Project Number 55332

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 hydrogeologic heterogeneity and the extent of contamination by combining information from 3D electric resistivity tomography (ERT) and/or 2D cross-borehole ground penetrating radar (XBGPR) surveys, statistical information about heterogeneity and hydrologic processes, and sparse hydrologic data. Because the electrical conductivity and dielectric constant of the vadose zone (from the ERT and XBGPR measurements, respectively) 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 42nd month of a 48-month project, (36 months funding + a 12 month no-cost extension) we have finished developing an inverse procedure for estimating values of unsaturated hydraulic conductivity and moisture release parameters within a three-dimensional (3D) heterogeneous vadose zone model. The procedure can take advantage of pressure head and/or moisture content measurements during transient or steady state flow scenarios to estimate the parameters. It also incorporates statistical information about the geological structure and point measurements of hydraulic conductivity. The model is being tested for its ability to invert parameter values for both deterministic and stochastic cases. Deterministic problems refer to the situations where all values of the head, moisture content distribution, initial and boundary conditions are known, while stochastic problems refer to the cases where the information is either not completely specified or is corrupted. For unidirectional flow in 3D media, the model works well in either case. However the model can encounter convergence problems associated with the nonlinearity in Richard's equation for 3D flow problems. We have implemented a Newton-Raphson iterative scheme to reduce the problem.

We have also investigated the effectiveness of tracer concentration and arrival time information for inverting unsaturated hydraulic parameters. Our results show that the pressure and moisture content data under steady-state flow conditions are more useful for inversion compared to tracer concentration and its arrival time. In addition, new sequential kriging and cokriging techniques have been developed to facilitate future hydrological inversion schemes.

A new stochastic ERT inversion code has been written and tested. Limitations found in the basic stochastic formulation have been alleviated by using an empirical method to increase the a-priori variance in the center of the image region where the sensitivity is small. Also 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, and it was found that increasing the number of surface electrodes substantially improves 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 to test the HHGIT method has been completed. The Sandia-Tech Vadose Zone facility (STVZ) is located adjacent to the New Mexico Tech campus in Socorro, New Mexico, on highly permeable ancestral Rio Grande stratified sand and gravel deposits. Facilities and instrumentation have been designed and constructed to provide a long-term research facility. An infiltration system, located at the center of the instrumented site, has been built 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. Twenty wells have been instrumented with nests of tensiometers, and twenty wells with time domain reflectometry (TDR) probes grouped with tensiometers, suction lysimeters, and thermocouples. Eight vertically installed ERT electrode strings, each with 17 electrodes with .076 meter spacing, and a grid of 36 surface electrodes have also been installed at the site. All instruments have been distributed in an axi-symmetrical pattern about the center of the infiltration pad, and all data collection systems are contained in a building immediately adjacent to the experimental area.

The site has been characterized geologically, hydrologically and geophysically. Geological characterization activities have involved developing a detailed map of subsurface sediments using direct observations in trenches and continuous core samples along with down-hole electrical conductivity logging. Quantitative textural measures have been obtained through particle size distribution analyses performed on one of the continuous core samples at 0.3 m intervals over the entire 11 m of core. Hydrologic characterization consisted of laboratory measurements of samples collected from the continuous core samples during drilling. Measurements have included saturated hydraulic conductivity, pressure versus saturation, and saturation versus electrical resistivity. Geophysical characterization consisted of analyzing pre-infiltration images generated by the ERT and XBGPR methods, as well as other geophysical well logs collected in the PVC access tubes. The different characterization techniques all show approximately 6m of interbedded sand, silt, clay and gravel where moisture contents are highest in the fine grained deposits and lowest in the coarse grained deposits. Underlying the 6 m of interbedded deposits is a more homogeneous fine to medium grained sand with occasional gravel lenses having a correspondingly homogenous moisture content profile.

Infiltration began in early March of 1999 at a rate of 2.7cm/day to produce unsaturated flow conditions. The ERT, XBGPR, neutron and tensiometer data show the wetted bulb expanding primarily downward with time, although some horizontal expansion is present, especially near the clays. The 2D and 3D imaging provided by the XBGPR and ERT, respectively, show the unsaturated flow field to be very heterogeneous in nature. These results emphasize the ability of geophysical imaging to provide more detailed information than that obtained from simple interpolation of down hole or point hydrologic measurements.

Preliminary results showed that standard methods such as Topp's equation for converting XBGPR images of dielectric constant, and Archie's law for converting ERT images of electrical resistivity, do not work well for the materials found at the site. Thus empirical relationships have been derived from lab measurements for conversion of the XBGPR images to moisture content. For the ERT images two different methods have been developed , one based on power-law equations with different coefficients for background and post-infiltration estimates, and the second based on co-Kriging of ERT and neutron data. In addition it appears that the estimates can be improved substantially by incorporating a-priori estimates of the background anisotropy into the ERT inverse models.

PLANNED ACTIVITIES

Currently, pressure head and moisture content data sets collected during the field infiltration experiments are being analyzed and pre-processed for use within the hydrologic inversion. Thus in the coming months we will be performing a cooperative inversion in which moisture information estimated from the ERT/XBGPR images will be used as input into the hydrologic inversion scheme do produce better estimates of subsurface hydrologic parameters. In addition, we are using the well log and continous core data along with the pre-infiltration geophysical images to construct multiple 2D and 3D hydrologic models. The infiltration experiment will then be simulated using these hydrologic models, and the changes in simulated moisture content compared to those observed in the geophysical images.