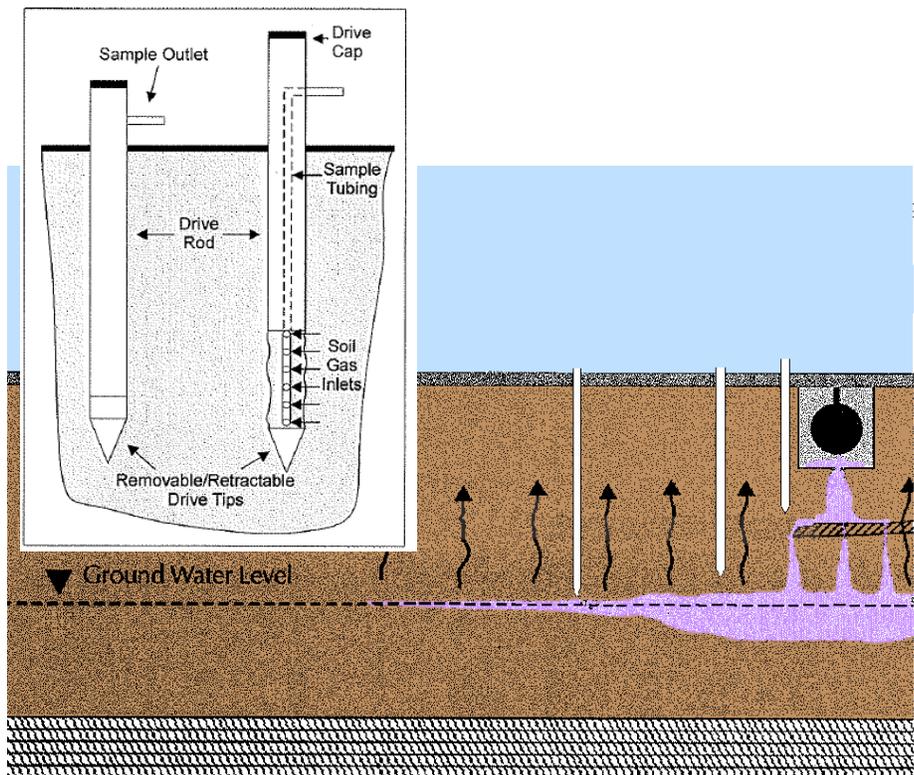


Division of Drinking and Ground Waters

Technical Guidance Manual for Ground
Water Investigations

Chapter 11

Soil Gas Monitoring For
Site Characterization



August 2008

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Director : Chris Korleski



**TECHNICAL GUIDANCE
MANUAL FOR
GROUND WATER INVESTIGATIONS**

CHAPTER 11

Soil Gas Monitoring For Site Characterization

**August, 2008
Revision 1**

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PREFACE

This document is part of a series of chapters incorporated in Ohio EPA's *Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring* (TGM), which was originally published in 1995. DDAGW now maintains this technical guidance as a series of chapters rather than as an individual manual. The chapters can be obtained at <http://www.epa.state.oh.us/ddagw/tgmweb.aspx>.

The TGM identifies technical considerations for performing hydrogeologic investigations and ground water monitoring at potential or known ground water pollution sources. The purpose is to enhance consistency within the Agency and inform the regulated community of the Agency's technical recommendations and the basis for them. In Ohio, the authority over pollution sources is shared among various Ohio EPA divisions, including the Emergency and Remedial Response (DERR), Hazardous Waste Management (DHWM), Solid and Infectious Waste (DSIWM), and Surface Water (DSW), as well as other state and local agencies. DDAGW provides technical support to these divisions.

Ohio EPA utilizes **guidance** to aid regulators and the regulated community in meeting laws, rules, regulations and policy. Guidance outlines recommended practices and explains their rationale. The Agency may not require an entity to follow methods recommended by this or any other guidance document. It may, however, require an entity to demonstrate that an alternate method produces data and information that meet the pertinent requirements. The procedures used to meet requirements usually should be tailored to the specific needs and circumstances of the individual site, project, and applicable regulatory program, and should not comprise a rigid step-by-step approach that is utilized in all situations.

Major Changes from the February 1995 TGM

The Ohio EPA Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring (TGM) was finalized in 1995. This guidance document represents an update to Chapter 11 (Supplementary Methods). Listed below are the major changes from the 1995 version.

