static and steady-stay flow conditions with a RMSE of 0.016 cm^3 cm^{-3}. Water fluxes were estimated successfully for both saturated and unsaturated conditions within a range of 2.0E-06 m/s to 7.2E-05 m/s. Solute breakthrough curves at different water contents were analyzed and the solute and thermal dispersivities were compared. The probe constitutes a new promising vadose zone measurement technique for combined heat and solute transport estimation and for water flux and dispersion measurements.

H12K-07 1730h

Reconstructing the Pore Space of Sand Samples

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The structure of the pore space is essential for flow and transport in soils. Size, shape and connectivity of the pores determine the distribution of air and water, pore water velocity and solute mixing. So, for a complete understanding of transport processes in soils, the pore geometry must be known. Some processes, for example the drainage of water, depend on narrow structures with sizes of a few micrometers. For this reason, a technique to measure 3D pore structures with high resolution is needed. This presentation will describe the image processing steps needed to provide a pore space with the highest possible fidelity to the measured sample. The projection data were acquired using an imaging system based on synchrotron radiation. This technique allows us to map the pore structure in the range of 10 microns. To transform the projection data into pore space volumes, a chain of actions involving back projection, the application of various filters to suppress noise and artifacts, and segmentation is needed. During experiments at the Swiss Light Source (SLS) we scanned sand samples with diameter 5 mm containing sand particles ranging from 100 to 300 microns with a voxel size of 3.5 microns. At the Hamburger Synchrotron Laboratory (HASYLAB) sand samples with diameter 15 mm containing particles ranging from 100 to 900 microns were mapped with a voxel size of 11 microns. In addition to the scanning of completely dry samples, we intend to investigate the water and air distribution for different degrees of water saturation. Comparing these measurements with numerical simulations, we hope to understand the processes of air and water distribution in more detail.

H12K-08 1745h

Colloidal Acceleration and Dispersion in Saturated Micromodels

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Size exclusion is a mechanism affecting the transport of colloidal contaminants in porous media. We developed polydimethylsiloxane (PDMS) micromodels to examine at the pore scale the effect of particle and pore size on saturated colloid transport. The micromodels were generated using a novel soft photolithography technique developed by Quake and Scherer (2000). This easy and inexpensive technique allows us to rapidly generate patterns that have dimensions in the range of those existing at the pore space. Three patterns were designed: two regular networks with 10-m and 20-m constant channel widths, respectively and a network combining two different channel widths, 10 and 20 m. Four sizes of colloids were transported through the micromodels at different pressure gradients. The transparency of the cured PDMS allowed optical microscopy observations of the transport and dispersion of the colloids within the pores. Particle trajectories, residence times and dispersion coefficients were determined from image analysis of at least 200 different individual colloids for each pressure, micromodel and colloidal size. According to our results, particles move more rapidly when colloid size increases and pore width decreases. The acceleration factor (ratio of colloid to water velocity) depends on micromodel geometry and colloid size, varying from 0.71 in the combined-width model to 2.5 in the 10-m constant-width model. Dispersion coefficients increase as a linear function of pore velocities. For a given micromodel and pore velocity, dispersion coefficients decrease with increasing colloid size. These findings emphasize the role of size exclusion on colloidal transport and the importance of taking into account particle and pore size when predicting colloid transport in the field. Reference Quake SR and Scherer A. 2000. From micro- to nanofabrication with soft materials. Science. 290 (5496): 1536-1540.

H21A MCC: 3022 Tuesday 0800h

Hydrogeophysics: Characterization and Monitoring of Subsurface Parameters and Processes I *(joint with NG, MR)*

Presiding: **S S Hubbard,** Lawrence Berkeley National Laboratory**; A Binley,** Lancaster University

H21A-01 0800h INVITED

Recent Advances in the Use of Electrokinetic Self-Potential Signals as an Effective Tool in Hydrogeophysics to Monitor Ground Water Flow

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Ground water flow generates detectable electrical signals at the ground surface through a conversion mechanism called streaming potential. These signals can be recorded in a passive way with a set of non-polarizable electrodes and a multi-electrode digital multimeter. These signals can be inverted to image the shape of the water table and its temporal variations using new self-potential tomography (SPT) algorithms. The signal-to-noise ratio seems high enough to expect an accuracy of 10 cm in the detrmination of the depth of the water table. Then, because the sensors are cheap, we can use an important number of measurement stations and we can obtain a great amount of information to invert in a cost-effective way. In this talk, we will discuss the physics of this hydro-electric and present both forward and backward methods to interpret field data. We will show examples from three field studies in which self-potential signals are associated with hydraulic head fluctuations. We will discuss the stability of the electrodes, the sources of noise, and new challenges in combining SPT with more classical electrical resistivity tomography (ERT).

