EPA 542-R-98-020
December 1998

Geophysical Techniques to Locate DNAPLs: Profiles of Federally Funded Projects

Prepared by the Member Agencies of the Federal Remediation Technologies Roundtable:

Federal Remediation Technologies Roundtable

U.S. Environmental Protection Agency
Department of Defense
- **U.S. Air Force**
- **U.S. Army**
- **U.S. Navy**

Department of Energy
Department of Interior
National Aeronautics and Space Administration
Tennessee Valley Authority
Coast Guard

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Geophysical Techniques to Locate DNAPLs:

Profiles of Federally Funded Projects

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, DC 20460

NOTICE

This document has been subjected to administrative review by all Agencies participating in the Federal Remediation Technologies Roundtable, and has been approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Preparation of this document has been funded wholly or in part by the U.S. Environmental Protection Agency under EPA Contract No. 68-W6-0014.

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INTRODUCTION

DNAPLs are separate-phase hydrocarbon liquids that are denser than water, such as chlorinated solvents (either as a single component or as mixtures of solvents), wood preservative wastes, coal tar wastes, and pesticides. They are present at numerous hazardous waste sites and are suspected to exist at many more. Due to the numerous variables influencing DNAPL transport and fate in the subsurface and, consequently, their ensuing complexity, DNAPLs largely go undetected, yet are likely to be a significant limiting factor in site remediation.

Most DNAPLs undergo only limited degradation in the subsurface, and persist for long periods while slowly releasing soluble organic constituents to ground water through dissolution. Subsurface DNAPL distribution is difficult to delineate accurately at some sites because DNAPLs migrate preferentially through selected pathways (*e.g.*, fractures and sand layers) and are affected by small-scale changes in the stratigraphy of an aquifer. Therefore, the ultimate path taken by DNAPL can be very difficult to characterize and predict.

Some of the more commonly-used techniques to locate DNAPL in the subsurface include use of monitoring wells, multi-level samplers, organic chemical analyses of soil samples at different depths, and soils borings or cone penetrometers to determine site stratigraphy. However, these techniques often miss DNAPL contamination in the subsurface, leading to incomplete site assessments and inadequate remedial designs. In addition, some of them require drilling into the subsurface, which can result in the creation of new pathways for continued vertical migration of free-phase DNAPLs.

On November 20, 1997, the Federal Remediation Technologies Roundtable held a meeting to discuss DNAPLs, which focused on technologies that are used not only to treat DNAPLs, but also to locate them in the subsurface. At this meeting, the Roundtable members decided to develop technology profiles on federally-funded projects that are using noninvasive geophysical techniques to locate DNAPLs in the subsurface. This report was developed in direct response to that request and is intended to provide a status report for researchers and practitioners on federal activities to develop these technologies.

Some of the information in this report was collected directly from members of Roundtable agencies or contacts that were referred by these members. Other information was collected from documents identified through online literature searches or websites that provide information on federally-funded projects. Most of the projects discussed in this report are still in the demonstration phase and commercialization of most of these technologies is still pending. Some of the projects listed in this report are still in the early stages of development, so little data is available on how well these techniques will work for locating DNAPL in the subsurface in the field.

FOR MORE INFORMATION

The Federal Remediation Technologies Roundtable is an interagency working group seeking to build a more collaborative atmosphere among the federal agencies involved in hazardous waste site remediation. By providing such opportunities, the Roundtable hopes to identify and publicize more efficient, cost-effective solutions to the Federal Government's hazardous waste challenges. To date, the focus of this group has been on the exchange of information regarding the use and development of innovative hazardous waste treatment technologies. For more information on the Roundtable's activities, visit the Roundtable's website at http://www.frtr.gov.

U.S. Department of Energy
Lawrence Livermore National Laboratory and
Oregon Graduate Institute of Research
Electrical Impedance Tomography

Technology Description

Electrical impedance tomography (EIT), the more generalized term for electrical resistance tomography, has been used to map temporally and spatially the extent of free DNAPLs in the subsurface. The intent of this technology is to differentiate between contaminated and non-contaminated soil by comparing electrical resistivity and phase measurements made at two or more frequencies. The EIT survey is conducted by placing a number of electrodes in boreholes or on the ground surface to sample the subsurface impedance distribution. EIT creates a two or three dimensional map of the electrical impedance distribution underground.

Due to the strong function of water content and water chemistry in rock and soil bulk resistivity, EIT is particularly effective at imaging subsurface processes involving changes in water saturation or water chemistry. This technology offers the advantage of potentially providing information on the identification of DNAPLs without the use of baseline data.

