FOCUSED LITERATURE SEARCH

GEOPHYSICAL METHODS FOR LOCATING AND/OR MONITORING DNAPLS

3D Multi-Offset, Multi-Polarization Acquisition and Processing of GPR Data: a Controlled DNAPL Spill Experiment
Bradford, John, Boise State University, Boise, ID.
SAGEEP 2004: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 22-26 February 2004, Colorado Springs, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. p 514-527, 2004

Researchers conducted a small (107 cm x 122 cm), controlled dense nonaqueous phase liquid contaminants (DNAPL) spill experiment to test 3D multi-fold ground-penetrating radar (GPR) techniques for quantifying DNAPL-induced permittivity anomalies. The model was confined within a cylindrical polyethylene tank; model material consisted of medium to coarse grained sand with a thin gravel layer near the base. The team injected twenty liters of a chlorinated solvent solution into the vadose zone just below the surface and monitored contaminant migration into and through the water saturated zone to the bottom of the tank. A comprehensive data set was compiled for testing a variety of data processing and analysis techniques, i.e., 900 MHz, multi-offset, 3D surface datasets in both TE and TM polarizations, 2D GPR transmission data, downhole TDR probe data, and post-injection soil samples for chemical analysis. Both reflection tomography from TE polarized surface data and crosswell tomography from transmission data reveal significant velocity anomalies associated with pooled DNAPL that approaches a saturation of 40%. Thin-bed, offset-dependent reflectivity analysis of TM surface data suggests the formation of a thin, highly saturated (80 to 100%) DNAPL zone at the top of the main DNAPL pool. This work indicates that detailed analysis of multi-offset, multi-polarization GPR data can improve the quantification of subsurface permittivity anomalies.

3-D Seismic Reflection Surveys for Direct Detection of DNAPL
Adams, Mary-Linda & B. Herridge (Resolution Resources, Inc., Ionia, MI); N. Sinclair (NFESC, Port Hueneme, CA); T. Fox & C. Perry (Battelle Memorial Institute, Columbus, OH).
Nonaqueous Phase Liquids: Remediation of Chlorinated and Recalcitrant Compounds. First International Conference on Remediation of Chlorinated & Recalcitrant Compounds, 18-21 May 1998, Monterrey, California. Battelle Press, Columbus, OH. 3-page poster presentation, 1998

High-resolution 3-D seismic reflection data have been collected at several sites where dense nonaqueous phase liquids (DNAPLs) are or are believed to be present. Confirmatory drilling and chemical analysis have been performed at some of these sites. The seismic surveys were performed to more completely characterize the structure and stratigraphy to delineate fluid migration pathways and traps. The feasibility of using seismic attribute analysis to directly image DNAPL also was demonstrated. Information from these studies can be used to better characterize sites and to position remedial systems more effectively.
http://www.rr-inc.com/Frame%20Pages/papers/dnapl/DNAPL%20poster.pdf

Acoustic Detection of Immiscible Liquids in Sand
Geller, J.T., M.B. Kowalsky, P.K. Seifert, and K.T. Nihei.
Geophysical Research Letters, Vol 27 No 3, p 417-420, 1 Feb 2000

Cross-well P-wave transmission at 90 kHz was measured in a sand pack before and after introducing n-dodecane, a nonaqueous phase liquid (NAPL). In one experiment, NAPL was introduced to form a lens trapped by a low permeability layer; a second experiment considered NAPL residual trapped behind the front of flowing NAPL. The results indicate that small NAPL saturations may be more easily detected with amplitude than with travel time data, but the relationships between the amplitude changes and NAPL saturation may be more complex than those for velocity.

Acoustic Visibility of Immiscible Liquids in Poorly Consolidated Sand
Kowalsky, M.B. (Univ of California, Berkeley), J.T. Geller, P.K. Seifert, K.T. Nihei, and L.R. Myer.
Expanded Abstract, Society Of Exploration Geophysics Annual Meeting, 1998. 4 pp.

To investigate the acoustic visibility of non-aqueous phase liquids in poorly consolidated sands, laboratory experiments were conducted in a 0.6 m diameter confining cell with water-saturated sand. Crosshole data was collected before and after dodecane, a lighter than water non-aqueous phase liquid (LNAPL), was injected from the bottom of the cell. These experiments show a strong acoustic sensitivity of dodecane for transmitted P-wave amplitudes (decreases of up to 65%) and a smaller, but measurable, acoustic visibility for velocity (decreases of up to 2%). Velocity difference tomograms were successful, but limited in resolution; they depict a low velocity region in the tank that corresponds to entrapped dodecane, as revealed by subsequent excavation of the sand cell.
http://www.seg.org/meetings/past/seg1998/techprog/rp3/papr1248.pdf

Borehole Geophysics for Investigations of Ground-Water Contamination in Fractured Bedrock
Williams, John, U.S. Geological Survey, Troy, New York.
U.S. EPA Technical Support Project Meeting, 22 October 2003, Niagara Falls, NY. PowerPoint presentation, 29 pp, 2003

The U.S. Geological Survey has applied borehole geophysical methods at sites contaminated with volatile organic compounds (VOCs) and underlain by sedimentary and crystalline bedrock in several parts of the country. These methods include gamma and induction logging; borehole imaging (acoustic and optical televiewer); and fluid-property logging (specific conductance and temperature), single- and cross-hole flowmeter testing (heat pulse and electromagnetic), and point sampling for VOCs under ambient and pumped conditions. Integrated analysis of the borehole geophysical logs helped to delineate lithology, correlate stratigraphic units, and define the distribution and orientation of bedding, foliation, and fractures. The analysis also helped to characterize the distribution of fracture-flow zones, quantify vertical flow between zones in open boreholes under ambient and pumped conditions, and estimate transmissivity, hydraulic head, and connectivity of the zones. The geohydrologic information gained through the application of borehole geophysics was useful for general site characterization and source identification, as well as the design and evaluation of monitoring and remediation programs. The presentation offers examples from a site affected by TCE.
http://www.epa.gov/tio/tsp/download/2003_meeting_fall/williams_john.pdf

Complex NAPL Site Characterization Using Fluorescence, Part 1: Selection of Excitation Wavelength Based on NAPL Composition
M.L. Kram, A.A. Keller, S.M. Massick, and L.E. Laverman, University of California, Santa Barbara.
Soil and Sediment Contamination: an International Journal, Vol 13 No 2, p 103-118, Mar/Apr 2004

Fluorescence has been demonstrated to be a viable method for detecting non-aqueous phase liquid (NAPL) contaminants comprised of polycyclic aromatic hydrocarbons (PAHs). Commercially available cone penetrometer (CPT) induced fluorescence based sensor platforms can be used to detect NAPLs such as petroleum oils and lubricants in situ. In addition, these approaches can be used to detect dense nonaqueous phase liquid (DNAPL) source zones by detecting commingled oils, fuels, and naturally occurring organic materials entrained by or in solution with DNAPLs and carried to depths below the water table. The currently available CPT based fluorescence systems are typically restricted to a single wavelength excitation source, each demonstrating specific advantages and disadvantages with respect to detection capabilities for particular fluorophores. Several neat NAPLs and mixtures were analyzed for specific fluorescence characteristics to determine the optimal excitation source for site characterization efforts. Commercially available CPT-based fluorescence detection systems have been ranked according to the potential for likelihood of detection. An optimal range of excitation wavelength can be determined for specific fluorophores within NAPL mixtures, and available systems can be ranked based on the specific contaminant and site characteristics. Optimal excitation sources are identified for common NAPL mixtures, including petroleum-based fuels and a lubricant mixed with a chlorinated solvent.
http://www2.bren.ucsb.edu/~keller/papers/Abstract44.pdf

Complex NAPL Site Characterization using Fluorescence, Part 2: Analysis of Soil Matrix Effects on the Excitation/Mission Matrix
Kram, Mark L. and Arturo A. Keller, University of California, Santa Barbara.
Soil and Sediment Contamination: an International Journal, Vol 13 No 2, p 119-134, Mar/Apr 2004

Commercially available cone penetrometer (CPT) devices can be used to delineate dense nonaqueous phase liquid (DNAPL) zones when this class of contaminant is found commingled with oils, fuels, and naturally occurring organic materials entrained by DNAPLs and carried to depths below the water table. This paper describes a study in which several neat and mixed NAPLs were added to different soil types and analyzed for specific fluorescence characteristics to determine the optical excitation source for site characterization efforts. Excitation/emission matrices were used to demonstrate that an optimized excitation wavelength can be determined for specific fluorophores within the NAPL mixtures, and that available systems can be ranked based on the specific contaminant and site soil types. The study revealed that impure silica-containing affect the emission signal, potentially leading to incorrect conclusions for several commercially available systems. A tunable excitation source probe system would be superior to any other commercially available system, provided the system would be relatively easy to operate and would have rapid in situ excitation emission matrix-generating capabilities for optimization in the field.
http://www2.bren.ucsb.edu/~keller/papers/Abstract45.pdf

