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EXAMPLES OF ALTERNATIVES TO CONVENTIONAL GROUND-WATER MONITORING WELLS AT SMALL, DRY OR REMOTE LANDFILLS

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1. Electromagnetic Induction (EMI)

Method: Frequency domain EMI uses a transmitter coil to generate an electromagnetic field that induces eddy currents in the earth below the instrument. Secondary electromagnetic fields created by the eddy currents are measured by a receiver coil that produces an output voltage that can be related to subsurface conductivity.

Can Delineate: Leachate (plume detected when contaminants change conductivity of ground water), also: soils/geology, buried wastes, possibly NAPLs.

Depth of Penetration:

- Station profiling: 0-60 meters standard; 100s of meters achievable
- Continuous profiling: 0-15 meters standard; 50 meters achievable

Station profiling currently is defined as one-time field point measurements; continuous profiling refers to monitoring over a timed interval, and is not limited to a single, one-time measurement.

Limitations:

- More susceptible to metals and powerlines on surface than ER.
- Lacks vertical resolution and depth of ER (resolution fades beyond three major subsurface layers or at depths >60 m).
- Data reduction less refined than with ER.
- Penetration >60 m expensive.

Advantages:

- Faster and less expensive than ER for mapping of shallow, conductive, contaminant plumes (<15 m).
- Equipment readily available.
- Rapid resolution and data interpretation.
- Better lateral resolution than ER in station profiling mode.
- Does not demonstrate ER's electrode contact problem and operates well through dry sands, concrete, blacktop, etc.

Cost: Low to moderate

Detects: Electrical conductivity

Implementability: Easy. Equipment is readily available and EMI surveys can be performed quickly at a reasonable cost.

Need for Permanent Stations: No. Equipment is mobile.

Practical for Annual/Semiannual Use: Yes. Surveys may be conducted at relatively low cost and method is non-destructive.

Applicability to Alaska and West U.S.: Station and continuous profiling depths adequate for both. *No information encountered in the literature suggests geologic limitations.*

Environmental Media Monitored: Electrically conductive solids and liquids - generally dominated by conductivity of pore fluid in saturated solids.

Continuous Monitoring Achievable: Yes. 0-15 meters standard; <50 meters achievable.

Current Uses: In the last decade, EMI has replaced DC resistivity as the most commonly used surface geophysical method for contaminant plume detection.

Case Studies:

- A high degree of correlation between EMI data and ground-water quality data is reported by Chapman and Bair (1992) in the identification of a brine plume resulting from controlled road surface application of brine (to simulate road de-icing). The EMI method was found to be more effective at greater depths, while ER methods were more reliable at shallow depths.

- Benson et al. (1985) assert that the degree of success of EMI methods in mapping contaminant plumes depends strongly on the electrical contrast between the contaminated ground water and the native, uncontaminated water.
- Conductivity has been linked to estimating TDS content, which may be used at landfills to estimate the extent of fill, to estimate the relative saturation of the fill, and identify changes in fill type (Jansen et al., 1992).

- EM methods were successfully used at an eastern Pennsylvania landfill to delineate the horizontal extent of all infilled materials, map existing contaminant plumes, and detect buried metallic objects in the landfill area. In addition, a conductive contaminant plume was detected and the observed lobe orientation indicates that the hydraulic movement of the plume is in direct response to leachate collection system operations (McQuown, et al., 1991).

- Davis (1991) reports successful delineation of two types of ground water contamination by use of EMI surveys. Zones of suspected ionic contamination (identified by high conductivity) were distinguished from zones of organic (NAPL) contamination (identified by low conductivity) at a former coal gasification plant. Subsequent monitoring well placement (based on the EMI data) yielded sample analyses which provided a high correlation of the type of contamination detected in the ground-water samples and by the EMI survey.

REFERENCES

Benson, R.C., M.S. Turner, W.D. Volgelson, and P.O. Turner. 1985. Correlation Between Field Geophysical Measurements and Laboratory Water Sample Analysis. Surface and Borehole Geophysical Methods in Ground Water Investigations, Second National Conference and Exposition, National Water Well Association, Dublin, Ohio, pp. 178-197.

Chapman, M.J., and E.S. Bair. 1992. Mapping a Brine Plume Using Surface Geophysical Methods in Conjunction with Ground Water Quality Data. Ground Water Monitoring Review, Summer, pp. 203-209.

Davis, J.O. 1991. Depth Zoning and Specialized Processing Methods for Electromagnetic Geophysical Surveys to Remote Sense Hydrocarbon Type Ground Water Contaminants. Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 905-913.

Jansen, J., B. Haddad, W. Fassbender, and P. Jurcek. 1992. Frequency Domain Electromagnetic Induction Sounding Surveys for Landfill Site Characterization Studies. Ground Water Monitoring Review, Fall, pp. 103-109.

McQuown, M.S., S.R. Becker, and P.T. Miller. 1991. Subsurface Characterization of a Landfill Using Integrated Geophysical Techniques. Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 933-946.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

U.S. Environmental Protection Agency. 1993b. Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites. A Reference Guide. EPA/625/R-92/007.

2. Electrical Resistivity (ER)

Method: The resistivity of subsurface materials is measured by injecting an electrical current into the ground by a pair of surface (current) electrodes and measuring the resulting potential field (voltage) between a second pair of (potential) electrodes. Increasing the spacing between the current and potential electrodes increases the depth of the sounding measurement. Wenner, Schlumberger, and dipole-dipole are the three arrays most commonly used.

Can Delineate: Leachate (plume detected when contaminants change conductivity of ground water), also: soils/geology, buried wastes, possibly NAPLs.

Depth of Penetration: Station profiling: 0-60 meters standard; up to kilometers achievable.

Limitations:

- Affected by cultural features (e.g., metals, pipes, buildings).
- Very susceptible to ground contact/electrode problems.
- Cannot be used in paved areas.
- Use limited in wet weather.
- Slower and less sensitive than EMI.
- Deep soundings are labor and time intensive.
- Data interpretation requires complex software and/or an expert (especially in non-horizontal strata).

Advantages:

- Superior to EMI for horizontal strata.
- Depth limited only by ability to extend electrode spacings.
- Results can be approximated in the field.

Cost: Low to moderate.

Detects: Resistivity

Implementability: Easy. Equipment widely available, mobile, easy to operate, and rapid.

Need for Permanent Stations: No. Equipment is mobile.

Practical for Annual/Semiannual Use: Yes. Station profiling may be conducted at relatively low cost and method is non-destructive.

Applicability to Alaska and West U.S.:

- Station profiling depth adequate for both
- Alaska and West U.S. in regions of unconsolidated and relatively homogeneous sediment (e.g., alluvial valleys, floodplains)
- Limited use in wet weather may apply to permafrost regions of Alaska

- West U.S. in regions of horizontal strata of any rock type (the range of resistivity of soils and geologic material are well established)

Can be used in regions of non-complex dipping strata, however data requires careful interpretation (e.g., expert)

Environmental Media Monitored: Conductive solids and liquids - expressed as resistivity (voltage).

Continuous Monitoring Achievable: No.

Current Uses: Conventional DC resistivity is commonly used for geologic/ hydrogeologic characterization and preliminary mapping of contaminant plumes. DC resistivity is less commonly used for mapping changes in plume configuration.

Case Study:

Using a Schlumberger array, Schoepke and Thomsen (1991) performed a subsurface geology investigation for the purpose of comparing three data interpretation methods for use in a glacial environment which is both geologically complex and inaccessible for drilling. The Ohm-Feet Method was found to be superior to the Barnes Layer Method and Moore's Cumulative Method for the identification of three aquitard/aquiclude layers by providing a stronger differentiation between hydrogeologic units, a better estimate of depth, and a higher degree of sensitivity in detecting small changes in resistivity.

REFERENCES

Shoepke, R.A. and K.O. Thomsen. 1991. Use of Resistivity Soundings to Define the Subsurface Hydrogeology in Glacial Sediments. Proceedings of the Fifth Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 917-929.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

U.S. Environmental Protection Agency. 1993b. Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites. A Reference Guide. EPA/625/R-92/007.

3. Self-Potential

Method: Electrodes are used to measure natural electrical potentials developed locally in the subsurface. **Spontaneous polarization** is a natural voltage difference that occurs as a result of electric currents induced by disequilibria within the earth. **Streaming potential** is an electrokinetic effect related to movement of fluid containing ions through the subsurface.

Can Delineate: Leachate (plume detected when contaminants change conductivity of ground water), also: soils/geology, buried wastes.

Can Not Delineate: NAPLs

Depth of Penetration: Station profiling, 0-tens of meters.

Limitations:

- Interpretation highly qualitative.
- Susceptible to interferences due to variations in lithology and vegetation.
- Methods are inferior to that of ER and EMI for mapping of contaminant plumes.

Advantages:

- Equipment simple and easy to operate.
- Can locate leakage paths (e.g., through a liner).

Cost: Low

Detects: Natural electrical potentials in the subsurface.

Implementability: Easy. Equipment is simple and easy to operate.

Need for Permanent Stations: No, however permanent stations may be constructed.

Practical for Annual/Semiannual Use: Yes. Method may be performed at low cost and is non-destructive.

Applicability to Alaska and West U.S.: Station profiling depth most likely achievable for both. *No information encountered in the literature suggests geologic limitations.*

Environmental Media Monitored: Electrically conductive solids and liquids.

Continuous Monitoring Achievable: No.

Current Uses: The Self-Potential method is most commonly used in mineral exploration where ore bodies are in contact with solutions of different compositions. Use at contaminated sites is uncommon.

REFERENCES

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

U.S. Environmental Protection Agency. 1993b. Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites. A Reference Guide. EPA/625/R-92/007.

4. Induced Polarization (IP) and Complex Resistivity

Method: Induced polarization (IP) measures the electrochemical response of subsurface material (primarily clays) to and injected current. Equipment and field procedures are similar to that for DC resistivity, in fact IP instrumentation can be used to conduct conventional ER surveys. The methods of IP and complex resistivity are nearly identical. Complex resistivity is a more refined version of IP in that the frequency characteristics of different materials are measured over a larger frequency spectrum. The result is improved differentiation of subsurface materials, however the instrumentation for signal detection and analysis is more complex and more expensive.

Can Delineate: Leachate (plume detected when contaminants change conductivity of ground water), also: soils/geology, buried wastes, possibly NAPLs.

Depth of Penetration: Station profiling, up to kilometers achievable.

Limitations:

- IP surveys are slower and more expensive than ER surveys and have many of the same disadvantages relative to EMI methods.
- In absence of clays, ground penetrating radar is likely to be better for detecting organic contaminants (method operates best in presence of clays).
- Injected currents may cause corrosion of buried metallic materials (pipelines, etc.).
- Susceptible to interference from buried cultural features (e.g., pipelines and metallic containers).

Advantages:

- More sensitive than conventional ER resistivity in differentiating subsurface materials.
- Might be superior to EMI methods for organic contaminant plume detection when organic contaminants interact with clays.

Cost: IP cost is low to moderate, complex resistivity cost is moderate to high.

Detects: Electrochemical responses of subsurface material (primarily clays) to an injected current.

Implementability: *No definitive data, however IP applications are similar to ER, suggesting a relatively simple implementation.*

Need for Permanent Stations: No. Equipment is mobile.

Practical for Annual/Semiannual Use: Yes. Surveys may be conducted at relatively low cost and method is non-destructive.

Applicability to Alaska and West U.S.:

- Station profiling depth adequate for both.
- Alaska and West U.S. in regions of unconsolidated and relatively homogeneous sediment (e.g., alluvial valleys, floodplains).

The primary advantage of the IP method is greater resolution for differentiation of clayey and non-clayey unconsolidated materials, suggesting that the method is best suited for the same environments as ER (alluvial valleys and floodplains), however it is unclear as to whether the use of IP would be limited to these environments.

Environmental Media Monitored: Electrically conductive solids and liquids.

Continuous Monitoring Achievable: No.

Current Uses: Has been used infrequently, but with success in groundwater exploration. Use of conventional IP has not been reported at contaminated sites. Use of complex resistivity for detection of organic contaminant plumes is in developmental stages.

REFERENCES

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

U.S. Environmental Protection Agency. 1993b. Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites. A Reference Guide. EPA/625/R-92/007.

5. Airborne Electromagnetics (AEM)

Method: Similar to surface EMI, however the survey involves that use of a transmitter in a plane, while the receiver is either fixed at the ground surface, or moving (e.g., placed in a separate plane, or carried by the same plane as a towed bird).

Can Delineate: Leachate (plume detected when contaminants change conductivity of ground water), also: soils/geology, buried wastes, possibly NAPLs.

Depth of Penetration: 0-100 meters

Limitations:

- Spatial resolution is usually too coarse for localized contamination investigations; provides much less detail than ER or EMI methods.

Advantages:

- Faster and might be more cost effective than surface methods where sites are inaccessible and/or large areas need to be evaluated.

Cost: Moderate.

Detects: Electrical conductivity variations across strata.

Implementability: Requires access to a plane, in addition to EMI equipment. Surface EMI implementation is quick and inexpensive.

Need for Permanent Stations: Not applicable.

Practical for Annual/Semiannual Use: Method is non-destructive, however cost-effectiveness would be determined by site specifics.

Applicability to Alaska and West U.S.:

- Profiling depth adequate for both.
- Alaska - may be used to locate shallow subsurface permafrost and aquifers.

No information encountered in the literature suggests geologic limitations.

Environmental Media Monitored: Electrically conductive solids and liquids - generally dominated by conductivity of pore fluid.

Continuous Monitoring Achievable: No.

Current Uses: Commonly used in mineral exploration, less frequently used in hydrogeologic studies.

