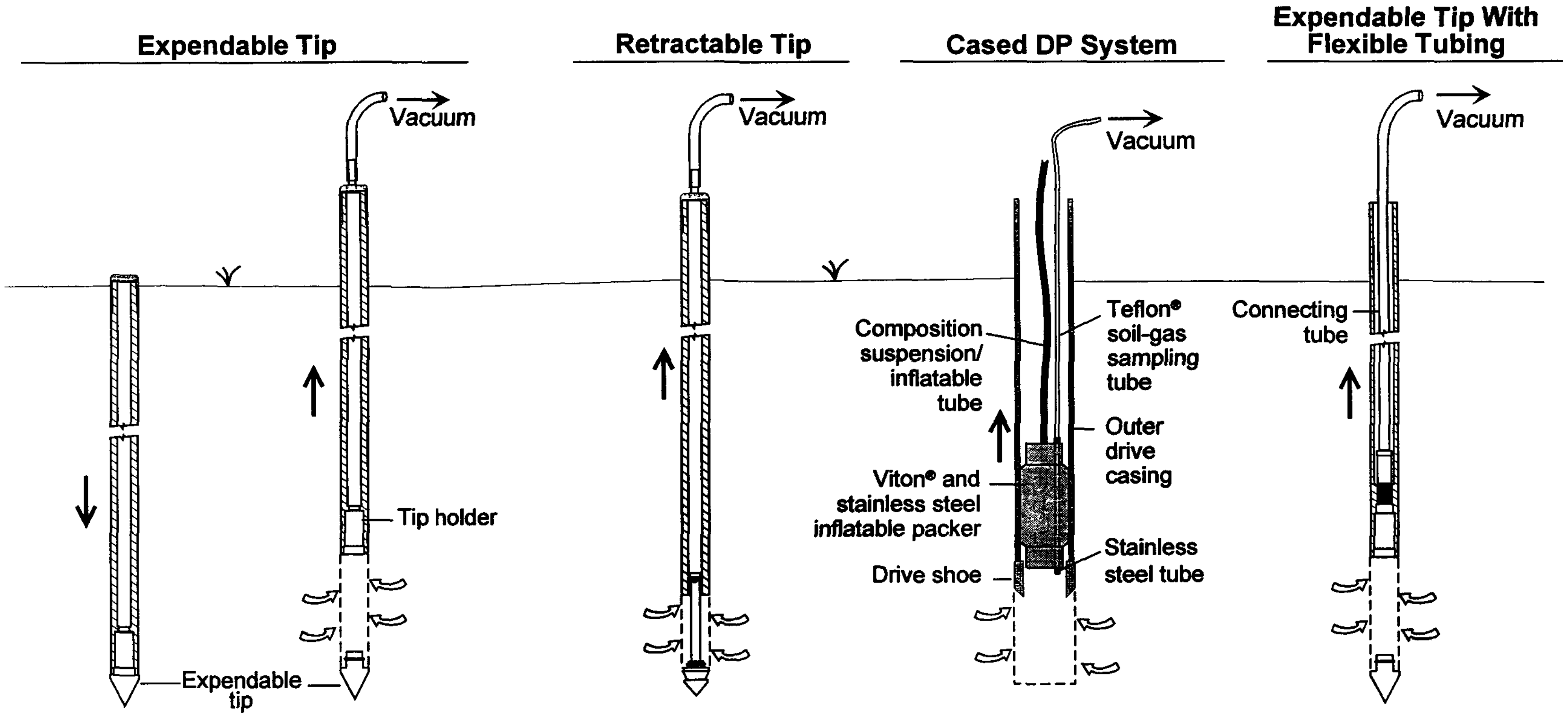
In active soil-gas sampling, a probe rod is pushed (either manually or mechanically) to a specified depth below the ground surface (bgs) into the vadose zone. A vacuum is applied to the rods (or tubing within the rods), and the sample is collected. The use of probe tips with larger diameters than the probe rods is a practice that should be discouraged when soil-gas sampling. Some DP practitioners use these large tips in order to reduce friction on advancing probe rods and therefore increase depth of penetration. This practice, however, will increase the likelihood of sampling atmospheric gases and diluting constituent concentrations.

There are four variations of soil-gas sampling tools and procedures: expendable tip samplers, retractable tip samplers, exposed samplers, and cased system sampling. Exhibit V-7 presents several soil-gas sampling tools.

Expendable Tip Samplers

Expendable cone-shaped tips, made of either steel or aluminum, are held in a tip holder as the DP rod advances (Exhibit V-7a_1). Once the desired depth has been reached, the DP rods are pulled back a few inches (Exhibit V-7a_2) and the tip can be separated from the tip holder, exposing the soil. Deeper samples can be collected in the same hole by withdrawing the probe and attaching another expendable tip. The previous tip can usually be pushed out of the way in most soils; however, some soils (*e.g.*, dense clays) may prevent the tip from moving and, therefore, prevent re-entry into the same hole.

Exhibit V-7
Types Of Direct Push Soil Gas Sampling Tools



a$_1$) DP rods equipped with expendable tip pushed to target depth.

a$_2$) DP rods withdrawn to expose target interval. Soil-gas sample collected through probe rods.

b) Soil-gas samples are collected through probe rods. Tip is removed with probe rods.

c) Soil-gas samples are collected through small-diameter tubing.

d) Soil-gas samples are collected through inner tubing.

Source: Geoprobe Systems and Precision Sampling, Inc.

The advantage of this method is that it allows retraction grouting (discussed in detail on page V-47). The major disadvantage of this method is that collection of deeper soil-gas samples in the same probe hole can be very time consuming because of the need to retract and re-insert the entire probe rod.

Retractable Tip Samplers

Retractable tips are similar to the expendable tips described above, except that the tip is physically attached to the tip holder by a small steel connecting tube (Exhibit V-7b). The connecting tube contains small holes, slots, or screens, and is held within the probe rod until the sampling depth is reached. As with the expendable tip sampler, the probe rod is withdrawn a few inches so that the tip can be dislodged, exposing the connecting tube.

Retractable tip samplers can be used to sample a single probe hole at multiple levels if the formation will not allow an expendable tip to be moved out of the way of the advancing probe rod. Generally, the probe rod should be withdrawn entirely from the probe hole in order to properly secure the tip. The probe rod should not be pushed back over the tip while in the hole because if the tip does not seat properly the assembly will be damaged. A disadvantage of this method is that it does not allow retraction grouting.

Exposed-Screen Samplers

Exposed screen samplers are probe rods that are fitted with slotted or screened terminal ends. They are similar to the exposed-screen samplers described in the groundwater sampling section which follows and which is depicted in Exhibit V-10a (page V-22). They may be made of steel or PVC and are exposed to the subsurface as they are driven to the sampling depth.

The major advantage of this tool is that it allows rapid sampling of multiple intervals within the same probe hole because the probe rod does not need to be retrieved before advancing to the next depth. The primary drawback is that if the slots are exposed to contaminants as the probe is pushed into the subsurface, sample contamination can result. In addition, the slots or screen may become clogged as the probe is pushed through fine grained soils, and retraction grouting can not be used with this method.

Sampling With Cased Systems

Soil-gas sampling can also be accomplished with cased DP systems. Once the sampling depth is reached, samples can be collected either directly through the outer casing or through disposable tubing (Exhibit V-7c). The major advantages of this method are that it creates less compaction of soils and it enables multiple level sampling. The major disadvantage is that it can be slower than single-rod methods.

Methods For Retrieving Active Soil-Gas Samples

Active soil-gas samples can be retrieved by two methods: soil gas can be drawn directly through the probe rods, or soil gas can be drawn through tubing inside the probe rods. Both methods are available with all the above-mentioned sampling tools.

Sampling Through Probe Rods

Soil gas can be pumped to the surface directly through probe rods, whether single-rod or cased systems. The advantage of this method is that it is relatively simple and less equipment is needed than for sampling through tubing. The drawbacks, however, are significant. First, because the volume of air within the probe rods is large (compared with sampling through tubing), the amount of time needed to purge the rods and collect a representative sample of soil-gas is relatively long. The increased volume of soil gas also increases the chances that short circuiting will occur, resulting in the sampling of atmospheric gases. This issue is particularly a problem with cased systems because the inside diameter of the casing can be much larger than single-rod systems. Second, the joints of most DP rods are not air-tight, so when the rod string is placed under vacuum, soil gas may be drawn from intervals other than the targeted zone.

Sampling Through Tubing

Sampling through tubing (Exhibit V-7d) is a method used to overcome many of the problems associated with sampling directly through the probe rods. The tubing is commonly made of polyethylene (PE) or Teflon® (polytetrafluoroethylene [PTFE]). The advantages of this method are that air is not withdrawn from the joints between rod sections, and purge volumes and sampling times are reduced. The disadvantage is that the tubing makes the sampling equipment more complicated and adds an additional expense.

Discussion And Recommendations

In general, sampling soil-gas through PE or PTFE tubing is the preferred method. Sampling directly through the probe rods can be successfully accomplished, but it requires longer sampling times and investigators must ensure that probe rod joints are completely sealed.

If a soil-gas survey requires multi-level sampling, retraction tip samplers are applicable; however, these samplers require multiple entries into the same probe hole. Exposed screen samplers and cased systems allow for rapid sampling without the problems associated with multiple entry (discussed previously in the *Direct Push Rod System* section). However, exposed samplers may also result in sample contamination if NAPLs are dragged down in the slots or screen.

If soil gas is to be sampled in fine-grained sediments, sampling through tubing should be used to minimize sample volumes and the rod string should be withdrawn a greater distance than normal in order to expose a larger sampling interval. Alternatively, expendable tip samplers and cased systems may be useful if macropores (*e.g.*, root holes, desiccation cracks) exist. These features may be sealed by the advancing probe rod. Expendable tip and cased systems may allow brushes to be inserted into the sampling zone to scour away compacted soil, thus restoring the original permeability. Exhibit V-8 provides a summary of the applicability of the soil-gas sampling tools discussed in this section.

Groundwater Sampling Tools

DP technologies can be used in various ways to collect groundwater samples. Groundwater can be collected during a one-time sampling event in which the sampling tool is withdrawn and the probe hole grouted after a single sample is collected; groundwater sampling tools can be left in the ground for extended periods of time (*e.g.*, days, weeks) to collect multiple samples; or, DP technologies can be used to construct monitoring wells that can be used to collect samples over months or even years.

In general, when the hydraulic conductivity of a formation reaches 10^{-4} cm/second (typical for silts), collection of groundwater samples through one-time sampling events is rarely economical. Instead, collection of groundwater samples requires the installation of monitoring devices that can be left in the ground for days, weeks, or months. In general, however, it is difficult to get an accurate groundwater sample in low permeability formations with any method (whether DP or rotary drilling) because the slow infiltration of groundwater into the sampling zone may cause a significant loss of VOCs. As a result, DP groundwater sampling is most appropriate for sampling in fine sands or coarser sediments.

As with soil-gas sampling, probe tips for one-time groundwater sampling events should not be larger than DP rods because they can create an open annulus

Exhibit V-8
Summary Of Soil-Gas Sampling Tool Applications

	Sampling Through Probe Rods				Sampling Through Tubing			
	Expendable Tip	Retractable Tip	Exposed Sampler	Cased DP System	Expendable Tip	Retractable Tip	Exposed Sampler	Cased DP System
VOCs less likely to be lost					✓	✓	✓	✓
Sample contamination is less likely	✓	✓		✓	✓	✓		✓
Multi-level sampling	✓	✓	✓[1]	✓[1]	✓	✓	✓[1]	✓[1]
Minimizes purge volume/sampling time					✓	✓	✓	✓
Allows retraction grouting[2]	✓			✓	✓			✓
Macropores may be re-opened in silts and clays	✓			✓	✓			✓

[1] Allows multi-level sampling without removing the tool each time.

[2] Refer to "Methods For Sealing Direct Push Holes" at the end of the chapter.

that could allow for contaminant migration. When installing long-term monitoring points, large tips can be used in conjunction with sealing methods that do not allow contaminant migration (*e.g.*, grouting to the surface).

Although most DP groundwater sampling equipment can also be used for determining groundwater gradients, using piezometers (*i.e.*, non-pumping, narrow, short-screened wells used to measure potentiometric pressures, such as the water table elevation) early in a site assessment is typically the best method. Piezometers are quick to install; they are inexpensive to purchase, and, because of their narrow diameter, they are quick to reach equilibrium. DP-installed monitoring wells may also be used for this purpose; however, they are more appropriate for determining groundwater contaminant concentrations once groundwater gradients and site geology have been characterized. Undertaking these activities first greatly simplifies the task of determining contaminant location, depth, and flow direction.

Methods now exist for installing permanent monitoring wells with both single-rod and cased DP systems (Exhibit V-9). These methods allow for the installation of annular seals that isolate the sampling zone. In addition, some methods allow for the installation of fine-grained sand filter packs that can provide samples with low turbidity (although the need for filter packs is an issue of debate among researchers). When samples are turbid, they should not be filtered prior to the constituent extraction process because organic constituents can sorb onto sediment particles. As a result, filtering samples prior to extraction may result in an analytical negative bias. For further information on the need for sediment filtration, refer to Nielsen, 1991.

The following text focuses on the tools used for single-event sampling. These tools can be divided into two groups--exposed-screen samplers and sealed-screen samplers. Exhibit V-10 presents examples of these two groups of groundwater samplers. Exhibit V-10a is a simple exposed-screen sampler; Exhibit V-10b is a common sealed-screen sampler; and Exhibit V-10c is a sealed-screen sampling method used with cased systems. Because new tools are continually being invented, and because of the great variety of equipment currently available, this *Guide* can not provide a detailed description and analysis of all available groundwater sampling tools. Instead, the advantages and limitations of general categories of samplers is discussed.

Exposed-Screen Samplers

Exposed-screen samplers are water sampling tools that have a short (*e.g.*, 6 inches to 3 feet) interval of exposed fine mesh screens, narrow slots, or small holes at the terminal end of the tool. The advantage of the exposed screen is

Exhibit V-9
Permanent Monitoring Well Installed With Pre-packed Well Screens

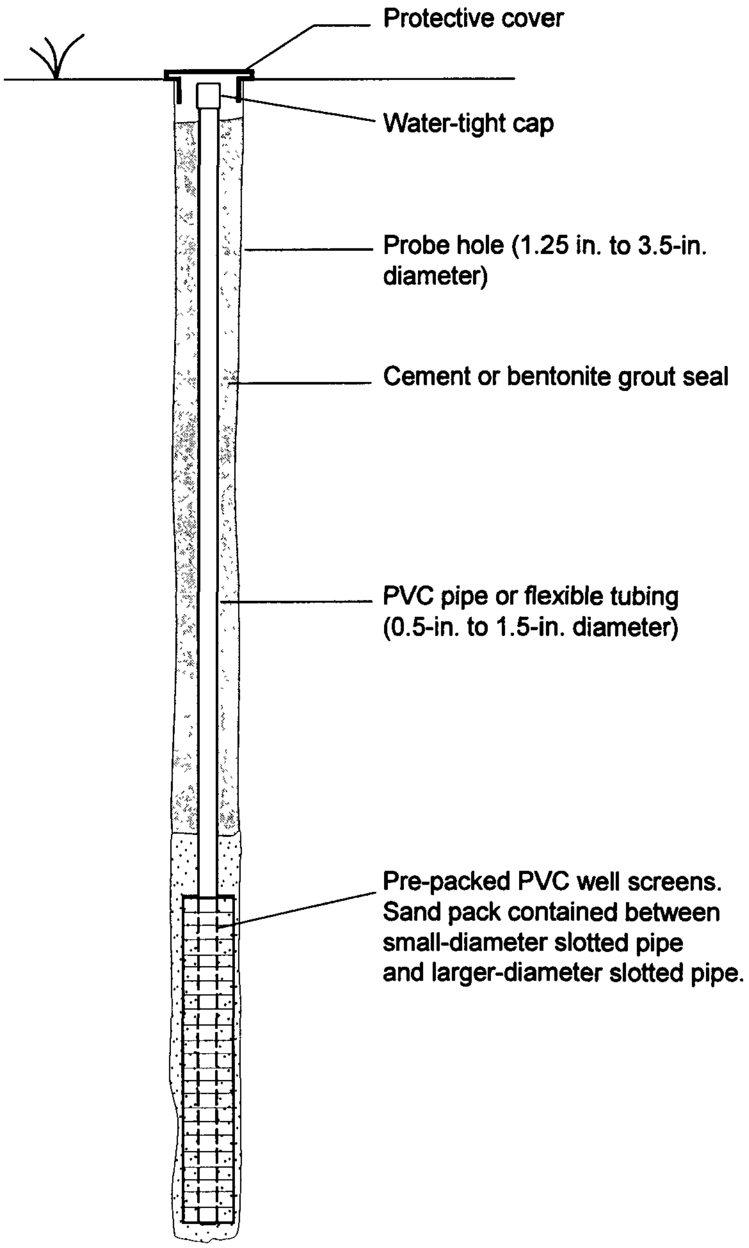
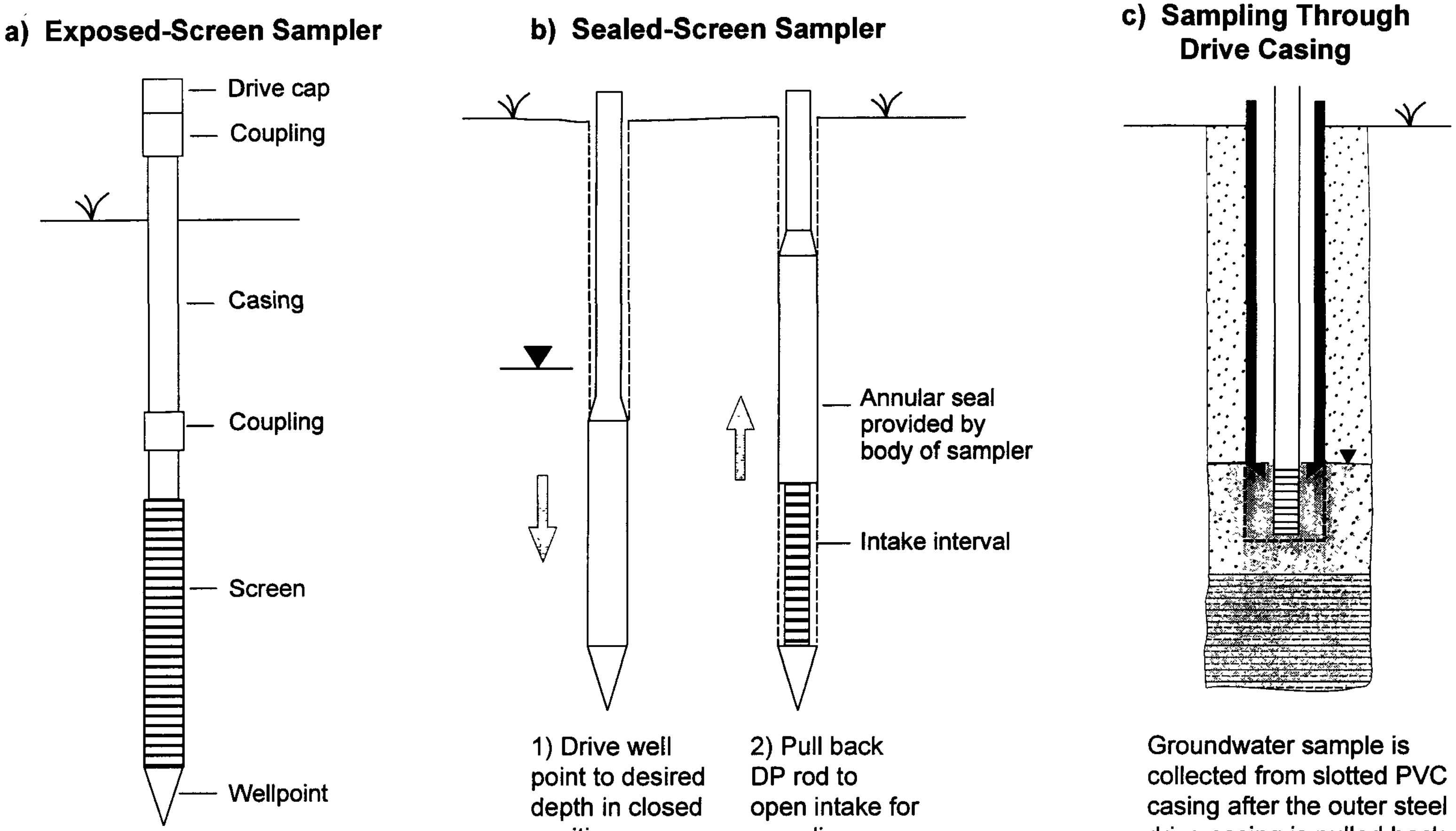


Exhibit V-10
Types Of Direct Push Groundwater Sampling Tools



1) Drive well point to desired depth in closed position.

2) Pull back DP rod to open intake for sampling.

Groundwater sample is collected from slotted PVC casing after the outer steel drive casing is pulled back.

Source: Aller, et al., 1991[1]

Source: Cordry, 1995[1]

Source: Precision Sampling, Inc.

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that it allows multi-level sampling in a single DP hole, without withdrawing the DP rods. The exposed screen, however, also causes some problems that should be recognized and resolved when sampling contaminants. These problems may include:

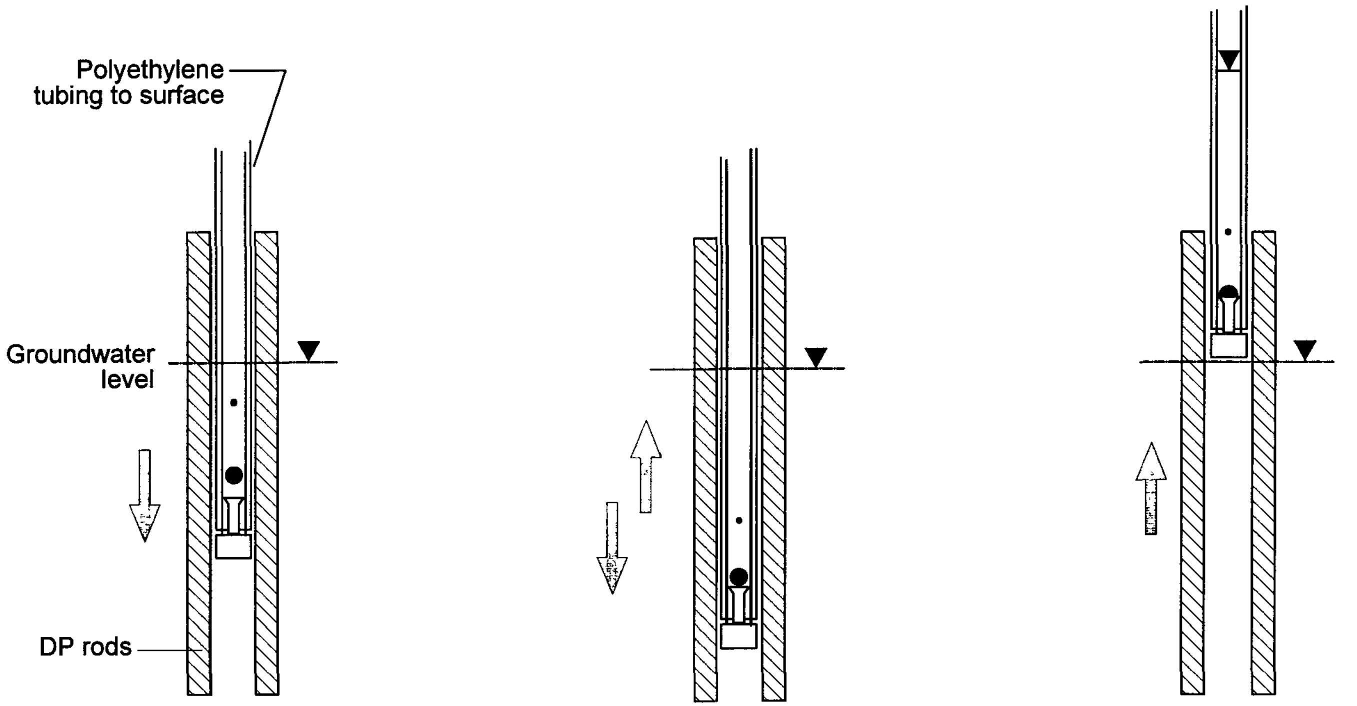
- Dragging down of NAPLs, contaminated soil, and/or contaminated groundwater in the screen;
- Clogging of exposed screen (by silts and clays) as it passes through sediments;
- The need for significant purging of sampler and/or the sampling zone because of drag down and clogging concerns; and
- Frigility of sampler because of the perforated open area.

There are several varieties of exposed-screen samplers. The simplest exposed-screen sampler is often referred to as a well point (Exhibit V-10a). As groundwater seeps into the well point, samples can be collected with bailers, check-valve pumps (Exhibit V-11), or peristaltic pumps. (Narrow-diameter bladder pumps may also soon be available for use with DP equipment.) Because well points are the simplest exposed-screen sampler, they are affected by all of the above mentioned limitations. As a result, they are more commonly used for water supply systems than groundwater sampling. They should not be used below NAPL or significant soil contamination.

The drive-point profiler is an innovative type of exposed-screen sampler that resolves many of the limitations of well points by pumping deionized water through exposed ports as the probe advances. This feature minimizes clogging of the sampling ports and drag down of contaminants and allows for collection of multiple level, depth-discrete groundwater samples. Once the desired sampling depth is reached, the flow of the pump is reversed, and groundwater samples are extracted. Purging of the system prior to sample collection is important because a small quantity of water is added to the formation. Purging is complete when the electrical conductivity of the extracted groundwater has stabilized. The data provided by these samples can then be used to form a vertical profile of contaminant distributions. Exhibit V-12 provides a schematic drawing of a drive-point profiler. Additional information about a drive-point profiling system is presented in Pitkin, 1994.

Another innovative exposed-screen sampler can be use in conjunction with cone penetrometer testing (CPT). This sampler allows for multi-level sampling by providing a mechanism for *in situ* clearing of clogged screens through the use of a pressurized gas and *in situ* decontamination of the sampling equipment with an inert gas and/or deionized water. Various CPT cones, which allow investigators to determine the soil conditions of the sampling zone, can be used simultaneously with this tool.