Complex NAPL Site Characterization Using Fluorescence, Part 3: Detection Capabilities for Specific Excitation Sources
Kram, Mark L. and Arturo A. Keller, University of California, Santa Barbara.
Soil and Sediment Contamination: an International Journal, Vol 13 No 2, p 135-148, Mar/Apr 2004

Commercially available cone penetrometer (CPT) devices can be used to delineate dense nonaqueous phase liquid (DNAPL) zones when this class of contaminant is found commingled with oils, fuels, and naturally occurring organic materials entrained by DNAPLs and carried to depths below the water table. This paper describes a study in which aviation and diesel fuels were diluted with chlorinated solvents and evaluated for fluorescence characteristics. Dilution of the complex NAPL mixtures led to changes in the corresponding excitation emission matrices. The optimal excitation source for aviation fuel remained relatively constant for each dilution, but sensitivity for each of the commercially available CPT excitation sources was strongly dependent on diesel concentration, whereby higher energy (lower wavelength) sources yielded improved sensitivity for lower concentrations. Field concentrations can be highly variable, so these observations support the need for multiple wavelength excitation sources for optimal detection capabilities, particularly when diesel fuel is present.
http://www2.bren.ucsb.edu/~keller/papers/Abstract46.pdf

A Conceptual Model for the Detection of NAPL Using Amplitude and Phase Variation with Offset (APVO) Analysis of Ground Penetrating Radar Data
Jordan, Thomas E. and Gregory S. Baker, Univ. at Buffalo, Buffalo, NY.
SAGEEP 2002: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 10-14 February 2002, Las Vegas, Nevada.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, 12GPR10, 18 pp, 2002

Conceptual models of nonaqueous phase liquid (NAPL) contaminated soils permitted an examination of the applicability of using amplitude and phase variation with offset (APVO) analysis on ground-penetrating radar (GPR) data for delineating NAPL in the vadose zone, capillary fringe, and saturated soils. The models considered antenna directivity, partial NAPL saturation values, and anticipated subsurface conditions that might result from NAPL releases. Previous research indicates that a pooled NAPL does not occupy 100% of the pore space of a soil; soil saturations are generally less than 50% for a light NAPL and less than 38% for a dense NAPL. Biodegradation, leaching, and permeability decreases associated with a NAPL release can increase the bulk conductivity of a soil, though the effects of these phenomena on different hydrogeologic zones vary. The authors examined the effects of antenna directivity and radiation patterns by incorporating effective relative permittivity data into Fresnel equations and compared the results with the APVO response for various hydrogeologic scenarios for GPR data collected in transverse magnetic and transverse electric modes.

Critical Review of Environmental Forensic Techniques: Part I
Morrison, Robert D., R. Morrison & Associates Inc., Escondido, CA.
Environmental Forensics, Vol 1, p 157-173, 2000

Many forensic techniques are available for age dating and source identification: aerial photography interpretation, corrosion models, the commercial availability of a compound, chemical associations with discrete type processes, chemical profiling, degradation models, and contaminant transport models. Though these techniques are rarely challenged or discussed in the literature, in environmental litigation, where they may be produced as scientific evidence, the governing assumptions and quality of the data are critically evaluated and frequently successfully challenged. This paper reviews five types of forensic techniques for contaminants such as chlorinated solvents and discusses their respective merits so that a user can decide which technique, or combination of techniques, is most appropriate for

developing the technical portion of a case.
http://www.dpraenvironmentalforensics.com/articles/Morrison_Dec_2000_Part1.pdf

Cross-Hole Complex Resistivity Survey for PCE at the SRS A-014 Outfall
Grimm, R. (Southwest Research Inst., Boulder, CO); G. Olhoeft (Colorado School of Mines, Golden).
SAGEEP 2004: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 22-26 February 2004, Colorado Springs, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. p 455-464, 2004

Crosshole complex resistivity (CR) imaging of the vadose zone was performed at the A-014 Outfall at the Savannah River site near Aiken, SC. Five vertical electrode arrays were installed with ~15-ft separations in and around a suspected DNAPL source zone to depths of 72 feet. Amplitude and phase data were edited for quality and then inverted to form 3-D images of the target volume. Lab analysis of nearby contaminated soil indicated that the CR response to the PCE/clay reaction was maximized near 50 mHz. PCE concentrations were measured at three drilling locations. The optimum performance at 1000 mg/kg in situ PCE was >80% detection true positives with <30% false positives at an effective resolution of 4 ft, approximately one-third of the interwell separation. The CR survey successfully predicted the general distribution of PCE at parts-per-thousand concentrations, specifically widespread near-surface contamination and a zone of discontinuous pods or stringers immediately below the source.

Detection Limits for Immiscible Liquid Organic Contaminants Using Proton Nuclear Magnetic Resonance
Bryar, Traci R. and Rosemary J. Knight, Stanford University, Stanford, CA.
SAGEEP 2003: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 6-10 April 2003, San Antonio, Texas.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, p 961-972, 2003

Laboratory measurements indicate that it is possible to quantify the amount of toluene contamination in a sediment using proton nuclear magnetic resonance (NMR). The detection limit for toluene in the presence of water depends on signal-to-noise ratio of the data, ratio of contaminant relaxation time to that of water, and amount of toluene relative to water. Using synthetic NMR data, these results can be extended to selected immiscible contaminants with similar viscosity and wetting properties. Predicted detection limits are presented for NMR determination of benzene, chlorobenzene, 1,1-dichloroethene, ethylbenzene, 1,1,1-trichloroethane, trichloroethene (TCE), toluene, and xylenes. Potentially, toluene, benzene, ethylbenzene, and xylenes could be accurately quantified in many sediments as long as the contaminant occupies at least 50% of the pore space. The sensitivity of NMR to chlorinated contaminants is lower, and it is likely that 1,1-dichloroethene could be accurately quantified in most sediments only if the contaminant occupied more than 75% of the pore space. This study provides guidelines for developing the use of NMR techniques for contaminant detection.

Determination of Porosity and DNAPL Saturation Values from Modeling of Noninvasive Ground Penetrating Radar Data
Sneddon, K.W., M.Sc. thesis, Colorado School of Mines, Golden. 2001

Abstract not available.

Determining and Mapping DNAPL Saturation Values from Noninvasive GPR Measurements
Sneddon, K.W. and G.R. Olhoeft (Colorado School of Mines, Golden); M.H. Powers (U.S. Geological Survey, Denver, CO).
SAGEEP 2000: Symposium on Application of Geophysics to Environmental and Engineering Problems, 21-25 February 2000, Arlington, VA.
Environmental and Engineering Geophysical Society, Wheat Ridge, CO, p 293-302, 2000

With the possible application to fluid-flow modeling, saturation values of dense nonaqueous phase liquids (DNAPLs) can be determined and mapped through the use of measurements acquired by noninvasive ground-penetrating radar (GPR). A controlled injection of perchloroethene (PCE) was performed in 1991 by the University of Waterloo into an isolated, water-saturated, sandy aquifer at Canadian Forces Base Borden. The U.S. Geological Survey used 500-MHz surface ground-penetrating radar (GPR) (among other methods) to monitor the location and migration of the subsequent plume. This paper describes how full-waveform GPR modeling of the data for relative dielectric permittivity versus depth may be used to calculate and map spatial distributions of DNAPL saturation over time using recursive solutions of the Bruggeman-Hanai-Sen (BHS) mixing formula.
http://www.g-p-r.com/sageep00.PDF

Dielectric Permittivity of Clay-Water-Organic Compound: Frequency Dependence
Canan, Birsen, Smoke Creek Instruments, Inc., Reno, NV.
SAGEEP 2001: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 4-7 March 2001, Denver, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, OCS-2, 12 pp, 2001

The effects of organic contaminants in a clay/water mixture were investigated via dielectric permittivity under controlled laboratory conditions. Four organic contaminants--trichloroethene (TCE), tetrachloroethene (PCE), ethylene glycol, and phenol--were added to previously prepared samples of clay/water mixtures, and their dielectric permittivities were measured. The dielectric permittivities of contaminated versus uncontaminated samples were compared to determine if there was any pattern to help to identify a particular organic contaminant via dielectric permittivity values of the mixtures. The following changes were noted, depending on the nature of the organic material: a decrease of the magnitude of dielectric permittivity and shift of the relaxation frequency to lower frequencies for ethylene glycol and phenol, and an increase in the magnitude of dielectric permittivity and shift of the relaxation toward higher frequencies for TCE- and PCE-contaminated samples between 100 KHz and 350 MHz frequencies.