REFERENCES

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

U.S. Environmental Protection Agency. 1993b. Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites. A Reference Guide. EPA/625/R-92/007.

6. Ground Penetrating Radar (GPR)

Method: A transmitting and a receiving antenna are dragged along the ground surface. The small transmitting antenna radiates short pulses of high-frequency radio waves (ranging form 10 to 1,000 mHz) into the ground and the receiving antenna records variations in the reflected return signal.

Can Delineate: Leachate (plume detected when contaminants change conductivity of ground water), also: soils/geology, buried wastes, possibly NAPLs.

Depth of Penetration: Continuous profiling: 1-25 meters; up to 100s of meters achievable.

Limitations:

- Depth of penetration less than that of ER or EMI, and is further reduced in moist and/or clayey soils and soils with high electrical conductivity.
- Bulkiness of equipment limits use in rough and inaccessible terrain.

Advantages:

- GPR provides the greatest resolution achievable by geophysical methods.
- Best penetration in dry, sandy or rocky areas (<25 m).

Cost: Moderate.

Detects: Reflected high-frequency radio waves.

Implementability: Equipment operation seems relatively simple. Bulkiness of equipment may impose limitations on the range of terrains surveyed.

Need for Permanent Stations: No, however permanent stations may be constructed.

Practical for Annual/Semiannual Use: Method is non-destructive, however cost-effectiveness would be determined by site specifics (e.g., accessibility of terrain).

Applicability to Alaska and West U.S.:

- Continuous profiling depth adequate for both.
- Alaska and West U.S. in arid regions (method well suited for sandy, rocky areas).

No information encountered in the literature suggests geologic limitations.

Environmental Media Monitored: Radio wave transmissivity of solids and liquids.

Continuous Monitoring Achievable: Yes.

Current Uses: Probably the most frequently used geophysical method after EMI and ER.

Case Studies:

- Annan et al. (1991) and Redman et al. (1991) have initiated an experiment in which to study geophysical anomalies associated with DNAPLS in the subsurface. The experiment involves several phases of controlled injections of a DNAPL (PCE) into a designated cell of the Borden Sand (Canada) the area around which is contained by a barrier wall, followed by the implementation of a GPR survey. At the time of publication, only the first round of the study had been completed, however preliminary results indicated that GPR methods may be able to delineate porosity variations as small as 2% within a "uniform" sand. Since DNAPL migration is regulated by permeability, this technique may have potential in the prediction and/or identification of likely migration pathways. Redman et al. (1991) reported that the pooled DNAPL could be detected with GPR. Researchers in this experiment were able to monitor the site with geophysical techniques before and after the injection, thus allowing comparisons in the data.

REFERENCES

Annan, A.P., P. Bauman, J.P. Greenhouse, and J.D. Redman. 1991. Geophysics and DNAPLS. Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 963-977.

Redman, J.D., B.H. Kueper, and A.P. Annan. 1991. Dielectric Stratigraphy of a DNAPL Spill and Implications for Detection with Ground-Penetrating Radar. 1991. Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 1017-1030.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

U.S. Environmental Protection Agency. 1993b. Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites. A Reference Guide. EPA/625/R-92/007.

7. Transient Electromagnetics/Time Domain Electromagnetics (TDEM)

Method: TDEM instruments use a large transmitter loop on the ground and a receiving coil to measure the decaying magnetic field generated by a descending eddy current that is generated when the transmitter loop current is suddenly turned off. These measurements can be interpreted in terms of the subsurface conductivity as a function of depth.

Can Delineate: Leachate (plume detected when contaminants change conductivity of ground water), also: soils/geology, buried wastes.

Can Not Delineate: NAPLs.

Depth of Penetration: Station profiling, 0-150 meters standard; 2000+ meters achievable.

Limitations:

- Not suitable for very shallow applications (less than about 150 feet).
- Site surface features might create difficulties in placement of the transmitter loop, which is typically 10 to 20 meters on a side.

Advantages:

- TDEM overcomes most of the disadvantages of EMI compared to ER, at a somewhat higher cost than EMI.
- Able to penetrate great depths.

Cost: Moderate to high.

Detects: Electrical conductivity.

Implementability: Limited primarily by surface features (accommodation of loop placement by local topography).

Need for Permanent Stations: No. Equipment is mobile.

Practical for Annual/Semiannual Use: Method is non-destructive, however may be cost-prohibitive on a frequent basis.

Applicability to Alaska and West U.S.:

- Limited application in shallow environments precludes use in Alaska and in West U.S. aquifers less than 50 m deep.

No information encountered in the literature suggests geologic limitations.

Environmental Media Monitored: Electrically conductive solids and liquids.

Continuous Monitoring Achievable: No. Measurements of the magnetic field can be made only after current is turned off and field begins to decay. However, discreet measurements can be made at a frequency sufficient to approximate continuous monitoring (expensive).

Current Uses: The development of TDEM equipment suitable for use at contaminated sites is relatively recent, but the increased depth of penetration and better resolution of layers is likely to result in greater use of this method.

REFERENCES

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

U.S. Environmental Protection Agency. 1993b. Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites. A Reference Guide. EPA/625/R-92/007.

8. Very-Low Frequency (VLF) Resistivity

Method: Similar to EMI and ER methods. VLF resistivity instruments measure the ratio of electric to magnetic fields generated by military communication transmitters (around 15 to 25 kHz). The depth of penetration of low frequency radio waves is related to the resistivity of the subsurface materials.

Can Delineate: Leachate (plume detected when contaminants change conductivity of ground water), also: soils/geology, buried wastes.

Can Not Delineate: NAPLs.

Depth of Penetration: Station and continuous profiling: 0-20 m standard for contaminant plumes; 60 m maximum penetration depth.

Limitations:

- Need to account for change in land surface (i.e., readings taken at different elevations are not comparable without adjustment).
- Resolution of two-layered earth requires that the resistivity of one of the layers be known or assumed.

Advantages:

- Transmitting waves are generated off site at no cost.
- Does not share contact resistance problems that can occur with ER methods.

Cost: Moderate to high.

Detects: Electrical conductivity.

Implementability: Easy. Similar to ER and EMI.

Need for Permanent Stations: No. Equipment is mobile.

Practical for Annual/Semiannual Use: Method is non-destructive, however cost-effectiveness would be determined by site specifics.

Applicability to Alaska and West U.S.: Limit of 20 m penetration for plume detection is well suited to Alaska's shallow aquifers; may be insufficient for some regions of the West U.S. *No information encountered in the literature suggests geologic limitations.*

Environmental Media Monitored: Electrically conductive solids and liquids.

Continuous Monitoring Achievable: Yes, 0-20 m standard for detection of plumes; <60 m achievable.

Current Uses: Value has been demonstrated at contaminated sites, but used less frequently than EMI and ER methods.

REFERENCES

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

U.S. Environmental Protection Agency. 1993b. Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites. A Reference Guide. EPA/625/R-92/007.

9. Seismic Refraction

Method: An artificial seismic source (hammer, controlled explosive charge) creates direct compressional waves that are refracted by traveling along the contact between geologic boundaries before signals from the wave reach the surface again. The refracted waves are sensed by receiving geophones, which are attached to a seismograph. The seismograph records the time of arrival of all waves, using the moment the seismic source is set off as time zero. Travel time is plotted against source-to-geophone distance to produce a time/distance (T/D) plot. Line segments, slope and break points in the T/D plot are used to identify the number of layers and depth of each layer.

Can Delineate: Leachate, also: soils/geology.

Can Not Delineate: Buried wastes or NAPLs.

Depth of Penetration: Station profiling, 1-30 meters standard; 200+ meters achievable.

Limitations:

- Use might be limited by cold or wet weather.
- Relatively time and labor intensive.
- Good data acquisition and interpretation requires experienced operator.
- Does not detect contaminants in ground water.

Advantages:

- Equipment is readily available, portable, and relatively inexpensive.
- Technique is accurate and provides rapid areal coverage.

Cost: Low to moderate.

Detects: Change in wave velocity through monitored strata.

Implementability: Easy. Equipment readily available.

Need for Permanent Stations: No. Equipment is mobile.

Practical for Annual/Semiannual Use: Possibly not. Detonations are destructive and method may become costly on a frequent basis.

Applicability to Alaska and West U.S.:

- Depth penetration of 30 m is applicable to Alaska and shallower West U.S. aquifers.
- Method may not be effective in permafrost regions of Alaska.

No information encountered in the literature suggests geologic limitations.

Environmental Media Monitored: Seismically conductive solids and liquids.

Continuous Monitoring Achievable: No.

Current Uses: Commonly used for near surface hydrogeologic studies and subsurface characterization of contaminated sites.

REFERENCES

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

U.S. Environmental Protection Agency. 1993b. Use of Airborne, Surface, and Borehole Geophysical Techniques at Contaminated Sites. A Reference Guide. EPA/625/R-92/007.

10. Neutron Probe (Nuclear Borehole Logging)

Method: Probe contains a source of neutrons and detectors that are arranged so that the output is primarily a function of the hydrogen content of the borehole environment. The various available probe designs can be broadly classified as surface probes which do not require a borehole and depth probes which require a borehole.

Radius of Measurement: 6.0-12.0"

Limitations:

- Inadequate depth resolution makes measurement of absolute soil moisture content difficult and limits its use in studying evaporation, infiltration, percolation, and placement of the phreatic water surface.
- The moisture measurement depends on may physical and chemical properties of the soil which are, in themselves, difficult to measure.
- Radioactive sources require special care in handling.
- The sphere of influence of depth probes does not allow accurate measurements of soil water at or near the soil surface, unless special instruments designed specifically for use on the soil surface are used.
- Boron, cadmium, chloride, hydrocarbons, and other fast neutron moderators can interfere with moisture determinations.
- Difficult to define horizontal distribution of water since moisture close to the neutron source has a more pronounced effect on counting rate than pore water at a greater distance.
- Might not be accurate enough to detect slight water content changes in the dry range to infer water movement.
- Less accurate for monitoring water movement than matric potential heads, especially when water flow is in channels that transmit water without detectable changes in water content.
- Chemicals might cause deterioration of some access tubes (e.g., aluminum).

Advantages:

- Rapid method of measuring moisture that is independent of temperature and pressure.
- Average moisture contents can be determined with depth.
- The system can be interfaced to accommodate automatic recording.
- temporal soil moisture changes can be easily monitored.
- Rapid changes in soil moisture can be detected.
- Readings are directly related to soil moisture.
- Measurements can be made repeatedly at the same site.
- Measurements are nondestructive once access tubes are installed
- Can be used under almost any borehole conditions.
- Moisture can be measured regardless of its physical state.

Cost: See case studies.

Implementability: Method is commonly used and technology is readily available.

Need for Permanent Stations: Access tubes or boreholes must be installed. Probes may be moved within access tubes.

Practical for Annual/Semiannual Use: Once installed, measurements may be made any time.

Applicability to Alaska and West U.S.: Applicable to arid regions. Areas where there is considerable moisture in the unsaturated zone may not be suitable.

Environmental Media Monitored: Moisture, regardless of physical state.

Continuous Monitoring Achievable: No.

Current Uses: Most commonly used nuclear method for measurement of soil moisture

Case Studies:

- Kramer et al. (1992) provide the following information: (1) neutron data can be statistically evaluated; (2) the minimum diameter of the access tubes required for the probes is 2 inches; (3) operation of the neutron probe requires minimal training; (4) the one-time cost of the probe is $4300 to $6900; (5) the probe weighs less than 30 lbs and is 1 foot long; (6) the probe can measure moisture changes of 1 to 5 volume percent; (7) neutron probes "are sensitive to hydrocarbon liquids"; (8) the radius of measurement is 6 to 24 inches; (9) boron and chlorine [Note: "chloride" indicated above] reduces radius of measurement and may make detection impossible; (10) results are best with 2-inch metal casings; (11) the probe may be used in grouted wells; (12) environments with a high degree of "background moisture" (e.g., clays) may make detection impossible; (13) to report data as units of volumetric soil moisture content, calibration curves must be developed from field or laboratory data.

- Kramer et al. (1990) determined that neutron probes may be used in wells with borehole diameters up to 14 inches and grout thicknesses up to 3 inches. Stainless steel access tubes produce better results than PVC.

- Reaber and Stein (1990) discuss the successful installation of neutron probes at a site in California (Colorado Desert Geomorphic Province). "The vadose zone monitoring network consists of four neutron probe access tubes installed at a 45 degree slope below the landfill." "Soil moisture measurements were made at 2.5 foot increments by lowering the neutron probe down the access tubes....Soil moisture contents will be monitored on a quarterly basis. The quarterly monitoring results will be compared with the background data and previous results to assess whether a significant change in soil moisture content has occurred. An increase in moisture content of 5% will be considered to represent a significant change....If a significant change in the soil moisture content is detected, the appropriate agencies would be notified, and an assessment program would be implemented to evaluate whether the change may be related to leakage from the landfill."

- Unruh, et al. (1990) discuss the successful application of neutron probes at a the Imperial Valley facility in Imperial Valley, California. The environment is arid, with evaporation rates of approximately 11 inches per month, and precipitation of 4 inches per year. The site is underlain by clays, silts and silty sands (the unsaturated zone is comprised of clays and silts). The neutron probe system consists of access tubes composed of 6-inch diameter steel casing. The expected operating life of the access tubes is 30 years. Quarterly monitoring has been conducted over a two-year period with good results.

