and movement in such networks and provides a means for testing previously proposed interface routing algorithms. The LBM offers a computational platform for measuring the hydraulic conductivity of unsaturated pore and fracture networks under different scenarios, including some that are not yet experimentally observable. We use a 2-D single-component multiphase LBM to simulate interface behavior at junctions where capillaries of various size and shape meet and consider the impact of changes in the capillary number on the resultant configurations. The LBM was tested using a simple bundle of capillaries in the context of a Poiseuille flow problem where flow occurs only in capillaries that remain filled at a particular fluid pressure. The unsaturated hydraulic conductivity for the equilibrium interfacial configuration in simple networks is calculated and compared with standard models based on pore size distribution and equilibrium pressure head.

H62G-13 1650h

Experimental Observations of Fluid Transport Across an Unsaturated Fracture-Intersection

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Fluid behavior in unsaturated fracture intersections was experimentally investigated in a glass fracture analog at four different flow rates. Three fractures symmetrically intersected at a single point. One of the fractures (vertical) was used to feed fluid to the intersection area and the subsequent 135 degree branches. Visualization data was collected using digital stills and video. Two flow modes were observed: film flow and capillary droplet accompanied by snapping rivulets. Distribution of film flow across the intersection was not limited to contiguous rock surfaces. The formation of a capillary bridge above the intersection allowed films to be distributed to either branch or both branches. During capillary droplet mode, two types of dynamics were observed at the intersection: (1) saturation of the intersection with continuation of droplet mode into the fracture branches; and (2) transition from droplet to film flow mode that did not saturate the intersection and resulted in film flow along both branches. Data suggests that the contact angle of the invading droplet is responsible for the mode of transport across the intersection. Rivulets where seen to stretch contiguously across the intersection and into both branches while connected to two droplet halves, a distance of 70 cm.

H71A MCC: Hall C Sunday 0830h

Conceptual Model Evaluation and Quantification of Groundwater Model Error Posters

Presiding: **T Scheibe,** Pacific Northwest National Laboratory**; M Hill,** U.S. Geological Survey

H71A-0774 0830h INVITED POSTER

Quantification of the Effect of Model Error on Groundwater Model Predictions and Risk Assessment

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Errors arising from the imperfect mathematical representation of the structure of a hydrologic system (model error) do not necessarily have any probabilistic properties that can be easily exploited in the construction of a model performance criterion. Furthermore, the existence of parameter uncertainty imposes additional difficulties in isolating and evaluating model error because it obscures the impact of model error on model predictions. A Bayesian approach is presented for quantifying model error in the presence of parameter uncertainty. Insight gained in updating the prior information on the model parameters is used to assess the correctness of the model structure, which is defined relative to the accuracy required of the model predictions. Model error is then evaluated for each measurement of the dependent variable through an examination of the correctness of the model structure for different accuracy levels. The effect of model error on each dependent variable is quantified as a function of location and time, and represents a measure of the reliability of the model in terms of each model prediction. Through a synthetic example it is shown that this method may assist in discriminating among models in terms of the correctness of the model structure, as well as in identifying possible causes of model error. Application to a problem of 90Sr migration to water wells at Chernobyl, Ukraine, demonstrates that the Bayesian model error analysis may also offer a more informative description of the uncertainties involved in risk assessments and decision analyses, and an alternative to the practice of adopting a bias towards conservative risk estimates in decision models.

H71A-0775 0830h INVITED POSTER

Uncertainty Inherent in Geologic Data, Interpretations and Conceptual Models Used in Groundwater Flow Modeling

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When using MODFLOW-2000, parameter estimation and the calculation of flow model uncertainty are generally based on a static hydrogeologic framework. Although the properties of hydrogeologic units may be estimated and uncertainty ascertained during model calibration, the spatial location of the boundaries of the units are not usually modified. As such, the hydrogeologic framework is essentially viewed as absolute, and as a result having no uncertainty. In reality there are numerous types of uncertainties inherent in geologic data that could be acknowledged and accounted for. Framework models often include mixtures of quantitative geologic data, interpretations based on quantitative data, and qualitative, tacit geologic knowledge. Interpolated surfaces are created from these data and then stacked in geologic or stratigraphic modeling software to create volumetric units. In many cases, more than one geologic conceptual model may honor all available data. Because the task of building a digital 3D framework model is labor-intensive and technically difficult, it is usually not possible to construct 3D frameworks to test all possible conceptual models and decisions regarding the preferred conceptual model are often made prior to the creation of a digital model. Once a model is completed in the digital realm, the technical capabilities of the software and visual appeal can effectively mask a lack of data or flaws in the conceptual model. What is needed is a way to explicitly identify uncertainty inherent in framework models so that alternatives can be explored more efficiently, and so that the geologic and mathematical sources of error are more transparent.