Exhibit V-11
Using The Check Valve Tubing Pump



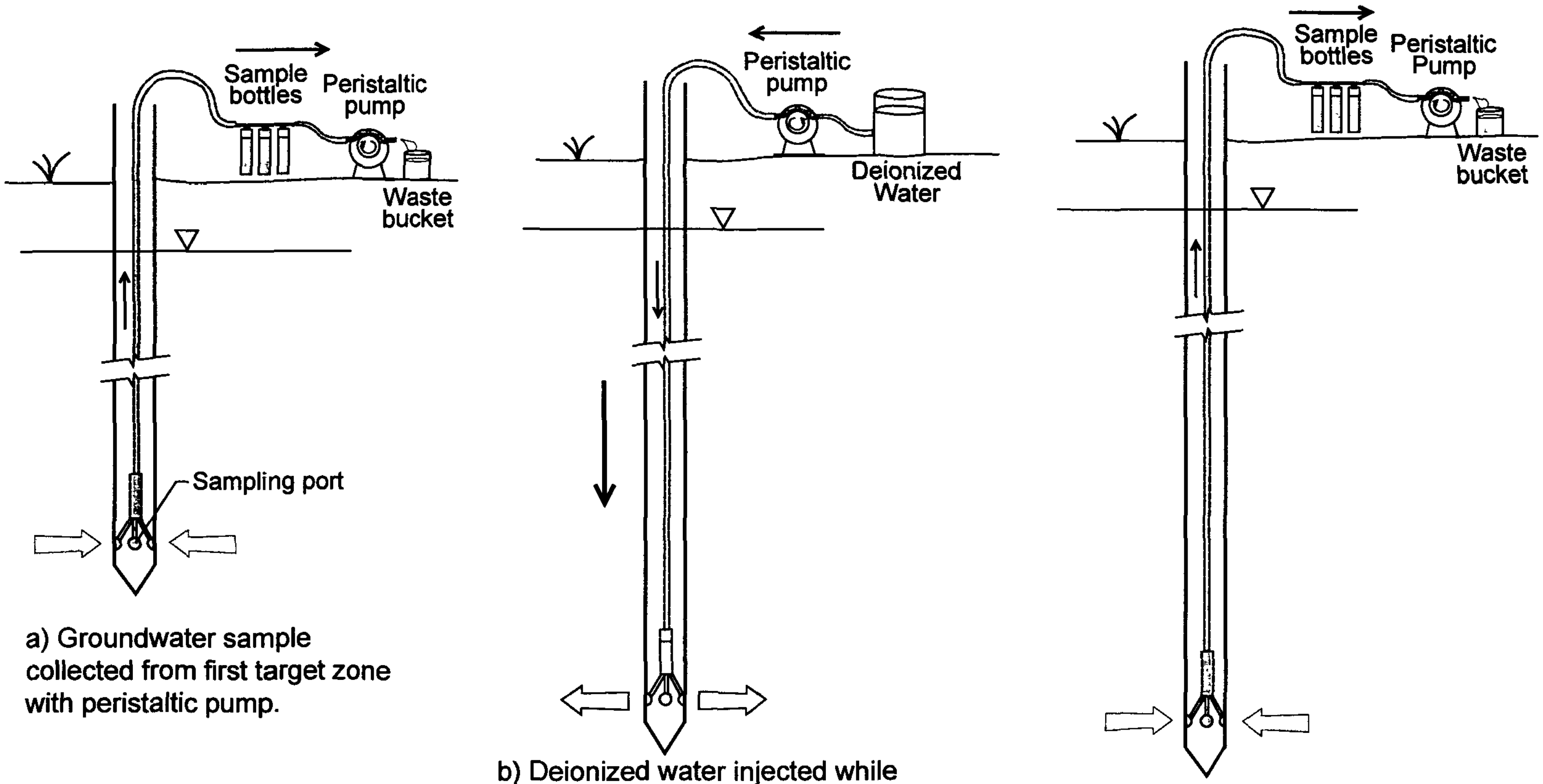
1) Insert tubing and check valve.

2) Oscillate tubing (pump).

3) Sample is recovered as water discharges at the surface.

Source: Geoprobe® Systems

Exhibit V-12
Using A Drive-Point Profiler



a) Groundwater sample collected from first target zone with peristaltic pump.

b) Deionized water injected while advancing tool to prevent sampling ports from becoming plugged.

c) Groundwater sample collected from second target zone with peristaltic pump.

Source: Precision Sampling, Inc.

Sealed-Screen Samplers

Sealed-screened samplers are groundwater samplers that contain a well screen nested inside a water-tight sealed body. The screen is exposed by retracting the probe rods once the desired sampling depth has been reached. They can be used for collecting accurate, depth-discrete samples. A very common type of sealed-screen sampler is presented in Exhibit V-10b.

The design of sealed-screen samplers is extremely variable. Many are similar to expendable or retractable tip samplers used for soil gas sampling. Some samplers are designed only for a single sampling event; others are designed to be left in the ground for an extended period of time (many weeks or even beyond one year) so that changes in concentrations can be monitored.

The main advantage of this type of sampler is that the well screen is not exposed to soil while the tool is being pushed to the target depth. Thus, the screen cannot become plugged or damaged, and the potential for sample contamination is greatly reduced. O-rings are used to make the sampler water-tight while it is being pushed to the sampling depth. (In order to ensure a water-tight seal, o-rings should be replaced frequently; water tightness can be checked by placing the sealed sampler in a bucket of water.) Sealed-screen samplers are appropriate for the collection of depth-discrete groundwater samples beneath areas with soil contamination in the vadose zone. Because there is no drag-down of contaminants or clogging of the sampling screens, sealed-screen samplers do not require purging.

Some sealed-screen samplers allow sample collection with bailers, check-valve pumps, or peristaltic pumps. (Bladder pumps can also be used with wide diameter cased DP systems.) The quantity of groundwater provided by these samplers is limited only by the hydraulic conductivity of the formation. Other samplers collect groundwater in sealed chambers, *in situ*, which are then are raised to the surface. Depending on their design, these samplers may be extremely limited in the quantity of groundwater that they can collect (*e.g.*, 250 ml per sampling event), and they may not collect free product above the water table. If the storage chamber is located above the screen intake, groundwater samples must be collected sufficiently below the water table to create enough hydrostatic pressure to fill the chamber. Only sampling chambers located below the screen intake are, therefore, useful for collecting groundwater or LNAPL samples at or above the water table.

Cased DP systems can also be used as sealed-screen groundwater samplers. After the target zone has been penetrated and the inner rods have been removed, well screen can be lowered through the outer casing to the bottom of the probe hole. The drive casing is then retracted (a few inches to a few feet) exposing the well screen (Exhibit V-10c). This method allows for the collection of deeper samples by attaching a sealed-screen sampling tool that is pushed into the formation ahead of the tip of the drive casing.

Discussion And Recommendations

Exposed-screen samplers are most appropriate for multi-level sampling in coarse-grained formations (*i.e.*, sediments of fine-grained sands and coarser material). They are typically used in a single sampling event. The major concern with using exposed-screen samplers is that they can cause cross contamination if precautions are not taken (*e.g.*, pumping deionized water through sample collection ports). As a result of these concerns, significant purging of the sampling zone is required.

Sealed-screen samplers are most appropriate for single-depth samples. When they are used in a single sampling event, they are appropriate in formations of fine-grained sands or coarser material because these soils typically allow rapid collection of groundwater. When they are used as either temporary or long-term monitoring wells, they can also be used in formations composed of silts. In addition, because sealed-screen groundwater samplers do not require purging of groundwater, they allow more rapid sampling from a single depth than exposed-screen samplers. Multi-level sampling with sealed-screened samplers is possible with cased and single-rod systems; however, with single-rod systems, the entire rod string must be withdrawn after samples are collected from a given depth. This practice with single-rod systems may create some cross contamination concerns in permeable, contaminated aquifers because the hole remains open between sampling events, allowing migration.

In addition, DP groundwater sampling tools have several advantages over traditional monitoring wells. DP tools allow groundwater samples to be collected more rapidly, at a lower cost, and at depth-discrete intervals. As a result, many more samples can be collected in a short period of time, providing a detailed 3-dimensional characterization of a site. Exhibit V-13 provides a summary of DP sampling tool applications.

General Issues Concerning Groundwater Sampling

There are several issues concerning the collection, analysis and interpretation of groundwater samples that affect both DP equipment and more conventional monitoring wells. Two major issues are the loss of VOCs and the stratification of contaminants.

Exhibit V-13
Summary Of Groundwater Sampling Tool Applications

	Exposed-Screen	Sealed-Screen
Multi-level sampling	✓[1]	✓[2]
Samples can be collected immediately, little or no purging required		✓[3]
Used to install long-term monitoring point	✓[4]	✓
Can be used in formations composed of silts		✓[5]
Appropriate below contaminated soil		✓

[1] Cross contamination may be an issue of concern, and purging is required.
[2] Multi-level sampling without withdrawing all DP rods is only possible with cased DP systems.
[3] Collection of a single sample is more rapid with this method.
[4] One type of exposed-screen sampler (*i.e.*, well points) has been used to install monitoring points, but this method is generally not recommended in zones of NAPL contamination. It may be appropriate at the leading edge of a contaminant groundwater plume.
[5] Sampling in silts is generally only appropriate when temporary monitoring wells are installed. Significant VOC loss may occur if water flows into sampling point over days, weeks, or months.

Loss Of VOCs

The ability of DP groundwater sampling methods to collect samples equivalent to traditional monitoring wells is a topic of continued debate and research. Loss of VOCs is the most significant groundwater sampling issue. All groundwater sampling methods--including methods used with traditional monitoring wells--can affect VOC concentrations to some degree. The key to preventing the loss of VOCs is to minimize the disturbance of samples and exposure to the atmosphere. Several studies that have compared VOC concentrations of samples collected with DP methods with samples collected by traditional monitoring wells have shown that DP methods compare favorably (Smolley *et al.*, 1991; Zemo, *et al.*, 1994).

Stratification Of Contaminants

Being able to take multiple, depth-discrete groundwater samples with DP equipment is both an advantage and a necessity. At least one recent study has shown that the concentration of organic compounds dissolved in groundwater can vary by several orders of magnitude over vertical distances of just a few centimeters (Cherry, 1994). Because DP sampling tools collect samples from very small intervals (*e.g.*, 6 inches to 3 feet), they may sometimes fail to detect dissolved contamination if the tool is advanced to the wrong depth. Therefore, multiple depths should be sampled to minimize the chances of missing contaminants. At sites with heterogeneous geology, contamination may be particularly stratified. Because the distribution of the contaminants is controlled by the site geology and groundwater flow system, the hydrogeology of the site must be adequately defined before collecting groundwater samples for chemical analysis.

The stratification of contaminants may also result in artificially low analytical results from traditional monitoring wells. These wells are typically screened over many feet (*e.g.*, 5 to 15 feet), while high concentrations of contaminants may be limited to only a few inches (in the case of LNAPLs, typically the top of the aquifer). The process of sampling groundwater, however, may cause the water in the well to be mixed, resulting in a sample that represents an average for the entire screen length (*i.e.*, very high concentrations from a specific zone may be diluted). DP methods avoid this problem by collecting depth-discrete samples.

Conclusion

The practice of collecting groundwater samples both with DP systems and with traditional monitoring wells is a subject of continued research and debate. Both methods can provide high quality groundwater samples for regulatory decisions. Both methods may also provide misleading information if appropriate procedures are not followed and/or if the hydrogeology of a site is not well characterized. Investigators and regulators must be aware of the issues that affect groundwater sample quality and interpretation in order to make appropriate site assessment and corrective action decisions.

In Situ Measurements Using Specialized Direct Push Probes

In addition to collecting samples of soil, soil-gas, and groundwater/NAPL samples, specialized DP probes are also available for collecting *in situ* geophysical, geochemical, and geotechnical measurements of subsurface conditions. Because these methods record vertical profiles, they are often called logging instruments. They provide objective information, but the interpretation of measurements may still be subjective, requiring correlation with actual samples. Information that can be collected with these tools includes stratigraphy, depth to groundwater, approximate hydraulic conductivity, and residual and free product location.

Cone penetrometer testing (CPT) is the most common method for collecting *in situ* measurements. In addition, several recent innovations have adapted some logging methods to other DP rigs. The following section discusses CPT and other logging tools currently available with DP rigs. The growth of this technology is very rapid; there are likely to be many new tools in the near future.

Cone Penetrometer Testing

CPT is a method for characterizing subsurface stratigraphy by testing the response of soil to the force of a penetrating cone. It was developed in the 1920s in Holland by the geotechnical industry and became commercially available in the United States in the early 1970s.

CPT is most commonly performed to depths ranging from 50 to 100 feet; however, depths as great as 300 feet are attainable under ideal conditions (*e.g.*, soft, unconsolidated sediments). Typically, 100 to 300 feet of CPT can be performed per day if the decontamination of probe rods (also referred to as cone rods when used with CPT) and the sealing of holes are necessary; productivity can be doubled when this is not necessary. Production rates can be significantly less if site access is limited or if significant soil, soil-gas, or groundwater sampling is performed.

Traditionally, CPT methods have been used less frequently at sites where investigation depths are less than 40 feet because CPT cones have been pushed with heavy, poorly-maneuverable rigs. Recently, lighter, more maneuverable DP rigs have become available to advance CPT cones. This innovation should make CPT more cost-effective for investigating sites that may have contamination located closer to the surface.

CPT uses sensors mounted in the tip or "cone" of the DP rods to measure the soil's resistance to penetration. The cone, presented in Exhibit V-14, is pushed through the soil at a constant rate by a hydraulic press mounted in a heavy truck or other heavy weight.

Several types of sensors are commonly available with CPT cones. These include piezometric head transducers (piezocones), resistivity sleeves, nuclear logging tools, and pH indicators. Most recently, CPT cones have incorporated sensors to measure the type and location of petroleum hydrocarbons in the subsurface (*e.g.*, laser induced fluorescence, fuel fluorescence detector). The electronic signals from the sensors are transmitted through electrical cables which run inside the cone rods and to an on-board computer at the ground surface, where they are processed. CPT cones can often measure several parameters simultaneously. An example of a CPT log with multiple parameters is presented in Exhibit V- 15.

DP rigs that perform CPT can also be used to collect soil, soil-gas, and groundwater samples. In fact, some CPT cones allow the collection of soil-gas or groundwater samples without removing the cone from the hole. Collection of soil samples (and in many cases groundwater samples as well) with CPT, however, currently requires the attachment of DP sampling tools in place of the CPT cone. Because removing cone rods and inserting DP sampling tools is time consuming, most CPT contractors will first advance a CPT hole to define the stratigraphy, then advance another DP hole a few feet away to collect soil or groundwater samples.

The following text describes the cones that are available only with CPT and is followed by a section which describes *in situ* logging tools available for both CPT and other DP systems.

Three-Channel Cone

The most common type of CPT cone is referred to as a three-channel cone because it simultaneously measures the tip resistance, sleeve resistance, and inclination of the cone. The ratio of sleeve resistance to tip resistance, which is referred to as the friction ratio, is used to interpret the soil types encountered (Chiang *et al.*, 1992). In general, sandy soils have high tip resistance and low friction ratios, whereas clayey soils have low tip resistance and higher friction ratios. As a result, this information can also be used to estimate the hydraulic conductivity of sediments. With the use of the other CPT channels, stratigraphic layers as thin as 4 inches can be identified.

Exhibit V-14
Components Of CPT Piezocone

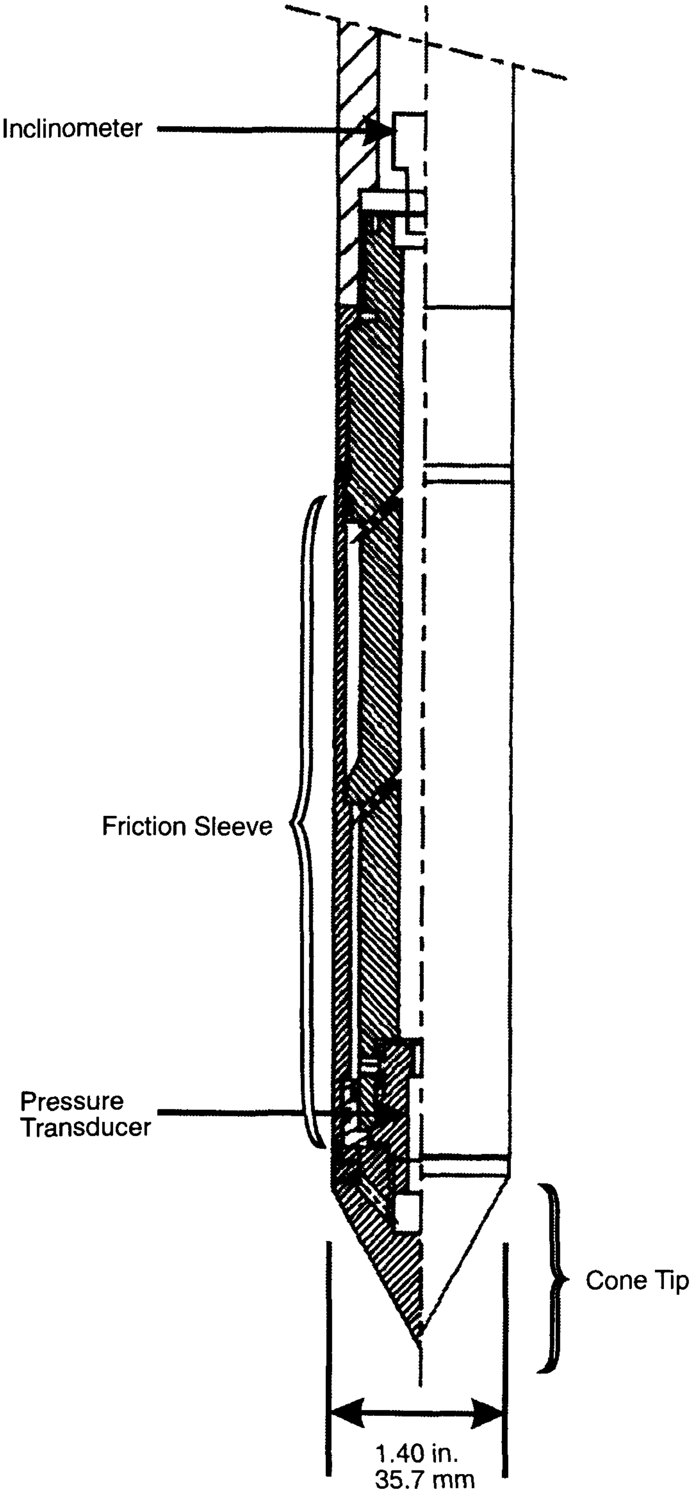
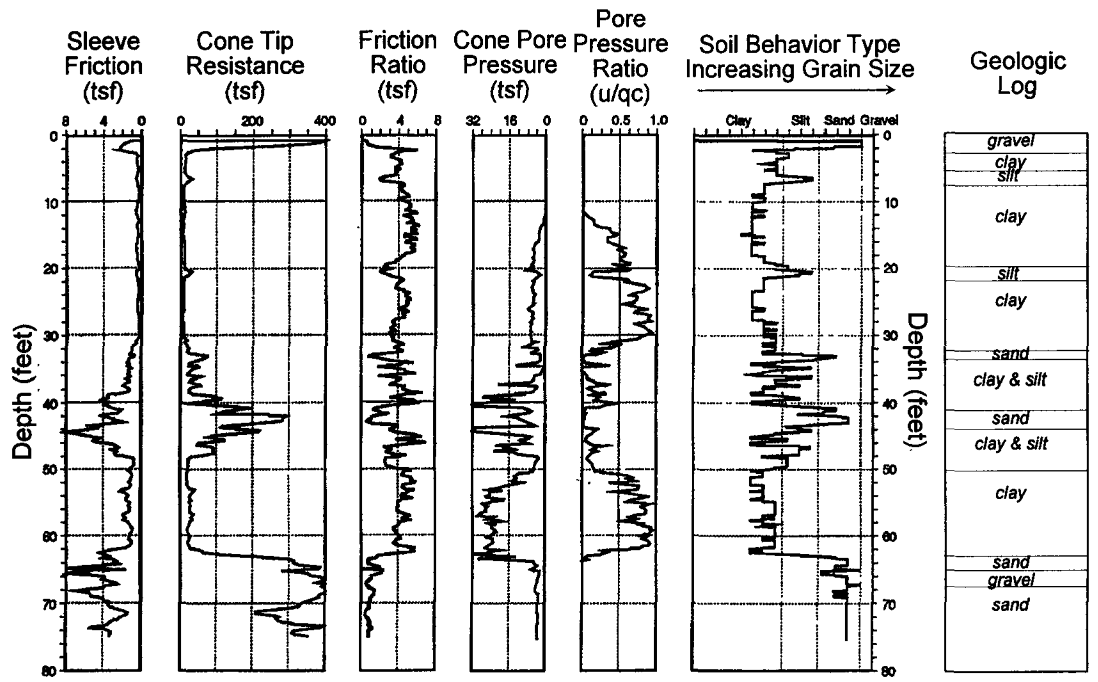
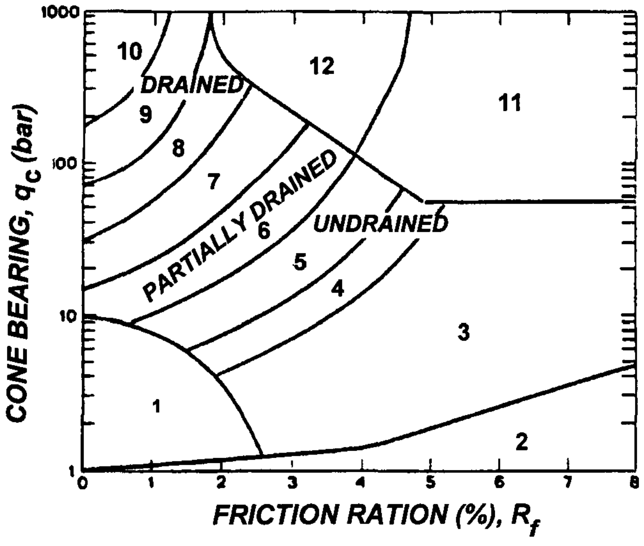


Exhibit V-15
Example CPT Data



Source: Berzins, 1993[1]

Exhibit V-16
CPT Soil Behavior Types



Zone	*Soil Behavior Types*
1	Sensitive fine grained
2	Organic material
3	Clay
4	Silty clay to clay
5	Clayey silt to silty clay
6	Sandy silt to clayey silt
7	Silty sand to sandy silt
8	Sand to silty sand
9	Sand
10	Gravelly sand to sand
11	Very stiff to fine grained
12	Sand to clayey sand

Source: Berzins, 1993[1]

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Three-channel cones record soil behavior rather than actual soil type because in addition to grain size, the soil's degree of sorting, roundness, and mineralogy can also influence tip resistance. As a result, a boring log may help in the interpretation of CPT data for site-specific conditions. In general, soil behavior type correlates well with soil type. An empirically produced plot of friction ratios and soil behavior types is presented in Exhibit V-16.

The inclinometer mounted in the three-channel cone provides a measurement of the inclination of the cone from vertical. Rapid increases in inclination indicate that the rods are bending, allowing the CPT operator to terminate the sounding (*i.e.*, cone penetrometer test) before the cone and/or rods are damaged.

Piezocone

The piezocone is similar to the three-channel cone, described above, except that a pressure transducer is also mounted in the cone (previously presented in Exhibit V-14) in order to measure water pressure under dynamic and static conditions. Pore-pressure dissipation tests can be performed by temporarily halting advancement of the tool and letting the pore pressure reach equilibrium. The slope of a plot of pore pressure versus time is proportional to the permeability of the soil and can be used to estimate hydraulic conductivity and define the water table.

Geophysical And Geochemical Logging Probes

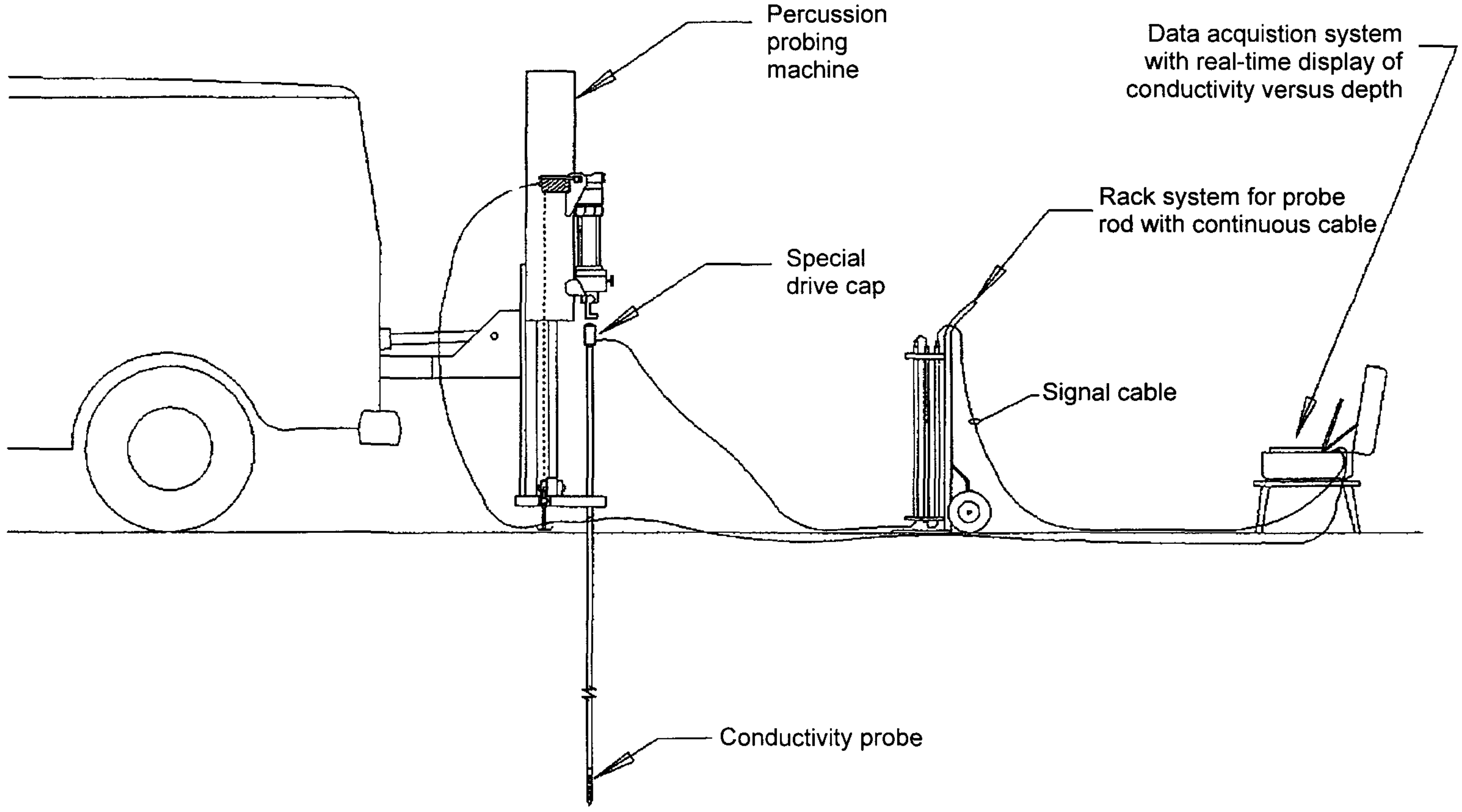
Logging probes are continually being developed for both CPT rigs and other DP probing equipment. The following section describes probes that are available for use with DP technologies in general. Information provided by these probes can be used to interpret site stratigraphy, moisture conditions, and in some cases, contaminant type and distribution.

Conductivity Probes

Conductivity probes measure the electrical conductivity of the subsurface sediments. Conductivity probes are available with CPT probes and, more recently, with small 1-inch diameter DP systems (Christy, 1994). Components of a small-diameter conductivity probe system are depicted in Exhibit V-17.