EIT has been demonstrated in both clay-rich and sandy soils. Results indicate that this technology is effective at depths of 10-500 feet, using 50-75% fewer boreholes than in conventional borehole-sampling techniques. Two- and three-dimensional imaging is possible, and updated survey images can be available in relatively short timeframes. The stainless steel alloy electrodes used in this geophysical approach are durable, relatively inexpensive, and easily emplaced.

Status

The Lawrence Livermore National Laboratory and Oregon Graduate Institute of Research and Technology used EIT to image a plume resulting from a release of 189 liters of perchloroethylene (PCE) into a saturated aquifer constructed of sand and two layers of bentonite. Results of this controlled spill test were similar to those obtained in earlier laboratory studies using complex resistivity. Although the electrical phase dispersion was just above the measurement uncertainty, spectral reconstructions of subsurface electrical resistivity were developed. Based on the results of this spill test, similar experiments were conducted at Hill Air Force Base, UT, to monitor geophysical changes occurring during the pumping of free-product DNAPL.

At Hill Air Force Base, EIT was used in combination with fiber optic chemical sensors and neutron logs to verify the presence of DNAPLs and monitor DNAPL changes during ground water pumping. Three multipurpose monitoring boreholes were installed, each containing 20 electrodes used to perform crosshole resistivity surveys in the depth range of 40-64 feet. The removal of DNAPL during pumping produced a drop in electrical resistivity, as the insulating fluids were displaced by relatively conductive ground water. The EIT difference images provided a 2-dimensional view of the zone in which DNAPL was removed from the ground and replaced by ground water over time. Electrical resistivity in the ground water basin decreased significantly within a relatively moderate amount of time, dropping by approximately 50 percent during the initial four months of system operation when 643 gallons of DNAPL were removed, and over 70 percent at the end of one year.

This technology is believed to be ready for commercial application for site characterization in soil remediation and ground-water projects, evaluation of cleanup techniques, cleanup process control, and detection and location of subsurface contamination involving DNAPLs.

Cost Information

EIT implementation costs range widely, depending upon the depths involved and imaging resolutions required. Typically, a 15-array electrode string housed in a single borehole may cost approximately $1,000. Additional costs for implementing this type of system, however, include those incurred for extensive data processing and the installation of monitoring wells if none exist. Data sets may be obtained and compiled as often as needed; users have reported collecting as many as 60,000 data points over a 24-hour period. Maintenance and calibration activities for ETI implementation are considered minimal.

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Open File # 97-0148: Summary of Geophysical Investigations for DNAPL Remediation at Savannah River Site, South Carolina, by K. J. Ellefsen, P.H. Nelson, R.J. Horton, and D.L. Wright. 20 p. (U.S. Geological Survey, Box 25046, Denver, CO 80225-0046). 1997

R.L. Newmark, W.D. Daily, K.R. Kyle, and A.L. Ramirez. January 1997. Monitoring DNAPL Pumping Using Integrated Geophysical Techniques. Lawrence Livermore National Laboratory Informal Report #UCRL-ID-122215.

Earth Sciences and Resources Institute, University of South Carolina, with funding from the U.S. Department of Energy M-Area Seepage Basin, Savannah River Site, SC Use of Seismic Reflection Amplitude Versus Offset (AVO) Techniques to Image Dense Nonaqueous Phase Liquids (DNAPL)

Technology Description

Seismic reflection profiling is a noninvasive geophysical technique that uses subsurface measurements to detect free-phase contaminants in the subsurface. To do this, seismic reflection techniques at frequencies of 120 Hz or higher are used obtain information that measures amplitude versus offset (AVO) anomalies. These anomalies are used to detect DNAPL-saturated sand versus water-saturated sand.

Seismic AVO analysis is based on the idea that changes in the fluid content of a reservoir (or aquifer) can cause a significant change in Poisson's Ratio (the lateral contraction per unit breadth divided by the longitudinal extension per unit length) that is visible in the seismic profile data as a function of offset. To successfully implement it for environmental applications, information on the P-Wave and S-Wave velocities and density of water-saturated and DNAPL-saturated sediments is required as input to the model. This AVO model is used to design field parameters for seismic profiles that are critical to the success of these projects. This modeling data will determine what is the minimum amount of DNAPL that can be imaged given the geologic conditions for a particular site and provide the necessary data for designing seismic acquisition parameters.