Geologic error and uncertainty inherent in any digital 3D framework model might be subdivided into five general categories: (1) interpolation, the construction of surfaces between data points; (2) inference, the presence of information that constrains the location or property of a feature without being actual data from that feature; (3) extrapolation, methods for extending calculated surfaces beyond the range of the data; (4) interpretation and geologic inference that are based on data, such as geologic cross sections; and (5) paradigms, which includes elements that are constructed based on a conceptual model of the system. These five categories are not strict statistical definitions but are concepts that describe types of uncertainty within the framework model, promote understanding of the logic that went into building the model, and allow effective scrutiny of the model and possible alternatives. These subdivisions help focus attention on where the framework model has the greatest likelihood of being accurate and where alternatives are possible and therefore, where and what methods should be used to quantify error in a particular aspect of the model. By quantifying error in the framework model, model developers and users are better equipped to evaluate the use of particular aspects of the model in groundwater flow modeling.

H71A-0776 0830h POSTER

The Connection Between Conceptual Model Errors and the Capabilities of Numerical Models

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Hydrologic conceptual models consider what characteristics and processes of groundwater systems are important to predictions of interest, and provide blueprints from which analytical and numerical models can be developed to provide quantitative analyses. We often like to think that these blueprints are developed independent of the characteristics of the model we plan to use, but the limitations of the models often impact the way we think about and conceptualize a given system. For example, one of the most perplexing problems in developing models is the appropriate scale for representation of hydrologic and physical features. Scale problems can be caused, for example, by hydraulic gradients that become dramatically steeper with proximity to a pumping well, rivers with widths that are small and dynamics that are fast relative to the adjacent groundwater systems with which they interact, and small geologic features that are important to simulating areas with contaminant plumes but elsewhere are less important. As suggested by these examples, scale problems occur in representing features of a wide range of sizes.

Our inability to accommodate such scale problems is a major contributor to groundwater model errors. Contributing difficulties include inadequate data and limitations of the capabilities of commonly used models. The issue of inadequate data has been addressed most through stochastic methods because data, computer capabilities, and numerical methods have not allowed us to build models capable of representing these variations deterministically. But these limitations are changing. New field data methods are providing unprecedented representations of subsurface characteristics and computers and software are getting more powerful. Are ground-water models ready to take advantage of these opportunities? A promising way to address some of these issues is to reduce the errors associated with scale problems through local grid and time-step refinement. Local grid refinement allows model grids to represent more detailed hydraulics and features as needed. The additional model capability encourages more accurate conceptual models, but this is only an improvement if the refined models are numerically robust and do not introduce other errors.

H71A-0777 0830h POSTER

The Neglected Art of Interpretive Ground-Water Modeling

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Nearly all numerical models being developed to study ground-water systems are of a type known as predictive models. These models require calibration to observations such as head, flow, and concentration, with the ultimate goal of predicting system response to some forcings. Available postaudits of predictive models have shown that predictions rarely are accurate. Among the likely reasons for this lack of success is that conceptual models of hydrologic systems are almost always incomplete and uncertain. Numerical models, however, can be used to improve conceptual models of flow systems. An approach known as interpretive modeling involves representation of a conceptual model of a system in a numerical model, and studying how the system might operate. Unlike predictive models, interpretive models are not necessarily calibrated. These models are useful to look at how well the available information on a system fits together, to test hypotheses about the way a system operates, and to study possible ranges of effects caused by changes to a system. An interpretive model, for example, could be used to study whether or not an observed inflection in a water surface could be caused by a geologic feature such as a fault or facies change. The main benefit of interpretive modeling is understanding and insight, instead of numbers, which is the goal of predictive modeling. Although the demand for predictive models by the water management community likely will remain high, we in the hydrologic sciences should strive to better educate water managers about the benefits of interpretive modeling.