1. Changed chapter title from Supplementary Methods to Soil Gas Monitoring for Site Characterization.
2. Removed section on the use of geophysics.
3. Removed section on In-Situ Ground Water Sampler. The information in that section has been revised and moved to Chapter 15: Use of Direct Push Technologies and Soil and Ground Water Sampling (February, 2005).
4. Noted in introduction that the focus of this chapter is for site characterization rather than obtaining data for vapor intrusion risk assessments. Please check with specific divisions for programmatic guidance on vapor intrusion investigations.
5. Added references for default Henry's Law constants. Also added the equation to convert between Henry's Law constants presented in atm-m³/mol and dimensionless Henry's Law constant.
6. Added information on using DPT for active soil gas sampling.
7. Added a note of caution regarding short circuiting when performing active sampling. A leak test should be performed to evaluate the possibility of short circuiting.
8. Expanded sections on active sampling methods, passive sampling methods, and surface flux chambers to include information from new and updated references.
9. Included references to new documents that have become available since 1995, including:
 - Updated existing references.
 - Added reference to the new ITRC document Vapor Intrusion Pathway: a Practical Guideline.
 - Added reference to a paper by Blayne Hartman on surface flux chamber method sampling.
 - Added 1997 US EPA reference Expedited Site Assessment Tools for Underground Storage Tank Sites.

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CHAPTER 11

SOIL GAS MONITORING FOR SITE CHARACTERIZATION

Soil gas sampling and analysis can be a rapid and cost-effective approach for preliminary delineation of the areal and/or vertical extent of subsurface contamination by volatile organic compounds (VOCs). Information can be obtained that is useful in developing ground water and soil sampling and analysis programs. Gasoline and many other organic liquids contain VOCs that can be emitted as vapors. If released into the subsurface, vapors emitted will occupy the void spaces between the individual grains within the formation. Soil gas surveys involve sampling and analyzing gases that occupy the pore spaces in the vadose zone. Conventional activities such as ground water sampling of monitoring wells and performance of soil borings always will be necessary to confirm and/or monitor subsurface contamination.

When an organic liquid is released into the subsurface, it generally migrates downward under the force of gravity until it reaches the water table. Depending on the characteristics of the liquid, it may float on the surface, sink to the bottom of the water-bearing zone, and/or dissolve into the ground water. Also, the contaminant may, in part, become adsorbed to sediments as it migrates through the vadose zone. Soil gas sampling can be used, in appropriate situations, to detect volatile organic vapors derived from all of these potential sources. The technique is most effective for contaminated soils and water table aquifers and is relatively ineffective for contaminated ground water overlain by extensive confining layers.

Soil gas surveying can be used to: 1) detect and identify specific VOCs in the subsurface, 2) determine the concentrations of each component in the gas phase, 3) identify sources and extent of multiple spill events, 4) predict the extent of soil and/or ground water contamination, 5) interpret mode of occurrence of contaminants (liquid, dissolved), 6) identify fuel products (diesel vs. gasoline), 7) help guide the placement of borings and monitoring wells and 8) initially monitor the progress of in-situ bioremediation systems. Benefits of soil gas surveys include low cost, rapid sampling, quantitative analysis of VOCs, thorough site coverage, and timely results. While soil gas sampling is widely employed in vapor intrusion investigations, that use is not the focus of this chapter. Please check with specific divisions for programmatic guidance on vapor intrusion investigations.

FACTORS OF CONCERN IN SURVEY DESIGN

Site-specific physical factors such as soil characteristics, geologic heterogeneity, depth to water table, and existence of natural or cultural confining zones affect vapor transport and, hence, the usefulness of soil gas surveys. Chemical and physical factors and concentrations of contaminants affect the degree to which compounds partition into the vapor phase. Changes in barometric pressure, temperature, and moisture content can affect soil gas flux and subsequent interpretation of the data. Also, use of proper sampling and analysis protocol and appropriate instruments with detectors sensitive to the contaminant of interest is required to detect volatiles (Crockett and Taddeo, 1987). Failure to understand and consider these factors can result in erroneous conclusions. Table 11.1 summarizes the factors.

Table 11.1. Factors affecting concentrations of soil gas vapors.

