

organic compounds (e) Quantification of surface water / groundwater interaction (f) Characterization of the biodegradation potential. The use of pharmaceuticals as tracers is limited by variations in input. These variations depend on the amount of drugs prescribed and used in the study area, the social structure of the community, the amount of hospital discharge, and temporal concentration variations. Furthermore, the analysis of trace amounts of pharmaceuticals is sophisticated and expensive and may therefore limit the applicability of pharmaceuticals as tracers. Finally, the transport and degradation behavior of pharmaceuticals is not fully understood. Preliminary experiments in the laboratory were conducted using sediment material and groundwater from the Berlin area to evaluate the transport and sorption behavior of selected drugs. Results of the column experiments show that clofibric acid exhibits no degradation and almost no retardation ($R_f = 1.1$) whereas ibuprofen is biodegraded (> 90 %) under aerobic conditions. Carbamazepine shows no degradation in the soil column experiments but significant retardation under the prevailing conditions. We conclude that clofibric acid will show the transport behavior of a conservative tracer, whereas ibuprofen may be used to characterize the biodegradation potential in the aerobic zone.

H21D-0888 0830h POSTER

On transient capture zone analysis: The importance of dispersion

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Transient analyses of capture zones of water supply wells are in many practical cases superior to commonly apply steady-state analyses. Recently there was increased number of case studies on this topic but most of them took into account the advection only (similarly to the most steady-state studies). In the transient case, however, taking into account only the advection without dispersion can produce substantial bias in the capture zone estimates. The advection flowpaths could be not representative for the potential contaminant flowpaths; the advection flowpath and arrival-time estimates could not be representative for the location and/or time of the potential plume arrival. We present synthetic studies and case study of water-supply wells in Espanola basin to demonstrate our conclusions. Obtained transient capture zone estimates are very sensitive to heterogeneity and properties of the medium; especially the porosity and dispersion parameters.

H21D-0889 0830h POSTER

Local and Regional Scale Simulation of River Aquifer Interactions.

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Overdraft of groundwater in Sacramento County, California has severely depressed regional groundwater levels and depleted base flows along the Cosumnes River. These developments continue to negatively impact riparian vegetation and threaten the fall migration of endangered Chinook salmon. In this study river aquifer interactions are investigated along a 200m reach of the Cosumnes River using continuous field measurements of riverbed temperature, water content and matrix potential to a depth of 10m below the riverbed. These data demonstrate complex seepage patterns including fracture flow and the formation of perched aquifers due to geologic heterogeneity. Riverbed sediment heterogeneity was characterized using geostatistical indicator simulations based on continuous core data. A 3-dimensional reach-scale model was developed using the TOUGH2 simulator. Modeling results suggest that the success of riparian vegetation may depend on the presence of perched aquifers. The reach-scale model will also provide better estimates of riverbed hydraulic properties for use in a larger regional-scale groundwater flow model. The regional model was developed based on detailed geostatistical simulations of the Cosumnes alluvial fan hydrostratigraphy using a version of MODFLOW that includes the ability to simulate unsaturated flow between the river and the aquifer. The regional model is used to assess management scenarios that are developed to improve fall flows and to enhance overall river ecology.

H21D-0890 0830h POSTER

Stable Isotopes in Snow: Implications for the Design of Precipitation Collectors and Studies of Groundwater Recharge