H71A-0778 0830h POSTER

Accounting for Conceptual Model Uncertainty via Maximum Likelihood Bayesian Model Averaging

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Analyses of groundwater flow and transport typically rely on a single conceptual model of site hydrogeology. Yet hydrogeologic environments are open and complex, rendering them prone to multiple interpretations. Adopting only one of these may lead to statistical bias and underestimation of uncertainty. A comprehensive strategy for constructing alternative conceptual-mathematical models, selecting the best among them, and using them jointly to render optimum predictions under uncertainty is being developed by the author. This paper proposes a Maximum Likelihood Bayesian Model Averaging approach, MLBMA, to rendering optimum predictions by means of several competing models and assessing their joint predictive uncertainty.

H71A-0779 0830h POSTER

Inverse-inverse analysis: A general methodology for exploring sensitivity and uncertainty of model predictions

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There are several methods available for estimating the uncertainty associated with forward model predictions which emphasize the importance of parameter and conceptual model uncertainty. Some of these methods apply inverse techniques that assume the forward model to be linear and the errors to be normal and linearly correlated. To circumvent these limitations, we propose an inverse-inverse method that can directly explore the sensitivity and uncertainty of inverse model parameter estimates and corresponding predictions to the calibration data and conceptual model. In this case we "optimize" the inverse model by searching for plausible conceptual model and calibration data (within the range of their uncertainty) which maximizes/minimizes a specific prediction obtained from the calibrated forward model. In more general sense, the inverse-inverse problem addresses the question, "what are the calibration targets (and their respective measurement errors) that would be required to produce a certain set of inverse-model estimates and/or forward-model predictions?" This type of analysis also addresses common problems associated with the inverse problem solutions such as unstability, nonuniqness, and nonlinear correlations of estimation errors. The inverse-inverse problem can be applied for problems such as optimization of data collection strategies and design of monitoring networks. The implementation of proposed methodology is computationally intensive but can be performed efficiently through parallelization. Results based on synthetic and real cases are presented.

H71A-0780 0830h POSTER

Objective Imprecision and Parameter Identifiability in Groundwater Systems

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When several stakeholders and decision-makers are involved in managing a water resources system, the management objectives are often subject to imprecision. The main purpose of this research is to explore the relationship between objective imprecision and the required reliability of a simulation model.

For decades, groundwater simulation models have been linked to optimization to build management tools. The general assumption is that there exists a single, centralized decision-making authority that defines the management objectives. However, when a single decision-maker is absent and rather replaced by multiple stakeholders, how to define meaningful objectives may become a task with an uncertain outcome. Imprecision in this case is not due to randomness but rather because of factors such as ambiguity, generality or vagueness, stemming from the use of linguistic variables to describe the states of the system.

The proposed methodology combines multiobjective optimization and multicriteria programming to generate a decision-making framework for groundwater management. A fuzzy decision-making model searches for the non-dominated set of solutions that are acceptable by a group of stakeholders. Thus the methodology combines three non-fuzzy objectives and one fuzzy objective to respectively define the search space and to evaluate the compliance of the solutions with additional environmental criteria that may be subject to imprecision because of the multidisciplinary nature of environmental issues. Once the decision-making framework is set up, the next step is to evaluate the reliability of the groundwater simulation model with respect to management application. A first-order analysis translates model parameter uncertainty to the decision and solution space, so that acceptable ranges of parameter uncertainty can be obtained by solving a nonlinear, nonconvex optimization problem, given acceptable uncertainty in the decision space.

H71A-0781 0830h POSTER

A Methodology for Validating Numerical Groundwater Models

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Groundwater validation is one of the most challenging issues facing modelers and hydrogeologists. With the increased complexity of groundwater models, a gap has been created between model predictions and the ability to validate or build confidence in the accuracy of these predictions. There does not exist a set of specific procedures and tests that can be easily adapted and applied to determine the validity of site-specific groundwater models. This is true for both deterministic and stochastic models, with the latter posing a more difficult and challenging problem when it comes to validation. The objective of this paper is to propose a general validation approach that addresses some of the important issues recognized in previous validation studies, conferences, and symposia as crucial to the process. An approach is proposed that links model building, model calibration, model predictions, data collection, model evaluations, and model validation in an iterative loop. The approach focuses on use of collected validation data to reduce model uncertainty and narrow the range of possible outcomes of stochastic numerical models. It is designed for stochastic numerical models utilizing Monte Carlo simulation approaches, but it can be easily adapted for deterministic models. The proposed methodology relies on the premise that absolute validity is not even a theoretical possibility and is definitely not a regulatory requirement. Rather, it highlights the importance of testing as many aspects of the model as possible and using as many diverse statistical tools as possible for rigorous checking and confidence building in the model and its predictions. It is this confidence that will eventually allow for regulator and public acceptance of decisions based on the model predictions. The upcoming application of this validation approach to a model dealing with an underground nuclear test site in rural Nevada is described.