Because clay units commonly have a greater number of positively charged ions than sand units, clay layers can typically be defined by high conductivity and

Exhibit V-17
Small-Diameter Direct Push Conductivity Probe



Source: Geoprobe® Systems

sand by low conductivity. These measurements, however, must be correlated with other logging information because conductivity may be the result of other conditions (*e.g.*, moisture content, soil density, mineral content, contaminants). Groundwater tends to increase the electrical conductivity of sediments. Consequently, the zone of saturation may be discernible in logging data if the water table is located in a known resistive layer (*e.g.*, sand) and the contrast is sharp. In a similar way, conductivity measurements may occasionally indicate hydrocarbon contamination if a significant quantity of residual or free product is located in a conductive layer (*e.g.*, clay) because hydrocarbons are resistive (*i.e.*, poorly conductive).

Nuclear Logging Tools

Nuclear logging tools are geophysical instruments that either detect natural radiation of a formation or emit radiation and measure the response of the formation. They have an advantage over other geophysical methods in being able to record usable data through metal casings. Nuclear logging tools can be advanced with DP probes to define the site stratigraphy, groundwater conditions, and, occasionally, subsurface contaminant distribution. They can be used with CPT cones, some small diameter probe rods, and inside of the outer drive casing of cased DP systems. There are primarily three nuclear methods--natural gamma, gamma-gamma, and neutron.

Natural gamma tools log the amount of natural gamma particles emitted by sediments. Because clays typically have a greater number of ions than sands, clays tend to have more radioactive isotopes that emit gamma radiation. By logging the change in gamma radiation, it is often possible to characterize the site stratigraphy. Gamma-gamma tools emit gamma radiation and measure the response of the formation. Because the response is related to the density of the soil, this method can also provide information about the stratigraphy as well as the porosity of soil. Neutron methods emit neutrons into a sediment and measure a response which is dependent on the moisture content. These methods can, therefore, be used to define the water table. In addition, if the stratigraphy and moisture conditions are defined with other methods, neutron logs can indicate the presence and thickness of free-phase petroleum hydrocarbons. A complete discussion of geophysical logging is presented in Keys (1989).

Chemical Sensors

Chemical sensors provide screening level analysis of petroleum hydrocarbons at a specific depth, without removing a soil or groundwater sample. When used over an extended area, they can rapidly provide a 3-dimensional characterization of the contaminant source area. There are several *in situ* chemical sensors that have recently been developed for use with DP technologies, and more may be available in the near future. Currently available methods are laser-induced fluorescence (LIF), fuel fluorescence detectors (FFD), and semipermeable membrane sensors. These three methods are discussed in more detail in Chapter VI, Field Methods For The Analysis Of Petroleum Hydrocarbon.

Discussion And Recommendations

In situ logging methods are ideal for heterogeneous sites with complex geology because they can rapidly provide continuous profiles of the subsurface stratigraphy. In addition, unlike boring logs, these logging methods provide an independent, objective measurement of the site stratigraphy. When *in situ* logging methods are used in combination with boring logs, data can be used to extrapolate/interpolate geologic units across a site. If boring log information is not available, several *in situ* logging parameters collected simultaneously will often provide similar information.

Investigators should be aware that *in situ* logging methods should generally be calibrated by pushing a probe next to at least one boring that has been continuously cored. In addition, while geophysical logging methods for defining stratigraphy produce reliable information about the primary lithology of the strata, they provide very little data regarding secondary soil features like desiccation cracks, fractures, and root holes. In silts and clays, these secondary soil features (*i.e.*, macropores) may control the movement of contaminants into the subsurface and may greatly influence the options for active remediation. At interbedded sites where defining macropores is important, continuous soil coring may be a better alternative. Exhibit V-18 presents a summary of *in situ* logging equipment used with DP technologies.

Exhibit V-18
Summary Of *In Situ* Logging Equipment Used With Direct Push Technologies

	DP Method	Application
Three-Channel Cone	CPT Only	Measures tip resistance, sleeve resistance, and inclination. It is used to determine soil behavior types which can be correlated with boring logs.
Piezocone	CPT Only	Measures the rate at which the water pressure returns to static conditions and can be used to estimate hydraulic conductivity and define the water table.
Conductivity Probe	DP	Measures the conductivity of stratigraphic layers and can be used in conjunction with other methods to determine soil type and, sometimes, contaminant location.
Natural Gamma	DP	Measures the natural gamma radiation emitted by a formation and can be used to determine stratigraphy
Gamma-Gamma	DP	Measures the response of a formation to gamma radiation and can be used to determine soil density/porosity.
Neutron Probes	DP	Measures the response of a formation to neutron bombardment and can be used to determine moisture content of soils.
Chemical Sensors	DP	Measures the presence of free or residual product and can be used to delineate source areas.

CPT = Available with cone penetrometer testing equipment only
DP = Available with CPT and other direct push equipment

Equipment For Advancing Direct Push Rods

A few years ago, small-diameter probes were advanced exclusively with manual hammers or rotohammers mounted in light-weight vans, and CPT rods were advanced using heavy (*e.g.*, 20-ton) trucks. Now, contractors mix and match DP rod systems and sampling tools depending on the objectives and scope of the investigation. It is not unusual to see DP rods, sampling tools, and CPT cones being advanced with a wide range of equipment, ranging from small portable rigs to heavy trucks. The following text describes some of the more common methods used to advance DP rods and sampling tools. Drawings of several types of equipment used for advancing DP rods are presented in Exhibit V-19.

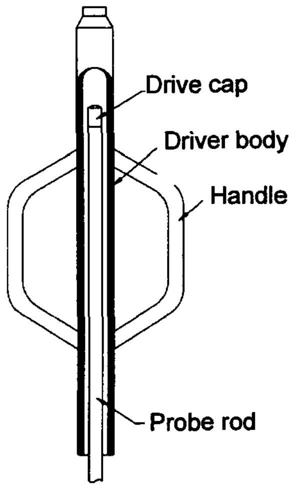
Manual Hammers

Manual hammers allow a single operator to advance small-diameter DP rods to shallow depths (Exhibit V-19a). Other names for this type of hammer are "fence post driver"or "slam bar," since it was adapted from hammers used to drive steel fence posts. Manual hammers are used mostly for driving 0.5- to 1-inch diameter soil-gas sampling tools and are best suited to advancing single DP rods to depths of 5 to 10 feet. The maximum attainable depth with this method is approximately 25 feet. These hammers are the smallest and lightest DP rod advancing equipment weighing between 30 to 60 pounds. As a result, manual hammers are the most portable method available, but they are capable of the least depth of penetration.

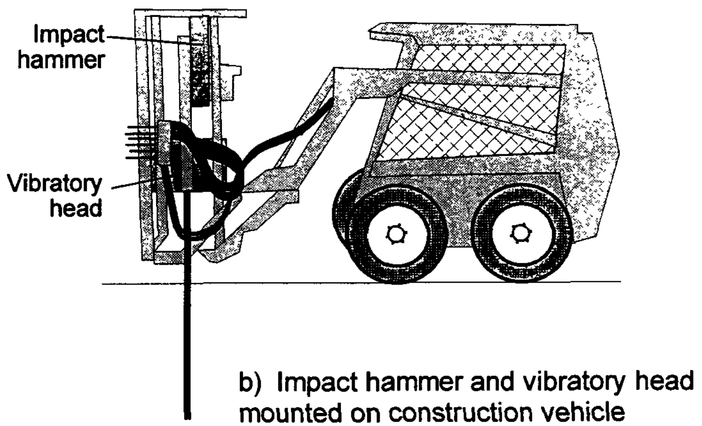
Hand-Held Mechanical Hammers

There are two types of hand-held mechanical hammers--jack hammers and rotohammers. Although rotohammers also rotate, they both apply high-frequency percussion to the DP rods, resulting in more rapid penetration and greater sampling depths than manual hammers can attain. Hand-held mechanical hammers are best suited to collecting soil, soil-gas, and groundwater samples using 0.5- to 1-inch diameter equipment. They may also be used to advance small-diameter cased DP rod systems. Typical attainable depth with this method is between 8 and 15 feet, while the maximum depth is approximately 40 feet. This equipment weighs between 30 and 90 pounds and is, therefore, extremely portable.

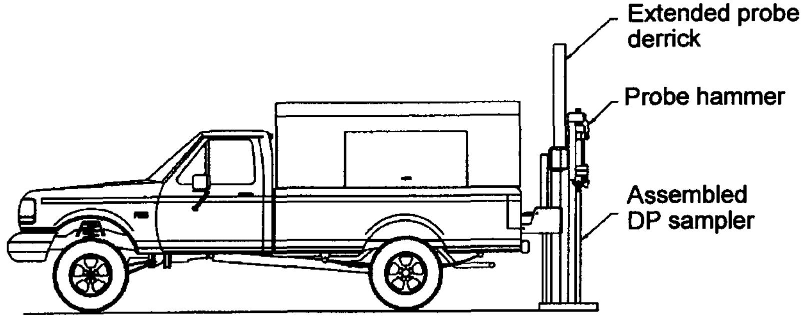
Exhibit V-19
Typical Equipment Used To Advance Direct Push Rods



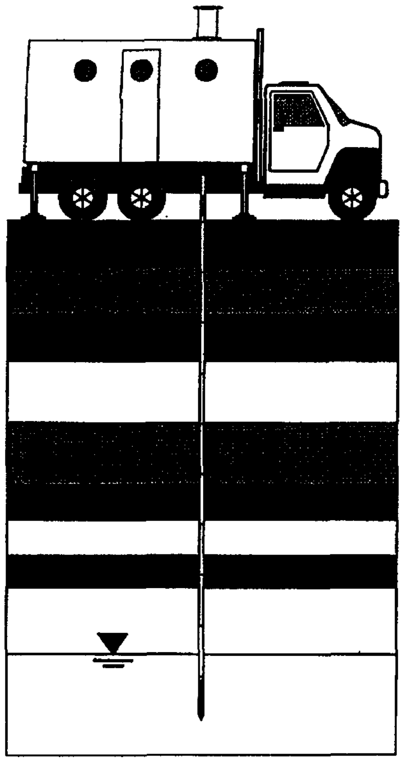
a) Hand held manual hammer



b) Impact hammer and vibratory head mounted on construction vehicle



c) Impact hammer mounted on pickup truck



d) DP rods pushed with hydraulic cylinders mounted inside large truck.

Percussion Hammers And/Or Vibratory Heads Mounted On Small Vehicles

The most common methods for advancing DP rods are percussion hammers and vibratory heads mounted on small vehicles (Exhibit V-19b and 19c). Hydraulic cylinders press the rods into the ground with or without pounding or driving. The pounding/driving action is typically provided by hydraulic post-hole drivers or percussion hammers mounted on the vehicle. The hammers pound on a drive head attached to the uppermost DP rod. On some rigs, vibratory heads clamp onto the outside of the DP rods, applying high-frequency vibrations. The vibratory action reduces the side-wall friction, resulting in an increased rate of penetration and greater sampling depths. Some rigs are mounted on trucks, some on vans, yet others on the front of Bobcat®-like construction vehicles. These types of rigs can be used to advance single DP rods or cased DP systems. The reactive weight is typically between 5,000 and 17,000 pounds. Depths of 20 to 50 feet are generally attainable, and maximum depths of around 150 feet have been recorded. This equipment is as mobile as the vehicle on which it is mounted.

Small Hydraulic Presses Anchored To The Ground

Small hydraulic presses that are anchored to the ground are fairly light-weight units (200 to 300 pounds) and portable so they can be quickly disassembled and reassembled at new sampling locations. The reactive weight for these rigs is created by the weight of the rig and the pull-down pressure applied against the anchor. On concrete floors, the base plates of the rigs are anchored with concrete bolts or anchoring posts (referred to as “deadmen”) that can be set in pre-drilled holes. On asphalt or open ground, earth augers are spun into the ground to anchor the rigs. Reactive forces as great as 40,000 pounds can be applied with these rigs. Hydraulic cylinders press the DP rods into the ground, usually without percussion hammers. These types of rigs are most commonly used for advancing CPT cones in areas that are difficult to access, but they can also be used to advance other types of DP rods and sampling tools. They can generally attain depths between 20 and 100 feet with a maximum attainable depth of approximately 200 feet.

Conventional Drilling Rigs

Conventional drilling rigs are commonly used to advance soil, soil-gas, and groundwater sampling DP tools inside of hollow-stem augers. In fact, open-barrel and split-barrel samplers have been advanced inside of hollow stem augers to collect soil samples for geotechnical investigations for decades. In geotechnical investigations, the force for advancing these samplers is applied by striking the DP rods with a 140-pound hammer dropped a distance of 30 inches as described in ASTM D1586 (American Society of Testing and Materials, 1984). In addition, many conventional drill rigs are now equipped with hydraulic percussion hammers to advance the DP sampling tools more rapidly. The reactive weight of conventional drill rigs is between 5,000 and 20,000 pounds. When they are used for DP sampling, they can generally attain depths of 20 to 80 feet with a maximum depth of approximately 200 feet. Because of their size, conventional drill rigs are less maneuverable than construction vehicles.

Trucks Equipped With Hydraulic Presses

Trucks equipped with hydraulic presses are commonly used to advance CPT cones (Exhibit V-19d). Because the force for advancing the rods comes from the weight of the truck, the maximum depth attainable with the DP rods depends on the weight of the truck. Generally, depths of 30 to 100 feet can be obtained; maximum penetration is about 300 feet. Most rigs weigh from 30,000 to 40,000 pounds. Although trucks weighing more than approximately 46,000 pounds are not allowed on public roads, CPT rigs as heavy as 120,000 pounds can be used if weight is added on site. Unlike other DP tools, the force applied to CPT cones is a static push; no pounding or vibration is applied to the rods which could damage the sensitive electrical components and circuitry in the cones.

Hydraulic cylinders mounted inside the trucks apply the static weight of the truck to the DP rods, pushing them into the ground. While designed for CPT applications, these large trucks are equally capable of advancing all other types of DP sampling tools using single-rod or cased DP systems. However, because the rigs were designed primarily for pushing CPT cones, few of them are equipped with hydraulic hammers or vibratory heads.

Discussion And Recommendations

The major differences among the kinds of equipment used to advance DP rods are their depth of penetration and their ability to access areas that are difficult to reach (*e.g.*, off-road, inside buildings). The depth of penetration is controlled primarily by the reactive weight of the equipment although other factors such as the type of hammer used (*e.g.*, vibratory, manual, percussion) can affect the attainable depth. Soil conditions generally affect all DP methods in a similar way. Ideal conditions for all equipment are unconsolidated sediments of clays, silts, and sands. Depending on their quantities and size, coarser sediments (*e.g.*, gravels, cobbles) may pose problems for DP methods. Semi-consolidated and consolidated sediments generally restrict or prevent penetration; however, saprolite (*i.e.*, weathered bedrock) is an exception.

The portability of equipment is controlled by its size and weight. For instance, 20-ton trucks with hydraulic presses would not be appropriate for rough terrain, and conventional drill rigs are often not capable of sampling below fuel dispenser canopies or below electrical power lines. On the other hand, manual hammers or hand-held mechanical hammers are capable of sampling in almost any location, including within buildings. Exhibit V-20 presents a summary of equipment for advancing DP rods.

Exhibit V-20
Summary Of Equipment For Advancing Direct Push Rods

	Reactive Weight (lbs)	Average Attainable Depth (ft)	Maximum Attainable Depth (ft)	Portability
Manual Hammers	30 to 60	5 to 10	25	Excellent
Hand-Held Mechanical Hammers	30 to 90	8 to 15	40	Excellent
Hammers Mounted On Vehicles	5,000 to 17,000	20 to 50	150	Good
Anchored Hydraulic Presses	200 to 40,000	20 to 100	200	Good
Conventional Drill Rig	5,000 to 20,000	20 to 80	200	Poor
Truck With Hydraulic Presses	30,000 to 120,000	30 to 100	300	Poor

One of the most important issues to consider when selecting DP equipment is the method for sealing holes. Because any hole can act as a conduit for contaminant migration, proper sealing of holes is essential for ensuring that a site assessment does not contribute to the spread of contaminants. The issue of sealing holes and preventing cross-contamination is not an issue unique to DP technologies. Conventionally drilled holes must also be sealed; in fact, they may pose an even greater risk of cross-contamination because the larger diameter holes provide an even better conduit for contaminants. Many of the recommendations presented here apply to both DP and conventional drilling methods; however, because of the small diameter of DP holes, DP technologies provide some additional challenges.

The selection of appropriate sealing methods depends on site-specific conditions. For example, at sites underlain by homogeneous soil and shallow groundwater, light non-aqueous phase liquids (LNAPLs) released from an UST quickly penetrate the unsaturated soil and come to rest above the water table. Because the LNAPLs are lighter than water, the water table becomes a barrier to continued downward migration. In these settings, DP probe holes pose little risk to the spread of contaminants.

However, at other sites, improperly sealed DP holes can cause significant contaminant migration. For example, at UST sites where there are LNAPLs perched on clay layers in the unsaturated zone, intrusive sampling can facilitate deeper migration of contaminants. In addition, where interbedded formations create multiple aquifers, unsealed holes may allow for the vertical migration of dissolved contaminants into otherwise protected lower aquifers.

The presence of dense non-aqueous phase liquids (DNAPLs) poses an additional risk of cross-contamination. Because DNAPLs are denser than water and typically have low viscosities, they can quickly penetrate soil and migrate below the water table. Although DNAPLs are usually not the primary contaminant at UST sites, they may be present as a result of the use of chlorinated cleaning solvents (*e.g.*, trichloroethylene, methylene chloride). DNAPLs may also be present at refineries and other industrial sites where LUST investigations are performed.

The objective of hole sealing is to prevent preferential migration of contaminants through the probe hole. At a minimum, the vertical permeability of the sealed DP hole should not be any higher than the natural vertical permeability of the geologic formation. In some formations, preferential migration may be prevented without the use of sealants. For example, in heaving, homogeneous sands, the hole will cave immediately as the probe is withdrawn, thus re-establishing the original permeability of the formation. Or, in some expansive clays, the hole may quickly seal itself. Unfortunately, it is usually impossible to verify that holes have sealed completely with these "natural" methods. As a result, more proactive methods of probe hole sealing are generally necessary.

DP holes are typically sealed with a grout made of a cement and/or bentonite slurry. Dry products (*e.g.*, bentonite granules, chips, pellets) may also be used, but they may pose problems because small granules are typically needed for the small DP holes. These granules absorb moisture quickly and expand, often before reaching the bottom of the hole, resulting in bridging and an incomplete seal. Recent technological innovations are aimed at keeping these granules dry until they reach the bottom of the hole and may help to make the use of dry sealing materials more common with DP holes.

There are four methods for sealing DP holes--surface pouring, re-entry grouting, retraction grouting, and grouting during advancement. The following text summarizes the advantages, limitations, and applicability of these methods. Additional information can be found in Lutenegger and DeGroot (1995).

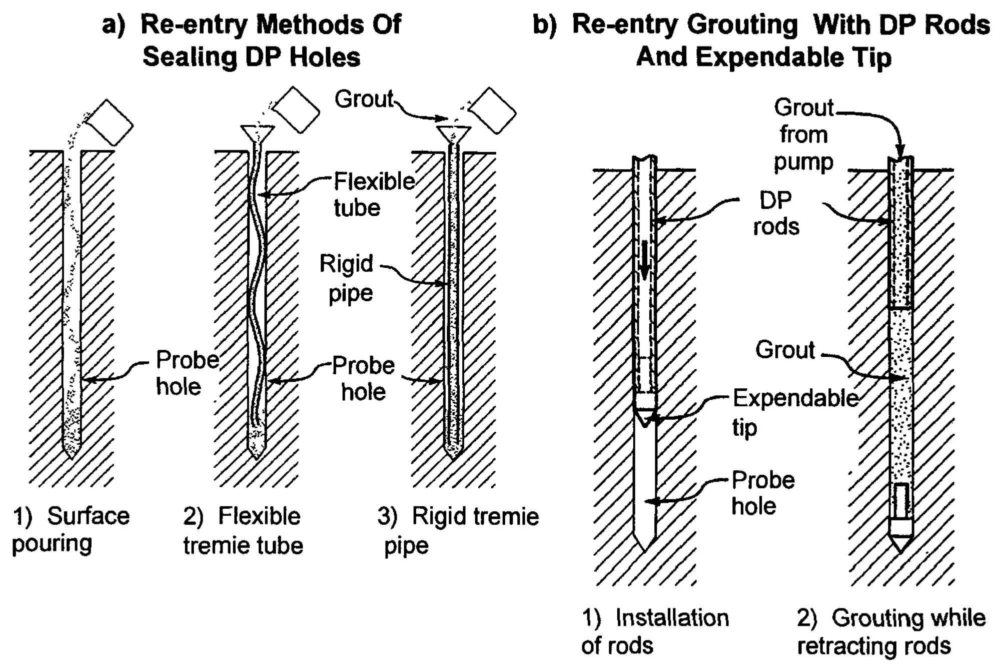
Surface Pouring

The simplest method for sealing holes is to pour grout or dry products through a funnel into the boring from the surface after DP rods have been withdrawn (Exhibit V-21a). This method is generally only effective if the hole is shallow (<10 feet), stays open, and does not intersect the water table. Usually, surface pouring should be avoided because the small DP holes commonly cause bridging of grout and dry bentonite products, leaving large open gaps in the hole.

Re-entry Grouting

Re-entry grouting is also a method in which the DP hole is sealed after the DP rods have been withdrawn from the ground. It is used to prevent the bridging of grout and to re-open sections of the hole that may have collapsed. One method is to place a flexible or rigid tube, called a tremie pipe, into the DP hole (Exhibit V-21a), and pump the grout (or pour the dry material) through the tremie pipe, directly into the bottom of the open hole. To ensure a complete seal by preventing bridging, the tremie pipe is kept below the surface of the slurry as the grout fills the hole. However, flexible or rigid tremie pipes may be difficult or impossible to use if the probe hole collapses. The flexible tremie pipe may not be able to penetrate the bridged soil and a rigid tremie may become plugged.

Exhibit V-21
Methods For Sealing Direct Push Holes

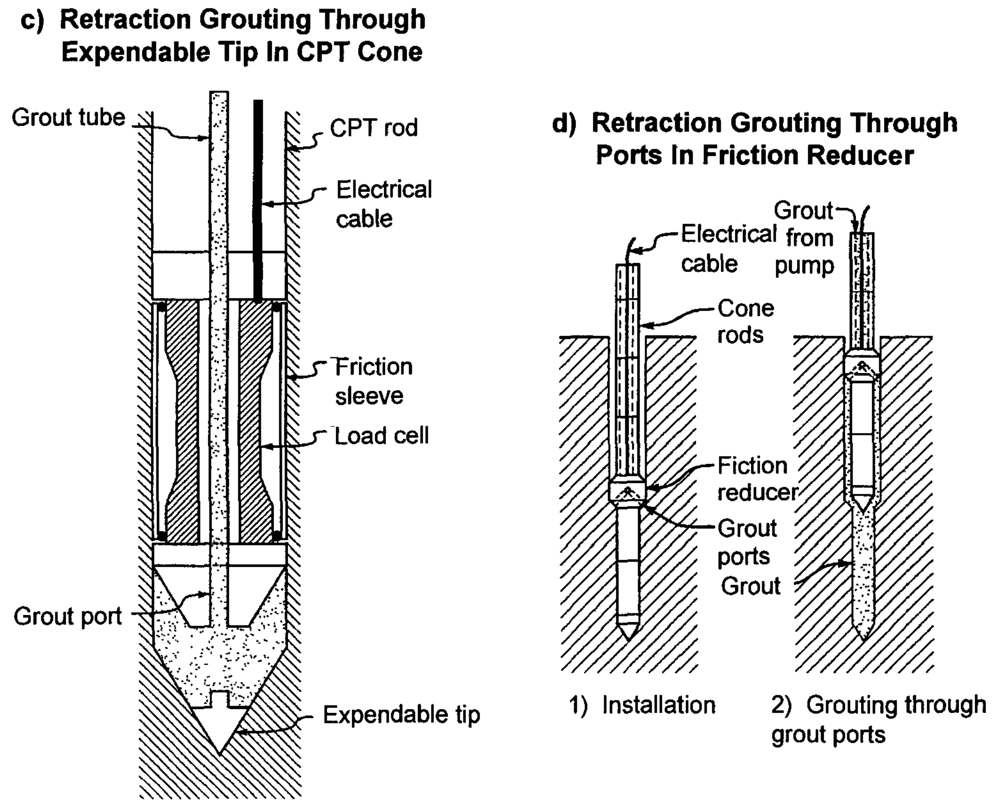


a) Re-entry Methods Of Sealing DP Holes

1) Surface pouring
2) Flexible tremie tube
3) Rigid tremie pipe

b) Re-entry Grouting With DP Rods And Expendable Tip

1) Installation of rods
2) Grouting while retracting rods



c) Retraction Grouting Through Expendable Tip In CPT Cone

d) Retraction Grouting Through Ports In Friction Reducer

1) Installation
2) Grouting through grout ports

Source: Lutenegger & DeGroot, 1995

If tremie pipes are not appropriate for sealing DP holes, re-entry with probe rods and an expendable tip may be used (Exhibit V-21b). This method allows the rods to be pushed through soil bridges to the bottom of the probe hole. The probe rods are then withdrawn slightly, and the expendable tip is knocked out (by lowering a small diameter steel rod inside the DP rods) or blown off (by applying pressure with the grout pump). Grout is then pumped through the DP rods as they are withdrawn from the hole.

Re-entry grouting with DP rods and expendable tips usually results in adequate seals; however, this method is not always reliable because, on occasion, DP rods may not follow the original probe hole, but instead create a new hole adjacent to the original one. If this happens, sealing the original hole may be impossible. This situation is rare but may be a problem when sampling:

- Soft silts or clays that overlie a dense layer. In this situation, the clays provide little support and may not guide the rods back to the original hole.
- In cobbly or boulder-rich sediments overlying a clayey confining formation. Here the probe may be deflected, and the underlying clays may not guide the rods into the original hole.
- Loose homogenous sands that overlie a clayey formation. Here the sands may collapse as the rods are withdrawn. Without a hole to guide the rods, the underlying clay may be penetrated in a slightly different location. In these environments, the likelihood of new holes being created with re-entry grouting increases with smaller diameter probe rods and with deeper investigations.

Retraction Grouting

Retraction grouting is a method in which the DP hole is sealed as the DP rods are being withdrawn. The DP rods act as a tremie pipe for grout that is either poured or pumped down the hole, ensuring a complete seal of the probe hole. Retraction grouting can be used with single-rod systems; however, its application is limited by the sampling method. With cased systems, retraction grouting can be used in any situation.

There are two methods for using retraction grouting with single-rod systems. One method can be used when expendable tips or well screens are attached to the probe rod for soil-gas or groundwater sampling. Grouting with these sampling tools occurs as described in re-entry grouting with expendable tips except there is only a single entry, and the sampling tool is also used for grouting. With well screens, the screen must be expendable. With both tools, grout may be poured or pumped into the ground as the rods are retrieved. Other sampling tools attached to single-rod systems do not allow retraction grouting because the end of the DP rods is sealed by the sampling tools.