<i>CHEMICAL/BIOLOGICAL CHARACTERISTICS</i>
<ul style="list-style-type: none"> ◦ Volatility of compounds (solubility and vapor pressure) ◦ Mobility in subsurface ◦ Concentration gradients ◦ Persistence in subsurface (half life, biodegradable capacity, interaction with other chemicals, etc.)
<i>HYDROGEOLOGIC CONTROLS</i>
<ul style="list-style-type: none"> ◦ Properties of the soil media: moisture content, total porosity, air porosity, grain size distribution, organic carbon content, redox potential. ◦ Heterogeneity of the subsurface materials ◦ Fluctuating water table ◦ Perched aquifer
<i>ANTHROPOGENIC CONTROLS</i>
<ul style="list-style-type: none"> ◦ Paving and buildings ◦ Utility conduits ◦ Pumping centers
<i>METEOROLOGICAL CONTROLS</i>
<ul style="list-style-type: none"> ◦ Barometric pressure ◦ Precipitation regime ◦ Temperature

CHARACTERISTICS OF CONTAMINANTS

Only chemicals that are present in the vapor phase are appropriate for soil gas sampling. This limits application to investigation of the presence of contaminants such as solvent chemicals and petroleum hydrocarbons, which are characterized by high vapor pressure, low molecular weights, and low aqueous solubilities.

These compounds can readily partition out of the liquid and/or ground water and into the soil gas phase as the result of their high gas/liquid partitioning coefficients. In general, the greater the amount of contaminant present, the greater the opportunity for volatiles to exist in soil pores; however, the relationship is not necessarily directly proportional. The amount of an organic compound that can be volatilized is limited (under static conditions) by factors controlling the equilibrium between the liquid and gas phase. Additionally, soil gas evolving from light non-aqueous phase liquids (LNAPLs) exhibit higher contaminant concentrations than soil gas coming from a contaminant in the aqueous phase.

The vapor pressure of a compound and its Henry's Law constant together control the extent to which a chemical partitions into the vapor phase. A compound's vapor pressure is a measure of the pressure that a vapor exerts when it is in equilibrium with its pure liquid or solid form and predicts the likelihood that the compound will enter into the vapor phase. Compounds with vapor pressures greater than 0.5 mm Hg are considered capable of being detected with active soil gas sampling methods (U.S. EPA, 1997).

Likewise, the Henry's Law constant of the compound can be used to determine the likelihood it will enter gas phase. Henry's Law constants are a function of the aqueous solubility, vapor pressure, and molecular weight of a compound. Note that care should be taken to determine the units of Henry's Law constant. Henry's Law constants may be expressed a number of ways, but the most common for environmental applications are $\text{m}^3\text{-atm/mol}$ or in its dimensionless form. Conversion between dimensionless Henry's Law constants (H') and Henry's Law constants in $\text{m}^3\text{-atm/mol}$ (H) is performed with the following equation:

$$\text{atm-m}^3/\text{mol} \times 41 = H' \quad (1)$$

Compounds having dimensionless Henry's Law constants greater than 0.1 are considered to be detectable with active soil gas sampling. Compounds with lower Henry's Law constants may be detected using passive soil gas techniques, though a precise lower limit is unable to be calculated because of local site and detection variations (U.S. EPA, 1997). Table A-5 of the Division of Hazardous Waste Closure Review Guidance (Ohio EPA, 2006) includes both forms of Henry's Law constants. The Division of Emergency and Remedial Response, Voluntary Action Program, Support Document for Development of Generic Numeric Standards and Risk Assessment (Ohio EPA, 2002) also provides default values.

It must be noted that many factors can influence these approximations. For example, compounds characterized by boiling points below 110°C are most mobile in soil gas (Thompson and Marrin, 1987). Vapors from hydrocarbons with boiling points greater than 150°C are usually detected only in the immediate vicinity of the source because of their low diffusion coefficients and tendency to adsorb onto soils.

When evaluating for the potential of ground water contamination, soil gas measurements for petroleum releases should be collected as close to the water table as possible (Thompson and Marrin, 1987). Chemicals that are altered by biological action or chemical transformation may be difficult to detect. Petroleum hydrocarbons may undergo biodegradation, particularly in the upper portions of the soil profile where oxygen is present. However, in the immediate vicinity of a strong hydrocarbon source, such as a leaking underground storage tank, vapors are generally detectable at or very near the ground surface. According to Marrin and Kerfoot (1988), halogenated hydrocarbons can biodegrade under anaerobic conditions. Compounds with minimal halogens can biodegrade under both anaerobic and aerobic conditions. Chlorinated hydrocarbons such as tetrachloroethylene (PCE) and trichloroethylene (TCE) can be biologically dehydrated in the subsurface to produce more volatile compounds (e.g., dichloroethene isomers and vinyl chloride).