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The stable isotopes 18-O and 2-H are widely used as tracers in the hydrologic system. Numerous studies have collected precipitation in order to determine its stable isotopic signature at locations around the world. This signature varies seasonally, theoretically allowing determination of the relative importance of snow and rain to groundwater recharge. Data for the isotopic signature of precipitation collected over large regions are often contoured, and used to make inferences about weather patterns and processes such as evaporation during rainfall. An issue that, until recently, has generally been ignored in hydrologic studies is that the isotopic composition of snow can change significantly prior to, and during melting. Many studies have compared the isotopic signatures of fresh snow and rain to that of groundwater in order to determine the proportion of each responsible for recharge. However, alteration causes the isotopic signature of snow to become heavier, appearing more rain-like as alteration increases. As a result, many mixing models based on fresh snow and fresh rain end members may provide flawed estimates of the proportion of groundwater recharge derived from snowmelt. We have installed precipitation collectors of various designs, similar to those commonly used in other studies. As two to three different designs of collectors are in place at each of several sites, the impact of the samplers on the isotopic composition of snow can be determined. Our data show that one commonly-used type of collector yields values that are significantly enriched compared to values for fresh snow. At one site in New Mexico, the bulk winter-season isotope values for this collector were -13.5 per mil for delta 18-O and -98 per mil for delta D, compared to the values -16.6 and -118 per mil yielded by a collector designed to prevent isotopic alteration of snow. Our results suggest that the duration of snowpack alteration affects the magnitude of isotopic shift. Where melt takes place quickly due to higher temperatures and/or lower amounts of fall, the isotopic shift is smaller than at sites where large amounts of snowfall and low temperatures allow long periods of alteration. Although collectors that allow the isotopic alteration of snow are inappropriate if values for fresh precipitation are desired, they can be useful for determining the relative importance of snow and rain in groundwater recharge. Mixing calculations from one of our field sites show that using a fresh snow signature in a mixing model would predict groundwater recharge was 40 % snow-derived and 60 % rain-derived. Using the isotopic signature of altered snowmelt from one of our collectors, the proportions were reversed, with snow making up 60 % of the recharge.

H21E MCC: Level 2 Tuesday 0830h

Dealing With Hydrogeologic Uncertainty in Practice: Data Collection, Models, Predictions, and Regulatory Guidelines II Posters

Presiding: T Harter, University of California, Davis; M C Hill, U.S. Geological Survey

H21E-0891 0830h POSTER

Sensitivity of Seawater Intrusion in Coastal Aquifers to a Hydraulic Barrier

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One of the challenging issues of water resources management is the vulnerability of coastal aquifers to seawater intrusion. Mitigating the impacts of seawater intrusion in coastal aquifers is a formidable task

that often requires minimizing extraction of freshwater and finding viable means to protect the freshwater aquifer either by reclaiming the already saline aquifer and/or limiting the advance of the interface farther inland. One of the methods that can be employed to mitigate the impacts of seawater intrusion involves creating a hydraulic barrier where injected freshwater alters the flow of intruding seawater by creating a localized zone of higher pressure in the aquifer. A hydraulic block can be created to contain the advance of seawater by a number of techniques that include injecting freshwater into the seawater intruded area and increasing the surface recharge through recharge ponds and canals. This research reports the results of a numerical modeling experiment where a hydraulic block is created by injecting freshwater into an already saline aquifer using injection wells. The comparison of concentration values at selected monitoring wells indicates that there is a significant improvement in the ambient water quality as a result of the injection of freshwater. The improvement in concentration is also noticed to vary from layer to layer. Information obtained from such numerical modeling experiments could be used to determine the locations of injection wells for efficient performance of the mitigation system.

H21E-0892 0830h POSTER

Ground-Water Capture Zone Delineation of Hypothetical Systems: Methodology Comparison and Real-World Applications