Discussion of "DNAPL Migration Through a Fractured Perching Layer" by Daniel B. Stephens, James A. Kelsey, Mark A. Prieksat, Mel G. Piepho, Chao Shan, and Mark D. Ankeny, July-August 1998 issue of Ground Water, v. 36, no. 4: 605-610 (U)
Tuck, David M., Westinghouse Savannah River Company, Aiken, SC.
WSRC-MS-98-00866, 14 pp, 1998

The reviewer notes that the visualization study of 1,1,1-trichloroethane (TCA) infiltration described by Stephens et al. (1998) is an elegant design, clearly demonstrating DNAPL behavior encountering a fractured perched layer. However, he questions their interpretation, stated in both abstract and conclusions, that rapid DNAPL penetration of the fracture was "in contrast to existing mathematical

solutions of hydrostatic initial conditions and full saturation below the fracture." He also comments on the experimental conditions.
http://sti.srs.gov/fulltext/ms9800866/ms9800866.pdf

DNAPL Detection Sensitivity of a High-Resolution Directional Borehole Radar
Moulton, Craig W. and David L. Wright, U.S. Geological Survey, Denver, CO.
SAGEEP 2003: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 6-10 April 2003, San Antonio, Texas.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, p 107-115, 2003

The U.S. Geological Survey has developed a directional borehole radar system (DBOR) for high-resolution imaging close to borehole wells. Physical and numerical modeling has been conducted to assess the ability of this radar to detect and map the location of dense nonaqueous phase liquids (DNAPLs) near a borehole. Physical modeling was conducted in a water-saturated silica sand-filled tank. Model targets included silica sand saturated with mineral oil and a paraffin cylinder. The oil/sand mixtures were sealed in plastic bags, molded into recognizable geometric shapes, and placed in the sand at various distances and orientations relative to the borehole. Physical modeling showed the paraffin and oil/sand rectangular targets and a thick wedge against the borehole-imaged well. The thick and thin wedges away from the borehole were more difficult to discern. The study results indicate that the radar system should be able to detect and map the location of small amounts of DNAPL in a controlled spill experiment to be conducted by the EPA.

DNAPL Detection Using Cross-Well Radar
Farid, M., A. Alshawabkeh, & C. Rappaport, Northeastern University, Boston, MA.
Center for Subsurface Sensing and Imaging Systems (CenSSIS) Student Posters, [PowerPoint presentation] 20 pp, 2002

Current DNAPL detection methods, such as direct push probe technologies (DPT) and in situ tracers have limitations, and there is a need for innovative, non-invasive methods for real-time monitoring of DNAPLs. Cross-well radar (CWR) uses high-frequency electromagnetic (EM) waves transmitted and received through antennas in the subsurface for monitoring DNAPLs in the subsurface. This presentation describes the Maxwell Equations for propagation and scattering of EM waves through the subsurface. A finite difference time domain (FDTD), originally developed for detection of mines using ground-penetrating radar, is revised and upgraded for 3-D wave propagation in soils. The space is discretized using Central Finite Difference operators, and Gaussian-type pulse is used as the excitation pattern. A 3-D absorbing boundary condition is developed for the dispersive soil media. To assess the possibility of using CWR to detect pooled DNAPL, illustrative examples with and without the presence of DNAPLs were analyzed. The results show some diagnostic points for detection of contaminated zones with DNAPL using CWR.
http://www.censsis.neu.edu/Education/StudentResearch/2001/abstracts/farid_m.html

DNAPL Site Characterization: a Comparison of Field Techniques
Griffin, Terry W. and Kenneth W. Watson, HSW Engineering, Inc.
The Third International Conference Remediation of Chlorinated and Recalcitrant Compounds, 20-23 May 2002, Monterey, California. Battelle Press, Columbus, OH. 2002

A field study was performed to compare several approaches to DNAPL characterization at a site where indirect and limited direct evidence of DNAPL exists. The study involved 3-D high-resolution seismic survey, field screening of soil cores with a flame ionization detector/organic vapor analyzer (FID/OVA), hydrophobic dye (Sudan IV)-impregnated reactive Flexible Liner Underground Technologies (Flute(R)) membrane used in combination with Rotasonic drill cores, centrifuged soil with Sudan IV dye, UV fluorescence, a Geoprobe(R)) Membrane Interface Probe (MIP(R)), and phase equilibrium partitioning evaluations based on laboratory analysis of soil samples. Sonic drilling provided continuous cores from which minor soil structures could be evaluated, and the OVA provided reliable preliminary data for identifying likely DNAPL zones within the cores. The Flute(R) membrane provided direct evidence for the presence of DNAPL. The MIP(R) probe provided rapid identification of probable DNAPL areas, as well as soil conductivity data. The 3-D seismic survey was of minimal benefit to the study, and the use of UV fluorescence and the centrifuging of samples with Sudan IV dye provided no benefit. Results of phase equilibrium partitioning calculations to infer the presence of DNAPL agreed well with the site screening data.
http://www.hsweng.com/img/DNAPL%20Battelle.pdf

Effect of Immiscible Liquid Contaminants on P-Wave Transmission Through Natural Aquifer Samples
Geller, Jil T. (Lawrence Berkeley National Lab, Berkeley, CA); J.B. Ajo-Franklin; E.L. Majer.
SAGEEP 2003, Symposium on the Application of Geophysics to Engineering and Environmental Problems, 6-10 April 2003, San Antonio, TX.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM. [Also available as LBNL-52131, 19 pp, 2003]

The authors discuss the results of core-scale laboratory experiments performed to examine the effect of nonaqueous phase liquid (NAPL) contaminants on P-wave velocity and attenuation in heterogeneous media. This work is part of a larger project to develop crosswell seismic methods for minimally invasive NAPL detection. The test site is the former DOE Pinellas Plant in Florida, which has known NAPL contamination in the surficial aquifer. Field measurements revealed a zone of anomalously high seismic attenuation, which may be due to lithology and/or contaminants (NAPL or gas phase). Intact core was obtained from the field site, and P-wave transmission was measured by the pulse-transmission technique with a 500 kHz transducer. Two types of samples were tested: a clean fine sand from the upper portion of the surficial aquifer, and clayey-silty sand with shell fragments and phosphate nodules from the lower portion. Either NAPL trichloroethene or toluene was injected into the initially water-saturated sample. Maximum NAPL saturations ranged from 30 to 50% of the pore space. P-wave velocity varied by approximately 4% among the water-saturated samples, while velocities decreased by 5 to 9% in samples at maximum NAPL saturation compared to water-saturated conditions. The clay and silt fraction as well as the larger scatterers in the clayey-silty sands apparently caused greater P-wave attenuation compared to the clean sand. The presence of NAPLs caused a 34 to 54% decrease in amplitudes of the first arrival. The central frequency of the transmitted energy ranged from 85 to 200 kHz, and was sensitive to both grain texture and presence of NAPL. The results are consistent with previous trends observed in homogeneous sand packs. More data will be acquired to interpret P-wave tomograms from cross-well field measurements, determine the cause of high attenuation observed in the field data and evaluate the sensitivity of seismic methods for NAPL detection.
http://www.osti.gov/dublincore/gpo/servlets/purl/809308-dSMrLv/native/809308.pdf

Electrical Impedance Tomography for Detection of DNAPL Contamination
Daily, William and Abelardo Ramirez, Lawrence Livermore National Laboratory, Livermore, CA.

SAGEEP 2004: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 22-26 February 2004, Colorado Springs, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. p 449-454, 2004

Using only spectral EIT images from the A-014 outfall and laboratory spectral impedance measurements of clean and contaminated outfall samples, researchers made predictions about DNAPL contamination at the outfall. Those predictions compared well with the actual depth distribution of contamination as determined from samples analyzed from a single borehole. Regions located away from the outfall and presumed free of DNAPL contamination did not show evidence of contamination in the EIT surveys. The results of this single test are consistent with the conclusion that EIT may be useful for locating subsurface DNAPL contamination.

Electrical Properties of Sand-Clay Mixtures Containing Trichloroethylene and Ethanol
Roberts, Jeffery J. and Dorthe Wildenschild, Lawrence Livermore National Lab, Livermore, CA.
SAGEEP 2002: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 10-14 February 2002, Las Vegas, Nevada.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, 12PET3, 12 pp, 2002

Laboratory experiments to measure electrical properties and permeability were performed on well-characterized sand/clay mixtures, among them samples containing 10% distributed clay and spiked with 20 and 500 ppm trichloroethene (TCE). Electrical properties measurements show that the addition of TCE has a small effect on electrical resistivity, with resistivity increasing with the addition of TCE. The influence of TCE on the electrical properties was most prominent in plots of loss tangent as a function of frequency. A loss tangent peak occurred at ~200 Hz. The height of the peak and the peak frequency both decrease with the addition of TCE. Further experiments were performed on samples containing a distinct clay layer parallel to current flow. The results indicate that electrical measurements are a useful tool for characterizing porous rocks and soils and that it is feasible to remotely detect the presence and follow the transport of contaminants such as TCE in the subsurface.