Cone penetrometer testing (CPT) allows a second method of retraction grouting with single-rod systems through the use of a small-diameter grout tube that extends from the cone to the ground surface inside the CPT rods. One variation utilizes an expendable tip that is detached from the cone by the pressure of the grout being pumped through the tube (Exhibit V-21c). Another variation of this method consists of pumping the grout through ports in the friction reducer instead of the cone (Exhibit V-21d). Most CPT contractors perform re-entry grouting instead of retraction grouting because the grout tube is very small and subject to frequent plugging.

With cased systems, retraction grouting can be used regardless of the type of sampling tools employed because the outer casing can maintain the integrity of the hole after samples have been collected. As a result, proper use of cased systems can ensure complete sealing of DP holes. This feature is presented in Exhibit V-22.

Grouting During Advancement

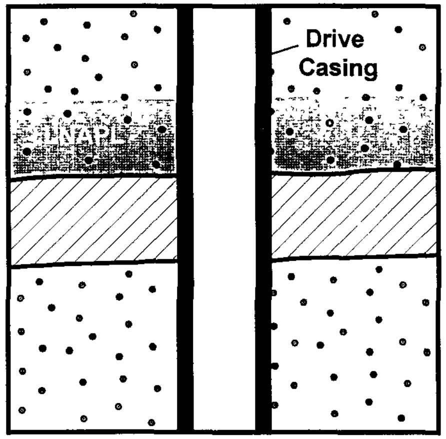
Grouting during advancement is a method that utilizes expendable friction reducers (*i.e.*, detachable rings that are fitted onto the DP probe or cone). The space between the probe rod and the hole, created by the friction reducer, is filled with grout that is pumped from the ground surface as the probe rod advances (Exhibit V-23). When the probe rods are withdrawn, the weight of the overlying grout forces the expendable friction reducer to detach. Additional grout is added, while the rods are being withdrawn, to fill the space that was occupied by the rods.

Discussion And Recommendations

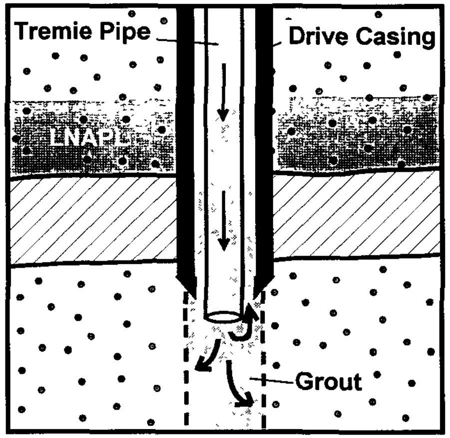
Surface pouring can be used in shallow holes (less than 10 feet bgs) that do not penetrate the water table and in which the formation is cohesive. This method is the least favorable and should only rarely be used because the small size of the DP holes increases the probability of grout or dry products bridging and not completely sealing.

Re-entry grouting is the next best alternative and is often adequate for providing a completely sealed hole. Re-entry grouting can be used if deflection of probe rods is not likely, if NAPLs are not present, or if NAPLs are present but do not pose a risk of immediately flowing down the open hole. Because DNAPLs

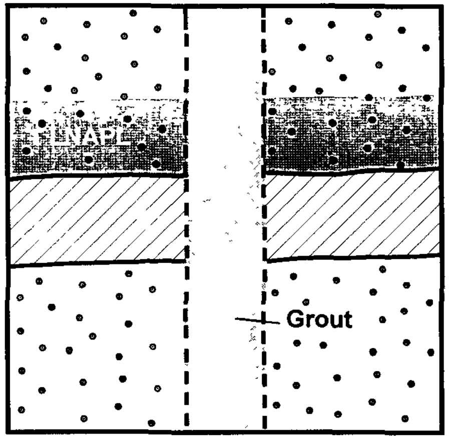
Exhibit V-22
Sealing Direct Push Holes With Cased Systems



1) With cased systems, steel drive casing is advanced as sampling proceeds. The casing remains in the ground as soil and groundwater samples are retrieved thereby preventing cross-contamination of deeper zones.

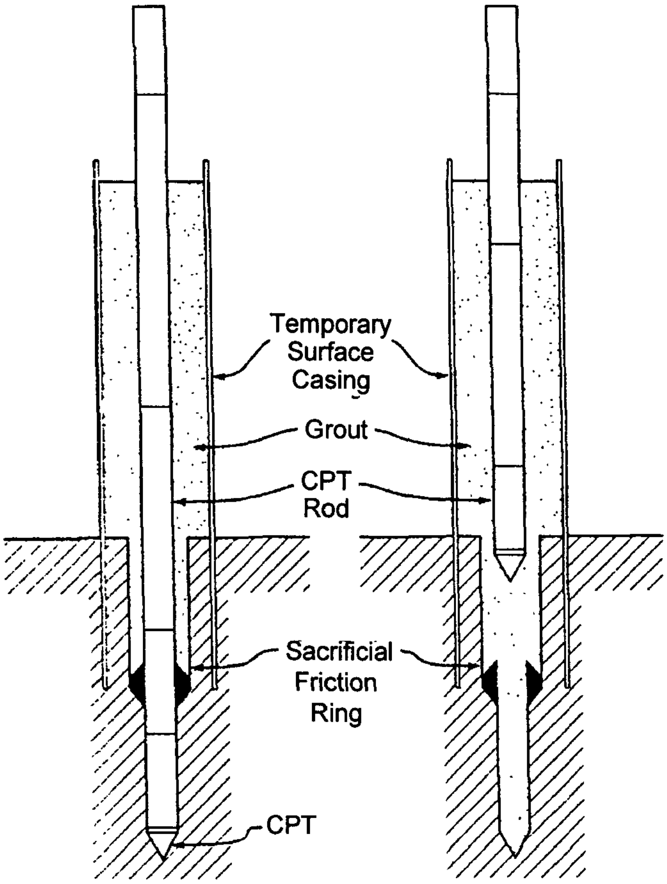


2) After the last sample has been collected, the drive casing is removed. Grout is pumped into the borehole as the casing is withdrawn.



3) Pumping grout as the drive casing is withdrawn ensures that the borehole is properly sealed.

Exhibit V-23
Sealing Direct Push Holes By Grouting During Advancement



1) Advancing cone. 2) Withdrawing cone.

Source: Lutenegger & DeGroot, 1995

are denser than water and tend to have low viscosities, they easily overcome the soil pore pressure and, therefore, require retraction grouting or grouting during advancement. If LNAPLs are present the risk of cross-contamination will depend on many other factors (*e.g.*, soil grain size, quantity of LNAPLs). Hence, while re-entry grouting may at times effectively prevent cross-contamination in source areas, it should be used judiciously.

Retraction grouting and grouting during advancement are the most effective sealing methods for preventing cross-contamination. They are required if:

- DNAPLs are present,
- Sufficient LNAPLs are present to rapidly flow down an open hole,
- A perched, contaminated water table is encountered, or
- Deflection of probe rods may occur.

A summary of DP hole sealing methods is presented in Exhibit V-24.

Exhibit V-24
Summary Of Direct Push Hole Sealing Applications

		Surface Pouring[1]	Re-entry Grouting	Retraction Grouting	Grouting During Advancement
NAPLs Not Present	Cohesive Formation	✓	✓	✓	✓
	Formation Collapses		✓	✓	✓
NAPLs Present	Cohesive Formation	✓[2]	✓[2]	✓	✓
	Formation Collapses		✓[2]	✓	✓
Deflection Of Probe Rod May Occur[3]				✓	✓

[1] This method should not be used if the DP hole intersects the water table.

[2] These methods may be used if there is not an immediate danger of NAPLs flowing down the open hole (*i.e.*, DNAPLs are not present or large quantities of LNAPLs are not perched on clay layers).

[3] There are three conditions when this might occur: Sampling in soft silts or clays that overlie a denser layer; sampling in cobbly or boulder-rich sediments overlying a clayey confining formation; sampling in loose homogenous sands that overlie a confining formation. Note that these situations are not typical. The likelihood of probe deflection increases with depth and decreases with the increase in probe rod diameters.

Direct Push Equipment Manufacturers

A list of DP equipment manufactures is included in Exhibit V-25 and a matrix of equipment is presented in Exhibit V-26. The equipment has not been evaluated by the U.S. EPA and inclusion in this manual in no way constitutes an endorsement. Because of the rapidly changing nature of the DP industry, these tables may quickly become outdated; therefore, readers should not use the tables as their only source of available manufacturers. These vendors are listed solely for the convenience of the reader.

Exhibit V-25
Direct Push Equipment Manufacturers

Art's Manufacturing & Supply 105 Harrison American Falls, ID 83211 (800) 635-7330	Boart/Longyear Company 2340 W. 1700 S. Salt Lake City, UT 84127 (801) 972-1395
Checkwell, Inc. 12 Linden Street Hudson, MA 01749-2045 (508) 562-4300	Christensen Mining Products/Acker P.O. Box 30777 Salt Lake City, UT 84127 (800) 453-8418
Clements Associates Inc. R. R. #1 Box 186 Newton, IA 50208 (515) 792-8285	Concord Environmental Equipment R. R. 1 Box 78 Hawley, MN 56549 (218) 937-5100
Conetec Investigations, Limited 9113 Shaughnessy Vancouver, British Columbia V6P 6R9 Canada (604) 327-4311	Diamond Drilling Contracting Company P. O. Box 11307 Spokane, WA 99211 (800) 325-1563
Diedrich Drill, Inc. P. O. Box 1670 La Porte, IN 46352 (800) 348-8809	Direct Push Technologies, Inc. 605 Alamitos Blvd. Seal Beach, CA (310) 430-3326
Foremost Drills/Mobile 1225 64th Ave., N.E. Calgary, Alberta T2E 8K6 Canada (403) 295-5800	GeoInsight 6200 Center St., Ste. 290 Clayton, CA 94517 (510) 672-0919

Geoprobe Systems 601 N. Broadway Salina, KS 67401 (800) 436-7762	Hogentogler & Co., Inc. P. O. Box 2219 Columbia, MD 21045 (800) 638-8582
KVA Analytical Systems P. O. Box 574 Falmouth, MA 02541 (508) 540-0561	Mavrik Environmental & Exploration Products 104 S. Freya Street Suite 218, Lilac Bldg. Spokane, WA 99202 (800) 376-4135
MPI Drilling P. B. Box 2069 Picton, Ontario *KOK 2TO Canada* (613) 476-5741	Precision Sampling, Inc. 47 Louise Street San Rafael, CA 94901 (800) 671-4744
ProTerra 867 Boston Road Groton, MA 01450 (508) 448-9355	QED Environmental Systems, Inc. 6095 Jackson Road P. O. Box 3726 Ann Arbor, MI 48106 (800) 624-2026
SIMCO Drilling Products Division Box 448 Osceola, IA 50213 (800) 338-9925	SimulProbe Technologies, Inc. 150 Shoreline Highway Bldg. E. Mill Valley, CA 94941 (800) 553-1755
Solinst Canada, Ltd. 35 Todd Road Georgetown, Ontario L7G 4R8 Canada (800)661-2023	Universal Environmental Engineering, Inc. 740 North 9th Ave., Suite E Brighton, CO 80601 (303) 654-0288
Vertek 120A Waterman Road South Royalton, VT 05068 (800) 639-6315	Xitech Instruments, Inc. 300-C Industrial Park Loop Rio Ranch, NM 87124 (505) 867-0008

Exhibit V-26
Matrix Of Manufacturers And Equipment[1]

Manufacturer	**Rod Systems**		**Sampling Tools**			**Specialized DP Probes**			**Equipment to Advance Rods**
	Single	**Cased**	**Soil**	**Soil Gas**	**Ground-water**	**CPT**	**Geophysical Probes**	***In Situ* Chemical Sensors**	
Art's Manufacturing & Supply		✓	✓	✓	✓				✓
Boart/Longyear Company			✓						
Checkwell, Inc.	✓		✓	✓	✓				✓
Christensen/ Acker			✓						
Clements Associates Inc.	✓		✓						✓
Concord Environmental Equipment	✓		✓	✓	✓				✓
Conetec Investigations, Limited	✓					✓	✓	✓	✓
Diamond Drilling	✓		✓						

Manufacturer	Rod Systems		Sampling Tools			Specialized DP Probes			Equipment to Advance Rods
	Single	Cased	Soil	Soil Gas	Ground-water	CPT	Geophysical Probes	*In Situ* Chemical Sensors	
Diedrich Drill, Inc.		✓	✓	✓	✓				✓
Direct Push Technologies, Inc.	✓		✓	✓	✓				✓
Foremost Drills/Mobile	✓		✓						
GeoInsight	✓		✓	✓	✓				
Geoprobe Systems	✓		✓	✓	✓		✓	✓	✓
Hogentogler & Co., Inc.	✓		✓	✓	✓	✓	✓	✓	✓
KVA Analytical Systems	✓		✓	✓	✓				✓
Mavrik Environmental			✓	✓	✓				✓
MPI Drilling	✓		✓						✓

Manufacturer	Rod Systems		Sampling Tools			Specialized DP Probes			Equipment to Advance Rods
	Single	Cased	Soil	Soil Gas	Ground-water	CPT	Geophysical Probes	*In Situ* Chemical Sensors	
Precision Sampling, Inc.	✓	✓	✓	✓	✓				✓
ProTerra	✓		✓	✓	✓				✓
QED Environmental Systems, Inc.			✓	✓	✓	✓			
SIMCO	✓		✓						✓
SimulProbe Technologies, Inc.			✓	✓	✓				
Solinst	✓		✓		✓				
Universal Environmental	✓								✓
Vertek	✓	✓	✓	✓	✓	✓	✓	✓	✓
Xitech	✓			✓					✓

[1] This matrix presents only a general list of the equipment manufactured that is discussed in this chapter. These manufacturers may manufacture other geophysical equipment in addition to what is listed here. In addition, these manufacturers may only supply specialized equipment for the listed methods, and not necessarily all the equipment that is needed.

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Chapter VI

Field Methods For The Analysis Of Petroleum Hydrocarbons

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Chapter VI
Field Methods For The Analysis Of Petroleum Hydrocarbons

Analysis of soil, soil-gas, and groundwater samples in the field is an essential element of expedited site assessments (ESAs). Field managers require field-generated data in order to complete a site assessment in a single mobilization. In recent years many field methods for petroleum hydrocarbon analysis have been developed and improved. These technological improvements can change the way site assessments are conducted by providing reliable data in the field that can then be used to select subsequent sampling locations.

Historically, the analysis of contaminated media during UST site assessments has been completed off-site in fixed laboratories that use certified analytical methods. While these methods provide a very high data quality level (DQL), their results may take days or weeks and their cost is relatively high. In addition, many studies have shown that samples can undergo significant degradation during the shipping and holding times before analysis.

The development and improvement of many field methods have allowed site assessments to be performed more rapidly and completely than is feasible with off-site analysis. By combining field methods of different DQLs, ESAs can improve the resolution of contaminant distribution and minimize analytical costs. Low DQL (*i.e.*, screening) methods can be used to provide a high density of data to determine source areas (*i.e.*, zones of non-aqueous-phase liquid [NAPL] contamination). Higher DQL methods can be used to identify low concentrations or specific chemicals of concern at select locations (*e.g.*, leading edge of contaminant plume). Data from higher DQL methods can also be used as part of a quality control check for the field analytical program.

Exhibit VI-1 is a summary table of the primary selection criteria for eight commonly available field methods applicable for the analysis of petroleum hydrocarbons. It is followed by a brief discussion of the DQL system used in this chapter. The majority of the chapter is dedicated to discussions of the eight field methods listed in Exhibit VI-1. Each method is summarized with a capabilities and limitations table. A brief description and discussion of emerging technologies (*i.e.*, new technologies that are subject to significant innovation in the immediate future) appears at the end of the chapter. In addition, Appendix B, at the end of the manual, provides the reader with a table of relevant U.S. EPA test methods for petroleum hydrocarbons.

The chapter is organized so that readers can use the summary table (Exhibit VI-1) for initial selection of the most appropriate methods for a specific situation. They can then make a final selection by referring to the discussions of the individual methods that follow. The simpler, lower DQL methods are presented first.

Exhibit VI-1
Summary Table Of Field Methods For Petroleum Hydrocarbon Analysis

Test Method	Media[1]			Analyte	Data Quality Level[2]	Analysis Time	Cost Per Sample[3]	Skill Level	Limitations
	S	SG	W						
Detector Tubes		✓	✓	>100 specific compounds	1A/1B	5 to 15 min	\$8 to \$27	Low	High degree of cross-reactivity
Fiber Optic Chemical Sensors		✓	✓	VOCs and SVOCs $\geq C_6$	1A/1B	3 to 5 min	<\$1 to \$10	Low	Does not measure specific constituents
Colorimetric Test Kits	✓		✓	Aromatic hydrocarbons	1A/1B	10 to 20 min	\$17 to \$42	Low-Medium	Colors may be difficult to distinguish
TOV Methods With FID/PID	✓	✓	✓	Total VOCs	1A/1B	1 to 30 min	<\$1 to \$10	Low-Medium	Does not measure specific constituents
Turbidimetric Test Kit	✓			TPH of mid-range hydrocarbons (*e.g.*, diesel fuel)	1B	15 to 20 min (25 per hour)[4]	\$10 to \$15	Low-Medium	Not useful for gasoline
Immunoassay Test kits	✓		✓	TEX/PAHs/ TPH	1B	30 to 45 min (5 to 8 per hour)[4]	\$20 to \$60	Medium	Cross-reactivity may affect interpretation
Portable Infrared Detectors	✓		✓	TPH of hydrocarbons C_6 to C_{26}	2	5 to 20 min	\$5 to \$30	Medium	VOCs are not accurately analyzed
Field GC	✓	✓	✓	Specific VOCs and SVOCs	2/3	10 to 60 min[5]	\$20 to \$70	Medium-High	Requires a skilled technician

[1] Soil (S), Soil-Gas (SG), Water (W)
[2] Data quality levels are discussed in further detail in the following text
[3] Includes estimation of capital costs and disposables -- excludes labor
[4] When run in batches
[5] Longer times result when high quality method preparations are performed

Data Quality Levels

Data quality levels (DQLs) represent a classification system of analytical methods by the quality of data they provide. DQLs are one of several criteria that can be used for selecting an appropriate analytical method. Exhibit VI-2 presents the summary table of the DQL classification system used in this manual, which was adapted from the classification system developed by the New Jersey Department of Environmental Protection (1994). The levels are organized in a data quality hierarchy in which DQL 1 provides screening information, DQL 2 provides quantitative data, and DQL 3 provides the most rigorous quantitative data. Every state will have its own definition and requirements for various field analytical methods and its own DQLs, so a complete list of QA/QC procedures for each level is not provided.

Data Quality Level 1: Screening

DQL 1 screening methods are divided into two subgroups: 1A and 1B. Both are used for an initial screening of samples or for health and safety evaluations. DQL 1A provides a general indication of the presence of contaminants, DQL 1B provides relative numerical values. All DQL 1 methods:

- May require confirmation with higher DQL methods; and
- Detect the presence of classes or groups of constituents.

Exhibit VI-2
Summary Of Data Quality Levels

Data Quality Level	General Field Applications
1A: Qualitative Screening	General presence of contamination (*e.g.*, "Yes/no," low/medium/high); health and safety
1B: Semiquantitative Screening	Approximation of contaminated zone; provides order of magnitude estimations (*e.g.*, 10s, 100s, 1000s)
2: Quantitative Delineation	Delineation of specific contaminants
3: Quantitative Clean Zone	Regulatory monitoring, determining clean samples

Data Quality Level 1A: Qualitative Screening

DQL 1A is designated for initial screening of soil, soil gas, and groundwater by providing a "yes/no" indication of contamination. Measurements made with these methods may not always be consistent because of the lack of sample control and inherent method variability. As a result, clean samples cannot be determined from this level. Examples of DQL 1A methods include ambient air analysis or jar headspace using flame-ionization detectors (FIDs) and photoionization detectors (PIDs).

Data Quality Level 1B: Semiquantitative Screening

DQL 1B provides a rough, order of magnitude (*e.g.*, 10s, 100s, 1000s) estimate of contamination. It can be used for defining the location of known types of contamination. QA/QC procedures include a calibration curve generated using matrix spiked standards, regular calibration checks, and field blank/background samples. An example of DQL 1B is the data from some immunoassay test kit methods.

Data Quality Level 2: Quantitative--Delineation

DQL 2 methods provide reliable data for the delineation of contaminants during a site assessment. Typically, they are laboratory methods adapted for the field (*e.g.*, portable GC methods). DQL 2 methods:

- Measure individual constituents (*e.g.*, benzene) or groups of constituents (*e.g.*, BTEX, gasoline/diesel range organics),
- Produce data that are highly reproducible and accurate when appropriate QA/QC procedures are used, and
- Accomplish contaminant delineation, which may be correlated with a higher DQL method.

Data Quality Level 3: Quantitative--Clean Zone

DQL 3 methods are approved laboratory methods (*e.g.*, U.S. EPA SW-846 Laboratory Methods) and are intended to provide the most reliable data practicable. These methods can be used for confirming "clean" samples and for regulatory monitoring. DQL 3 can be performed both off-site in a fixed laboratory or on-site in a mobile laboratory.

There are eight commonly available field analytical methods that can be used to detect petroleum hydrocarbons. Whenever any of these methods are used to determine the constituent concentrations, the use of appropriate standards is essential. There are two aspects to creating appropriate standards--using constituents that match as closely as possible the constituents (or type of contamination) found at the site and using the media (*e.g.*, soil, groundwater) that will be analyzed at the site. For example, if a silty soil contaminated with weathered gasoline is to be analyzed, free product found at the site may be used to spike a background sample of silty soil. If free product is not available, gasoline (from the local USTs) may be artificially weathered (*e.g.*, allow to sit in the sun for a period of time) and used to spike the silty soil.

The following text contains discussions of each method, including its operating principles, method descriptions, and method capabilities. At the end of each method discussion is a table of important selection criteria.

Detector Tubes

Detector tubes measure volatile gases and can be used for analyzing individual constituents or compound groups (*e.g.*, petroleum hydrocarbons). In addition to their frequent use for health and safety measurements, detector tubes can also be used as screening tools for volatile hydrocarbon contamination.

Operating Principles

Detector tubes are glass tubes that change color when exposed to specific gases. The glass tubes are sealed and filled with a porous solid carrier material which is coated with color reagents. The breakaway ends of the tube are snapped off and a known volume of air is drawn through the tube at a fixed flow rate using a hand or electric pump. As air passes through the tube, a stain is produced by the reaction of target constituents with the reagents inside the tube. The investigator reads the concentration from a scale on the tube. For most of the detector tubes that are used for hydrocarbon assessments, the length of the stain in the tube is proportional to the concentration of the constituent. In addition to visual observations, gas-specific measurements can be made using an optical analyzer.

Method Descriptions

Detector tubes provide a direct measurement of volatile hydrocarbon vapors in ambient air. They can also provide an indirect indication of soil and groundwater contaminant concentrations when used in field test kits for analysis of soil gas and headspace for liquids.

Ambient Air Measurements

Simple ambient air measurements can be made by inserting a detector tube into a hand pump or mounting it in an optical analyzer, drawing air through the tube, and reading the results. For hand-held pumps, readings can be taken in the ambient air directly above the soil or groundwater samples. Test kits are available for on-site identification and classification of ambient air above unknown liquids during an emergency response. Attachments are also available that allow for the testing of ambient air in monitoring wells or sumps.

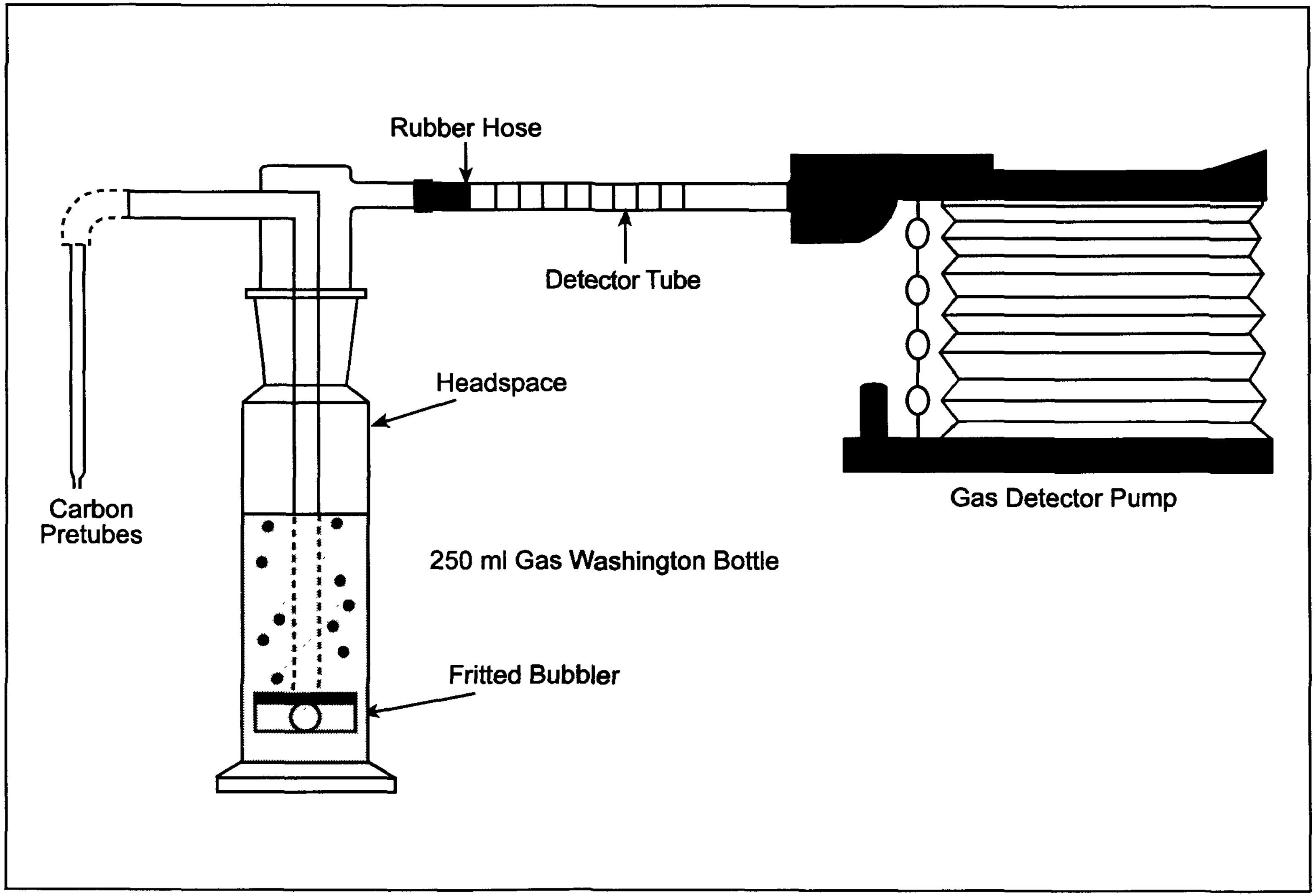
Soil-Gas Test Kits

Soil-gas test kits allow for active soil-gas sampling and analysis with detector tubes. This method utilizes a probe that is driven into the soil to a desired depth. A detector tube is inserted into a sampling chamber near the tip of the probe and connected to the ground surface with an extension tube. After air is drawn through the detector tube, the probe is removed for reading. For a more complete discussion of active soil-gas sampling, refer to Chapter IV, Soil-Gas Surveys.