H21A-02 0815h

Modelling Streaming Potential (SP) Signals Induced by Water Movement in the Vadose Zone

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Field estimation of soil water flux has a direct application for water resource management. Standard methods are often difficult to apply because of the heterogeneity of the subsurface. In the present study, we show that Streaming Potential (SP) monitoring can provide a cost-effective tool to help estimate the nature of the hydraulic transfers (infiltration or evaporation) in the vadose zone. We have modelled the SP response induced by the electrokinetic effect of rainfall infiltration and evaporation in an unsaturated porous medium. Our model based on Richards' equation shows that SP signals of several millivolts are generated, i.e. easily recordable with standard SP equipment and that they allow to characterize the upward or downward water flux. We have then compared our model results to two SP and hydraulic data sets acquired during both rainfall infiltration and evaporation phases and they confirmed that SP measurements allow effectively to estimate the direction of the water flux at the scale of the electrode separation (usually several decimetres), i.e. at a much larger scale than tensiometric measurements. Moreover, as streaming potential coupling coefficients are related to the nature and concentration of solutes, SP could be used in the future to characterise contaminant fluxes in soils.

H21A-03 0830h

Hydrogeophysics in the Coastal Zone: Spatial and Temporal Constraints on Groundwater Processes from Coincident Wells and Geophysical Surveys

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The electrical conductivity contrast between fresh and saline groundwaters renders DC resistivity imaging and inductive EM methods particularly useful for studying hydrologic problems in the coastal zone. However, such settings also pose unique logistical challenges, ranging from difficulty acquiring geophysical data in salt marsh or intertidal zones to complications in the analysis of geophysical data that are strongly affected by high conductivity salt water. In this study, we first describe a new inversion algorithm for inductive EM data collected in high conductivity settings where the linear relationship between induced magnetic field strength and integrated terrain conductivity breaks down. The inversion, which is based on a robust, convergent, regularized least squares approach that accounts for the nonlinearity in mutual dipole induction, produces an "image" of subsurface fresh and saline pore water distributions that closely matches the actual distribution inferred from geochemical analyses of groundwater recovered from coincident shallow monitoring wells at a permeable upland site. In the second part of the study, we report on key results from 5 years of electrical and inductive EM surveys conducted at intratidal to interannual time scales coincident with > 50 shallow monitoring wells in uplands and salt marshes of the Georgia Bight. Combining inversions of EM data, the results of extensive DC resistivity surveys, and geochemical analyses of groundwaters from our well networks, we delineate submarsh freshwater discharge pathways to adjacent estuaries, describe the dynamics of fresh and saline groundwater interactions and exchange during a tidal cycle, and constrain possible Hele-Shaw convection cells within salt marshes.

H21A-04 0845h

A Comparison of Surface and Surface-Borehole ERT Arrays for Monitoring Subsurface Hydrologic Processes at the INEEL Site

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Electrical resistivity tomography (ERT) is emerging as a leading tool for tracking hydrological processes at intermediate scales. Uses include the characterization of geological structure, slowly varying water contents, and rapidly changing water content or solute concentration during infiltration and flushing. The technique makes use of the simultaneous interpretation of 10's to 1000's of individual measurements to characterize multidimensional electrical conductivity distributions in the subsurface. Although ERT has been used widely in subsurface hydrology, some major limitations still exist to its optimal application. Specifically, data acquisition is to be optimized, and the combined effects of multiple components that contribute to the bulk electrical conductivity (i.e. water content, solute concentration, and medium properties) must be identified to allow for more quantitative analysis of heat or mass transport. This can be achieved through improved survey design, which combines hydrologic understanding in the identification of suitable ERT targets and optimization of data acquisition for hydrologic interpretation. We demonstrate that the wise selection of the arrays composing a survey can improve the ability to characterize subsurface hydrologic processes. The selection is based on comparisons of the sampling volumes of surface based ERT arrays with those that make use of both surface and borehole electrodes. The method is applied to a specific example of vadose zone monitoring at the Idaho National Environmental and Engineering Laboratory (INEEL).