. Franklin et al. (1992) provide details of neutron probe monitoring at six facilities in California. The authors discuss three objectives that the access tube system should meet: (1) "The design should position the access tubes in the most likely pathway of waste constituent migration on the basis of a well considered and developed conceptual migration model;" (2) "The system must be installed in relatively dry materials to provide a high contrast to moisture migration;" and (3) "It should be in materials that allow the instrument to detect significant moisture changes, some coarse-grained materials reach saturation within instrumental variation ranges." The authors report that the installation costs for vertical designs is $75 to $90 per linear foot. Installation costs for horizontal designs is $10 to $40 per linear foot. Operation costs for both designs is approximately $20 per linear foot per quarterly event.

REFERENCES

Franklin, J.J., M.E. Unruh, and V. Suryasasmita. 1992. Neutron Probe Monitoring in the Unsaturated Zone, Case Histories from Several Sites Comparing Problems and Utility of Horizontal and Vertical Access Tube Installations. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 103-117.

Kramer, J.H., S.J. Cullen, and L.G. Everett. Summer 1992. Vadose Zone Monitoring with the Neutron Moisture Probe. Ground Water Monitoring Review, pp. 177-188.

Kramer, J.H., L.G. Everett, and S. Cullen. 1991. Innovative Vadose Zone Monitoring at A Landfill Using the Neutron Probe. Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 135-149.

Kramer, J.H., L.G. Everett, and L.A. Eccles. 1990. Effects of Well Construction Materials on Neutron Probe Readings with Implications for Vadose Zone Monitoring Strategies. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 1303-1317.

Reaber, D.W. and T.L. Stein. 1990. Design and Installation of a Detection Monitoring Network at a Class I Facility in an Arid Environment. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 299-311.

Unruh, M.E., C. Corey, and J.M. Robertson. 1990. Vadose Zone Monitoring by Fast Neutron Thermalization (Neutron Probe) -- A 2-Year Case Study. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 431-444.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume I and Volume II. EPA/625/R-93-003a and EPA/625/R-93/003b.

11. Borehole Geophysical Techniques

The following Borehole Geophysical methods that allow the use of cased boreholes:

I. *Electric Logs*

Fluid Conductivity -- Only effective in screened portion of well. Commonly used in logging uncased bedrock wells. Borehole must be filled with conductive fluid. Used at contaminated sites to obtain information on the concentration of dissolved solids in borehole fluid; locating sources of saltwater leaking into artesian wells, aiding in interpretation of electric logs. Detects dispersion, dilution, and movement of waste. Detects location of water level or saturated zones. A specially designed probe that records only the electrical conductivity of the borehole fluids by placing electrodes inside a protective housing. The most common type of probe measures the AC-voltage drop across two closely spaced electrodes, which is a function of the resistivity of the fluid between the electrodes. The probes commonly include temperature sensors that allow simultaneous measurement of temperature and fluid resistivity because temperature corrections are usually required for the readings.

Limitations:

- Calibration required with fluids of known conductance and measurements need to be corrected to standard temperature.
- Disturbance in the borehole by drilling, cementing, fluid density differences, and thermal convection will affect measurements and might require months to reestablish chemical equilibrium.
- Setting of screens at the wrong depth can cause the measurement of fluid conductivities that are not representative of fluid in the aquifer.

Advantages:

- Relatively simple and inexpensive type of log.
- Interpretation is relatively straightforward (as long as first two limitations are considered).

II. *Electromagnetic Logs*

a. Induction (specifically, Slimhole EM Probe) -- Casing must be non-metallic. Borehole may be wet or dry. Detects conductive plumes. Detects location of water level or saturated zones. Used at contaminated sites to perform lithologic characterization; locating the zone of saturation; performing physical and chemical characterization of formation fluids/ ground-water quality. The slimhole EM probe is a relatively new tool designed specifically for use in fresh water and has gained rapid acceptance for use in ground-water studies. The probe contains a transmitter coil on the upper part, which induces eddy current in the formation around the borehole, and a receiver on the lower part. Conductivity is measured using the same principles as surface EM induction measurement. A major advantage of the slimhole EM probe is that it can be used in wet or dry holes (2 inches minimum diameter) and can be used in PVC cased holes. (Also same general advantages and limitations of surface EM methods.)

b. Dielectric -- For low frequency tools, casing must be non-metallic (high frequency method does not work in cased holes). Borehole may be wet or dry. Casing must be minimum of 5" - 6.5" diameter (i.e., larger than a typical monitoring well). This is a relatively new tool with great potential for characterization of hydrocarbon contaminated sites and porosity. The tool currently is not commonly used, but its use at contaminated sites has been to measure formation porosity and measure hydrocarbon thickness on ground water. (The tool was developed by the petroleum industry to distinguish between fresh water and oil.) Dielectric tools use electromagnetic waves to measure the dielectric permittivity (or dielectric constant) of a formation. This is a measure of the relative ability of electrically charged particles in a formation to be polarized by an electric field. Dielectric logging devices are either low frequency or high frequency. (Frequencies used in the low frequency tools are an order of magnitude higher than EMI tools.) The tool uses transmitting antennas to measure phase shift and attenuation. Measurements can be used to calculate porosity in the saturated zone, and relative water and hydrocarbon saturation.

Limitations:

- New tool, not commonly used.
- Require large hole diameter.
- High frequency tools do not work in cased holes.
- Primary use appears to be in detecting hydrocarbons, unsure of effectiveness in detecting inorganic contaminants.

Advantages:

- Can be used as an alternative to density and neutron logs if the radioactive sources are a concern.
- Good potential for characterizing NAPLs.
- Low frequency tools penetrate 15 to 45 inches, are relatively sensitive to borehole irregularities, and can be run in open or nonmetallic cased holes.

III. *Nuclear Logs*

a. Gamma-Gamma (density log, transmittance log, gamma ray attenuation, gamma ray transmission, gamma ray absorption, gamma ray scattering) -- Borehole may be wet or dry. Detects location of water level or saturated zone, detects moisture content. Used at contaminated sites to measure bulk density, porosity, and moisture content. A beam of gamma photons is directed at the borehole sides and a detector records the radiation that is attenuated and scattered in the borehole and surrounding rock. For deep boreholes, the scattering method is usually used, with a single-probe configuration that has the source and detector on the same unit. These probes can use either a single-source or a dual-source. for near surface monitoring of soil moisture, the double tube transmission method is more commonly used, in which the source and detector are lowered down tow parallel boreholes.

Limitations:

- Field instrumentation is expensive, difficult to use, and requires frequent maintenance.
- Radioactive sources require special handling.

- Large variations in bulk density and moisture content can occur in highly stratified soils and limit spatial resolution.
- Unreliable in soils that swell and shrink with water content changes or with freeze and thaw.
- Instrument are susceptible to electronic drift and instabilities in the count rate.
- Soil temperature variations might affect accuracy of measurements.
- Failure to install equidistant dual access tubes will introduce errors in measurements.
- Double-tube method limited to relatively shallow depths because of difficulties in installing equidistant tubes to greater depths.
- Installation of equidistant tubes for double-tube method also difficult in steep terrain an din rocky materials.
- Accurate measurement of moisture requires independent measurement of dry bulk density.
- Leakage of water from perched layers along the wall of the casing might cause erroneous moisture measurement.
- Mixtures of water and other liquids will yield erroneous logs unless calibrated for the mixture.
- Water moving through the sampling area at a constant rate will not change water content resulting in erroneous interpretation that there is no water movement in the soil profile.

Advantages:

- Good method for measuring formation properties (bulk density, porosity, and moisture content).
- Data can be obtained over very small horizontal or vertical distances (layers of soil as thin as 1 cm).
- Average moisture contents can be determined with depth.
- The system can be interfaced to accommodate automatic recording.
- Temporal soil moisture changes can be easily monitored with high accuracy and precision.
- Measurements are nondestructive once access tubes are installed.
- Can be used to calculate porosity when the fluid and grain densities are known.
- Can be used under almost any borehole conditions.
- Near-surface measurements are more accurate than for neutron depth probes.

b. Neutron [SEE NEUTRON PROBE] -- Borehole may be wet or dry. Detects location of water level or saturated zone, detects moisture content.

c. Neutron-Activation -- Borehole may be wet or dry. A relatively new method that is used at contaminated sites to perform remote identification of elements present in ground water and adjacent rocks and to detect the flow of fluids behind casing. The method uses neutrons to "activate" stable isotopes in the borehole and identify the activated element by measuring the amount and energy level of emissions. A large number of elements can be detected with this method, with sensitivities ranging from ppm to percentage levels, depending on the element.

Limitations:

- Instrumentation is complex.
- Larger neutron source is required compared to conventional neutron logging in order to keep neutron activation time within practical limits.
- Radioactive sources require special handling and generally limits use to deep boreholes (a neutron generator does not emit radiation when it is turned off).
- Equipment may not be readily available.

- Quantitative analysis is not likely to be as accurate as laboratory analysis using the same technique.
- Logging slow if neutron source is weak or elements of interest require a long activation time.

Advantages:

- Can be used in a wide variety of borehole conditions.
- The same probe can be used to create a standard gamma log and for neutron thermalization measurements.
- Semi-quantitative analysis of major elements is possible.
- Measuring variations in the concentration of aluminum provides information on clay content.
- Carbon-to oxygen rations and silicon-to-calcium rations from neutron activation logs can be interpreted in terms of lithology and in-situ hydrocarbons.

f. Neutron-Lifetime -- Borehole may be wet or dry. Currently limited use in ground-water investigations (used by petroleum industry to distinguish between oil, gas, and saltwater in cased wells), however may be used at contaminated sites to measure salinity and porosity, and to detect flow of fluids behind casing. The method is a variant of the neutron activation technique. The method uses a pulsed-neutron generator and a synchronously gated neutron detector to measure the rate of decrease of the neutron population. The rate of neutron decay is greatly affected by the chlorine concentration, providing a measurement of salinity and porosity similar to resistivity logs. The method also can be used to detect flowing water behind casings a part of mechanical integrity testing.

Limitations:

- More expensive than conventional neutron log.
- Equipment may not be readily available.
- Radioactive sources require special handling and generally limits use to deep boreholes.

Advantages:

- Borehole effects can be greatly decreased compared to conventional neutron logs by delaying the measuring gate.
- Can provide useful data though casing and cement.
- Neutron generator does not emit radiation when it is turned off.

Radius of Penetration:

Fluid Conductivity: Within borehole
Induction: 30 inches
Dielectric: 15 to 45 inches for low frequency tools
Gamma-Gamma: 6 inches
Neutron: 6-12 inches
Neutron-Activation: Less than Neutron
Neutron-Lifetime: Less than Neutron

General Limitations:

- Most methods would allow owner/operator to determine only that a leachate release had occurred; would not allow owner/operator to determine if hazardous constituents were present. Neutron activation would allow owner/operator report ppm or percentage levels of inorganic elements. Dielectric logs would allow owner/operator to detect the presence of hydrocarbons.

- Borehole geophysical surveys typically are not conducted on the same borehole on a routine basis. Employing routine borehole geophysical monitoring would require routinely drilling boreholes (highly impractical) or casing boreholes and routinely conducting borehole geophysical surveys in the same manner as one would routinely collect ground-water samples.

- Because borehole geophysical surveys do not monitor a large area laterally, the placement of monitored boreholes would have to be considered carefully to be certain of detecting contamination. Because the direction of migration of a release in the unsaturated zone is less predictable than one in the saturated zone, adequately locating boreholes in the unsaturated zone may be more difficult than locating wells.

- It may be unacceptable to implement on a regular basis methods that emit radiation.

Cost: Would need to contact vendors for specific information. To be cost effective, the cost of 1) hiring staff/equipment to perform borehole geophysical monitoring at specified frequency or 2) purchasing equipment and hiring or teaching staff to operate equipment would have to be less than ground-water sampling and laboratory analysis.

Implementability: Some types of equipment are not readily available.

Need for Permanent Stations: Yes. In order for the method to be practical, permanent cased boreholes would have to be established.

Practical for Annual/Semiannual Use: If permanent, cased boreholes were established, boreholes could be monitored at any frequency, cost being the only prohibition.

Applicability to Alaska and West U.S.: Most methods would be applicable in both Alaska and the U.S. West. Neutron activation and neutron lifetime may be applicable only in the U.S. West where wells would be deep enough to use radioactive sources.

Case Studies:

- Mack (1993) discusses the successful application of EM and natural gamma borehole geophysical logging to delineate contaminant plumes in an unconsolidated glacial aquifer at a landfill in Vermont.

- Manchon (1990) discusses the successful application of SP and resistivity logging to detect a contaminant plume at a facility in the Gulf coastal region of the Southwestern U.S.

REFERENCES

Darr, P.S., R.H. Gilkeson, and E. Yearsley. 1990. Intercomparison of Borehole Geophysical Techniques in a Complex Depositional Environment. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 985-1001.

Mack, T.J. Winter 1993. Detection of Contaminant Plumes by Borehole Geophysical Logging. Ground Water Monitoring and Remediation, pp. 107-114.

Manchon, B. 1990. Theory- Rendering Injected Subsurface Waste Non-Hazardous as Demonstrated by Geophysical Logs. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 1017-1031.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume I and Volume II. EPA/625/R-93-003a and EPA/625/R-93/003b.

12. Cone Penetrometer (CPT)

Method: The CPT is a cone-shaped instrument attached to a drill rod that is pushed onto soils to measure resistance to penetration. The use of the CPT is governed by ASTM Standard D3411-86. CPTs are driven by hydraulic rams mounted on a heavy (20 ton) truck. Two types of cones are available, mechanical and electronic. The mechanical cone is less expensive and easier to operate, however is time consuming, labor intensive, and limited to shallow depths. The electronic CPT uses a cone-tipped cylindrical probe (piezocone) which contains instruments capable of measuring pore water pressures, which can indicate the presence of moisture bearing zones. At selected depths, the advance of the CPT is stopped to perform a pore pressure dissipation test, the results of which provide a measurement of the permeability of the soil at that depth. Processing of piezocone measurements produces stratigraphic profiles that identify saturated zones and variations in permeability.

