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.

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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

the field and distribute parameters derived from these observations to watershed scales using land cover classification. In this approach, fluxes are extrapolated to larger scales without regard for gradients in environmental drivers. There is evidence that transpiration fluxes change at stand edges, which would magnify the uncertainty in watershed scale fluxes as the spatial heterogeneity of land cover increases. An initial conceptual framework for spatial transpiration will be presented that builds on the fact that canopy stomatal conductance is regulated primarily by leaf water potential when water fluxes are high and of significant hydrologic import. Species plasticity in canopy stomatal conductance, which determines its spatial variability in response to environmental drivers, follows a linear relationship that is keyed off of an easily quantifiable reference conductance. Numerous recent studies have shown that vegetation regulates water fluxes according to internal set points in leaf water potential, despite large variations in environmental drivers such as soil moisture. These internal set points provide for simple, yet mechanistically sound models of transpiration. The transfer of predictive uncertainty in transpiration to basin scales is illustrated using multi-year data from the Chequamegon Ecosystem - Atmosphere Study (ChEAS), with supporting data from other sites. Suitable parameter sets for quantifying predictive uncertainty are derived using a flexible, fuzzy logic approach. A series of simulation experiments are conducted in which the fragmentation of forest cover is increased, thereby increasing edge effects that alter total water fluxes.

H21B-03 0845h

In-stream Indicators to Reduce Parameter Uncertainty in Hydrologic Models

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Many automatic parameter estimation procedures resemble pure curve fitting approaches that use computer power to process data and utilize the degrees of freedom available in hydrologic models. Current efforts to estimate physically plausible model parameters focus on incorporating information and knowledge, derived from the observed data, into the calibration process. We extract information from historical streamflow records using in-stream indices that are intrinsic and representative of the basin hydrological response. A suite of in-stream indices from a variety of different temporal scale that is robust and differentiable was identified from 40 years of daily streamflow data from the Leaf River basin (1950 km2), Mississippi. Subsequently, an automatic procedure, which selects hydrologic model parameters [Sacramento Soil Moisture Accounting SAC-SMA] that acceptably reproduce the indices in the simulation, was developed. The results showed that the initial SAC-SMA parameter range was reduced significantly, and all the model parameters are well identifiable. Moreover it was found that the resulting parameter ranges provided an uncertainty envelop on the predictions that enclosed different components of the hydrograph very well.

H21B-04 0900h

Multifractal Prediction in Hydrology

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One of the main axes of the current hydrological research and engineering is the general forecast of extreme events and the development of new tools for their prediction, prevention and alert. Deterministic models based on various physical and/or statist ical approaches face concrete difficulties to capture the phenomena of extreme precipitation and discharges. The chain of 'precipitation-discharge-sedimentation' process remains even more unresolved issue. It is well known that one of the main difficulties for the description of hydro-meteorological extremes is the colossal variability of their intensities over a wide range of space-time scales. To contribute to the process of hydrological forecast improvement, our group uses the multifractal framework. It allows not only to explain the power-law fall-off of probability distributions for hydrological-meteorological extremes, but also to explore a connection of the observed variability with the physics, so to capture the phenomena within a full hierarchy of scales and intensities. First of all, we analyze space-time distributions of precipitation and discharges over different hydrological regions. A multifractal data analysis performed in the space-time domain produces - amongst other things - a physica lly-based tool for the clear distinction and multifractal description of flash-floods. We illustrate these methods on two recent flooding events in France: the Abbeville phreatic floods in 2001 and the flash floods in Gard in 2002. Furthermore, after multifractal analysis of several sediment time series, we obtain first results directed to the parameterization and prediction of the 'precipitation-discharge-sedimentation' process.