Electrical Properties of Sand-Clay Mixtures Containing Trichloroethylene and Ethanol
Roberts, Jeffery J. and Dorthe Wildenschild, Lawrence Livermore National Lab, Livermore, CA.
Journal of Environmental & Engineering Geophysics, Vol 9 No 1, p 1-10, 2004

In a series of laboratory experiments to measure electrical properties and permeability of sand/clay mixtures, the addition of TCE had a small effect on electrical resistivity: resistivity was greater at higher concentrations of TCE. The influence of TCE on electrical properties was most prominent in plots of loss tangent as a function of frequency. These plots showed that loss-tangent peaks occurred at 200 Hz and that peak and peak frequency were smaller at higher concentrations of TCE. Additional experiments were performed on a sample that contained a distinct clay layer parallel to the current flow. The authors found electrical measurements to be useful tools for characterizing porous rocks and soils and feasible for remote detection and subsurface transport monitoring of contaminants such as TCE.

Fusion of Tomography Tests for DNAPL Source Zone Characterization: Technology Development and Validation
Strategic Environmental Research & Development Program. Cleanup CU-1365, 1 pp, Sep 2003

This project will develop algorithms that fuse different types of information using a stochastic approach to provide a cost-effective characterization, monitoring, and predictive technology for the DNAPL source zone. This technology exploits recently developed hydraulic/pneumatic tomography and expands the concept to the development of a conservative and partitioning tracer tomography to image the subsurface and DNAPL distributions without extensive invasive sampling. The new technology uses a stochastic fusion of information methodology to assimilate results of hydraulic, conservative, and partitioning tracer tomography surveys to derive the best estimate of the DNAPL residual distribution and to quantify its uncertainty. Specifically, it first analyzes the information derived from hydraulic tomography to identify three-dimensional (3-D) hydraulic heterogeneity. It then improves the estimate of the heterogeneity by incorporating new information acquired from the conservative tracer tomography. Afterward, the improved hydraulic heterogeneity is used to simulate the hydraulic tomography such that more detailed information about the response of the subsurface becomes available. This new information is used to update the estimate of the heterogeneity. The iterative process continues until the available information and measurements are fully utilized for identifying the heterogeneity that controls the spatial distribution of DNAPL. Upon completion, the newly derived knowledge of the heterogeneity is used to design partition tracer tomography tests and combined with the tracer data to accurately depict the spatial distribution of DNAPL residual saturation in the source zone. The techniques will be tested and validated in both numerical experiments and a sandbox. This project began in FY 2003. Contact: Dr. Walter A. Illman, Univ. of Iowa, Iowa City, 319-335-1827, walter-illman@uiowa.edu.

FY03 DNAPL Characterization of the A-14 Outfall
Riha, B.D.
Report No: WSRC-TR-2003-00540, 47 pp, Jan 2004

Residual dense nonaqueous phase liquid (DNAPL) contamination continues to be one of the most challenging remediation and characterization problems at the Savannah River site. Chlorinated solvents were usually released as DNAPLs to the subsurface, where they move in an unstable fashion driven by gravitational and capillary forces. They are often retained in small discrete blobs in fine grained materials in the vadose zone and contaminate ground water by slow continuous release through dissolution and diffusion. Locating these small sources is a difficult but crucial part of remediating a contaminated site. Several methods have been developed to locate subsurface DNAPL, but nearly all are intrusive and can only identify DNAPL in close proximity to the access hole. Minimally invasive geophysical methods to locate residual DNAPL have been proposed and developed, but few methods are capable of the spatial resolution required. Complex resistivity measurements sensitive to DNAPL (perchloroethene) interactions with clay (smectite) have recently shown promise in laboratory experiments. Based on these laboratory results, field tests of the complex resistivity technique were performed at the A-014 outfall.
http://sti.srs.gov/fulltext/tr2003540/tr2003540.pdf

A Geophysical Method for Detection and Quantification of Dense Non-Aqueous Phase Liquids (DNAPL) in the Subsurface
Stewart, Mark (Univ. of South Florida, Tampa); Loren North (CDM, Ft. Myers, FL).
SAGEEP 2003: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 6-10 April 2003, San Antonio, Texas.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, p 1042-1058, 2003

A field site was selected that is known to be heavily contaminated with DNAPL, principally TCE. The site is on a large barrier island complex in the southeastern Unites States. Site stratigraphy consists of about 50 ft of sands, silts, and some clay, with silt content generally increasing with depth. Researchers measured the dielectric constant by a probe on a CPT tool string and calculated porosity from bulk density measurements obtained with an active gamma logging tool. The gamma logs were run in small diameter wells adjacent to the CPT locations. Natural gamma and thermal neutron logs were also run in the boreholes. The natural gamma logs suggest that low permeability units are present at elevations of -9, -20 and -31 feet mean sea level (ft msl). Calculated fractional DNAPL volume, the DNAPL volume over total volume, shows three peaks in DNAPL volume at elevations of -8, -18, and -30 ft, or just above the low permeability units. DNAPL volume averages about 0.10, with maximum values of about 0.25. Porosity ranges from about 0.3 to 0.55. DNAPL saturation is the DNAPL volume divided by pore volume, and is a measure of the volume of available pore space occupied by DNAPL. Again, the highest DNAPL saturation values are just above the three fine-grained layers. DNAPL saturation averages about 25% in the contaminated zone, with maximum values of about 45 %. The method shows significant promise for quantifying DNAPL volume and saturation using direct-push technologies, making it very suitable for saturated, unconsolidated soils contaminated with residual DNAPL.

GRORADAR(TM): Acquisition, Processing, Modeling, and Display of Ground Penetrating Radar Data: Ver. 4.0
Olhoeft, G.R.
Seventh International Conference on Ground Penetrating Radar, 27-30 May 1998

GRORADAR is a commercial software package designed to acquire, process, display, and model ground-penetrating radar data. It can acquire GPR data from digital sources in the DZT, DT1, and RD3 data formats, or read arbitrary digital data with user described formatting. It will also digitize and process older analog data with separate range gain and time calibration files. Processing or manipulation of the image data includes ringing and background removal, noise filters, edge enhancement, horizontal rubber sheeting to known marker locations, topographic correction to EDM surveying data, complex parabola fitting (for object size, object depth and intervening material velocity estimation), 2D velocity migration. Single wavelet scans may be extracted, and then full-waveform, far-field modeled in one dimension, including fully dispersive, frequency dependent electrical and magnetic properties. Sand/clay/water/air/iron mixture concentrations can be estimated from the dispersive model material property results. After calibration with a metal plate, automatic modeling is possible for asphalt or concrete pavement thickness, including a statistical estimate of uncertainty. The modeling portions may be used without data to forecast how well ground penetrating radar may work at a site. Hardcopy output can be obtained at any point in the processing or modeling to HP-GL and PostScript printers. A free demonstration version is available. The DOS version of GRORADAR(TM) is now freeware.
http://www.g-p-r.com/

GRORADAR(TM) Version 2002.05: Processing, Modeling and Display of Dispersive Ground Penetrating Radar Data. Manual
Olhoeft, Gary R., 27 pp, 2002

This manual provides instructions for installing and running the GRORADAR software, with an overview of the commands, operations, options, field data display, and import menu. It presents

examples for metallic pipe, plastic pipe, survey wheel, arbitrary data, and pavement thickness, http://www.g-p-r.com/groradar.pdf

Ground-Water Contamination in Fractured Bedrock at the University of Connecticut Landfill
Johnson, Carole, U.S. Geological Survey, Storrs, CT.
U.S. EPA Technical Support Project Meeting, 22 October 2003, Niagara Falls, NY. PowerPoint presentation, 48 pp, 2003

Surface and borehole geophysical methods were used with hydraulic and geochemical data to characterize lithology, fractures, and hydraulic properties of crystalline bedrock and to determine the nature and extent of ground-water contamination from a landfill and former chemical-waste disposal pits in an upland region of the Willimantic River Basin, CT. Bedrock wells provide a domestic water supply. Detection of volatile organic compounds (i.e., organic solvents and chlorinated hydrocarbons) in domestic bedrock wells in the mid-1980s led to an ongoing investigation. Surface geophysical methods--electromagnetic induction, 2-D direct-current resistivity, square-array direct-current resistivity, and seismic refraction--were used to target potential discharge of contaminants from the landfill for further investigation. Two shallow, electrically conductive anomalies identified near site surface waters were interpreted as leachate plumes and confirmed by field identification of leachate-impacted sediments and surface-water screening, sampling, and analysis. Two sheet-like conductive anomalies were detected in bedrock and were further investigated by borehole drilling, borehole geophysical logging, and water sampling. Boreholes were installed to depths of 30 feet in the glacial deposits, and 125 to 300 feet in the bedrock. Conventional geophysical logging, acoustic and optical imaging, single-hole directional radar reflection, flowmeter logging under ambient and pumped conditions, and discrete-interval hydraulic testing, sampling, and monitoring were conducted in 16 bedrock boreholes. Borehole geophysical methods were used to investigate the conductive anomalies identified by surface geophysical methods, the location and orientation of fractures that intersect and surround each well, the direction and magnitude of ambient flow in the well, and the transmissive fractures that could provide pathways for contaminant migration.
http://www.epa.gov/tio/tsp/download/2003_meeting_fall/johnson.pdf