SITE PHYSICAL FACTORS

Successful detection of volatiles by soil gas sampling requires transport of VOCs over some distance. The transport is dependent on the chemical/physical properties of the contaminant and hydrogeologic and soil conditions.

The predominant transport mechanisms for soil gas are diffusion and convection. Diffusion is the result of thermal motion of molecules subject to a concentration gradient. Convection is the result of a pressure gradient causing mass flow in a gaseous phase. Both processes are independent of topography or hydraulic gradient. The soil gas concentration tends to decrease with increasing distance both horizontally and vertically away from the source. Studies have shown that concentrations drop more rapidly horizontally than vertically (Crockett and Taddeo, 1987). Though vertical transport by diffusion predicts a linear increase in VOC concentration with depth, hydrogeologic/geologic heterogeneities, soil porosity, moisture content, and sorption equilibria within the subsurface can affect VOC vapor gradients. During the upward migration of soil gas, the vapor may encounter a clay or human-made structure that may cause it to diffuse horizontally and result in a plume that is slightly larger than the source. Vapor transport through wet clays is limited compared to transport across dry porous sand (Crockett and Taddeo, 1987). Paved areas can cause near-surface concentrations to be significantly higher because they prevent off-gassing. Also, migration pathways can be directly influenced by anthropogenic structures such as utility conduits, which are typically backfilled with permeable sand and gravel.

Shallow conditions present a difficulty with soil gas surveys because the concentration gradient in soil gas can be very steep and slight variations in the ground water elevation can result in large variations in VOC concentrations. If the water table is close to the surface, it is difficult to acquire samples that are reliable and representative. In addition, if samples must be acquired from 2 feet or less, there is an increased likelihood that they will be diluted by air or affected by barometric pressure. However, Tillman et al. (1989b) caution that it is possible to sample at too great a depth. If this occurs, then accumulations of vapors, such as those that may occur above a contaminated perched water table, may be missed. Slight variations in depth of samples collected close to the water table can produce large apparent concentration variations. Less variability in results is apparent with increased distance above the water table. Thus, an understanding of site geology is vitally important.

SITE METEOROLOGICAL FACTORS

Meteorological changes such as barometric pressure, temperature, and moisture content can affect soil gas flux; therefore, these effects need to be understood in the acquisition and interpretation of data. A high pressure system during sampling creates a lower volatile flux at shallow depths than during a period of low pressure. Freezing and thawing conditions can have an effect on flux. Soil gas can become concentrated beneath the frozen cap. The temperature of soil gas can affect the rate at which volatilization occurs in the subsurface. Studies have shown that VOC concentrations can increase during early afternoon and decrease in late afternoon, roughly correlating with daily temperature changes (Karably and Babcock, 1989). Increased moisture content can increase the rate of movement of volatiles through soils because water tends to displace non-ionic species from the adsorption site. However, according to Tillman et al. (1989a), a period of heavy rainfall often causes a

decrease in the gas flux due to the near-surface saturated conditions and the stripping of soluble components out of the soil gas. To eliminate the effects of meteorological changes, soil gas samples should be taken over the shortest period of time possible.

SAMPLING AND ANALYSIS TECHNIQUES

Appropriate methods for soil gas sample acquisition and analysis depend on site conditions and survey objectives. Before methods are selected, contaminant properties, site-specific hydrogeologic conditions, human-made interferences, and why and how the data will be utilized should be understood clearly (Crockett and Taddeo, 1987). Accurate detection of VOCs requires use of proper protocol and appropriate instruments with detectors sensitive to the contaminant of interest. The selection of techniques influences the subsequent interpretation of the data.

Soil gas sampling techniques fall into several categories: active, passive, surface flux chambers, and head space measurements. The techniques selected should be dependent on the objective of the study. It is imperative that those conducting surveys are experienced with the methods and are familiar with site conditions.