Liquid Test Kits

The liquid test kits consist of two types of headspace analyses: A bottle system where the liquid sample is aerated, partitioning volatiles from the liquid into the headspace; or a sealed sample bottle is agitated and the headspace is subsequently analyzed. The aerating test kit system utilizes a fretted bubbler tube fitted in a wash bottle containing the water sample that the investigator has measured to a specific volume. A known quantity of air is drawn through the bubbler to aerate the sample, volatilizing the constituents according to their Henry's law constant. The headspace then passes through detector tubes for analysis of the headspace in the bottle. The headspace concentration is correlated to a water concentration using calibration and temperature corrections. Exhibit VI-3 depicts a liquid extraction apparatus that can be used with detector tubes.

Exhibit VI-3
Detector Tube Liquid Extraction Apparatus



Source: U.S. EPA, 1990

Method Capabilities And Practical Considerations

Detector tubes are available for hundreds of compounds including many specific petroleum hydrocarbons and various general classes of petroleum hydrocarbons (*e.g.*, aliphatics). Detector tubes used in hydrocarbon analyses generally provide readings in the parts per million (ppm) range, although some can detect as low as 100 parts per billion (ppb). In addition, because detector tubes and pumps are precalibrated, the procedures are relatively easy to learn. Detector tubes provide DQL 1A information with ambient air and soil-gas test kit analysis. Because liquid test kit analysis is performed under more controlled conditions, detector tubes are able to provide DQL 1B information when used with this method.

A major limitation of this method is that the reagents in the detector tubes are generally cross-reactive with compounds of similar chemical behavior. Consequently, false positive and inaccurately high readings are possible. In addition, detector tubes can only be used in specific ambient temperature ranges as specified by the manufacturer. The minimum temperature is typically 32° F (0° C) and the maximum temperature typically ranges from 86° to 104° F (30° to 40° C). A summary of the capabilities and practical considerations for analysis using detector tubes is shown in Exhibit VI-4.

Fiber Optic Chemical Sensors

Fiber optic chemical sensors (FOCS) are used for *in situ* qualitative and semiquantitative measurements of volatile and semi-volatile hydrocarbons in groundwater and soil vapor. Some FOCS are used for detecting leaks of liquid and vapor-phase petroleum products. They can also be used for continuous monitoring of groundwater wells, soil vapor wells, and vapor extraction wells.

Operating Principles

FOCS use an optical fiber coated with a hydrophobic/organophyllic chemical to detect hydrocarbons. FOCS operate on the principle that the index of refraction of the optical fiber coating changes in direct proportion to the concentration of hydrocarbons in air or water. As hydrocarbons partition into the organophyllic coating, the change in the effective index of refraction can be determined by measuring the amount of light transmitted through the optical fiber. The response depends on the total number and type of hydrocarbons present. Exhibit VI-5 is a schematic drawing of FOCS operating principles.

Exhibit VI-4
Summary Of Detector Tube Method Capabilities And Practical Considerations

	Ambient Air	Soil Vapor Test Kit	Liquid Test Kit
Compounds Detected	100s of specific compounds and compound groups including benzene, toluene, xylenes, gasoline, aliphatic hydrocarbons, MTBE, O_2, CO_2, and H_2S.		
Measuring Range	Varies with analyte. Most compounds can be detected in the ppm range, some as low as 100 ppb.		
Limitations	Cross reactivity may result in false positives or inaccurately high readings because many tubes are sensitive to chemically similar compounds (*e.g.*, benzene tubes also measure toluene to some degree). Minimum ambient air temperature is typically 32° F, maximum is typically between 86° and 104° F.		
Time For Analysis	2 to 5 minutes	10 to 15 minutes (includes probe placement)	5 to 10 minutes
Difficulty of Procedure	Low		
Data Quality Level	1A	1A	1B
Cost Per Sample[1]	$8	$27	$14

[1] Based on 100 analyses, includes cost of tube, pump, and test kit.

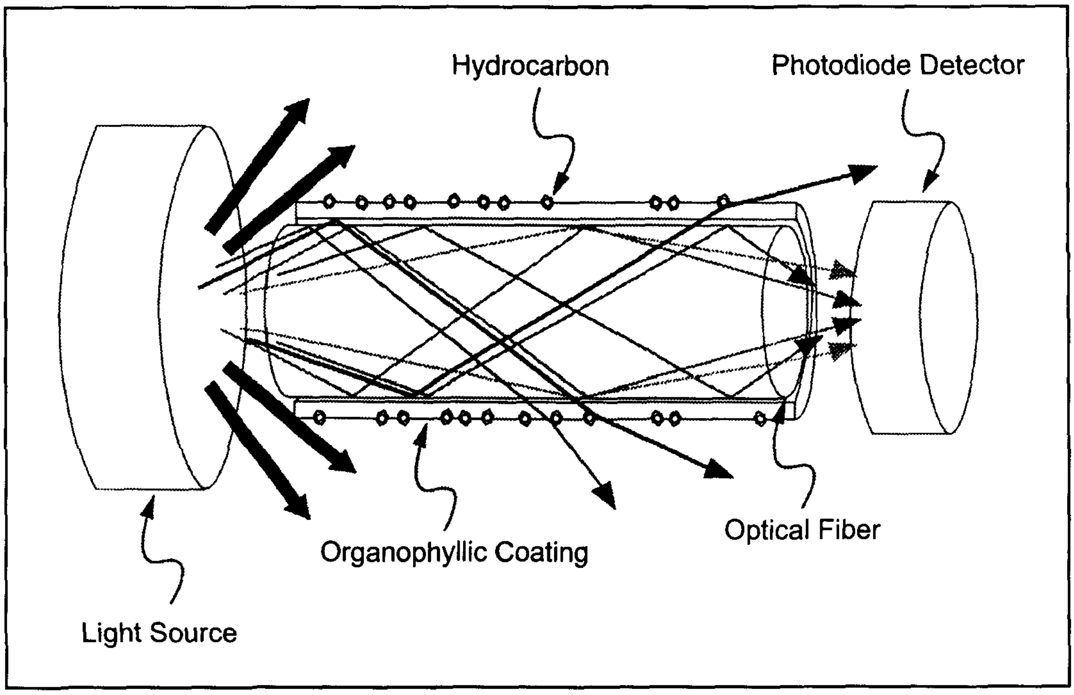
Method Descriptions

FOCS are typically used for the *in situ* measurement of groundwater monitoring wells and soil vapor wells. They can also be used to analyze the ambient air immediately above soil or for soil headspace analysis.

Water Wells

Before an analysis is performed, the probe sensor is cleaned and calibrated to zero in a solution of distilled water that is within 9° F (5° C) of the temperature of the well water. Calibrations are checked daily or periodically between samples

Exhibit VI-5
Schematic Drawing Of FOCS Operating Principles



Source: Modified from ORS Environmental Systems product literature

using field standards or standards provided by the manufacturer (*e.g.*, p-xylenes, isopropanol).

To measure hydrocarbon concentrations in groundwater wells, the meter is set to measure continuously, and the probe is removed from the zero solution and lowered down the well to the desired depth. Readings are also affected by changes in temperature during analysis. If the well water temperature changes by more than 0.18° F (0.1° C) every 4 seconds, a 5-minute analysis is required to compensate for the temperature variations. Because results are site-specific, response factors are used to obtain specific constituent concentrations for specific wells with known contaminants (using a ratio of laboratory results to probe sensor results for a specific well being tested).

Vapor Wells

Before an analysis is performed, the probe sensor is cleaned, zeroed in a Tedlar bag with 5 liters of zero air (*i.e.*, air that contains less than 0.1 ppm total hydrocarbons), and calibrated using field standards or standards provided by the manufacturer (*e.g.*, p-xylenes, isopropanol). Calibrations must be checked daily or periodically between samples.

To measure hydrocarbon concentrations in vapor wells, a humidity tube is used to zero the probe to the humidity in which the measurement will be made. The probe sensor is then lowered to the desired depth. When the readings have stabilized, the measurement can be recorded. The time required to reach a stable reading is related to the temperature difference between the temperature at which the probe sensor was zeroed and the temperature of the well. Well-specific response factors may be used to obtain a specific concentration for that well. After the measurement is completed, the probe must remain above ground for 5 minutes to allow any vapors in it to dissipate.

Method Capabilities And Practical Considerations

FOCS are capable of detecting VOCs and SVOCs with six or more carbon atoms. Thus, benzene (C_6) can be detected while methane (C_1) cannot. The response of the sensor probe is directly related to the quantity of hydrocarbons present in a sample, calibrated to a p-xylene response. However, highly soluble constituents yield a lower response than less soluble constituents. For example, benzene, which is approximately 10 times more soluble in water than p-xylene, responds with one-tenth the sensitivity of p-xylene. In addition, the response is affected by temperature. FOCS, therefore, almost always require temperature compensation, which is usually built into the sensor. The optimal temperature range of FOCS is generally between 50° and 86° F (10° and 30° C).

Because the readings provide a relative value, a response factor (empirically determined by the manufacturer) must be used to estimate contaminant levels once the constituents and their relative ratios have been determined. The strongest correlation of results with GC analysis comes either from a single well monitored over time or from wells contaminated by the same source. Exhibit VI-6 presents a summary of FOCS method capabilities and limitations.

Colorimetric Test Kits

Colorimetric test kits provide qualitative or semiquantitative screening of aromatic hydrocarbons in soil and water. They can generally provide information about compound groups (*e.g.*, BTEX, PAHs) but can also help determine concentrations of specific compounds. A portable spectrophotometer has recently been developed to aid in the evaluation of concentrations in samples, however, the

Exhibit VI-6
Summary Of FOCS Method Capabilities And Practical Considerations

	Water	Vapor
Compounds Detected	VOCs and SVOCs ≥ C_6 (Benzene)	
Lower Detection Limits	0.1 to 5 ppm	3 to 65 ppm
Limitations	Does not measure specific constituents Concentrations at specific locations must be calculated by comparing historical DQL 3 results with FOCS results Free product saturates coating and exceeds meter scale Optimal temperature range is between 50° and 86° F.	
Time For Analysis	3 to 5 minutes	
Difficulty of Procedure	Low	
Data Quality Level	1A/1B	
Cost Per Sample[1]	<$1 to $10	

[1] Reflects the averaged cost over an extended period of time including consumables (*e.g.*, calibration standards) and the capital cost of equipment, ranging from $5000 to $6900.

primary method of evaluation is by visual comparison of sample results with calibrated photographs of specific substances (*e.g.*, gasoline, diesel fuel).

Operating Principles

Colorimetric test kits that are designed for hydrocarbon analysis create intensely colored aromatic compounds through the Friedel-Crafts alkylation reaction. This reaction utilizes a catalyst (*e.g.*, $AlCl_3$) to attach an alkyl group to an aromatic hydrocarbon (*e.g.*, benzene). In these test kits, an alkylhalide (*e.g.*, carbon tetrachloride [CCl_4]) is typically used as both an extracting agent for the hydrocarbons and as a reagent. Once the catalyst is added, the reaction proceeds. The resulting color (*e.g.*, orange, violet) provides information about the type of constituent; the intensity of the color is directly proportional (within a specific range) to the concentration. Exhibit VI-7 presents a common Friedel-Crafts alkylation reaction utilized in colorimetric test kits.

Method Descriptions

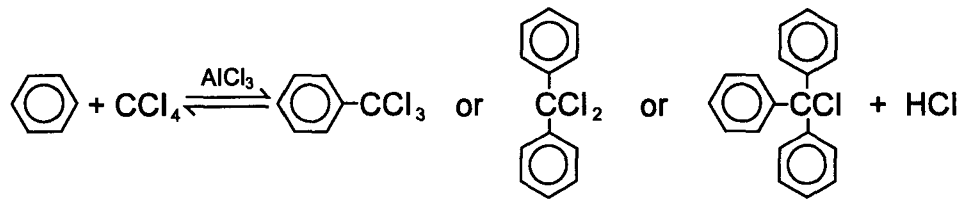
Colorimetric test kits are available for soil and water analysis. The kits provide the reagents and equipment needed for the extraction and colorimetric analysis of aromatic hydrocarbons. Color charts, created from known concentrations of various constituents, are used for comparison with field results to determine the constituents and their approximate concentrations.

Water Test Kit

The water test kit requires the following steps:

- Pour the water sample into a separatory funnel;
- Add the solvent/extract (an alkylhalide) to the sample, agitate it, and wait until solvent/extract has settled to the bottom of the separatory funnel;
- Drain the extract into a test tube;
- Add the catalyst and agitate it while the reaction proceeds between the aromatics and the alkylhalide; and
- Compare the color of the sample in the test tube (precipitate) with the color chart standard.

Exhibit VI-7
Example Of Friedel-Crafts Alkylation Reaction Utilized In Colorimetric Test Kits



Soil Test Kit

The soil test kit requires the following steps:

- Measure a soil sample;
- Add the solvent/extract to the soil, agitate it vigorously, and wait for the solvent/extract to separate;
- Pour the extract into a test tube;
- Add the catalyst and agitate; and
- Compare the color of the sample in the test tube (precipitate) with the color chart standard.

Method Capabilities And Practical Considerations

Colorimetric test kits can be used to analyze aromatic hydrocarbons (with particular sensitivity to PAHs) in soil and water. In soil, the detection limit is generally in the 1 to 10 ppm range; in water it is less than 1 ppm. Colorimetric test kits are effective for analysis of gasoline, diesel fuel, and other fuel oil contamination. A particular advantage of this method is that it is not dependent on analyte volatility, making it especially useful for older spills and for heavier fuel oils.

One of the major limitations of the method is that when comparing samples with the color chart photos, constituent concentrations and colors (*i.e.*, type of constituent) can be difficult to determine when constituent concentrations are low. In addition, if the contamination is a mixture of constituents, lighter aromatics (*e.g.*, BTEX) which turn to shades of orange will be hidden by heavier constituents (*e.g.*, PAHs) which turn to shades of violet. As a result, constituents present in the sample should be known before analysis.

There are a number of potential interferences for this type of analysis. First, the presence of chlorinated solvents may result in false positive analysis with water or soil. Second, color interferences for organic-rich or clayey soils may make color interpretation difficult. Clay soils may also pose additional problems because the sample tends to clump, making contaminant extraction difficult. Finally, the reaction products are sensitive to UV radiation, becoming darker with time and causing the potential for overestimation of constituent levels. Constituents and concentrations should, therefore, be determined within 30 minutes of color formation.

A health and safety issue involved with the use of this method is that analysis of all water samples and soil samples with hydrocarbon concentrations less than 1000 ppm requires a heptane-carbon tetrachloride solution to be used for sample extraction. Therefore, reagents and waste products must be properly handled and disposed of after use, typically, they are shipped back to the manufacturer. For analysis of soil samples with greater than 1000 ppm hydrocarbons, a much more environmentally safe heptane solution (without tetrachloride) can be used for extraction.

Both soil and water test kits provide data for screening level analysis. Because the soil test provides variable response to a wide range of aromatic hydrocarbons, has several interferences, and can be difficult to use, it is classified as a DQL 1A analysis. The water analysis is more accurate and allows for an order of magnitude determination of contamination. As a result, it is capable of providing DQL 1B analysis. A summary of the capabilities and practical considerations for analysis using colorimetric methods is shown in Exhibit VI-8.

Analysis With Reflectance Spectrophotometer

A portable reflectance spectrophotometer and associated software have been developed that allow objective measurement of color intensity. Future innovations may allow quantification of specific constituents and increase the upper level of measurement. It is available for approximately $4,500.

Total Organic Vapor Analytical Methods With Flame Ionization And Photoionization Detectors

Total organic vapor (TOV) analytical methods detect the total volatile organic compounds in a sample. Although, they provide information about the relative magnitude of contamination, TOV methods are unable to distinguish specific compounds.

Operating Principles

There are two types of instruments commonly used in TOV analysis--flame ionization detectors (FIDs) and photoionization detectors (PIDs).

Exhibit VI-8
Summary Of Colorimetric Test Kit Method Capabilities And Practical Considerations

	Soil Test Kit	Water Test Kit
Compounds Detected	Monoaromatic and polyaromatic hydrocarbons	
Measuring Range	Benzene 1 to 200 ppm	Benzene 0.2 to 10 ppm
	Toluene 0.5 to 250 ppm	Toluene 0.2 to 10 ppm
	Gasoline 1 to 1,000 ppm	Gasoline 0.5 to 20 ppm
	Diesel 1 to 1,000 ppm	Diesel 0.5 to 20 ppm
	JP-5 1 to 2,000 ppm	Naphthalene 0.1 to 2.5 ppm
Limitations	Mixtures of constituents may make colors difficult to distinguish without spectrophotometer. Investigators should know constituents present before analyzing samples UV light degrades the color of samples (*i.e.*, they become darker) approximately 30 minutes after color formation. Extraction of constituents may be difficult in clays. Organic and clay-rich soils may interfere with color. Carbon tetrachloride must be used, and properly disposed of, for analysis < 1000 ppm.	
Time For Analysis	10 to 20 minutes	10 to 15 minutes
Difficulty Of Procedure	medium	low-medium
Data Quality Level	1A	1B
Cost Per Sample[1]	$17 to $42	

[1] Initial 30 analyses cost $42; subsequent analyses may cost as little as $17.

Flame Ionization Detectors

FIDs use a hydrogen flame to ionize organic vapors. The measured electrical current that is generated by the free ions, called the instrument response, is related to the concentration of volatile compounds present in the sample. While FIDs provide significant response to most organic vapors, they are more sensitive to aliphatic (or chained) hydrocarbons because these compounds burn more efficiently than aromatic (or ringed) hydrocarbons. FIDs are typically calibrated with methane.

Photoionization Detectors

PIDs use an ultraviolet lamp to ionize organic vapors. As with FIDs, the instrument response is related to the electrical current generated by the ionized compounds. Compounds with higher ionization potentials (*e.g.*, aliphatics) require more energy for ionization; therefore, the strength of the UV lamp determines the compounds that are ionized. UV lamps range in energy from 8.4 to 11.7 eV. Isobutylene is typically used as the calibration gas for PIDs. These instruments are most sensitive to aromatic hydrocarbons (*e.g.*, BTEX compounds), but some aliphatics can also be detected with the higher energy lamps.

Comparison Of Flame Ionization Detectors And Photoionization Detectors

In addition to the response differences to aliphatic and aromatic hydrocarbons, other factors to consider when selecting an FID or PID include the following.

- Response factors for specific constituents, which differ between types of instruments and among manufacturers, are important to know when calculating actual concentrations. For example, an FID calibrated with methane may respond 150 percent greater when exposed to the same concentration of benzene but the response may be only 25 percent for ethanol.
- FIDs remain linear from 1 to 1,000 ppm_v (parts per million by volume), and some can even reach 10,000 ppm_v; PIDs remain linear from 1 to 300 ppm_v, with some reaching 750 ppm_v under ideal conditions.
- Most PIDs are affected by high electrical currents (*e.g.*, power lines).
- PIDs can operate in conditions of high relative humidity and low O_2, but they require the calibration gas to approximate the test conditions. FIDs

can operate in humid condition, but low O_2, high CO_2, or windy environments will extinguish the FID flame.

- FIDs require more training than PIDs.
- FIDs require a source of ultra-pure hydrogen that may not always be available and requires special handling and shipping.
- PIDs are subject to false low values when methane (CH_4) concentrations are greater than 1 percent; FIDs have the opposite problem of being sensitive to methane and providing to false positive.
- Both instruments are adversely affected by low air flow and, although FIDs are more sensitive to slightly weathered gasoline (because of the presence of several aliphatics), neither is effective for detecting highly weathered gasoline, nor is either instrument accurate when ambient air temperatures are below 32° F (0° C).

Exhibit VI-9 provides a summary of the comparison between FIDs and PIDs.

Exhibit VI-9
Comparison Of FIDs And PIDs

	FIDs	PIDs
Compounds Detected	Aliphatic hydrocarbons (*e.g.*, butane, hexane), less sensitive (although significant response) to aromatics (*e.g.*, BTEX compounds)	Aromatic hydrocarbons and some aliphatics
Linear Range of Detection	1 to >1,000 ppm_v	1 to <300 ppm_v
Unfavorable Environmental Conditions	High CO_2, low O_2 (<15%), high winds, temperature below 32° F	High humidity (*e.g.*, 90%), >1% CH_4, low O_2 (<15%), temperature below 32° F
Miscellaneous Issues	Requires a hydrogen source Requires more training than PIDs High methane levels may be interpreted as contamination	Adversely affected by electrical power sources (*e.g.*, power lines and transformers) Methane can depress readings

Method Descriptions

TOV analytical methods provide an indirect indication of soil or groundwater contaminant concentrations by measuring the organic constituents that partition into the headspace. There are three general types of methods used with FIDs and PIDs--ambient air measurements, headspace screening, and headspace analysis. Each provides a varying degree of data quality.

Ambient Air Measurements

Ambient air measurements are performed by taking direct readings with either an FID or a PID in the air immediately above soil or groundwater samples. It is commonly used as a screening method to determine which soil or water samples should be analyzed with a higher data quality method. It is also used to help determine future sampling locations.

Headspace Screening

In order to perform a headspace screening, a soil or groundwater sample is placed in an airtight container, typically a glass jar or polyethylene bag, leaving one-half to one-third empty. The container is then either shaken, heated, or left to sit for a period of time in order to allow the hydrocarbons to partition into the headspace *(i.e.*, the air space above the sample). The headspace is then measured with an FID or PID. The use of a polyethylene bag allows for a steady sample flow rate to the instrument, however, hydrocarbons partitioning from the bag may affect the analysis so a blank sample should be tested and the results factored into the analyses.

This method involves a more controlled sample analysis than ambient air measurements. As a result, headspace screening provides more consistent readings that can be used for estimating relative concentrations. However, readings remain relatively inconsistent, because volatilization of contaminants is affected by:

- Soil type;
- Moisture content;
- Ambient air dilution into jar;
- Temperature variations; and
- Time to prepare and analyze sample.

Headspace Analysis

Headspace analysis is similar to headspace screening but the procedures are more controlled and the results more accurate. A measured quantity of a soil or groundwater sample is placed in a polyethylene bag. For soil samples, a specified volume of deionized water is also placed in the bag in order to facilitate a more consistent partitioning of organic vapors. The bag is then inflated and the sample is agitated. After a specified time, an FID or PID is used to measure the headspace. QC procedures include the development of a calibration curve using field standards. These standards help in the interpretation of instrument responses and provide a comparison with samples of known concentrations.

Method Capabilities And Practical Considerations

Ambient air measurements are classified as DQL 1A analysis because these readings are highly variable and little or no QA/QC is used with sample analysis. The lower detection limit is generally around 100 ppm_v but may be significantly lower under ideal conditions (*e.g.*, no wind, no humidity, high O_2 levels). Headspace screening measurements are also only qualitative and fall within the DQL 1A range, however, their detection limits are generally between 10 and 100 ppm. Headspace analysis is classified as DQL 1B, semiquantitative, method because it provides an order of magnitude indication of contamination, but it does not provide information about the concentration of specific constituents. The lower detection limit with this method may be as low as 0.1 ppm for gasoline in water, but it is generally above 1 ppm. For all three methods, soil samples that are clay rich or contain high organic content may provide inconsistent results. In addition, gasoline should be relatively fresh or only slightly weathered for useful results.

TOV analysis is one of the least expensive analytical methods available. A summary of the capabilities and practical considerations of these three analytical methods using an FID or PID is summarized in Exhibit VI-10.

Turbidimetric Test Kits

Turbidimetric test kits are used for measuring the total petroleum hydrocarbon (TPH) content in soil. These test kits provide quantitative screening of soils for the presence of mid-range petroleum hydrocarbons (*e.g.*, diesel fuel, fuel oils, grease). Turbidimetric test kits can be used to identify source areas of contamination in the vadose zone. This method is also being adapted for analysis of TPH in water and may soon be commercially available.

Exhibit VI-10
Summary Of Total Organic Vapor Method Capabilities And Practical Considerations

	Ambient Air	Headspace Screening	Headspace Analysis
Compounds Detected	FIDs: Aliphatics (*e.g.*, butane), less sensitive to aromatics (*e.g.*, BTEX)		
	PIDs: Aromatics, some aliphatics		
Lower Detection Limits			
Gasoline in water	>100 ppm	10s to 100s ppm	0.1 to 1 ppm
Gasoline in soil	>100 ppm	10s to 100s ppm	1 to 10 ppm
Diesel in soil	>100 ppm	100s ppm	10s to 100s ppm
Limitations	Clay-rich or high organic content may provide inconsistent results. Best used with relatively fresh or only slightly weathered gasoline.		
Time For Analysis	2 minutes	10 to 30 minutes	10 to 30 minutes
Difficulty Of Procedure	low	low	medium
Data Quality Level	1A	1A	1B[1]
Cost Per Sample[2]	< $1	$1 to $5	$10

[1] Only if constituents are predetermined.

[2] Equipment costs are typically between $4,000 and $8,000.

Operating Principles

Turbidimetric soil test kits indirectly measure the TPH in soil by suspending extracted hydrocarbons in solution and then measuring the resulting turbidity (*i.e.*, the relative cloudiness of a solution) with a turbidity meter. The suspending solution causes extracted TPH to separate out of solution (*i.e.*, precipitate) while remaining suspended. Because the concentration of petroleum hydrocarbons in the soil is directly proportional to the turbidity measurement, a standard calibration curve can be developed to estimate TPH.

Method Description

Turbidimetric soil test kits utilize extraction solvents, analytical reagents, and a portable turbidity meter to determine contamination levels. The three steps in the test are as follows.

- Extraction: A methanol-based (chloroflorocarbon-free) solvent is used to extract hydrocarbons from the soil sample. The sample is then agitated, and the soil is allowed to settle.

- Filtration: The extract is then separated from the soil with a filter and placed in a vial with a developing solution.

- Analysis: When the developing solution equilibrates, a reading is taken with the turbidity meter. The turbidity value is proportional to the amount of petroleum hydrocarbons present.

The constituents should be identified before using this method so that a response factor can be selected from a reference table provided by the manufacturer. The meter can be calibrated using an extraction solvent vial as a blank and the calibration standard provided with the kit. Samples can be run individually or batched. Optimum performance and throughput are accomplished by running groups of 10 samples along with a blank and a standard.

Method Capabilities And Practical Considerations

Turbidimetric test kits are primarily used to screen petroleum hydrocarbons in soil. The method, which is sensitive to heavier molecular weight hydrocarbons (*e.g.*, diesel fuel), is capable of detecting C_{12} to C_{30} hydrocarbons with greatest sensitivity at the high end of the range. Turbidimetric soil test kits provide results in the part per million (ppm) range. Organic-rich soils may limit the effectiveness of the extraction or cause a positive interference. Background levels outside the zone of contamination can be used for a correction of results. The effective temperature range of this method is between 40° and 113° F (4° to 40° C). In addition, high moisture content in the soil sample may dilute the concentration of hydrocarbons in the extract resulting in negative interference. A summary of turbidimetric method capabilities and practical considerations is presented in Exhibit VI-11.

