Chapter 4

Tools and Techniques for Expediting Site Characterization

4.1 Introduction

Expedited site characterization (as described in Section 3.2.7) encompasses the use of tools and methodologies that streamline data collection, increase field program flexibility, and allow for real-time on-site access to results. Fundamentals key to an expedited site characterization include:

- On-site or rapid decision-making capabilities
- Use of field and analytical tools that facilitate real-time data collection and interpretation.
- Use of non-intrusive or minimally intrusive geophysical and / or sampling techniques
- Flexibility in the overall site characterization and remediation process

The tools and techniques described in this chapter offer alternatives to, and in some cases, advantages over more traditional approaches to environmental assessment of sites. These tools and techniques are less intrusive, and generally allow completion of data collection in a more expeditious manner. In addition, the majority of these tools allow practitioners immediate, on-site access to results rather than requiring samples be sent to analytical laboratories for analysis. Having the data available in real time while implementing the sampling program allows the investigator to modify the sampling program based on early results. The investigator can then make informed decisions about subsequent sampling locations to cover an area of interest or to define the boundaries of identified problem areas.

In addition to being faster and less intrusive, these tools and techniques are cost-effective, taking many samples and producing a large amount of data in a short time. This is especially useful in expedited site characterizations, where the goal is to first collect more data points of lesser quality in order to focus resources on those areas of greatest concern. Subsequent phases of field work can then be implemented to collect fewer data points of better quality at predetermined locations, if necessary, to complete the site characterization.

These tools and techniques can be combined to form a site-specific expedited field program. Prior to developing such a program, however, thought must be given to the project's data needs and the ways in which the data will be used. Once these DQOs have been formulated, different site characterization tools and techniques can then be brought together, as appropriate for different site conditions. Flexibility in decision-making during the field program will also be required to ensure that only necessary and useable data points are collected. Each tool and technique in this chapter has strengths and weaknesses. The following table summarizes available information. Additional information is presented in the chapter proper for use by the practitioner. The order in which the tools and techniques discussed in this chapter does not reflect any ranking of their relative effectiveness.

Expedited Site Characterization Tools and Techniques

Name	Description	Benefits	Limitations	Approximate Cost
Direct Push Methods/Limited Access Drilling				
Direct Push/Limited Access Drilling (Geoprobe, Power Punch, Strataprobe, Precision Sampling, and others)	Used to collect soil, groundwater and soil gas samples and for identifying stratigraphy and nonaqueous phase liquids.	• Faster, cheaper way to explore subsurface characteristics • Can be linked to on-site analysis for real time mapping • Widely available • Can install small diameter wells and vapor extraction points • Less intrusive • Produces small volume of investigation-derived waste	• Limited range of use (with refusal/depth limited to <100 ft max; typically 25 to 30 feet) • Does not allow for large well installations • Limited use at locations with buried obstructions (e.g., foundations and coarse grain materials) • Potential for cross-contamination from single-tube rigs.	$1,000 - $1,500 per day; typical production 10-15 shallow (<40 ft) pushes per day
Cone Penetrometer	Push sampler used for geologic logging and to collect in situ measurements of geologic properties and pore pressure. Can be used to collect soil gas and groundwater samples.	• Rapid collection of objective stratigraphic information • Can penetrate harder zones than most direct push methods • Produces small volume of investigation-derived wastes	• Does not collect soil samples for analysis or inspection • Large, heavy rig may limit access • Cannot install wells • Potential for cross contamination from single-tube rigs	Typically one-third that of conventional soil borings, on per foot basis
Simulprobe	Driven sampler used to collect soil, groundwater, and soil gas samples through a casing or auger advanced to desired sampling depth.	• Collects soil and either groundwater or soil gas samples at same stratigraphic interval on the same push • Can be used with field instrument to screen for VOCs while pushing • Can be used in conjunction with a variety of drilling methods	• Limited availability • Multiple moving parts increases potential for breakage or sticking • Depth to which sampler can be pushed limited	Tools rent for $150/day or $650/week, plus rig cost of about $1,500 per day.
Hydropunch	Direct push tool used to collect depth-discrete groundwater samples at a discrete level in a single push.	• Collects groundwater sample at a discrete depth • Can be used with field instrument to screen various depths	• Data subject to interference from turbidity • Potential for cross-contamination if sampler is driven across hydrostratigraphic zones	Tools rent for $150/day or $650/week, plus rig cost of about $1500 per day.
Waterloo Profiler	Direct push sampler used to collect depth-discrete groundwater samples at various levels in a single push. Useful in identifying thin, high-concentration plumes that may be missed or underestimated (via dilution) with monitoring well sampling.	• Generates a vertical profile of groundwater quality on a single push (typical vertical separation of about 2 to 5 feet) • Faster and less prone to cross-contamination (vertically) than multiple pushes with conventional push samplers	• Sampling depth generally limited by drilling method • Not applicable to low-permeability settings • Tool available through limited number of vendors	$1,500 to $2,000 per day (2-person crew, including all decon and support equipment); typical production is 150 - 200 ft per day. Waterloo sampler equipment may be purchased from Solinst Canada, Inc., for $US 2,700.

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Multi-Level Groundwater Samplers				
Westbay System	Fixed multi-level sampler built for a specific well installation. Access is through a single standpipe with mechanical "ports" that are opened and closed during sampling. Used to provide multi-level sampling and hydraulic head measurements.	• Provides direct samples of formation water • Allows head measurements	• Mechanically complex • Not adjustable or portable between wells • Requires specially constructed wells	Approximately $30,000 for a 5-level system ranging from 50 feet to 200 feet in depth. Includes installation but not sample analysis.
Waterloo Sampler	Fixed multi-level sampler built for a specific well installation. Access is through bundled flexible tubes that are accessible at the surface. Used to provide multi-level sampling and hydraulic head measurements in specially-constructed well. Smaller "drive point" units available for shallow installation.	• Provides direct samples of formation water • Reduces purge volumes • Removable or permanent systems available	• Mechanically complex • Specially-ordered materials necessary • Removable packer system sometimes difficult to cost-effectively reuse • Requires trained technician for installation	Approximately $25,000 for a 5-level system ranging from 50 feet to 200 feet in depth. Includes installation but not sample analysis.
Diffusion Multi-Layer Sampler (DMLS)	Portable multi-layer dialysis cell passive groundwater sampler. Used to characterize vertical variation in groundwater quality in either open rock boreholes or in wells with long well screens. Can be used to estimate groundwater flow velocity using borehole dilution method.	• Portable between wells • Allows vertical characterization of groundwater in a single borehole or well • Requires no purging	• Not widely used • Does not allow head measurements • May not be appropriate for zones with strong vertical gradients	About $3,000 for 2- to 3-meter-long units. Cost increases with increasing length. Need to add additional costs related to sample analysis and equipment installation.
Discrete Point Samplers				
Discrete Point Samplers	Discrete point sampler used to collect representative groundwater sample at a distinct elevation or points of inflow in either open boreholes or screened wells.	• Permits groundwater sampling from discrete vertical depth • Minimizes mixing of water from different levels during sample collection • Portable	• May require training to operate sampler • May be difficult to obtain complete seal	$150-$2,000 for purchased sampler.

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Analytical Field Screening				
Rapid Optical Screening Tool (ROST)	Sampling and screening technology used to field screen for petroleum hydrocarbons and other contaminants.	• Rapid, real-time geologic and hydrocarbon data • Can be used to converge on area of interest • Works for both fuel (aromatic) hydrocarbons and creosote (polycyclic aromatic hydrocarbons) • Generates little investigation-derived wastes during sampling	• Limited availability • Limited to unconsolidated geology (same as CPT) • Provides only relative concentration data	$4,000 to $4,500 per day (reflects recent cost reduction). Production up to 300 feet per day.
X-Ray Fluorescence (XRF)	Field screening tool used to analyze trace metals in soil, sludges, and groundwater.	• No waste generated • Little sample preparation required • Easily transported to the field	• Limited penetration depths • Susceptible to interference from water, petroleum, and soil variability • Poor detection limits for some metals • Radioactive source in analyzer	$2,000/week.
Colorimetric Field Test Kits	Field test kits used to detect the presence or determine the concentrations of contaminants in soil and water.	• Inexpensive and easy to use • Available for a wide range of concentrations for hundreds of chemicals • Can be used for remote sampling	• Relatively high detection limits • Possible interference by naturally occurring chemicals and other contaminants • Possible difficulty in reading colorimetric matches in low light	Handby Kits - $1300/30 samples PetroFLAG - $800/10 samples Petrosense - $150/week Quick Testr - $275/week
Immunoassay Field Screening	Field test kit used to detect target chemicals in soil and other samplers. Most kits use competitive enzyme-linked immunosorbent assay (ELISA) type.	• Produces rapid, real-time analytical data onsite • Can be used to select samples for laboratory analysis and to define limits of contamination	• Requires site-specific calibration • Does not speciate individual PAHs • Does not work effectively at MGP sites where crude oil was used • Does not produce quantified concentrations of target chemicals • Requires test runs to ensure adequacy	Approximately $20 - $55/sample excluding labor
Mobile Laboratory	Mobile facility providing onsite soil, water, and air analyses.	• Rapid onsite detection of contaminants • May reduce mobilization/demobilization charges for field projects • Can rapidly perform time-critical analyses	• More expensive for standard turn-around analysis • Not all mobile laboratories use USEPA analytical methods	$2,500 to $3,000 for rental; $13 to $30/sample for expendables.

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Geophysical Surveys				
Electromagnetics	Non-intrusive electromagnetic geophysical tool used to locate buried drums, landfills, bulk buried materials, etc. Can be used to determine depth to the water table and to delineate electrically-conductive (high dissolved solids) contaminant plumes.	• Non-intrusive • Can provide large quantities of detailed data in short time	• Need expert subconsultant to plan survey and interpret data • Data affected by power lines and metal buildings, cars, or other large metal items • Problematic in iron-rich soils and fill with large amounts of diffused metal wastes	Approximately $3,500, including data collection and interpretation for a one-acre site.
Seismic Refraction	Non-intrusive geophysical surveying tool used to determine depth to bedrock and/or water table. Can be used to define bedrock surface, buried channels, etc.	• Non-intrusive • Can provide large quantities of detailed data in short time	• Need expert subconsultant to plan, collect, and interpret data • Data subject to interference from complex geologic strata • Needs to be correlated with other site-specific subsurface data • Heavy traffic or numerous surface obstructions may be problematic	Approximately $10,000 including data collection and interpretation for a one week survey.
Ground Penetrating Radar (GPR)	Non-intrusive geophysical surveying tool used to locate buried waste, drums, tanks and voids, and to determine the depth and thickness of soil and bedrock.	• Non-intrusive source and detectors • Can provide large quantities of detailed data in short time	• Need expert subconsultant to plan, collect, and interpret data • Data deteriorates with increasing surface moisture or clay in subsurface • Problematic in iron-rich, deeply weathered soils	$10,000/week for 5 to 7 line miles of interpreted data.
Magnetometry/Metal Detection	Non-intrusive geophysical survey tool used to detect and map buried drums, metallic pipes, utilities and cables, tanks and piping. Also used to delineate trenches and landfills with metal debris.	• Non-intrusive • Relatively easy for non-expert to use • Can provide large quantities of detailed data in short time	• Depth and detail not obtainable • Cannot distinguish between types of metallic objects • Nonferrous metallic objects are invisible	$500/month for equipment rental costs only.
Electric Logging	Includes electrical resistivity methods, induction logs, self-potential logs, and fluid conductivity logs. Uses electrical resistivity to identify different hydrogeologic zones around a borehole.	• Rental equipment available • Specialized training not required • Quantitative data may require corrections	• Requires uncased borehole • Electrical resistivity and self-potential techniques require conductive borehole fluids • No quantitative measurements (other than depth) • Induction logging requires a dry borehole or borehole with non-conductive fluids	$1,200 - $2,500 day. (Can log 5-7 100-foot wells per day.)

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Geophysical Surveys, cont.				
Mechanical Logging	Includes flow-meter and caliper logging. Used to identify water-producing zones. Flow-meter logging provides semi-quantitative flow measurements when used in conjunction with caliper log (which measures borehole size and roughness and locates fractures and washouts).	• Provides direct measurement of vertical flow in well bore	• Flow-meter logging is relative insensitive at low velocities • Most applications of flow-meter logging requires a pumping or flowing well • Caliper logging is required for interpretation of flow-meter log	$500 - $600 per well, when run as part of multiple log suite. Flow-meter only (with caliper) is approximately $1,500 - $2,500 per well.
Acoustic (Sonic) Logging	Uses acoustic energy to determine the relative porosity of different formations. May be used to identify the top of the water table, locate perched zones, and assess the seal between a casing and formation material.	• Useful for characterizing rock aquifers • Allows porosity determination without use of radioactive source	• Not applicable in shallow wells or in unsaturated conditions • Relatively complex test; requires skilled operator for reliable results	$1,500 - $4,500 per well.
Radiometric Logging	Includes neutron logging and natural gamma logging. Used to estimate the porosity and bulk density of a formation and to locate saturated zones outside casing. Gamma logging is used to evaluate downhole lithology, stratigraphic correlation, and clay or shale content.	• Rental equipment available • Specialized training not required • Good tool for performing infiltration studies	• Neutron logging requires handling radioactive source and may be limited to case boreholes • Natural gamma logging may provide a non-unique response • Natural gamma logging may respond to the presence of phosphate minerals of micas or may mistake feldspar for clay or shale	For neutron logging, $2,500 to $5,000 per well depending on well depth and number of other logs run in conjunction. For natural gamma logging, $1,200 - $2,500 day. (Can log 5 - 7 100-foot wells per day).
Thermal Logging	Uses temperature differentials for flow and injectivity profiling, in conjunction with flow-meter logging.	• Supplements flow-meter log for identification of producing zones	• Requires fluid-filled borehole for testing • Interpretation of log complicated if internal borehole flow is present	$500 - $600 per well, when run as part of multiple log suite. Temperature log only $1,500 - $2,500 per well.
Video Logging	Downhole videotaping to provide visual inspection of a well interior, detecting damaged sections of screen and casing, and to detect fractures, solution cracks and geologic contacts in uncased holes.	• Allows visual inspection of the interior of the well	• Requires very clear water for successful survey • Not suitable for open boreholes in unconsolidated formations	$400 to $3,000 per well.

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Soil Gas Surveys				
Passive Soil Gas	Measures relative concentration of contaminants through subsurface detectors sensitive to diffusion.	• Can be more sensitive than active soil gas, soil, or groundwater sampling for detecting presence of trace contaminants • Can be used in areas of low-permeability soil	• Does not measure direct concentration • May be difficult to collect data at depth for vertical characterization • Requires 2 to 4 weeks for sample collection	Approximately $250 per sample location, including analysis and reporting; about $50 - $100 per location installation and retrieval.
Active Soil Gas	Uses a vacuum pump to induce vapor transport in the subsurface and to instantaneously collect samples of contaminants in the vapor phase.	• Provides real-time data • Rapid results allows user to converge on areas of interest • Provides direct measure of vapor concentration • Can be used to evaluate vertical changes in soil gas concentrations	• Samples must be collected at least 10 to 20 feet bgs • Cannot be used in areas of relatively low permeability • May be adversely affected by transient processes (e.g., barometric pressure) and stationary features (e.g., pavement)	Approximately $3,000 to $4,000 per day
Contaminant Migration Evaluation				
Push-Pull Natural Attenuation Test	Injection/withdrawal test (single well) to document and quantify microbial metabolism.	• Can document microbial metabolism, loss of degraded contaminants, production of degradation products, and yield estimates of zero- and first-order decay constants • Can use wells already installed • Provides in situ data	• Not widely used • Can have difficulty when decay rate is slow relative to groundwater flow rates	$12,000 to $15,000 for 2 to 3 wells at one site for BTEX. Costs may be higher for other contaminants (because of more expensive analysis).
Partitioning Interwell Tracer Test (PITT)	Injection/withdrawal test (2 wells) to quantify volume and estimate distribution of nonaqueous phase liquids (NAPLs).	• Can provide quantitative estimates of NAPL volume • Can be used to design remediation methods targeting a NAPL source • Is relatively accurate compared with other in situ tests that utilize point values or small aquifer volumes	• Expensive • Technology is patented • Most experience is with solvents	$100,000 to $400,000 depending on scale of test.
In Situ Bio/Geochemical Monitor (ISM)	Allows for in situ measurement of biochemical reaction rates and retardation factors for both organic and inorganic compounds through the subsurface introduction and monitoring of tracers and reactants.	• Reduces the time and cost of obtaining site-specific biological and geochemical data • Provides in situ measurements of biochemical reaction rates • Provides estimated rates of denitrification during biodegradation • Provides estimated retardation rates for organic and inorganic compounds	• Testing is complex and requires trained personnel • Small aquifer volume tested means results may be affected by small-scale variations in aquifer properties • Typically applicable only with permeabilities $>10^{-4}$ cm/sec	$3,000 for equipment only.