H71A-0782 0830h POSTER

Influence of Conceptual Model Selection on Three-Dimensional Tracer Transport: Comparison of Predictions and Observations in a Nonuniform Sand Aquifer

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This paper presents the results of a field study involving bromide transport through an unconfined sand aquifer with a nonuniform permeability distribution. The tracer test was conducted in preparation for a pilot-scale surfactant enhanced aquifer remediation demonstration in Oscoda, Michigan, USA. A bromide pulse was injected through an array of three fully screened wells and extracted through a single fully screened well approximately 8m away. Concentrations were measured at the extraction well and at 26 individual multilevel sample ports located between the injection and extraction wells. Four alternative modeling approaches were used to explore the influence of conceptual model selection on predictions of three-dimensional transport. In these approaches, alternative representations of the distribution of hydraulic conductivity, K, were employed: 1) a uniform, effective K; 2) perfect stratification with uniform effective K values assigned to each 0.3m layer; 3) conditional sequential Gaussian simulation; and 4) conditional sequential indicator simulation. Grain size distribution information from 167 core samples and hydraulic conductivity measurements from 10 repacked samples provided the basis for geostatistical modeling of the spatial variability of model parameters (variance $\ln(K) = 0.29$). Geostatistical realizations were simulated on a 0.3 x 0.3 x 0.3m grid increment, commensurate with the grain size distribution measurement scale of support. Standard simulation software packages MODFLOW and MT3DMS were used to model three-dimensional groundwater flow and bromide transport. Conceptual models incorporating formation variability are better able to capture observed breakthrough behavior at the fully screened extraction well. Comparisons of simulated breakthrough curves with individual multilevel observation ports demonstrate generally good agreement at points located near the injection wells and poor agreement at points located farther away. This behavior could be explained by the presence of smaller scale preferential flow pathways that were not incorporated in the chosen conceptual models.

H71A-0783 0830h POSTER

Identification of Errors in the Hanford Site-Wide Groundwater Flow Model by Inverse Modeling of Alternative Conceptual Models

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A regional-scale, three-dimensional groundwater flow and transport modeling effort has been undertaken to quantify the environmental consequences of past waste disposal activities and support ongoing environmental management activities at the U.S. Department of Energy's Hanford Site. An important aspect of this effort is the identification and quantification of uncertainties associated with model predictions. It is recognized that such uncertainties arise not only from selection of inappropriate groundwater model parameters (parameter error), but also from the underlying conceptualization of the groundwater system (model error). Therefore, we have adopted an approach to uncertainty characterization that involves the evaluation of multiple alternative conceptual models (ACMs) within an inverse modeling framework.

The initial step in implementation of the framework was the development of a multi-processor implementation of the UCODE inverse modeling system and application of the inverse framework to update parameter estimates from a prior deterministic model. A preliminary first-order uncertainty analysis was performed based on the model results. At the same time, site geologists developed an improved conceptual model of the 3D structure of the aquifer system. Inverse modeling of the updated conceptual model led to estimates of some parameters, especially specific yield, that were not plausible, indicating that there were problems with the conceptual model. As a result, additional ACMs were developed and subjected to inverse analysis, including an alternative with modified boundary conditions (leaky underlying bedrock), an alternative incorporating surface recharge modifications based on surface run-on from an adjacent topographic feature, and an alternative incorporating an improved description of the timing and volume of waste discharges arriving at the water table (upper model boundary). Model predictions of transient hydraulic heads under each ACM were compared to 69,000 historical head observations, and estimated parameters were evaluated for plausibility. Based on this analysis, an improved conceptual model that led to decreased predictive uncertainty and utilizes plausible estimated parameters was achieved. Ongoing refinement of the model is focused on a stochastic conceptualization of the structure of low-permeability mud units and parameter zonation for hydraulic properties in the uppermost transmissive layer of the aquifer.

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H71A-0784 0830h POSTER

Comparison of Model Error for Alternative Conceptual Models of Sediment Geometry at the Hanford Site, Southeast Washington

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A number of uncertainties exist in the hydrogeology of the Hanford Site, and the high costs and risks associated with cleanup of sites contaminated with radioactive wastes requires that the uncertainty associated with alternative remediation decisions must fully reflect the uncertainty associated with these decisions.