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A capture zone is the aquifer volume through which ground-water flows to a pumping well over a given time of travel. Determining a well's capture zone aids in water-supply management by creating an awareness of the water source. This helps ensure sustainable pumping operations and outlines areas where protection from contamination is critical. We are delineating the capture zones of hypothetical conceptual models that resemble the Fairbanks, Alaska floodplain both in aquifer parameters and boundary conditions. We begin with a very simple hydrogeologic system and gradually add complexity such as heterogeneity, anisotropy, multiple wells, and zones of permafrost. Commonly-used delineation methods are applied to each case. These include calculated fixed-radius, analytical and numerical models. The calculated fixed-radius method uses a mathematical equation with several simplifying assumptions. Analytical techniques employ a series of equations that likewise assume simple conditions, although to a lesser degree than the fixed-radius method. Our chosen numerical model is MODFLOW-2000, which offers a particle-tracking package (MODPATH) for delineating recharge areas. The delineations are overlaid for each conceptual model in order to compare the capture zones produced by the different methods. Contrasts between capture zones increase with the complexity of the hydrogeology. Simpler methods are restricted by their underlying assumptions. When methods can no longer account for complexities in the conceptual model, the resulting delineations remain similar to those of simpler models. Meanwhile, the zones generated by more sophisticated methods are able to change with changes to the conceptual model. Hence, the simpler methods now lack accuracy and credibility. We have found that these simpler techniques tend to overestimate the capture zone. Water-supply managers must consider such inaccuracies when evaluating the costs of each method. In addition to comparing delineation methods, we are using the series of hypothetical MODFLOW cases to aid in modeling a site within the Fairbanks floodplain. We learn how the site-specific complexities may affect the capture zone by examining the effect of each modification to the hypothetical models. The area is located on Fort Wainwright, AK and consists of multiple water-supply wells. They are screened through a formation known as the Chena Alluvium, which is composed of braided-stream deposits. The wells supply water to a power plant for cooling and to a water treatment plant for drinking water use. The power plant discharges heated water into a cooling pond while the water treatment plant releases back-wash water into a small discharge pond. The Chena River is also nearby, approximately 0.4 km from the wells. Data available from the pumping-well facilities, observation wells, and geologic logs are used to determine input parameters for the model.

H21E-0893 0830h POSTER

Improvements in Groundwater Flow Modeling Through the Integration of Resistivity Logs and Hydraulic Conductivity

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In this study cokriging is used to estimate hydraulic conductivity by using spatial cross correlation between hydraulic conductivity and borehole geophysical data (a transform of the formation factor). Experimental pseudo cross variograms are used instead of a cross-variogram because there are few locations where conductivity and formation data are both measured. Uncertainty in the estimates of the experimental variogram is investigated using unconditional sequential Gaussian realizations. Confidence intervals for the experimental variogram values have been calculated assuming variogram sills are either normally, lognormally, or chi^2 distributed. Variogram models that show highest and lowest continuity within the 95% confidence limit are used for cokriging. The generated hydraulic conductivity field is then used in a high-resolution groundwater model created using telescopic mesh refinement (TMR) from a regional flow model of the Chicot Aquifer in southwestern Louisiana. Results are analyzed to assess variogram uncertainty on the groundwater flow model. Spatial images and flow predictions using univariate models based on sparse conductivity data are compared with corelogalized models using both conductivity and resistivity data, and the effects on model accuracy and robustness are discussed.

H21E-0894 0830h POSTER

Factors Influencing Groundwater Monitoring Strategies in a System With an Unconfined Aquifer Overlying a Fractured Bedrock Aquifer

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Factors influencing groundwater monitoring strategies are examined for the case where an unconfined aquifer overlies a fractured bedrock aquifer. A contaminant source is located at the ground surface. Flow and transport in the bedrock aquifer is represented as a three-dimensional discrete fracture network within a permeable rock matrix. Using this scenario, we examine how various factors interact to determine plume geometry, and contaminant detection thresholds in the unconfined and bedrock aquifers as a function of well location within the subsurface. Factors considered include the hydrologic properties of the unconfined aquifer (hydraulic conductivity, porosity), the geometric properties of the fractured network (density, length, aperture), and matrix permeability. These simulation results provide guidelines for the design and evaluation of a subsurface monitoring network.

H21E-0895 0830h POSTER

Optimal Management Strategy for Groundwater Protection and Restoration Along with Discussions on Related Issues

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Contamination of groundwater systems is an increasingly critical problem. The limited available resources or budget for groundwater protection and restoration and sustainable development in a country or region require a corresponding strategy for groundwater protection and restoration to maximize resource or budget utilization and minimize an adverse impact on the sustainable development. An innovative strategy for groundwater protection and restoration has been established based on the optimization principles and