URL: http://www.multifractal.jussieu.fr

H21B-05 0915h

Affect of Temporal Rainfall Variability and the Width Function on the Peak-Flow Scaling Exponent in the Goodwin Creek Basin

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Observations show that peak-streamflow scaling exponents change from one rainfall event to another in the Goodwin Creek basin, MS. We develop a space-time equation for streamflows to investigate this phenomenon. The equation is formulated by assuming that rainfall is uniform in space and that the mean rainfall time series for an event is non-stationary. Observations of rainfall from Goodwin Creek support these assumptions. We also assume that channel velocity is constant throughout a basin, meaning there is no channel storage, and that Hortonian overland flow is the only mechanism of runoff generation. It is observed to be the dominant runoff process in Goodwin Creek. Finally, we use the observation that the mean of the width-function maxima are related to spatial scale as a Power Law. With these assumptions, equations are developed for streamflow $Q(n,t)$ and peak streamflow $Q_p(n)$, where t is time and n is the number of river network links in a basin and represents spatial scale. The peak flow equation is tested against observed scaling exponents for more than forty rainfall events. Tests show that the equation makes excellent first-order predictions of the observed variability in the peak-flow scaling exponents.

H21B-06 0930h

On the Importance of Linear vs Non-Linear Response in Estimating Base Flow Features for Ungauged Catchments in Southern Texas

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Various equations have been derived and applied in the study of groundwater base flows. Many studies have confirmed the applicability of a linear storage-discharge relationship in describing groundwater outflows into stream channels from adjoining aquifers. This result has been used in studies of base flow to estimate various catchment-scale, effective hydraulic parameters such as saturated hydraulic conductivity, drainable porosity, and base flow recession constant. However, other studies have found that a nonlinear formulation of catchment response is more appropriate, and an explanation of this difference from a physical basis remains an unsolved problem. In a study of six catchments in southern Ohio, eastern Kentucky, and southern West Virginia (within the Ohio River Forecast Center of the National Weather Service), preliminary results showed that two catchments exhibited nonlinear recession behavior, while the others behaved in a linear fashion. As judged by flow statistics and hydrograph comparison, Sacramento model performance based on a method for a priori parameter estimation was better for the two non-linear catchments than for the linear catchments. In particular, base flow recession parameters were significantly better for the nonlinear catchments. Better physical understanding of this difference could lead to improved a priori estimation of base flow parameters. However, the potential to do so is increased (1) by examining a different geographical region and (2) analyzing a larger sample of catchments. In this paper, a set of 23 catchments in southern Texas is examined in order to further explore the occurrence and significance of linear vs. nonlinear catchment hydraulic behavior. We discuss implications for improving Sacramento a priori parameter estimates as well as regionalization of its parameters.

H21B-07 0945h

Improved Understanding of the 3D Hillslope Spatial Structure as a Prerequisite for Understanding the Hydrological Behaviour of Ungauged Basins.

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We study the first-order controls on hydrological behaviour of hillslopes and catchments. This hillslope response is driven by precipitation, but controlled by the geological, topographic, hydraulic, pedologic and ecological properties of the hillslope. In the common case of soil mantled landscapes, where water storage in perched groundwater tables is an important process and saturation excess overland flow dominates, a primary control on hillslope hydrology is formed by the geometry and properties of the soil layer. Improved dating techniques have enabled the formulation of geomorphological and pedological process laws that are supported by data. Using these laws, the prediction of the spatial structure of this soil layer becomes possible, enabling the a priori prediction of associated model parameters, based on assumptions regarding lithology, weathering, surface processes like erosion etc. In this paper we will give some examples of this approach. A simplified Landscape Evolution Model (LEM) is used to simulate the evolution of relief and regolith. From both the dynamic equilibrium and transient states of this LEM, parameters for the hillslope hydrological model can be collected. In our case, we apply the semi-distributed, physically based, hillslope-storage Boussinesq model' [*Troch et al.*, The hillslope-storage Boussinesq (hsB) model for subsurface flow and variable source areas along complex hillslopes: 1. Formulation and characteristic response, WRR, in press]. Model parameters for this hsB model include hillslope width and gradient, regolith depth, drainable porosity and saturated conductivity. We present some examples where the LEM is used to predict both surface and soil layer geometry. We show how the evolution of these parameters through geomorphological time results in trends in the characteristic (e.g. unit) hydrograph at the hillslope scale. This approach can be scaled up to the catchment or regional scale by investigating how model parameters differ for hillslopes draining to first, second etc. order channels. This relationship in combination with established scaling laws for channel network helps predicting the hydrographs on these larger scales. Examples of this scaling are also presented.