Prior uncertainty analyses of Hanford groundwater model predictions have focused on uncertainties in model parameters (e.g., hydraulic conductivity) given an assumed conceptual model of hydrogeologic structure. In this study we evaluated predictive uncertainty related to the model structure conceptualization. Our study has focused on two major elements of the hydrogeologic structure of the Hanford Site: the geometry of mud units that occur within the aquifer, and the parameter zonation for hydrologic properties of the uppermost conductive portion of the aquifer. For each structural element, we have developed alternative conceptual models that have been evaluated by inverse modeling. The geometry and continuity of mud units exert a strong influence on groundwater flow and contaminant transport at the site. A detailed study of the spatial distribution of the three mud units was performed using a data set consisting of the presence/absence of each mud unit at several hundred boreholes, as well as the thickness if a mud unit was present. The spatial analysis proceeded in two stages. A series of stochastic simulations of the mud units were prepared using geostatistical methods. The stochastic simulations were numerically ranked and a subset of the best and worst simulations (as determined by the connectedness of the aquifer given the simulated mud distributions) was used as inputs to an inverse model. Inverse modeling was performed using UCODE and a finite element flow and transport code (CFEST) and used to test the fit of over 76,000 observed potentiometric head data for several alternative models of the mud distribution. Those conceptual models included the previously existing base case (geologists interpretation) and the median and the extremes of the set of stochastic realizations. We compared the overall inverse model fit and the range of estimated parameters for the four alternative conceptual models to identify the relative magnitude of parameter uncertainty versus conceptual model uncertainty (model error).

We used similar methods to study the spatial distribution of aquifer sediment in Unit 1, the uppermost aquifer unit at the site. Unit 1 is the most heterogeneous of the transmissive units, and the spatial distribution of sediment in Unit 1 (e.g., gravel, sand, or silt), has a critical effect on the transport of contaminants at the site because of the source configuration and location of the water table. Geostatistical simulations of the sediment type zonation were generated and ranked based on the relative amounts and the geometry of sediment zones of varying hydraulic conductivity. Selected simulations reflecting the range of alternative conceptual models of Unit 1 zonation were used as the basis for additional inverse model runs (parameter estimation). The results of the inverse modeling (parameter estimates and model fits to observations) again were compared to identify relative contributions of parametric and conceptual model uncertainty to overall predictive uncertainty.

H71A-0785 0830h POSTER

Three-Dimensional Parameter Structure Identification: A Case Study of the Central Part of the Western San Joaquin Valley, California

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In this research, we propose a three-dimensional parameter structure identification procedure for a regional-scale aquifer. The procedure simultaneously identifies the parameter values, parameter pattern, and parameter dimension. These three unknowns are the values, location and number of basis points associated with a chosen parameterization. Parameter structure identification seeks to find the optimal values, location and number of basis points by minimizing the fitting residual of head observations. In this research, a universal parameterization (UP) that unifies zonation and interpolation for the inverse solution is developed. The UP generates a distribution between a pure zone structure and a continuous structure over a set of shape parameters. It shows greater flexibility in manipulating spatial distribution and spatial optimization. When a non-smooth field is investigated, the UP outperforms all other parameterization schemes. For each given level of parameter structure complexity, we have developed a global-local optimization approach, in which a genetic algorithm (GA) simultaneously searches for the best inverse solution. And then, a quasi-Newton method revisits the fitting residual minimization and improves the GAs results. We use sensitivity equation to calculate the derivatives of head with respect to the values and locations of basis points as well as the shape parameters. MODFLOW solves the groundwater flow and sensitivity equations. We demonstrate the developed methodology by a case study located in the central part of the western San Joaquin Valley, California. The unknown distributed parameter is the hydraulic conductivity of the semi-confined aquifer above the Corcoran Clay Member of the Tulare Formation. For the given set of observations, we have identified the parameter structure of the horizontal and vertical hydraulic conductivity in three dimensions with an appropriate complexity level.