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Other Tools				
Micro-Scale Extraction (for PAHs)	Alternative laboratory extraction procedure for mono- and polycyclic aromatic hydrocarbons, chlorinated phenols, PCBs, mineral oil, and selected nitrogen- and sulfur-containing aromatic hydrocarbons prior to analysis.	• Small sample volumes required • Fast laboratory turnaround times • Minimal laboratory wastes • Quantitative results for individual components	• Relatively new procedure	Dependent upon analysis. Can reduce costs by over 50% in certain situations.
PAH Sample Filtration	In-field or laboratory filtration of water samples prior to PAH analysis to estimate the 'true' dissolved concentration by removing potential for colloidal contribution of PAHs.	• Eliminates high bias in PAH concentration measurements introduced by artificial colloidal entrainment • Inexpensive • Requires minimal training to implement	• Low bias resulting from elimination of naturally-occurring colloidal transport of PAHs • Dissolved or colloidal contaminants may adsorb onto the filter or apparatus	Minimal cost when compared to overall analytical costs. (Typical PAH analysis costs $200 to $300/sample.)
Inverse Specific Capacity Method	Specific application of push sampler (Geoprobe and others) to link groundwater quality data obtained from push sampler with an estimate of hydraulic conductivity in the sampled zone	• Allows vertical profiling of variations in horizontal hydraulic conductivity to be assessed	• Provides hydraulic conductivity for only small volume of aquifer • Need site-specific permeability data from conventional means (pumping or slug tests in wells) to convert specific capacity to hydraulic conductivity • Only appropriate for zones having permeability ranging from 10^{-1} to 10^{-5} cm/sec	Negligible cost, assuming that a peristaltic pump and push sampler already are in use at the site (assumes typical time for test ranges from 5 to 10 minutes).
Hand Augering/Trenching/ Pot Holing	Field surveying and sampling technique.	• Inexpensive where labor is cheap • Can be used to expose buried objects • Discrete and can get into tight locations	• Hand augering and test pits are depth limited • Pot holing and test pits are visible to public • Borehole/slope stability problems • Waste management may be a problem	Materials and equipment costs are minor. Cost is dependent on local labor costs.
Noise and Fugitive Emissions Controls	Barriers and controls to minimize noise and fugitive emissions during site characterization and remediation.	• Protects community and workers • Limits noise and air pollution • Minimizes the migration/transport of contaminants	• May be cost- and effort-prohibitive on a large scale • Controls may make field work logistically more complex and/or limit rate of completion	Ranges from $200-$500/day for water sweeping to >$10,000 for complete site enclosure.

4.2 Tools and Techniques for Expediting Site Characterization

Described below are 13 categories of new and existing tools and techniques that are currently available for expediting characterization of former MGP sites. The cost of using the tools and techniques and the results generated will vary from site to site depending upon accessibility, cost of labor, types and concentrations of contaminants found, hydrogeology, and other characteristics. Although many of these tools and techniques have been used successfully at former MGP sites, practitioners should choose tools based on the particular conditions at their site(s). Where possible, references are listed so that readers can contact representatives of projects where the tools and techniques have been used.

4.2.1 Direct-Push Methods/Limited Access Drilling

Tools in this category provide faster and cheaper ways to explore subsurface characteristics than have been available in the past. These methods are typically less intrusive, generate fewer investigation-derived wastes than past techniques, and permit sample collection in areas with limited clearance. When combined with on-site data analysis, these tools provide a powerful way to survey soil (and groundwater) for contaminants.

Some of the tools described herein may be limited to depths of 25 to 30 feet; others, however, are not depth-constrained. These tools generally create small-diameter boreholes and therefore do not allow for the installation of large wells. In addition, they may only allow for one-time “snapshot” or “grab” sampling. Tools included in this category are:

- Direct-Push Limited Access Drilling Techniques (such as GeoProbe™, Power Punch™, Strataprobe™, and Precision Sampling™)
- Cone Penetrometer
- Simulprobe™ Sampler
- Hydropunch™
- Waterloo Profiler
- Westbay System
- Diffusion Multi-Layer Sampler
- Waterloo System
- Point Sampler or Dual Packer Sampling

4.2.1.1 Direct-Push/Limited Access Drilling

Tool Description

A wide range of direct-push and limited access drilling techniques is available for collecting soil, vapor, and groundwater samples and for identifying stratigraphy or NAPLs. Some vendors, such as GeoProbe™, have also developed specific application probes (e.g., the conductivity probe) that can be used in conjunction with a drilling rig to survey a site or install small-diameter wells. These drilling methods have been successfully applied at former MGP sites for delineating source areas, screening aquifers for plumes before well installation, and collecting subsurface information in hard-to-access areas.

Direct-push drilling rigs typically consist of hydraulic-powered percussion / probing machines designed specifically for use in the environmental industry. "Direct push" describes the tools and sensors that are inserted into the ground without the use of drilling to remove soil and make a path for the sampling tool. These drilling rigs rely on a relatively small amount of static (vehicle) weight combined with percussion for the energy to advance a tool string. The small rig size allows work in limited access areas. Below is a photograph showing a typical direct-push drilling rig.

Operational Considerations

Direct-push drilling rigs, such as the GeoProbe™, are more efficient at drilling in shallow, soft areas but are not typically capable of drilling through a thick subsurface structure such as a gas holder foundation. Although limited in depth and often unable to drill through buried foundations at an MGP site, this technology can provide useful information about the location and depth of buried structures without puncturing them, which would create a route for cross contamination. In addition, this technique is effective for collecting soil, groundwater, and soil vapor grab samples. It is most efficient to depths of approximately 30 to 50 feet (depending on soil type).

Applications and Cost

Vendors of direct-push drilling rigs include GeoProbe™, Power Punch™, Strataprobe™, and Precision Sampling™. This drilling technology is well understood and provides reliable results. The cost of a direct-push drilling rig is approximately $1,000 to $1,500 per day, not including sampling tools and related expenses.

Benefit

- Small rig size suitable for tight spaces around aboveground structures or utility areas such as substations
- Small volume of investigation-derived waste (IDW) produced
- Continuous coring or discrete soil samples both possible
- Sampling of soil, groundwater, and vapor possible along with installation of small-diameter wells

Limitations

- Limited use at locations with buried obstructions (e.g., foundations)
- Potential for cross contamination from single-tube rigs
- Rods can get lost in tight soils
- Small diameter wells installed using these direct-push rigs may be difficult to develop
- Water samples collected from direct-push tubes typically contain considerable suspended sediment; may yield biased results for turbidity-sensitive constituents such as lead and PAHs
- Repeated pushes required from ground surface in order to vertically profile a site (i.e., collect water samples at different depths at the same location) unless special equipment (i.e., Waterloo system) is used
- Impractical (because of slow sample collection) in low-permeability soil or when attempting to collect samples at relatively shallow depths below water table

Case Study

Chico/Willows/Marysville (CWM) Former MGP Sites

Both GeoProbe™ and Precision Sampling™ direct-push drilling rigs were used at PG&E's CWM former MGP sites. The rigs were used to:

- Collect deep soil and grab groundwater samples from within active substations
- Collect grab groundwater samples to delineate the extent of offsite groundwater contamination so that downgradient monitoring wells could be placed at the edges of plumes (to act as sentry wells against continued downgradient plume migration)

- Quickly establish the extent of lampblack and coal tar in shallow soils at the locations of former lampblack separators, lampblack dumps, and tar pits

When the rigs were unable to drill through obstructions, this helped verify the location, depth, and extent of buried foundations. Soil samples from depths beneath former foundations (collected when the drilling rig was able to push through the former foundations) provided information about the types and volume of buried MGP wastes. At locations where cross contamination was a significant concern, Precision Sampling's dual-tube direct-push drilling rig was used to minimize the amount of soil and/or waste that may be transported downward by the driving rod.

4.2.1.2 Cone Penetrometer (CPT)

Tool Description

CPTs were initially developed as engineering tools for determining the capacity of soils to support foundations and pilings. These tools are a quick, reliable, and well-tested means to determine the continuity of stratigraphy, the depth to the water table, and the thickness of stratigraphic layers. More recently, the hydraulic pushing equipment on a modern CPT rig has been used to advance probes and samplers into subsurface soils. Examples of such probes/samplers include vapor samplers, soil samplers, the Hydropunch™, LIF probes, and resistivity probes.

A traditional CPT survey is a continuous penetration test in which a cone-shaped rod is forcibly pushed into the soil with hydraulic rams. Sensors electronically measure the resistance at the cone's tip and along the cone's sides. The function of the relative density of the sediment is then correlated to the soil textures to determine the site's stratigraphy. A schematic figure of a CPT rig is shown below.

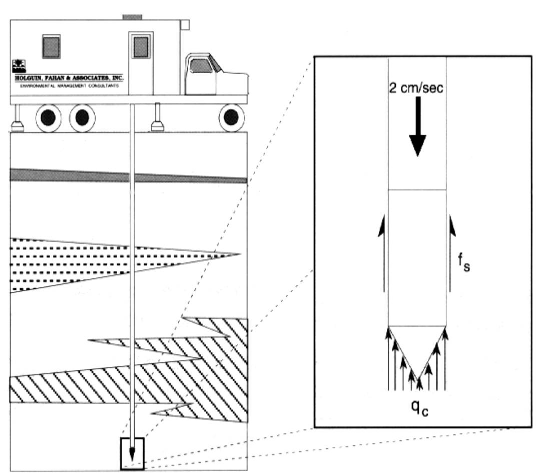


FIGURE 1 - SCHEMATIC DIAGRAM OF CPT
(qc = tip stress, fs = friction stress)

Reference: Holguin, Fahan & Associates, Inc.

Operational Considerations

Modern CPT rigs are capable of collecting the same data as conventional drilling rigs. CPT data are high quality, most often meeting DQOs, cost effective, and typically pose minimal health and safety concerns. In addition, CPT testing does not generate any drill cuttings. CPT drilling rigs can generally penetrate to depths of 100 to 150 feet below ground surface (bgs) in normally consolidated soils. The principal disadvantage of CPT rigs is that they cannot penetrate as deeply as conventional drilling rigs.

Applications and Cost

There are several CPT vendors in the United States, most of whom support both traditional geotechnical CPT projects and modern environmental investigations. The types of CPT-mounted sampling equipment and probes vary, however, among vendors. Costs for CPT are typically about 30 percent (on a per-foot basis) of the cost of conventional soil borings installed using traditional methods such as hollow-stem auger drilling. CPT costs are comparable with the modern direct-push drilling technologies offered by GeoProbe™, Precision Sampling, Inc., and others.

Benefits

- Can penetrate harder zones better than most direct-push methods
- Produces small volume of IDW
- Can be used for sampling groundwater and soil gas

Limitations

- Potential for cross-contamination from single-tube rigs
- Does not allow continuous coring or discrete soil samples
- Cannot be used to install wells
- Large, heavy rig may preclude access to some locations

4.2.1.3 Simulprobe™ Sampler

Tool Description

The Simulprobe™ sampler is a soil, soil gas, and groundwater sampling tool designed to be driven by either push or drive sampling technology. The sampler reduces the potential for cross-contamination by precharging its sample canister with nitrogen and by covering the sampler with a latex condom. Precharging the sampler with nitrogen prevents water from entering the sample canister until the sample is collected. The condom ensures that the sampler remains uncontaminated until driven into undisturbed soil.

One significant advantage of the Simulprobe™ sampler is the ability to obtain a soil core sample at the exact depth where the grab groundwater or soil gas sample was obtained. This allows the user to determine the lithology at the point of sampling. In addition, the Simulprobe™ sample chamber fills at a slower rate than other samplers (controlled by the rate at which the nitrogen is bled off), thereby reducing turbidity. The sampler also has a settling chamber so that any excess sediments that enter the chamber settle out before the water sample is transferred. The adjacent photograph shows a Simulprobe™ sampler.

The Simulprobe™ provides continuous sampling of soil gas in the vadose zone. When the probe is pushed through the vadose zone, soil gas is extracted under the vacuum and measured continuously in an organic vapor analyzer located above ground surface. If desired, a syringe can be inserted and a sample of soil gas can be extracted and analyzed by gas chromatography (GC) at any time.

Operational Considerations

Sampling with the Simulprobe™, as with other similar tools, is limited by the depth to which the tool can be driven. Other geologic conditions, such as flowing sands, also limit the tool's effectiveness and range.

When a grab groundwater sample is collected using the Simulprobe™ sampler, the water canister is first charged with nitrogen (usually 60 pounds per square inch [psi]/100 feet of hydrostatic head), and the entire sample device is covered with a latex condom. The Simulprobe™ is then slowly lowered to the bottom of a borehole and hammered 21 inches into the subsurface to collect a soil core. The device is then pulled back 2 to 3 inches to retract the sliding drive shoe and expose the circular screen. A valve is opened to allow the nitrogen pressure to bleed off from the water canister so water can enter the sample chamber under ambient hydrostatic pressure. After the water sample has been collected, the water canister is repressurized to prevent leakage into the sampling device, pulled out of the borehole, and emptied into appropriate sample containers.

Applications and Cost

The latex condom covering the Simulprobe™ sampler is designed to minimize cross-contamination during sampling, therefore making the Simulprobe™ a tool for grabbing groundwater samples before well installation, especially in areas where cross-contamination is of concern. Combined with push- or hammer-driven sampling (such as GeoProbe™) and in-field analysis, it provides a fast, effective method for obtaining survey-level data for refining monitoring well and groundwater plume locations. In addition, collecting soil samples at the same interval as the sampled groundwater allows for better linkage between hydrostratigraphy and groundwater and contaminant movement in the subsurface.

The rental cost of the Simulprobe™ sampler alone (direct from the vendor) is approximately $150 per day or $650 per week. Drilling costs can add approximately $1,500 per day to total sample collection costs. Sampling depth and frequency, site hydrostratigraphy, and buried obstructions can significantly impact the tool's effectiveness.

Benefits

- Collects soil and either groundwater or soil gas samples at the same stratigraphic interval in the same push
- Can be used with field instruments to screen for volatile organic compounds while pushing
- Field tested and proven
- Can be used in conjunction with a variety of drilling tools
- Latex condom minimizes cross-contamination during sampling
- Nitrogen or helium can be used to purge the canister to create an inert atmosphere before sample collection, thereby improving the quality of chemical parameters for natural attenuation monitoring
- Canister attachments can be used as pneumatic bailers inside wells or boreholes (e.g., for sampling below NAPL layers)

Limitations

- Limited availability (though may be available through local drilling firms)
- Multiple moving parts increase potential for breakage or sticking
- Depth to which the sampler can be pushed / driven limited

Case Study

Chico Former MGP Site

Field investigations conducted at PG&E's Chico former MGP site identified PAHs and petroleum hydrocarbons in the shallow water-bearing zone. However, the hydrostratigraphy below the water-bearing zone was not known, nor was information available on the water quality of deeper water-bearing zones. In order to determine the vertical extent of MGP-related constituents in groundwater and to identify the next deeper, unimpacted zone for monitoring (as a sentry well), the Simulprobe™ sampler was used with resonant sonic drilling. Grab groundwater samples were then collected from the two water-bearing zones directly underlying the shallow groundwater.

The first, deeper water-bearing zone was identified at 47 feet bgs. Grab groundwater samples were successfully collected from this zone using the

Simulprobe™. Because naphthalene-like odors were detected in the field from this groundwater zone, the Simulprobe™ was advanced to the next deeper water-bearing zone, identified at 97 feet bgs. Flowing sands encountered at this depth combined with the vibrations from the resonant sonic drilling jammed the sampler and prevented collection of a grab groundwater sample. Use of the Simulprobe™ is not recommended with a resonant sonic drilling rig or where flowing sands are present.

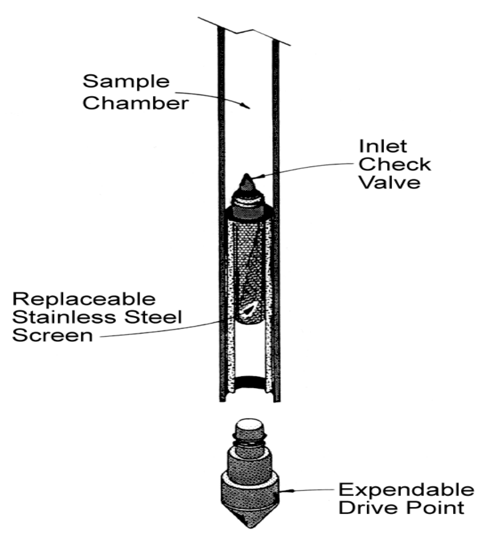
4.2.1.4 Hydropunch™

Tool Description

The Hydropunch™ is a direct-push tool for collecting a depth-discrete groundwater sample inside a boring without installing a well. The Hydropunch™ has been successfully used for collecting grab groundwater samples at former MGP sites to quickly delineate the extent of a groundwater plume without well installation or to quickly determine the best location or depth for screening a monitoring well.

The Hydropunch™ sampler is advanced with a hammer-driven tool to collect a groundwater sample from a particular depth. The sampler is pushed to the proper groundwater sampling zone and then withdrawn to expose an inlet screen. The screened interval is approximately 3 to 5 feet long. Groundwater can be collected from multiple depths within a single borehole although the tool must be withdrawn between samples. The following figure is a schematic diagram of the Hydropunch™ sampler.

Operational Considerations



The key factor affecting the accuracy of groundwater analytical results collected via the Hydropunch™ sampler is the turbidity of the grab sample. Because the sample is collected from a borehole instead of a developed well, the sample may be turbid. If the sample is not filtered before laboratory analysis, hydrophobic chemicals (such as PAHs and metals) sorbed onto the suspended sediments may cause erroneously high concentrations. In addition, the Hydropunch™ sampler limits the sample volume collected per push, so this tool is best used in a permeable zone where there is reasonable recharge into an area 3 to 5 inches thick. It is possible to attach a peristaltic pump to the Hydropunch™ sampler to pump larger volumes of samples if volatilization is not an issue. Finally, as with any single-tube direct-push probe or sampler, there is a potential for cross-contamination between groundwater zones. However this concern can be mitigated by using conductor casings. Floating-layer hydrocarbons may be sampled with a small-diameter bailer lowered through the push rods in one of the Hydropunch™ tools.

Applications and Cost

The Hydropunch™ sampler is a fast and inexpensive method for collecting a groundwater sample without installing a well. The Hydropunch™ is well understood and provides reliable results.

The cost of a Hydropunch™ sampler is approximately $150 per day, in addition to the drilling rig and associated equipment.

Benefits

- Provides reliable data
- Field tested and proven

Limitations

- Data subject to interference from turbidity
- Potential for cross-contamination if sampler is driven across hydrostratigraphic zones

Case Study

Stockton Former MGP Site

Grab groundwater sampling at the Stockton former MGP site was performed using the Hydropunch™ sampling tool for field screening to determine monitoring well locations at the edge of the plume. Samples were collected from two depths and sent to a laboratory for rapid analyses. Sample results were used successfully to determine whether the proposed well locations were at the edge of the groundwater plume (analytical results showed no detectable levels of contamination). Alternate well locations were identified when the Hydropunch™ samples showed detectable levels of contaminants.