considerations of both risk assessments of groundwater contamination and difficulties or costs of groundwater remediation and protection measures. Site investigations and groundwater modeling are two critical components to implement this strategy. Cost for groundwater protection and restoration can be categorized as Existing Contaminated Site Investigation Cost (ECSIC), Existing Contaminated Site Remediation Cost (ECSRC), Projected Contamination Site Investigation Cost (PCSIC), Projected Contamination Site Protection Cost (PCSPC), and Projected Contamination Site Remediation Cost (PCSRC). The objective function for optimization analyses consists of risk reduction components with variables of the above different costs from all individual site remediation and protection measures. The optimal distribution of the limited available resources is determined by such proper selections of those variables that the objective function reaches its maximum. Several important issues related to implementations of the strategy for groundwater protection and restoration are discussed. Those issues include uncertainty from aquifer heterogeneity, modeling for fractured geologic media, irreversible sorption, and implementations of natural attenuation. Specifically, Monte Carlo simulations through a numerical flow and transport model can be performed to develop a heterogeneity dispersivity matrix to account for the effects of different attributes of aquifer heterogeneity. In addition, two alternatives including discrete fracture groundwater flow modeling and REV (Representative Elementary Volume) equivalent continuum approaches are discussed for groundwater flow and contaminant transport modeling in fractured rocks. Moreover, irreversible sorption or slow desorption could significantly increase remediation time and cost. Therefore, it is important to appropriately determine and apply the desorptive partition coefficients under various soil conditions for modeling. Finally, differences of the sequence and contents for analyses and assessment of feasibility of natural attenuation are examined between existing contaminated sites and projected contamination sites.

H21E-0896 0830h POSTER

Stochastic Optimization For Water Resources Allocation

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For more than 40 years, water resources allocation problems have been addressed using deterministic mathematical optimization. When data uncertainties exist, these methods could lead to solutions that are sub-optimal or even infeasible. While optimization models have been proposed for water resources decision-making under uncertainty, no attempts have been made to address the uncertainties in water allocation problems in an integrated approach. This paper presents an Integrated Dynamic, Multi-stage, Feedback-controlled, Linear, Stochastic, and Distributed parameter optimization approach to solve a problem of water resources allocation. It attempts to capture (1) the conflict caused by competing objectives, (2) environmental degradation produced by resource consumption, and finally (3) the uncertainty and risk generated by the inherently random nature of state and decision parameters involved in such a problem. A theoretical system is defined throughout its different elements. These elements consisting mainly of water resource components and end-users are described in terms of quantity, quality, and present and future associated risks and uncertainties. Models are identified, modified, and interfaced together to constitute an integrated water allocation optimization framework. This effort is a novel approach to confront the water allocation optimization problem while accounting for uncertainties associated with all its elements; thus resulting in a solution that correctly reflects the physical problem in hand.

H21E-0897 0830h POSTER

The Effect of Heterogeneity on Salinization in the Western San Joaquin Valley

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Salinity in the upper, semi-confined aquifer of the Western San Joaquin Valley, California, is locally high

due to downward transport from irrigated shallow saline soils. We are using a stochastic approach for implementing a risk analysis of future aquifer salinization. A key issue for the analysis is an appropriate geostatistical characterization of the alluvial aquifer stratigraphy. Due to a lack of aquifer tests and other hydraulic data, we are using a hydrostratigraphically based transition probability/Markov chain approach to build our geostatistical model. Commonly, geostatistical models are used to model local variability in hydrogeologic properties, but with little regard to regional variability. However, our study area consists of four distinct geologic units: upper fan, distal fan, inter-fan and Sierran sand. Each of these units represents a different depositional environment with potentially distinct facies assemblages. The geostatistical analysis, which is based primarily on drillers logs and soil maps, shows that hydrostratigraphic facies categorization, facies mean lengths, facies proportions, and juxtapositional preferences among the hydrostratigraphic facies are significantly different between the four units. The proportion of coarse material in the upper fan is about 10 percent higher than that of the distal fan and inter-fan unit. The lateral mean lengths of fine material in distal fan unit are around two times those in upper fan unit. The juxtapositional preferences also vary considerably between these three units. The Sierran sand unit consists of three hydrostratigraphic facies, while four facies can be distinguished in the other three units of the Coast Ranges alluvium. Sensitivity analysis indicates that such differences significantly affect the groundwater flow and salt transport. Therefore, the regional spatial variability model of aquifer properties must distinguish the four sub-regional hydrogeologic units. We developed a composite geostatistical aquifer simulator to account for these sub-regional differences. In the hydrostratigraphic simulation, continuity between adjacent units with different geostatistical properties is preserved through step-wise simulation of individual units using sequential conditional simulation. Soil maps and well drilling logs are also used as conditional data. Probability of early arrival of highly saline water in the extensive interconnected coarse-textured materials is computed from Monte Carlo simulations of groundwater flow and transport through these synthetic hydrostratigraphic facies assemblages.