H21A-05 0900h

Suitability of Archie's Law For Interpreting Electrical Resistivity Data

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Electrical resistivity tomography (ERT) is examined as a method to provide spatially continuous images of saline tracer concentrations during transport through unconsolidated fluid-saturated media. It is frequently accepted that there exists a quantitative relationship between the electrical conductivity of dilute electrolytes in pore water and bulk electrical conductivity of the subsurface measured using resistivity methods. The assumed relationship is typically Archie's Law. We tested the applicability of Archie's Law to field-scale data collected over a 10 m by 14 m area. A 20-day weak-dipole tracer test was conducted, in which 2 g/L NaCl were introduced into the upper 30 m of the saturated zone in a coarse sand and gravel aquifer. Cross-well ERT data were collected at 4 geophysical monitoring wells and inverted in 3-D. Fluid electrical conductivity was measured directly from a multi-level sampler. The change in the direct measurements of fluid electrical conductivity exceeded the change in bulk conductivity values in the tomograms by an order of magnitude. The estimated Archie formation factor from the field data was not constant with time, due largely to smoothing during the image reconstruction process. We illustrate by modeling synthetic cases over the field site that the ERT response is difficult to match to measured fluid conductivities due to the variability in the effects of regularization, which change in both space and time. Analysis of both the field data and synthetic cases suggest that Archie's Law cannot be used to directly scale ERT conductivities to fluid conductivities.

H21A-06 0915h

Instrument Spatial Weighting Functions and the Meaning of Measurements in Heterogeneous Porous Media

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Instruments that are designed to measure hydraulic conductivity (K) based on multi-dimensional flow fields, such as the gas mini-permeameter, weight various portions of the flow domain differently when determining a single K value, even under homogeneous and isotropic conditions. For natural heterogeneous materials, virtually all flow fields are 3-D, even those set up using standard permeameters and small cores. Thus the question of how a given instrument weights different portions of a domain is fundamental to understanding the meaning of a measurement. Recently, the instrument spatial weighting function (ISWF) has been derived for steady-state measurement procedures using compressible or incompressible fluids and identified physically as the ratio of the hydraulic energy dissipation rate at each point of a homogeneous domain to the total energy dissipation rate throughout the flow domain [Molz et al., WRR, 39(4), DAN-1, 2003]. Such an ISWF identifies the points of a domain that most influence a measurement and has units of erg/cc.sec/erg/sec or 1/cc (inverse volume); the concept generalizes to other types of geophysical measurements. The present work shows that the existing ISWF development extends naturally to transient K measurements, such as those made using a slug test or pumping test. When measurements are made in heterogeneous domains, the "measured" K value results from a complex interaction between the ISWF and the heterogeneity. Given known K distributions, ISWFs are calculated for K measurements made on cores. A rather general dilemma appears to arise in that one is led to conclude that in order to calculate the ISWF, and hence have a well-defined measurement, one must know the K distribution before the measurement is made. Implications for the well-known up-scaling problem in porous media are discussed.

H21A-07 0930h

Amplitude Variation With Offset (AVO) Analysis of Ground Penetrating Radar Data for Direct Detection and Delineation of NAPL Contamination

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Amplitude and phase variation with offset analysis of ground penetrating radar data (APVO/GPR) can improve the differentiation of non-aqueous phase liquid (NAPL) from stratigraphic changes. Previous controlled experiments have shown that common offset (CO) GPR methods can detect the presence of NAPL in soil by examining amplitude and travel time (velocity) anomalies. Unfortunately, stratigraphic changes such as the presence of a silt or clay lens or perched water table may produce similar amplitude and velocity anomalies. Therefore, it is difficult to delineate NAPL in a terrain with unknown stratigraphy exclusively using CO data collection methods. Forward models based on the Fresnel equations predict that amplitude responses exist at various incidence angles that will allow for differentiating NAPL from hydrogeologic changes. Models generated as part of this study indicate that analyzing the difference in amplitude responses from linearly polarized electric field vertically oriented (EV) to the horizontally oriented (EH) signals at various incidence angles improves target discrimination. A case history is presented demonstrating that collecting common-midpoint (CMP) GPR data using EH and EV polarized signals at anomalous CO amplitude responses and analyzing the data using APVO and normalized residual polarization (NRP) methods can improve the detection and differentiation of NAPL from stratigraphic changes in the subsurface. These results are corroborated using a capacitively coupled resisitivity instrument and subsequent intrusive sampling.