4.2.1.5 Waterloo Profiler

Tool Description

The Waterloo Profiler (patent pending) is a groundwater sampling tool designed to collect depth-discrete groundwater samples in a single borehole with one probe entry. The Profiler consists of a tip containing multiple screened ports located around it. The Profiler tip is connected to 3-foot lengths of heavy-duty threaded steel pipe that extends to the ground surface. The Profiler is advanced by pushing, pounding, or vibrating the steel pipe into the ground using one of Precision Sampling, Inc.'s custom-made sampling rigs. Groundwater samples are conveyed to the surface via small-diameter tubing that is attached to a fitting inside the Profiler tip. The internal tubing, made of stainless steel or Teflon, passes up through the inside of the pipes to a pump and sample collection station located at the ground surface (Precision Sampling, 1998). Chemical concentrations in highly stratified formations can vary by several orders of magnitude over vertical distances of 1 foot. One significant advantage of the Waterloo Profiler is its ability to vertically profile contaminants in microstratigraphy without having to withdraw and reinsert the probe. This minimizes cross-contamination and the need for frequent tool decontamination between sample collection. The Profiler can be pushed through clay and silt beds without plugging, which makes vertical profiling easy.

Operational Considerations

Sampling with the Waterloo Profiler, as with similar tools, is limited by the depth to which the tool can be driven. Other geologic conditions, such as fine-grained sediments, also limit the tool's effectiveness and range.

Sample collection with the Waterloo Profiler is the most time-consuming part of sampling operations. Sample collection can vary from 10 minutes per sample in coarse-grained sand and gravel to 30 minutes in fine- to medium-grained sand. Groundwater sampling with the Waterloo Profiler is not recommended for lithology with sediments finer than fine-grained sands because of the lengthy sampling time required.

Applications and Cost

The Waterloo Profiler is a useful tool for rapid vertical profiling of hydrostratigraphy down to a maximum of 100 feet bgs. (Actual maximum depth is dependent on site-specific conditions and is typically shallower than 100 feet). The tool allows for delineation of contaminants in highly stratified formations where microstratigraphy plays a significant role in contaminant migration.

The cost of the Waterloo Profiler plus direct-push rig adds approximately $1,600 per day to total sample collection costs. Sampling depth and frequency, site hydrostratigraphy, and buried obstructions can have significant impact on the tool's effectiveness.

Reference: Precision Sampling, Inc.

Benefits

- Allows multiple depth-discrete groundwater sampling in a single borehole (i.e., sampler does not have to be withdrawn between samples)
- Less prone to cross-contamination than multiple pushes with conventional push sampler

- Can be used with field instruments to screen for volatile organic compounds while pushing
- Field tested and proven
- Allows for delineation of contaminant pathways in microstratigraphy

Limitations

- Profiler available only through a limited number of vendors
- Limited by depth to which the sampler can be pushed / driven
- Shallow groundwater sampling via peristaltic suction-lift pump may cause volatilization of some contaminants during sampling
- Groundwater sample collection recommended only for fine-grain sands and coarser materials

4.2.1.6 Multi-Level Groundwater Samplers

Multi-level groundwater samplers are used to collect groundwater samples at multiple, discrete levels within a single monitoring well. These types of groundwater samplers are equivalent to a series of nested monitoring wells but require only one casing in a single borehole.

The tools discussed below include several types of multi-level groundwater samplers:

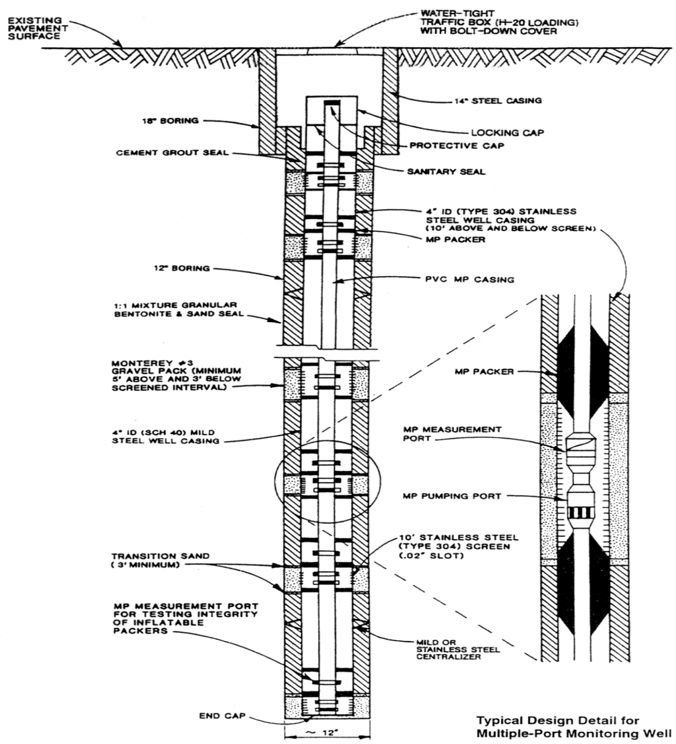
- Westbay System
- Waterloo System
- Diffusion Multi-Layer Sampler (DMLS)

4.2.1.6.1 Westbay System

Tool Description

The Westbay System is a fixed, multi-level sampler built for installation in a multi-port monitoring well. It is designed to collect groundwater samples and hydraulic head measurements at multiple, discrete levels in a single monitoring well. Multi-port monitoring wells are like a series of nested monitoring wells but require only one casing in a single borehole. The Westbay System incorporates valved couplings, casings, and permanently inflated packers into a single instrumentation string that is installed inside a cased borehole with multiple screened intervals, allowing multi-level groundwater monitoring for a fraction of the installation cost of nested monitoring wells.

The following figure shows the typical design detail for a Westbay System multi-port monitoring well.



Typical Design Detail for Multiple-Port Monitoring Well

FIGURE NOT TO SCALE

Operational Considerations

Westbay System multi-port monitoring systems are complex and require trained technicians to install. Monitoring wells must be designed specifically to conform with the Westbay System requirements. Field quality control procedures enable verification of the quality of the well installation and operation of the testing and sampling equipment.

Groundwater samples from Westbay monitoring wells are collected without repeated purging. In addition, Westbay is currently developing instruments to enable the use of in situ sensors to monitor various chemical parameters.

Applications and Cost

The Westbay System is useful for MGP sites where multiple groundwater zones exist and discrete monitoring of multiple screened zones is required.

One of the primary cost savings with the Westbay System is that several discrete groundwater zones can be sampled by installing only one well. Fewer boreholes mean lower drilling costs, a shorter project schedule, and less IDW (e.g., drill cuttings and fluid). This can result in substantial savings in waste management, site access approval, noise abatement, and project management. In addition, fluid samples are collected from the Westbay monitoring wells without repeated purging (the groundwater in each zone is not in contact with the atmosphere), which can lead to significant cost reductions at sites where purge water must be stored, transported, and treated before disposal. The cost of installing a Westbay System is approximately $30,000 for a five-level system that can range from 50 to 200 feet in depth. The price does not include the cost of installing the monitoring well and does not include sample collection or analysis.

Benefits

- Reduces the amount of drilling

- Provides reliable data
- Field tested and proven

Limitations

- Mechanically complex
- Requires well construction to specific Westbay specifications
- Not portable between wells

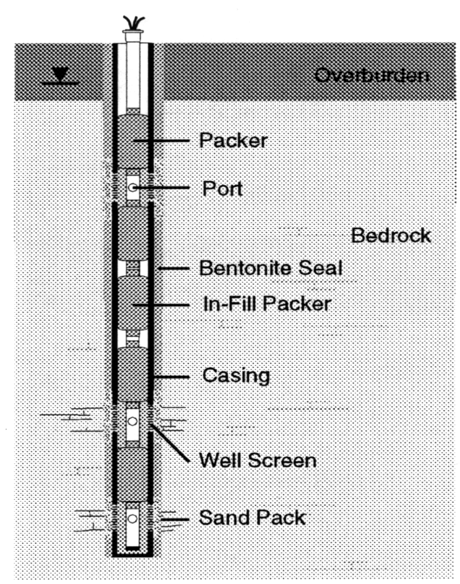
4.2.1.6.2 Waterloo System

Tool Description

The Waterloo System is used to obtain groundwater samples, hydraulic head measurements, and permeability measurements from multiple isolated zones in a single monitoring well. The Waterloo System uses modular components held firmly together to form a sealed casing string composed of casing, packers, ports, a base plug, and a surface manifold. Monitoring ports are isolated by packers at each desired monitoring zone and are individually connected to the surface manifold with narrow-diameter tubing. Formation water enters the port, passes into the stem, and rises to its static level in the monitoring tube attached to the stem. A sampling pump or pressure transducer may be dedicated to each monitoring zone by attachment to the port stem, or the monitoring tubes may be left open to allow sampling and hydraulic head measurements with portable equipment. A section of the sampler is shown in the following figure.

Operational Considerations

A typical Waterloo System can be installed in a few hours by one trained technician and an assistant. Purge volumes are small, and dedicated pumps for all zones can be purged simultaneously. Because the groundwater in each zone is not in contact with the atmosphere, formation water may be sampled without repeated purging. The Waterloo System may be used in hollow-stem augers, temporary casing, or cased and screened wells.



Permanent or Removeable Packers
in Casing or Well Screen

Applications and Cost

The Waterloo System is useful for MGP sites with multiple groundwater zones when discrete monitoring of the zones is required. Project costs may be reduced by limiting the number of wells installed and maximizing the number of groundwater zones sampled. The purge volumes necessary for groundwater sampling using the Waterloo System are likely to be smaller than those from conventional nested monitoring wells.

The cost of installing the Waterloo System is approximately $25,000 for a five-level system that can range from 50 to 200 feet in depth. This price does not include the costs of monitoring well installation or sample collection or analysis.

Benefits

- Reduces the number of wells needed for multiple-zone monitoring
- Reduces purge volumes and may reduce time required for purging/sampling relative to conventional monitoring well requirements
- Provides reliable data
- Removable or permanent systems available

Limitations

- Mechanically complex
- Specially ordered materials necessary
- Removable packer system sometimes difficult to cost-effectively reuse
- Requires trained technician for installation

Contact

Solinst Canada Ltd., (800) 661-2023, www.solinst.com

4.2.1.6.3 Diffusion Multi-Layer Sampler (DMLS™)

Tool Description

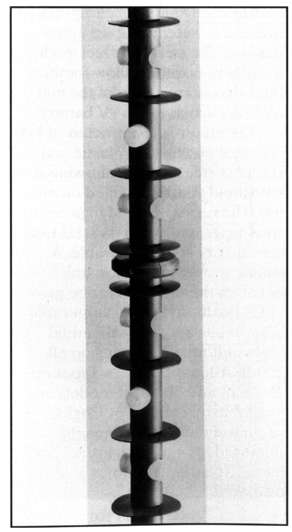
DMLS ™ is portable, multi-layer device that can collect groundwater samples at multiple intervals in the same monitoring well. The DMLS ™ uses dialysis cells separated by seals that fit the inner diameter of the well. This arrangement allows natural diffusion of groundwater into the unit at different elevations. Once the DMLS ™ is lowered into either an open rock borehole or a groundwater monitoring well with a long screen, the dialysis cells are exposed to water in the borehole and natural diffusion gradients permit external formation water to reach equilibrium with the water in the dialysis cells. The water flowing from the formation into the stratified dialysis cells is separated by seals; therefore, each dialysis cell contains a groundwater sample from a different layer.

The basic unit of the DMLS ™ is a 5-foot-long polyvinyl chloride (PVC) rod with a variable number of dialysis cells and nylon membranes separated from each other by seals. A string of up to five rods can be formed. Vertical layers of groundwater as narrow as 3 inches can be segregated and sampled. The rods fit into 2-inch-diameter and larger wells.

The following figure shows the typical design detail for a DMLS ™ multi-level groundwater sampler.

Operational Considerations

Once the DMLS™ is lowered into a well, it should remain undisturbed for 7 to 10 days to allow stratification of the water flowing from the formation. Once stratification of the formation water is complete and the water in the sampling cells is representative of ambient conditions, the rods are pulled to the surface and the sampling cells are removed and sent to a laboratory for analysis. The sampling cells in the rods can then be replaced, and the process can be repeated. The DMLS™ may be left in the water for periods of time that conform to individual sampling schedules. For example,DMLS™ sampling cells may be collected and replaced every three months.



Because the DMLS™ relies on natural groundwater diffusion principles, no purging is required. The DMLS™ does not permit head measurements.

Applications and Cost

The DMLS™ is useful for MGP sites where monitoring wells have long screens and a vertical characterization of the screened aquifer is desired.

The DMLS™ reduces costs because several vertical groundwater zones can be sampled by installing only one well. Having fewer boreholes reduces drilling costs, shortens project schedules, and produces less secondary waste (e.g., drill cuttings and fluid). The result is substantial cost savings in waste management, site access approval, noise abatement, and project management. Groundwater samples are collected from DMLS™ monitoring wells without repeated purging (the groundwater in each zone is in direct contact with the formation water), which can significantly reduce costs at sites where purge water must be stored, transported, and treated before disposal.

The cost of the DMLS™ is approximately $3,000 for a 10-foot-long unit. The price does not include labor costs for installing the DMLS™ rods, nor does it include costs for sample collection or analysis.

Benefits

- Allows vertical characterization of groundwater in a single borehole or well
- Requires minimal training for installation
- Requires no purging

Limitations

- Not widely used

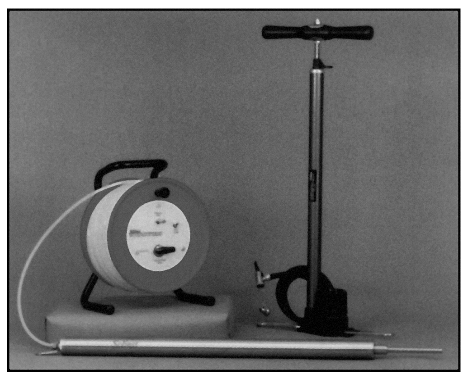
- Does not permit head measurements
- May not be appropriate for zones with strong vertical gradients

4.2.1.7 Discrete Point Samplers

Tool Description

Floating product layers (e.g., LNAPL) or sinking product layers (e.g., DNAPL) may cause stratification of contaminant concentrations in groundwater. Discrete point samplers are used to represent groundwater at distinct elevations or points of inflow in either open boreholes or screened wells. Discrete point samplers are designed to minimize disturbance and/or mixing that would be caused by pumping and purging water from different zones.

Several tools are available that have been designed to collect groundwater samples at discrete points in either open boreholes or in screened wells. Solinst Canada, Ltd., manufactures a number of samplers designed for use in wells screened over multiple water-bearing zones. Two examples are the Model 429 Point Source Bailer and the Model 425 Discrete Interval Sampler. The Model 429 Point Source is a stainless steel bailer with dual ball valves that prevent the mixing of water from multiple depths during retrieval of a sample from a specific depth. The Solinst Model 425 Discrete Interval sampler (shown in the figure below) is a stainless steel sampler connected by tubing that is pressurized before the device is lowered into a well; pressurization prevents water from entering the sampler until the sampling zone is reached. When the desired sampling depth is reached, pressure is released, and hydrostatic pressure fills the sampler and tubing with water directly from the sampling zone. When the sampler is filled, it is repressurized and raised to the surface; the sample is decanted using the sample release device provided, which avoids degassing of the sample (Solinst, 1998).



Solinst also manufactures a Triple Tube Sampler that uses a narrow-diameter pump and packer assembly to seal off a discrete interval in groundwater. A nitrogen-inflated packer is placed just above the desired sampling point within the sampling tube. The packer seals against the walls of the sampling tube and isolates the formation water standing in the tube. A second nitrogen line applies pressure down the sampling tube. The water is pushed to the surface through the coaxial tubing. The cycle is repeated until purging and sampling are complete.

The Solinst Triple Tube Sampler is similar to the Waterloo Profiler multi-level groundwater sampler discussed in Section 4.2.1.5 except that the Solinst sampler is designed to sample from wells whereas the Waterloo Profiler is a direct-push sampler designed to collect grab groundwater samples without boreholes or wells (Solinst, 1998).

Operational Considerations

The Solinst Model 429 Point Source Bailer and the Solinst Model 425 Discrete Interval Sampler do not require or allow purging prior to sampling. It is assumed that a sample collected at a discrete depth is representative of the formation water flowing through the well at that depth. The Solinst Triple Tube Sampler does permit purging of the discrete interval being sampled.

Applications and Cost

Discrete point samplers are useful for field scenarios where heterogeneities exist in the vertical distribution of contaminant concentrations in groundwater in an open borehole or screened well.

The purchase costs for Solinst Model 429 Point Source Bailer, Solinst Model 425 Discrete Interval Sampler, and the Solinst Triple Tube Sampler are approximately $150, $675, and $2,000, respectively.

Benefits

- Permits groundwater sampling from a discrete vertical point in a well or borehole
- Minimizes mixing of water from different levels during sample collection
- Fits in small-diameter wells/boreholes
- Is portable (the Triple Tube Sampler may be dedicated)
- Solinst Triple Tube Sampler is usable for purging in addition to sampling

Limitations

- May require limited training to operate equipment (especially the Triple Tube Sampler)
- May be difficult to obtain a complete seal with the Solinst Triple Tube Sampler

Contact

Solinst Canada Ltd., (800) 661-2023, www.solinst.com

4.2.2 Analytical Field Screening

Field screening tools allow practitioners to detect the presence and determine the estimated concentrations of chemical constituents in the field. As noted above, combining these tools with direct-push grab sampling techniques allows rapid and cost-effective preliminary screening of former MGP sites by pinpointing areas of contamination that require further, focused field investigations. Once these areas are identified, field screening tools can be used to gather further data so that remediation alternatives can be evaluated. In some cases, the tools can also be used to gather confirmatory data during remediation.

Tools included in this category are:

- Laser Induced Fluorescence (LIF) (such as ROST™)
- X-ray fluorescence (XRF) (such as the Spectrace 9000, SEFA-P, or X-MET 880)
- Colorimetric testing (such as Hach Kits, Draeger Tubes, Sensidyne, Handby Kits, PetroSense™, and PetroFLAG™)
- Immunoassay testing (such as Strategic Diagnostics)
- Portable laboratories

4.2.2.1 Rapid Optical Screening Tool (ROST™)

Tool Description

The ROST™ is a sampling and screening technology used to field screen for petroleum hydrocarbons and other contaminants. Like its military sister, the SCAPS, ROST™ is designed to offer a suite of CPT tools on a single platform. Using fiber-optic technology with LIF, ROST™ provides rapid, real-time, in situ delineation of subsurface petroleum hydrocarbon contamination down to depths of 150 feet.