Depth of Penetration:

- 38 m (125 ft) maximum, effective in finer soils and gravelly sands.
- If borehole is pre-drilled, achievable depth is limited only by depth of borehole.

Limitations:

- The sensitive electronic equipment requires a high level of maintenance.
- Achievable depth limited by characteristics of subsurface strata.
- The CPT provides no physical record of soil types; information obtained with the CPT must be inferred or correlated with field observations.
- Size and design of the rigs used to drive the CPT limit the types of areas that can be accessed.

Advantages:

- Minimal site disturbance.
- Method provides high resolution data and depth discrete measurement of hydrostatic pressure and relative permeability.
- Rapid collection of data.
- Conductivity sensors installed in CPTs can be effective in identifying contaminant plumes.

Cost: Low to moderate.

Detects: Penetration resistance; the addition of specialized probes may also allow measurement of in situ pore pressure, resistivity, and sampling of formation fluid and gas, and soil.

Implementability: Relatively easy. Equipment is highly portable.

Need for Permanent Stations: No. The CPT method does not provide a permanent sampling location.

Practical for Annual/Semiannual Use: Yes. Method provides minimal site disturbance and surveys can be conducted quickly.

Applicability to Alaska and West U.S.:

- Achievable depths suitable for Alaska, but method would be limited to shallower West U.S. aquifers.
- Technique conducive to finer grained, uncemented soil and rock. Consolidated rock would require pre-drilling. Not recommended in regions of coarse grained alluvial and glacial fill.

Environmental Media Monitored: Pore water.

Continuous Monitoring Achievable: No. Method generates a stratigraphic profile log.

Current Uses: Originally developed for geotechnical testing of soils for foundation and engineering properties. The CPT provides high resolution stratigraphic and hydrogeologic data which are used to characterize the extent of contaminant plumes, thus optimizing the number and location of wells required for effective site assessment and monitoring.

Case Studies:

- Smolley and Kappmeyer (1991) describe the use of the CPT in conjunction with the Hydropunch for the purpose of investigating a ground water contaminant plume associated with a semiconductor manufacturing facility in California. The CPT was used to define the stratigraphy, consisting of alternating layers of clays, silts, and sands of variable thicknesses. CPT data correlated well with adjacent conventionally drilled and sampled soil borings. 77 CPTs were conducted and 40 Hydropunch samples were collected in 29 days. The authors note that the CPT/Hydropunch technique can be completed in 25 to 35% of the time needed to install monitoring wells, and ground water samples can be collected at 20 to 50% of the cost of installing monitoring wells.

- Erchul (1990) reports that a CPT fitted with a conductivity sensor was effective in identifying a contaminant plume associated with a toxic waste lagoon containing solvents and plasticizers. Conductivity measurements in the soils at two sites surrounding the lagoon corresponded to measurements of the sludge within the lagoon, which suggested that the soil at these sites was contaminated with sludge material. This interpretation was confirmed by soil discoloration. In addition, a laboratory experiment indicated that the flow rate of a contaminant (kerosene), as distinguished by tracking a signature of decreased conductivity, could be determined with the use of a conductivity CPT.

REFERENCES

Berzins, N.A. 1992. Use of the Cone Penetration Test and BAT Groundwater Monitoring System to Assess Deficiencies in Monitoring Well Data. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 327-339.

Erchul, R.A. 1990. A Conductivity Cone Penetrometer to Detect Contaminant Plume Flow Rate. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground

Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 419-428.

Smolley, M. and J.C. Kappelmeyer. 1991. Cone Penetrometer Tests and HydroPunch Sampling: A Screening Technique for Plume Definition. Ground Water Monitoring Review, v. 11, no. 2, pp. 101-106.

Smythe, J.M., P.B. Bedient, and R.A. Klopp. 1988. Cone Penetrometer Technology for Hazardous Waste Site Investigations. Proceedings of the Second National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio. pp. 71-94.

Zemo, D.A., Y.G. Pierce, and J.D. Gallinatti. 1992. Cone Penetrometer Testing and Discrete-Depth Groundwater Sampling Techniques: A Cost-Effective Method of Site Characterization in a Multiple Aquifer Setting. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 299-306.

13. Hydropunch

Method: The Hydropunch is a device that collects one-time ground-water samples in unconsolidated material. It consists of a probe with a sample chamber that can be driven to the desired depth by either conventional drill rods or cone penetrometer (CPT) rods. The outer sleeve of the probe is pulled back exposing a well screen. Ground water enters the screen under hydrostatic pressure and fills the sample chamber. The Hydropunch is capable of collecting ground-water sample volumes between 500 and 1200 mL.

Depth of Penetration:

- 150 feet maximum (highly dependent on type of soil material).
- If borehole is pre-drilled, then only limitation is depth of borehole.

Limitations:

- Provides one-time sample only.
- Cannot be used in very gravelly or consolidated formations.
- Problems in penetrating well-sorted coarse sand might result in a zone of significant contamination being bypassed during sampling.
- The Hydropunch does not provide a permanent ground-water monitoring point for repeated sampling.

Advantages:

- Allows relatively rapid collection of ground-water samples with minimal disturbance of the ground surface.
- Cost-effective method for preliminary contaminant plume delineation based on actual ground-water sampling.
- Can be used in most materials that can be augered or sampled with a split spoon.
- Is less intrusive than conventional drilling methods; by generating no soil cuttings, the problems and costs of disposal of potentially contaminated soil cuttings and purge water are alleviated.

Cost: 30 to 45% of the cost of installing a conventional monitoring well (*relative estimate*).

Implementability: Easy. Equipment is inexpensive and readily available.

Need for Permanent Stations: Not applicable. The Hydropunch does not provide a permanent monitoring station.

Practical for Annual/Semiannual Use: Although less intrusive and initially less expensive than conventional monitoring well installation, repeated monitoring costs by this method, if necessary, may exceed that of permanent well installation, sampling, and analyses.

Applicability to Alaska and West U.S.:

- Required depths may be achieved for both (deeper aquifers in West U.S. may require pre-drilling of boreholes).
- Coarse, gravelly alluvial deposits may pose limitations; Hydropunch use may be restricted to less consolidated surficial deposits.

Environmental Media Monitored: Ground water.

Continuous Monitoring Achievable: No.

Current Uses: Relatively new method that has gained rapid acceptance as a preliminary reconnaissance method. The results presented in the literature generally agree that the quality of the Hydropunch sample data is comparable to data obtained from monitoring wells, which provides a level of confidence suitable for detailed plume delineation programs.
Case Studies:

- Hydropunch technology, in conjunction with a field gas chromatograph, was employed at Myrtle Beach Air Force Base, SC, to delineate the horizontal and vertical extent of a chlorinated solvent plume in the surficial aquifer. Ground-water samples were collected at four discrete depth intervals within predominantly unconsolidated sediments at each of 35 borings completed at the site. Each ground-water sample was analyzed in the field for DCA, TCA, DCE, TCE, and vinyl chloride using a field gas chromatograph by means of a modified U.S. EPA Method 8010. Total VOC concentrations were used to generate contamination contour maps at each of the four sampled depths. The contour maps illustrated the migration pathways of the solvents, which are heavier than water and therefore tend to sink downward through an aquifer system. The Hydropunch/gas chromatograph data were collected within a relatively short period of time, followed by the placement of additional borings to fully delineate the plume boundaries. Within six weeks from the initiation of field work, the 40-acre plume was delineated. Based upon the Hydropunch/gas chromatograph data, 10 permanent wells were installed to monitor plume movement (Prochaska et al., ?).

- The Hydropunch was evaluated in a study at the Savannah River Site in which ground-water samples collected by the Hydropunch were compared to those collected from adjacent monitoring wells. All samples were analyzed for volatile organic contaminants by use of a field gas chromatograph. Preliminary statistical results, using the paired t-test method, suggest that there are no significant differences in contaminant concentration between Hydropunch samples and monitoring well samples (Bergren et al., 1990).

- A separate study at the Savannah River Site also conducted for the purpose of comparing the quality of ground-water samples between the Hydropunch and monitoring wells yielded similar favorable findings. This study was conducted near a coal-pile runoff basin and the target analytes included major cations, major anions, and trace metals, which were analyzed by laboratory methods (Kaback et al., 1990).

- Parks and Hess (1992) provide a rough comparison of costs between using standard site characterization methods vs. using a Hydraulic Sampling Probe (HSP). They state: "Overall, the traditional multiphased site characterization can easily require $100,000 to

$200,000 and take several years to complete." They state that 60 to 70 HSP samples "can be collected and analyzed during a one week investigation at a cost of $10,000 to $15,000. This cost includes analyses in a mobile laboratory parked at the site. Even with the submittal of confirmatory samples, thai approach can reduce analytical costs by 75%..".

REFERENCES

Bergren, C.L., R.C. Tuckfield, and N.M. Park. 1990. Suitability of the Hydropunch for Assessing Groundwater Contaminated by Volatile Organics. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Method. National Ground Water Association, Dublin, Ohio, pp. 387-401.

Edge, R.W. and K. Cordry. 1989. The HydroPunch: An In Situ Sampling Tool for Collecting Ground Water from Unconsolidated Sediments. Ground Water Monitoring Review. v. 9, no. 3, pp. 177-183.

Kaback, D.S., C.L. Bergren, C.A. Carlson, and C.L. Carlson. 1990. Testing A Ground Water Sampling Tool: Are the Samples Representative? Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Method. National Ground Water Association, Dublin, Ohio, pp. 403-417.

Parks, J.H. and E.C. Hess. 1992. Environmental Data Collection and Field Screening During Borehole Drilling and Hydraulic Penetrometer Probing Operations. Proceedings of the HMC/Superfund Conference, pp. 182-187.

Prochaska, K., J. Hartness, and L. Janis. Rapid Delineation of a Chlorinated Solvent Plume Using a HydroPunch and Field GC. Site Assessment/Remediation. pp. 54-57.

Smolley, M. and J.C. Kappelmeyer. 1991. Cone Penetrometer Tests and HydroPunch Sampling: A Screening Technique for Plume Definition. Ground Water Monitoring Review, v. 11, no. 2, pp. 101-106.

U.S. Environmental Protection Agency. 1993. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

Zemo, D.A., T.A. Delfino, J.D. Gallinati, V.A. Baker, and L.R. Hilpert. 1992. Field Comparison of Analytical Results from Discreet-Depth Ground-Water Samplers: BAT Enviroprobe and QED Hydropunch. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Method. National Ground Water Association, Dublin, Ohio, pp. 341-355.

14. BAT System

Method: A special ground-water/soil-gas sampling cone, with a filter mounted inside its stainless steel shaft, either is place in the subsurface as a permanent installation or attached to cone penetration rods and pushed into the ground. The probe contains an evacuated glass sampling tube that connects to the filter element with a hypodermic needle when the desired sampling depth is reached. 50 mL samples are collected in the field with pre-sterilized and pre-evacuated glass vials that are sent directly to the laboratory. Two types of BAT samplers are available: the MK2 probe and the Enviroprobe.

Depth of Penetration:

- 100 feet max (highly dependent on type of soil material).
- If borehole is pre-drilled, then only limitation is depth of borehole.

Limitations:

- Provides one-time sample only (unless permanent installation is used).
- Cannot be used in very gravelly or consolidated formations.
- One-time sample volumes are smaller than Hydropunch.
- Problems in penetrating well-sorted coarse sand might result in a zone of significant contamination being bypassed during sampling.

Advantages:

- Allows relatively rapid collection of ground-water samples with minimal disturbance of the ground surface.
- Cost effective method for preliminary contaminant plume delineation based on actual ground-water sampling.
- Can be used in most materials that can be augered or sampled with a split spoon.
- Permanent installation for routine sampling is possible.
- Can be used to sample soil gases and soil water in the vadose zone.

Cost: Not determined.

Implementability: Easy. Similar to Hydropunch implementation.

Need for Permanent Stations: No, however the BAT system will allow permanent station installation.

Practical for Annual/Semiannual Use: Although less intrusive and initially less expensive than conventional monitoring well installation, repeated monitoring costs by this method, if necessary, may exceed that of permanent well installation, sampling, and analyses.

Applicability to Alaska and West U.S.:

- Required depths may be achieved for both (deeper aquifers in West U.S. may require pre-drilling of boreholes).
- Coarse, gravelly alluvial deposits may pose limitations; BAT sampler use may be restricted to less consolidated surficial deposits.

Environmental Media Monitored: Ground water.

Continuous Monitoring Achievable: No.

Current Uses: Collecting in situ ground-water samples; measuring pore-water pressure and hydraulic conductivity.

Case Studies:

- Blegen et al. (1988) performed a field comparison in which the performances of seven ground-water devices were evaluated to determine if these devices would yield accurate, precise, and representative data. The sampling devices included a bladder pump, a bladder pump below a packer, a bailer, the Westbay MP System, two in situ BAT devices, and a BAT well probe. The samplers were installed at a site contaminated by a benzene-chlorobenzene plume in the eastern portion of Las Vegas Valley, NV. The comparison was based on the ability of the devices to recover representative concentrations of these volatile organic compounds, as defined by a series of 23 existing monitoring wells in the area known as the Pittman Lateral Transect. The sampling devices were ranked by their ability to minimize volatilization during the sampling process (i.e., those devices which recover the highest levels of VOCs are considered the most accurate). Based upon this assumption and results of the Tukey multiple comparisons test, the BAT sampling devices and the bladder pump produced the most accurate results, while the bailer and Westbay MP System were the least accurate. In terms of precision, the bladder pump ranked highest, followed by the BAT devices, pump/packer combination, Westbay, and the bailer.