H21E-0898 0830h POSTER

A Stochastic Differential Equation Approach To Multiphase Flow In Porous Media

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The motivation for using stochastic differential equations in multiphase flow systems stems from our work in developing an upscaling methodology for single phase flow. The long term goals of this project include: I. Extending this work to a nonlinear upscaling methodology II. Developing a macro-scale stochastic theory of multiphase flow and transport that accounts for micro-scale heterogeneities and interfaces. In this talk, we present a stochastic differential equation approach to multiphase flow, a typical example of which is flow in the unsaturated domain. Specifically, a two phase problem is studied which consists of a wetting phase and a non-wetting phase. The approach given results in a nonlinear stochastic differential equation describing the position of the non-wetting phase fluid particle. Our fundamental assumption is that the flow of fluid particles is described by a stochastic process and that the positions of the fluid particles over time are governed by the law of the process. It is this law which we seek to determine. The nonlinearity in the stochastic differential equation arises because both the drift and diffusion coefficients depend on the volumetric fraction of the phase which in turn depends on the position of the fluid particles in the experimental domain. The concept of a fluid particle is central to the development of the model described in this talk. Expressions for both saturation and volumetric fraction are developed using the fluid particle concept. Darcy's law and the continuity equation are then used to derive a Fokker-Planck equation using these expressions. The Ito calculus is then applied to derive a stochastic differential equation for the non-wetting phase. This equation has both drift and diffusion terms which depend on the volumetric fraction of the non-wetting phase. Standard stochastic theories based on the Ito calculus and the Wiener process and the equivalent Fokker-Planck PDE's are typically used to model dispersion processes. However, these models, in their usual form, cannot represent multiphase barrier effects. These effects occur at the interface between adjacent materials with different permeabilities. For example, in tracking a DNAPL plume, the behavior of the plume at an interface depends on the pressure-saturation curves involved in forming the interface. In the model, the control of the flow of DNAPL particles across an interface is accomplished using a jump term which derives from the Ito formula. This jump term is based on capillary diffusivity and the pressure-saturation curves of the sands forming the interface. Computational aspects of the approach are discussed in some detail along with results of applying the model.

H21E-0899 0830h POSTER

Uncertainty in Characterization of Source Zone DNAPL Entrapment Architecture Using Mass Flux Measurements Due to Geologic Heterogeneity

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The presence of dense non-aqueous phase liquids (DNAPL) in source zones in the subsurface generates continuous mass flux long after the initial spill. Observed dissolved concentration in a screened monitoring well downstream of a DNAPL source zone will provide very little information on the entrapment architecture that is needed to design effective remediation schemes. Non-intrusive techniques based on partitioning tracer methods will only provide volume estimates that are in error under complex entrapment architecture that may include pools. The possibility of using mass flux measurements downstream of the source zone to determine DNAPL entrapment architecture is investigated. Determination of locations where mass flux is generated within the source zone will assist in targeting the hotspots for DNAPL mass removal through remediation. Using stochastic methods, we have demonstrated that mass flux emanating from the entrapment zone is controlled largely by the vertical distribution of the DNAPL. The proposed method involves vertical sampling of the solute mass flux by collecting concentration and water flux data downstream of the source zone using multilevel samplers. The mass flux data are analyzed using an experimentally validated mass transfer model incorporated into MODFLOW and RT3D and inverse modeling using UCODE to determine DNAPL entrapment architecture as well as the hydrodynamically accessible mass in the source zone. The accuracy of the method in relation to the distance from the source zone where flux measurements are made and vertical distribution of the sampling ports is evaluated. This theoretical study also evaluated possible errors associated with uncertainty resulting from our inability to fully characterize the heterogeneity of the subsurface below the spill.