The ROST™ consists of a sensor-tipped, hydraulically advanced, penetrometer probe with a self-contained data collection and analysis system housed within a CPT truck. Additional probes incorporate video imaging technology and soil moisture measurements while the latest CPT sampling devices allow for the collection of soil, water, or gas samples with analytical confirmation or other measurements. A diagram of ROST™/SCAPS is shown in the figure on the following page.

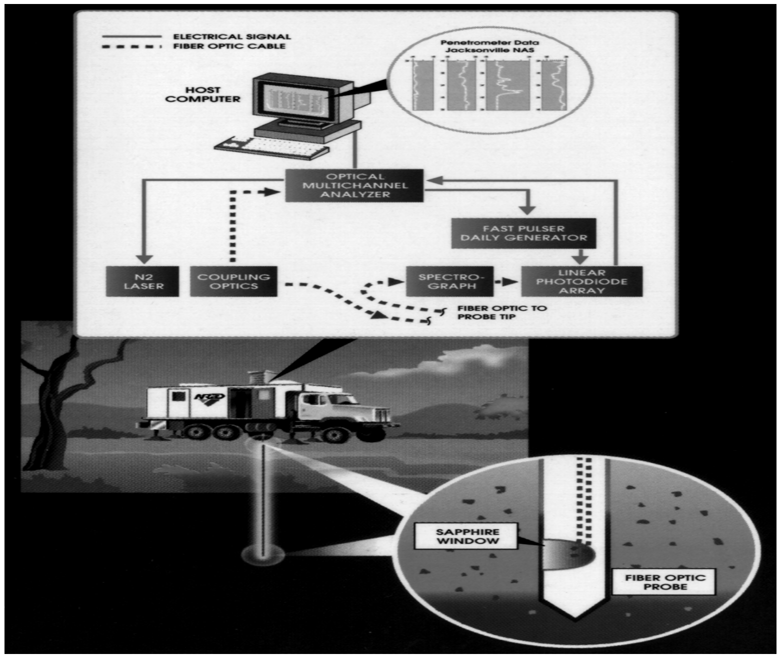
Operational Considerations

Operational considerations with ROST™ sampling technology are similar to those of cone penetrometers. Depths are limited to 100 to 150 feet bgs in normally consolidated soils, shallower in coarser materials. The ROST™ sampling technology does not produce soil cuttings and can provide real-time, in situ field screening for petroleum hydrocarbons. The ROST™ can also detect small deviations in concentrations, thereby making it useful in mapping areas with significant subsurface structures/materials. Microwells can also be installed using this tool.

Applications and Cost

The ROST™ sampling technology is useful for field surveys and initial characterization of sites, and for post-remediation confirmation for petroleum hydrocarbons. The system is limited to the depths of the CPT and by the sensors currently available.

ROST™ costs approximately $4,000 to $4,500 per day with production up to 300 feet (around 10 pushes) per day.



Benefits

- Provides rapid, real-time geology and hydrocarbon data
- Can be used to converge on an area of interest
- Works for both fuel (aromatic) hydrocarbons and PAHs
- Generates little waste during testing/sampling
- Verified by USEPA and certified by California EPA

Limitations

- Limited availability (only two commercial licenses currently held)
- Limited to unconsolidated geology (same as CPT)
- Only relative concentration data provided

Case Study

North Cavalcade Superfund Site, Houston Texas

The North Cavalcade Street Superfund Site is a former wood treating facility, located in northeastern Houston, Texas. The site encompasses approximately 21 acres, and was used for treating wood from 1946 to 1964. Initially, creosote was employed as the primary wood preservative, but later operations also included pentachlorophenol. Operations included wood storage and pole peeling, and a treatment plant with pressure vessels, storage tanks, and drip racks.

The site is relatively flat with elevations ranging from 43.2 feet to 53.8 feet above mean sea level. The water table occurs at depths ranging from approximately 2 to 5 feet bgs. Surficial soils are part of the Beaumont Formation, which is composed of clays, silts, and silty sands. The depositional environment was fluvial and deltaic, and the deposits can be characterized as stream channel, point bar, mud flat, and coastal marsh. The majority of the soils are composed of continuous and noncontinuous clay to silty clay layers with two principal sand to silty-sand layers located at average depths of 15 feet and 30 feet bgs. The various clay layers are known to be fractured to various degrees. The site is intersected by at least three and possibly four relatively minor surface faults with displacements of 2 to 5 feet. At least one of these faults is known to be active.

The site was divided into separate soil and groundwater operable units during the feasibility study. The soil operable unit consists of approximately 10,000 cubic yards of contaminated soil that was excavated and stockpiled into a bioremediation cell. The groundwater operable unit was addressed through a pump-and-treat system consisting of 19 wells, pumps, a treatment plant, and three groundwater infiltration galleries. The pump-and-treat system operated at an average flow rate of 12 gallons per minute for 24 months. It removed approximately 7,000 gallons of DNAPL out of approximately 11,500,000 total gallons of extracted water. The pump-and-treat system was subsequently discontinued due to a drastic decline in the amount of DNAPL recovered.

Previous information sources of subsurface data consisted mainly of a limited number of boring logs and soil samples. In order to gather more information on the horizontal and vertical extent of DNAPL that exists in the subsurface and to refine the site conceptual model, the CPT/ROST™ technology was selected as the most cost effective option for data collection. A total of 101 pushes were completed at an average depth of approximately 45 feet for data collection. The data from the cone penetrometer portion of the tool, which is displayed similar to well logs, were used in the construction of isopach and structure maps and fence diagrams to aid in the characterization of the subsurface. Based on an extensive correlation of the pushes, it was determined that the tool's lithologic determinations were internally consistent and correlated well with the existing data. Also, due to the greatly increased number of data points, two and possibly three additional faults were located.

The ROST™ data, like that from the CPT portion of the tool, was provided in a format similar to a well log with total fluorescence graphed versus depth. Windows of the "waveform," which consisted of a graphical presentation of the breakdown of the total fluorescence into four wavelengths, were also presented on this log for various peak fluorescence values. This enabled a quick identification of the type of hydrocarbon contamination present at a given depth. Additionally, another log was provided which displayed the total fluorescence signature and a continuous breakdown of this signal into the four component wavelengths, which allowed more detailed analyses of the different types of hydrocarbons.

The data from the ROST™ portion of the tool was used to gain an understanding of the vertical and horizontal extent of creosote contamination, and the relative concentration of the creosote contamination in three dimensions. Due to the tool's ability to detect a wide range of hydrocarbon contamination, other sources of hydrocarbon, such as diesel, gasoline, and oil, were also discovered. Interestingly, four of the pushes, which are located adjacent to a known pipeline easement exhibit a relatively strong oil-like signature at shallow depths. It is postulated that this represents leaks in the pipeline. Because the focus of the investigation was creosote, these signals were filtered out from the total fluorescence signal by running the data through a FORTRAN program written specifically for that purpose. Refinement of this filtering methodology, although effective, is currently somewhat primitive and is undergoing further development.

When creosote was encountered, it was usually found at several depths within a given push. The tops of the creosote occurrences were tabulated by depth and by whether they occurred in a sand or a clay. It was determined that almost all of the creosote hits occurred within the two sands zones, with the lower sand zone registering the majority of the hits. The deepest creosote contamination that was observed occurred at a depth of approximately 50 feet bgs. Based on these data, the remediation strategy of the site has re-focused on the lower sand zone.

CPT/ROST™ has proven cost-effective for the determination of lithology and the delineation of creosote contamination at the North Cavalcade Superfund site. Also, based on its performance at the site, its effectiveness appears to extend to the identification of other less dense hydrocarbon signatures. The CPT/ROST™ offers advantages in both price and the rapidity with which the data can be acquired. This technology is being evaluated for use at two additional creosote sites.

Contact

Joe Kordzi, USEPA Region VI, 214-665-7186

4.2.2.2 X-Ray Fluorescence (XRF)

Tool Description

Energy dispersive XRF is used to analyze trace metals (e.g., mercury, chromium, lead, cadmium, copper, nickel, and arsenic) in soils, sludges, and groundwater. The technique uses x-rays (high-energy electromagnetic radiation) to penetrate the soil matrix and excite metals. Radiation emitted from fluorescence of the metals is measured to quantify the concentrations of metals present in the soil.

XRF analyzers yield semiquantitative results with detection from a few to a few hundred parts per million (ppm) depending on the soil matrix and the metals being analyzed. XRF is generally considered a screening tool because of its relatively high reporting limits. The XRF analyzer is easily transported to the field and very fast (reportedly 5 to 40 samples per hour can be analyzed depending on sample preparation and measurement times).

Operational Considerations

Several manufacturers supply XRF analyzers including TN Spectrace (the Spectrace 9000) and Metorex Inc. (the HAZ-MET 920, HAZ-MET 940, and the X-MET series). XRF analyzers contain a radioactive source that may require special handling. Although XRF methods do not require soil samples to be digested (as do conventional analytical methods), some sample preparation (e.g., drying and homogenization) may be required. XRF analyzers are susceptible to interference from water, petroleum, and soil heterogeneity. Nontechnical personnel may operate XRF analyzers with minimal training.

Applications and Cost

XRF methods are mostly used as screening tools for trace metals. Because of their relatively high detection limits, these methods are best suited to site characterizations requiring metal screening at relatively high levels.

The cost to rent an XRF analyzer is approximately $2,000/week. A comparative conventional analytical method (inductively coupled plasma) is 30 to 40 percent more expensive and requires that samples be digested.

Benefits

- No IDWs generated
- Easily transportable to the field
- Does not require digestion of soil samples

Limitations

- Sample preparation required (e.g., drying and homogenization)
- Poor detection limits on some metals, especially as a result of matrix interference
- Limited penetration depth
- Not well suited to measure liquid samples
- Radioactive source in the analyzer

Contacts

Jim Moore, TN Spectrace, (512) 388-9100, x208

James R. Pasmore, Metorex Inc., (541) 385-6748 or (800) 229-9209

4.2.2.3 Colorimetric Field Test Kits

Tool Description

Colorimetric field test kits are used to detect the presence or determine the concentrations of contaminants in soil and water. Because detection limits are generally in the low ppm range, field test kits are primarily used as a screening tool for site characterization. Colorimetric field test kits may be used to screen for a broad range of inorganic parameters, total hydrocarbons, selected organic compounds, and selected explosive compounds.

Colorimetry is generally performed by mixing reagents in specified amounts with the water or soil sample to be tested and observing the color change in the solution. The intensity of the color change is an indicator of the concentration of the chemical of interest. The color change is either observed visually (compared with color charts) or electronically with a handheld colorimeter.

It is important to understand the limitations of the specific test kit being used, including the chemicals it can detect. Some kits are susceptible to interference from both naturally occurring organic matter and other co-contaminants.

Specific vendor technologies discussed below include Handby, PetroFLAG™, PetroSense™, and Quick Testr field test kits. Handby field test kits are generally used to screen for petroleum-derived substances in soil and water. Results are quantified by comparison to substance-specific calibration photographs. Handby kits are also available to quantify PAHs. The PetroFLAG™ test kit for soil is primarily used to detect petroleum hydrocarbons with detection limits ranging from 20 to 2,000 ppm. The PetroFLAG™ test kit can use either a conservative calibration to estimate total hydrocarbons present or it can be calibrated to specific hydrocarbons. The Dexsil Corporation, which markets the PetroFLAG™ test kit, indicates that PAHs can be measured using the technology. The PetroSense™ PHA-100 Petroleum Hydrocarbon Analyzer (PetroSense™), marketed by FCI Environmental Inc., combines fiber optic chemical sensor technology and digital electronics to measure the vapor concentration of TPHs in soil and benzene, toluene, ethylbenzene, and xylenes (BTEX) in water. Envirol Inc., markets Quick Testr field test kits, which can estimate total cPAHs in soil. Quantitative results are obtained by establishing a site-specific correlation between test kit and laboratory results.

Operational Considerations

The Handby Kit is susceptible to positive interference if extremely large quantities of organic matter (e.g., peat) are present. The PetroFLAG™ is sensitive to a wide range of hydrocarbons including natural waxes and oils. For both the Handby Kit and PetroFLAG™, the user must test background samples and calibrate the equipment to detect only foreign (i.e., not naturally occurring) substances.

The Handby Kit analyzes a sample in less than 10 minutes; detection limits typically range from 1 to 1,000 ppm for soil and 0.1 to 20 ppm for water. Approximately 25 samples per hour can analyzed using the PetroFLAG™ field test kit. The PetroSense™ analyzer is very sensitive to turbidity and temperature in water samples. Preconditioning and calibration for the PetroSense™ take approximately 30 minutes; sample analysis takes less than 10 minutes. The PetroSense™ probe may be lowered directly into a borehole for analyzing in situ groundwater. The Quick Testr field test kit for cPAHs in soil reportedly takes less than 20 minutes per sample to analyze. The Quick Testr must be used in temperatures ranging from 40 to 110°F.

Applications and Cost

Test kits are most useful as screening tools. Colorimetric test kits are available for different media and contaminants. Prices vary with the type of kit. Most test kits include some of the following equipment: hand-held analyzer, glassware, reagents, and scales. The more expensive units use electronic colorimeters, and the less expensive units usually use visual colorimetric matches. Handby kits for soil or groundwater cost about $1,300 including enough reagent for 30 samples, and $550 for an additional 30 samples. The PetroFLAG™ kit for soil costs about $800 with enough reagent for 10 samples, and $250 for an additional 10 samples. The Petrosense™ rents for about $150/week plus minimal costs for calibration standards. The Quick Testr analyzer rents for about $275/week plus $40 per sample for consumables.

Benefits

- Rapid on-site screening tool
- Kits available for petroleum-derived substances and polynuclear aromatic hydrocarbon (PNAs)
- Useful for remote sampling
- Generally requires minimal training

Limitations

- Relatively high detection limits
- Possible interference by naturally occurring chemicals and other contaminants
- Possible difficulty reading colorimetric matches under low light conditions

Contacts

Dexsil Corporation (PetroFLAG™), (203) 288-3509, www.dexsil.com

Envirol, Inc. (Quick Testr), (801) 753-7946 or (435) 753-7946, www.environl.com

FCI Environmental Inc. (PetroSense™), (702) 361-7921

Handby Environmental Laboratory Procedures, Inc., (Handby Kit), (512) 847-1212

4.2.2.4 Immunoassay Screening

Tool Description

Immunoassay testing can be used in the field to detect target chemicals in soil and other samples. Most immunoassay-based test kits for analyzing environmental contaminants are of the competitive enzyme-linked immunosorbent assay (ELISA) type. In competitive ELISAs, the sample to be tested is combined with a labeled enzyme and an antibody to which both the contaminant in the sample and the enzyme will bind. The contaminant and the enzyme compete for the limited number of antibody binding sites that are available. Each will bind to a number of sites that is proportional to its concentration in the mixture, so the relative concentration of the contaminant can be determined.

The relative concentrations of enzymes and contaminants are indicated by color-producing reagents, which are added after the antibody with contaminants and enzymes bound to it is separated from whatever material is left over. Color development is catalyzed by the enzymes and then terminated by a stopping reagent. A spectrophotometer reads the absorbance or reflectance of the antibody-contaminant-enzyme complex; the color detected by the spectrophotometer is proportional to the enzyme's concentration and inversely proportional to the contaminant's concentration. Thus, the concentration of contaminant in the soil or other sample tested can be inferred.

Operational Considerations

Field immunoassay test kits can operate in temperature ranges from 40 to 100°F. Soil moisture content in excess of 30 percent can decrease extraction efficiency. Reactivity and / or interference from the surrounding soil matrix can have either a positive or negative effect on results. A work environment protected from sunlight and wind is recommended, and operator training by the manufacturer is encouraged.

To effectively use immunoassay test kits for field screening at MGP sites, a site-specific correlation study should be performed first. PAH immunoassay test methods measure PAH compounds based on molecular structure. Laboratories use gas chromotography / mass spectrometry (GC / MS) for ion identification to quantify 16 different PAHs. The presence of any of the more than 30 PAHs can be detected, but without identifying specific types or quantifying concentrations.

Immunoassay test kits should not be used at MGP sites where crude oil was used as a fuel source because the widely varied composition of feedstocks for oil-fired plants does not allow correlation to a standard based on simple feedstock. MGP sites where coal was used as a fuel source yield much better correlation factors between analytical laboratory data and immunoassay test kit data in field tests.

Applications and Cost

Immunoassay test kits may be an effective screening tool for PAHs, TPHs, and other chemicals typically detected at coal-fueled MGP sites. Immunoassay test kit cost per sample is $25-55 (excluding labor) depending on batch size and product line. Field lab instrumentation can be rented for $450 / week or purchased for $1,700-2,000.

Benefits

- Rapid, real-time analytical data on-site
- Can be used to select samples for laboratory analysis and to define limits of contamination during an investigation

Limitations

- Requires site-specific calibration

- Does not speciate individual PAHs
- Does not work effectively on MGP sites where crude oil was used as fuel
- Does not produce quantified concentrations of target substance being analyzed
- Requires a trial period or test runs to confirm satisfactory performance

Contact

Dwight Denham, Strategic Diagnostics, Inc., (714) 644-8650

Case Study

Georgetown Former MGP Site

In 1930, the Georgetown Coal Gas plant was demolished after about 20 years of operation. The objectives of using immunoassay kits at the Georgetown Former MGP Site were to evaluate the entire site quickly and to find areas with actionable levels of PAHs, determine the extent and depth of each contaminated area, and compare in-laboratory methods with immunoassay results in terms of accuracy, cost, and time. Of the 36 samples analyzed at the site, the PAH immunoassay test kits were consistent with in-laboratory results with the exception of five false positives from the immunoassay test method. By not performing laboratory analysis of the samples determined to be negative via immunoassay (as defined by a concentration less than 1 ppm), a savings of approximately $4,000 would have been realized. Used as a screening tool, the immunoassay results can be very useful in determining which samples to send to a lab (immunoassay costs were approximately one tenth of laboratory analysis).