High Resolution Seismic Reflection to Characterize and Plan Remediation at Hazardous Waste Sites, ESTCP Cost and Performance Report
U.S. DoD, Environmental Security Technology Certification Program (ESTCP), 28 pp, Oct 1999

This report presents cost and performance data for the 3-D seismic reflection survey technique used to generate high-resolution imaging of subsurface geologic, subsurface hydrogeologic, and subsurface dense nonaqueous phase liquid (DNAPL) contaminant source areas at four DoD sites: Letterkenny Army Depot near Chambersburg, PA; Alameda Naval Air Station, Alameda, CA; Tinker Air Force Base, Oklahoma City, OK; and Allegany Ballistics Laboratory, Mineral County, WV. At Allegany Ballistics Laboratory, the seismic survey and an extensive sampling effort were funded and conducted outside of this project, and only geologic predictions, not DNAPL targets, were investigated. The results of this demonstration show that 3-D seismic surveys were not effective at directly detecting DNAPL. Of the 27 total targets evaluated at Letterkenny Army Depot, NAS Alameda, and Tinker AFB, only one target was found to contain DNAPL, so the project did not meet the objective of detecting DNAPL at 90% of the targets. The only successful target was based on an anomaly in the seismic imagery that appeared indistinguishable from other anomalies believed to be caused by contrasts between geologic

strata. The threshold concentration level used to positively determine the presence of DNAPL was 110 ppm. Overall, the four demonstration sites appear to possess high enough levels and large enough plumes of dissolved-phase halogenated organic contamination to suggest that free-phase DNAPL sources are likely to be present.
http://www.estcp.org/documents/techdocs/199601.pdf

Integrated Geophysical Characterization of a NAPL-Contaminated Site Using Borehole and Laboratory Measurements
Ajo-Franklin, J.B. (Stanford Univ., Stanford, CA); J.T. Geller, E.L. Majer, J.E. Peterson, K.H. Williams, and J.M. Harris (Lawrence Berkeley National Lab, Berkeley, CA).
Eos Trans. AGU Fall Meet. Suppl., Vol 83 No 47, Abstract T22B-1142, 2002

The authors present preliminary results from an on-going geophysical investigation of the former DOE Pinellas site in Pinellas County, FL, a site with confirmed NAPL contamination. The goal of the work is to demonstrate the combined use of high-resolution crosswell seismic and crosswell radar data for characterization of NAPL distribution in near-surface environments. Borehole conductivity, gamma, and cone penetrometry measurements have provided secondary information to constrain lithology. Tomographic techniques were used to obtain cross-sectional velocity and attenuation maps for both the seismic and radar surveys. Subsequent correlation with gamma log data and core properties allowed mapping of several layers of clay-rich sediment that could affect both the downward and lateral migration of contaminants. Continuous cores extracted from several locations on site allowed calibration of the rock-physics relationships used in interpretation of both the crosswell and logging data. Though conclusive geophysical evidence of NAPL pools has not yet been obtained, regions of anomalous seismic attenuation were detected that could not be explained by borehole effects or lithology and may be caused by regions of partial gas or NAPL saturation. Toluene and TCE, two NAPLs present at the Pinellas site, will be used as experimental contaminants in core measurements.

Integrated Geophysical Detection of DNAPL Source Zones
Blackhawk Geoservices Inc., Golden, CO.
NTIS: ADA409159, 68 pp, Nov 2001

Identification of subsurface organic contamination, particularly dense nonaqueous phase liquids (DNAPLs), is a high priority for remediation of numerous sites, including those of DoD and DOE. Complex resistivity (CR) is the only geophysical method that has been demonstrated in the laboratory to have high sensitivity to organic compounds, by detecting responses indicative of clay-organic electrochemistry. Direct detection of organics in the field has been elusive, in part due to the difficulty of obtaining robust measurements at very low contaminant levels in the presence of heterogeneous geological materials and interference by metallic utilities and remediation plumbing. This project sought to improve the capability to detect DNAPL by better geophysical imaging of geological pathways that control DNAPL movement and direct detection by detailed comparison of CR lab-to-field data using this improved imaging. For the first goal, algorithms were developed for the joint tomographic imaging of seismic and resistivity data. The method requires that an empirical relationship can be established between seismic and resistivity; if values are ultimately tied to specific lithologies, then the final tomographic product can be an actual geological cross-section. Because shallow subsurface investigations are now commonly performed using a cone penetrometer (CPT), a new vibratory seismic source has been developed to identify sites with clay/organic reactions measurable in the lab from core samples, perform reconnaissance field surveys, and proceed to detailed 2D or 3D

cross-hole imaging.
http://handle.dtic.mil/100.2/ADA409159

Laboratory Complex Resistivity Investigation of Organic Contaminants: Denver Federal Center Soils
Sneddon, Kristen Warner, Colorado School of Mines, Golden.
SAGEEP 2001: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 4-7 March 2001, Denver, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, OCS-3, 15 pp, 2001

The physical properties of DNAPLs often render monitoring-well data misleading by underestimating actual concentrations present in the liquid and vapor phases. The presence of smectite-rich soil at the Denver Federal Center site and the occurrence of chemical degradation of volatiles through dechlorination suggests the use of complex resistivity as a monitoring tool sensitive to clay/organic reactions. This study involves controlled contamination of site soils in the laboratory to aid the interpretation of complex resistivity field data.

Laboratory Experimental Setup for Cross-Well Radar
Farid, Mohammad, A.N. Alshawabkeh, & C.M. Rappaport, Northeastern Univ., Boston, MA.
SAGEEP 2003: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 6-10 April 2003, San Antonio, Texas.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, p 623-634, 2003

Cross-well radar is a technique that uses ground penetrating radar, with antennas that are lowered into sampling wells in situ by cable. Radar waves are emitted from a transmitting antenna in one well and propagate through the ground to a receiving antenna in a second well to image the dielectric properties of soils for detecting contaminants, such as DNAPLs. A prototype model of infinite soil media was experimentally simulated by constructing a SoilBed facility. The objective of this paper is to explain and evaluate different factors affecting experimental data collection and calibrating the results.

Mapping DNAPL Transport Contamination in Sedimentary and Fractured Rock Aquifers with High Resolution Borehole Seismic Imaging. FY01 Annual Report
Geller, J.T.; E.L. Majer; J.E. Peterson; K.H. Williams; S. Flexser.
Report No: LBNL-49385, 44 pp, Dec 2001

The objectives of this project are to develop, demonstrate, and evaluate in the field the utility of high-frequency seismic imaging methods to detect and characterize nonaqueous phase liquid (NAPL) contamination in sedimentary and fractured rock aquifers. Field tests consist of crosswell seismic tomography acquired before, during, and after any remediation action that would potentially affect fluid distributions. Where feasible, other characterization data are obtained, such as crosswell radar, borehole conductivity, and cone penetration testing (CPT). Crosswell data are processed to obtain tomographic images, or two-dimensional distributions, of velocity and attenuation. The interpretation of the tomograms utilizes all available site characterization data to relate the geophysical attributes to lithology and fluid phase heterogeneities. Interpretations are validated by evaluation and testing of field cores. Laboratory tests on core retrieved from surveyed locations are performed to determine the relationships between geophysical parameters and solid and fluid phase composition. In the case of

sedimentary aquifers, proof of principle has been demonstrated previously in homogeneous sand-packs at the centimeter and half-meter scale. The field tests will provide proof of principle at the field scale by working in an unconsolidated sand aquifer with known presence of NAPL. The ability to scale up from the laboratory to the field is evaluated by conducting field measurements over a range of frequencies that overlap the lowest frequencies used in the laboratory tests. In the fractured rock case, previous field work has shown that fracture zones can be detected by crosswell seismic tomography. Laboratory studies have demonstrated that the seismic wave signature is sensitive to the fracture stiffness, and that stiffness is affected by fracture-filling fluids. The field and laboratory experience provide a physical basis for the potential detection of fractures that would be the important flow paths for NAPL contaminants.
http://www.osti.gov/dublincore/gpo/servlets/purl/792956-KTSDox/native/792956.pdf

Mapping of TCE and PCE Contaminant Plumes Using a 3-D Induced Polarization Borehole Data
Briggs, Victoria (MIT, Cambridge, MA), et al.
SAGEEP 2004: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 22-26 February 2004, Colorado Springs, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. p 472-483, 2004

In situ complex resistivity (CR) or induced polarization (IP) data were collected from a 3D array of surface and borehole electrodes over an area known to be contaminated with dense nonaqueous phase liquids (DNAPLs), primarily tetrachloroethene (PCE) and trichloroethene (TCE). The design of the surface and cross-borehole array allowed a 3D IP inversion. Data were measured at two frequencies (1/4 and 1/16 Hz) and inverted for resistivity magnitude and phase. When the inversion results were compared with PCE and TCE contaminant concentrations measured from core samples, the phase and imaginary resistivity correlated well with concentration data from two of three ground truthing boreholes where the TCE and PCE concentrations were above 1mg/kg.