URL: <http://cesep.mines.edu>

H21E-0900 0830h POSTER

Block-Effective Macrodispersion for Numerical Modeling of Reactive Solute Transport in Heterogeneous Porous Media

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The use of numerical simulations for predicting solute movement in groundwater continues to increase in popularity. Simulation accuracy is limited by the fact that, for most sites, few hydraulic conductivity measurements are available leading to a coarse description of the aquifer. Also, even with modern computers, the computational burden of simulating detailed fine grids can lead to the use of large grid blocks. If the hydraulic property variations at scales smaller than those measured and modeled on the numerical grid are neglected, solute spreading will be under-predicted. Rubin et al. (1999) introduced the concept of block-effective macrodispersion to account for the dispersive effects of small-scale variability. The derivation of the tensor ensures that only the otherwise un-modeled variability is accounted for. Block-effective macrodispersion tensors have been shown to accurately account for the effect of un-modeled heterogeneity on the spreading of conservative solutes (Rubin et al., 2003). Modeling of field results has shown that, in many cases, to accurately model solute transport in groundwater, sorption must be accounted for (e.g. Brusseau and Srivastava, 1997). We have derived block-effective macrodispersion coefficients for reactive solutes that experience instantaneous equilibrium sorption with a spatially variable retardation factor and for solutes that experience linear kinetic sorption. We have found that for instantaneous equilibrium sorption, the spatial correlation between the retardation factor and hydraulic conductivity does not affect the transverse block-effective macrodispersion coefficient, while the longitudinal one is affected in the same manner as the total macrodispersion coefficient. Namely, a negative correlation between the retardation factor and hydraulic conductivity increases the longitudinal block-effective macrodispersion coefficient. Both longitudinal and transverse coefficients also depend on the expected value of the retardation

factor. Brusseau, M. L. and R. Srivastava, *J. Contam. Hydrol.*, 28(1-2), 115-155, 1997. Rubin, Y., A. Bellin, and A. E. Lawrence, *Water Resour. Res.*, 2003, in press. Rubin, Y., A. Sun, R. Maxwell, and A. Bellin, *J. Fluid Mech.*, 395, 161-180, 1999.

H21E-0901 0830h POSTER

Solute Transport in a Nonstationary, Fractured Porous Medium: A Dual-Permeability Approach

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The need to assess quantitatively the safety of waste repositories in deep geological media has aroused the development of efficient models of groundwater flow and contaminant transport in fractured media. Application of stochastic methods to fluid flow and transport in fractured media is relatively new research area. But their studies are limited to the solute transport in stationary velocity field without considering the boundary conditions, and these strict assumptions limit the application of the stochastic theories to solute transport in complicated natural media. Another limitation exists in their studies is that they can just calculate the mean concentration and related spatial moments, but it is very hard to use their methods to get the solution for uncertainties associated with the predicted mean plume, more specifically, the variance of perturbation concentrations. In this study, we develop a nonstationary stochastic theory for contaminant transport in fractured, heterogeneous media. A dual-permea-

H21F MCC: 3022 Tuesday 1020h

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

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

H21F-01 1020h INVITED

Time-Lapse Geophysics for Aquifer Characterization and Remediation Monitoring

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Time-lapse monitoring of subsurface processes is an emerging and promising area of hydrogeophysics. The use of non-invasive or minimally invasive geophysical methods to indirectly measure time-varying fluid saturation, solute concentration, and other hydraulic and geochemical conditions facilitates cost-effective aquifer characterization and remediation. The USGS Office of Ground Water, Branch of Geophysics, in cooperation with USEPA, DOD, and university researchers, has applied time-lapse geophysics for site characterization and remediation monitoring at a number of sites. This talk presents recent examples of applied research, including: (1) application of cross-borehole and surface-to-borehole radar methods to monitor vegetable-oil emulsion injections for biostimulation at a Navy site in Fridley, MN; (2) application of borehole and cross-borehole radar methods to monitor steam injections for remediation of VOCs at the former Loring Air Force Base, ME; (3) application of electrical resistivity tomography to monitor saline tracer tests at the Massachusetts Military Reservation, MA; (4) use of borehole and cross-borehole flowmeter and a discrete-zone packer system to characterize bedrock aquifer hydraulics and water quality at the University of Connecticut landfill, Storrs, CT; and (5) application of crosshole radar methods to monitor a saline tracer in fractured bedrock at the USGS Mirror Lake Site, NH. The goals of these studies are (1) to provide increasingly quantitative information about the subsurface, critical for developing models of aquifer structure, dynamics, and processes, and (2) identification of the spatial and temporal distributions of tracers, contamination, and fluids injected to enhance degradation of contaminants.