4.2.2.5 Mobile Laboratories

Tool Description

Under the right conditions for field programs in which rapid site assessment is necessary, mobile laboratories can provide rapid on-site, soil, air, and water sample analyses.

Field characterization programs are often conducted in phases of field sample collection and analysis. The results from the first phase are used to plan the sampling strategy of the second phase. The results from the second phase are used to plan sampling for a third phase, and so on until delineation of contaminants is complete. The time spent between phases waiting for analytical results from standard offsite laboratories translates into additional costs for repeated mobilization / demobilization of drilling equipment and field personnel. Mobile laboratories can provide same-day results for field sampling, allowing field personnel to make quick decisions about the locations of subsequent sampling. It is not necessary to demobilize then remobilize the sampling effort.

Operational Considerations

The analytical capabilities of mobile laboratories vary considerably among companies. However, several laboratories are equipped to analyze PAHs in addition to petroleum hydrocarbons and other common contaminants. Some mobile laboratories are also equipped to analyze natural attenuation parameters in the field. Many natural attenuation parameters (e.g., dissolved oxygen, oxidation-reduction potential, ferrous iron, hydrogen, methane, ethane, and ethene) require rapid analysis for accurate reporting, so mobile laboratories can be very effective for analyzing these parameters.

Several mobile laboratories can identify and quantify PAHs by SW846 Methods 8100, 8270, and 8310. Prior to selecting a mobile laboratory, it is important to determine the quality of data required (e.g., are results from immunoassay methods acceptable, or are gas chromatography / mass spectrometry procedures warranted). Similar to offsite laboratories, mobile laboratories require trained chemists to run analyses and perform QA / QC functions.

Applications and Cost

The decision to use a mobile rather than an offsite laboratory depends on a number of factors, including quality of data required, number of samples to be analyzed, types of analyses required, possibility of access to a fixed laboratory, and cost of onsite versus offsite analysis.

If the mobile laboratory does not require specialized instrumentation, the cost of sample analysis may be 10 to 15 percent less than the cost of sending samples offsite and requesting rapid turnaround (Onsite Laboratories, 1998). It is important to note that the cost of laboratory analyses at both onsite and offsite situations varies markedly among laboratories and that unit costs depend on the number of samples to be analyzed. Approximate laboratory rental costs are $2,500 to $3,000 plus $13 to $30 per sample for expenditures.

Benefits

- Extremely rapid turnaround analytical results
- May reduce mobilization / demobilization charges for drilling and field personnel
- Can rapidly perform time-critical analyses, such as for natural attenuation parameters

Limitations

- May be more efficient to send samples for rapid turnaround at an offsite laboratory
- More expensive than standard turnaround analysis
- Not all mobile laboratories use USEPA analytical methods

4.2.3 Geophysical Surveys

Geophysical surveys encompass a broad group of tools historically used by the geophysical, mining, and petroleum industries for mapping geological formations. All of these tools operate from the surface to sense buried obstructions and objects, changes in geologic formations, and / or the location of groundwater, thus minimizing uncertainty about what might be unearthed during excavations and giving additional information to conceptual and numerical modeling of groundwater flow. These tools are generally grouped into one of two categories: surface geophysical and borehole geophysical.

Surface geophysical tools are nonintrusive and include:

- Electromagnetics
- Seismic Refraction
- Ground-Penetrating Radar
- Magnetometry / Metal Detection

Borehole geophysical tools are designed to be put into a well or borehole. They include:

- Electrical Logging (including single-point and multi-electrodes)
- Mechanical Logging
- Sonic Logging
- Radiometric Logging
- Thermal Logging
- Video Logging

In general, all geophysical tools work on a “preponderance of evidence” basis. That is, an individual geophysical method does not typically provide definite results. Rather, several methods are used in conjunction at a site to provide information concurrently through their results.

4.2.3.1 Electromagnetics

Tool Description

Electromagnetic surveys (EMS) comprise two subclasses of surveys: magnetometer surveys and terrain conductivity electromagnetic surveys. Both types of surveys are nonintrusive geophysical surveying techniques that have traditionally been used to detect geologic features (e.g., formations with magnetic properties). More recently, EMS has been successfully applied with ground-penetrating radar (GPR) surveys at former MGP sites to locate buried obstructions and objects such as old underground storage tanks, buried sumps and pits, and current and abandoned utility lines.

Magnetometer surveys are conducted by using an instrument that measures the varying intensity of magnetic fields produced by natural objects (e.g., rocks) and man-made objects (e.g., utility lines). Interpreting the magnetic readings produced by the magnetometer allows conclusions to be drawn about the location of the buried objects.

Terrain conductivity electromagnetic surveys are conducted by remote seismic inductive electric measurements made at the surface. The apparent conductivity of subsurface formations and objects is measured by a conductivity meter consisting of a receiver coil and a separate transmitter coil that induces an electric source field in the ground. Lateral variations in conductivity values generally indicate a change in subsurface conditions. The figure below is an example of an output from a terrain conductivity electromagnetic survey.

Operational Considerations

Soil factors that affect the accuracy of EMS include moisture content, iron content, and dissolved salts and ions. EMS results can also be affected by electromagnetic interference. Overall, EMS results are best interpreted in parallel with other geophysical survey techniques, such as ground-penetrating radar surveys, that provide correlating information.

Applications and Cost

EMS uses a nonintrusive source and detectors and is therefore ideal for screening sites for buried objects. It is a fast, relatively inexpensive method to obtain "ballpark" data. Under favorable conditions (low moisture, low iron content, low electromagnetic interference), EMS's resolution and accuracy improve. EMS is well understood and provides reliable results.

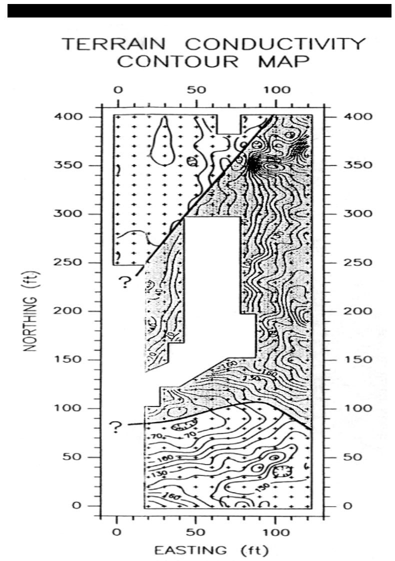
The cost of an EMS survey varies depending upon access to the site (directly related to the time required to perform the field work) and detail desired (e.g., the target depth to which a survey is to be conducted). Typically, an EMS survey on a 1-acre site will take 3 to 4 days to complete, costing around $3,500.

Benefits

- Provides reliable data
- Field tested and proven

Limitations

- Requires expertise to plan, collect, and interpret data
- Data subject to interference from soil moisture or clay in the subsurface and nearby electromagnetic sources (e.g., power lines)
- May be problematic in iron-rich, deeply weathered soils



Case Studies

Chico Former MGP Site

Available historical information for PG&E's Chico former MGP site indicated multiple locations for the historical buried feedstock tank. Terrain conductivity electromagnetic surveys were performed in conjunction with GPR to determine whether the tank still existed and, if so, to better estimate the tank's location (thereby determining if soil contamination observed in the general area might be from the tank or from a different former MGP structure). At the time of the surveys, the site consisted of the former MGP sheet-metal generating building and an adjacent substation. There was significant interference in the EMS survey from the adjacent substation, but the GPR survey was able to place the location of the former buried feedstock tank farther west than the location estimated from historical Sanborn Fire Insurance maps.

Stockton Former MGP Site

Terrain conductivity electromagnetic surveys were also used at PG&E's Stockton former MGP site to delineate debris-filled areas, covered pits and sumps, and concealed foundations associated with the former MGP. The terrain conductivity electromagnetic surveys correlated well with the estimated locations of former MGP structures as determined by a GPR survey.

Contact

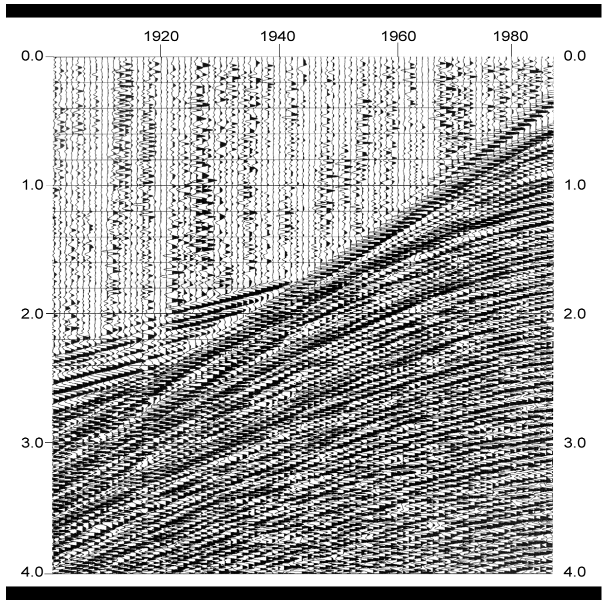
Robert Doss, Pacific Gas and Electric Company, (415) 973-7601

4.2.3.2 Seismic Refraction

Tool Description

Seismic refraction is a nonintrusive geophysical surveying technique that can be used to determine depth to bedrock, thickness of surficial fracture zones in crystalline rock, extent of potential aquifers, and depth of the water table.

Seismic refraction surveys are conducted by measuring the velocity of elastic waves in the subsurface. Elastic waves are generated by a source (hammer blow or small explosion) at the ground surface, and a set of receivers is placed in a line radiating outward from the energy source to measure the time between the shock and the arrival. The velocity of the elastic waves in the subsurface increases with increasing bulk density and water content. The depth of various strata and objects may be calculated if their wave velocities are sufficiently different. The survey data are processed and interpreted, typically along with other geologic information and geophysical surveys, to provide a picture of subsurface conditions. The following figure exemplifies the output from a seismic refraction survey.



Three-dimensional / three-component (3-D / 3-C) seismic imaging can be an extremely powerful tool for characterizing the hydrogeological framework in which contaminants are found at MGP sites. 3-D / 3-C seismic imaging is a nonintrusive geophysical surveying technique that can delineate subsurface geophysical features including: bedrock channels, clay layers, faults, fractures, and porosity. In addition, 3-D / 3-C seismic imaging can identify trench / pit boundaries and differences in soils and wastes (Hasbrouck et al., 1996).

3-C imaging entails analysis of one-component compression-wave and two-component shear-wave data. Two-dimensional (2-D) seismic refraction surveys use only one–component compression-wave data. The 3-D / 3-C seismic imaging uses shear-wave data to map much thinner features than can be detected with 2-D surveys; 3-D / 3-C imaging can determine anisotropy (i.e., preferred grain orientation, periodic layering, and depositional or erosional lineation), which may correlate to preferential contaminant transport pathways (Hasbrouck et al., 1996).

Operational Considerations

Interpretations of seismic refraction surveys are most reliable in cases where there is a simple two- or three-layer subsurface in which the layers exhibit a strong contrast in seismic velocity. For shallow investigations (i.e., up to approximately 10 feet deep), the energy source for the elastic waves is a hammer blow on a metal plate set on the ground surface. For a deeper investigation or at sites with noise interference (heavy machinery or highways), an explosive source is necessary. High gravel content in the soil matrix may diminish the quality of the data.

3-D / 3-C seismic imaging data can be processed so that cross sections are oriented from any angle and specific zones of interest can be displayed and interpreted. Specially developed 3-D / 3-C software is necessary to process the data, and skilled data interpretation is required (Hasbrouck et al., 1996).

Overall, seismic refraction results are best interpreted in parallel with other geophysical survey techniques (such as magnetometer surveys and electromagnetic terrain surveys) or well logs, which provide correlating information.

Applications and Cost

Where deep groundwater, consolidated materials, or both make test drilling relatively expensive, it may be advantageous to get as much information as possible by seismic refraction. Seismic refraction is a nonintrusive survey method that is well understood and provides reliable results.

3-D/3-C seismic imaging can be used for subsurface characterization. The relatively high cost of 3-D/3-C seismic imaging may be justified in situations where site entry is restricted because of high levels of subsurface contaminants and a three-dimensional picture of the sites's subsurface is required without intrusive sampling.

The cost of a seismic refraction survey varies depending upon access to the site (directly related to the time required to perform the field work) and the level of detail desired (e.g., the target depth to which the survey is to be conducted). Typically, one week of seismic refraction surveys may yield 3 to 5 line miles of interpreted data for approximately $10,000.

Benefits

- Provides reliable data
- Field tested and proven
- Minimizes the number of times an area must be accessed for subsurface characterization and maximizes the amount of information gathered
- 3D/3C seismic refraction provides greater level of detail (e.g., thinner features) than traditional 2-D seismic surveying results

Limitations

- Requires expertise to plan, collect and interpret data
- Data subject to interference from complex geological strata
- 3D-3C seismic refraction relatively expensive
- Needs to be correlated with other site-specific subsurface data such as drilling logs
- Heavy traffic or numerous surface obstructions can be problematic

Contact

Dennis Olona, U.S. Department of Energy, Albuquerque, NM, (505) 845-4296

4.2.3.3 Ground-Penetrating Radar (GPR)

Tool Description

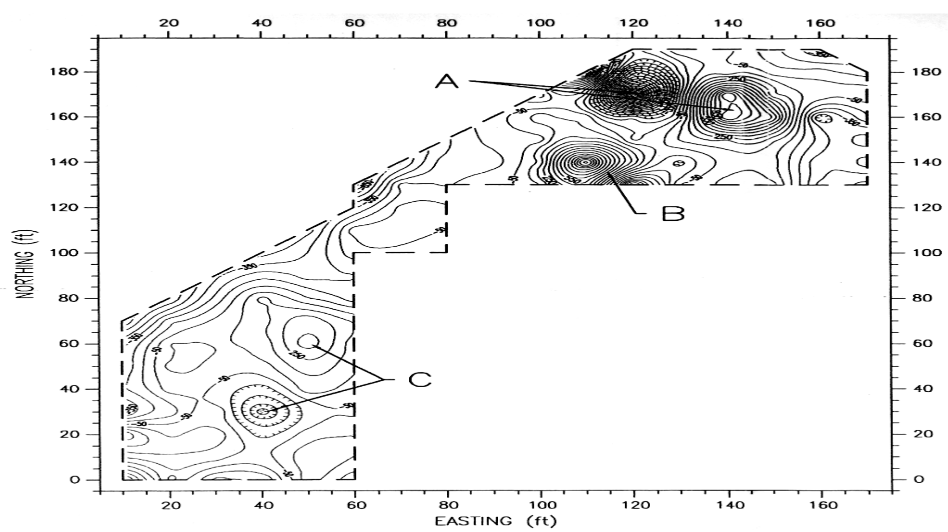
GPR is a nonintrusive geophysical surveying technique that has traditionally been used to detect geologic features (e.g., fractures and faults). More recently, GPR has been successfully applied with EMSs at former MGP sites to locate buried obstructions and objects such as old foundations, underground storage tanks, buried sumps and pits, current and abandoned utility lines, and concrete rubble.

GPR surveying emits high-frequency electromagnetic waves into the subsurface. The electromagnetic energy that is reflected by buried obstructions is received by an antenna at the surface and recorded as a function of time. The recorded patterns are interpreted, typically along with other geologic information and geophysical surveys, to provide a picture of subsurface conditions. The following figure is an example of an output from a GPR. Results are best interpreted in parallel with other geophysical survey techniques, such as magnetometer surveys and EMSs, which provide correlating information.

Applications and Cost

GPR uses a nonintrusive source and detectors and is therefore ideal for screening sites for buried objects. It is a fast, relatively inexpensive method to obtain "ballpark" data. Under favorable conditions (low moisture, low iron content, low electromagnetic interference), GPR's resolution and accuracy is best. GPR is well understood and provides reliable results.

The cost of a GPR survey varies depending upon access to the site (directly related to the time required to perform the field work) and the level of detail desired (e.g., the target depth to which the survey is to be conducted). Typically, one week of GPR surveys yields 5 to 7 line miles of interpreted data for around $10,000.



Benefits

- Field tested and proven

Limitations

- Requires expertise to plan, collect, and interpret data
- Data subject to interference from soil moisture or clay in the subsurface
- May be problematic in iron-rich, deeply weathered soils

Case Study

Chico Former MGP Site

Historical information for PG&E's Chico former MGP site indicated multiple locations for the buried former feedstock tank. Ground-penetrating radar was used in conjunction with EMS to determine whether the tank still existed and to verify its location (in order to determine whether soil contamination observed in an area might be from the tank or from a different former MGP structure). Although there was significant interference in the EMS survey from an adjacent substation, the GPR survey placed the location of the former buried feedstock tank farther west than the location estimated from historical Sanborn Fire Insurance maps. Interpretation of the survey data identified the location of the tank excavation but was not able to confirm whether or not the tank was still in place.

Contact

Robert Doss, Pacific Gas and Electric Company, (415) 973-7601

4.2.3.4 Magnetometry/Metal Detection

Tool Description

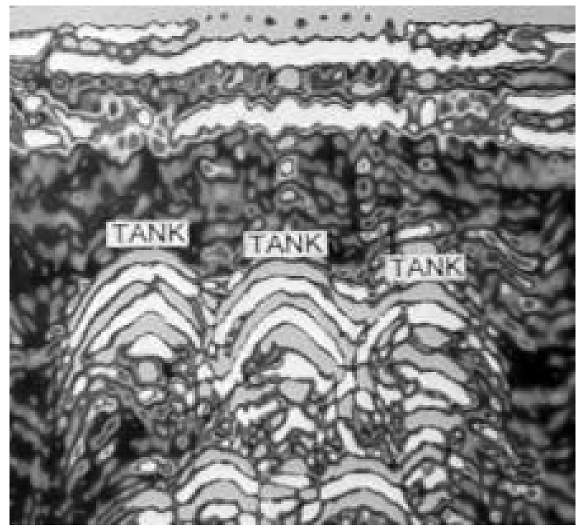
Magnetometry is a nonintrusive electromagnetic geophysical surveying technique commonly used in the construction industry to detect and map buried drums, metallic pipes, utilities, cables, and piping before excavation, demolition and/or construction. This technology has also been applied to former MGP sites to identify buried utilities before drilling and to survey and map historical MGP structures such as buried piping, tanks, and other metal structures.