H71A-0786 0830h POSTER

Evaluating Pumping Tests With Geologically-Constrained Models in a Heterogeneous Alluvial Aquifer, Lawrence Livermore National Laboratory, California

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Analytical methods for evaluating pumping test data are based on several assumptions, many of which are not valid in a heterogeneous, fluvial setting – particularly the assumption of a homogeneous, constant thickness aquifer of infinite extent. Pumping test data in heterogeneous aquifers are likely better analyzed using a numerical modeling approach that can account for realistic heterogeneities. We evaluate pumping test results at the Lawrence Livermore National Laboratory site using a numerical model based on geologically constrained realizations of the alluvial aquifer, generated with transition probability geostatistics.

Relatively mature paleosols within the alluvial deposits mark unconformities that separate stratigraphic zones for this aquifer. This provides the stratigraphic framework in which distributions of hydrofacies were simulated. Top and bottom surfaces for each paleosol unit identified in geophysical well logs and core were interpolated using a linear regression algorithm. Distributions of hydrofacies within each stratigraphic zone and paleosol unit were modeled separately using transition probability geostatistics, conditioned to geophysical well log and core data. This helps preserve measured channel orientations, lengths, and widths within each stratigraphic zone and paleosol unit. Separate realizations from each stratigraphic zone and paleosol unit were merged producing a final realization of the entire alluvial aquifer, then hydraulic conductivity and storativity values were assigned to each hydrofacies type. Preliminary results from this approach provide a better match between simulated and observed pumping tests than approaches that do not incorporate the geologic character.

H71A-0787 0830h POSTER

Use of Model Error as a Screening Tool for Selecting a Model Structures for a Lab-Scale NAPL Dissolution Experiment

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Deficiencies in groundwater modeling can be attributed to two reasons: imperfect mathematical description of the physical process and uncertainty in the adopted values of model specific parameters. While the effect of parameter uncertainty on the model performance has been the subject of extensive research, little attention has been paid to the effects of the imperfect or mis-conceptualization of the model structure. The error resulting from the imperfect formulation of the model structure, referred here as model error, is not random but systematic and thus grows asymptotically with increase in forecast length. For a given problem, the availability of multiple model structures leads to the question– which model structure is the best choice and why?

To illustrate the problems related to the selection of model structure, an attempt has been made here to model a data set from a lab-scale NAPL dissolution experiment. The laboratory model setup is composed of a sand tank fitted with extraction and injection wells and multilevel observation ports. TCE NAPL was released into the system and breakthrough concentrations were observed. Laboratory measured values of the physical properties of the porous medium, such as hydraulic conductivity and porosity, were assumed to be the true known values. The observed concentration breakthroughs were assumed to represent true measurements from an unknown model response. Then the dissolution process of the TCE NAPL source was simulated by using steady-state and transient dissolution models. The interaction of contaminants with the porous media was simulated under equilibrium and rate-limited sorption models. The simulated result was compared to the observed breakthroughs to quantify the model error for a particular model structure. This work is a preliminary attempt to illustrate how laboratory observed concentration breakthrough data could be used as a screening tool to select a suitable model structure from a set of available competing model structures.

H71A-0788 0830h POSTER

Sensitivity Analysis of Nonpoint Source Pollution in Deep Alluvial Aquifer Systems

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The alluvial aquifer system of the central part of western San Joaquin Valley, California is composed of a highly heterogeneous semi- confined aquifer overlying a similarly complex confined aquifer. This study examines the risk of locally accelerated transport of saline groundwater in the upper semi-confined aquifer due to the presence of highly permeable pathways within the alluvial fan. Our estimate shows that it takes highly saline shallow groundwater 200-600 years to migrate downward to the lower depths of the semi-confined aquifer and the confined aquifer. A sensitivity analysis is performed to determine the effect of uncertainty in the geostatistical parameters. Well drilling logs and soil map information provide the basic data for analysis. A transition probability/Markov chain geostatistical model, which is constructed to quantify the spatial variability of the aquifer system hydrostratigraphy, is integrated with a groundwater flow model and a transport model to estimate the probability of early arrival of highly saline water in the extensive interconnected coarse-textured materials. Multiple realizations of the aquifer hydrostratigraphy are generated and Monte Carlo simulations of salt-transport are performed. The risk of early arrival time according to sensitivity analysis is significantly affected by the number of hydrostratigraphic facies of the aquifer, the proportion of coarse sediments, the mean length of important stratigraphic units, particularly the ratio of length and thickness of coarse materials, and the degree of entropy (juxtapositional preference) among the hydrostratigraphic facies. The sensitivity analysis allows us to quantify the degree of uncertainty in risk predictions due to stochastic parameter uncertainty in the geostatistical-sedimentologic model.