H21F-02 1040h

Use of Crosshole Radar Tomograms for Geostatistical Estimation and Simulation of Interwell Permeability: Limitations due to Tomographic Resolution

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Crosshole geophysical tomograms (radar, seismic, and electrical) provide qualitative information about aquifer structure and properties. Increasingly, tomograms are used as auxiliary data for quantitative geostatistical estimation and simulation of hydrologic properties. Such work requires inference of the relationship between geophysical properties (e.g., radar wave velocity) and hydrologic properties of interest (e.g., permeability). Empirical site-specific relationships between radar velocity and permeability are based on (1) co-located estimates at boreholes that bound tomograms, or (2) laboratory measurements. These approaches assume that the inferred correlation between inverted radar velocity and measured permeability applies uniformly throughout the interwell region; however, tomographic resolution is known to vary spatially due to acquisition geometry, wave behavior, data error, and regularization. Blurring and inversion artifacts occur in regions traversed by few or only low-angle raypaths; thus, the correlation between permeability and tomographic estimates of radar velocity may be considerably weaker than expected. Use of low-resolution tomograms as auxiliary data may lead to unreliable predictions of the permeability distribution and under-prediction of the connectivity of high- and low-permeability regions. Thus, tomograms that provide valuable qualitative information may have limited value for geostatistical purposes. We demonstrate a modeling approach to assess the utility of tomograms for geostatistical simulation and estimation. In a series of realistic synthetic examples using linear straight-ray radar tomography, we consider the independent and combined effects of varying data error, permeability and velocity correlation structure, well separation, and the regularization used in inversion. For each scenario, we (1) generate realizations of velocity and log-permeability, assuming a correlation coefficient of 0.9 between the two properties, (2) simulate crosshole travel-time data, (3) perform tomographic inversion and calculate the model resolution matrix, and (4) evaluate the relationships between inverted velocity and synthetic velocity, and inverted velocity and synthetic permeability. Depending on tomographic resolution, the correlation coefficient between log-permeability and estimated radar velocity can degrade from 0.9 to less than 0.2. Our results demonstrate that (1) a correlation between permeability and velocity derived in laboratory measurements will not, in general, apply to tomograms; (2) a correlation between co-located borehole permeability measurements and tomographic velocity estimates may not be representative of the true permeability-velocity relation throughout the interwell region; and (3) the correlation between inverted velocity and synthetic permeability varies spatially and will be poorer in regions of lower tomographic resolution. These results illustrate important limitations that should be considered in utilizing tomograms for stochastic simulation and estimation of aquifer properties.

H21F-03 1055h

Full-Inverse Statistical Calibration: A Monte Carlo approach to determining field-scale relationships between hydrologic and geophysical variables

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Successfully defining field-scale relationships between hydrologic and geophysical variables is a fundamental problem that makes hydrologic estimation based on geophysical data possible. Today, site-specific relationships are commonly calibrated empirically using lab measurements, in-situ well logs, or reconstructed geophysical images. This direct approach to calibration can often fail, however, for reasons such as: 1) failure to account for differences in measurement scales, 2) poor representation of heterogeneity in the calibration data set due to sparse sampling, and 3) the introduction of processing artifacts that can impact the interpretation of geophysical data. To overcome issues such as these we introduce the concept of Full-Inverse Statistical (FIST) calibration, a Monte Carlo approach to rock physics calibration. In FIST calibration, geostatistical simulation is used to generate multiple synthetic