Exhibit VI-11
Summary Of Turbidimetric Method Capabilities And Practical Considerations

	Soil Test Kit	
Compounds Detected	It is most sensitive to "middle" chain hydrocarbons (*e.g.*, C_{12} to C_{30}), including diesel fuel and kerosene.	
Measuring Range	Diesel	13 to 2000 ppm
	Used Motor Oil	19 to 2000 ppm
Limitations	Light-weight petroleum hydrocarbons (*e.g.*, gasoline) are not detected. Organic-rich soil may limit the effectiveness of the extraction or cause positive interferences. High soil moisture content may cause negative interferences. Filtration may be difficult with clay soils. Effective temperature range is 40° to 113° F.	
Time For Analysis	15 to 20 minutes	
	25 samples per hour when batched	
Difficulty Of Procedure	Low-Medium	
Data Quality Level	1B	
Cost Per Sample[1]	\$10 to \$28	

[1] Initial 30 analyses cost \$28; subsequent analyses may cost as little as \$10.

Immunoassay Test Kits

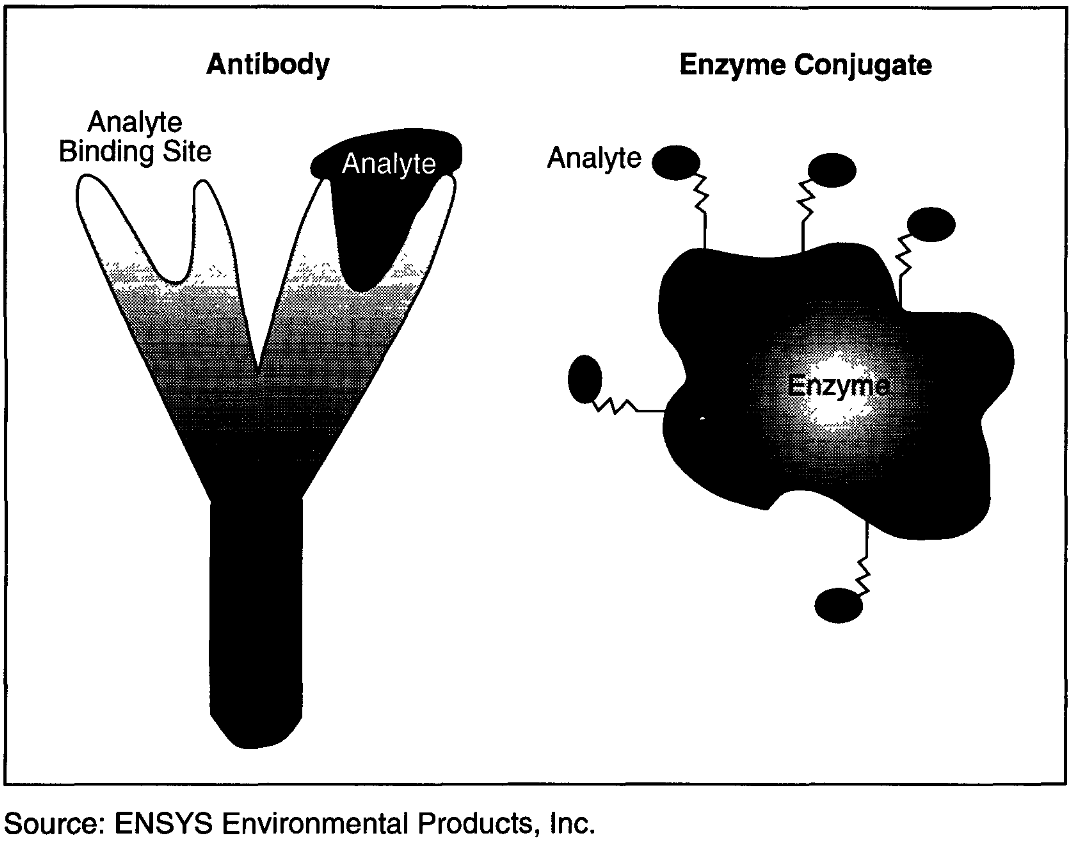
Immunoassay test kits can be used to measure petroleum hydrocarbons in soil and water. Test kits may measure groups of compounds (*e.g.*, short chain hydrocarbons, TEX) or a general assay range (*e.g.*, PAHs, TPH). Although they provide quantitative screening information, immunoassay test kits can determine if samples are above or below an action level (*i.e.*, whether a sample is "clean").

Operating Principles

Immunoassay test kits use antibodies (*i.e.*, proteins developed by living organisms to identify foreign objects as part of their immune systems) to identify and measure target constituents (*i.e.*, antigens) through the use of an antibody-antigen reaction. Antibodies are very useful for identifying specific compounds because they have binding sites that are designed to preferentially bond to specific antigens, as depicted in Exhibit VI-12. This technology has been used for decades by the medical industry.

In order to facilitate analysis, immunoassay test kits utilize special reagents, called enzyme conjugates, to allow for color development. Enzyme conjugates, as depicted in Exhibit VI-12, are a combination of molecules of the constituent of interest attached to specialized enzyme molecules. During analysis, the enzyme conjugate and the sample are mixed with the antibodies at

Exhibit VI-12
Schematic Drawings Of Antibody And Enzyme Conjugate



Source: ENSYS Environmental Products, Inc.

approximately the same time causing them to compete for binding sites on the available antibodies. When the constituents of interest have had time to bind to the antibodies, the system is washed and a substrate solution is added. This solution reacts with any enzyme conjugate that remains bound to the antibodies, producing a color. As a result, for most immunoassay test kits, the color is inversely proportional to the contaminant concentration (*i.e.*, the darker the color, the lower the concentration). The final concentration can be determined by comparing the color developed in the sample with that of a reference standard, either visually; with a portable photometer; or with an optical reflectance meter.

Method Descriptions

Although the procedures developed by the manufacturers of immunoassay test kits may vary, a number of steps can be outlined. Methods are available for both water and soil analysis. Water samples are analyzed directly, but soil samples require an extraction process that results in an indirect analysis.

Test kits are used for semiquantitative screening. This procedure involves setting an action level and observing whether the contaminant concentration is above or below that level. Multiple action levels can be set to place the sample within a discrete range (*e.g.*, above 100 ppm but below 500 ppm). Multipoint calibration curves can be used to further define concentrations (*e.g.*, above 200 ppm but below 250 ppm). These calibration curves are generated using standards that are provided by the manufacturer. Multiple analyses can be run in batch assays for both types of test kits. Standards and blanks are run with each batch.

Water Test Kits

To perform a water analysis:

- The water sample is placed in a reaction cell or test tube that contains the analyte-specific antibodies;
- An enzyme conjugate is added;
- After a specific period of time has passed, the sample is then washed, leaving behind analyte and/or enzyme conjugate bound to antibodies;
- The color development reagents (*i.e.*, substrate solution) are added and allowed to incubate;
- A stop solution is added; and
- The contaminant concentration is evaluated.

Soil Test Kits

Soil test kits utilize the same steps as water test kits except they have additional steps involved in extraction of analytes. The soil test kit analysis steps are as follows:

- An alcohol-based solvent (typically methanol) is added to the soil sample to extract the contaminant;
- The mixture is agitated to disaggregate the soil and extract the contaminants;
- The soil extract is placed in a reaction cell or test tube containing antibodies;
- The enzyme conjugate is added; and
- The remaining part of the test is conducted like the water test described above.

Method Capabilities And Practical Considerations

Immunoassay test kits are available for both water and soil analysis of short chain hydrocarbons (TEX), PAHs, and petroleum fuels (TPH). Tests can be performed for DQL 1B screening, however, constituent concentrations can be determined to be lower than a set action level with a high degree of certainty within a test kit's detection limit. As a result, they can be used for determining "clean" samples. In general, immunoassay test kits are best suited for analyzing short and middle chain hydrocarbons (<7 ring aromatic compounds and $<C_{11}$ aliphatic compounds). They are not effective for analyzing lubricating or hydraulic oils. Lower detection limits for petroleum analyses in water are generally in the ppb range and for soil in the ppm range. Upper detection limits are not provided because samples with high constituent concentrations can be diluted to a measurable range.

A number of issues affect the interpretation of immunoassay test kit results and should be clarified.

- Immunoassay test kits are designed to test for specific analytes or range of analytes; these kits are not capable of measuring a category as broad as all petroleum hydrocarbons. As a result, TPH tests do not measure every constituent present in fuel.
- Cross-reactivity occurs and may result in false positives. For example, an assay designed to detect TEX may give a positive result in the presence of a high concentration of PAHs (*e.g.*, naphthalene). The cross-reactivity

data for many hydrocarbon constituents and mixtures are available from the manufacturer; this information is important in interpreting test results.

- "BTEX" test kits actually measure a broad range of short-chain hydrocarbons because benzene is difficult to detect. These test kits give results that correspond with TEX concentrations for gasoline constituents and are designed for selectivity to xylenes with varying sensitivity for other aromatics.
- Immunoassay test kits must be used within each manufacturer's specified temperature range, which is generally between 40° and 90° F (4° and 32° C) and must be stored under conditions specified by the manufacturer (ranging from refrigeration at 40° F to room temperature). In addition, these kits must be used before the expiration date to provide valid data.

There are two problems that are specific to soil analysis. First, organic and clay-rich soils may limit the effectiveness of soil extraction and require longer extraction times than other soil types. Second, field extraction of PAHs may be less effective than the extraction methods used in the laboratory, and excessive amounts of oil in soil samples will interfere with the analysis of PAHs. Exhibit VI-13 presents a summary of immunoassay test kit method capabilities and practical considerations.

Portable Infrared Detectors

Portable infrared (IR) detectors measure the total petroleum hydrocarbons (TPH) in soil and water samples. Field methods involve a modification of U.S. EPA Method 418.1 or U.S. EPA SW-846 Method 8440 (U.S. EPA, 1997). IR detectors are most effective for mid- to heavy-range hydrocarbons.

Operating Principles

Portable IR detectors are spectrophotometers that measure the absorbance of IR radiation as it passes through sample extracts. The method operates under the principle that the hydrogen-carbon bond of petroleum hydrocarbons will absorb IR radiation at specific wave lengths, typically between 3.3 and 3.5 microns. Once contaminants are extracted from water or soil samples, absorption measurements can be directly related to TPH concentrations through the use of appropriate calibration standards.

Several petroleum hydrocarbons are shown in Exhibit VI-14. The top graph presents the IR spectra for two aliphatics--hexane and hexadecane; the

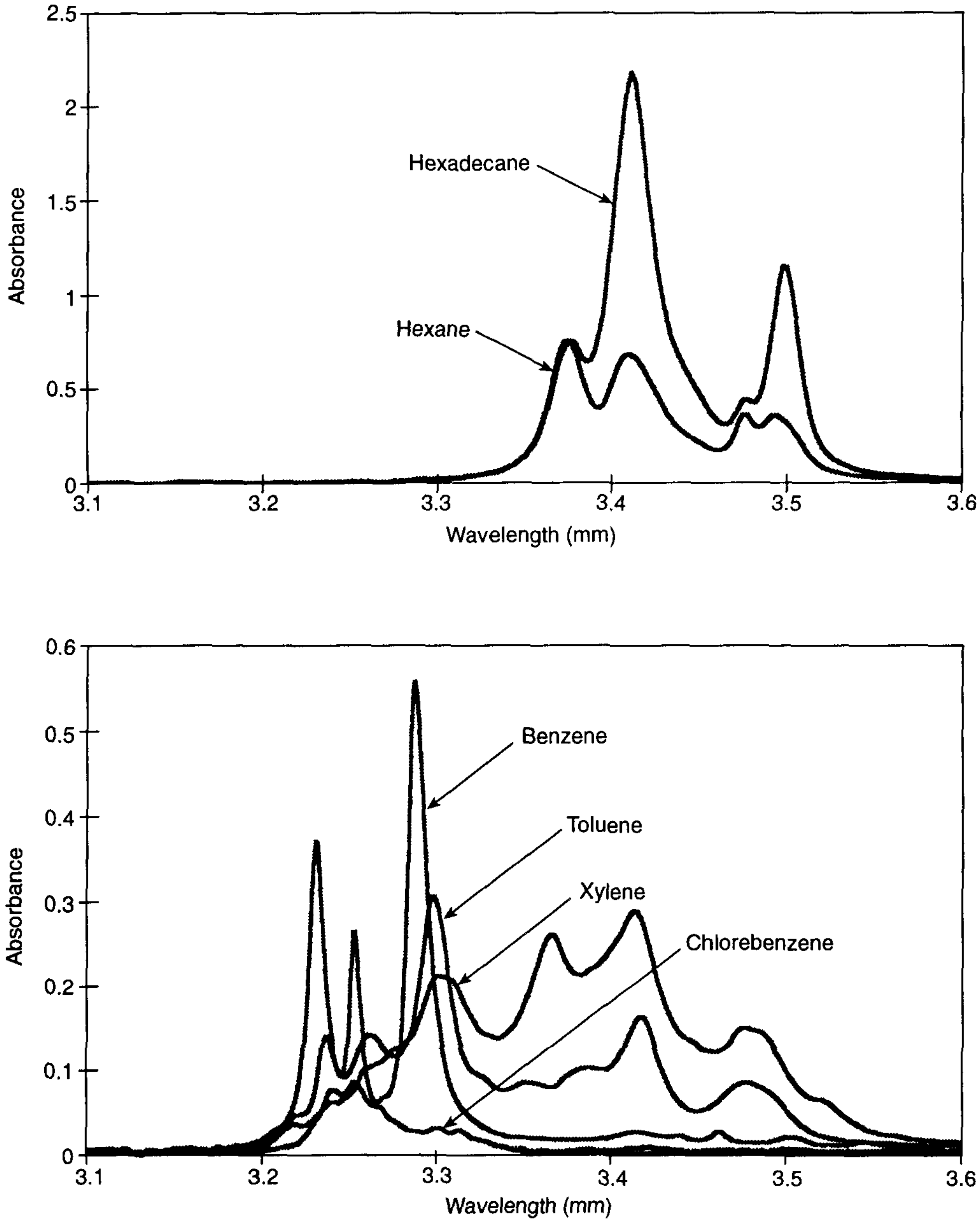
Exhibit VI-13
Summary Of Immunoassay Test Kit Method Capabilities And Practical Considerations

	Water Test Kit	Soil Test Kit
Compounds Detected	• Short chain hydrocarbons (TEX) • PAHs • TPH	
Lower Detection Limit	TEX 100 ppb PAHs 10 ppb TPH 100 ppb	TEX 2 ppm PAHs 1 ppm TPH 5 ppm
Limitations	Antibodies may cross react with petroleum contaminants not targeted. Kits must be used between 40° and 90° F. Kits may be damaged if frozen or exposed to prolonged heat. Organic and clay-rich soil may limit effectiveness of extraction (soil kits only) . Field extraction of PAHs with methanol is not as rigorous as laboratory extraction (soil kits only).	
Time For Analysis	30 to 45 minutes	
	8 tests per hour when running batches	5 tests per hour when running batches
Difficulty of Procedure	Medium	
Data Quality Level	1B	
Cost Per Sample[1]	\$20 to \$60	

[1] Cost decreases with greater number of samples

bottom graph presents the IR spectra for several aromatics--benzene, toluene, xylene, and chlorobenzene. The concentration for all these constituents is approximately 500 ppm, except for hexane which is about 250 ppm. Note that peak response for the aliphatics is at wave lengths of approximately between 3.4 μm and 3.5 μm. The peak response for the aromatics is approximately between

Exhibit VI-14
Infrared Spectra For Selected Aliphatic And Aromatic Hydrocarbons



Source: General Analysis Corporation

wavelengths of 3.3 μm and 3.4 μm. Also note that the absorbance scale is different for aliphatics and aromatics, the aliphatics absorbance is much greater and, as a result, measurements may be biased toward them.

Method Description

Analysis of petroleum hydrocarbons with portable IR detectors requires that calibration standards be developed so that sample measurements can be correlated to actual concentrations. Calibration standards are preferably made with the constituents that are present at the site. If necessary, reference standard specified in U.S. EPA Method 418.1 may also be used, but this standard is best suited for the measurement of aliphatic hydrocarbons and it will give only approximate values.

For analysis of soil, samples must first be chemically dried by adding anhydrous sodium sulfate. For both soil and water samples a solvent that will not interfere with the analysis is added for extraction of hydrocarbons and manually shaken for a period of time. Method 418.1 uses Freon-113™ (1,1,2-trichloro-1,2,2-trifluroethane). The SW-846 method utilizes supercritical CO_2 for extraction into perchloroethane (PCE). Analysis can then be completed with Method 8440. Field extraction procedures generally consist of a single extraction while laboratory procedures typically consists of at least three extractions. A silica gel should then be added to remove polar nonpetroleum hydrocarbons (*e.g.*, esters and fatty acids) that can cause false positives. The extract is then poured into a quartz curvette for measurement with the infrared spectrophotometer.

Method Capabilities And Practical Considerations

Infrared spectroscopy is useful for measuring the TPH of hydrocarbons in the C_6 to C_{26} range, however, results are biased toward hydrocarbons greater than C_{12} because of their greater response to IR, and because larger hydrocarbons volatilize less during extraction. As a result, it is not effective for measuring VOCs. In addition, responses are typically biased toward aliphatic hydrocarbons because of their larger response to IR when wave lengths between 3.4 μm and 3.5 μm are used. If wave lengths around 3.3 μm are used, aromatic hydrocarbons can also be measured with minimal interference from aliphatics as long as compounds are known and appropriate standards are used. Detection limits are approximately 2 ppm for soil analysis and 0.08 ppm for water analysis.

Another limitation of this method is that results can not be correlated with health or environmental risks because all hydrocarbons are grouped together and presented as one number. Positive results may be related to compounds found naturally in organic and clay-rich soils, or in petroleum products, which are not carcinogenic. As a result, although they give results at DQL 2, IR data require correlation with constituent specific methods as well (*e.g.*, GC analysis).

In addition, there are also a number of natural interferences with this method. Soil type is an important consideration because the extraction efficiency is much higher in sands than in clays. Furthermore, although most non-petroleum hydrocarbons can be removed by silica gel treatment, terpenes, which are found in conifers, citrus oils, and eucalyptus are not removed and can cause false positives.

The operational temperature range of IR spectroscopy is generally between 40° and 104° F (4° and 40° C) but may vary between manufacturers. The difficulty of this procedure is medium compared with other field methods. The cost and the time of analysis depend primarily on the number of extractions used per sample and the soil type (because clays require a longer extraction time). Each extraction takes about 5 minutes; analysis time is less than one minute. Exhibit VI-15 presents a summary of IR spectroscopy method capabilities and limitations.

Field Gas Chromatographs

Field gas chromatographs (GCs) are used for constituent-specific analysis of soil, soil-gas, and water samples for volatile and semi-volatile hydrocarbons. They have the capability to provide the highest data quality of all commonly used field analytical methods.

Operating Principles

Gas chromatographs are comprised of two major components: A column that separates individual constituents and a detector that measures the signal response of constituents. The column is a long, thin, coiled tube. An inert carrier gas (*e.g.*, hydrogen, helium, nitrogen, or zero air) is used to transport constituents through the column. Because compounds with low molecular weights and high volatility travel through the column faster than heavier compounds with low volatility, the constituents of a sample separate through the distance of the column. Discrimination of constituents is often difficult if two or more compounds exit the column at the same time (*i.e.*, coelute). The likelihood of compounds coeluting decreases with increasing column length.

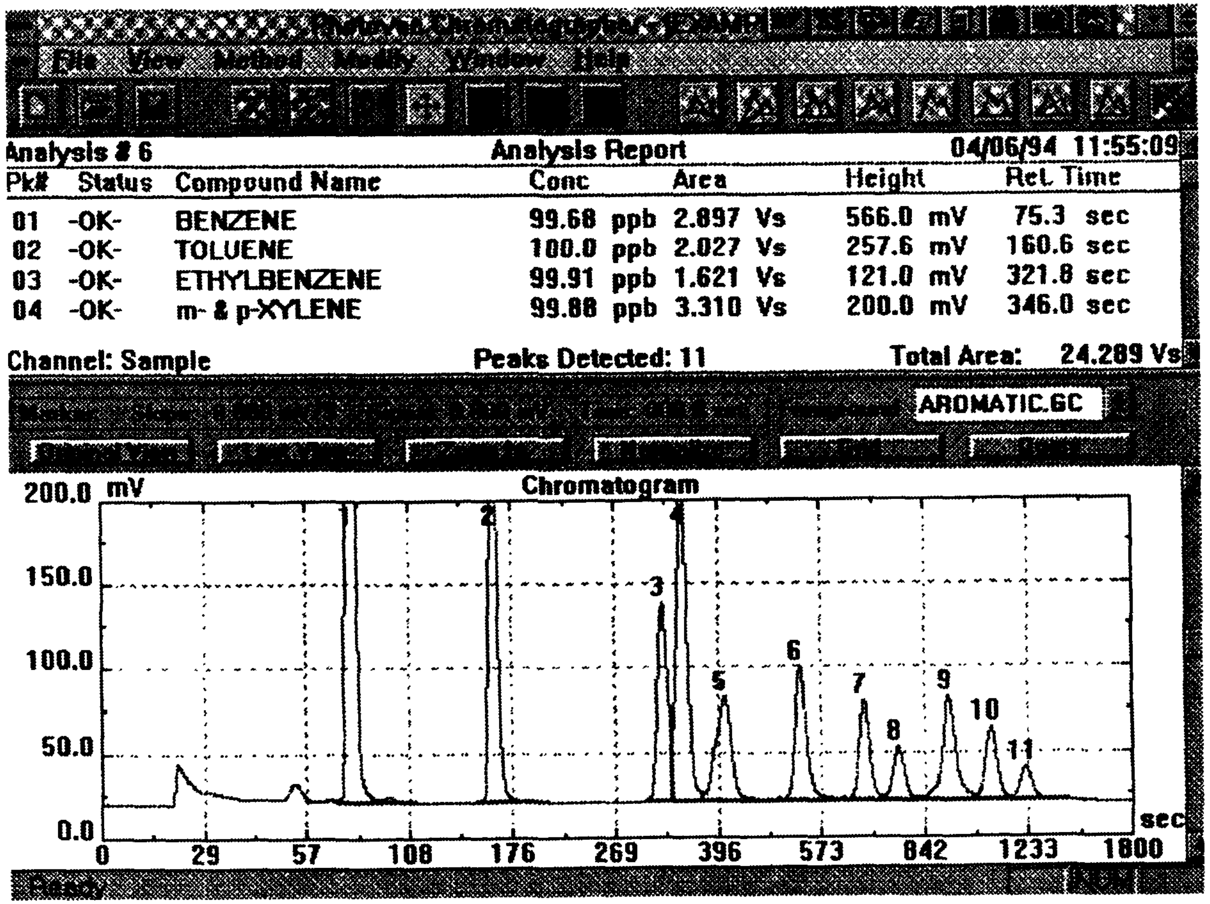
A detector is located at the end of the column. For hydrocarbon investigations, the most applicable detectors are PIDs and FIDs. The design of PIDs and FIDs is modified slightly for GC analysis, allowing for greater detection

Exhibit VI-15
Summary Of Infrared Spectroscopy Method Capabilities And Practical Considerations

	Soil Analysis	Water Analysis
Compounds Detected	C_6 to C_{26} range hydrocarbons	
Detection Limit	2 ppm	0.08 ppm
Limitations	Lighter petroleum hydrocarbons (*e.g.*, BTEX) are not accurately detected because of their volatility. Results are biased toward medium and heavy hydrocarbons compounds (*i.e.*, $\geq C_{12}$) unless appropriate standards are used. Extraction efficiency in clays may be lower than in other soil types. Organic and clay-rich soils may result in false positives unless appropriate standards and IR wavelengths are used because many non-petroleum hydrocarbons (*e.g.*, terpenes) are also extracted and analyzed. Health and environmental risks are difficult to determine from TPH levels. Operating temperature range is generally between 40° and 104° F.	
Time For Analysis	5 to 20 minutes	
Difficulty Of Procedure	Medium	
Data Quality Level	2	
Cost Per Sample	$5 to $30	

limits. The detector responses are displayed on either a chart recorder or a computer screen to form a chromatogram (*i.e.*, the detector reponses plotted against retention time for a sample). The integrated area under each response peak is proportional to the concentration of that constituent. Constituents are identifed through a comparison of retention times with standards. Exhibit VI-16 is an example of a chromatogram created by a portable GC.

Exhibit VI-16
Example Of A Portable GC Chromatogram



Analysis # 6 | Analysis Report | 04/06/94 11:55:09

Pk#	Status	Compound Name	Conc	Area	Height	Rel. Time
01	-OK-	BENZENE	99.68 ppb	2.897 Vs	566.0 mV	75.3 sec
02	-OK-	TOLUENE	100.0 ppb	2.027 Vs	257.6 mV	160.6 sec
03	-OK-	ETHYLBENZENE	99.91 ppb	1.621 Vs	121.0 mV	321.8 sec
04	-OK-	m- & p-XYLENE	99.88 ppb	3.310 Vs	200.0 mV	346.0 sec

Channel: Sample | Peaks Detected: 11 | Total Area: 24.289 Vs

Source: U.S. EPA, 1995

There are two types of field GCs currently used for assessing petroleum releases--portable and transportable. Both types utilize the same basic operating principles, however, their capabilities differ and, as a result, so do their applications.

Portable GCs

Portable GCs are durable, compact, and light weight. Portability is possible because these GCs are equipped with internal batteries and carrier gas supplies. These features, however, limit the available energy supply that is needed for rapid temperature ramping (*i.e.*, heating) of the column. Instead, portable GC columns are heated isothermally.

Transportable GCs

Transportable GCs are typically mounted in a mobile laboratory, but because they require external power and gas supplies, they are not portable. Most transportable GCs are capable of rapid temperature ramping of the column, and many transportable GCs can be certified to perform U.S. EPA, SW-846 methods. As a result, they can provide data in the field that are equivalent to the data generated by certified fixed laboratory GCs.

Comparison Of Portable And Transportable GCs

The primary advantages of portable GCs are that they are easily carried into the field and that the time they require for analysis is generally shorter than for transportable GCs. Analysis with portable GCs is generally less than 10 minutes while transportable GCs commonly require 10 to 40 minutes (although 60 minutes may be required for some methods). Portable GCs tend to use PID detectors because hydrogen gas is not required. As a result, many aliphatic compounds cannot be detected with this equipment.

The primary advantage that transportable GCs have over portable GCs is that transportable GCs are capable of providing better constituent separation and, therefore, more accurate identification and quantitation of constituents. Greater separation of constituents is possible because transportable GCs generally use longer capillary columns than portable GCs (10 to 15 meters versus 30 to 60 meters). In addition, rapid temperature ramping of transportable GC columns and consistent temperature control of the entire GC system provides better separation and reproducibility than the isothermal heating of portable GCs.