- Zemo et al. (1992) conducted a field comparison which evaluated the performances of a BAT Enviroprobe and a Hydropunch. This study was conducted at a site of small areal extent in northern California at which shallow ground water is affected by low to moderate concentrations of VOCs. Four sampling locations were assigned randomly to each sampling device. At each location, two samples were collected and submitted for analysis. The results were evaluated by analysis of variance. Statistical results indicate no statistically significant differences in chlorinated aliphatics concentrations in samples collected by the two devices, suggesting that the two devices may be used interchangeably where chlorinated aliphatic compounds are the target analytes. However, a statistically significant difference in analytical results for chlorobenzene was observed between the two devices, suggesting that they may not be interchangeable when sampling for chlorinated benzenes.

REFERENCES

Blegen, R.P., J.W. Hess, and J.E. Denne. 1988. Field Comparison of Ground-Water Sampling Devices. Proceedings of the Second Annual Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Las Vegas, Nevada.

Mines, B.S., J.L. Davidson, D. Bloomquist, and T.B. Stauffer. 1993. Sampling of VOCs with the BAT Ground Water Sampling System. Ground Water Monitoring & Remediation, v. 13, no. 1, pp. 115-120.

Pohlmann, K.F., R.P. Blegen, J.W. Hess, and J.E. Denne. Undated. Field Comparison of Ground-Water Sampling Devices for Hazardous Waste Sites: An Evaluation Using Volatile Organic Compounds, USEPA Office of Research and Development, EMSL-Las Vegas, USEPA Cooperative Agreement #CR812713-01, 102 pp.

U.S. Environmental Protection Agency. 1993. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume 1: Solids and Ground Water. Appendices A and B. EPA/625/R-93-003a.

Zemo, D.A., T.A. Delfino, J.D. Gallinati, V.A. Baker, and L.R. Hilpert. 1992. Field Comparison of Analytical Results from Discreet-Depth Ground-Water Samplers: BAT Enviroprobe and QED Hydropunch. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 341-355.

15. Geoprobe

Method: The Geoprobe is a small diameter percussion driven probing tool which can be used for the recovery of soil vapor, soil core and ground-water samples. Mechanized, vehicle mounted soil probe systems apply both static force and hydraulically powered percussion hammers for tool placement. The Geoprobe is driven to the depth desired below the water table; then the detachable drive point is removed from the end of the rod, allowing ground water to enter the rod at the base of the hole. Polyethylene tubing (with a bottom check valve) is then lowered inside the rods to the base of the hole. The check valve allows ground water to enter the tubing and prevents it from escaping. When enough water is collected, the tubing is extracted from inside the rods, and the water in the tubing is decanted into a glass vial.The two versions of the Geoprobe used for ground-water sampling are the screen point ground water sampler and the mill-slotted well point.

Depth of Penetration: Static force alone, 0-10 meters; applying percussion force, in excess of 21 meters.

Limitations:

- Only applicable at shallower depths.
- Depth achieved dependent on type of subsurface material; probing ineffective in cemented soils or rock.
- Mill-slotted well point: design does not allow closing of slots while probe is being driven, thus subjecting samples to potential cross contamination.

Advantages:

- Equipment is mobile.
- Method does not produce borehole cuttings, thus alleviating the problems and costs of cuttings and purge water disposal.
- Less intrusive than well installation.
- Sample collection is rapid.
- Tool allows collection of soil, soil gas, and ground-water samples.
- Allows on-site delineation of VOCs (using an on-site laboratory).

Cost: Lower than conventional monitoring well installation, sampling, and analyses.

Implementability: Easy. Equipment is mobile, sample collection is rapid and relatively inexpensive.

Need for Permanent Stations: Permanent stations not necessary. One presumably could monitor in approximately the same locations during each sampling event, but sampling points typically are at a higher density than typical monitoring wells.

Practical for Annual/Semiannual Use: Although less intrusive and initially less expensive than conventional monitoring well installation, repeated monitoring costs by this method, if necessary, may exceed those of permanent installation, sampling, and analyses.

Applicability to Alaska and West U.S.:

- Achievable depths adequate for Alaska and shallower West U.S. aquifers.

- Suitable for finer grained, less consolidated materials; highly cemented soils and rock may pose limitations.

Environmental Media Monitored: Ground water, soil, and soil gas.

Continuous Monitoring Achievable: No.

Current Uses: As a recent technology, the Geoprobe is noted as a successful, faster and less expensive alternative to traditional monitoring wells.

Case Studies:

- The Winter 1994 issue of "The Probing Times," Geoprobe's newsletter reports that a Model 5400 Geoprobe pushed probes to a record 120 feet on Long Island. The operation took 1½ hours. "The Probing Times" requests that users call them when they are able to push the Geoprobe 100 feet or greater.

REFERENCES

Christy, T.M. and S.C. Spradlin. 1992. The Use of Small Diameter Probing Equipment for Contaminated Site Investigation. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 87-101.

Hess, E., J. Parks, R. Mastrolonardo, and K. Thomsen. 1992. Environmental Data Collection and Field Screening During Borehole Drilling and Hydraulic Penetrometer Probing Operations - Unsaturated Zone. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 765-774.

Wyckoff, J.S. and J.A. Simon. 1992. Recent Developments in Cleanup Technologies. Remediation. Autumn. pp. 459-464.

16. Alternate Ground-Water Monitoring Constituents

Method: Owner/operators would establish a ground-water monitoring system consisting of background and point of compliance wells as directed by the Federal Criteria. Owner/operators would be allowed to monitor ground water for constituents other than those listed on Appendix I. Possible alternate ground-water monitoring constituents include the following:

Water quality constituents necessary for Stiff/Piper diagrams:

- Sodium
- Potassium
- Calcium
- Manganese
- Chloride
- Sulfate
- Nitrate
- Carbonate

Constituents that are considered leachate indicators:

- BOD
- COD
- TOC
- Calcium, magnesium, sodium, chloride, sulfate
- Stable isotopes (e.g., "light" hydrogen is preferentially metabolized in landfills undergoing methanogenesis, ground water is preferentially enriched in deuterium)
- conductivity
- Ph (e.g., research indicates that biodegradation of organic contaminants causes an acidification of ground water in oxidizing environments)
- Hardness (may be related to increasing acidity caused by degradation of organic matter)
- Alkalinity (may be related to increasing acidity caused by degradation of organic matter)
- redox potential
- TDS
- Phosphate
- Ammonia
- Total Kjeldahl Nitrogen (TKN)
- Microbiologic toxicity (LMB system (laser/microbe bioassay). Method uses nineteen isogenic strains of bacillus sybtilis. The response of the bacteria to toxic substances in the solution (e.g., ground-water sample) is monitored by differential light scattering from a laser beam. The different strains of bacteria respond differently to different toxicants and a computer analyzes the measure responses to the known responses to identify the type and concentration of toxicant. LMB is a new technique that has received limited field testing. The ability of the method to distinguish compounds in a real-world complex mixture has not been demonstrated.

The monitoring data could be evaluated using one or more of the following methods:

- Statistical analyses
- Stiff diagrams
- Piper diagrams
- Ion scatterplots

Limitations:

- Would require the installation and sampling of ground-water monitoring wells.
- Would allow owner/operator to determine only that a leachate release had occurred; would not allow owner/operator to determine if hazardous constituents were present.
- May rely on somewhat subjective analyses of data (e.g., Stiff or Piper diagrams), although standard statistical approaches could be applied.
- Many water quality constituents may be naturally occurring (although statistical analyses should account for background).

Advantages:

- Lower cost.
- Greater availability of laboratories (this alternative could be combined with allowing the use of field test kits to provide even easier implementation and lower costs.

Cost: Presumably, the cost of monitoring the selected alternate constituents would be cheaper than monitoring for the Appendix I constituents.

Implementability: Easy. The availability of laboratories to conduct geochemical or water quality analyses is would be greater than laboratories conducting hazardous constituent analyses.

Practical for Annual/Semiannual Use: Yes. Analyses could be conducted at a frequency at least as great as ground-water monitoring outlined in the MSWLF Criteria.

Applicability to Alaska and West U.S.: Applicable to both Alaska and the U.S. West. Option would likely be more costly in the U.S. West where monitoring well depth would be greater.

REFERENCES

Gron, C. Summer 1993. Organic Halogen Group Parameters as Indicators of Ground Water Contamination. Ground Water Monitoring and Remediation, pp. 148-158.

Lee, G.F. and R.A. Jones. 1991. Groundwater Pollution by Municipal Landfills: Leachate Composition, Detection, and its Water Quality Significance. Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 257-271.

Siegel, D.I., D. Stoner, T. Bymes, and P. Bennett. 1990. A Geochemical Process Approach to Identify Inorganic and Organic Ground-water Contamination. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio,, pp. 1291-1301.

17. Field/On-site Laboratory Analyses

Method:

1. Portable Gas Chromatographs with Flame Ionization detector (FID), Photoionization detector (PID), or Electron Capture Detector (ECD). The method is a well established laboratory technology for which experience in field applications is moderate to limited. There are commercially available portable instruments and commercial/custom mobile laboratories available.. The method can be used to analyze air/gaseous and water/aqueous/liquid matrices for volatile and semivolatile organics. Gas chromatography involves the separation of gaseous constituents on a stationary phase in a column, which is either a solid or liquid held on a solid support. Once the analytes have been separated in the column, they are eluted one after another, and then enter a detector attached to the column exit. A FID or PID can be used to detect specific compounds after they have been separated in the GC.

Limitations:

- Less sensitive than mass spectrometers.
- Slower response time than mass spectrometers and calibration is time-consuming.
- Require library of retention times to identify compounds and non-target compounds may be difficult to identify if they are not in library or quality of library match is too low.
- Require bottled gas.

Advantages:

- Fairly portable.
- Very good specificity of compounds, depending on detector, with excellent ability to resolve most components in very complex mixtures.
- Fair sensitivity (ppb to ppm).
- Inexpensive compared to mass spectrometer ($10,000 to $20,000 vs. $50,000 to $200,000.
- GC is the most well developed and accurate field analytical technique for organic compounds when used with an appropriate detector.

2. Flame Ionization detector (FID) (e.g., OVA), Photoionization detector (PID) (e.g., HNu) and argon ionization detector (AID). These methods are well established and routinely used commercially available portable instruments. The methods can be used to analyze air/gaseous matrices for volatile organics. A PID reports concentrations as total ionizable compounds. A FID reports concentrations of total organics as the ppm equivalent to a calibration compound (usually methane). An AID is similar to a PID, with the exception that a PID uses an ultraviolet lamp as an ionizing source, whereas an AID uses and argon lamp.

Limitations:

- Are not specific in their identification of contaminants.
- FID is more complicated than PID and requires hydrogen gas.
- AID is somewhat less sensitive than FID and PID.

Advantages:

- FIDs, PIDs, and AIDs are highly portable and easy to use.
- Relatively inexpensive (about $5,000).
- FID is sensitive to a larger number of VOCs than PID.
- Very rapid response time.
- AID is the most durable detector.

2. Colormetric analyses. Hach test kits are available for Al, Cd, Cr, Co, Cu, Fe, Pb, Mn, Ni, N, P, Ag, and Zn. Hanby test kits are available for petroleum hydrocarbons and PAHs. Other test kits are available for explosives (TNT, RDX), PCBs, and chlorinated organics. Chemical colormetric kits are a well established laboratory technology for which experience in field applications is moderate to limited. Other colormetric kits are a well established and routinely used field technology. Both methods are commercially available as portable instruments for testing water/aqueous/liquid matrices.

Limitations:

- Time consuming if a large number of samples needs to be analyzed.
- Each analyte of interest requires different reagents and test procedures making analysis of multiple analytes time consuming.
- Strict QA/QC procedures are more difficult to follow in the field using test kits.
- Availability of test kits for toxic organics is limited.
- Use of colormetric test kits for field screening of contaminants is promising, but relatively new.

Advantages:

- Relatively simple.
- Best suited for preliminary screening where there only a few analytes or contaminants of concern.
- Field test kits are available for most heavy metals.

3. Immunoassay Techniques for analyzing BTX, PCB, PCBs, pesticides. This method is a well established laboratory technology for which experience in field applications is moderate to limited. The method is commercially available as a field portable instrument for testing water/aqueous/liquid matrices. Immunochemical techniques involve the use of antibody reagents that react with the analyte of interest to produce reactions that can be analyzed colorimetrically.

Limitations:

- Time consuming if a large number of samples need to be analyzed.
- Each analyte of interest requires different reagents and test procedures making analysis of multiple analytes time consuming.
- Strict QA/QC procedures are more difficult to follow in the field using test kits.
- Availability of test kits for specific toxic organics is relatively limited at this time.

Advantages:

- The best suited technique for preliminary screening where only a few contaminants or analytes are of concern.
- Simple, rapid, and inexpensive.
- Potential exists for specific field tests for a large number of toxic organics with very low detection limits (ppb).

4. Ion-selective electrodes for analyzing ammonia, bromide, calcium, chloride, fluoride, hydrogen sulfide, and nitrate. This method is a well established laboratory technology for which experience in field applications is moderate to limited. There exist commercially available portable instruments. The method is suitable for water/aqueous/liquid matrices. Electrodes are designed to detect the presence and concentration of specific ions using a reference electrode. Boreholes must be uncased or screened and filled with fluid.

Limitations:

- Proper calibration is difficult due to interference form different constituents present in many ground waters.
- Some parameters may inhibit electrode's output.
- Constituents for which specific electrodes have been developed are limited.