ACTIVE SAMPLING METHODS

Active sampling methods provide an instantaneous picture of the soil atmosphere at a particular location. Active techniques involve physically withdrawing soil gas through probes or sampling points installed in the soil, usually by pumping. Active methods are necessary for quantitative analysis, and are most useful when the chemicals of concern (COCs) are VOCs. Active soil gas sampling may be used to identify releases, delineate contaminant source areas and VOC plumes, to optimize the placement of soil borings and monitor wells, and to monitor the effectiveness of remedial systems (U.S. EPA, 1997).

Active sampling methods are particularly useful when the following are desirable:

- Vertical profiling information
- Three-dimensional information
- Real time data
- Quantitative contaminant data.

However, active soil gas sampling may not be effective for identifying semi-volatile organic compounds (SVOCs) or low volatility compounds. It is not easily conducted in soils with very low permeability or high soil moisture content soils (US EPA, 1997).

Probe Installation

Soil gas can be sampled by driving a hollow probe into a borehole using a slam bar, direct push technology (DPT), or larger drill rigs, and evacuating a small amount of vapor. Openings in the tube near the leading edge allows for soil gas to enter. The sample can be extracted by inserting a needle through the evacuation line and drawing gas from the stream, or by withdrawing a sample through inert tubing inserted into the probe. Sample tubes can also be buried to create more permanent sample locations. Multilevel samplers may be

created by nesting sample tubes within a single borehole. Samples can be analyzed in the field by gas chromatography (GC) or transported for laboratory analysis.

Both large-volume and small-volume probes have been used. The internal volume of the probe significantly affects the measurement process and the utility of the resulting data (Devitt et al., 1987). Small probes can be used to attempt to measure "true" soil gas concentrations. The small volume permits the air inside the probe to be purged and a small (e.g., 1 mL) sample to be collected without substantially altering the gas equilibrium. The use of a large probe typically involves sampling several liters of soil gas. This may not permit a representative sample to be collected under most conditions, but allows for the soil gas to be concentrated prior to analysis or for multiple aliquots to be extracted.

The large probes are typically used for investigations that seek to determine relative concentrations or that are concerned with whether or not contamination affects a given area. Devitt et al. (1987) cited various researchers and how they applied both small and large probes.

Driven probes can be installed through landscaped areas, through concrete or asphalt covers, or inside buildings with relatively little disturbance of the surrounding area. The technique is relatively sensitive and can be used to measure subsurface gas concentrations while avoiding surface interference. Samples also can be obtained below impermeable layers. The technique is well suited for ground water investigations, except in the presence of wet or clayey soils or near surface rock strata. The method is labor- and time-intensive, and sampling ports can clog, making sample extraction difficult.

DPT platforms and tools are often used for soil gas sampling. DPT systems may be used to obtain one-time grab samples, or to install soil gas implants for long-term monitoring (McCall et al., 2006). A number of different systems have been developed for soil gas sampling, and are listed in Chapter 15.

Active Sampling Considerations

Due to a lack of connected air-filled pores, active soil gas methods generally are not effective at high soil moisture content (above 80- to 90- percent saturation). Sampling procedures can be used to compensate for high soil moisture conditions, but these methods are often time consuming (U.S. EPA, 1997).

It is important to use sample techniques that minimize the vacuum applied to the soil to reduce the potential for desorption of contaminants from soil, especially when sampling fine-grained materials (ITRC, 2007). Testing should be conducted to determine the optimal purge volume and rate for the soil conditions. Varying the purge volume and rate until the contaminant concentrations stabilize can determine the optimal volume and rate for sampling.

Improper sealing of a sampling probe can allow atmospheric gases to be exchanged with soil gas, commonly known as short circuiting. Rapidly decreasing contaminant levels during sampling, or detection of atmospheric gases, can indicate short circuiting is occurring. Sealing the probe hole, typically done using wet bentonite, can minimize the potential for short circuiting and help ensure that the sample being retrieved is composed of actual soil

gas from the sampling depth. A leak test should be conducted using a tracer compound or a “shut-in” test (U.S. EPA, 1997). More information on short circuit testing can be found in ITRC (2007).

PASSIVE SAMPLING METHODS

Passive soil gas sampling involves use of a sorbent sampler. The device is buried underground and used to collect gas over a given period of time (2 to 6 weeks), after which the devices are removed and analyzed in the laboratory. Devitt et al. (1987) discussed sorbent systems designed by various researchers.