Status

The Earth Sciences and Resources Institute completed a demonstration of this technology in 1996 with funding from the Department of Energy. It was conducted at the M-Seepage Basin at the Westinghouse Savannah River Site in Aiken, SC, where an estimated two million pounds of residual solvents from an eight-million-gallon unlined surface impoundment leaked into a basin over a thirty-year period. In 1988, the basin was closed, backfilled, and covered with an impermeable cap. Chlorinated solvents, including free-phase constituents, have been found in the groundwater near the basin since 1981.

The primary objective of this project was to test the feasibility of using high-resolution seismic techniques and direct hydrocarbon indicator analyses to image free-phase and dissolved-phase DNAPLs at the M-Area Basin. Other objectives were to use the seismic data to map the subsurface geology and to determine the geologic controls on the distribution of the DNAPL plume.

A three-fold approach for implementing the project was taken. This included: 1) evaluation of existing geological and geophysical data to estimate the amount and distribution of DNAPL; 2) seismic modeling to determine whether or not an AVO anomaly would be expected from DNAPL saturated sediments; and 3) acquisition and processing of a "seismic line" to image the DNAPL. Two wells were drilled on anomalies recognized by seismic data and DNAPLs were found at the predicted depth in the parts per million range (head space data). Therefore, researchers concluded that DNAPLs could be imaged in the subsurface using high-resolution seismic data.

Other demonstration projects being planned are at the Tank Area of DOE's Hanford Site in Richland, WA, and the Portsmouth Gaseous Diffusion Plant in Portsmouth, OH. In addition, projects currently are being negotiated with DoD.

Contaminants Identified at the Site

The majority of the DNAPL located at the site is composed of trichloroethylene (TCE), tetrachloroethylene (PCE), and trichloroethane (TCA).

Cost Information

The costs for implementing a seismic reflection profiling project is driven by the costs for the following: development of geophysical vertical seismic profiles and the scoping and logging of existing wells; design of a seismic survey specifically for the site where the technology will be implemented; review of 2-D reflective seismic data at group spacings; acquisition of 2-D data, processing and interpretation of data; and mobilization of data from the site to a data processing center.

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Use of Seismic Reflection Amplitude Versus Offset (AVO) Techniques to Image Dense Nonaqueous Phase Liquids (DNAPL) at the M-Area Seepage Basin, Savannah River Site, SC, M.G. Waddell, W.J. Domoracki, and T.J. Temples. Copyright © 1996, 1997 the Earth Sciences and Resources Institute and the Board of Trustees, University of South Carolina.

Website

http://www.esri.sc.edu/FACILITIES/seismic/3dseep.htm

U.S. Geological Survey
M-Area Settling Basin, Savannah River Site, SC
Cross-Well Radar

Technology Description

Cross-well radar technology is a geophysical alternative to ground-penetrating radar, which already has been used to monitor the migration of DNAPLs in saturated, unconsolidated sediments. Ground-penetrating radar, however, is inappropriate for monitoring remediation far below the ground surface if the radar waves would be highly attenuated. This problem is overcome with cross-well radar technology because the antennas are within the zone being remediated. As a result, cross-well radar has the potential for providing effective monitoring of subsurface conditions during remediation and for decreasing remediation costs.

Cross-well radar technology employs antennas that are lowered by cable into sampling wells. Radar waves emitted from an antenna in a single well are transmitted to a receiving well. Changes in the radar waves, which result from the geology and the pore fluids, are used to establish inferences about the geology and the pore fluids. To improve data interpretation, data from cross-well radar systems may be used in conjunction with data collected from dielectric logging, which provides detailed information on the geology and the pore fluids near the well.

Because the electromagnetic properties of water and DNAPL differ significantly, monitoring DNAPL remediation likely is easier in the saturated zone than it would be in the unsaturated zone. In either case, the concentration of DNAPL must be high for the DNAPL to have a noticeable effect on the radar waves.

Status

A feasibility test of cross-well radar was conducted by the U.S. Geological Survey near the M-Area Settling Basin at the U.S. Department of Energy's Savannah River Site, SC. Experiments were performed to determine how radar data collected in the unsaturated and saturated zones were affected by sediments and well grout, which could attenuate radar waves to an undetectable level. Five wells, at distances of 4-5 meters from one another, were installed at different depths. Two of these wells extended approximately 10 meters below the water table, which is located approximately 40 meters below ground surface.

As a relatively new geophysical approach for identifying DNAPL in near-ground-surface areas, cross-well radar technology requires additional field testing to evaluate more fully its effectiveness and potential for commercialization. The Savannah River Site feasibility study, which included tests utilizing various types of bore-hole radar equipment, yielded successful results in both the unsaturated and the saturated zones.