H71A-0789 0830h POSTER

Relative Importance of Dispersive and Diffusional Processes in Aquifers Containing a Connected High-conductivity Network: Assessment of the Relative Conductivity Peclet Number Criterion

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Recent studies of solute transport in highly heterogeneous aquifers have revealed the importance of well-connected networks of high-conductivity materials on solute transport. Despite comprising only a small percentage of an aquifers volume, connected high-conductivity channels have been demonstrated to control the behavior of solute plumes and sometimes, produce greatly asymmetric, non-Gaussian plume patterns with near-source peaks and extensive spreading in low-concentration regions. Such plume patterns can be caused by diffusional mass transfer into and out of high-conductivity channels, and cannot be described adequately by classical advection-dispersion theory. This study is aimed at quantifying the relative importance of diffusional mass transfer versus classical dispersion in flow fields controlled by connected high-conductivity networks. The ultimate goal is to develop guidance for selecting the most appropriate model, either diffusional or dispersive, for a given set of field conditions. In 2-D and 3-D numerical experiments three end-member high-conductivity network configurations are investigated, i.e., low-conductivity matrix containing straight high-conductivity channels parallel to the dominant flow direction, low-conductivity matrix containing straight high-conductivity channels perpendicular to the dominant flow direction, and low-conductivity matrix containing hypothetical but geologically plausible high-conductivity channels generated using invasion percolation theory. In all three cases, systematically increased conductivity ratios are assigned to the low-conductivity matrix versus high-conductivity channels. The effects on plume development of different solute source sizes and shapes (relative to the interchannel spacing) are investigated. A Relative Conductivity Peclet Number (RCPN) is suggested as a useful criterion to quantify the relative importance of diffusional mass transfer versus spreading due to dispersion. The RCPN criterion takes into consideration the matrix versus channel conductivity contrast, the geometry of channel network, and the magnitudes of molecular diffusion and local dispersion. As the RCPN becomes small, plumes appear Gaussian. As the RCPN becomes large the plumes are asymmetric, exhibit tailing, and their shapes are controlled by local relative preferred pathways. A series of simulation experiments suggest that the RCPN criterion is capable of providing a good quantitative measure of plume behavior and thus provides some guidance for model selection.

H71A-0790 0830h POSTER

An Explanation of 03Anomalous03 Specific Yield in Unconfined Aquifers

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Interpretations of pumping tests in unconfined aquifers using the theories of Dagan (1967) and Neuman (1974) systematically result in unrealistically low values of specific yield. Addition of Boulton0304s empirical fitting parameter resulted in a partial improvement of specific yield estimates and a better fit of observed data near the water table in few cases (Moench, 1997).

However, in was proven that the unsaturated zone does not play an important role in the processes below the water table, and the empirical fitting parameter does not have clear physical meaning. Analysis of numerous sites indicates that data were collected in alluvial aquifers. Such aquifers exhibit a major geological condition that is not represented by neither of above mentioned three existing models- deviation of the aquifer base from aquiclude conditions. This aquifer base can be represented as an aquitard that is capable of vertical water movement inside the aquitard and water release to the upper unit.

We present a more realistic model of alluvial aquifer with the aquitard at the base. For typical parameters of the alluvial sand/gravel aquifer and clay aquitard, the piezometer responses differ from the responses predicted by Neuman0304s (1974) model at intermediate times and only at the later times these responses have similar asymptotic behavior.

Using this unconfined aquifer/aquitard (AA) model, we investigate the aquitard effect on effective parameter values. Results indicate that (1) presence of the aquitard may strongly affect the aquifer response and data interpretation; (2) use of the contrast in hydraulic conductivity for discriminating aquifer and aquitard units in the steady-state conditions should be replaced with the hydraulic diffusivities, defined as the ratio of the hydraulic conductivity to the specific storage.