Best suited where low concentrations are expected, sorbent samplers provide integrated samples that compensate for fluctuations in soil gas concentration (Devitt et al., 1987). Passive sampling methods are more effective than active sampling when the COCs include SVOCs and low volatility compounds. They are also more effective in low permeability and high moisture soils (U.S. EPA, 1997). The sampling duration can be varied to ensure that a sufficient sample is collected to allow for analytical detection. Since gas-phase diffusivity, which would enable a calculation of concentration from the adsorbed mass in the sampler, is unknown in the vadose zone, contaminant concentration data cannot be determined from this method (ITRC, 2007). Therefore, while passive sampling is useful for determining whether contamination exists, it but does not provide quantitative information.

Because the sampling devices are installed just below the ground surface (between 3 inches and 4 feet), installation is quick and a large number of devices can be installed per day. However, the use of passive devices requires a much greater turnaround time for sample acquisition. Some techniques may cause dilution of samples by mixing with the air or cause contamination of the sample from the sampling apparatus (U.S. EPA, 2997).

As they are both less expensive and less intrusive than active sampling methods, as well as being easy to deploy, passive sampling methods are particularly useful for obtaining screening level information, particularly at large sites. If vertical data or quick sample turnaround are not required, passive sampling can be a cost-effective sample method. Table 11.2 provides a comparison of active versus passive soil gas sampling applications.

TABLE 11.2 Active vs. Passive Soil-Gas Sampling (After US EPA, 1997)

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

SURFACE FLUX CHAMBERS

Surface flux chambers are enclosures, usually dome- or box-shaped, placed directly on a surface such as the ground or a floor. After the flux chamber has been left in place for a period of time the concentration in the chamber is measured. The air is passed through a chamber and the gas exiting the chamber is analyzed or collected for later analysis. Two types of surface flux chamber methods are available: static and dynamic. The static method works by passively capturing contaminants that flux into the trapped and stagnant chamber volume. The concentration builds over time, and samples for analysis are taken either at the end of the incubation period or at regular intervals throughout the incubation period. In the dynamic-chamber method, gas is continuously introduced into the chamber, while an equivalent amount of gas is allowed to escape. Once the system is assumed to reach steady-state (after four or five chamber-residence times), the concentration in the outlet gas is monitored with a meter, or a sample of the outlet gas is collected (Hartman, 2003). The dynamic-chamber method is most useful where higher contaminant fluxes are expected. The static-chamber method is preferable where lower contaminant fluxes are anticipated (ITRC, 2007). Best results are obtained by using sophisticated sampling techniques (e.g., stainless steel evacuation) and/or sensitive detection systems (e.g., GC) (Devitt et al., 1987).

Limitations of the surface flux chamber method include:

- Dilution of sample with the dynamic-chamber method, which decreases the sensitivity of the method.
- Caliche, semi-impermeable soils, and/or soils saturated with water block the migration of soil gas.
- Concentrations of soil gas collected at the surface generally are lower than the subsurface soil gas concentrations, making contaminant detection difficult.

HEAD SPACE MEASUREMENTS

Head space measurements are useful for screening an area during preliminary evaluation. They can be obtained from subsurface structures or from soil samples.

Subsurface Structures

Head space measurements from subsurface structures involve collecting grab samples or utilizing a portable hydrocarbon analyzer in wells, storm sewers, underground utility lines, or other human-made structures. This technique can be used during the first phase of an investigation. The results obtained can assist in developing protocol for subsequent work. The limitations of this technique include interference from methane in sewer lines and diffusion of volatile hydrocarbon species out of unsealed structures. In addition, negative test results are inconclusive.

Soil Samples

Head space measurements of a soil sample (e.g., from a hand auger, driven tube, or split spoon) can also be used. Containers should be properly decontaminated and meet the same standards as containers submitted for laboratory analysis. Several approaches can be taken. The container can be half-filled with soil, sealed, and allowed to equilibrate with the ambient temperature. Measurements can be taken from volatilization of the gas into the vacant space using a portable detector (Holbrook, 1987). Other techniques involve placing the sealed container in a hot water bath (70° C) to volatilize the organic compounds (Jermakian and Majka, 1989).

Head space measurements from soil samples typically are simple and quick to perform. They can be used to analyze soil gas from discrete or composite samples at incremental depths down to the water table. This technique has been used to collect shallow soil gas to assess deeper sources of vapors. Devitt et al. (1987) recommended this technique when the sampling crew has a modest level of technical expertise or when sophisticated sampling equipment is neither available nor cost-effective. Limitations include:

- Primarily suited for measuring adsorbed organics rather than free organics in the interstitial pore spaces.
- Loss of volatile hydrocarbons when the sample is removed from the ground or transferred for analysis.
- Loss of volatile hydrocarbons due to degradation of organic compounds from the time delay between sampling and analysis.