Advantages:

- Relatively new method with good potential for detection monitoring and preliminary water quality characterization.

- ASTM describes standard terminology, measurement technique, and conditions affecting measurements.

5. Gas detector tubes (for use with soil gas analysis). This method available as a well established and routinely used commercially available portable instrument for detecting volatile organics and toxic gases. Method measures the concentration of specific gases and organic/inorganic vapors by discoloration, which proportional to the amount of material present.

Limitations:

- Generally are inadequate for ambient air sampling due to the low sample volume collected.
- Cross sensitivity to other gases is common.
- Difficult to obtain accurate readings.
- Slow response time is typical.

Advantages:

. Easy to use and relatively inexpensive.
- Most useful in detecting higher concentrations of contaminants.
- ASTM Guidance.

6. Portable X-Ray Fluorescence (XRF) Spectrophotometer. This method is a well established laboratory technology for which experience in field applications is moderate to limited. It is available as a commercially available portable instrument and associated with commercial/custom mobile laboratories. It is used for detecting metals in soil/solid and water/aqueous/liquid matrices. XRF uses primary x-rays to irradiate a solid sample, which causes elements in the sample to emit secondary radiation of a characteristic wavelength. Concentration of an element is proportional to the intensity of the secondary radiation emission. Metals detected: As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sn, and Zn.

Limitations:

- Detection limits for portable instruments (10s to 100s ppm) typically are an order of magnitude higher than ICP-AES.
- Laboratory use with liquid samples requires preconcentration of precipitation, which is time consuming.

- Relatively shallow depth of penetration of soil materials (mm) means that grinding of samples is generally required.

Advantages:

- About 1/10th the cost of conventional laboratory analyses.
- Sample preparation is minimal compared to conventional analytical techniques.
- Allows simultaneous determination of several elements.
- Very portable instruments available.

7. Field tests for pH, alkalinity, acidity, Eh, dissolved oxygen, temperature, electrical conductance. These methods are all well established and routinely used field technologies.

General Limitations:

- Would require the installation and sampling of ground-water monitoring wells.
- Data quality generally much lower than laboratory analyses (most field tests provide Level 1 or "screening" quality data).
- Some methods are semi-quantitative (i.e., provide "less than/greater than" results, or comparisons with color charts).
- Some methods are not contaminant-specific.
- Single field method is not available that provides analysis for full suite of Appendix I constituents. Multiple field methods would be required or option would need to be combined with Alternate Ground-Water Monitoring List option. Moreover, using numerous different test kits, as opposed to analyzing for selected "indicator parameters", may become costly.

General Advantages:

- Samples may be analyzed on-site, does not require incurring laboratory expense.
- Many field analyses provide contaminant-specific results.
- Most of the methods are widely available.
- Most methods are very easy to use (with possible exception of certain field GC methods).

Cost: Cost for each parameter is expected to be considerably less than corresponding laboratory analysis.

Implementability: With the exception of some field GC methods, field tests generally very easy to use. Most methods require establishing and following field QC procedures.

Practical for Annual/Semiannual Use: Practicality for annual/semi-annual use is equivalent to "standard" ground-water monitoring.

Applicability to Alaska and West U.S.: Applicable to both Alaska and the U.S. West.

Environmental Media Monitored: Aqueous, solid, and gaseous media. See "Method" description above.

Current Uses: Field tests are used widely.

REFERENCES

Beemster, B.J. and K. Schlager. 1991. In-situ Ultraviolet-Visible Absorption Spectroscopy: A New Tool for Groundwater Monitoring. Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio,, pp. 3-15.

Crouch, M.S. 1990. A Semi-Quantitative Approach to Soil Vapor Surveys. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Method. National Water Well Association, Dublin, Ohio, pp. 267-277.

Engle, S.W., R.O. Harrison, A. Scallan, and M.C. Meckes. 1992. Site Characterization Alternative: Hydraulic Probe Sampling and Mobile Laboratory Analysis. Proceedings of the HMC/Superfund Conference, pp. 238-241.

Kerfoot, H.B. 1990. Field Evaluation of Portable Gas Chromatographs. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 247-265.

Mapes, J.P., K.D. McKenzie, L.R. McClelland, S. Movassaghi, R.A. Reddy, R.L. Allen, and S.B. Friedman. 1991. Rapid, On-Site Screening Test for Pentachlorophenol in Soil and Water -- PENTA RISc™. Proceedings of the Hazardous Materials Control/Superfund Conference, pp. 522-526.

Murphy, T.M., L.A. Korner, and J.D. Brookshire. 1990. A Comparison of Portable Gas Chromatograph (GC) Headspace Analyses of Ground Water and Soils with Laboratory Results. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 405-418.

Newman, J.L. and G.W. Corbell. 1990. Continuous In Situ Measurements of Nitrates and Other Contaminants Utilizing Specialized Geophysical Logging Devices. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 953-967.

Nielsen, G.L., J.D. Austin, and D. Schmitt. 1992. Optimizing the Use of Field-Portable Gas Chromatographs During Environmental Contamination Investigation and Remediation Projects. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 369-384.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume I and Volume II. EPA/625/R-93-003a and EPA/625/R-93/003b.

18. Fiber Optic Chemical Sensors (FOCS)

Method: A variety of chemical sensors using fiber optic technology are in developmental stages. FOCS are made of a reagent phase, which is physically confined or chemically immobilized at the end of an optical fiber. The reagent phase contains a chemical or immunochemical indicator that changes its optical properties, usually absorbance or fluorescence, when it interacts with the analyte. The optical fiber is a strand of glass or plastic, ranging from tow to several hundred microns in diameter, and acts as a conduit to propagate light to and from the FOCS. The FOCS is placed in the subsurface using a cone penetration rig or into a ground-water monitoring well. The fiber optic cable is attached to a spectrophotometer or fluorometer, which contains a light source (light bulb or laser) and a detector . An excitation signal form the light source is transmitted down the cable to the FOCS, and the sensor fluoresces and provides a constant-intensity light source that is transmitted back up the cable and detected as the return signal. If the target contaminant is present, the intensity of the return signal is reduced and the intensity of light that is recorded by the detector is inversely proportional to the concentration. Fiber optic sensors also are used with the colorimetric borehole dilution techniques. Analyses that can be conducted with solid fiber method include BTEX, DCE, TCE, Carbon tetrachloride, chloroform diesel fuel, JP-5, gasoline and phenol. Analyses that can be conducted with porous fiber method include humidity, pH, ammonia, ethylene CO, hydrazines, and BTX. Immunochemical fiber optics are used to detect semivolatile organics. All methods can detect contaminants in aqueous, solid, and gaseous matrices.

Depth of Penetration: Can be used at any depth.

Limitations:

- Fiber optics is a developing technology with potentially useful field applications, but limited operational and field experience.
- Equipment not readily available.
- Field performance of remote laser-induced fluorescence has been poorer than laboratory results, perhaps due to temperature fluctuations and affect of increased vibration of optics.
- Numerous separate sensors are required for discrimination between specific compounds.
- Turbidity might interfere with readings.

Advantages:

- Provide selective in situ real-time measurements in the field.
- Eliminate sample handling and chain-of-custody concerns.
- Potential for specific detection of a large number of specific organic compounds (theoretically over half the organics on EPA's priority pollutant list)
- Sensors can be placed in small boreholes (0.5-inch diameter), reducing drilling and monitoring well installation costs, or can be used with cone penetration rigs for rapid field screening.
- Field instrumentation is potentially very portable (small enough to fit in a coat pocket).
- Potential for greatly reduced costs compared to conventional sampling and analytical methods for organic contaminants.

Cost: Not determined.

Implementability: Technology is not yet widely available or tested.

Need for Permanent Stations: For routine ground-water monitoring, permanent stations, rather than routine surveys, probably would be the most cost effective.

Practical for Annual/Semiannual Use: Yes. At permanent monitoring stations, assuming cost is not considered.

Applicability to Alaska and West U.S.: Possible limitations include turbidity in ground water.

Environmental Media Monitored: Ground water, soil, soil gas.

Continuous Monitoring Achievable: No.

Current Uses: Relatively new development with excellent potential.

Case Study:

> Beemster et al. (1992) discuss a the advantages of fiber optic probes over fiber optic sensors. Fiber optic sensors are limited by the life of the reagent and the need to use multiple probes to detect multiple contaminants. Fiber optic probes measures the absorption signature of the sample (transmitted wavelengths of light), information that is converted to information about the presence and concentration of the chemicals of interest. The authors note that "The use of ultraviolet-visible absorption spectrometry (UVAS) for direct chemical analysis requires some initial information about the absorption signatures of the individual target chemicals and the background absorption characteristics from other chemicals in the solution to be analyzed. This is not an overwhelming burden for long term monitoring applications where the initial costs to prepare and process a group of samples used as an algorithm training set...are modest when compared to the recurring costs of sample extraction, transport and laboratory analysis." The authors also discuss Liquid Atomic Emission Spectrometry (LAES). LAES can be operated through a flow-through cell or optical probe. Both instruments have been tested only in the laboratory.

REFERENCES

Beemster, B.J., K.J. Schlager, C.A. Bergstrom, and K.M. Rusch. 1992. In-Situ Fiber-Optic Absorption and Emission Spectrometry For Simultaneous Multiple Component Analysis in Groundwater. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 357-368.

Morlock, C.R. 1990. In Situ Monitoring of Gasoline Concentration with Fiber Optic Chemical Sensors. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 31-38.

Smith, J.E., T.M. Bond, J.A. Gilbert, and K.M. Leonard. 1988. Proceedings of the Second National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 3-16.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume I and Volume II. EPA/625/R-93-003a and EPA/625/R-93/003b.

19. SEAMIST

(Science and Engineering Associates Membrane Instrumentation and Sampling)

Method: SEAMIST is a recently developed system that involves placement of a membrane packer in an open borehole. Soil-gas sampling ports attached to flexible tubing are attached to the membrane to create an in situ multilevel sampling system. Multilevel soil pore liquid sampling is accomplished by the placement of absorbent collectors on the outside of the membrane, with leads for measuring electrical resistance running up the inside of the membrane. Stabilization of the resistance readings serves as an indicator that the absorbent pad has equilibrated with the moisture content of the borehole wall. The flexible membrane is then retrieved by a reversal of the process, and the absorbent pads are removed for fluid extraction in the laboratory.

Depth of Penetration: Hundreds of feet.

Limitations:

- Cannot be used in unstable boreholes (i.e., heaving sands).
- Is a new technique for which there has been relatively little experience or independent testing.

Advantages:

- A unit supports the hole wall against the sloughing, eliminating the need for casing and backfilling, provided the borehole is basically stable.
- Multi-level soil-pore liquid and gas sampling from the same borehole is possible, and the method potentially can be used with any type of instrumentation that can be fastened to the membrane fabric.
- Materials are relatively inexpensive, allowing permanent installation, if desired.

Cost: Assumed prohibitive.

Implementability: Not currently implementable because of lack of testing/availability of equipment.

Need for Permanent Stations: Permanent stations are optional.

Practical for Annual/Semiannual Use: Cost may be prohibitive for some time.

Applicability to Alaska and West U.S.: No relevant limitations were noted.

Environmental Media Monitored: Soil-pore liquids and soil gases, might eventually be adapted for ground-water sampling.

Continuous Monitoring Achievable: The literature indicates that the ability to continuously monitor would depend on the type of instrumentation attached to the membrane.

Current Uses: New method for which there is relatively little experience. USDOE is providing R&D funding.

<u>Case Studies:</u>

- Mallon, et al. (1992) discuss the use of SEAMIST to detect tritium in soil. The SEAMIST systems were used in 40-foot boreholes that were drilled with a 4-inch bit.

- Keller (1991) states that "For long term installations, the interior of the membrane can be filled with water or sand.... Later the sand or water can be flushed or blown our to the hole, and the membrane and instrumentation can be removed or replaced." In another mode of application, the membrane is lowered into an uncased hole for 5 to 10 minutes (the borehole must only stay open for this period of time). The author also indicates the technique may be used in a cased borehole.

- Keller and Lowry (1990) state: "The system can install any instrument which can be fastened to the membrane and inverted with it (e.g., thermocouples, thermocouple psychrometers, fiber optics, etc.) or any instrument which can be lowered on the tether (e.g., video camera, neutron probe, natural gamma log, etc.)....A permanent installation (or semi-permanent) is possible by filling the emplaced membrane with sand, grout, foam or other preferred material to hold the membrane against the hole wall."

REFERENCES

Keller, C. 1991. So, What's the Practical Value of SEAMIST? Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 59-73.

Keller, C. 1992. A Serious Vadose Defense of Ground Water from Landfill Contamination -- New Concept, Old Principles. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 73-84.

Keller, C. and B. Lowry. 1990. A New Vadose Zone Fluid Sampling System for Uncased Holes. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 3-10.

Mallon, B., S.A. Martins, J.L. Houpis, W. Lowry, and C.D. Cremer. 1992. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 161-176.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume I and Volume II. EPA/625/R-93-003a and EPA/625/R-93/003b.

20. Vacuum-Pressure and Vacuum High-Pressure Porous Cup Lysimeters

(Suction/Soil Lysimeter, High Pressure-Vacuum Type Porous Cup Sampler, Deep Pressure Vacuum Lysimeter, Ceramic Points)

Method: A porous cup or plate (usually ceramic) is attached to a small diameter tube (usually PVC) that is placed in the soil. A rubber plug is placed in the other end of the tube and small diameter tubing beginning at the base of the ceramic cup runs though the plug to the surface. A second line is placed in the porous-cup-tipped tube, which ends just below the stopper. The shorter line is connected to a pressure-vacuum source. When the unit is in place, a vacuum is applied to draw soil water into the sampler. Pressure is applied to push the sample into the flask.