Distances between wells strongly influence the effectiveness of this monitoring technique. As the distance between transmitting and receiving wells increases, radar wave amplitudes become lower, creating greater difficulty in distinguishing the wave from background noise. In addition, the effectiveness of cross-well radar technology depends upon the geological and hydrologic environment in which it is used. DNAPL quantity probably is the limiting factor in the use of cross-well radar, with the most effective applications being those that involve large quantities of DNAPL. As is the case with other geophysical monitoring techniques, the success of cross-well radar technology in identifying contaminants in very low concentrations is minimal. Nonetheless, because of the high spatial resolution of the measurements, detailed information about the geology between wells is obtained, and this information is invaluable for planning and conducting remediation.

Cost Information

The costs for implementing a cross-well radar technology project, including research activities, field work, and data analysis, are driven by the field testing, equipment, and spacing of wells.

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Bore Hole Radar Tomography and Dielectric Logging at the Savannah River Site by D. L. Wright, J. D. Abraham, K. J. Ellefsen, and J. Rossabi; Proceedings of the Seventh International Conference on Ground Penetrating Radar, p. 539; May 27-30, 1998; University of Kansas, Lawrence, Kansas.

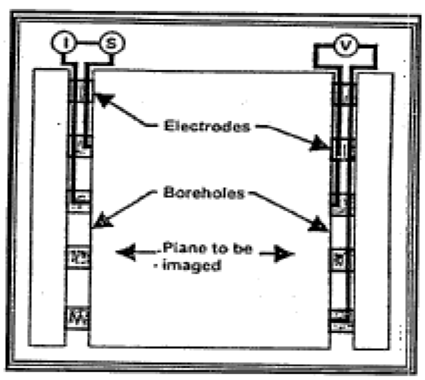
Air Force Research Laboratory
Airbase and Environmental Technology Division
Tyndall Air Force Base
Integrated Geophysical Multi-Sensor Detection of DNAPL Source Zones

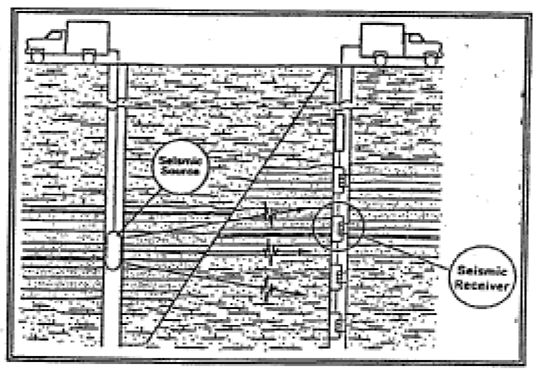
Technology Description

Under the Strategic Environmental Research and Development Program (SERDP), Blackhawk Geometrics, Inc., of Golden, Colorado, is developing a methodology for using integrated geophysical multi-sensor detection to provide cost-effective three-dimensional imaging of DNAPL distribution and migration at different spatial resolutions and, at the highest available resolution, to image DNAPL. The Lead Agency for this project is the Air Force.

The project will take on a three-fold approach to characterize the physical heterogeneity that controls DNAPL migration and to image DNAPL distribution in the subsurface. First, joint 3-D tomographic inversion of surface seismic refraction and electrical resistivity data will be used to broadly delineate subsurface geology. Second, high resolution joint 2-D and 3-D crosshole tomography data will be collected using downhole seismic refraction and electrical resistivity sensors in permanent four-inch wells and/or temporary two-inch borings. Third, the same downhole electrical sensors will be used to perform Induced Polarization tomography to image DNAPL with the geological constraints from the above two steps. This approach will provide new cost-effective, minimally-invasive technologies for 3-D geophysical imaging of DNAPL with a minimum of investigative derived waste.

Concept drawings of the electrical resistivity (L) and seismic (R) sensor emplacements.





The initial focus of this project is to develop laboratory data to support electromagnetic tomography measurements of DNAPL distribution, and to conduct a two-dimensional tomographic image field test. The project will begin with an initial laboratory demonstration of the technique followed by development of field equipment and a field demonstration in the year 2000.

The results will include development of computer software, downhole seismic and electrical instruments, and case histories focused on Departments of Defense and Energy sites. It is believed that this project will result in high-resolution 3-D images of geological structures and DNAPLs in the subsurface through data collection in the field and 3-D computer tomographic imaging for monitoring DNAPL migration in real time. When this approach becomes available, SERDP believes it will facilitate the design of new treatment/remediation technologies, and improve risk assessment and estimates of realistic costs for remediation alternatives.