Magnetometer surveys use an instrument that measures the varying intensity of magnetic fields produced by buried metallic objects. The magnetic readings produced by the magnetometer can be interpreted so that conclusions can be drawn about the location of the buried objects. The following figure is an example output from a magnetometer survey.

Operational Considerations

Soil factors that affect the accuracy of magnetometry include moisture content, iron content, and dissolved salts and ions. In addition, magnetometry surveys are typically depth limited and cannot distinguish among types of metallic objects. Nonferrous objects are invisible to magnetometry survey instruments.

Applications and Cost



Magnetometry uses a nonintrusive source and detectors and is therefore ideal for screening sites for buried objects. It is a fast, inexpensive method to obtain "ballpark" data on the location of buried metallic objects. Under favorable conditions (low moisture, low iron content, low electromagnetic interference), magnetometry resolution and accuracy is best. Magnetometry is well understood, well accepted, and provides reliable results.

The cost of a magnetometry survey varies depending upon access to the site (directly related to the time required to perform the field work), the size of the area to be surveyed, and the level of detail desired (e.g., the target depth to which the survey is to be conducted). Typically, a magnetometry survey on a 1-acre site with 10-foot grid spacing will take 3 to 4 days to complete. Equipment rental may cost approximately $500 per month, exclusive of labor (for both testing and data interpretation) and other related expenses.

Benefits

- Field tested and proven
- Widely accepted

Limitations

- Details obtainable only at relatively shallow depths
- Cannot distinguish among metallic objects
- May be problematic in iron-rich, deeply weathered soils or where there is a lot of scattered metal debris
- Nonferrous objects will not be visible to the technology

4.2.3.5 Borehole Geophysical Methods

Borehole geophysical methods are used to physically characterize sediments, rocks, and fluids in boreholes and wells. Data are acquired by moving a string of instruments up or down a borehole and measuring the response. Depending on the specific information required, one or more borehole geophysics techniques may be used in a single well. The radius of the investigation depends on the particular instrument used.

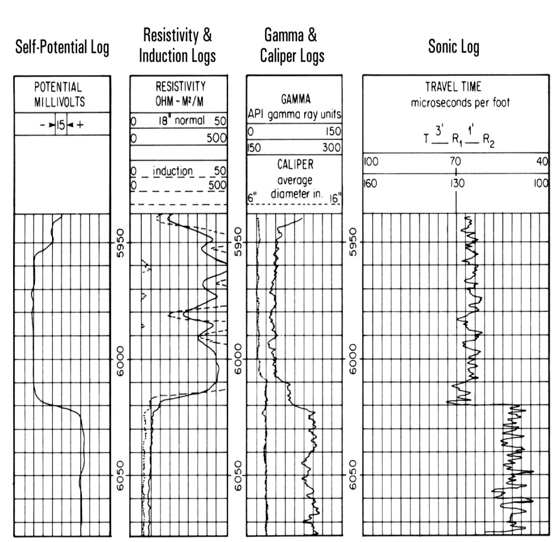
The tools discussed below include several categories of borehole survey techniques:

- Electrical
- Mechanical
- Sonic
- Radiometric
- Thermal
- Video

Borehole geophysical logging is a useful tool for site characterization. Because of the mobilization effort required and because multiple logging techniques can be used simultaneously, borehole geophysical surveys are most cost effective when performed as part of a multiple-log suite.

Geophysical logs provide a continuous profile of response versus depth in a well or boring. Typically, direct soil sampling is undertaken only at 5-foot intervals. A substantial amount of information can be obtained from a few logging runs into a well. In addition, data can be correlated between adjacent wells. Examples of some of the well logs that may be produced with the techniques discussed herein is shown below.

In general, borehole logging is relatively expensive (including actual logging and post processing), and equipment must be transported to the site. In addition, the radius of the investigation may be small and may not be representative of the bulk formation.



4.2.3.5.1 Electrical Logging

Tool Description

Electrical logging includes electrical resistivity methods, induction logs, self-potential logs, and fluid conductivity logs. Electrical resistivity relies on different electrode configurations to give information on different zones around the borehole. The characteristics (e.g., thickness, permeability, salinity) of a region energized by particular current electrode configuration can be estimated by measuring variations in current among electrodes. Many variations of electrical resistivity logging exist in which different electrode configurations are used including: normal logs, lateral logs, guard logs, and micrologs. Using empirical constants specific to the particular rocks in the area and the drilling fluid, electrical resistivity is also used to estimate porosity, water and hydrocarbon saturation, and permeability.

An induction log is a profile of resistivity obtained by utilizing electromagnetic waves. This technique is used in dry holes or boreholes that contain nonconductive drilling fluid. Lithologic boundaries show up on induction logs as gradual changes in apparent resistivity.

On self-potential logs, measurements of potential differences between an electrode on the sonde (probe) and a grounded electrode at the surface are made in boreholes filled with conductive drilling fluid. The self-potential effect originates from the movement of ions at different speeds between two fluids of differing concentration, in this case groundwater and drilling fluid. Self-potential logging can be used to identify the boundaries between geological beds based on the differing rates of penetration of drilling mud into the lithology. In hydrocarbon-bearing zones, self-potential logs show less deflection than normal.

Fluid conductivity logging uses an electrical conductivity probe to profile water quality by depth. It is used to select sampling depths and also used in conjunction with a flow-meter log (see Section 4.2.3.5.2, Mechanical Logging) to identify water-producing zones.

Operational Considerations

The electrical logging techniques described here require an open borehole. Borehole fluids must be electrically conducting if electrical resistivity and self-potential logging are to be used. Induction logging, however, requires either a dry borehole or nonconducting fluids in the borehole. Single-electrode logging yields a poor response in saltwater aquifers and provides qualitative data elsewhere. Multi-electrode logging permits quantitative data and estimates of formation water salinity. Fluid conductivity logging yields less precise information in highly saline waters.

Applications and Costs

The cost of electrical logging is approximately $1,200-$2,500 per day. Five to seven wells can be logged per day. Fluid conductivity logging is approximately $500-$600 per well when performed as part of a multiple-log suite and approximately $1,500-$2,500 per well when done alone.

Benefits

- Quantitative data may require corrections

Limitations

- The electrical logging techniques described require an uncased borehole
- Electrical resistivity and self-potential techniques require conductive borehole fluids
- Induction logging requires a dry borehole or borehole with nonconductive fluids
- Induction logging may be complex and provide poor results in situations of high-resistance formations, thin beds, and shallow wells
- Poor response in saltwater aquifers

4.2.3.5.2 Mechanical Logging

Tool Description

Flow-meter and caliper logging are two different types of mechanical logging. Flow-meter or spinner logging incorporates mechanical flow meters to measure horizontal and vertical groundwater flow rates. These flow rates can be used to identify permeable zones in a formation. When used in conjunction with the caliper log, the flow meter yields semiquantitative measurements of groundwater into the borehole.

A mechanical flow meter measures the velocity of fluid in a borehole by means of low-inertia impellers that are turned by the fluid flow. Turning of the impellers causes a magnet mounted on the impeller shaft to rotate and generate electrical signals. Mechanical flow meters are capable of measuring flow rates down to about 2 feet per minute (ft/min). A newer electromagnetic flow meter uses thermal principles to measure flow rates as low as 0.1 ft/min.

Mechanical flow-meter logging can be done under natural (non-pumping) or forced-flow (pumping) conditions. Pumping flow-meter logs can be used to estimate the relative transmissivity of different water-bearing zones; non-pumping flow-meter logs can be used to identify the direction and magnitude of vertical well-bore flow caused by vertical gradients.

Another common type of mechanical logging uses the caliper log, which measures borehole diameter and roughness. The tool itself has a number of feelers (usually four) attached. The feelers are electromechanical devices, held by springs against the wall of the hole, that send information to the surface. The information from the log is used mainly to estimate the volume of cement that might be required to seal around a collapsed region, to verify well-construction details, and to provide lithologic information. Information gained from the caliper log is used to estimate velocity losses in the gap between the borehole wall and the flow-meter impeller, thereby correcting velocity measured by the flow-meter log. The key use of the caliper log data is to correlate vertical velocity data to vertical flow data by allowing the area of the borehole to be factored into the vertical profile.

Operational Considerations

Flow-meter logging requires a minimum flow of approximately 2 ft/min. Caliper logging requires an open borehole, which may be difficult to achieve in deep, unconsolidated deposits. Conductor casing may be necessary to contain unconsolidated sediments near the top of the well.

Applications and Costs

The cost of flow-meter logging is roughly $500 to $600 per well when performed as part of a multiple-log suite. The cost of flow-meter logging (with recommended caliper logging) is $1,500 to $2,500 per well.

Benefits

- Caliper log is widely available, rapid, and inexpensive
- Flow meter logging is relatively simple and inexpensive

Limitations

- Flow-meter logging is relatively insensitive at low velocities
- Most applications of flow-meter logging require a pumping or flowing well during the survey
- A caliper log is needed for interpretation of flow-meter logs

4.2.3.5.3 Sonic Logging

Tool Description

Sonic logging, also known as continuous velocity or acoustic logging, is used to determine the relative porosity of different formations. Sonic logging may also be used to determine the top of the water table, to locate perched water-bearing zones, and to assess the seal between a casing and formation material.

A probe containing one or more transmitters that convert electrical energy to acoustic energy is lowered into the borehole on a cable. The acoustic energy travels through the formation and back to one or more receivers also located on the tool. The acoustic energy is converted back to an electrical signal, which is transmitted back to the surface by the receivers and recorded.

Sonic logging determines the seismic velocities of the formations traversed. The average velocity of the acoustic wave passing through the formation depends on the matrix material and the presence of fluid in the pore space. The speed of the wave is slowed by the presence of pore fluid; therefore, sonic logging provides a measure of fluid-filled pore space. The velocity of the solid matrix can be determined by laboratory analysis of core samples.

Operational Considerations

Sonic logging can be performed in a borehole cased with metal; however, the results are most representative of formation properties if logging is performed in an open borehole. The borehole must be fluid-filled for signal transmission to occur. Obtaining meaningful results in unconsolidated materials with low groundwater velocities may be difficult.

Applications and Costs

Sonic logging may be used for site characterization where information is needed on the relative porosity of different formations and the location of water-bearing zones. The cost of sonic logging is approximately $1,500 to $4,500 per well.

Benefits

- Widely available
- Suitable for uncased or cased boreholes although the results are more representative of the formation if the borehole is uncased
- Useful for characterizing rock aquifers to identify high-porosity zones that may transmit water
- Allows porosity determination without use of radioactive source

Limitations

- Interpretation of the data may require expertise
- The borehole must be fluid-filled
- Not applicable in shallow wells or in unsaturated conditions

4.2.3.5.4 Radiometric Logging

Tool Description

The radiometric logging techniques discussed here include neutron logging and natural gamma (or gamma) logging. Neutron logging is used to estimate porosity and bulk density, and, in the vadose zone, to locate saturated zones outside a borehole or well casing. Natural gamma logs are used to evaluate downhole lithology, stratigraphic correlation, and clay content of sedimentary rocks.

Both logging techniques are based on the process by which particles of mass or energy are spontaneously emitted from an atom. These emissions consist of protons, neutrons, electrons, and photons of electromagnetic energy that are called gamma rays. Radiometric logs either make use of the natural radioactivity produced by the unstable elements U^{238}, Th^{232}, and K^{40}, or radioactivity induced by the bombardment of stable nuclei with gamma rays or neutrons.

In neutron logging, nonradioactive elements are bombarded with neutrons and stimulated to emit gamma rays. The sonde (probe) contains a neutron source, and the neutrons collide with atomic nuclei in the wall rock and emit gamma rays, which are measured by a gamma-ray detector also on the sonde. The amount of gamma radiation from neutron logging correlates directly with the proportion of water-filled pore space in a rock unit.

Natural gamma radiation logging uses a detector mounted on a sonde to measure the gamma rays produced by radioactive elements in a formation. Because different types of formations contain different amounts of radioactive elements, gamma logging is used primarily to determine lithology, stratigraphy, and the clay or shale content of a rock.

Operational Considerations

Neutron and gamma logging techniques can be used in cased holes, which means they offer a distinct advantage under some circumstances. Neutron logging requires handling of a radioactive source.

Applications and Costs

Neutron logging costs approximately $2,500 to $5,000 per well (depending on well depth and the number of other logs run at the same time). Gamma logging costs are on the order of $1,200 to $2,500 per well; approximately five to seven 100-foot wells can be logged per day.

Benefits

- Radiometric logging is suitable for both uncased and cased boreholes
- Specialized training is not required for gamma logging
- Radiometric logging is useful in characterizing rock aquifers to identify high-porosity zones that may transmit water.

Limitations

- Gamma rays detected using neutron and natural gamma logging come from the formation only within a few feet from the well
- Lithology must be determined by other logs before porosity estimates can be made using the neutron logging technique
- Neutron logging requires special training, transportation, and permits to allow handling of a radioactive source; its availability is also limited
- Neutron logging may only be allowed in cased holes in some states (e.g., Oregon)

4.2.3.5.5 Thermal Logging

Tool Description

Thermal logging is primarily used to locate water-bearing zones. It can also be used to estimate seasonal recharge or a source of groundwater. A temperature sensor, usually a thermistor mounted inside a protective cage, is lowered down a water-filled borehole. The probe is lowered at a constant rate and transmits data related to the temperature change with change of depth to surface. The natural variation of temperature with depth is called the geothermal gradient. Water-bearing zones intersected by the borehole may cause changes in the geothermal gradient, which is shown on the temperature log. Seasonal recharge effects may also be detected because the influx of recharge water changes the natural temperature regime. It is also possible to assess the source of groundwater if the regional sources have characteristic temperatures.

Operational Considerations

Thermal logging may be performed in an open or cased borehole; however, the borehole must be fluid-filled. Thermal logging should be performed several days after drilling is complete to ensure that water in the boring is representative of ambient conditions.

Applications and Costs

Thermal logging is often combined with other borehole geophysical methods. The cost of thermal logging is approximately $500 to $600 per well (depending on the total depth logged) as part of a multiple-log suite. The cost of temperature logging when no other borehole geophysical methods are used is approximately $1,500 to $2,000 per well.

Benefits

- Thermal logging is widely available, rapid, and inexpensive
- Data are easy to interpret unless internal borehole flow is present

Limitations

- Temperature measured is that of borehole fluid, which may not be representative of surrounding formation
- This technique requires a fluid-filled borehole
- Interpretation of log is complicated if internal borehole flow is present

4.2.3.5.6 Video Logging

Tool Description

Video logging a borehole can provide visual inspection of the interior of a well, detecting damaged sections of screen and confirming well construction details. In uncased boreholes, video logs can detect fractures, solution cracks, and geological contacts if turbidity in the well is low.

Operational Considerations

Video logging requires very low turbidity in the well for a successful survey. Both monochrome and color videography are available; however, color is preferred because interpretation of images is easier.

Applications and Cost

Video logging is primarily used to detect fractured bedrock and the integrity of screens and casing. Video logging may cost from $400 to $3,000 per well.

Benefits

- Video logging allows visual inspection of well interior
- Video logging is useful for troubleshooting potentially damaged casings

Limitations

- Video logging requires an open borehole and is therefore not useable with unconsolidated formations

- The borehole walls must be clean and the groundwater relatively clear

4.2.4 Soil Gas Surveys

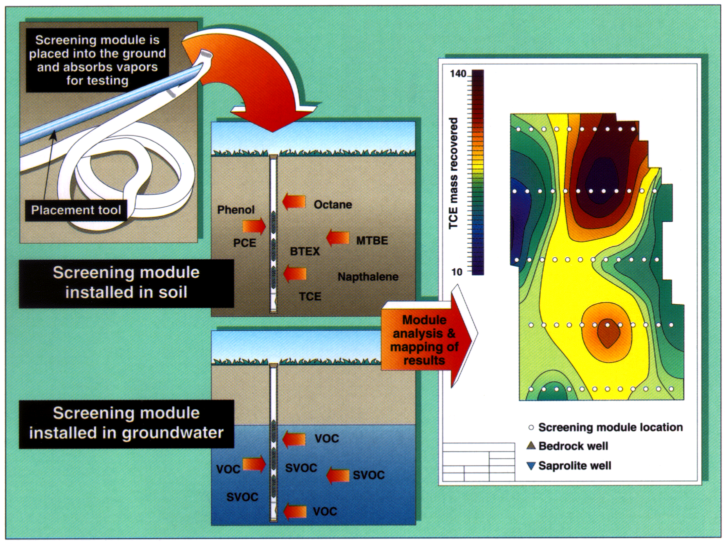
Soil gas measurements can successfully predict actual concentrations of MGP residues in soil and water. MGP residues are present in the soil as a gas because of their vapor pressure and solubility. Measuring the amount and composition of these gases can indicate the extent of source areas and groundwater plumes. Soil gas investigations, used in conjunction with physical soil and groundwater sampling, can provide a more thorough and cost-effective site investigation than borings and well samples alone. Soil gas surveys are grouped in two categories: passive and active. Passive soil gas surveys measure the relative concentration of contaminants through subsurface detectors sensitive to diffusion. Active soil gas surveys relatively quickly withdraw soil vapors using a vacuum pump system to analyze the concentration of contaminants in the vapor phase. The active gas soil gas technique provides real-time concentration data; the passive soil gas technique provides a time-integrated relative concentration that may detect less volatile compounds. Each of these methods of soil gas sampling is discussed in more detail below.

4.2.4.1 Passive Soil Gas Survey

Tool Description

Passive soil gas surveys use subsurface detectors sensitive to diffusion to measure the relative concentration of contaminants. Passive methods involve integrated sampling over time and collection of the sample on an absorbent material. Because sampling is integrated over time, fluctuations in soil gas availability resulting from changing ambient and subsurface conditions are minimized. Passive soil gas sampling does not disrupt the natural equilibrium of vapors in the subsurface as is the case with active sampling methods. Passive gas sampling only provides qualitative results because it does not measure the specific amount of contamination per unit of contaminated material. Because passive soil gas sampling occurs over a period of at least a few days, it can detect heavy organic compounds with lower vapor pressures, such as PAHs.

