Project ID: **55332**

Project Title: **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 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 33rd month of a 36-month project, a geostatistically based 3D inverse model for transient flow in the vadose zone has been completed. Here the moisture/pressure and unsaturated hydraulic conductivity/pressure relationships are described by the van Genuchten- Mualem formulas. In addition, we have developed an innovative technique to sequentially incorporate soil-water pressure and water content data observed at different times within the inverse model. This sequential technique not only eliminates numerical difficulties associated with simultaneous inclusion of multiple data sets but also increases efficiency of the inverse solution.

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.

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 near the center of the imaging region where the model sensitivity to the data is relatively small. To alleviate these problems the a-priori variance is increased in the center of the image region where the sensitivity is small, and 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 at which data is being collected to test the HHGIT method has been completed. 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, 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 have been instrumented with nests of tensiometers, and four wells with time domain reflectometry (TDR) probes grouped with tensiometers, suction lysimeters, and thermocouples. 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. 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 consisted of exposing deposits through trenching, and core samples analyzing drillers logs, and making measurements of grain size distributions on samples collected during drilling and trenching. Hydrologic characterization consisted of laboratory measurements of samples collected during drilling. Measurements include saturated hydraulic conductivity as well as both pressure and electrical resistivity versus saturation. 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 5m of interbedded sand, silt, clay and gravel of moderate saturation overlying 7m of more homogenous and less saturated fine sand.

Infiltration began in early March of 1999 at a rate of 2.5cm/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 heterogenous in nature. These results emphasize the importance of geophysical imaging for determining the flow field as simple interpolation of the neutron and tensiometer data from the well locations would miss structures identified by the geophysical imaging techniques.

Currently we are working on methods to convert the geophysical images to spatial estimates of moisture content. Preliminary results show 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. Rather, empirical relationships derived from lab measurements are being developed which at least by initial indication should provide fairly accurate conversions from the respective geophysical parameters to moisture content.

PLANNED ACTIVITIES

In the coming months, we will be developing a maximum-likelihood algorithm to estimate the statistical structure of heterogeneity of the hydrologic parameters which is an input parameter to our inverse scheme. We will then assess the effect of uncertainty associated with this structure on our hydrologic inverse models. 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, and the XBGPR inversion results with the hydrological inversion scheme. This will involve two different approaches. 1) Performing a cooperative inversion in which moisture information derived from the hydrological models will be converted to resistivity/dielectric constant data via co-Krieging to improve the ERT/XBGPR inversion, and vice versa. 2) Coupling the ERT and hydrologic inverse schemes together to produce a full joint ERT/hydrological inversion routine.

As the experiment continues and the flow regime approaches steady state, inversions will continue to be made on both on the ERT and XBGPR data sets as well as subsets of the data, and the results converted to images of moisture content. These in turn will be compared to borehole neutron logs to determine uncertainty and accuracy in the moisture content estimates. Towards the end of next year we will employ the geophysical images and the hydrologic inversion results to develop a 3D model and interpretation of fluid flow within the vadose zone at the test site.