Status

This project is an FY98 new start under the Strategic Environmental Research and Development Program (SERDP) with a proof-of-concept demonstration in FY98 followed by development and, potentially, certification under the Environmental Security Technology Certification Program for Dem/Val. The technology is not commercially-available at this time, but potential users of this technology include the Department of Defense, Department of Energy, the Environmental Protection Agency, the Air Force Research Laboratory, Sandia National Lab, and Lawrence Berkeley National Lab.

Cost Information

FY1998 funds for this project are $120,000. It is estimated that collection of 3-D surface seismic and electrical data may take 2 days and that downhole seismic and direct current (DC) resistivity measurements may take 1 day. Downhole Induced Polarization measurements may take only a few hours. To install a temporary well with a cone penetrometer takes a few hours and costs only $2K plus mobilization cost.

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SERDP Home Page
http://www.serdp.gov/

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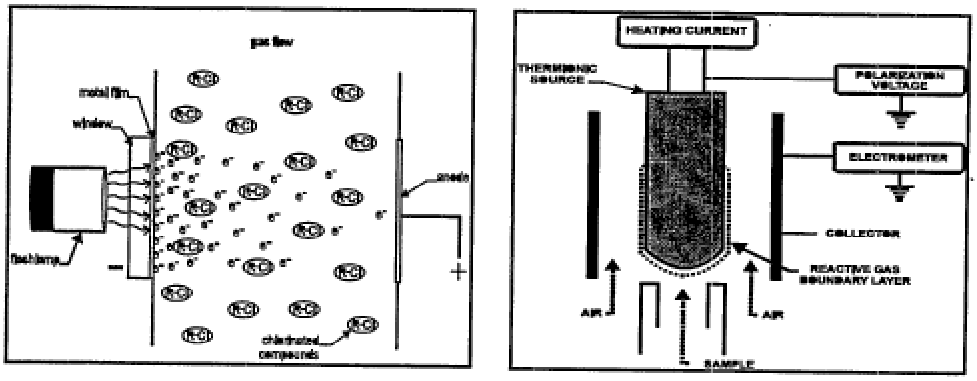
(Note: These authors can lead to other literature on Complex Resistivity, Induced Polarization, and Resistive Tomography.)

Air Force Research Laboratory
Airbase and Environmental Technology Division (AFRL/MLQ)
Negative Ion Sensor for DNAPL Detection

Technology Description

Under the Strategic Environmental Research and Development Program (SERDP), Dakota Technologies, Inc. (DTI) of Fargo, North Dakota, is pursuing development of a Negative Ion Sensor for DNAPL detection. This technology will use a downhole detector integrated with conventional cone penetrometers to detect gas-phase chlorine anions generated from chlorinated solvents in the subsurface. Two concepts are being investigated: one based on thermionic ionization sensing and the other based on a photoemissive electron capture detector (ECD).



Concept graphics of the ECD (Left) and Thermionic Ionization (Right) sensors

Status

This technology was an FY98 new-start project selected for funding under the SERDP program. Development of this technology began in 1998 with field demonstrations in 1999, 2000, and 2001. DTI has set up separate workstations for laboratory studies of thermionic ionization sensing and electron capture sensing. Both methods use a commercially-available heated membrane interface probe (MIP) to transfer contaminants as vapors from the soil media to the sensing element. Experiments have shown that there is very little differential selectivity of the membrane to the passage of water or TCE. The response when a 500 ppb aqueous solution of TCE in water is flowed over the membrane is three times greater than the background signal from water alone. In separate experiments, known amounts of TCE were presented directly to the sensor. A mass limit of detection less than 2 pg was found. Placing moist soil (near water saturation conditions) directly on the membrane gave a preliminary limit of detection of 300 micrograms TCE/kg of soil (wet weight).

Contaminants Identified at the Site

The primary contaminants of interest are TCE and PCE.

Cost Information

No cost information is available at this time.

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Air Force Research Laboratory
Airbase and Environmental Technology Division (AFRL/MLQ)
Horizontal Characterization

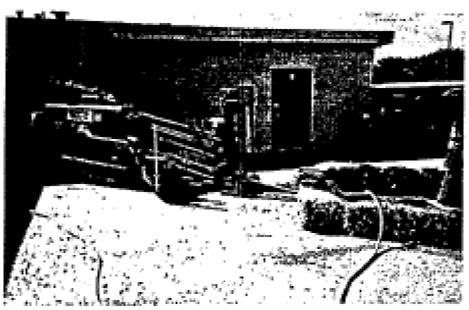
Technology Description

Horizontal Characterization integrates the advantages of horizontal drilling with the advances in remote sensing to permit detection and characterization of DNAPLs in the subsurface in areas inaccessible to conventional drilling and direct push technologies, such as underneath buildings, roadways, and runways.