Mapping Structural Pathways for DNAPL Transport in Karst Using Induced Polarization
Hughes, Larry J. (EnSafe Inc., Memphis, TN); Norman R. Carlson (Zonge Engineering & Research Organization, Inc., Tucson, AZ).
SAGEEP 2003: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 6-10 April 2003, San Antonio, Texas.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, p 849-856, 2003

This paper describes an application of induced polarization (IP) to map either clays or TCE migration from a leaking landfill to identify buried, sediment-filled sinkholes. Following the detection of TCE in an offsite spring, state regulators wanted to drill and sample a deep structure beneath the landfill to maximize the chances of finding the dense contaminant. An IP survey in a test section of a capped landfill in Tennessee produced a 3D map of subtle linear anomalies, interpreted as structures and karst development. The structures are enhanced beneath thicker parts of the landfill. Successive depth slices show that the enhancement effect progresses from broad areas beneath the landfill to narrower, deeper, linear zones downgradient from it. Possibly an IP effect occurs because of clays within the structures, and/or migrating conductive leachate may preferentially "light up" these structures to IP, providing an indirect map of contaminant migration pathways. The IP survey results were used to site two monitoring wells from which to gain TCE data.

Modeling Borehole Dipole Antenna Patterns for Cross-Well Radar DNAPL Imaging
Farid, M., A.N. Alshawabkeh, and C.M. Rappaport.
Proceedings of the 12th Pan-American Conference on Soil Mechanics and Foundation Engineering, Cambridge, Massachusetts, 22-25 June 2003, p 261-268.

Abstract not available.

Modeling GPR Data to Interpret Porosity and DNAPL Saturations for Calibration of a 3-D Multiphase Flow Simulation
Sneddon, K.W., M.H. Powers, and R.H. Johnson (U.S. Geological Survey, Denver CO); E.P. Poeter (Colorado School of Mines, Golden).
U.S. Geological Survey Open-File Report 02-451, 29 pp, 2002

Dense nonaqueous phase liquids (DNAPLs) are a pervasive and persistent category of groundwater contamination. In an effort to better understand their unique subsurface behavior, a controlled and carefully monitored injection of PCE (perchloroethene) was performed in conjunction with the University of Waterloo at Canadian Forces Base Borden in 1991. Of the various geophysical methods used to monitor the migration of injected PCE, the U.S. Geological Survey collected 500-MHz ground penetrating radar (GPR) data. These data are used in determining calibration parameters for a multiphase flow simulation. GPR data were acquired over time on a fixed two-dimensional surficial grid as the DNAPL was injected into the subsurface. Emphasis is on the method of determining DNAPL saturation values from this time-lapse GPR data set. Interactive full-waveform GPR modeling of regularized field traces resolves relative dielectric permittivity versus depth profiles for pre-injection and later-time data. Modeled values are end members in recursive calculations of the Bruggeman-Hanai-Sen (BHS) mixing formula, yielding interpreted pre-injection porosity and post-injection DNAPL saturation values. The resulting interpreted physical properties of porosity and DNAPL saturation of the Borden test cell, defined on a grid spacing of 50 cm with 1-cm depth resolution, are used as observations for calibration of a 3-D multiphase flow simulation. Calculated values of DNAPL saturation in the subsurface at 14 and 22 hours after the start of injection, from both the GPR and the multiphase flow modeling, are interpolated volumetrically and presented for visual comparison.
http://pubs.usgs.gov/of/2002/ofr-02-451/OFR-02-451-508.pdf

Monitoring Controlled DNAPL Contaminations Using GPR
Mayer, V., K.-J. Sandmeier, and H. Wilhelm, Univ. of Karlsruhe, Karlsruhe, Germany.
Proceedings of th 3rd meeting of the Environmental and Engineering Geophysical Society, European Section, Aarhus, Denmark, 8-11 September 1997, p 283-286, 1997

Abstract not available.

Monitoring DNAPL Pools under Controlled Conditions Using GPR
Mayer, V., K.-J. Sandmeier, and H. Wilhelm, Univ. of Karlsruhe, Karlsruhe, Germany.
Field Screening Europe. Kluwer Academic Publishers, p 133-136, 1997

Abstract not available.

Monitoring In-Situ Cleanup Using Resistivity Imaging
Thompson, M.D. (Argonne National Lab, Argonne, IL); S.F. Miller; W.A. Mandell; P.L. Wilkey; J.M. Cooper.
SAGEEP 2002: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 10-14 February 2002, Las Vegas, Nevada.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, 13ESC2, 2002

At Hunter Army Airfield, GA, remediation activities allowed the testing of 2-D electrical resistivity imaging for monitoring cleanup actions. The site was contaminated by low levels of perchloroethene (PCE) at 5 to 40 ug/L, and an in situ oxidation-reduction technique was decided upon for remediation. Theorizing that chloride ions produced during the reaction would increase the electrical conductivity of the pore-fluid, the investigators chose to map this increase using resistivity methods. They saw a marked decrease in electrical-resistivity from pre- to post-injection. Profiles collected simultaneously with the injection showed an initial increase in resistivity followed by the expected decrease after an overnight hiatus. The increased resistivities were most likely caused by displacement of the natural groundwater by either the injected material or the generated steam. The results suggest that resistivity methods can be used to monitor oxidation-reduction types of remediation, which could benefit cleanup efforts by reducing the number of monitoring wells needed and providing near real-time assessment of remedy performance.

NAPL Contaminant Location with High-Frequency Crosswell Seismic Methods
Geller, Jil T., Ernest L. Majer, Jonathan Ajo-Franklin, Kenneth H. Williams, and John E. Peterson.
Lawrence Berkeley National Laboratory Environmental Remediation Technology Research Summary, p 94, 2003

Researchers obtained baseline crosswell data (before remediation) at two contaminated sites where remediation is now in progress. They also measured P-wave transmission on cores from one of the sites, as a function of NAPL/water saturation. At the northeast site of the former DOE Pinellas Plant in Florida, trichloroethene (TCE), toluene, methylene chloride, weathered oils, and resins all contaminate the 30-ft-deep surficial aquifer. In laboratory tests on core from selected survey boreholes, NAPL TCE and toluene caused significant reductions in P-wave velocity and increases in P-wave attenuation relative to water-saturated conditions. The crosswell seismic and radar surveys, within and outside of the area identified as having NAPL, reveal continuous sedimentary layers where NAPL could be trapped. Regions of anomalously high P-wave attenuation occur throughout the surveyed region, which may arise from lithology, biogenic gas, NAPL, or a combination of these. At the Paducah Gaseous Diffusion Plant in Kentucky, researchers collected crosswell seismic data at the location of a historic TCE spill, estimated to be as large as 500,000 gallons, before beginning a demonstration of six-phase heating remediation. Crosswell data in a NAPL-free area showed generally consistent lithology, with measurable differences, compared to the contaminated site. The contrast in the acoustic velocities of many NAPL contaminants (such as TCE and toluene) in water significantly affect P-wave attributes in natural-aquifer core samples tested in the lab. Possible locations of NAPL areas were identified from comparing P-wave attributes in an uncontaminated zone, but these are uncertain because of the unknown contribution of well-completion and lithology variations. Post-remediation surveys will be essential to determine the visibility of NAPL contrasts with water and their signature at the field scale, as well as the efficacy of crosswell seismic imaging for monitoring the remediation of NAPL-contaminated sites.
http://www-esd.lbl.gov/research_sums_02-03/environmental/pdf/geller.pdf

Non-Invasive Determination of the Location and Distribution of DNAPL Using Advanced Seismic Reflection Techniques
Temples, T.J., M.G. Waddell, and W. Domoracki, Univ. of South Carolina, Columbia.
Groundwater, Vol 39 No 3, p 465-474, 2001

Seismic reflection amplitude analysis technology was implemented to directly detect the presence of subsurface DNAPL (i.e., CCl4) at the 216-Z-9 crib, 200 West Area, DOE Hanford Site, WA. Model results were incorporated in the interpretation of the seismic data to determine the location of any seismic amplitude anomalies associated with the presence of high concentrations of CCl4. Seismic reflection profiles were collected and analyzed for the presence of DNAPL. Structure contour maps of the contact between the Hanford fine unit and the Plio/Pleistocene unit and between the Plio/Pleistocene unit and the caliche layer were interpreted to determine potential DNAPL flow direction. Models indicate that the contact between the Plio/Pleistocene unit and the caliche should have a positive reflection coefficient. When high concentrations of CCl4 are present, the reflection coefficient of this interface displays a noticeable positive increase in the seismic amplitude (i.e., bright spot). Amplitude data contoured on the Plio/Pleistocene-caliche boundary display high values indicating the presence of DNAPL to the north and east of the crib area. The seismic data show good agreement with the well control in areas of high concentrations of CCl4.