Transportable GCs are available with a variety of detectors, including PIDs and FIDs.

Method Descriptions

Field GCs are capable of performing soil, soil-gas, and water analyses. Soil-gas samples are the simplest to analyze because they do not require sample preparation. Soil and water samples, however, require preparation of which a couple of options are available.

Soil-Gas Analysis

Soil-gas samples are collected as described in Chapter IV, Soil-Gas Surveys. Analysis can be performed with GCs through direct injection of the sample by two methods. A microliter syringe or a loop injector (*i.e.*, a sample container that has been adapted for automatic injection via a pump internal to the GC) can be used.

Soil And Water Analysis

There are generally three methods used for analyzing soil and water samples for petroleum hydrocarbons with GCs. The simplest method is static headspace which is used for analysis of VOCs with both portable and transportable GCs. Solvent extraction is also used with both portable and transportable GCs. It is commonly used for SVOCs. The more complicated, time-consuming method called "purge and trap," is most effective for VOCs and is typically not performed with portable GCs because the energy requirements are excessive.

Static Headspace

The static headspace method is described in SW-846 Method 5021 (EPA, 1997). A version of this method has been modified for use by portable GCs. Static GC headspace analysis of water involves placing an aqueous sample in a sealed septum vial (analysis of a soil sample involves placing soil in a septum vial with analyte-free water), agitating, and then placing the sample in a water bath at constant temperature. Volatile hydrocarbons from the sample partition into the headspace, eventually reaching equilibrium. The concentration of volatile hydrocarbons in the headspace is representative of the concentration of dissolved volatiles in the water. An aliquot of the headspace is then withdrawn from the vial with a gas-tight microliter syringe and injected directly into the GC column.

Solvent Extraction

The solvent extraction method provides higher hydrocarbon recovery than the static headspace method for SVOCs. A specified mass of soil is dispersed in an organic solvent which partitions the hydrocarbons into the solvent (*e.g.*, pentane). The solvent can then be introduced into the GC by using direct injection.

Purge And Trap

The purge-and-trap method provides higher hydrocarbon recovery and lower detection limits than the static headspace method. It is conducted with transportable GCs because of the high energy requirements. Prepared samples are sparged with an inert gas (usually helium) in a purge chamber at ambient temperature causing volatile hydrocarbons to be transferred from the aqueous to the vapor phase. The vapor passes through an adsorbent trap that strongly retains selective hydrocarbon constituents. The sorbent is then heated to release hydrocarbon constituents and an effluent sample is directly transferred into the GC column for analysis.

Method Capabilities And Practical Considerations

Field GCs provide quantitative, constituent-specific analysis of volatile and semi-volatile hydrocarbons. In particular, field GCs can resolve key constituents for evaluating risk and determining corrective action criteria. Field GCs can measure constituent concentration in the part per billion (ppb) range for soil, soil-gas, and water with a lower detection limit of between 1 to 10 ppb, depending on the method and equipment. Samples with concentrations of less than one thousand ppb can be analyzed without dilution. GC analyses are the primary method for determining “clean zones” when delineating contamination. They also be used to identify the type of hydrocarbon/fuel contamination (*e.g.*, gasoline, diesel fuel). In addition, they are the only available field method for determining MTBE concentrations.

Limitations of field GCs include the following:

- Variations in temperature must be minimized and ambient air must not be contaminated.
- Analytical schemes for field GCs are usually not set up to measure low volatility and nonvolatile hydrocarbons (*e.g.*, crude oil).
- A wide range of hydrocarbons (*e.g.*, gasoline to fuel oil) are typically not measured in a single analysis.
- Highly contaminated samples may require dilution to prevent them from exceeding the maximum calibration range of the detector.
- Nontarget constituents may interfere with peak resolution if they have similar retention times or coelute with the target compounds. If many interfering peaks are present, the separation may not be adequate to determine constituent concentrations. In this case, total chromatogram integration can be used to determine the total VOCs.
- A greater level of operator training is required for field GCs than with other field analytical methods. Although portable GCs may require less training than transportable GCs, both methods typically require a chemist or someone with significant chemistry training.

DQLs are dependent on the analytical method, the QA/QC procedures, and the equipment capabilities. In addition, differences in the construction of portable and transportable GCs (*e.g.*, column heating, column length, temperature control) control the attainable DQL. Portable GCs are capable of providing DQL 2 information, and transportable GCs may provide DQL 3 data. Exhibit VI-17 presents a summary of field GC method capabilities and limitations.

Exhibit VI-17
Summary Of Field GC Method Capabilities And Practical Considerations

	Water	Soil	Soil-Gas
Compounds Detected	Constituent-specific volatile/semivolatile hydrocarbons		
Lower Detection Limits	1 to 10 ppb		
Limitations	Does not measure wide range of hydrocarbons in a single analysis (*e.g.*, gasoline to fuel oil). Samples >1000 ppb may require dilution to prevent exceeding maximum range of detector. Non-target compounds that coelute with target compounds will cause a positive bias in the interpretation of results. Operation affected by extreme temperature and contaminated working environments. Requires high degree of training.		
Time For Analysis	Portable: <10 minutes		
	Transportable: 10 to 60 minutes depending on constituents and method		
Difficulty Of Procedure	Medium-High	High	Medium
Data Quality Level	Portable 2		
	Transportable 2/3		
Cost Per Sample	Portable $20 to $50		
	Transportable $50 to $70		

Emerging Methods

Several new field analytical methods are currently available for use in expedited site assessments. They are classified as emerging because they are recent developments and/or they are undergoing rapid change. Accordingly, information in this text is not presented in as much detail as in the previous section because details may soon become outdated. These methods include two types of GC/mass spectrometry (MS) and three types of *in situ* sensing methods that are used in conjunction with direct push technologies described in Chapter V.

Gas Chromatography/Mass Spectrometry

Gas chromatography/mass spectrometry (GC/MS) systems operate under the same principles as the field GCs, but instead of using a PID or FID as the detector, they use a mass spectrometer. Because MS records constituent specific mass spectra (*i.e.*, a spectrum of molecular fragments produced from the ionized parent compound, that is resolved according to the mass-to-charge ratio), it allows for identification of specific compounds.

GC/MS systems have been available in fixed laboratories for many years. Recently, portable and transportable GC/MS has been developed. These systems are typically not needed at UST sites because the types of contaminants are generally known. In addition, it is inappropriate for TPH analysis. If, however, chlorinated hydrocarbons migrate onto the site, or confirmation of specific constituents is necessary, GC/MS may be appropriate. GC/MS detectors are no more sensitive than GC/PID or GC/FID detectors, and they can be less sensitive for certain analytes.

Portable GC/MS

Portable GC/MS systems have been designed primarily for air monitoring, but they can also be used for headspace analyses. They are equipped with internal batteries and carrier gas supplies. Because of these features, portable GC/MS systems (as with portable GC/PIDs) have a limited energy supply and, consequently, operate isothermally. In addition, these features also limit the types of constituents that can be analyzed.

Transportable GC/MS

Compared with laboratory-grade systems, transportable GC/MS systems are smaller, more rugged, lighter in weight, and use less power. Typically, GC/MS systems have been used to analyze chlorinated contaminants. GC/MS methods can be used to confirm and delineate the leading edges of contaminant plumes and to verify contaminants suspected with GC/PID/FID (*e.g.*, MTBE). EPA Methods 624 and 8260 (VOCs) and 8270 (SVOCs) can be performed using transportable GC/MS systems. In general, GC/MS systems are well-suited for analyzing a broad range of constituents, especially heavier molecular weight constituents (*e.g.*, PAHs) which are not as easily resolved by GC methods alone.

In Situ Analysis Using Direct Push Technologies

Several methods have recently been developed for the *in situ* analysis of petroleum hydrocarbon contamination using direct push (DP) probes. They are typically used in conjunction with several other sensors (*e.g.*, soil conductivity, temperature, friction/resistance) to provide detailed, objective logging information. These measurements provide screening level information about the presence of contamination while at the same time logging soil for various parameters including soil type and depth to groundwater.

There are three emerging methods currently available for *in situ* analysis with DP systems--laser-induced fluorescence (LIF), fuel fluorescence detectors (FFD), and semi-permeable membranes. All three systems can be used with sensors that simultaneously measure other parameters (*e.g.*, soil conductivity, temperature). The results from these methods can be used in an ESA to develop and refine the conceptual model by identifying the contaminant location, tracing lithologic units across the site and revising geologic cross sections, tracing specific conductivity zones which may serve as preferential migration pathways, and defining the thickness and lateral continuity of aquifers, aquitards, or other definable units (*e.g.*, clay, sand lenses). The results from these *in situ* measurements can be used to effectively select sample locations and to verify the results by direct sampling and analysis with a higher DQL method.

Laser-Induced Fluorescence

Two laser-induced fluorescence (LIF) systems have been developed for use as part of a cone penetrometer test (CPT): The Rapid Optical Screening Tool (ROST^{TM}) System developed by the Air Force, and the Site Characterization and Analysis Penetrometer System (SCAPS) developed by the Navy as part of collaborative effort with the Army and Air Force under the auspices of the Tri-Service SCAPS Program. The ROST™ system is currently available from a single CPT firm, and the SCAPS technology is available only for use by federal and state agencies.

The method uses a fiber-optic based LIF sensor deployed with a standard 20-ton cone penetrometer which simultaneously provides a continuous log of subsurface materials. Two fiber-optic cables run from the sensor up through the penetrometer rods. A pulsed nitrogen laser transmits ultraviolet (UV) light down one of the fibers to the sensor probe and through a sapphire window built into the side of the cone penetrometer tip. The UV light that exits the window causes fluorescence of the polynuclear aromatics present in the soil adjacent to the probe. The induced fluorescence signal is returned over a second fiber to the above ground analytical equipment where it is dispersed with a spectrograph and measured with a photodiode array.

The LIF system can provide qualitative information on polynuclear aromatic hydrocarbons (PAHs). The ROST™ system uses wavelength-time plots to identify the general type of petroleum hydrocarbon present. The SCAPS system is intended to provide initial information on the distribution of hydrocarbons in the soil and water prior to collecting soil cores and samples, and selecting locations for groundwater monitoring wells. It provides information on contaminant distribution with a continuous log of soil conditions.

Fuel Fluorescence Detector

A fuel fluorescence detector (FFD) has been developed for *in situ* measurement of TPH as part of a cone penetrometer test. The FFD system uses a 254-nm ultraviolet light source that is focused on soil or groundwater through a sapphire window. If aromatic hydrocarbons are present, the resulting fluorescence will return through a fiber-optic cable for analysis at the ground surface. The FFD system provides a detection limit of 100 ppm TPH (in sand), and it can detect a broad range of petroleum hydrocarbons including gasoline, diesel fuel, and jet fuel. In general, most aromatic hydrocarbons with less than four rings can be detected. Creosote cannot currently be detected with this method. Potential future developments may include the use of a spectrometer for determination of specific types of fuels.

Semipermeable Membrane Sensor

A semipermeable membrane sensor probe is an emerging technology that can be used to detect the presence of volatile hydrocarbons above and below the water table using DP rigs with percussion hammers. The sensor operates by allowing volatile constituents in the subsurface to diffuse across a thin permeable polymer membrane on the side of the probe. The inside surface of the membrane is swept with a constant flow of an inert carrier gas. Volatile hydrocarbons in the soil adjacent to the probe cross the membrane and are carried to the surface where they can be analyzed (*e.g.*, PID, FID, GC). Hydrocarbons in various phases (*e.g.*, gas, sorbed, dissolved, free product) can be detected. The lighter, more volatile constituents cross the membrane faster than heavier molecular weight hydrocarbon constituents. The membrane can operate in an ambient temperature mode or at an increased temperature of up to 250° F (121° C) to increase the movement of volatile constituents through the membrane. Heating the membrane can also significantly increase the sensitivity of the systems and decrease the time required to remove residual contaminants from the membrane.

Petroleum Hydrocarbon Analytical Equipment Manufacturers

A list of petroleum hydrocarbon analytical equipment manufacturers is included below in Exhibit VI-18. The equipment has not been evaluated by the U.S. EPA and inclusion in this manual in no way constitutes an endorsement. These vendors are listed solely for the convenience of the reader.

Exhibit VI-18
Petroleum Hydrocarbon Analytical Equipment Manufacturers

Detector Tubes	
Mine Safety Appliances Company P.O. Box 426 Pittsburgh, PA 15230 (412) 273-3000 (800) 672-2222	National Draeger, Inc. P.O. Box 120 Pittsburgh, PA 15230 (412) 788-5605 (800) 922-5518
Sensidyne, Inc. 16333 Bay Vista Drive Clearwater, FL 34620 (813) 530-3602 (800) 451-9444	
Fiber Optic Sensors	
FCI Environmental, Inc. 1181 Grier Drive Building B Las Vegas, NV 89119 (702) 361-7921 (800) 510-3627	ORS Environmental Systems 32 Mill Street Greenville, NH 03048 (603) 878-2500 (800) 228-2310
Colorimetric Test Kits	
Hanby Environmental Laboratory Procedures, Inc. 501 Sandy Point Road Wimberly, TX 78676 (512) 847-1212 (800) 304-2629	

<table>
<tr><th colspan="2">Total Organic Vapor (TOV) Detectors (PIDs and FIDs)</th></tr>
<tr><td>Control Instruments Corp. (FIDs)
25 Law Drive
Fairfield, NJ 07004-3295
(201) 575-9114</td><td>Foxboro Analytical (FIDs and Dual FID/PID)
600 North Bedford
East Bridgewater, MA 02333
(800) 321-0322</td></tr>
<tr><td>Gas Analysis Systems Company
3825 26th Street, West
Bradenton, FL 34205
(914) 755-8806</td><td>HNU Systems, Inc. (PIDs)
160 Charlemont Street
Newton, MA 02161
(617) 964-6690
(800) 724-5600</td></tr>
<tr><td>MSA Baseline Industries (FID/PIDs)
P.O. Box 649
Lyons, CO 80450
(800) 321-4665</td><td>Photovac Monitoring Instruments (FID/PIDs)
25-B Jefryn Boulevard, West
Deer Park, NY 11729
(516) 254-4199</td></tr>
<tr><td>Thermo-Environmental Instruments, Inc. (PID/FID)
8 West Forge Parkway
Franklin, MA 02038
(508) 520-0430</td><td></td></tr>
<tr><th colspan="2">Turbidimetric Test Kit</th></tr>
<tr><td>Dexsil Corporation (PetroFLAG)
One Hamden Park Drive
Hamden, CT 06517
(203) 288-3509</td><td></td></tr>
<tr><th colspan="2">Immunoassay Test Kits</th></tr>
<tr><td>Strategic Diagnostics, Inc. (Includes products by D Tech, EM Science, ENSYS, Omnicon, and Millipore)
375 Pheasant Run
Newtown, PA 18940
(800) 544-8881</td><td></td></tr>
</table>

Portable Infrared Spectrophotometers

Foxboro Analytical 600 North Bedford East Bridgewater, MA 02333 (800) 321-0322	General Analysis Corporation 140 Water Street, Box 528 South Norwalk, CT 06856 (203) 852-8999
Horiba Instruments, Inc. 17671 Armstrong Avenue Irvine, CA 92714 (800) 446-7422	

Portable Gas Chromatographs

Foxboro Analytical 600 North Bedford East Bridgewater, MA 02333 (800) 321-0322	Gas Analysis Systems Company 3825 26th Street, West Bradenton, FL 34205 (914) 755-8806
HNU Systems, Inc. 160 Charlemont Street Newton, MA 02161 (617) 964-6690 (800) 724-5600	Microsensor Systems, Inc. 62 Corporate Court Bowling Green, KY 42103 (410) 939-1089
Microsensor Technology, Inc. 41762 Christy Street Fremont, CA 94358 (510) 490-0900	OI Analytical P.O. Box 9010 College Station, TX 77842 (409) 690-1711
Photovac Monitoring Instruments 25-B Jefryn Blvd., West Deer Park, NY 11729 (516) 254-4199	Sentex Sensing Technology, inc. 553 Broad Avenue Ridgefield, NJ 07657 (201) 945-3694 (800) 736-8394

Transportable Gas Chromatographs

Gas Analysis Systems Company 3825 26th Street, West Bradenton, FL 34205 (914) 755-8806	GOW-MAC Instrument Company P.O. Box 25444 Lehigh Valley, PA 18002 (610) 954-9000
Hewlett Packard 2850 Centerville Road Wimington, DE 19808 (302) 633-8000	HNU Systems, Inc. 160 Charlemont Street Newton, MA 02161 (617) 964-6690 (800) 724-5600

Microsensor Technology, Inc. 41762 Christy Street Fremont, CA 94358 (510) 490-0900	MSA Baseline Industries P.O. Box 649 Lyons, CO 80450 (800) 321-4665
Perkin Elmer Corporation 761 Main Avenue Norwalk, CT 06859 (203) 763-1000 (888) 732-4766	Shimadzu Scientific Instruments, Inc. 7102 Riverwood Drive Columbia, MD 21046 (410) 381-1227 (800) 477-1227
SRI Instruments 3882 Del Amo Boulevard Suite 601 Torrance, CA 90503 (310) 214-5092	Varian Analytical Instruments 505 Julie River Road Suite 150 Sugarland, TX 77478 (800) 926-3000
Gas Chromatograph/Mass Spectrometer	
Bruker Instruments, Inc. 19 Fortune Drive Manning Park Bollerica, MA 01821 (508) 667-9580	INFICON Two Technology Place East Syracuse, NY 13057 (315) 434-1264
Teladyne Electronic Technologies 1274 Terrabella Mountain View, CA 94043 415 968-2211	Viking Instruments 3800 Concorde Parkway Suite 1500 Chantilly, VA 22021 (703) 968-0101
Laser Induced Fluorescence	
Fugro Geosciences, Inc. 6105 Rookin Houston, TX 77074 (713) 778-5580	
Fuel Fluorescence Detector	
Applied Research Associates, Inc. Vertek Division 120A Waterman Road South Royalton, VT 05068 (800) 639-6315	

Semipermeable Membrane Sensor	
Geoprobe Systems, Inc. 601 North Broadway Salina, KS 67401 (913) 825-1842	

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Appendix A

Data Requirements For Corrective Action Evaluations

Appendix A
Data Requirements For Corrective Action Evaluations

Key Parameters	Methodology/Source
Regional And Site-Specific Hydrogeologic Conditions	
Regional Geology/Hydrogeology	Soil, bedrock, and aquifer properties from published maps/reports.
Site-Specific Soil Characteristics	Observations/analysis of samples from impacted and non-impacted areas.
Site-Specific Aquifer Properties	Observations/measurements from impacted and non-impacted areas.
Site-Specific Attenuation Factors	Observations/analysis of samples for natural attenuation factors/biodegradation parameters (DO, NO_3, SO_4, Fe, Mn^{+2}, CH_4, CO_2)
Evaluating Constituents Of Concern (COC)	
Source, Nature Of Release, And COC	Evaluate historical data, release reports, site specific information
Affected Media	Soil/groundwater/vapor sampling and analysis for concentration/distribution of COC
Maximum COC Concentrations	Analysis of soil, groundwater, and/or vapor samples, identify presence or absence of NAPLs
Potential Receptors And Land Use	
Receptor Survey	State and local health department water supply maps/records. Site-specific receptor survey to locate unrecorded private wells/nearby structures.
Land Use Survey	Site-specific survey to identify land use (residential, commercial, industrial), review local zoning ordinances/land use plans.
Exposure Assessment	
Transport Media	Site-specific transport media through which COC may migrate (*e.g.*, soil gas, groundwater).
Transport Mechanism	Primary transport mechanism (*e.g.*, leaching, vapor/groundwater migration)
Exposure Pathways	Primary exposure pathways (*e.g.*, ingestion of soil or groundwater, vapor inhalation, dermal contact)
Points Of Exposure	Review receptor survey and site-specific information to identify points of exposure

Appendix B

Table Of U.S. EPA Test Methods For Petroleum Hydrocarbons

Appendix B
Table Of U.S. EPA Test Methods For Petroleum Hydrocarbons

SW-846 Method	Water/ Waste Water Method	Analytes	Primary Equipment	Sample Preparation[1]
4030[2]		TPHs	Immunoassay	Included in kit
4035[2]		PAHs	Immunoassay	Included in kit
8015[3]		Aliphatic and Aromatic Hydrocarbons; Nonhalogenated VOCs	GC/FID	Extraction (SVOCs)[4]; Purge-and-Trap and Headspace (VOCs)[4]; Azeotropic Distillation (Nonhalogenated VOCs)[3, 4]
8021[3, 5]	502.2/602	Aromatic VOCs	GC/PID	Purge-and-Trap[4]
8100		PAHs	GC/FID	Extraction[4]
8260[6]	524.2/624	VOCs	GC/MS	Purge-and-Trap, Headspace, Azeotropic Distillation[4]
8270	525/625	SVOCs	GC/MS	Extraction[4]
8310	610	PAHs	High Performance Liquid Chromatography	Extraction[4]
8440[7]	418.1[8]	TPH	IR Spectrophotometer	Supercritical Fluid Extraction from soils[4]

[1] These are the standard methods of preparation for the corresponding method. They may vary depending on specific analytical needs.

[2] Sceening method for soils

[3] MTBE can be analyzed with U.S. EPA SW-846 Method 8015 or 8021, however, 8021 has lower detection limits, is subject to less interference in highly contaminated samples, and tends to be more economical by providing BTEX data in the same analysis. Concerns about coelution with some alkanes requires at least one confirmitory analysis with SW-846 Method 8260 per site.

[4] See Chap. 4 of SW-846 for specific appropriate methods.

[5] 8021 replaces 8010 and 8020.

[6] The old method, 8240, is replaced by 8260.

[7] This method is similar to 418.1, however, perchlorethane (PCE) is used as an IR solvent instead of Freon-113.

[8] 418.1 is used extensively although it is not on the list of promulgated methods.

Abbreviations

Abbreviations

atm	atmosphere(s)
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene(s)
C	Celsius/Centigrade
COC	constituent(s) of concern
CPT	cone penetrometer test
CSA	conventional site assessment
DO	dissolved oxygen
DP	direct push
DQL	data quality level
EM	electromagnetic method
ER	*electrical resistivity*
ESA	expedited site assessment
eV	electron volts
F	Fahrenheit
FFD	fuel fluorescence detector
FID	flame ionization detector
FOCS	fiber optic chemical sensor
ft	foot/feet
gal.	gallon(s)
GC	gas chromatograph
GPR	ground penetrating radar
HSA	hollow stem auger
ID	inside diameter
IR	infrared
LIF	laser induced florescence
LNAPL	light non-aqueous-phase liquid
LUST	leaking underground storage tank
MAG	*magnetometry*
MD	metal detection
MTBE	*methyl tertiary-butyl ether*
μg	microgram(s)
μm	micrometer(s)
MW	monitoring well
MS	mass spectrometry
NAPL	non-aqueous-phase liquid
nm	nanometer(s)
OD	outside diameter
PAH	polyaromatic hydrocarbons
PCE	perchlorethane
PE	polyethylene

PID	photoionization detector
ppb	parts per billion
ppm	parts per million
PTFE	polytetrafluoroethylene (Teflon®)
PVC	polyvinylchloride
QA	quality assurance
QC	quality control
ROST™	Rapid Optical Screening Tool
SCAPS	Site Characterization and Analysis Penetrometer System
SED	state environmental department
SR	seismic refraction
SVOCs	semivolatile organic compounds
TEX	toluene, ethylbenzene, and xylene(s)
TOV	total organic vapor
TPH	total petroleum hydrocarbons
UST	underground storage tank
UV	ultraviolet
VOCs	volatile organic compounds

Glossary

Glossary

absorption: The penetration of atoms, ions, or molecules into the bulk mass of a substance.

adsorption: The retention of atoms, ions, or molecules on the surface of another substance.

air permeability: Permeability of soil with respect to air. Measured in darcys or units of centimeters per second. An important parameter in the design of soil-gas surveys.

aliphatic: Of or pertaining to a broad category of carbon compounds distinguished by a straight, or branched, open chain arrangement of the constituent carbon atoms. The carbon-carbon bonds may be either saturated or unsaturated. Alkanes, alkenes, and alkynes are aliphatic hydrocarbons.

aliquot: A measured portion of a sample taken for analysis. One or more aliquots make up a sample.

alkanes: Aliphatic hydrocarbons having the general formula C_nH_{2n+2}. Alkanes can be straight chains, branched chains, or ring structures. Also referred to as *paraffins*.

alkenes: The group of unsaturated hydrocarbons having the general formula C_nH_{2n} and characterized by being highly chemically reactive. Also referred to as olefins.

alkynes: The group of unsaturated hydrocarbons with a triple carbon-carbon bond having the general formula C_nH_{2n-2}.

alkylated aromatics: The class of ringed aromatic compounds containing one or more aliphatic side chains.

anaerobic: In the absence of oxygen.

analyte: The element, ion, or compound that an analysis seeks to identify; the element of interest.

annular space, annulus: The space between two concentric tubes or casings, or between the casing and the borehole wall.

aquifer: A geologic formation capable of transmitting significant quantities of groundwater under normal hydraulic gradients.

aquitard: A geologic formation that may contain groundwater but is not capable of transmitting significant quantities of groundwater under normal hydraulic gradients. In some situations aquitards may function as confining beds.

aromatic: Organic compounds that are unsaturated and contain at least one 6-carbon benzene ring.

auger: A tool for drilling/boring into unconsolidated earth materials (soil) consisting of a spiral blade wound around a central stem or shaft that is commonly hollow (hollow-stem auger). Augers commonly are available in flights (sections) that are connected together to advance the depth of the borehole.

azeotrope: A mixture with a fixed boiling point that cannot be further separated by fractional distillation.

azeotropic distillation: A technique which uses the ability of selected organic compounds to form binary azeotropes with water to facilitate the separation of the compounds from complex mixtures.

barrel sampler: Open-ended steel tube used to collect soil samples. The sampler has a sharpened end, or "shoe," that is pushed or driven into the ground. A soil core is collected inside of sampler.

batch: A group of samples prepared at the same time in the same location using the same method.

bentonite: A colloidal clay, largely made up of the mineral sodium montmorillonite, a hydrated aluminum silicate. Because of its ability to expand when moist, bentonite is commonly used to provide a tight seal around a well casing.

biodegradation: A process by which microbial organisms transform or alter (through metabolic or enzymatic action) the structure of chemicals introduced into the environment.

bladder pumps: Also known as squeeze pumps, bladder pumps operate by the compression of a flexible bladder housed inside the pump. Water enters the bladder through a check valve. Once the bladder is filled, it is squeezed by compressed air that has been injected into the housing surrounding the bladder. Water cycles through the bladder in evenly spaced pulses.

blank: See "method blank."

borehole: Hole made with boring (drilling) equipment. Also used in reference to hole made by DP equipment, but "DP hole" and "probe hole" are preferred terms in the latter case.

boring logs: The record of formations penetrated, drilling progress, record of depth of water, location of contaminants, and other recorded information having to do with the drilling well.

calibration: The establishment of an analytical curve based on the absorbance, emission intensity, or other measured characteristic of known standards. Used to define the linearity and dynamic range of the response of the analytical equipment to the target compounds.

calibration standards: A series of known standard solutions used by the analyst for calibration of the instrument (*i.e.*, preparation of the analytical curve).

capillary fringe: The zone of a porous medium above the water table within which the porous medium is saturated by water under pressure that is less than atmospheric pressure.

cased DP system: A rod system consisting of inner rods and outer drive casing. Also referred to as "dual-tube" DP systems. The soil sampling barrel is attached to inner rods. The inner rods and outer casing are typically driven simultaneously. The sampling tool is then withdrawn, emptied, and re-inserted, while the outer drive casing is left in the ground to keep the hole open. Minimizes sloughing and contamination of soil samples.

check-valve tubing pump: A water sampling tool consisting of plastic tubing with a check valve attached to the bottom. Also referred to as a Waterra® pump. Oscillation of the tubing moves water up through it. The check valve prevents water from draining out of the tubing when it is withdrawn from the well. In this way, the tubing acts like a long, skinny bailer.

composite underground storage tank: A fiberglass coated steel tank.

conceptual model: A written description or illustrated picture of the geologic, hydrogeologic, or environmental conditions of a particular area.

conductivity: A coefficient of proportionality describing the rate at which a fluid (*e.g.*, water or gas) can move through a permeable medium. Conductivity is a function of both the intrinsic permeability of the porous medium and the kinematic viscosity of the fluid which flows through it.

conductivity probe: A DP tool that measures the electrical conductivity of the soil to define lithology.

cone: Down-hole sensor used with CPT. At a minimum, consists of load cells to measure tip resistance and side-wall friction.

cone penetrometer testing (CPT): A DP system used to measure lithology based on the penetration resistance of the soil. Sensors are mounted in the tip (cone) of the DP rods to measure tip resistance and side-wall friction. Electrical signals are carried to digital processing equipment at the ground surface, where plots of soil type versus depth are recorded. It defines the type of soil based on calibration curves, not site-specific conditions. Therefore, CPT data requires on-site calibration/correlation with actual soil cores.

confining layer: A geologic formation characterized by low permeability that inhibits the flow of water (see also aquitard).

constituent: An essential part or component of a system or group (*e.g.*, an ingredient of a chemical mixture). For instance, benzene is one constituent of gasoline.

constituent(s) of concern: Specific chemicals that are identified for evaluation in the site assessment process.

conventional site assessment: A site assessment in which the majority of sample analysis and interpretation of data is completed off-site. The process typically requires multiple mobilizations in order to fully determine the extent of contamination.

cross contamination: The movement of contaminants from one depth to another due to invasive subsurface activities.

cross reactivity: The potential for constituents that are not the target compound to be detected as the target compound by an analytical method.

cuttings: The spoils created from conventional drilling with hollow stem auger or rotary drilling equipment. Cuttings are not generated with DP equipment.

deadmen: Anchors drilled or cemented into the ground to provide additional reactive mass to DP sampling rigs. The rigs are able to pull against the anchors, thus increasing the force that can be applied to the DP rods.

dense non-aqueous phase liquid (DNAPL): A non-aqueous phase liquid (NAPL) with a specific gravity greater than 1.0. Because the specific gravity of water is equal to 1.0, DNAPLs sink through the water column until they encounter a confining layer. DNAPLs flow along the surface of the confining layer and can migrate in directions contrary to the hydraulic gradient. Because DNAPLs are found at the bottom of aquifers (rather than floating on the water table) typical monitoring wells will not indicate whether DNAPLs are present. DNAPLs are typically chlorinated hydrocarbon solvents or very heavy petroleum fractions and are, therefore, not usually of concern at petroleum UST sites.

direct push: A growing family of tools used for performing subsurface investigations by driving, pushing, and/or vibrating small-diameter hollow steel rods into the ground. Also known as "direct drive," "drive point," or "push" technology.

downgradient: It the direction of decreasing static (potentiometric) head..

