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A Hybrid Hydrologic-Geophysical Inverse Technique for the Assessment and Monitoring of Leachates in the Vadose Zone

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Research Objective

The objective of this study is to develop and field test a new, integrated Hybrid Hydrologic-Geophysical Inverse Technique (HHGIT) for characterization of the vadose zone at contaminated sites. This new approach to site characterization and monitoring can provide detailed maps of hydrogeological heterogeneity and the extent of contamination by combining information from electric resistivity tomography (ERT) surveys, statistical information about heterogeneity and hydrologic processes, and sparse hydrologic data. Because the electrical conductivity of the vadose zone (from the ERT measurements) can be correlated to the fluid saturation and/or contaminant concentration, the hydrologic and geophysical measurements are related.

Research Progress and Implications

As of the 21st month of a 36-month project, a three-dimensional stochastic hydrologic inverse model for heterogeneous vadose zones has been developed. This model employs pressure and moisture content measurements under both transient and steady flow conditions to estimate unsaturated hydraulic parameters. In this model, an innovative approach to sequentially condition the estimate using temporal measurements has been incorporated. This allows us to use vast amounts of pressure and moisture content information measured at different times while keeping the computational effort manageable.

Using this model we have found that the relative importance of the pressure and moisture content measurements in defining the different vadose zone parameters depends on whether the soil is wet or dry. We have also learned that pressure and moisture content measurements collected during steady state flow provide the best characterization of heterogeneity compared to other types of hydrologic data. These findings provide important guidance to the design of sampling scheme of the field experiment described below.

To provide images from ERT data that includes the same statistical information as the hydrologic inverse model, a new stochastic ERT inversion code has been written and tested. During testing, we found that the basic stochastic assumptions used to construct the solution provide poor results. We believe the problem lies in the assumption that the mean and variance of the electrical conductivity are stationary across the region of interest. Two different methods have been incorporated to improve the solution: 1) the a-priori variance is increased in the center of the image region where the sensitivity is small, and 2) the inversion process is initialized with a starting model that is derived by Kriging apparent resistivity values calculated from ERT measurements made between adjacent electrodes.

A study comparing surveys where data were collected with different electrode configurations has been completed. Surprisingly, pole-pole surveys provided improved resolution over dipole-dipole surveys. Also, increasing the number of surface electrodes substantially improved image quality. Because surface electrodes are generally less expensive to implement than borehole electrodes, increasing the number of surface electrodes decreases the number of boreholes needed to monitor a volume, thus reducing implementation costs. These results are being applied to design ERT surveys proposed at a number of DOE sites.

The construction of a test site at which data will be collected to test the HHGIT method is nearing completion. The Sandia-Tech Vadose Zone Infiltration Test Site (STVZITS) is located adjacent to the New Mexico Tech campus in Socorro, New Mexico, on highly permeable ancestral Rio Grande sands and gravels. Facilities and instrumentation have been designed and constructed to provide a long-term research facility.

An infiltration system, to be located at the center of the instrumented site, has been designed to produce a constant flux boundary condition across a 3m by 3m infiltration pad. Thirteen wells cased with PVC provide subsurface access for neutron moisture probes as well as other geophysical devices; sixteen wells for nests of tensiometers; and four wells for time domain reflectometry (TDR) probes grouped with tensiometers, suction lysimeters, and thermocouples, have been emplaced axi-symmetrically about the center of the infiltration pad. The location and depths of these sensors has been determined partly from the aforementioned hydrological simulations as well as the characterization process described below. Eight vertically installed ERT electrode strings and a grid of 36 surface electrodes have also been installed at the site. Each string contains 17 electrodes ranging in depth from the surface to a depth of 12m depth. The ERT electrodes are also arranged axi-symmetrically about the infiltration pad. A three-channel ERT data acquisition system has been built and tested. Background data set has been collected and the data is being processed. All data collection systems are contained in a building immediately adjacent to the experimental pad.

The site has been characterized geologically, hydrologically and geophysically. Geological characterization consisted of drillers logs, and measurements of bulk density and grain size distributions on samples that were collected during drilling and trenching. Hydrologic characterization consists of measurements of hydrologic sensors and neutron tubes prior to the beginning of the infiltration, and laboratory measurements of samples collected during drilling. These measurements include pressure versus saturation, saturated hydraulic conductivity and electrical resistivity at different water saturations.

In addition to the baseline ERT measurements, cross well GPR, conductivity and natural gamma well logs made between and within the PVC cased wells have been employed successfully to geophysically characterize the site (other methods including surface GPR and TEM have been attempted with less success). The different characterization techniques all show approximately 5m of interbedded sands, silts, clays and gravels of moderate saturation overlying 7m of fairly low clay, semi-homogenous drier sands.

Planned Activities

In the coming months, we will be developing a maximum likelihood algorithm to estimate the statistical structure of heterogeneity which is one of the input parameters to our inverse models. We will then assess the effect of uncertainty associated with this structure. A Newton-Raphson iterative solution will be implemented in the forward hydrologic model to improve the solution for highly nonlinear problems. We will also begin integrating the stochastic ERT code with the hydrological codes. In the near term (this summer) this involves performing a cooperative inversion in which moisture information derived from the hydrological models will be converted to resistivity data via co-Krieging to improve the ERT inversion, and vice versa. During the fall and winter, the two routines will be coupled together into a full joint ERT/hydrological inversion routine.

Starting in mid to late June, water infiltration will begin at the STVZTS. ERT and hydrologic data will be collected daily during the two or three weeks after starting infiltration, and less frequently afterwards as the system approaches steady state. After steady state has been reached, a salt pulse will be introduced to study contaminant transport in unsaturated yet steady state conditions. This fall a slope adjacent to the test site will be excavated to provide samples for the continued geologic, hydrologic and geophysical characterization. From these samples we will determine if it is possible to estimate saturated hydraulic conductivity from bulk density and grain size distribution measurements.

Inversions will be made both on the full ERT and hydrologic data sets as well as subsets of the data as the data become available. The results of these inversions will be compared to borehole geophysical logs (conductivity and neutron) and with cross-borehole GPR surveys. We will also investigate converting the velocity images obtained with the GPR to images of moisture content via Topp’s equation as a possible additional source of geophysically derived hydrologic information.