Noninvasive Contaminant Site Characterization Using Geophysical-Induced Polarization
Morgan, F.D. (Massachusetts Inst. of Technology, Cambridge); J. Sogade; D. Lesmes; D. Coles; Y. Vichabian; F. Scira-Scappuzzo; W. Shi; A. Vandiver; W. Rodi.
The 225th ACS National Meeting, New Orleans, LA, March 23-27, 2003. Abstract ENVR 240, 2003

An ongoing study encompasses laboratory studies of coupled effects of rock/soil microgeometry and contaminant chemistry on induced polarization (IP), an investigation of electromagnetic coupling (EMC) noise, and development of 3D modeling and inversion codes. Spectral induced polarization (SIP) requires extensions to higher frequencies (above the typical 100Hz threshold) and EMC becomes the major limitation for field implementation, because conventional correction methods are inadequate at required higher frequencies. The authors outline a proposed methodology based on a model of all EMC components that addresses the EMC problem by coupling IP and electromagnetic induction in modeling and inversion. Examples of application of IP and SIP to contaminant mapping and detection for time-domain IP and SIP are presented for the FS-12 plume at the Massachusetts Military Reservation and a suspected DNAPL plume at Savannah River site.

Noninvasive Monitoring of DNAPL Migration Through a Saturated Porous Medium Using Electrical Impedance Tomography
Chambers, J.E. (British Geological Survey, Keyworth, Nottingham, UK); M.H. Loke (Univ. Sains Malaysia, Penang, Malaysia); R.D. Ogilvy; P.I. Meldrum.
Journal of Contaminant Hydrology, Vol 68 No 1-2, p 1-22, Jan 2004

Electrical impedance tomography (EIT) was used to monitor the movement of a fluorinated hydrocarbon dense nonaqueous phase liquid (DNAPL) through a saturated porous medium within a laboratory column. Impedance measurements were made using a horizontal plane of 12 electrodes positioned at regular intervals around the center of the column. A 2D inversion algorithm, which incorporated the cylindrical geometry of the column, was used to reconstruct resistivity and phase images from the measured data. Despite significant measured phase changes due to DNAPL

contamination, differential phase images revealed only weak anomalies associated with DNAPL flow; these anomalies could be seen only in the initial stages of the experiment during peak flow through the plane of electrodes.

Porous Media Contamination: 3-Dimensional Visualization and Quantification Using X-Ray Computed Tomography
Goldstein, L. (McGill Univ., Montreal, QC, Canada); S.O. Prasher; S. Ghoshal.
2004 Joint Assembly of the Canadian Geophysical Union, American Geophysical Union, Society of Exploration Geophysicists, and Environmental and Engineering Geophysical Society, 17-21 May 2004, Montreal, Canada. Eos Trans. AGU, Vol 85 No 17, Joint Assembly Supplement, Abstract NS23A-10, 2004

Spilled nonaqueous phase liquids (NAPLs) migrate downward, and a significant fraction will become trapped in the soil matrix. These trapped NAPL globules partition into the water and/or vapor phase and serve as source zones, or continuous sources of contamination. Reliable methods are needed to detect and delineate these NAPLs in the subsurface. X-ray computed tomography (CT) can detect small atomic density differences of solid, liquid, gas, and NAPL phases, and hence has potential for nondestructive quantification of NAPL mass and distribution in soil cores. NAPLs such as gasoline and other oil products, chlorinated solvents, and PCBs possess a characteristic and predictable X-ray attenuation coefficient that permits their quantification in porous media at incident beam energies. Methodologies have been developed for generating and analyzing X-ray CT data for the study of NAPLs in natural porous media and validated in the lab using homogeneous and heterogeneous soil columns with known quantities of gasoline and tetrachloroethene. The results serve as proof of concept that a typical medical X-ray CT scanner has the potential to accurately quantify selected NAPLs in natural soils.

Preliminary Characterization of a NAPL-Contaminated Site using Borehole Geophysical Techniques
Ajo-Franklin, Jonathan B., Jil T. Geller, Ernie L/ Majer, John E. Peterson, Ken H. Williams, and Jerry M. Harris.
SAGEEP 2003: Proceedings of the 15th Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, p 202-220, 2003

The former DOE Pinellas site in Florida has confirmed nonaqueous phase liquid (NAPL) contamination. The eventual goal of an on-going geophysical investigation is the effective use of integrated crosswell geophysical methods, specifically seismic and radar tomography, to remotely detect zones of high NAPL saturation. This paper describes early efforts at using a combination of seismic and radar information to understand site geology and possible contaminant signatures. It also presents the current approach to consistent acquisition, preprocessing, tomographic inversion, and interpretation of joint seismic/radar profiles. Though direct geophysical evidence of NAPL pools has not yet been obtained, several regions of anomalous seismic attenuation were detected. These attenuating regions could not be explained by borehole effects or lithology and may be caused by regions of partial gas or NAPL saturation. Possible gas sources include biogenic production from contaminated regions and side-effects from previous remediation activities. Work at the Pinellas site will focus on constraining the mechanism responsible for the observed seismic attenuation, developing a more complete model of site soil properties, and applying more quantitative approaches to the

integration and analysis of seismic and radar images.
http://pangea.stanford.edu/~jfrank/work/sageep2003paper_ver6.pdf

Reprocessing GPR Data from the CFB Borden Experiment Using APVO/GPR Techniques
Jordan, Thomas E. and Gregory S. Baker, University at Buffalo.
SAGEEP 2004: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 22-26 February 2004, Colorado Springs, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. p 506-513, 2004

The authors reprocessed GPR data from a 1991 Canadian Forces Base (CFB) Borden experiment to determine if a modified amplitude and phase variation with offset analysis of the ground penetrating radar (APVO/GPR) data is a feasible technique for monitoring a dense nonaqueous phase liquid (DNAPL) release. Modeling indicates that conductivity is inversely related to the maximum absolute value reflection coefficient max R observed for incidence angles of 0 through 89 degrees. The injection of a low conductivity DNAPL into a saturated sand decreases conductivity by displacing some ground water. Conductivity values then increase as the DNAPL migrates vertically downward. The model indicates that values of max R increase as DNAPL is injected followed by a decrease as the DNAPL drains. Detecting changes in the amplitude of reflectors due to zones of anomalously conductive liquids might present an additional method for monitoring NAPL releases, and the APVO/GPR technique also could be useful for determining the conductivity of subsurface reflectors.

Review of Geophysical Characterization Methods Used at the Hanford Site
Last, G.V. and D.G. Horton, Pacific Northwest National Laboratory, Richland, WA.
Report No: PNNL-13149, 113 pp, Mar 2000

Geophysical methods have been used for characterization of hydrogeologic conditions and/or contaminant distributions at the Hanford site since the mid to late 1940s. A review of these geophysical methods is presented in two parts: 1) shallow surface-based geophysical methods and 2) borehole geophysical-logging methods. Nearly all types of surface-based geophysical methods have been tested, such as ground-penetrating radar (GPR), numerous electromagnetic, magnetic, seismic, and gravity methods. Over 250 geophysical surveys have been conducted at the Hanford site. For example, the ability of seismic reflection and amplitude versus offset (AVO) analysis techniques was tested to determine the location and distribution of dense nonaqueous-phase liquids (DNAPLs) near the 216-Z-9 Trench. The most widely used geophysical methods are GPR, frequency-domain electromagnetics (i.e., Geonics EM-31), and metal detectors. The geologic formations that make up the vadose zone are unconsolidated; thus, virtually every borehole is cased with schedule 40 steel pipe. The casing, and in later years a grout annular seal, have been the biggest factors in determining the types of logging methods used. Traditionally, gross gamma ray and neutron moisture probes were the two most commonly used downhole tools. Recently, spectral gamma-ray logging has replaced gross gamma-ray logging for most applications. Many other techniques--including prompt fission neutron logging and neutron-gamma logging for specific elemental analyses--have been tested and/or used for contaminant and lithologic characterization in the subsurface.
http://www.pnl.gov/main/publications/external/technical_reports/13149.pdf

RPM -- Residual Potential Mapping; a New Approach to Mise-a-Lamasse
Baldyga, Christopher A. and James B. Fink, hydroGEOPHYSICS, Inc., Tucson, AZ.

SAGEEP 2004: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 22-26 February 2004, Colorado Springs, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, p 851-855, 2004

This presentation suggests a modification to the conventional approach to the detection and mapping of low-contrast hydrogeophysical targets that will enhance low contrast targets. The mise-a-la-masse method is a simple application of electrical methods where a buried conductive feature is electrically energized and the resulting distorted electric field on the ground surface is mapped. The normal interpretation of mise-a-la-masse data depends on the ability to observe the desired Efield distortions caused by the energized target. In the case of low physical property contrasts, distortions can be very difficult to see, if visible at all. The primary field observed in the proximity of the energizing electrode dominates the response. Unless the target is particularly conductive and/or rather shallow, it will not produce an E-field distortion distinct from the primary field. The RPM approach allows the energizing source to be close to, but not necessarily in direct contact with, the target. Steel casings have been used as electrodes, electrodes have been lowered into monitoring wells, and electrodes have been placed in abandoned test boreholes. Examples are presented, including that of the Tucson International Airport located in Tucson, AZ, where unregulated disposal of large amounts of solvents containing TCE occurred within the industrial complex. This area was designated a Superfund site due to the vertical and lateral migration of the TCE plume and thus required extensive remediation.