Gore-Sorbers® and Emflux® are both patented technologies that use passive soil gas principles. The Gore-Sorbers® Module uses a granular absorbent within an inert Gore-Tex® membrane that only permits vapor transfer into the module. Each thin, cord-like, module is placed in the shallow subsurface for a period of 2 to 4 weeks and then removed and shipped to a laboratory for analysis. Emflux® samples consist of a sampler vial containing an adsorbent cartridge. The samplers are placed at a depth of approximately 3 inches below grade for 72 hours, after which they are removed and sent to a laboratory for thermal desorption and analysis. Results of a passive gas survey is shown below.



Operational Considerations

As opposed to active gas sampling, passive soil gas sampling can be used in areas with relatively low soil permeability. Installation and retrieval of samples can be accomplished with minimal training and equipment. Soil gas samples should be taken at points deep enough to avoid background contamination from surface spills or exhaust. Installations directly beneath concrete or paved surfaces should be to a depth below the zone of lateral migration of soil gas to avoid misleading results. Depths of at least 2 to 3 feet are typically sufficient to insure good sampling. It may be difficult to obtain passive soil gas data for vertical characterization; active soil gas sampling is often used to vertically characterize contamination. Passive gas sampling may be applied directly in a saturated zone.

Application and Cost

Passive gas testing has been used for many different types of contaminants (including MGP residues) and is becoming more popular because of its low cost and flexibility in different types of soil. Using soil gas sampling data in conjunction with other site-specific data can be a cost-effective method for delineating MGP residues.

Passive soil gas testing is approximately $250 per sample location (including analysis and reporting) and $50 to $100 per location for installation and retrieval.

Benefits

- Easy to use
- Can be used in areas of relatively low permeability
- Can be more sensitive than active soil gas, soil, or groundwater sampling

Limitations

- May not correlate well with active soil sampling results
- Does not measure direct concentration
- Data at depth for vertical characterization may be difficult to collect
- Gore Sorber® passive detector must remain in situ for 14 days, whereas Emflux® passive detector must remain in situ for only 3 days

Case Study

McClellan Air Force Base (AFB)

Past disposal practices at McClellan AFB, located near Sacramento, California, from 1936 to the late 1970s, contaminated the soil and groundwater of more than 3,000 acres. Contaminants include caustic cleaners, electroplating chemicals, heavy metals, industrial solvents, low-level radioactive wastes, PCBs, and a variety of fuel oils and lubricants.

As part of a test location for innovative technologies, McClellan AFB tested the Gore-Sorber® Module, primarily to monitor VOCs (perchloroethylene [PCE] , trichloroethylene [TCE], and cis-1,2-dichloroethylene [CIS-1, 2-DCE]). A very good correlation was observed between the relative contamination levels measured by the survey and actual levels determined using active soil gas sampling (Elsevier Sciences, 1997).

Contacts

Paul Henning, Quadrel Services (Emflux® Module), (800) 878-5510

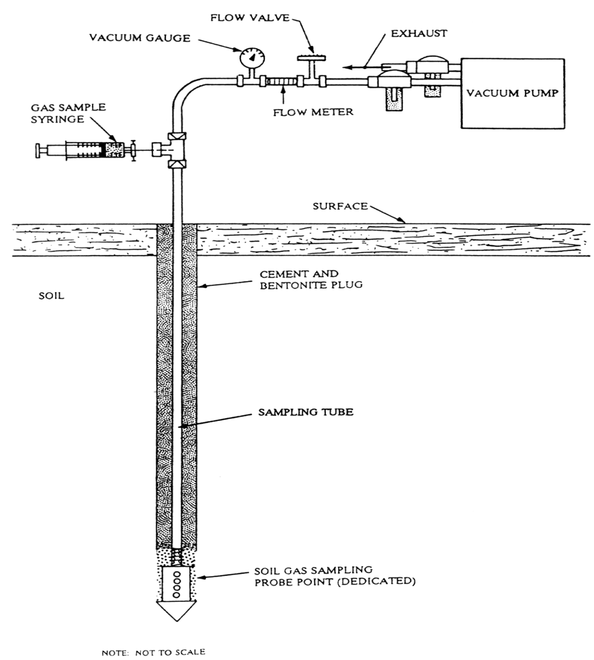
Gore Technologies (Gore-Sorber®), Mark Wrigley (410) 392-3406 and Andre Brown (415) 648-0438

4.2.4.2 Active Soil Gas Survey

Tool Description

Active soil gas surveys use a vacuum pump to induce vapor transport in the subsurface and to instantaneously collect samples of contaminants in the vapor phase. Active soil gas surveys provide a snapshot of vapor concentration in the subsurface, in contrast to passive soil gas surveys, which provide time-integrated sampling data.

Because active soil gas sampling provides real-time data, a relatively coarse sampling grid is initially used; this grid can be refined in areas of interest (e.g., areas with relatively high contaminant concentrations) for additional sample collection. The following figure shows a schematic of one type of active soil gas sampling device. (Adapted from “Handbook of Vadose Zone Characterization and Monitoring” by L.G. Wilson, et al., 1995.)



Other active soil gas sampling methods also use a vacuum pump; however, a gas sampling bag, an evacuated canister / vial, or a solid adsorbent may be used instead of a gas sampling syringe. The active soil gas sampling method that uses a solid adsorbent is similar to passive soil gas sampling techniques except that active soil gas sampling uses vacuum pressure instead of diffusion to pull the vapor sample through the solid adsorbent.

Operational Considerations

The vacuum used in active soil gas sampling disrupts the equilibrium soil gas vapor in the subsurface by forcibly drawing the vapor and soil gas from the soil matrix surrounding the sampling point. Active soil gas sampling typically must be done at least 10 to 20 feet bgs; passive soil gas sampling, by contrast, typically occurs at 3 feet bgs. It may be difficult to collect an active soil gas sample in an area of relatively low soil permeability. Active soil gas surveys may not be used in the saturated zone and may result in false negative or low soil gas concentration measurements in areas of elevated soil moisture.

Active soil gas sampling may be adversely affected by transient processes such as barometric pressure changes, earth tides, and precipitation, as well as by stationary features such as buried foundations. Active soil gas sampling data should be interpreted to account for the fluctuations these transient processes may create in the data.

Laboratory sample holding / extraction times are dependent on the specific active soil gas sampling method used. The solid adsorbent active gas sampling method requires relatively long sample holding / extraction times. The gas syringe active gas sampling method (shown in the figure above) requires relatively short sample holding / extraction times.

Applications and Cost

Active soil gas sampling is well suited to delineating areas of higher and lower VOC concentrations. Passive soil gas sampling may be better suited to measuring lower contaminant concentrations and less volatile compounds such as PAHs because of the time-integrated nature of the sampling methodology. Active soil gas sampling costs approximately $3,000 to 4,000 per day.

Benefits

- Provides real-time data
- Provides rapid results that allow the user to converge on areas of interest
- Provides a direct measure of vapor concentration
- Can be used to evaluate vertical changes in soil gas concentrations

Limitations

- Requires samples collected at least 10 to 20 feet bgs
- Cannot be effectively used in areas of relatively low permeability
- May not be effective in detecting semivolatiles (e.g., PAHs)
- May be affected by barometric and other transient processes
- Subsurface equilibrium vapor conditions disrupted by vacuum

Contacts

Tracer Research, (800) 989-9929

Transglobal Environmental Geosciences, (800) 300-6010

4.2.5 Contaminant Migration Evaluation

Three techniques for evaluating the movement and degradation of contaminants in aquifers include a Push-Pull Natural Attenuation Test, a Partitioning Interwell Tracer Test (PITT), and an In Situ Bio / Geochemical Monitor (ISM) test. Each of these are discussed in more detail below.

4.2.5.1 Push-Pull Natural Attenuation Test

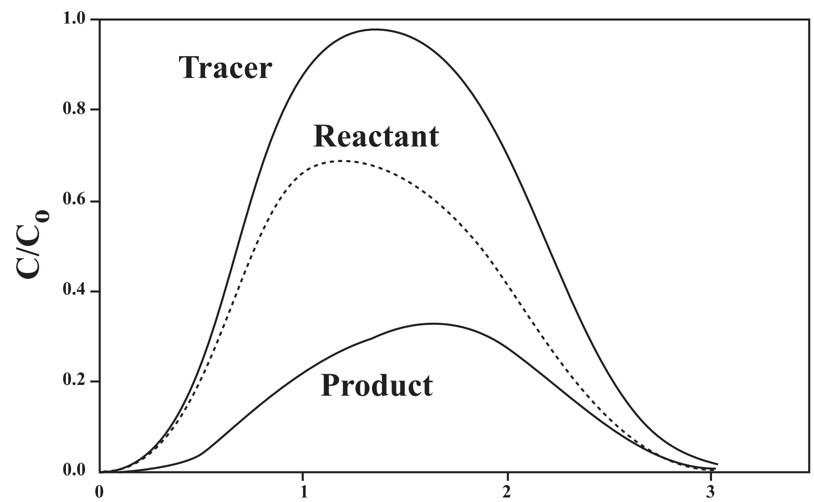
Tool Description

The push-pull natural attenuation test is an infrequently used single-well injection / extraction test used to obtain quantitative information on in situ microbial metabolic activity. A push-pull test is conducted in three steps:

1. Inject in an existing monitoring well a pulse of test solution consisting of water, a conservative tracer, and microbial substrates (electron acceptors and donors).
2. Allow the test solution to interact with indigenous microorganisms and then extract a slug of water / tracer / microbial substrates from the same well.
3. Measure the tracer, substrate, and product concentrations from the extracted slug of the test solution / groundwater mixture, and use measurements to calculate rates of microbial activities.

This method provides direct estimates of rates for microbial activity and mass balances for reactants.

The following figure shows an idealized breakthrough curve for a process generating a single product from a single reactant. The curves show the typical relationship between contaminant concentration and time, providing information on the way advection, dispersion, diffusion, and biodegradation affect contaminant movement within the aquifer.



Operational Considerations

Push-pull tests require specially trained field personnel although an individual test typically only requires a few hours, so several tests can be completed by a single operator in a day. The test solution used during the injection phase of a push-pull test is composed of various electron acceptors and donors (e.g., sodium bromide) that depend on the objectives of the sampling. The tracer selected should have a decay rate similar to or greater than the groundwater flow rate.

Applications and Cost

Push-pull tests are ideal for situations in which quantifiable estimates of microbial activity are desired for potential natural attenuation scenarios.

The cost of push-pull tests for a site contaminated with BTEX is approximately $12,000 to $15,000 for two to three wells, including analytical costs. The costs are very dependent on the specific analyses required.

Benefits

- Can document microbial metabolism, loss of degraded contaminants, production of degradation products, and estimates of zero- and first-order decay constants
- Provides in situ data (versus in an artificial laboratory environment)

- Can be used in wells that are already installed
- Can assay a wide variety of processes
- Is field tested

Limitations

- Is a fairly new test; not widely used
- Can be difficult to use when decay rate is slow relative to groundwater flow rate

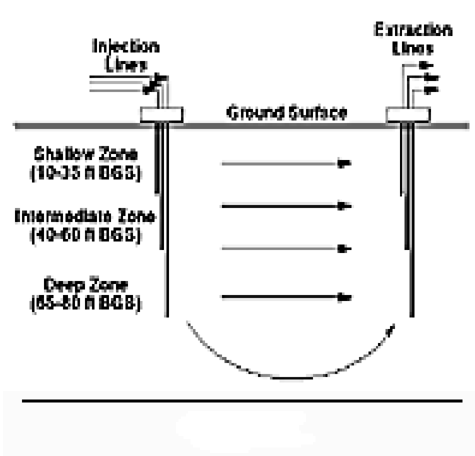
4.2.5.2 Partitioning Interwell Tracer Test (PITT)

Tool Description

The PITT is an in situ technology that measures the volume and percent saturation of NAPL contamination trapped in water-saturated and vadose zone sediments. The PITT technology is primarily used to:

- Quantify and locate NAPL contamination
- Assess the performance of remediation activities
- Quantify water saturation in the vadose zone

The technique is essentially a large-scale application of chromatography. The migration of a partitioning tracer between an injection well and an extraction well is retarded relative to a nonpartitioning tracer because it spends a portion of its residence time in the immobile residual NAPL. The chromatographic separation of the tracers indicates the presence of NAPL in the interwell zone and is used to determine the volume of NAPL present. The figure below shows a typical injection-extraction system.



The PITT technique can be used before and after an in situ remedial activity, such as surfactant flooding, to estimate the fraction of NAPL removed and the volume of NAPL remaining.

Operational Considerations

The PITT technique requires wells situated so that the potential NAPL source is within the radius of influence of the wells used to inject/withdraw the conservative and nonconservative tracers. It is important for the tracers to be nontoxic and to have nondetectable background concentrations and for the partitioning tracer to have an affinity for the particular NAPL found at the site.

Applications and Cost

The PITT technique is ideal for in situ characterization of NAPL and is limited by the well network available to perform the injection / withdrawal tests and the project budget.

The cost of PITT technology may range from $100,000 to $400,000 depending on the scale of the test.

Benefits

- Provides quantitative estimates of NAPL volume
- Can be used to design remediation methods targeting a NAPL source
- Is relatively accurate compared with other in situ tests that utilize point values or small aquifer volumes

Limitations

- Expensive
- Technology is patented
- Not economical for smaller sites
- Most application experience is with solvents

Case Study

Hill Air Force Base, Utah

The PITT technique was used at Hill AFB in 1996 to demonstrate surfactant remediation of a DNAPL-contaminated site. Partitioning interwell tracer tests were used to estimate the volume of DNAPL in place and to assess the performance of the surfactant remediation. Three constituents make up more than 95 percent of the DNAPL present at the site: TCE; 1,1,1-trichloroethane (1,1,1-TCA); and PCE. Approximately 99 percent of the DNAPL source within the test volume was recovered by the surfactant remediation leaving a residual DNAPL saturation of only approximately 0.0004. The PITT technique successfully provided quantitative estimates of DNAPL volume before and after an in situ remedial activity at this site.

4.2.5.3 In Situ Bio/Geochemical Monitor (ISM)

Tool Description

Chemical and biochemical reactions affect the geochemical composition of groundwater and the migration and persistence of inorganic and organic contaminants. The ISM allows in situ measurement of biochemical reaction rates and retardation factors for both soluble organic and inorganic compounds. The ISM maintains the geochemical integrity of sediment and groundwater and may be less expensive than collecting similar data via conventional tracer tests.

Installed below the water table, the ISM isolates a small section of the aquifer with minimal disturbance of the geological medium. Groundwater is removed from the test chamber, reactants and tracers are added, and it is reinjected into the test chamber. Samples are then collected for laboratory analysis to monitor the biological and geochemical reactions occurring within the test chamber (Solinst, 1998).

Operational Considerations

The ISM requires saturated aquifers with a hydraulic conductivity greater than 10^{-4} centimeters per second (cm/sec). The monitor is installed through the center of a hollow-stem auger with a special "trap door" cutting head and pushed into the soil using either a hydraulic ram or vibrating hammer. The ISM consists of a stainless steel test chamber, open at the bottom and bounded at the top by a set of coarse and fine mesh screens. These screens are used to draw groundwater into the test chamber. A depth-adjustable central spike with a fine mesh screen extends into the test chamber. In biodegradation studies, groundwater samples are collected via the spike. To create a one-dimensional flow system in retardation studies, water is injected through the spike and collected from the outer screens (Nielsen, 1996; Solinst, 1998).

The ISM has a relatively complex design and requires knowledgeable personnel to design, implement, and interpret tests. A numerical model may be necessary to estimate degradation rate constants from test data (Neilsen, 1996).

Applications and Cost

The ISM can be used in aquifers with a hydraulic conductivity greater than 10^{-4} cm/s where in situ biochemical reaction rates and retardation factors must be determined. The cost of ISM is approximately $3,000 for equipment purchase only, not including installation, analyses, and trained personnel (Solinst, 1998).

Benefits

- Reduces the time and cost of obtaining site-specific biological and geochemical data (as compared with injection-withdrawal and field tracer tests)
- Provides in situ measurement of biochemical reaction rates
- Provides estimated rates of denitrification during biodegradation
- Provides estimated retardation factors for organic and inorganic compounds

Limitations

- Design, implementation, and interpretation of ISM tests are complex and require knowledgeable personnel
- A numerical model may be necessary to help estimate the degradation rate constant
- Typically applicable only with permeability greater than 10^{-4} cm/sec
- Small aquifer volume tested means results may be affected by small-scale variations in aquifer properties

Contact

Solinst Canada Ltd., (800) 661-2023, www.solinst.com

4.2.6 Other Tools

Listed below are other tools and techniques that offer a range of advantages for expediting site characterization but do not fit in one of the categories previously described. These tools include:

- Microscale solvent extraction
- PAH sample filtration
- Inverse specific capacity method
- Hand-augering / trenching / pot holing
- Noise and fugitive emission controls
- Information management

4.2.6.1 Microscale Solvent Extraction

Tool Description

Conventional laboratory analysis of PAHs in soil and water matrices may take 2 weeks from the time samples are received to the time the results are released. Current EPA-approved Methods 8240, 8270, and 8310 require a 24-hour extraction period before analysis can be run. EPRI has developed a technique for analysis that requires smaller sample volumes and shorter laboratory turnaround times than conventional techniques. Because microscale solvent extraction (MSE) methods require smaller sample volumes, MSE analytical methods are ideal for alternative collection methods that yield smaller sample volumes (e.g., Geoprobe™ and Hydropunch™) (EPRI, undated).

MSE methods are microextraction techniques used by a lab to prepare samples for analysis by gas chromatography. Microextraction is defined as a single-step extraction process with a high liquid-sample-to-solvent ratio. Historically, microextraction techniques have been limited by extraction inefficiencies, in precision, and elevated detection limits. However, recent MSE methods involve multiple microextraction steps as needed to improve analyte recovery and reduce detection limits. EPRI reports that the comparison of MSE results to standard USEPA methods ranges from good to excellent.