Status

The initial phase of this project was conducted with Air Force Science and Technology funding by Mission Research Corporation of Albuquerque, New Mexico. It demonstrated the integration of horizontal drilling with the ROST™ laser induced fluorescence technology. Characterization of several penetrations were accomplished by pulling a bottom hole assembly fitted with a sapphire window and fiber optics back through the borehole while retracting the horizontal drill assembly. An initial proof-of-concept demonstration was accomplished in an abandoned oil field that penetrating 180 feet at depths up to 20-feet.

A second demonstration of horizontal characterization took place at Kirtland AFB, Albuquerque, New Mexico, the week of September 14, 1998. In this demonstration, the area underneath an active gasoline service station was characterized to determine the presence of hydrocarbons or other contaminants. A horizontal-drill string was inserted, passed under the building, and exited on the opposite side. The ROST sensor was attached to the drill string and pulled into the borehole, under the building, to characterize the contamination. A horizontal well was installed into one of the six boreholes using the same pullback technique for development of a soil vapor extraction or bioventing well.



The current system, using entrance and exit holes, has the capability to characterize distances up to 400 ft and depths to 70 feet with bore rates of several feet per minute. The continuing development program for horizontal characterization technology will provide a "measurement while drilling" capability rather than requiring an entrance and exit hole as described above. Directional measurement while drilling will allow characterization of the horizontal extremities of the contaminant with one penetration and over longer distances.

Cost Information

Horizontal drilling is commercially available through commercial equipment purchase/lease or as a vendor service. It has been shown to be very cost effective over vertical drilling in those applications where appropriate. Integrating characterization and measurement while drilling has the potential to eliminate multiple vertical borings translating to cost savings. The increased rate of penetration and reduced quantity of investigative derived hazardous waste also provides significant cost benefits.

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Air Force Research Laboratory
Airbase and Environmental Technology Division
Hill Air Force Base
Complex Resistivity

Technology Description

Complex Resistivity technology is based on the electro-chemical interaction between the contaminant and the clay in the subsurface. This electro-chemical interaction produces a deviation in the current/voltage relationship for particular frequencies, dependent upon the contaminant and clay under scrutiny. Comparing the response identified in the field data with controlled laboratory data allows a determination of the presence of the contaminant of interest. The primary advantage of this technology is that no invasion is required into the subsurface except the insertion of an electrode at the surface. The instrumentation used in this project was laboratory equipment tailored specifically for this demonstration. However, the equipment must be refined and ruggedized for commercialization. The technology is not commercially-available at this time.

Status

The initial phase of this project, which was supported by Air Force Science and Technology funding, has been completed at Hill AFB, Utah. This phase provided a proof of concept demonstration of Complex Resistivity (also known as Induced Polarization) at an existing, well-characterized site contaminated with DNAPL. The contaminated site used in this demonstration was Operable Unit 2 (OU-2) at Hill AFB, Utah, which was a disposal pit for chlorinated solvents and other contaminants. The site is located at the northern perimeter of the base on a relatively flat area, which slopes about 300 ft downward toward the nearby valley. The soil is sandy, silty clay at the surface to 15 feet below ground surface, followed by a

10-foot thick layer of sand, a 10-foot thick layer of gravel and sand, and a 25-foot thick layer of silty clay. The area of contamination lies in three unconfined aquifers in these geologies. This demonstration identified areas of interaction between the clay containment barrier and the contaminant indicating a potential breach in the containment wall.

Development of Complex Resistivity is continuing through the Strategic Environmental Research and Development Program (SERDP) as project CU-1090, Integrated Geophysical Sensor Detection of DNAPL Source Zone Identification. This SERDP project integrates surface complex resistivity with surface seismic refraction, seismic and electrical downhole tomography, and downhole induced polarization to provide 3-D imaging of DNAPLs in the subsurface.

Contaminants Identified at the Site

The solvent fraction measured from soil samples is approximately 75% TCE with smaller percentages of TCA, PCE, methylene chloride, toluene, and Freon.

Cost Information

Currently, there are no definite cost or savings estimates for this technology. However, it is intuitive that the cost of describing a subsurface DNAPL source using this non-invasive technology would be far less than drilling or boring using conventional technologies.