Sediment Sampling at the A-014 Outfall for Comparison with Complex Resistivity Measurements
Rossabi, Joseph, Brian Riha, & Dennis Jackson, Savannah River Technology Center, Aiken, SC.
SAGEEP 2004: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 22-26 February 2004, Colorado Springs, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. p 484-495, 2004

Chlorinated solvents released as dense nonaqueous phase liquids (DNAPLs) to the subsurface move in an unstable fashion driven by gravitational and capillary forces. They are often retained in small discrete blobs in fine grained materials. Several methods have been developed for locating these small sources of subsurface DNAPL, but nearly all are intrusive and can identify DNAPL only in close proximity to the access hole. Minimally invasive geophysical methods to locate residual DNAPL have been proposed and developed, but few methods are capable of the spatial resolution required. Complex resistivity measurements sensitive to tetrachloroethene (PCE) interactions with clay (smectite) have shown promise in laboratory experiments, leading to field tests of the technique performed at the A-014 outfall of the Savannah River site (SRS). An area of approximately 10 m x 15 m was selected where sampling and analysis had confirmed residual DNAPL. After complex resistivity measurements were made, 400 depth-discrete soil samples at five selected locations within the test area were collected and analyzed to compare with the geophysical results. The authors discuss their findings regarding the performance of this geophysical technique.

Seismic Reflection Technology for the Detection of DNAPLs
U.S. DOE, National Energy Technology Laboratory, TMS Tech ID: 2306, 2 pp, Sep 2002

Seismic reflection technology is a non-invasive, geophysical technique that is capable gathering information about the subsurface used to generate images of geologic strata and DNAPL contamination. Other valuable subsurface characteristics such as porosity, permeability, and clay content can also be determined. The use of seismic reflection to map geologic stratigraphy is not new.

The innovative aspect of this project is a data analysis method, called Amplitude Versus Offset (AVO), which can be used to detect the presence of DNAPL contamination. Direct detection of DNAPL using AVO, in conjunction with images of stratigraphy, provides environmental managers with new insight regarding pathways for DNAPL migration and location of DNAPL contamination. The University of South Carolina's Earth Science and Resources Institute, has demonstrated the technology at Savannah River Site's M-Basin, Hanford's 200 West Area, the Pantex site, and the Charleston Naval Weapons Station. The technology is also scheduled to return to SRS to perform a seismic survey at the location of the Dynamic Underground Stripping (DUS) project. Contact: Michael G. Waddell, Univ. of South Carolina, mwaddell@esri.sc.edu.
http://www.netl.doe.gov/products/em/IndUnivProg/pdf/2306.pdf

Subsurface Characterization in Karstic, Fractured Bedrock, Redstone Arsenal, AL
Zondlo, Thomas F., Shaw Environmental, Knoxville, TN.
U.S. EPA Technical Support Project Meeting, 22 October 2003, Niagara Falls, NY. PowerPoint presentation, 52 pp, 2003

Over the last two years, the Army has completed a detailed investigation of the subsurface in Operable Unit 10 at Redstone Arsenal to delineate the vertical and horizontal extent of DNAPLs and dissolved phase plumes within the bedrock. Standard investigations conducted from 1998 through 2001 indicated the presence of DNAPLs within the overburden, highly karstic upper bedrock, and a solutionally enlarged bedding plane fracture interval at a depth of approximately 150-180 ft bgs. Continuous groundwater monitoring in well clusters and dye trace results indicated that all of these zones were hydraulically interconnected in a very dynamic fashion. Implementation of any remedial action requires the delineation the extent of the DNAPLs within the bedrock. The data acquired through this investigation was expected to support identification of remedial alternatives and to delineate the possibly lateral and vertical limits of practicability with respect to remediation. The methods employed included gridded hydropunch sampling of the overburden to delineate the limits of hotspots indicative of DNAPLs, a reflection seismic survey to define likely DNAPL migration pathways in the bedrock and potential points of accumulation, detailed subsurface characterization of the bedrock to depths of roughly 300 ft bgs (to the regional aquitard), construction of monitoring well clusters, and continuous monitoring. Subsurface characterization included rock coring and UV fluorescence screening, open hole geophysical logging, FLUTe reactive ribbon liner surveys for detection of DNAPLs, hydrophysical surveys, and packer testing/sampling.
http://www.epa.gov/tio/tsp/download/2003_meeting_fall/zondlo.pdf

A Survey of Department of Energy-Sponsored Geophysical Research for Shallow Waste Site Characterization
Guillen, D.P. and R.C. Hertzog, Idaho National Engineering and Environmental Lab, Idaho Falls, ID.
Vadose Zone Journal Vol 3, p 122-133, 2004

DOE scientists have used geophysical imaging techniques--electromagnetic, ground-penetrating radar, electrical, seismic, and nuclear magnetic resonance (NMR)--to characterize the shallow subsurface. These efforts have sought the development of high-resolution imaging capabilities to capture important details of the heterogeneous nature of subsurface properties and processes. The researchers are attempting to couple nonintrusive survey geophysical measurements (e.g., electrical surveys) with detailed quantitative precise point-sensor measurements (e.g., lysimeters and vapor-port systems) or borehole (e.g., NMR, neutron-based moisture, and geochemical tools) measurements to extend

high-precision knowledge away from the borehole. Multiple geophysical methods are needed to constrain the uncertainty in determining critical subsurface physical properties. Further studies will be undertaken to develop understanding of the manner in which contaminants travel through the vadose zone. This paper describes some applications of geophysical methods to various contaminated areas at Idaho National Engineering and Environmental Laboratory.

Three Dimensional Self-Potential Inversion for Subsurface Contaminant Detection and Mapping at the DOE Savannah River Site, South Carolina
Minsley, Burke (MIT, Cambridge, MA), et al.
SAGEEP 2004: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 22-26 February 2004, Colorado Springs, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. p 465-471, 2004

Self-potential (SP) data are collected using a 3D array of non-polarizing electrodes, consisting of a surface grid and four borehole arrays, over an area known to be contaminated with DNAPLs (dense nonaqueous phase liquids). The self-potential method is commonly used to measure the electric field produced by electrokinetic, thermoelectric, or electrochemical coupling processes that take place in the subsurface. Electrical currents that exist due to the redox reactions at depth traverse the resistive subsurface and are manifested as a potential field that is measured at the surface and borehole locations. A 3D inversion algorithm is used to find the electrical current source model that supports the measured data, taking into account the resistivity structure derived from an induced polarization survey at the same field location. The sources and sinks of electrical current are related to the zones of redox activity, and thus to the areas of contamination. These results correlate with chemical concentration data obtained from a series of ground-truth well measurements taken at the site.

Use of Seismic Reflection Amplitude Versus Offset (AVO) Techniques to Image Dense Nonaqueous Phase Liquids (DNAPL)
Waddell, Michael G., William J. Domoracki, & Tom J. Temples, Univ. of South Carolina, Columbia.
SAGEEP 2001: Symposium on the Application of Geophysics to Engineering and Environmental Problems, 4-7 March 2001, Denver, Colorado.
Environmental and Engineering Geophysical Society, Denver, CO. CD-ROM, CHP-3, 12 pp, 2001

Field experiments were conducted to determine the location and distribution of subsurface DNAPL contamination at two DOE sites by means of 2-D, high-resolution seismic reflection surveys and borehole geophysical data. These studies make use of seismic reflection AVO technology to directly detect the presence of subsurface free-phase DNAPL. At the Savannah River and Hanford sites, research consisted of site evaluation, seismic model studies, seismic acquisition, processing, and interpretation. The seismic model studies were undertaken prior to field acquisition to determine the likelihood of an AVO response from the DNAPL.

Using Spatially Integrated Crosswell Geophysics for Environmental Site Assessment
Ajo-Franklin, Jonathan B.; Jil T. Geller; Jaime Urban; Jerry Harris.
2004 Joint Assembly of the Canadian Geophysical Union, American Geophysical Union, Society of Exploration Geophysicists, and Environmental and Engineering Geophysical Society, 17-21 May 2004, Montreal, Canada. Eos Trans. AGU, Vol 85 No 17, Joint Assembly Supplement, Abstract NS23A-09, 2004

This poster presentation depicts the application of an adaptive tomography flow to the Pinellas crosswell radar and seismic profiles in an investigation of DNAPL contamination at the Pinellas site in Florida.
http://pangea.stanford.edu/~jfrank/work/AGU_springPoster2.pdf