DP hole: A hole in the ground made with direct push equipment.

DP rod: Small diameter hollow steel rod that is pushed, driven, or vibrated into the ground in order to investigate and sample the subsurface. DP rods used with CPT rigs may be referred to as "cone rods"; DP rods used with other DP systems may be referred to as "probe rods."

drilling fluids: Fluid used to lubricate the bit and convey drill cuttings to the surface with rotary drilling equipment. Usually composed of a bentonite slurry, muddy water, or air. Can become contaminated, leading to cross contamination, and may require special disposal. Not used with DP methods.

drive cap: A steel cap that is attached to the top of the sequence of DP rods. Percussion hammers pound on the drive head, rather than the DP rods, to prevent damaging the threads on the rod connections.

drive casing: Heavy duty steel casing that is driven along with the sampling tool with cased DP systems. The drive casing keeps the hole open between sampling runs, and is not removed until the last sample has been collected.

drive head: See "drive cap."

drive shoe: The sharp, beveled end of a DP soil sampling tool. The shoe is beveled out, so that the soil core is cut cleanly. The beveled surface of the shoe forces soil to the outside of the sampler, where it is pushed into the formation.

drive-point profiler: An exposed groundwater DP system used to collect multiple depth-discrete groundwater samples. Ports in the tip of the probe connect to an internal stainless steel or Teflon tube that extends to the ground surface. Samples are collected via suction or air-lift methods. Deionized water is pumped down through the ports to prevent plugging while driving the tool to the next sampling depth.

dual tube DP system: See "cased DP system."

duplicate: A second aliquot of a sample that is treated the same as the original sample in order to determine the precision of the analytical method.

electrical conductivity: A measure of a substance ability to transmit an electrical current. Units are typically expressed in millimhos/meter when geophysical measurements are made.

electrical resistivity: A measure of a substance ability to inhibit the transmission of an electrical current. Units are typically expressed in ohms/meter when geophysical measurements are made. Electrical resistivity is the reciprocal of electrical conductivity.

electrical resistivity geophysical methods: Methods of measuring subsurface conditions through the use of an electrical current that is applied to the ground through a set of electrodes. Another set of electrodes is then used to measure the resulting voltage. The greater the distance between electrodes, the deeper the investigation.

electromagnetic geophysical methods: Methods of measuring subsurface conductivities by low frequency electromagnetic induction. A transmitter coil radiates an electromagnetic field which induces eddy currents in the subsurface. The eddy currents, in turn, induce a secondary electromagnetic field. The secondary field is then intercepted by a receiver coil. The voltage measured in the receiver coil is related to the subsurface conductivity.

enzyme: Any of numerous proteins or conjugated proteins produced by living organisms and functioning as biochemical catalysts.

evaporation: The process by which a liquid enters the vapor (gas) phase.

expedited site assessment: A process for collecting and evaluating site information in a single mobilization. Parameters assessed include site geology/hydrogeology, nature, and distribution of the chemicals of concern, source areas, potential exposure pathways, and points of exposure. An ESA employs rapid sampling techniques, field analysis and hydrogeological evaluation, and field decision making to provide a comprehensive "snap-shot" of subsurface conditions.

expendable tip: A disposable steel or aluminum tip that attaches to the end of DP rods. The tip seals the DP rods or sampling tool while it is driven through the soil. Once the desired sampling depth has been reached, the rods are pulled back, exposing the target interval.

field analytical methods: Methods or techniques that measure physical properties or chemical presences in soils, soil-gas, and groundwater immediately or within a relatively short period of time to be used during a site assessment. Measurement capabilities range from qualitative (positive/negative) response to below parts per billion quantitation. Accuracy and precision of data from these methods depends on the method detection limits and QA/QC procedures.

field manager: An individual who is on site and is responsible for directing field activities and decision-making during the site assessment. The field manager should be familiar with the purpose of the site assessment, pertinent existing data, and the data collection and analysis program. The field manager is the principle investigator, developing and refining the conceptual model of site conditions. This individual should have the necessary experience and background to perform the required site characterization activities, to accurately interpret the results, and to direct the investigation.

false negative: A negative result when the concentration of the target constituent is above the detection limit of the analytical method.

false positive: A positive result when the concentration of the target constituent is below the detection limit of the analytical method.

field blank: Any sample submitted from the field identified as a blank.

fill: Man-made deposits of natural soils or rock products and waste materials.

fluorescence: The emission of electromagnetic radiation (*e.g.*, visible light) by a substance during exposure to external electromagnetic radiation (*e.g.*, x-rays).

fracture: A break in a rock formation due to structural stresses. Faults, shears, joints, and planes of fracture cleavage are all types of fractures.

free product: A petroleum hydrocarbon in the liquid ("free" or non-aqueous) phase (see also non-aqueous phase liquid, NAPL).

friction reducer: A wide section of the DP cone or probe designed to enlarge a boring so that the DP rods above the friction reducer do not inhibit the advancement of the probe. Expendable friction reducers can be used for grouting on advance.

ground penetrating radar: A geophysical method that uses high frequency electromagnetic waves to obtain subsurface information. The waves are radiated into the subsurface by an emitting antenna. When a wave strikes a suitable object, a portion of the wave is reflected back to the receiving antenna.

groundwater: The water contained in the pore spaces of saturated geologic media.

grout: Cement and/or bentonite slurry used to seal DP holes and other exploratory borings. It is also used to seal the annular space around well casings to prevent infiltration of water or short-circuiting of vapor flow.

headspace: The vapor/air mixture trapped above a solid or liquid in a sealed vessel.

Henry's Law: The relationship between the partial pressure of a compound and the equilibrium concentration in the liquid through a proportionality constant known as the Henry's Law Constant.

Henry's Law Constant: The ratio of the concentration of a compound in air (or vapor) to the concentration of the compound in water under equilibrium conditions. Henry's Law Constants are temperature dependent.

heterogeneous: Varying in structure or composition at different locations in space.

holding time: The maximum amount of time a sample may be stored before analysis.

hollow stem auger drilling: A conventional drilling method that uses rotating augers to penetrate the soil. As the augers are rotated, soil cuttings are conveyed to the ground surface via spiral flights. Hollow stem augers allow the rig operator to advance DP tools inside of the augers.

homogeneous: Uniform in structure or composition at all locations in space.

hydraulic conductivity: A coefficient of proportionality describing the rate at which water can move through a permeable medium. Hydraulic conductivity is a function of both the intrinsic permeability of the porous medium and the kinematic viscosity of the water which flows through it. In older documents, hydraulic conductivity is referred to as the coefficient of permeability.

hydraulic gradient: The change in total potentiometric (or piezometric) head between two points divided by the horizontal distance separating the two points.

hydrocarbon: Chemical compounds composed only of carbon and hydrogen.

hydrophilic: Having an affinity for water ("water-loving"), or capable of dissolving in water; soluble or miscible in water.

hydrophobic: Tending not to combine with water, or incapable of dissolving in water; insoluble or immiscible in water ("water-fearing"). A property exhibited by non-polar organic compounds, including the petroleum hydrocarbons.

immunoassay: A test for a constituent or class of constituents based on the antibody/antigen reaction.

infrared radiation: Electromagnetic radiation with wave lengths greater than visible light but less than microwave radiation.

inner barrel: Internal sample barrel seated inside of a cased DP systems.

in situ: In its original place; unmoved; unexcavated; remaining in the subsurface.

injection: Introduction of the analytical sample into the instrument excitation system for the purpose of measuring absorbance, emission, or concentration of an analyte.

ionization potential: The energy required to ionize a particular molecule.

isoconcentration: More than one sample point exhibiting the same analyte concentration.

isopleth: The line or area represented by an isoconcentration.

intrinsic permeability: A measure of the relative ease with which a permeable medium can transmit a fluid (liquid or gas). Intrinsic permeability is a property only of the medium and is independent of the nature of the fluid.

kinematic viscosity: The ratio of dynamic viscosity to mass density. Kinematic viscosity is a measure of a fluid's resistance to gravity flow--the lower the kinematic viscosity, the easier and faster the fluid will flow.

laser induced fluorescence: A method for measuring the relative amount of soil and/or groundwater contamination with an *in situ* sensor. Laser light is transmitted to the sensor, where it fluoresces in proportion to the concentration of petroleum hydrocarbons adjacent to the sensor.

light non-aqueous phase liquid (LNAPL): A non-aqueous phase liquid (NAPL) with a specific gravity less than 1.0. Because the specific gravity of water is equal to 1.0, LNAPLs float on top of the water table. Most of the common petroleum hydrocarbon fuels and lubricating oils are LNAPLs.

linear range: The concentration range over which the analytical curve remains linear.

liners: Tubes lining DP soil sampling tools. Used to collect soil cores for chemical and/or lithologic analysis. Commonly made of stainless steel, brass, or plastic. Liners can be covered with caps to prevent loss of volatile constituents. Also known as sample sleeves.

lithology: Mineralogy, grain size, texture, and other physical properties of granular soil, sediment, or rock.

lower detection limit: The smallest signal above background noise that an instrument can reliably detect.

lower explosive limit (LEL): The concentration of a gas below which the concentration of vapors is insufficient to support an explosion. LELs for most organics are generally 1 to 5 percent by volume.

macropores: Soil pores that are secondary soil features such as root holes or desiccation cracks. They can create significant conduits for vertical migration of NAPL, dissolved contaminants, or vapor-phase contaminants.

magnetic geophysical methods: Methods of determining subsurface conditions by measuring the earth's total magnetic field at a particular location. Because buried ferrous materials distort the magnetic field, a magnetic anomaly is created and their location can be approximated.

matrix spike: Aliquot of a matrix (water or soil) fortified (spiked) with known quantities of specific compounds and subjected to the entire analytical procedure in order to indicate the appropriateness of the method for the matrix by measuring recovery.

matrix spike duplicate: A second aliquot of the same matrix as the matrix spike (above) that is spiked in order to determine the precision of the method.

metal detection geophysical methods: Methods designed to specifically locate metal in the subsurface through electromagnetic induction (see electromagnetic geophysical methods). When the subsurface current is measured at a specific level, the presence of metal is indicated with a meter reading, with a sound, or with both.

method blank: An analytical control consisting of all reagents, internal standards, and surrogate standards, that is carried through the entire analytical procedure. The method blank is used to define the level of laboratory background and reagent contamination.

microorganisms: Microscopic organisms including bacteria, protozoans, yeast, fungi, mold, viruses, and algae.

mobilization: The movement of equipment and personnel to the site, conducted during a continuous time frame to prepare for, collect, and evaluate site assessment data.

moisture content: The amount of water lost from a soil upon drying to a constant weight, expressed as the weight per unit weight of dry soil or as the volume of water per unit bulk volume of the soil. For a fully saturated medium, moisture content equals the porosity.

molecular weight: The amount of mass in one mole of molecules of a substance as determined by summing the masses of the individual atoms which make up the molecule.

monoaromatic: Aromatic hydrocarbons containing a single benzene ring.

non-aqueous phase liquid (NAPL): Contaminants that remain as the original bulk liquid in the subsurface (see also free product).

nonsealed DP tools: Sampling tools that are not sealed as they are advanced through the soil. Examples of these tools are barrel samplers and split-barrel samplers. Can yield erroneous chemical results because samples collected with these devices can be a composite of samples from different horizons. Can result in cross-contamination of samples.

nuclear logging: A down-hole geophysical logging method that uses naturally occurring or induced radiation to define lithology, groundwater conditions, or contaminant distributions.

olefins: See "alkenes."

organophyllic: A substance that combines with organic compounds.

outer drive casing: Same as drive casing.

oxidation-reduction (redox): A chemical reaction consisting of two half-reactions; an oxidation reaction in which a substance loses or donates electrons, and a reduction reaction in which a substance gains or accepts electrons. Redox reactions are always coupled because free electrons cannot exist in solution and electrons must be conserved.

packer: An inflatable gland, or balloon, that is used to create a temporary seal in borehole, probe hole, well, or drive casing. Made of rubber or non-reactive materials like Viton®.

paraffins: See alkanes.

perched aquifer: A lens of saturated soil above the main water table that forms on top of an isolated geologic layer of low permeability.

percussion hammer: A hydraulic or pneumatic hammer, much like a jackhammer, that is used to pound DP rods into the ground. Commonly used in the construction industry to break concrete.

peristaltic pump: A type of suction-lift pump that creates a vacuum by turning a rotating head against flexible tubing. Generally limited to approximately25 feet of lift.

permeability: Also referred to as intrinsic permeability. It is a qualitative description of the relative ease with which rock, soil, or sediment will transmit a fluid (*i.e.*, liquid or gas). Often used as a synonym for hydraulic conductivity or coefficient of permeability, however, unlike hydraulic conductivity, permeability is not a function of the kinematic viscosity of the fluid that flows through it.

petroleum: Crude oil or any fraction thereof that is liquid at standard conditions of temperature and pressure (60° F at 14.7 psia). The term includes petroleum-based substances comprised of a complex blend of hydrocarbons derived from crude oil through the process of separation, conversion, upgrading, and finishing, such as motor fuels, jet oils, lubricants, petroleum solvents, and used oils.

pH: A measure of the acidity of a solution. pH is equal to the negative logarithm of the concentration of hydrogen ions in a solution. A pH of 7 is neutral. Values less than 7 are acidic, and values greater than 7 are basic.

piezocone: A type of CPT cone that incorporates a pressure transducer to measure hydrostatic pressure.

piezometer: A nonpumping well, generally of small diameter, which is used to measure the elevation of the water table or potentiometric surface. A piezometer generally has a short well screen; the water level within the casing is considered to be representative of the potentiometric surface at that particular depth in the aquifer.

piezometric head: Hydrostatic pressure in an aquifer, relative to a common datum, such as mean sea level. The piezometric head in an unconfined aquifer is the water table. The piezometric head in a confined aquifer occurs above the top of the aquifer.

piezometer nest: A set of two or more piezometers set in close proximity to one another but screened at different depths. This allows for determination of vertical flow gradients or differences in water chemistry with depth.

piezometric surface: An outdated term for "potentiometric surface."

piston sampler: Sealed soil sampling tool that uses an internal piston to seal the tool while it is pushed or driven to the target zone. Once the sampling zone has been reached, the internal piston is unlocked, and the tool is driven to fill the sample barrel. The tool is removed from the ground to retrieve the sample.

polyaromatic hydrocarbon: Aromatic hydrocarbons containing more than one fused benzene ring. Polyaromatic hydrocarbons are commonly designated PAH.

polynuclear aromatic hydrocarbon: Synonymous with polyaromatic hydrocarbon. Designated PNA.

porosity: The volume fraction of a rock or unconsolidated sediment not occupied by solid material but usually occupied by liquids, vapor, and/or air.

***potentiometric* surface**: The surface to which water in an aquifer will rise by hydrostatic pressure.

pressure gradient: A pressure differential in a given medium (*e.g.*, water, air) which tends to induce movement from areas of higher pressure to areas of lower pressure.

probe hole: Synonym for DP hole (the hole resulting from advancement of DP tools).

protocol: Describes the exact procedures to be followed with respect to sample receipt and handling, analytical methods, data reporting and deliverables, and document control.

purge and trap (device): Analytical technique (device) used to isolate volatile (purgeable) organics by stripping the compounds from water or soil with a stream of inert gas, trapping the compounds on an adsorbent such as a porous polymer trap, and thermally desorbing the trapped compounds into the gas chromatographic column.

purging: Removing stagnant air or water from sampling zone or sampling equipment prior to collecting the sample.

quality assurance: Documentation designed to assure that proper sampling and/or analysis protocol are being followed.

quality control: The implementation of protocols designed to assure that the final sampling or analytical results are reliable.

re-entry grouting: A grouting method that requires re-entering the probe hole with special DP rods or tremie pipe for grouting. In some circumstances, the DP rods used for grouting may not go down the same hole as the hole created by the DP sampling tool. Generally inferior to retraction grouting.

retainers: Plastic or steel retaining caps that prevent soil cores from falling out of sample barrel when they are withdrawn from the ground. Also referred to as "soil catchers."

retention time: In chromatography, the time between when a sample is injected and the time the chromatographic peak is recorded.

retractable tip: A steel tip that is connected to the DP rods so that it can be detached at a designated depth while still being removed when the DP rods are withdrawn. The tip is connected to the tip holder with a small-diameter steel rod.

rotary drilling: A conventional drilling method that uses water- or air-based fluids to cool the drill bit and remove drill cuttings from the borehole.

rotohammers: A hand-held, high-frequency impact hammer used to advance small-diameter DP rods.

sample: A portion of material to be analyzed that is contained in single or multiple containers.

saprolite: A soft, earthy, clay-rich, thoroughly decomposed rock formed in place by chemical weathering of igneous or metamorphic rocks. Forms in humid, tropical, or subtropical climates.

saturated zone: The zone in which all the voids in the rock or soil are filled with water at a pressure that is greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.

sealed DP tools: Soil, groundwater, and soil-gas sampling tools that are sealed while they are pushed to the target depth.

seismic reflection: A method of determining subsurface conditions by creating acoustic waves and measuring the travel time as they reflect off of materials of different composition.

seismic refraction: A method of determining subsurface conditions by creating acoustic waves and measuring their travel times to the surface as they interface with two materials having different acoustic velocities.

semiquantitative: Numeric values which only approximate the true concentration of the analytes. Provides an order of magnitude of concentrations (*e.g.*, 10s, 100s, 1000s).

semivolatile organic compounds: A general term for organic compounds that volatilize relatively slowly at standard temperature (20° C) and pressure (1 atm).

shoe: See "drive shoe."

short circuiting: As it applies to soil gas surveys, the entry of ambient air into the extraction well without first passing through the contaminated zone. Short circuiting may occur through utility trenches, incoherent well or surface seals, or layers of high permeability geologic materials.

***single-rod* DP system**: A DP rod system that uses a single sequence of rods to advance the sampling tool or sensor.

Site Characterization and Analysis Penetrometer System: Also referred to as "SCAPS," it is an *in situ* sensor that uses laser-induced fluorescence to determine the relative amounts of polyaromatic hydrocarbons in the subsurface. The sensor is mounted in the cone of CPT equipment. Developed by the U.S. military.

slam bar: A hand-held weight used to pound DP rods into the ground. Originally designed for steel fence posts.

slough: Soil that falls into a probe hole after a sampling tool or *in situ* sensor has been withdrawn.

soil catchers: Flexible attachments on the bottom of soil sampling tools that allow soil to enter the sampler but inhibit soil from falling out while the sampler is being retrieved. Also referred to as "soil retainers."

soil moisture: The water contained in the pore spaces in the unsaturated zone.

solubility: The amount of mass of a compound that will dissolve in a unit volume of solution.

sorption: A general term used to encompass the processes of absorption, adsorption, ion exchange, and chemisorption.

sounding: A general term indicating the recording of vertical measurements. Commonly used to describe vertical measurements collected with geophysical methods and cone penetrometer testing.

source area(s): The location(s) of liquid hydrocarbons or the zone(s) of highest soil or groundwater concentrations, or both, of the chemical(s) of concern.

sparge or sparging: Injection of air below the water table to strip dissolved volatile organic compounds and/or oxygenate the groundwater to facilitate aerobic biodegradation of organic compounds.

specific gravity: The dimensionless ratio of the density of a substance with respect to the density of water. The specific gravity of water is equal to 1.0 by definition. Most petroleum products have a specific gravity less than 1.0, generally between 0.6 and 0.9. As such, they will float on water--these are also referred to as LNAPLs, or light non-aqueous phase liquids. Substances with a specific gravity greater than 1.0 will sink through water--these are referred to as DNAPLs, or dense non-aqueous phase liquids.

split-barrel sampler: A nonsealed soil sampling tool that is split longitudinally. The split barrel allows easy removal of soil cores. Some split-barrel samplers can hold stainless steel liners, which facilitate preservation of samples for chemical analysis (the steel liners minimize the loss of volatile organic compounds). Also known as a split-spoon sampler.

standard analysis: An analytical determination made with known quantities of target compounds; used to determine response factors.

stratification: Layering or bedding of geologic materials (*e.g.*, rock, sediments).

stratigraphy: The formation, composition, and sequence of sediments, whether consolidated or unconsolidated.

Tedlar® bags: Gas-tight bags constructed of non-reactive material (Tedlar) for the collection and transport of gas/vapor samples.

thin-walled tube samplers: A thin-walled non-sealed soil sampling tool used to collect undisturbed soil samples. Used in unconsolidated fine sands, silt, and clay. Larger diameter thin-walled tube samplers are referred to as Shelby tubes.

total petroleum hydrocarbons (TPH): A measure of the concentration or mass of petroleum hydrocarbon constituents present in a given amount of soil or water. The term "total" is a misnomer--few, if any, of the procedures for quantifying hydrocarbons are capable of measuring all fractions of petroleum hydrocarbons present in the sample. Volatile hydrocarbons are usually lost in the process and not quantified, and some non-petroleum hydrocarbons are sometimes included in the analysis.

total recoverable petroleum hydrocarbons (TRPH): A U.S. EPA method (418.1) for measuring petroleum hydrocarbons in samples of soil or water. Hydrocarbons are extracted from the sample using a chlorofluorocarbon solvent (typically Freon-113) and quantified by infrared spectrophotometry. The method specifies that the extract be passed through silica gel to remove the non-petroleum fraction of the hydrocarbons. The comparable SW-846 method is 8440 which uses perchlorethane (PCE) as an IR solvent instead of Freon-113.

tremie pipe: A flexible or rigid pipe used to convey grout to the bottom of a boring or probe hole.

ultraviolet radiation: Electromagnetic radiation with wave lengths less than visible light but greater than x-rays.

unconfined aquifer: An aquifer in which there are no confining beds between the capillary fringe and land surface, and where the top of the saturated zone (the water table) is at atmospheric pressure.

unsaturated zone: The zone between land surface and the capillary fringe within which the moisture content is less than saturation and pressure is less than atmospheric. Soil pore spaces also typically contain air or other gases. The capillary fringe is not included in the unsaturated zone.

upgradient: It the direction of increasing static (potentiometric) head.

upper detection limit: The largest concentration that an instrument can reliably detect.

vadose zone: The zone between land surface and the water table within which the moisture content is less than saturation (except in the capillary fringe) and pressure is less than atmospheric. Soil pore spaces also typically contain air or other gases. The capillary fringe is included in the vadose zone.

vapor pressure: The force per unit area exerted by a vapor in an equilibrium state with its pure solid, liquid, or solution at a given temperature. Vapor pressure is a measure of a substance's propensity to evaporate. Vapor pressure increases exponentially with an increase in temperature.

vibratory head: An assembly made of hydraulically operated vibrators that clamp onto DP rods. High-frequency vibration helps advance DP rods in fine-grained soil. Usually accompanied by simultaneously applying pressure to the DP rods.

volatile organic compounds: A general term for organic compounds capable of a high degree of vaporization at standard temperature (20° C) and pressure (1 atm).

volatilization: The process of transfer of a chemical from the aqueous or liquid phase to the gas phase. Solubility, molecular weight, and vapor pressure of the liquid and the nature of the gas-liquid interface affect the rate of volatilization.

water table: The water surface in an unconfined aquifer at which the fluid pressure in the pore spaces is at atmospheric pressure (the phreatic surface).

weathering: The process during which a complex compound is reduced to its simpler component parts, transported via physical processes, or biodegraded over time.

zero air: Atmospheric air that has been purified to contains less than 0.1 ppm total hydrocarbons.

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