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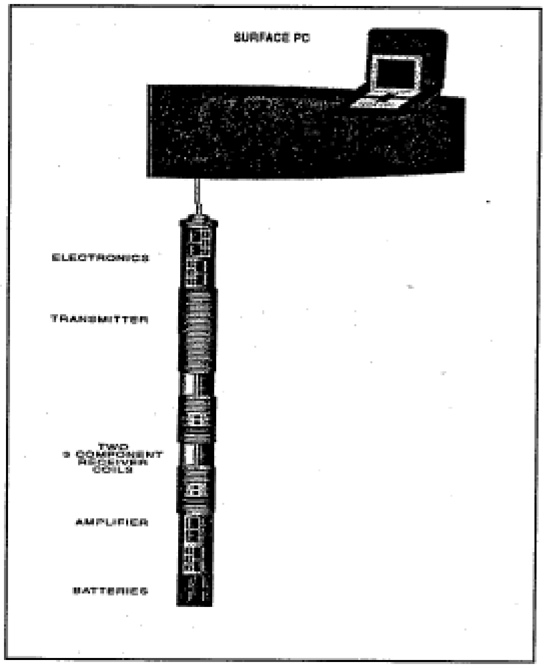
(Note: These authors can lead to other literature on Complex Resistivity, Induced Polarization, and Resistive Tomography.)

Air Force Research Laboratory
Airbase and Environmental Technology Division (AFRL/MLQ)
3D Inversion Imaging

Technology Description

3-D Inversion Imaging uses multiple imaging sources resolved through dynamic software to obtain a three-dimensional depiction of subsurface DNAPL contamination. It uses a standard cone penetrometer that is equipped with an innovative electromagnetic transmitter and multiple receivers to gather the scanned electromagnetic signature of the subsurface. The data from multiple penetrations is integrated to increase the acuity of the three-dimensional depiction of the DNAPL contamination.



Status

This project is being conducted under the Small Business Innovation Research (SBIR) program. Currently, the contractor, TechniScan of Salt Lake City, Utah, is building the first device to be used in a demonstration of the technology in FY99. The technology is not commercially-available at this time.

Cost Information

No cost information is available at this time.

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(Note: These authors can lead to other literature on complex resistivity, induced polarization, and resistive tomography.)

Environmental Security Technology Certification Program
High Resolution 3-D Electromagnetic Resistivity Survey

Technology Description

High resolution 3-D electromagnetic (EM) resistivity survey is a geophysical technique used to generate 3-D images of subsurface features, based on their resistivity properties. It is a relatively noninvasive technology that reduces the time and expense of field characterization, but requires a thorough understanding of the local geology to properly evaluate resistivity data for indications of contamination, and still requires the drilling of wells. Recent advances in instrumentation has enabled the application of this technique to relatively shallow plumes, yet the maximum depth of a surveyed region is 300 feet deep.

High resolution 3-D electromagnetic resistivity survey allows for full imaging of LNAPL sites by generating high-resolution 3-D images of subsurface LNAPL contamination zones and local geologic features to locate zones of contamination and high permeability. It is believed that this technology allows for more effective monitoring and implementation of remediation systems that require fewer wells once these zones are located. However, results of the demonstration projects are inconclusive regarding its ability to delineate DNAPL sites.

To perform a 3-D resistivity survey, a low-frequency electromagnetic source coil transmits a long wavelength/time-varying magnetic-field signal into the ground. An in-well receiver that is finely tuned to the source-signal frequency is used to measure magnetic field flux signals. Once these signals are continuously emitted, the receiver in the well records voltage measurements at 0.1-foot intervals from the near-surface to the bottom of the well (at depths up to 300 feet). The source coil is then moved to another surface location on a predetermined grid, and new measurements are taken until a 3-D matrix of voltage data has been collected and is converted into resistivity data.

Naturally occurring ferromagnetic materials in the subsurface do not cause significant to measurable resistivities, and therefore do not affect this technology. Also, since the instrumentation is located either down-hole or in a sheltered enclosure, weather conditions do not affect the data collection process. The processed data can be presented either in three dimensions or as depth-specific-slice and cross-section images.

The following steps are taken to conduct a 3-D EM resistivity survey,. First, two or more receiver wells with receiver sensors placed inside them (to provide redundant resistivity data to assure repeatability of results) need to be installed. Second, a magnetic field needs to be induced into the earth at the transmitter coil locations situated around the well. These coils are typically placed at 20-foot spacings, but at 10-foot spacings in areas of interest on the site. Third, the electromagnetic signals are recorded as the receiver sensors are raised in the well. The data is then processed to generate a 3-D representation of relative resistance of the site. Subsurface NAPL contamination is located by examining the localized regions of increased resistivity.