H71B MCC: Hall C Sunday 0830h

Fundamental Advances in Understanding of Pore-Scale Transport Phenomena in Porous Medium Systems II Posters

Presiding: **M Hilpert,** Johns Hopkins University**; D Zhang,** Los Alamos National Laboratory

H71B-0791 0830h POSTER

Liquid Vapor Interfacial Stability Under Slow Laminar Flow in Microchannels

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We address the question of whether liquid-vapor interfaces in microchannels remain stable under slow laminar flow conditions. This is an important issue for development of constitutive relationships for hydraulic conductivity of unsaturated porous media based on liquid configuration under equilibrium conditions. We controlled water flow rates and matric potentials in glass capillary channels of square and triangular cross sections. Video microscope imagery was used to deduce liquid-vapor radii of curvature and liquid velocity at different locations within a channel. Preliminary results show remarkable stability of the liquid vapor-interface under slow laminar flows (capillary number $= 3.71\times10^{-8}$). Measured velocities were in excellent agreement with model predictions assuming steady and equilibrium conditions. Ongoing work focuses on identification of limits of the assumption of stable interfaces based on energy dissipation considerations.

H71B-0792 0830h POSTER

The Impact of Two-Phase Saturation History on Three-Phase Flow Characteristics of Sediments: A Pore-Scale Model

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Predictive field-scale models of the concurrent movements of three fluids require accurate predictions of macroscopic three-phase flow properties such as relative permeabilities and capillary pressures. Since direct experimental measurements of such properties are very difficult and empirical correlations are often not reliable, the use of physically-based three-phase pore-scale models has become an appealing alternative. In this paper, we describe the features of our advanced three-phase quasi-static pore network model which integrates a realistic representation of pore connectivity and morphology, a realistic description of fluid displacement mechanisms, and a sound representation of wetting properties of the rock. The model works with three-dimensional, disordered networks of cylindrical ducts with triangular, rectangular, and circular cross-sections obtained directly from the analysis of micro-CT images of rock samples. This approximation allows one to capture the flow of water in filaments along the pore corners, NAPL in intermediate layers, and gas in the pore center. All pore-level displacement mechanisms: piston-type, snap-off, cooperative pore-body filling, and double-displacements are considered with arbitrary wettability and spreading. Permeabilities of the phases are computed with accurate expressions of the hydraulic conductance of each phase in the network elements for different pore geometries and phases configurations. The model is used to simulate gas injection processes into porous media that initially contain water and NAPL after a two-phase drainage or imbibition processes. The gas injection is performed using a *cluster-based invasion percolation algorithm with trapping.* The profound effects of two-phase saturation history on describing three-phase transport properties of a porous medium are illustrated by performing a series of gas injection processes using different initial water/NAPL saturations and configurations.

H71B-0793 0830h POSTER

Predicted Disappearance of Saturation Hysteresis in Coarse Granular Media Based on Capillary and Gravity Scaling, and Experimental Tests

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Since the classic work of W. B. Haines (1930), hysteresis in the relation between matric (capillary) potential versus water content has been recognized as a basic aspect of interactions between water and variably saturated porous media. This lack of unique correspondence between potential and saturation has well-recognized consequences for equilibrium, flow, and transport. Although hysteresis in moisture characteristic relations has several causes, the existence of different pore-sizes within porous media (the "ink bottle" effect) is primary. This capillarity-dependent phenomenon has a grain-size limit imposed by the influence of gravity, and more generally by the relations between surface and body forces, and length scales. Above this limit, capillary hysteresis vanishes. The grain-size associated with vanishing of capillary hysteresis was predicted in two ways; first with a simple pore-size model, and second by Miller-Miller scaling. Both methods predict that hysteresis vanishes when characteristic grain-sizes exceed about 8 mm, when the water-air surface tension is 72 mN/m, and when the body force is due to ordinary gravity. More generally, capillary hysteresis is predicted to disappear when the Haines Number (dependent on grain-size, surface tension, the body force, density difference between immiscible fluids) exceeds 8. The predicted critical grain-size was experimentally supported through measurements of drainage and wetting curves of sands and gravels, with grain-sizes ranging from 0.2 up to 11 mm. We also consider effects of interfacial tension variation (surfactants), variation of the body force (centrifugal field), and capillarity associated with grain-surface roughness.

H71B-0794 0830h POSTER

Simulation of Flow and Transport in a Single Fracture Using the Reynolds Equation: Macroscopic Effects of Underestimating Local Head Loss

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Fluid flow in a single fracture is commonly simulated using the Reynolds equation. Recent work suggests that this depth-averaged approach underestimates head loss in regions of changing aperture. Implementing an ad hoc correction in the numerical formulation of the Reynolds equation allows us to modify local head loss, and calibrate simulation results to existing experimental data. Calibrated flow fields provide an improved estimate of longitudinal dispersivity, demonstrating the importance of adequately describing local head loss.