Material Property Estimation for Direct Detection of DNAPL Using Integrated Ground-Penetrating Radar Velocity, Imaging and Attribute Analysis

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Research Objectives

The focus of our work is direct detection of DNAPLs, specifically chlorinated solvents, via material property estimation from surface ground-penetrating radar (GPR) data. We combine sophisticated GPR processing methodology with quantitative attribute analysis and material property estimation to determine the location and extent of residual and/or pooled DNAPL in both the vadose and saturated zones. An important byproduct of our research is state-of-the-art imaging which allows us to pinpoint attribute anomalies, characterize stratigraphy, identify fracture zones, and locate buried objects. Implementation and verification of these methodologies will be a significant advance in GPR research and in meeting DOE's need for reliable in-situ characterization of DNAPL contamination. Specifically, the work is geared toward addressing six key issues that have been identified as critical technology needs, both at specific DOE sites, and on a complex wide basis. These include:

1) Determining spatial and depth distribution of DNAPL contamination
2) Characterizing in-situ physical properties of sediments
3) Locating preferred hydrologic pathways
4) Characterizing horizontal and vertical dimensions of contaminant plumes
5) Determining variation in plume geometry due to important geologic features
6) Providing innovative, low-cost characterization approaches to extending subsurface data

Many DNAPLs, including chlorinated solvents, have much lower dielectric permittivity and conductivity than water. A contrast in electric properties is induced when DNAPL displaces water in the sediment column resulting in an anomalous GPR signature. To directly identify zones of DNAPL contamination, we focus on three aspects of reflected wave behavior - propagation velocity, frequency dependent attenuation, and amplitude variation with offset. Velocity analysis provides a direct estimate of dielectric permittivity, attenuation analysis is used to identify variations in conductivity, and AVO behavior is used to estimate the dielectric permittivity ratio at a reflecting boundary. Areas of anomalously low dielectric permittivity and low conductivity are identified as potential DNAPL source zones. Preliminary work, which included theoretical development, modeling, and test pit studies, was highly successful and illustrated significant potential for quantitative direct detection methodologies in identifying shallow DNAPL source zones. It is now necessary to determine the consistency with which we can predict the location of DNAPL source zones, what level of residual contamination can be detected, and how accurately we can predict contaminant concentration. To this end, the project has three primary objectives:

1) Develop a suite of methodologies for direct detection of DNAPLs from surface GPR data
2) Controlled field verification at well characterized, contaminated sites
3) Exploratory contaminant detection in a field setting to be verified through direct sampling

Field experiments for the project will be conducted at the Savannah River and Hanford sites, and five DOD sites (Dover AFB, DE; McClellan AFB, CA; Port Hueneme, CA; Wurtsmith AFB, MI; Hill AFB, UT).

Research Progress and Implications

This report summarizes work after six months of a three-year project. In January, 2000, we conducted a 2160 sq. ft., 3-D, multi-offset, GPR survey in the vicinity of the A-014 outfall of A/M Area (U) at the Savannah River Site. The survey was designed to encompass a newly discovered shallow DNAPL zone (- 20 ft) with little or no contamination near the edges and a strongly contaminated zone near the center. The contaminants are thought to consist primarily of PCE. Preliminary analysis (pre-stack depth migration velocity analysis) of a profile near the center of the 3-D patch indicates a high velocity (low dielectric permittivity) zone that may be associated with a DNAPL pool (Figure 1). Using a time average equation to calculate saturation values, the high velocity zone is consistent with 35 - 60% DNAPL concentration assuming 24 - 0 % air saturation respectively. The high velocity zone does not correlate directly with previous cone penetrometer tests (Jackson et al, 1999), is consistent with higher DNAPL concentration than indicated in the direct samples, and therefore may be associated with the primary source pool in the vicinity. Assuming analysis of the full dataset is consistent with the initial findings, the presence of a DNAPL pool will be verified through direct sampling. Identification of the primary source pool will aid significantly in the implementation of a remediation plan.

Additional work that has been completed to date includes integrating three-phase flow and GPR response modeling to simulate a controlled tetrachloroethylene (PCE) injection experiment which will be conducted at Dover AFB in June and July of 2000. Fluid concentrations output by the flow model are used to generate a dielectric permittivity model using a time average equation. The GPR response is then calculated using an 2-D, acoustic, finite difference scheme. The acoustic code is appropriate for modeling wavefield kinematics and amplitudes assuming zero conductivity. Modeling results are being used in experiment planning.

Planned Activities

In early May of 2000, we will conduct a two week field experiment in the 200 area at the Hanford site. The primary focus of the work will be DNAPL detection in the vicinity of the carbon tetrachloride crib. In June and July of 2000, we will conduct a controlled injection experiment at Dover AFB, DE. Fifty liters of PCE will be injected in both the vadose and saturated zones then monitored for 30 days. The experiment will provide the opportunity to test both direct detection methodologies and the predictive capabilities of three-phase flow modeling coupled with GPR response modeling. From November, 2000 to November, 2001, we will conduct field experiments at Hill AFB, UT, Wurtsmith AFB, MI, McClellan AFB, CA, and Port Hueneme, CA. Each experiment will last 10 -15 days and will be conducted over known NAPL source zones.

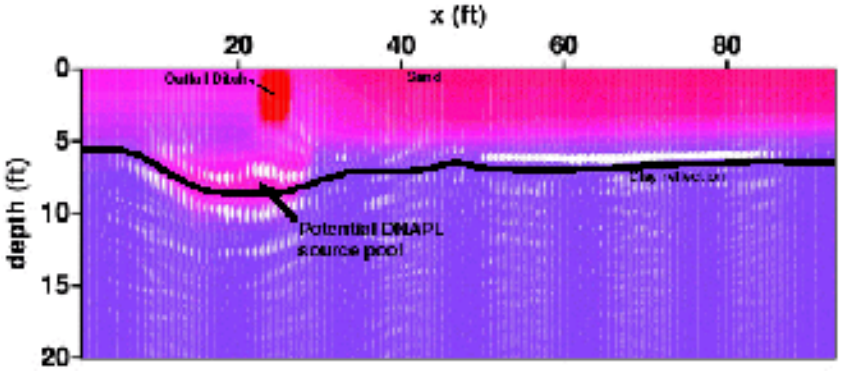

Figure 1 GPR velocity model and migration overlay for the Savannah River survey.

Reference

Jackson, D.G., Hyde, W.K., Rossabi, J., and Riha, B.D., 1999, Characterization activities to determine the extent of DNAPL in the vadose zone at the A-014 outfall of A/M Area (U): Technical Report WSRC-RP-99-00569, Westinghouse Savannah River Company, Aiken, SC.