Soil type, head space volumes, temperature, handling techniques, and storage times need to be held constant to compare relative concentration levels between samples.

ANALYSIS TECHNIQUES

A wide variety of techniques exist to analyze soil gas. These range from handheld devices that measure total levels of VOCs to laboratory gas chromatographs that measure minute quantities of individual constituents. The selection of a method is dependent on the objective of the survey and the compounds of interest.

Handheld analyzers can be used to measure gross levels of VOCs and using such a device is often one of the first steps of an investigation. The technique is quick, simple, and economical and can save substantial amounts of time and money by providing input data for selection of additional sampling strategies (Devitt et al., 1987). However, because of their high sensitivity to ambient changes, the data obtained from a handheld analyzer cannot be used as a mapping tool (Tillman et al., 1989b). Also, negative test results are inconclusive.

The use of a **gas chromatograph (GC)** is more definitive in identifying individual components of soil gas. Samples can either be analyzed in the field using a portable GC unit or taken to a laboratory for analysis by a laboratory-grade unit. The use of portable GCs generates data on the same day the sampling is completed; however, field GC analysis often is slow overall and may not provide the low detection limits that laboratory technology provide. Mobile labs with laboratory-grade GCs provide top quality results and allow field analysis.

Selection of an appropriate detector also is critical to a successful survey. The detector should be sensitive to the volatiles to be analyzed and offer appropriate detection limits. A variety of detectors that measure different classes of VOCs can be used with the gas chromatograph. These include a flame ionization detector (FID), a photoionization detector (PID), an electron capture device (ECD) and the Hall electrolytic conductivity detector. A FID can be used when the objective is to detect the presence of petroleum hydrocarbons. An ECD can be used if the objective is to measure the existence of chlorinated hydrocarbons. The Hall detector may be used to detect halogenated compounds, including vinyl chloride, but it is much less sensitive than the ECD to the primary solvents such as trichloroethene (TCE), tetrachloroethane (PCE), and 1,1,1-trichloroethane (TCA) (Ballestrero et al, 2006). A PID can be used to measure some components of both hydrocarbon and chlorinated hydrocarbons. If the objective is to determine the presence of the full range of EPA Volatile Priority Pollutants, then both the GC/FID and the GC/ECD analysis should be conducted.

INTERPRETATION OF DATA

Including soil gasses affected by biodegradation (e.g., oxygen, carbon dioxide, methane, hydrogen sulfide) in a soil gas survey can supply information regarding contaminant source area and plume, as long as background samples are also collected for comparison. Use of these parameters is effective primarily when the contaminants are SVOCs or non-volatile, or if a volatile contaminant is present but has not been directly detected (U.S. EPA, 1997).

To obtain maximum benefits from soil gas data, proper interpretation based on experience and knowledge of the underlying principles is essential (Crockett and Taddeo, 1987). One of the most common mistakes is to extend the interpretation beyond the scope of the survey design (Marrin, 1988). For example, a survey designed to locate contaminant source areas

probably is not appropriate for delineating contaminant plume characteristics at the same location. Soil gas surveying is effective only for specific types of contaminants and should be interpreted with careful regard to the physical chemistry of the contaminant and the hydrogeologic environment (Marrin and Kerfoot, 1988).

Quantitative relationships between VOC concentrations in soil gas and ground water can be difficult to establish due to variability in subsurface conditions across a site (Marrin, 1988). Even under the most homogeneous conditions, correlation coefficients can only be calculated on an order-of-magnitude basis. Heterogeneities in the subsurface (i.e., moisture content, air-filled porosity, grain size distribution, pavement) cause differences between soil gas and ground water plume characteristics; however, the lack of statistical correlation does not mean that soil gas analyses are not indicative of ground water conditions (Marrin, 1988).

Using soil gas contours to define the boundary of a contaminant plume in ground water rarely is successful because compounds characterized by low to moderate air/water partitioning coefficients are not present at high enough concentrations in soil gas to be detected and because compounds with high partitioning coefficients have usually diffused in soil gas beyond the ground water plume (Marrin, 1988).

