EMSP

2001 Annual Report

2nd Year of Project

The Dynamics of Vadose Zone Transport: A Field and Modeling Study Using the Vadose Zone Observatory

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Research Objective

A stated need of the DOE EM program is a better understanding of basic vadose zone fluid flow and contaminant transport processes for the purpose of making improved estimates of contaminant release rates and fluxes across the vadose zone to the water table at DOE sites such as the tank farms at Hanford. We investigate details of the modes of contaminant transport with the aid of infiltration experiments designed to elucidate how vadose zone characteristics such as preferential pathways, heterogeneities, and relative permeabilities influence the transport of contamination in liquid, gas and colloidal phases to the water table. Beyond enhancing our basic understanding of vadose zone transport processes, this EMSP project is designed result in a vadose-zone-transport-characterization methodology that can be generalized to other DOE sites.

Research Facility/Tools/Personnel

To pursue these goals, we are continuing to utilize the LLNL Vadose Zone Observatory (VZO) to carry out a cost-effective study of multiphase fluid flow in a heterogeneous unsaturated zone bearing dynamic resemblance to one type of Hanford vadose regime. The observatory (Fig. 1) consists of almost twenty instrumented boreholes and monitoring wells which traverse the 70-foot unsaturated zone including eight wells containing electric resistance tomography (ERT) arrays, four wells for electromagnetic induction tomography (EIT) and water table sampling, and four boreholes with multilevel gas-sampling ports, soil temperature sensors, gypsum blocks, tensiometers and lysimeters. The observatory uses several multichannel data loggers to continuously store information about surface barometric pressure, subsurface gas-phase pressure, subsurface temperature, capillarity and water-table levels that is downloaded into computers for later analysis. Using the capabilities of the VZO, we will continuously monitor the progress of an infiltration event simultaneously using both geophysical volumetric imaging techniques as well as more conventional hydrologic measurements (e.g., subsurface temperature, gas-phase pressure, tensiometry and lysimetry) that involve making observations at discrete points throughout the infiltration volume. An advantage of this approach is that volumetric imaging provides a context for interpreting the discrete observations, while discrete measurements provide a more detailed picture of changes in the vadose zone that cannot be obtained from the volumetric imaging observations themselves. Beyond this, the VZO permits samples of moisture and gases to be taken from many different depths in the vadose zone and from the water table. This ability to sample is critical to our infiltration experiments, which include a variety of chemical and isotopic gas- and liquid-phase tracers and colloidal particles. The release of chemical and

isotopic tracers during infiltration events is an important feature of these proposed experiments since such tracers permit evaluation of the potentially complicated relationship between actual chemical transport and fluid flow in the unsaturated zone as determined by ERT or other imaging methods.

We are also now using the ERT laboratory at LLNL for experiments to better understand the relationship of subsurface imaging of electrical conductivity distributions to groundwater movement. In combination with internal laboratory LDRD support in this area we have constructed a scaled test section simulating the distribution of electrodes at the VZO. Imaging experiments using the test section are being carried out to investigate the effect of electrode distribution and inversion algorithms on a given flow volume as it moves across the vadose zone to the water table.

To support ongoing ERT research at the VZO and in the ERT laboratory, we have found it necessary to develop our own ERT data acquisition and analysis capability. To this end, we purchased several major pieces of equipment with EMSP support and have formed a collaboration with the Imaging Laboratory at Rensselaer Polytechnic Institute in Troy, New York. The work associated with this collaboration is ongoing and will be reported in the subsequent 3rd year report.

Research Progress & Implications

The focus of research this year has centered on examining the relationship between subsurface imaging and groundwater transport to the water table. Two main experiments were performed during this reporting period (the chemistry results of one of them were described in the previous annual report because of an overlap in reporting periods. Furthermore, field experiments may also overlap fiscal years for budgetary reasons.)