Status

This technology currently is being demonstrated at Alameda Naval Air Station, CA, and Tinker AFB, OK, as part of an ongoing site characterization project through the Department of Defense's Environmental Security Technology Certification Program. Demonstrations at these two sites should be completed soon.

Cost Information

The cost of conducting the survey is driven by the type of equipment used, efforts for data acquisition and data interpretation, computer processing services, and the size of the grid spacings.

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Environmental Security Technology Certification Program
High Resolution 3-D Seismic Reflection Survey

Technology Description

High resolution, three-dimensional seismic reflection imaging uses seismic waves to detect materials with different densities at depths of 3 to 3,000 feet beneath the surface. It is based upon the principle that when an impact is introduced at the surface, acoustic waves will spread throughout the subsurface until they are bounced back to the surface when material with a different acoustic impedance is encountered. The travel time of these acoustic waves is used to determine the depth and thickness of subsurface features. While there is no current data that suggests this technique can specifically detect DNAPLs, it can detect the preferential pathways where DNAPL may migrate after a spill occurs.

In order to conduct a high resolution 3-D seismic reflection survey, a geologic model based on background research, photographs, and previously-collected physical samples is compiled. A vertical seismic profile (VSP) is then developed to measure velocity values and actual near surface seismic velocities. It is developed by placing a hydrophone into the well bore at 10 foot increments from the bottom of the hole to the surface. After each measurement is made, the sensor is moved 10 feet up the well bore. Signals are recorded with the seismograph. Next, a 3-D seismic grid is designed and the locations for each receiver are flagged or spray-painted on the ground survey in order to begin the 3-D seismic reflection survey. The seismic reflection survey begins with a preliminary reflection, or noise test. This noise test, along with the size and depth of the features to be imaged, is then used to develop the survey design. The geophones are implanted at 20 foot spacings, using two lines of 24 geophones per 48-channel seismograph.

The equipment used in the survey includes: a 48-channel seismograph; a sledge hammer to stack coherent signal and cancel noise; 30 Hz geophones to record ground motions with a flat frequency response of 30-00 Hz; and a CDP cable to connect the geophone sensors to the seismograph using 102 pairs of #22 gauge wire and waterproof connectors.

Once the data are collected, they are processed in the field and interpreted in a processing center to develop a three-dimensional model of the subsurface. This model is then used to delineate the subsurface stratigraphy, identify pathways of potential contaminant migration, and directly detect dense contaminants, including DNAPLs.

It is believed that this technology will help reduce the time and expense required to properly characterize hazardous waste sites. This will, in turn, enable researchers to more effectively monitor and install remediation systems with substantially fewer wells.

Status

This technology is being demonstrated at Alameda Naval Air Station, CA; Tinker AFB, OK; Letterkenny Army Depot, PA; and Allegheny Ballistics Lab, Rocket Center, WV, as part of an ongoing site characterization project through the Department of Defense's Environmental Security Technology Certification Program. At Letterkenny Army Depot, some drilling and sampling have been conducted to support the results from the seismic survey; only three targets were fully investigated. At Alameda Naval Air Station, the demonstration is expected to be completed this Fall and results so far indicate a usefulness of the technique. Contamination samples were taken from shallow depths, but deeper sampling was not conducted due to a thick clay layer near the surface. 19 targets were sampled, yet only three were shallow enough to sample. At Tinker AFB and Allegheny Ballistics lab, drilling and sampling activities have yet to be conducted.

Cost Information

The cost of conducting a high resolution 3-D seismic reflection survey is driven by the types of equipment used at the site, data acquisition and data interpretation efforts, and computer processing services.

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U.S. Environmental Protection Agency
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
Partitioning Tracers for DNAPL Characterization

Technology Description

Through the use of partitioning tracers, it is possible to determine the NAPL quantity present in a tracer flow field. This is accomplished by selecting tracers that partition into the NAPL phase with predictable or measurable relationships. Laboratory-scale batch and column tests have shown the potential use of long-chain alcohols as partitioning tracers for quantifying DNAPL content in aquifers and of perfluorocarbons for accomplishing the same in the vadose zone.

The test involves the displacement of a suite of reactive and non-reactive tracers through the subsurface zone of interest. Breakthrough curves of the tracers are measured at extraction wells, and if desired, at intermediate points in the flow field between injection and extraction wells. If the partitioning behavior of the tracers between aqueous and NAPL phases is known, the retardation of the reactive tracers relative to the non-reactive tracers can be used to estimate the quantity of NAPL within the swept volume. Information regarding the spatial distribution of NAPL within the flow field can be obtained by establishing a 3-dimensional monitoring network.

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