URL: http://www.geophysics.buffalo.edu

H21A-08 0945h

Electrical Resistance Tomography Field Trials to Image CO2 Sequestration

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If geologic formations are used to sequester or store carbon dioxide (CO_2) for long periods of time, it will be necessary to verify the containment of injected CO2 by assessing leaks and flow paths, and by understanding the geophysical and geochemical interactions between the CO2 and the geologic minerals and fluids. Remote monitoring methods are preferred, to minimize cost and impact to the integrity of the disposal reservoir. Electrical methods are especially well suited for monitoring processes involving fluids, as electrical properties are most sensitive to the presence and nature of the fluids contained in the medium. High resolution tomographs of electrical properties have been used with success for site characterization, monitoring subsurface migration of fluids in instances of leaking underground tanks, water infiltration events, subsurface steam floods, contaminant movement, and assessing the integrity of subsurface barriers. These surveys are commonly conducted utilizing vertical arrays of point electrodes in a crosswell configuration. Alternative ways of monitoring the reservoir are desirable due to the high costs of drilling the required monitoring boreholes Recent field results obtained using steel well casings as long electrodes are also promising. We have conducted field trials to evaluate the effectiveness of long electrode ERT as a potential monitoring approach for CO2 sequestration. In these trials, CO2 is not being sequestered but rather is being used as a solvent for enhanced oil recovery. This setting offers the same conditions expected during sequestration so monitoring secondary oil recovery allows a test of the method under realistic physical conditions and operational constraints. Field experience has confirmed the challenges identified during model studies. The principal difficulty are the very small signals due to the fact that formation changes occur only over a small segment of the 5000 foot length of the electrodes. In addition, telluric noise can be comparable to the signal levels during periods of geomagnetic activity. Finally, instrumentation stability over long periods is necessary to follow trends in reservoir behavior for several years. Solutions to these and other problems will be presented along with results from the first two years of work at a producing field undergoing CO2 flood. If electrical resistance tomography (ERT) imaging can be performed using existing well casings as long electrodes, it will substantially reduce the cost to monitor CO2 sequestration. This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

H21B MCC: 3020 Tuesday 0800h

Hydrologic Predictions in Ungauged Basins: PUB II *(joint with NG)*

Presiding: **T Wagener,** University of Arizona**; J C Schaake,** NOAA National Weather Service

H21B-01 0805h INVITED

Gauging the ungauged basin: How to diagnose catchment function from field reconnaissance to long-term observation.

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Despite the widespread gauging (usually rainfall and runoff) of watersheds around the world for the past century, little thought has been given to gauging strategies in the context of what to measure, where to measure, and when. We explore in this talk whether or not gauging should be a mechanical and prescriptive approach or, perhaps alternatively as a diagnostic tool to probe how a catchment works. The following questions will be explored: Does a one size-fits-all approach work for basins in different climates, geological situations and vegetative environments? What are the minimum number and location of measurements necessary to even characterize a basin? Should we standardize our gauging for all catchments? How should concepts, theories and modeling inform where and what to measure? These questions have not been explored in detail since the early days of the International Hydrological Decade back in the 1960s. Nevertheless, it is these basic questions that may help us to reveal simplicity from the hitherto measured complexities of gauged basins developed thus far. As we move from the traditional headwater research basin to mesoscale basins and beyond, we need to rethink what it might mean to "gauge" a basin. How might we rapidly assess first order process controls from say a few days of field reconnaissance or perhaps some combination of assessed climate-vegetation-geologic controls on annual water balance, monthly flows, event dynamics, water age, geographic and time source components of flow. This talk presents some ideas on a road map to gauging within the PUB framework and considers how new approaches may reconsider the tradeoffs between precision and accuracy for spatial completeness, new data content and characterization of the gross stocks and flows of water (and things carried with the water) in a basin.

H21B-02 0830h

Predictive Uncertainty and Scalability of Transpiration in Heterogeneous Watersheds

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Spatially variable water fluxes from transpiration represent a significant and as yet largely unquantified source of uncertainty in the prediction of ungauged basins. Current models of transpiration can be traced to "center-of-stand" approaches that quantify fluxes in