The main infiltration experiment involved the release of 400 gallons (1500 l) of bromide and sodium chloride spiked Hetch Hetchy water. This event produced a smaller response in concentration changes of bromide and iodide at the watertable which was not expected considering that the water release contained a very high level of bromide tracer and that a previous event showed strong evidence for the transport of tracer immediately to the water table, that is, flow along preferential paths. One possibility that is being considered is that swelling of clayey soils associated with an immediately preceding freshwater injection may have reduced the downward flow of spiked vadose zone water to the watertable that was associated with the second injection event.

As in all previous electrical imaging studies, ERT observations indicated rapid changes in vadose zone saturation down to the water table level in a few hours. ERT is sensitive to resistivity changes in the 2-5% range. An electromagnetic induction tomography (EMIT) tool (Fig. 2) was simultaneously fielded in collaboraition with Electromagnetic Instruments (EMI) of Berkeley and Technoscan Inc of Salt Lake City with the support of an SBIR contract. The single-hole, 3-D, 2-receiver tool was able to detect resistivity changes that were comparable to those obtained with the ERT method. An earlier imaging experiment involved the use of a Lawrence Berkeley ground penetrating radar tool (GPR) at the Vadose Zone Observatory. The cross-borehole system was limited by the highly conductive silty soils of the site with observations between holes that were no more than 2-3 meters apart representing the upper limits of separation that could be achieved. The short range of the GPR system prevented comparison with the EMIT and ERT systems during this staged infiltration event. The result suggests that no one technique for subsurface imaging is optimal at all contaminated sites of interest.

ERT images (Fig. 3; 2 sets of images using different levels of masking) of the 400 gallon release described above show the formation of a downward propagating plume that does not appear to significantly penetrate the watertable at the bottom of the image. (Similar results were obtained from the phase-shift information obtained simultaneously with the magnitude of the resistivity.)This implies that no significant conductivity changes were produced in the water table owing to the arrival of heavier salty water. This observation is certainly consistent with not observing increased concentrations of bromide at the water table as indicated by our water table sampling. To date, our ERT observations and the observations of changes in water table chemistry have tended to agree in terms of what the observations tell us about transport during a given infiltration event. However, the picture of transport that we obtain may indeed vary from event to event. This may be due in part to sampling, but more likely it is a result of real changes in transport characteristics of the site between and during events.

Just prior to the end of the reporting period, we carried out another 400-gallon injection experiment to investigate the relationship between streaming potential associated with the movement of subsurface fluids and the change in conductivity distribution imaged by ERT. Figure 4 shows the distribution of surface copper/copper sulfate electrodes on a 6x6 grid. The electrodes were placed beneath paper paint buckets to minimize conductivity fluctuations associated with diurnal temperature changes. With wiring modifications, the subsurface electrode arrays used for ERT imaging where also used for subsurface SP measurements. Both SP and ERT observations suggested that water might be moving downward more efectively at southeast electrode well which indicates that a different pathway was used compared to earlier infiltration observations. Further analysis will be performed to investigate the contribution of SP in tracking plumemigration.

With partial support from EMSP, we published a major journal article in *Environmental Science & Technology* (*ES&T*) on modeling electrical heating in the subsurface. The article was featured on the cover of the November 15, 2000 issue of the journal (Fig. 5). The simulation capability described in the *ES&T* article represents one component needed for our new modeling effort to develop a simulator that will allow quantitatively improving subsurface models of infiltration using actual ERT imaging observations.

The National Science Foundation Center for Subsurface Sensing and Imaging Systems (CenSSIS) has selected the EMSP sponsored LLNL Vadose Zone Observatory as a Soilbed Testbed for the development of new and improved subsurface imaging techniques. Discussions continue with CenSSIS participants on possible collaborations. A proposal to NSF on enhancing instrumentation

Planned Activities

We continue to pursue leveraging our EMSP program funding in the area of integrating observations into vadose zone models of infiltration and anticipate utilizing observations from the Vadose Zone Observatory to enhance numerical simulations of infiltration at the site. In collaboration with CenSSIS participants we anticipate using the VZO as a testbed for comparision of subsurface imaging techniques with electric resistance tomography observations as a baseline.