As a screening tool, MSE methods provide quantitative results for individual PAH components at the site characterization or remediation stages of a project. Several states have approved MSE methods for specific projects either in lieu of certified laboratory analysis or as a percentage of samples being submitted to a certified laboratory for confirmation analysis.

Operational Considerations

MSE methods were originally developed for use at an on-site laboratory; therefore, these methods can easily be used in an on-site laboratory to perform expedited characterization of PAHs.

Soil sample volumes required for MSE analytical methods can be up to six times smaller than those for conventional laboratory analysis. Turnaround times for MSE methods range from 12 hours to 2 weeks; in contrast, laboratories following conventional EPA protocol may have turnaround times ranging from 24 hours to 4 weeks.

Many conventional laboratories may not have instrumentation and protocol readily available for MSE methods. Analytical laboratories chosen to use MSE methods should be interviewed and audited prior to contracting and use.

Applications and Cost

MSE methods are applicable during the site characterization or remediation stages of a project where quantified concentrations of PAHs are needed.

The cost of MSE depends on the laboratory (prices vary widely) and the types and numbers of samples to be analyzed. Analytical costs can be as much as 50 percent lower than costs for conventional analyses. In addition, using MSE methods may significantly reduce overall project costs because of rapid turnaround times on lab results (which could translate into fewer mobilizations/demobilizations of field crews) and lower sample volumes (which permit alternative drilling/sampling techniques to be implemented).

Benefits

- Small sample volumes
- Fast laboratory turnaround times
- Minimal laboratory waste
- Quantitative results for individual components

Limitations

- Relatively new procedure

Contact

Electric Power Research Institute, (800) 313-3774

4.2.6.2 PAH Sample Filtration

Tool Description

When monitoring wells are constructed or aquifers are disturbed (e.g., pumped at rates higher than natural groundwater flow), small particles called colloids are mobilized in the groundwater. Although it is common practice to require turbidity during sampling to be less than 5 nephelometric turbidity units (NTUs), in practice it may be difficult to acheive (unless low-flow sampling techniques are employed). Artificially suspended particles become entrained in groundwater at flow rates higher than the natural groundwater flow rate and these suspended particles may bias concentration data higher than true concentration levels. PAHs are relatively immobile, hydrophobic compounds that tend to sorb onto soil particles. Because PAHs have low aqueous solubility values and a high affinity to sorb onto artificially mobilized suspended particles, it may be more representative to filter

PAH samples that are collected under high turbidity conditions (Backus, 1993; and Saar, 1997).

A standard environmental filter has a pore diameter of 0.45 micrometers (mm). Research has shown that naturally transported colloids may have diameters up to 2 mm. Therefore, a drawback to sample filtering is that naturally transported colloids may be filtered, in addition to the artificially mobilized colloids, and contaminant concentrations may be understated depending on the importance of natural colloid transport at a particular site (Backus, 1993).

In deciding whether to filter groundwater samples or not, the potential for natural and artificial colloid transport should be considered. Because sampling turbid groundwater often necessitates the use of field filters, it is recommended that all attempts be made to lower the turbidity (e.g., low-flow sampling) and thereby avoid filtering altogether. Analysis of both filtered and unfiltered samples from the same location may provide an indication of the relative impact of colloidal transport; however, it cannot distinguish between natural and artificial colloidal transport.

Operational Considerations

Turbidity is often highest in formations characterized by reducing conditions and fine-grained or poorly sorted lithologies. Typically, filtering is not an issue with samples collected from higher permeability (and presumably lower turbidity) formations. For groundwater samples collected in a temporary monitoring well or borehole, turbidity will most likely be relatively high, so it may be justifiable to field filter because of the large amount of artificially entrained colloids (Backus, 1993).

The ultimate use of the sampling data should also be considered when deciding whether or not to filter a groundwater sample. In general, the following guidelines may be used in making this decision:

- Filtered samples should be used whenever groundwater samples are collected to determine whether water quality has been affected by a hazardous substances release that includes metals or chemicals susceptible to colloidal transport.
- Samples should not be filtered when a water supply well is sampled.
- For data to be used in risk assessment, unfiltered samples should also be considered if the hydrogeologist suspects that colloidal transport could be significant.
- It is generally recommended that both filtered and unfiltered samples be collected at the same time for comparison.

Several different filter types are available at equipment supply stores. Filtration may occur in an open filter funnel with filter discs (the sample is pulled through the filter with a vacuum system) or by using an in-line filter where the sample is pushed through a self-contained, enclosed filter. Many different filter sizes are available. A 0.45-mm filter should be used unless some information is known regarding the distribution of natural and artificial colloids at a particular site.

Applications and Cost

Field filtering of PAH samples is applicable to groundwater samples that have relatively high turbidity levels (e.g., greater than 5 NTUs). One key drawback, however, is that filtering also removes naturally transported colloids. The presence of naturally transported colloids should be taken into consideration when analyzing the results.

The cost of field filtering equipment is nominal compared with the cost of sample analysis and may add a small labor cost to complete the field filtering. Analyzing both filtered and unfiltered samples doubles analytical costs and raises the labor costs associated with groundwater sampling.

Benefits

- Eliminates the high bias in PAH concentration measurements introduced by artificial colloidal entrainment
- A simple technology requiring minimal training

Limitations

- PAH concentrations determined from filtered samples may not include naturally transported colloids and create a low bias
- Dissolved or colloidal contaminants may adsorb onto the filter or apparatus

4.2.6.3 Inverse Specific Capacity Method

Tool Description

The hydraulic conductivity of the interval yielding water to permanent monitoring wells is routinely estimated by pumping tests or slug tests conducted in a well. The inverse specific capacity method estimates the hydraulic conductivity of the depth interval that provides the water sample in a temporary monitoring well.

Specific capacity refers to the flow of water yielded by a well at a drawdown or drop in the water surface. The specific capacity test is usually estimated by pumping a well at a fixed rate and monitoring the drop in the level of water in the well over time. The inverse specific capacity method sets the drawdown at a predetermined level and then measures the yield required to maintain this predetermined drawdown (Wilson, 1997).

Operational Considerations

The inverse specific capacity test is conducted using the GeoProbe™ as a temporary monitoring well. Once the GeoProbe™ (or similar technology) rods are pushed to the desired depth, ¼” plastic tubing, a peristaltic pump, and a measuring cup collect the inverse specific capacity data. Typically, a peristaltic pump can lift up to 40 feet of head; therefore, when groundwater is more than approximately 40 feet bgs, the inverse specific capacity method is not feasible.

Site-specific permeability data from conventional means (pumping or slug tests) are needed to calibrate the inverse specific capacity data if quantitative data are desired. In addition, the inverse specific capacity method is only appropriate for zones with hydraulic conductivities ranging from 10^{-1} to 10^{-5} cm / sec (Wilson, 1997).

Applications and Cost

The inverse specific capacity method can be used with any direct-push drilling technique where groundwater can be sampled via suction lift using a pump on the surface. The cost is negligible assuming that a peristaltic pump and push sampler are already in use at the site. The typical time for a test ranges from 5 to 10 minutes.

Benefits

- Provides quantitative estimates of hydraulic conductivity in a temporary monitoring well
- Allows variation in horizontal hydraulic conductivity to be assessed in the vertical direction for preferential pathway identification

Limitations

- Provides hydraulic conductivity estimates for a small volume of aquifer
- Requires hydraulic conductivity values from conventional monitoring wells on site for calibration
- Only approved for zones having permeability ranging from 10^{-1} to 10^{-5} cm / sec

4.2.6.4 Hand Augering/Trenching/Pot Holing

Tool Description

Hand augering, trenching, and pot holing are well-accepted, simple techniques for gathering shallow geologic information and for surveying and delineating wastes from former MGP sites. All three methods require minimum equipment and result in the gross collection of geologic and analytical information.

Hand augers are thin-tube cylinders that are driven by hand into the ground. Typically 18 inches in length, hand augers split lengthwise to allow insertion of three stainless steel or brass rings. When driven into the ground, soil is pushed into the rings, which are then removed and used for sample analysis.

Trenching and pot holing both use equipment such as shovels or backhoes to excavate soil. Trenching is basically excavation along a single axis, often designed to create vertical walls that can then be mapped for geologic strata. Pot holing incorporates the random or sequential digging of pits and is typically used to grossly delineate the extent of MGP residues. A photograph of a typical trench is shown below.

Operational Considerations

Trenching and pot holing are easy exploratory techniques that often do not require regulatory (e.g., boring) permits. They are especially effective at large sites with few above- or underground obstructions and where labor is inexpensive. Both techniques will, however, create significant quantities of waste, which can be costly to handle and dispose of if found to be hazardous.

Similar to trenching and pot holing, hand augering is effective at sites where labor is inexpensive. In contrast to trenching and pot holing, hand augering is effective for sites where there are significant above- or underground obstructions and/or at sites where generation of wastes is a significant concern. In contrast to trenching and pot holing, hand augering is limited to the depth to which the sampler can be driven, often a maximum of 3 to 5 feet bgs**.**

Applications and Cost

As noted above, trenching, pot holing, and hand augering are inexpensive if labor is inexpensive. The costs for the techniques vary directly with local labor costs.

Benefits

- Can be used to expose buried objects
- Discrete and can get into tight locations (hand augering)

Limitations

- Hand augering and pot holing are depth limited
- Trenching and pot holing are visible to the public
- Borehole and slope stability may be a problem
- Waste management may be a problem with trenching and pot holing

Case Study

Marysville-1 Former MGP Site

The MGP formerly operating at PG&E's Marysville Service Center was originally located in what is now an operating substation. Because of clearance restrictions and operating limitations, standard drilling methods (e.g., hollow-stem auger drilling) could not be conducted within the substation. Hand auger sampling was initially performed within the substation in areas historically thought to contain some former MGP structures (e.g., the generating and scrubbing building, lampblack dump, and gas holder). Soil samples collected via hand augering indicated that MGP residues did exist in soil within the substation. Partial substation de-energizing was subsequently arranged, and limited access drilling (via Precision Sampling's limited-access direct-push drilling rig) was conducted to approximately 28 feet bgs within the substation.

Contact

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4.2.6.5 Noise and Fugitive Emission Controls

Tool Description

During site characterization and remediation, noise and / or emission controls may be required for regulatory, political, and safety reasons. Sound barriers, such as curtains or berming, may be necessary to minimize noise in residential areas during 24-hour drilling or near school / community centers during the day. One primary disadvantage of sound barriers and tenting to control noise is that decreased air flow may result in the work area, so emission controls (such as ventilation blowers) may have to be increased.

Construction activities such as grading, excavation, material handling, and travel on unpaved surfaces can generate substantial amounts of dust. Water sweeping or soil stabilization may be necessary at sites where airborne dust could pose a health and safety risk. Foam suppressants and chemical applicants such as magnesium chloride are also used to control dust. A site can be completely enclosed (tented) to prevent dust migration off-site; however, ventilation of work areas may be required.

Operational Considerations

All alternatives to control noise and fugitive emissions should be considered. If, for example, several days of 24-hour construction in a residential area are required, it may be more cost effective to forgo noise control and place nearby residents in hotels during the noisiest construction. Seasonal and diurnal constraints such as cooler weather or the calmest periods of the day should be factored into the remediation schedule. To control noise from generators and other construction equipment, one alternative is to use an electrical power source or advanced muffler systems. Monitoring the effectiveness of the controls is critical. Noise monitors are readily available from field equipment catalogs and provide constant-readout, time-averaged, or peak sound levels. Airborne emission levels are often monitored visually or with the use of a hand-held meter that gives real-time measurements of dust, aerosols, fumes, and mists. Monitoring of noise or dust levels may occur at the project site perimeter if off-site migration is the primary concern; monitoring may take place close to sources if worker safety is the primary concern.

Applications and Cost

Noise and / or fugitive emission controls should be used at any site where regulatory, health, or community concerns dictate action. The cost and level of effort to implement noise and / or emission controls vary widely. Water sweeping at a smaller construction site may cost from $200 to $500 per day; renting and installing a sound barrier around a drilling operation may cost $5,000; and complete enclosure of a site could easily add tens of thousand of dollars to project costs.

Benefits

- Protects community and workers
- May satisfy regulatory requirements
- Limits noise and air pollution
- Minimizes migration / transport of contaminants during remediation

Limitations

- Noise emission control on a large scale may involve prohibitive cost and effort
- Controls may make investigations / remediations logistically more complex and / or may limit the rate of completion

4.2.6.6 Information Management

Tool Description

There is a growing awareness of the importance of information management in expediting and streamlining remedial action planning, coordination, and execution. In particular, information management tools can:

- Ensure that the quality and integrity of environmental data are maintained throughout the site investigation process.
- Facilitate data interpretation and remedial selection.

At the project level, information management tools allow geologists, engineers and project managers to plot and view site characterization data quickly and efficiently. At a management level, a database management system may provide a “big picture” of critical issues, significantly improving an environmental manager’s communications with decision makers both within their organizations and with regulatory agencies. The efficiencies gained through the effective use of database and information management systems allows resources to be shifted from labor-intensive data manipulation to analyzing data through efficient management and focusing on solutions and project closure.

A variety of commercial software packages are available to support this type of initiative. The most common characteristic of these systems is that the system architecture is designed around a common premise that all project information can be assigned a spatial address, converted to electronic formats, and entered into a geographic information system (GIS) project database.

The architecture of a GIS-based information management system must allow for multi-level participation in information use since all information is derived from a common database. Once construction of the database architecture is complete, any portion of the database can be accessed depending on user needs but not changed. This approach allows all information to be available in one location significantly reducing time spent searching for information — a common challenge without effective data management tools. The features and benefits of using a GIS-based information management system are as follows:

Feature	Benefit
Data associated with unique spatial address	High quality data integrity
Information available electronically in one location	Time accessing information reduced
Elimination of manual data handling	Reduction in data transcription errors and compounding of errors over the remainder of the project

If correctly utilized, GIS-based information management systems can reduce cycle times for completing site characterization and remediation activities.

Operational Considerations

Prior to the purchase and/or development of an information or database management system, specific project needs must be evaluated. Questions to be answered include the following:

- What kind of data may be expected?
- How much data may be expected?
- Who will be the direct users of the package (e.g., one computer operator, multiple personnel)?
- How would prospective system users interact with the system (e.g., read-only access)?
- What is the level of the users' computer literacy?
- How would the data be manipulated (e.g., tables, boring logs, cross-sections, figures, interaction with groundwater flow models)?
- How much would the client need to spend?
- What are the software's system requirements (e.g., memory, coprocessor speed)?

The answers to these questions will aid the manager in selecting the right package for the project. Options will range from sophisticated GIS packages such as ArcInfo, to less sophisticated software packages built on common computer software such as ACCESS and AutoCAD.

Applications and Cost

Data and information management packages are applicable to all projects that generate data. The level of sophistication required will vary, however, from site to site. Smaller sites may be able to use common software packages such as ACCESS, DBASE, LOTUS, and EXCESS to easily tabulate and sort data. Larger projects may look towards more sophisticated, expensive software such as ArcInfo or BOSS GMS. Costs, too, will vary considerably depending on the management system purchase, associated hardware costs, and labor costs for data entry and system maintenance.

Benefits

- Helps ensures data quality and integrity
- Facilitates data use and interpretation
- Combined with electronic deliverables from analytical laboratories, may reduce data entry costs
- May reduce labor costs associated with report preparation

Limitations

- System may act only as data repository
- No single system may be able to fulfill all project requirements

Case Study

Bordentown Gas Works, Bordentown, New Jersey

The Public Service Electric and Gas Company (PSE&G) former Bordentown Gas Works site is located in a mixed commercial and residential area in Bordentown, New Jersey. The site was used as an MGP from approximately 1853 to 1900 and as a gas distribution regulating station until 1960. Since the demolition and clearing of structures, the site has remained vacant and remains the property of PSE&G.

A pilot project was initiated by PSE&G as part of an ongoing joint effort between PSE&G and the New Jersey Department of Environmental Protection (NJDEP) to continue to streamline remedial processes associated with MGP cleanups. A remedial investigation was previously conducted at the site, indicating that remedial actions were required:

- Collect additional site characterization data to support PSE&G’s remedial objective
- Conduct a remedial alternative analysis

- Prepare and submit a remedial action selection report to NJDEP. The report included a comprehensive evaluation of environmental conditions at the site using a GIS-based data management system developed and applied by Woodard & Curran, Inc.

The Woodard & Curran environmental data management system was selected to aid in data evaluation to understand the site's environmental conditions; facilitate real-time interpretation of subsequent field work activities to complete site characterization; streamline mapping and interpretation of geologic and contaminant profiles; and assist in the evaluation of viable remedial options. The system consisted of a customized software platform based on ESRI's ArcView® as the overall platform and GIS\Solutions' GIS\Key™ as the application software for environmental data. The key benefit of utilizing ArcView® is that the software has the ability to import information from a variety of software packages (including those specifically designed for environmental data management) increasing the robust performance of this system.

The data management work performed by Woodard & Curran, Inc., on this project consisted of the following tasks:

- Electronic loading of environmental data (approximately 10,000 records) into the system
- Querying of data to understand site conditions and identify data gaps in concert with the NJDEP
- Development of a supplemental investigation work plan to address data gaps
- Input of supplemental data (approximately 4,000 records) for use in mapping, assessment of environmental conditions at the site, and identification of areas of concern for evaluation of remedial alternatives
- Review of findings in a series of workshops with the NJDEP prior to preparation of the remedial action selection report

This project resulted in improvements in the overall site investigation process, including reductions in cycle time for data collection, compilation and interpretation. Supplemental field work activities filled in the data gaps and allowed the project team to focus on remedial alternatives. Field and laboratory data were in the system within one week of completion and were available to the project team for interpretation and analysis immediately thereafter. The project team conducted technical workshops to keep NJDEP apprised of results throughout the process. The data management system was used at project meetings to conduct "what if" scenarios, creating contaminant isopleths and assisting in understanding hydrogeologic features at the site. The final report included a summary of findings and conclusions that were developed in concert with NJDEP throughout the project. In summary, the application of the information management system assisted the project team and resulted in the following:

- Reductions in time and cost required to complete the site investigation
- Increased reliability of data interpretation
- A simplified way of presenting site environmental data to NJDEP and permitted them to be part of the project team evaluating site conditions and remedial alternatives in real time

Contacts

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