REFERENCES

- Ballestrero, T., B. Herzog, and G. Thompson. 2006. Monitoring and Sampling the Vadose Zone. In: David M. Nielsen (editor), Practical Handbook of Ground-Water Monitoring. Lewis Publishers, Inc. Chelsea, Michigan. pp. 207-247.
- Crockett, E. L. and A. R. Taddeo. 1987. A Technical Evaluation Of Soil Gas Analysis For Use at a Hazardous Waste Site. Cambridge Analytical Associates, Inc. Boston, Massachusetts.
- Devitt, D. A., R. B. Evans, W. A. Jury, and T. A. Starks. 1987. Soil Gas Sensing for Detection and Mapping of Volatile Organics. National Water Well Association. Dublin, Ohio.
- Hartman, B. 2003. How to Collect Reliable Soil-Gas data for Upward Risk Assessments, Part 2: Surface Flux-Chamber Method. In: LUSTline Bulletin 44. New England Interstate Water Pollution Control Commission. Lowell, Massachusetts. Pp. 14-18.
- Holbrook, T. 1987. Hydrocarbon Vapor Definition Using Ambient Temperature Headspace Analysis. In: Proceedings of the National Water Well Association/American Petroleum Institute (NWWA/API) Conference on Petroleum Hydrocarbons and Organic Chemicals in Ground Water. National Water Well Association. Dublin, Ohio. pp. 317-328.
- ITRC. 2007. Vapor Intrusion Pathway: A Practical Guideline. Interstate Technology & Regulatory Council Vapor Intrusion Team.
- Jermakian, D. A. and C. J. Majka. 1989. Groundwater Monitoring Needs and Requirements. Part 6: Application for Field Headspace Analysis and Soil Gas Analysis. Hazardous Materials Control. March/April. pp. 34-38.
- Karably, L. S. and K. B. Babcock. 1989. Part 5: The Effects of Environmental Variables on Soil Gas Surveys. Hazardous Materials Control. Jan/Feb. pp. 36-43.
- Kerfoot, H. B. 1988. Is Soil Gas Analysis an Effective Means of Tracking Contaminant Plumes in Ground Water? What are the Limitations of Technology Currently Employed? Ground Water Monitoring Review. Vol. 8, No. 2, pp. 54-57.
- Kram, M. L. 2006. DNAPL Characterization Methods and Approaches: Performance and Cost comparisons. In: David M. Nielsen (editor), Practical Handbook of Ground-Water Monitoring. Lewis Publishers, Inc. Chelsea, Michigan. pp.473-516.
- Marrin, D. 1988. Soil Gas Sampling and Misinterpretation. Ground Water Monitoring Review. Vol. 8, No. 2, pp. 51-54.
- Marrin, D. and H. B. Kerfoot. 1988. Soil Gas Surveying Techniques. Environmental Science and Technology. Vol. 22, No. 7, pp. 740-745.

- McCall, W., D. M. Nielsen, S. P. Farrington, and T. M. Christy. 2006. Use of Direct-Push Technologies in Environmental Site Characterization and Ground-Water Monitoring. In: David M. Nielsen (editor), Practical Handbook of Ground-Water Monitoring. Lewis Publishers, Inc. Chelsea, Michigan. pp. 345-471.
- Nielsen, D. M., G. L. Nielsen, and L. M. Preslo. 2006. Environmental Site Characterization. In: David M. Nielsen (editor), Practical Handbook of Ground-Water Monitoring. Lewis Publishers, Inc. Chelsea, Michigan. pp. 35-205.
- Tillman, N. and K. Ranlet and T. J Meyer. 1989a. Soil Gas Surveys: Part 1. Pollution Engineering. Vol. 21, No. 7, pp. 86-89.
- Tillman, N., K. Ranlet and T.J. Meyer. 1989b. Soil Gas Surveys. Part II/Procedures. Pollution Engineering. Vol. 21, No. 8, pp. 79-84.
- Thompson, G., and D. Marrin. 1987. Soil Gas Contaminant Investigations: A Dynamic Approach. Ground Water Monitoring Review. Vol. 7, No. 3, pp. 88-93.
- U.S. EPA, (1997). Soil Gas Surveys. In: U.S. EPA, 1997. Expedited Site Assessment Tools For Underground Storage Tank Sites. Solid Waste and Emergency Response. EPA 510-B 97-001.