Information Access

Carrigan, C.R. and J.J. Nitao, Predictive and diagnostic simulation of in situ electrical heating in contaminated, low permeability soils. *Environmental Science & Technology*, 34, 4835-4841, 2000. (Cover article)

Carrigan, C.R., sidebar contributions (3 total, p. 943 in particular) to DOE "Vadose Zone, Science & Technology Solutions",Book published by Battelle Press, 2000.

Carrigan, C.R., Contaminant migration to the watertable -- A looming societal nightmare. Invited lecture to Center for Subsurface Sensing and Imaging Systems (CenSSIS) Industrial Collaboration Conference, Nov. 13-15, 2000. PowerPoint presentation available at http://www.censsis.neu.edu/mainframe_seminar_ws01.html

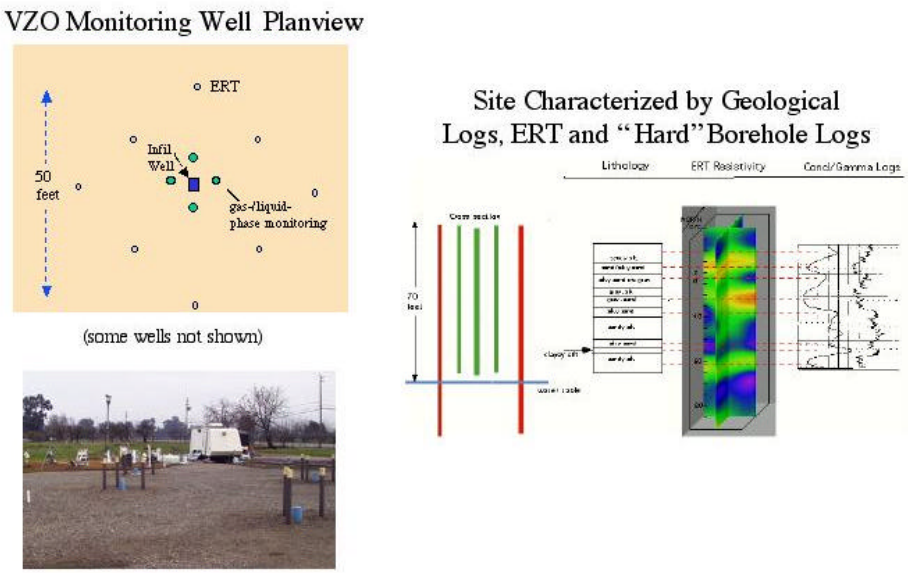

Figure 1

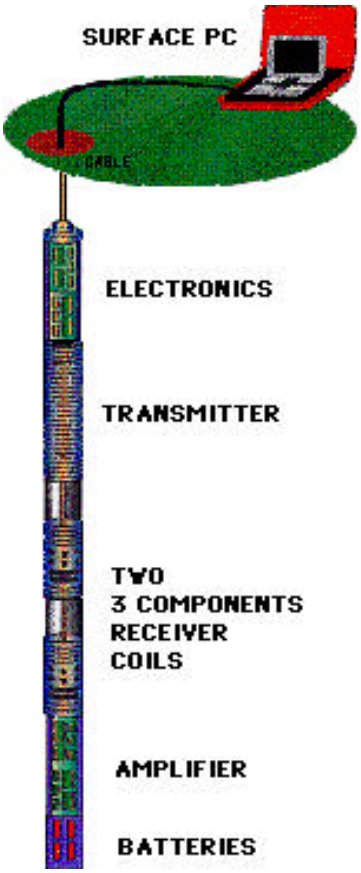

Figure 2

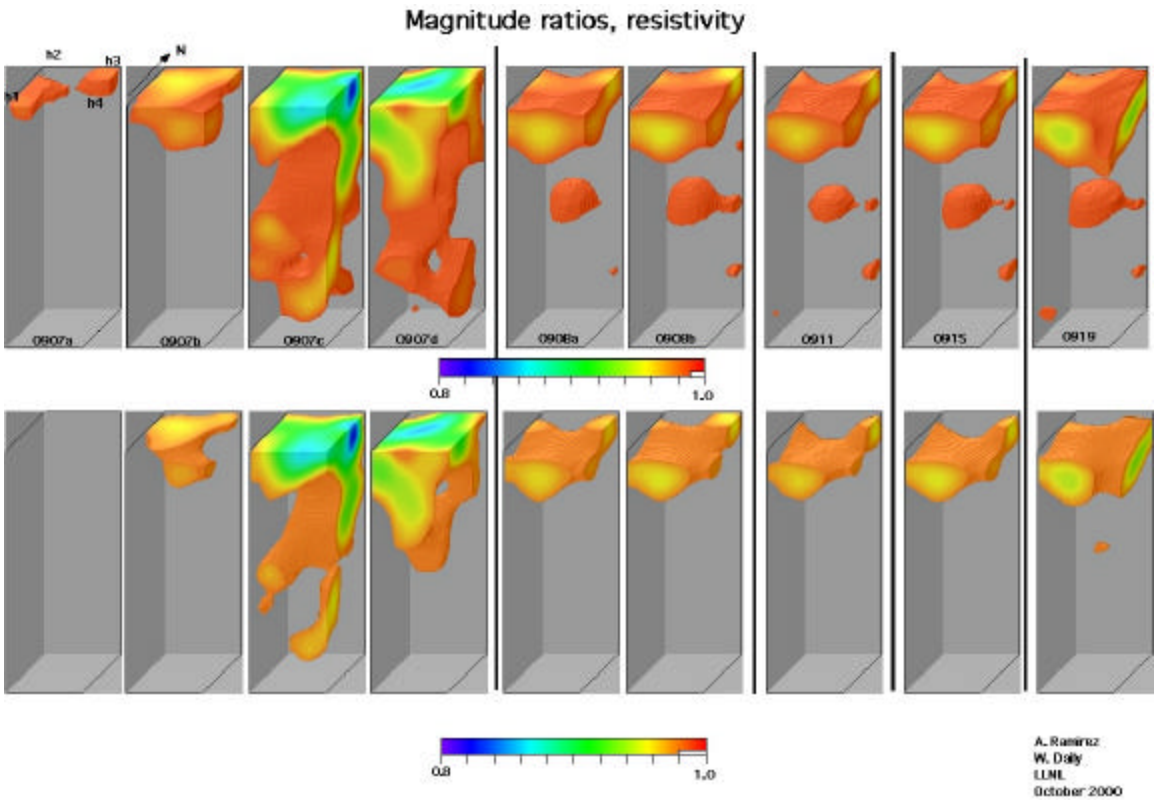

Figure 3

Figure 4

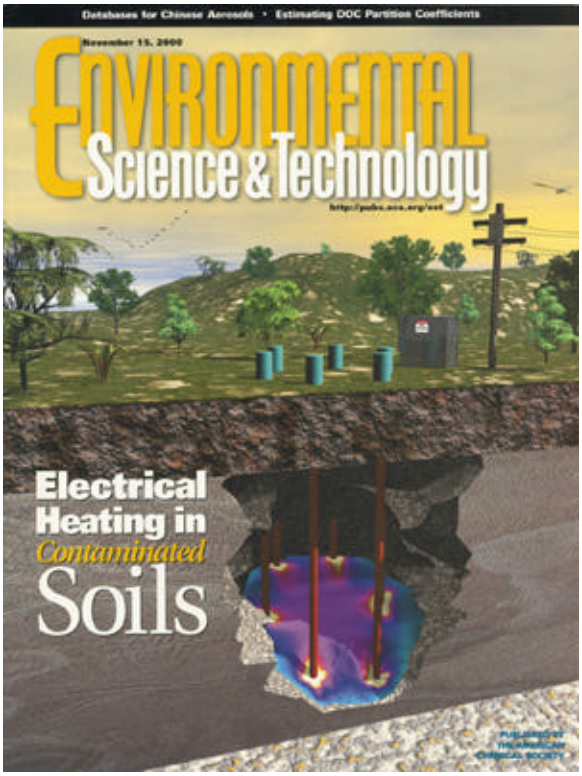
Databases for Chinese Aerosols • Estimating DOC Partition Coefficients
November 15, 2000
Environmental Science & Technology
Electrical Heating in Contaminated Soils

Figure 5