The High-Pressure Vacuum sampler is similar to the vacuum-pressure sampler except that the sampler is divided into two chambers connected by the line with a one-way valve. When vacuum is applied, the pore water is pulled into the upper chamber. When pressure is applied to drive the sample into the container at the surface, the one-way valve prevents any of the sample from being pushed out the porous cup.

Depth of Penetration: Vacuum pressure, 50 feet; Vacuum High-Pressure, 300 feet.

Limitations:

- Does not sample ground water (leaves questions regarding how owner/operator will evaluate data/release to ground water).
- Will not work in very dry or frozen soils.
- The small volumes of soil pore water sampled may not be representative.
- Suction may affect soil-water flow patterns, so installation of tensiometers is required to determine the correct vacuum to apply.
- Samples might not be representative of pore water because method does not account for relationships between pore sequences, water quality, and drainage rates.
- Contact between cup and soils difficult to maintain in very coarse textured soils, such as gravels, and exposure to freeze-thaw might break contact with soil.
- Cup might be plugged by solids or bacteria.
- Chemistry of soil pore water might be altered in passage through cup (sorption of metals, ammonia, chlorinated hydrocarbons).
- PTFE cups have limited operational ranges.
- Dead space, where fluid in the cup is not brought to the surface, might occur if the discharge tube hangs on the lip of the cup during installation, and some PTFE samplers have permanent dead space.
- Generally is not suitable for bacterial sampling due to screening and adsorption.
- Heavy metals might be sorbed on the porous-cup matrix.
- Some solution is forced back through the walls of the cup when pressure is applied. The high pressure-vacuum type sampler overcomes this problem.

Advantages:

- Allows direct sampling of soil water.
- Can analyze samples for any constituents, although samples may provide inaccurate results for some constituents, as noted above.

- ASTM guidance.
- Several units can be installed in the same borehole for sampling soil water at different depths.
- Successive samples can be obtained from the same depth.
- Inexpensive and simple.
- Can be installed below landfills prior to construction to monitor seepage when facility is operating.

Cost: Sampling and analysis costs assumed to be the same as for "standard" ground-water monitoring wells. Savings in cost should occur with actual equipment (materials), shallower depth of installation, and smaller diameter of borehole. Because of widespread use, equipment costs are probably inexpensive when compared to monitoring well casing and screen.

Implementability: Relatively easy.

Need for Permanent Stations: Yes. Equipment is not mobile.

Practical for Annual/Semiannual Use: Could be implemented at least as frequently as "standard" ground-water monitoring.

Applicability to Alaska and West U.S.: Effectiveness hindered in areas where soils are frozen, in coarse soils, or where subjected to freeze-thaw. Consequently, does not appear applicable to areas where surface transportation will be interrupted as a result of weather conditions (e.g., Alaska). Effectiveness also hindered in areas where soils are very dry (e.g., portions of the U.S. West). Applicability also questionable in portions of the U.S. West underlain by coarse soils. Applicability of various sampler materials will vary with soil moisture conditions (see Case Studies, below).

Environmental Media Monitored: Soil pore water in the unsaturated zone.

Continuous Monitoring Achievable: Not realistically.

Current Uses: Probably the most common method of soil pore water sampling.

Case Studies:

- McGuire and Lowery (1992) studied the effectiveness of vacuum lysimeters constructed of different materials. They found:
  - "In soils with higher moisture content, with larger, more uniform pores (5µm), such as fritted-glass and stainless steel, collected soil water solution at a faster rate and more sample volume for a specific period than the finer-pored (1.2µm) ceramic sampler."
  - "...at lower soil moisture contents, the ceramic sampler performed best and was able to maintain higher vacuums and exclude air entry."
  - PTFE samplers performed poorly.
  - "The ceramic sampler operates over a wider range of soil moisture conditions than do stainless steel, fritted-glass and PTFE samplers. It is well suited for those monitoring applications where sampling is necessary during varying moisture conditions.
  - "Stainless steel and fritted-glass are adapted from those applications where sample collection is desired for a short period when a wetting front is moving thorough the soil.

These samplers perform best in finer-textured soils at soil moisture conditions ranging from near saturation to FMC [field moisture capacity]."

- Gilfilian (1990) presents results of a 24-month field study on the use of PTFE vacuum pressure lysimeters in Wasilla, Alaska. The lysimeters were used to collect samples 5 and 10 feet below municipal wastewater drainfield beds. The author concluded that the operation of the lysimeters was satisfactory, although the following operational difficulties were noted: (1) "during periods of sub-freezing temperatures, an insulated box was placed over the lysimeter sampling tubes, pump, and vacuum lines which prevented the formation of ice on the vacuum line;" and (2) during the first year "vacuum conditions could not be maintained in many of the lysimeters in accordance with the manufacturer's recommendations" and the 5-foot samplers had to be replaced with tube type lysimeters.

- Durant, et al. (1993) report that EPA research has shown that PTFE lysimeters only operate at soil moisture levels between 0 and 7 centibars. They cited research which has shown that most ceramic pressure-vacuum lysimeters only operate at moisture levels between 0 and 60 centibars, and often are installed where soils are too dry. The authors suggest that problems with lysimeters are often traced to improper installation or operation.

REFERENCES

Durant, N.D., V.B. Myers, and L.A. Eccles. EPA's Approach to Vadose Zone Monitoring at RCRA Facilities. Winter 1993. Ground Water Monitoring and Remediation, pp. 151-158.

Gilfilian, R.E. 1990. Cold Climate Application of Lysimeters for Monitoring the Vadose Zone. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 475-482.

McGuire, P.E. and B. Lowery. 1992. Evaluation of Several Vacuum Solution Samplers in Sand and Silt Loam at Several Water Potentials. Fall 1992. Ground Water Monitoring Review, pp. 151-160.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume I and Volume II. EPA/625/R-93-003a and EPA/625/R-93/003b.

21. Thermocouple Psychrometer

(also: Spanner/Peltier psychrometer, Richards-Ogata/wet-loop psychrometer, thermocouple hygrometer, in situ hygrometer)

Method: Soil water potential is calculated based on measurement of relative humidity within the soil voids. Calibration curves relating relative humidity to water potential, osmotic potential, and temperature (if temperature in the subsurface varies) need to be developed in the laboratory. The dew point method is more accurate than the wet bulb method.

Water content can be estimated if a moisture characteristic curve is developed. The soil moisture characteristics curve is a commonly used relationship to define soil hydrologic properties and can be determined from field measurements, laboratory measurements, or empirical relationships.

Soil water flux in the unsaturated zone may be measured by one of several methods: the instantaneous profile method, the draining profile method, the hydraulic gradient method, and the unit hydraulic gradient method.

Depth of Penetration: Have been installed at depths as great as 300 feet.

Limitations:

- Would allow owner/operator to determine only that a leachate release had occurred; would not allow owner/operator to determine if hazardous constituents were present.
- Does not monitor ground water (leaves questions regarding how owner/operator will evaluate data/release to ground water).
- Water content estimates prone to errors due to hysteresis.
- Even in very dry soils, the relative humidity is high, making accurate calibration difficult.
- Good contact between bulb and surrounding material might be difficult to achieve.
- Provides only point measurements.
- Accurate calibration curves for deep regions of the vadose zone might be difficult to obtain.
- Instruments are expensive, fragile, and require great care in installation.
- Contamination of the chamber interior or thermocouple can result in erroneous readings.
- Interference from dissolved solutes is likely in calcium-rich waste and acid media and can cause thermocouple wire corrosion problems.
- Perform very poorly in very wet media (water pressure >1 bar).
- Accuracy of near-surface measurements is adversely affected by diurnal changes in heat flux.
- Unsealed cup units are susceptible to attack by fungi and bacteria.
- Ceramic cup psychrometers respond slowly to rapid changes in moisture content.

Advantages:

- In situ pressure measurements are possible for very dry soils in arid regions.
- Continuous recording of pressures is possible.
- Can be interfaced with portable or remote data collection systems.
- Depth is no limitation.

Cost: Equipment is expensive. Currently no information on cost advantage relative to sampling and analysis of ground water.

Implementability: The use of the equipment has been established, however problems with installation and maintenance may make the method less attractive.

Need for Permanent Stations: Yes. The equipment is permanently installed and cannot be moved.

Practical for Annual/Semiannual Use: Yes. Can provide continuous measurements.

Applicability to Alaska and West U.S.: Applicable only to the U.S. West.

Environmental Media Monitored: Pore water in the unsaturated zone.

Continuous Monitoring Achievable: Yes. Method can continuously record pressure.

Current Uses: Widely used in agricultural research; sometimes used at hazardous waste sites in the arid west.

REFERENCES

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume I and Volume II. EPA/625/R-93-003a and EPA/625/R-93/003b.

22. Soil Gas Probes

Method: Grab samples are collected from a moving stream of soil gas, which is pumped through a hollow probe that is driven into the soil, or from permanently installed tubes at one or more levels in the soil. The probes can be manually or pneumatically driven, or installed in boreholes. Relatively nonvolatile NAPLs can be detected using stream injection. The samples usually are analyzed in the field using portable analytical instruments. Grab usually are taken at the same depth at a number of surface locations for areal characterization of soil-gas concentrations. Where the vadose zone is thick, or discontinuous impermeable layers exist at a site, samples can be taken at different depths at the same location to define vertical changes in soil-gas concentration.

Depth of Penetration: Depends on density of subsurface material and method of penetration/coring. Soil gas probes with cone penetration rigs can penetrate 100 to 150 feet with favorable soil conditions; greater depths are possible if holes are drilled before insertion of the soil gas probe. Coring depth limits are defined by the type of drilling/coring method used.

Limitations:

- Does not monitor ground water (leaves questions regarding how owner/operator will evaluate data/release to ground water).
- Grab-sampling results are highly depth-dependent and sampling results might be misleading if the correct depth is not sampled (based on site-specific factors, such as moisture conditions, air-filled porosity, and depth to ground water, and compound-specific factors, such as solubility, volatility, and degradability).
- Method interferes with local VOC concentrations as a result of pumping to retrieve sample.
- Nonvolatile contaminants will not be detected.

Advantages:

- ASTM guidance.
- Method is non-destructive.
- Hollow-probe samplers allow collection of multiple samples in a relatively short period of time.
- When combined with on-site gas chromatography, results are available in minutes.
- Problems associated with handling and transporting gas samples are minimized.

Cost: Cost of soil gas survey probably much less than installation of ground-water monitoring wells, however over time costs may be equal. Permanent soil gas installations potentially considerably cheaper than equivalent number of monitoring wells.

Implementability: Widespread acceptance and use indicates method is very implementable.

Need for Permanent Stations: Permanent stations not necessary. One presumably could monitor in approximately the same locations during each sampling event, but sampling points typically are at a higher density than typical monitoring wells.

Practical for Annual/Semiannual Use: Although less intrusive and initially less expensive than conventional monitoring well installation, repeated monitoring costs by this method, if necessary, may exceed those of permanent installation, sampling, and analyses.

Applicability to Alaska and West U.S.: Applicable to both Alaska and the U.S. West.

Environmental Media Monitored: Soil gas.

Continuous Monitoring Achievable: No.

Current Uses: Widely used for preliminary site characterization where volatile contaminants are known or suspected.

Case Studies:

- Tuttle and Chapman (1992) discuss the application of hydraulic probes to collect soil, soil gas, and shallow ground water. Probes were driven to depths of up to 40 feet when driven using the engine of a four-wheel drive pick-up truck. From 15 to 25 samples were collected and analyzed a day. Analysis of samples by Gas Chromatograph took less than 15 to 30 minutes in some cases.

- Herrara and Taylor (1990) discuss the application of soil gas sampling at a facility in southern California. The site is underlain by fine to medium grained sands with discontinuous interbeds of gravel silt, and clay, and silts and clays. The authors make the point that "the movement of soil gas through the unsaturated zone is a complex process that is influenced greatly by subsurface stratigraphy. The subsurface is often a heterogeneous environment consisting of a variety of soils with varying permeabilities, porosities, and moisture contents. All of these factors influence soil gas migration." They also explain that "the lateral extent of the soil gas halo will be greater with increased depth of the unsaturated zone."

- Crockett and Tadeo (1988) discuss several limitations/advantages of soil gas sampling, including: (1) soil gas sampling detects only volatile contaminants; (2) soil gas sampling only measures concentrations of volatiles near the probe; (3) soil gas sampling can allow good delineation of lateral contaminant distribution; and (4) soil gas concentrations can decrease following rainfall, and can be influenced by highly moist environments; therefore, soil gas sampling may be more effective in arid regions.

- Crouch (1990) discusses the analysis of soil vapor samples using gas detector tubes rather than gas chromatography. The results are considered semi-quantitative. He explains that are detector tubes available for over 200 specific volatile compounds. The high detection limits associated with detector tubes make them feasible only for highly contaminated samples, however.

- Tolman and Thompson (1990) contend that the "most common problems associated with soil gas investigations are geologic barriers, unsuitable target compounds and the tendency to overinterpret soil gas data." They explain that the most common geologic barrier is saturated sediments.

- A soil gas sampling program reported by Joyner and Thomsen (1990) detected a 200-foot diameter carbon tetrachloride spill area within a 370-acre site in Hastings, Nebraska. Shallow soil gas samples (1 to 3 feet) were collected by hammering a probe into the ground. Shallow to Mid-level (up to 22 feet) samples were collected using a Geoprobe. The Geoprobe could not penetrate some formations.

REFERENCES

Crockett, E.L. and A.R. Taddeo. 1988. A Technical Evaluation of Soil Gas Analysis for Use at a Hazardous Waste Site. KVA Analytical Systems, Technical Publication #5.

Crouch, M.S. 1990. A Semi-Quantitative Approach to Soil Vapor Surveys. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 267-277.

Herrera, P.D. and D. Taylor. 1990. Identification of Multiple Groundwater Sources with Sources with Soil Gas Sampling. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 279-287.

Joyner, S. and K.O. Thomsen. 1990. Areal and Vertical Soil Gas Sampling Techniques Used to Locate and Characterize a VOC Source. 1990. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 235-246.

Karp, K.E. Winter 1993. A Diffusive Sampler for Passive Monitoring of Underground Storage Tanks. Ground Water Monitoring and Remediation, pp. 101-106. [This paper addresses passive soil gas sampling.]

Kerfoot, H.B. and M.J. Prattke. 1992. False Positive Indications of Leachate Effects on Ground water Due to the Use of Volatile Organic Compounds as Indicator Parameters: A Field Study of Gas Migration. Proceedings of the Sixth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Ground Water Association, Dublin, Ohio, pp. 119-132.

Kerfoot, W.B. 1989. Pneumatic Hammer Soil Vapor Probes and Miniature Piezometers in Use at a Gasoline Spill Site. Proceedings of the Third National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 15-29.

Kerfoot, W.B. 1991. Site Use of Advective Flux Probes for Soil Gas and Soil Analysis. 1991. Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 17-30.

Kerfoot, W.B. Summer 1992. Defining Limits with Pneumatic Hammer Soil Probes. KVA Analytical Systems, Technical Publication #8, pp. 259-276.

Parks, J.H. and E.C. Hess. 1992. Environmental Data Collection and Field Screening During Borehole Drilling and Hydraulic Penetrometer Probing Operations. Proceedings of the HMC/Superfund Conference, pp. 182-187.

Rizvi, S.S.H. and S.J. Fleischacker. Determination of VOCs in Subsurface Soils Using Soil Gas Sampling: A Case Study. [SOURCE UNKNOWN] pp. 479-484.

Tolman, K.J. and G.M. Thompson. 1990. Mobile Soil Gas Sampling and Analysis: Applications and Limitations. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 261.

Tuttle, J.C. and G.H. Chapman. 1992. Site Characterization Alternative: Hydraulic Probe Sampling and Mobile Laboratory Analysis. Proceedings of the HMC/Superfund Conference, pp. 228-237.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume I and Volume II. EPA/625/R-93-003a and EPA/625/R-93/003b.

23. Dielectric Sensors

Method: Used at contaminated sites to measure soil moisture content. Basic principles are similar to the induced polarization surface geophysical method, except that sensors are placed below the ground surface. A variety of capacitive sensors have been developed that measure the dielectric properties of soil, which are primarily related to water content. These sensors depend upon specific electrode configurations and detailed calibration. Dielectric probes, which measure vertical soil moisture profiles in a cased hole similar to neutron probes, are a relatively recent development. Dielectric probes have significant advantages over neutron probes and other nuclear methods for measuring soil moisture.

Depth of Penetration:

Limitations:

For Sensors:

- The moisture sensor must be implanted properly to minimize disturbance to the soil.
- The long-term reliability and maintenance of the calibration is uncertain, especially if the ionic concentration of the soil water changes.
- Cost of readout devices and interfaces with remote collection platforms is high

For Probes:

- Special care is required to make sure that there are no air gaps outside the access tube, because relatively limited radial penetration gives more weight to measurements near the borehole compared to neutron probe.
- Less sensitive at high moisture contents than low moisture contents.
- Air-soil interface affects accuracy of measurements in the upper 20 to 50 cm of soil.

Advantages:

For Sensors:

- With accurate calibration, can provide accurate values for soil moisture.
- Can be placed at any depth for obtaining moisture profile data.
- A wide variety of sensor configurations, from very small to large, ar possible, allowing some control over the sensor volume of influence.
- Capacitive sensors have high precision and the property they measure (dielectric constant) is primarily related to water content.

For Probes:

- Provide better resolution in measuring vertical soil moisture profiles than neutron probes.
- Are less expensive than neutron probes and the time domain reflectometry sensors.
- Are as accurate as neutron probes without having to deal with radioactive materials.
- Can be used to accurately determine position of a wetting front and ground-water level in soil.

Cost: Not determined.

Implementability: Not determined.

Need for Permanent Stations: Not determined.

Practical for Annual/Semiannual Use: Not determined.

Applicability to Alaska and West U.S.: Not determined.

Environmental Media Monitored: Soil vapor.

Continuous Monitoring Achievable: Not determined.

Current Uses: Numerous prototypes have been developed. Relatively recent development of commercially available units means that this method is likely to be used more commonly in the future.

REFERENCES

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume I and Volume II. EPA/625/R-93-003a and EPA/625/R-93/003b.

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24. Time Domain Reflectometry

Method: Used at contaminated sites to measure soil moisture content and to measure soil bulk electrical conductivity. Use of time domain reflectometry to measure soil moisture content is a relatively recent development that shows great promise for field applications. Volumetric water content can be determined based on measuring the travel time and the attenuation of the amplitude of an electromagnetic pulse launched along one or more transmission lines (coaxial, two-, three-, or four-rod probes) embedded in the soil. Portable probes can be used to make multiple near-surface measurements or in situ probes of varying length can be installed vertically to different depths, or horizontally at different din the side of a trench. The TDR trace can be recorded either on a photograph of the oscilloscope display or on an X-Y recorder. The measured dielectric constant is converted to volumetric water content using an empirically derived equation that can be applied to many soils. Electrical conductivity also can be estimated from the attenuation of the signal.

Depth of Penetration: Tools can be placed at any depth.

Limitations:

- Can measure soil moisture and electrical conductivity of soils.
- The moisture sensor must be implanted properly to minimize disturbance of the soil.
- Long-term reliability and maintenance of the calibration is uncertain, especially if the ionic concentration of the soil water changes.
- Cost of readout devices and interfaces with remote collection platforms is high.

Advantages:

- With accurate calibration, can provide accurate values for soil moisture.
- Can be placed at any depth for obtaining moisture profile data.
- A wide variety of sensor configurations, from very small to large, are possible allowing some control over the sensor volume of influence.
- Readily amenable for use with automatic data acquisition systems.
- Available from several commercial sources.

Cost: Not determined.

Implementability: Relatively new method.

Need for Permanent Stations: Yes. Probes would need to be installed in permanent positions.

Practical for Annual/Semiannual Use: Cost potentially would be only prohibition.

Applicability to Alaska and West U.S.: No relevant limitations noted.

Environmental Media Monitored: Soil water.

Continuous Monitoring Achievable: Not determined.

Current Uses: Relatively new method with good potential for field applications.

Case Study:

Redman et al. (1991) discuss how TDR probes detected a change in dielectric permittivity of soil resulting from the injection of PCE (a DNAPL) at the Borden site.

REFERENCES

Redman, J.D., B.H. Kueper, and A.P. Annan. 1991. Dielectric Stratigraphy of a DNAPL Spill and Implications for Detection with Ground-Penetrating Radar. 1991. Proceedings of the Fifth National Outdoor Action Conference on Aquifer Restoration, Ground-Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 1017-1030.

U.S. Environmental Protection Agency. 1993a. Subsurface Characterization and Monitoring Techniques. A Desk Reference Guide. Volume I and Volume II. EPA/625/R-93-003a and EPA/625/R-93/003b.

25. Other Technical Options

The following technical options were removed from consideration due to non-suitability as alternative methods to ground-water monitoring at MSWLFs in the arid West or Alaska:

Geophysical Methods:

Gravimetrics: Commonly used for detecting variation of thickness of unconsolidated material over bedrock, mapping of landfill boundaries, detecting cavity, sinkholes, and subsidence.

Method involves the detection of anomalies of the earth's gravitational field. Gravity data obtained in the field must be corrected for elevation, rock density, latitude, earth-tide variations, and the influence of surrounding topographic variations. Microgravity surveys are difficult to implement, very expensive, the equipment is delicate and very susceptible to temperature changes, and the results are often ambiguous. Gravimetrics has not been demonstrated in the literature as a useful tool at contaminated sites. Widely used in mineral exploration. Not commonly used for site-specific investigations.

Magnetotellurics (MT): Commonly used for mapping of large geologic structures, regional ground water mapping, mapping of brine contamination from unplugged wells, water saturated fracture tracing in rock, and detection of fault displaced masses of rock.

Telluric currents are natural electric currents that flow in the subsurface in response to ionospheric tidal effects and lightning associated with thunderstorms. MT methods involve the measurement of magnetic and electrical fields associated with the flow of telluric currents. The method is influenced by localized changes in conductivity of near-surface materials, which produce static effect errors. These static effects can result in erroneous readings at all frequencies, which makes accurate interpretations of the data difficult. MT methods are relatively inexpensive for mapping brine, however most other electrical and EMI methods are more accurate and easier to use. MT methods have been used primarily in connection with regional geological investigations related to mineral exploration.

- Lluria (1990) demonstrated the usefulness of controlled source audio-frequency magnetotellurics (CSAMT) in identifying potential deep fractured bedrock aquifers in the Western Cordillera.

Lluria, M.R. 1990. Controlled Source Audio-Frequency Magnetotellurics: An Effective Surface Geophysical Tool in the Exploration for Ground Water Hosted in Fractured Bedrock Aquifers. Proceedings of the Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. National Water Well Association, Dublin, Ohio, pp. 1143-1157.

Sonar/Fathometry: Both methods are designed to perform water bottom surveys and are therefore of limited applicability to Alaska and the West U.S.

Gamma-Spectrometry Borehole Geophysical Logging: Borehole may be wet or dry. Only use would be to identify artificial radioisotope contaminants in the subsurface. Equipment is expensive.

Unsaturated Zone Monitoring Methods:

Electrical Resistance Sensors (Four-electrode soil moisture probe, Electrical resistance blocks, porous block method, soil moisture blocks): Measures soil water potential. Commonly used for irrigation timing and other qualitative field-monitoring programs. Less common for accurate measurement of soil hydrologic properties. Small changes in electrolyte concentration of the soil water (which may well occur at contaminated sites) will affect resistivity readings).

Electrothermal Methods (Thermal diffusivity, heat diffusion/dissipation sensors): Used to measure water potential and gradients in the unsaturated zone. Used to measure soil temperature. Can be used to estimate water content (if moisture characteristic curve is developed). Not commonly used. Might be difficult to install at depth in the unsaturated zone.

Osmotic Tensiometers: Measures combined osmotic and pressure potential of water in the unsaturated zone. Not commonly used. Thermocouple psychrometers are the preferred method for measuring combined osmotic pressure and pressure potential.

Four-Probe Electrical Resistivity (Four electrode techniques/sensors): Measures in situ soil salinity in the shallow unsaturated zone. Used for locating brine and chloride plumes and for estimating water content. Can detect shallow saline ground water. Will not detect pollutants that do not change the electrical conductivity of the subsurface. Limited to shallow depths.

EC Probes (Four-electrode salinity probe, electrical conductivity probe, portable salinity probe, four-electrode conductivity cell): Used to obtain small volume soil salinity measurements. Will not detect pollutants that do not change the electrical conductivity of the subsurface. Limited depth of 1.5 meters.

Porous Matrix Salinity Sensors (ceramic salinity sensors, in situ salinity sensors): Used to monitor soil salinity, measure water content. Most suitable for land treatment areas and irrigated fields. Commonly used in agricultural research where continuous monitoring of soil salinity is required. No depth limitation.

EM Soil Sensor: Measures electrical conductivity in the soil rooting zone. Depth limited to 1 to 2 meters.

Vacuum-Type Porous Cup Lysimeter (Suction/soil lysimeter, tension lysimeter, soil-water extractors), Vacuum Plate Sampler, Membrane Filter, Hollow Fiber, Ceramic Tube Sampler, Capillary Wick Sampler, Trench Lysimeter, Pan Lysimeter, Glass Block Lysimeter, Wicking Type Sampler, Nylon Sponge, Ceramic Rod: Used to sample soil pore fluids in the unsaturated zone. Limited to depths less than 2 meters (1 to 4 meters for membrane filter).

Free-Drainage Samplers (Zero-tension samplers, tension-free lysimeters, pan lysimeter, collection lysimeter/manifold collector, trench lysimeter, caisson lysimeter, free-drainage glass block sampler, pan-type collectors, wicking-type sampler): Use is relatively uncommon. Installation procedures are time-consuming and complex. Depth is limited by depth of trench or culvert into which equipment is installed.

Soil Gas -- Static: Static sampling can be performed in two ways. (1) An in situ adsorbent (e.g., activated charcoal rod) is buried in the soil for a few days to weeks. The adsorbent is retrieved and analyzed for volatile organic compounds in a laboratory by mass spectrometry or gas chromatography. (2) Grab samples are collected from containers placed in the soil surface, which collect quiescent soil-gas samples. These samples usually are analyzed in the field using portable analytical instruments. These methods are only suitable for near surface investigation.

Tank/Pipeline Leak Sensors (more than 200 liquid hydrocarbon and hydrocarbon vapor detectors or sensors available, over 90 leak detection systems are available that involve detection of organic vapors as an indication that underground USTs are leaking. Vapor wells and U-tubes are commonly used): Most methods are limited to depths less than 2 meters.

Soil Monitoring Methods:

Soil Borings: Soil samples are collected through the advancement of soil borings. Soil samples may be analyzed for any constituents. Soil pore water also may be extracted from the samples and analyzed. The method is impractical to employ on a routine basis.