H12F-07 1510h

Use of Thermal Information to Estimate Stream Baseflow

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During most times of the year, ground-water has a distinctly different temperature than the streams to which it discharges. As a result, areas of enhanced ground-water discharge (baseflow) may appear as thermal anomalies in the stream water or stream bed temperature. Stream water temperatures monitored in the thermal infrared range, implying that it may be possible to characterize stream baseflow through air- or space-borne thermal sensing. There are a number of impediments to this approach, however, including vertical mixing in the water column, heat exchanges with the atmosphere and stream bed, differential solar heating, and stream water dilution. Stream water dilution is particularly important because the heat balance on a stream reach requires knowledge of streamflow into the reach. Temperature surveys and streambed profiles were collected on a slow-moving stream in Southwestern New York State. Estimates of baseflow from temperature data were compared to estimates from differential current meter readings along four stream reaches. The approaches compared well, but errors depended greatly upon the acquisition of concurrent temperature and stream velocity information. Thermal profiles were not indicative of ground-water inflow, probably due to local variations in streambed permeability or the presence of focused discharge areas. Integration of streamflow modeling (based upon digitial elevation models and aerial photographs) and thermal imaging may lead to the ability to remotely predict baseflow. Further field testing and development of data assimilation techniques will be required, however, before this technique becomes generally practical.

H12F-08 1525h

Uncertainty Associated with the Remote-sensing of Stream Temperatures at Multiple Spatial Scales

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Stream temperature is an important water quality indicator, particularly in the Pacific Northwest where endangered fish populations are sensitive to elevated water temperature. Regional assessment of stream temperatures from the ground is limited by sparse sampling of temperatures in both space and time. Remotely sensed thermal infrared (TIR) images can be used to derive spatially distributed estimates of the radiant skin temperature of streams. Even for fully resolved streams, however, our limited ability to compensate for atmospheric and emissivity effects constrains the accuracy of stream temperature measurements. When the stream is not fully resolved, it is the effect of mixed image pixels and thermal scattering from the near-bank environment that dominates both the accuracy and uncertainty of stream temperature measurements. Whereas airborne thermal sensors can resolve smaller streams than spaceborne sensors, their limited spatial coverage and cost makes satellite-derived TIR data an attractive option. We examine the accuracy and uncertainty associated with recovered stream temperatures for a range of stream sizes and pixel resolutions, using remotely sensed airborne (MASTER) and satellite (ASTER, LANDSAT-TM) TIR measurements. We find that when the stream width is resolved by fewer than 3 pixels, the accuracy of TIR measurements significantly decreases, and the uncertainty is greater, largely due to the reduction of mixed pixels (bank and stream). This limits the use of satellite TIR to temperature recovery for large rivers (currently, 180 m stream widths with Landsat- TM).

URL: http://depts.washington.edu/strmtemp/

H12G MCC: 3024 Monday 1340h

Dealing with Hydrogeologic Uncertainty in Practice: Data Collection, Models, Predictions, and Regulatory Guidelines I

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

H12G-01 1340h

A Perspective on Simulations of Environmental Systems and Prediction Uncertainty

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Prediction uncertainty is the likely discrepancy between model predictions and the actual, unrealized system responses. Contributions to uncertainty include anything that causes inaccurate predictions. This can include numerical model solution error and capability limitation, data error and deficiency, and conceptual model error. For example, using conceptual models to build simulations forces ideas about system behavior that are often vague and(or) wrong to be tested against measurements. Closer correspondence between the simulation and measurements often indicates the model more accurately represents a system. However, when models are calibrated, predictive capability can be degraded by fitting measurements too closely. This can occur when the model is overparameterized and close model fit is achieved by fitting measurement and other errors. The connection between such errors and prediction accuracy is clear, and thorough evaluation of such errors and the possibility of overfitting are critical. This is especially true for stochastic and Bayesian methods applied to models with many parameters, for which overfitting is controlled using prior information and smoothness constraints that may not be well understood by the modeler. When a reasonably accurate simulation of a system has been achieved through careful model development, calibration, and error evaluation, the simulation itself becomes an invaluable tool for sensitivity analysis, data assessment, and uncertainty evaluation. Three categories of sensitivity and data assessment methods include techniques for identifying (1) the importance of observations important to parameter values (observations that dominate model calibration); (2) parameter values that dominate the predictions; and (3) observations that dominate the predictions. For instance, gradient-based methods such as composite scaled sensitivities, prediction scaled sensitivities and the value of improved information, and the observation-prediction statistic are used to address the three categories, respectively. These local-sensitivity methods assume model linearity, but have found to be useful for nonlinear ground-water models. More computationally intensive methods that do not assume model linearity include variance-based global sensitivity analysis methods for identifying parameters important to predictions, and jackknife and bootstrap methods for identifying observations that dominate predictions. Uncertainty evaluation methods can be categorized as gradient, selective sampling, and random sampling methods. Gradient methods include linear and nonlinear confidence intervals, and are limited to propagating uncertainties related to parameter values. Selective sampling often involves establishing a most probable and one or more worst-case scenarios. Random sampling includes Monte Carlo methods such as Latin-Hypercube sampling, and can produce results similar to nonlinear confidence intervals if only parameter values are sampled and if simulations with poor model fit are omitted. Model development and evaluation are obviously complex endeavors involving a number of steps. To make wise societal decisions based on environmental model predictions, it is important to establish solid methods for evaluating the importance of observations and parameters to predictions and for quantifying prediction uncertainty.

H12G-02 1355h

Addressing Uncertainty in Predictive Groundwater Modeling in the Context of a Major Regulatory Permitting Process

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Regulatory assessments of the environmental impacts from proposed natural-resource development often require detailed information regarding potential project effects on water resources. Understanding these impacts is important for both disclosure to the public and determination of regulatory compliance in permitting. Many such projects involve pumping substantial quantities of groundwater to access the desired resource; in some cases, nearby surface water resources may be adversely affected by this groundwater withdrawal. In addition, some projects involve the management of waste materials that have the potential to contaminate area groundwater and surface waters. Because the regulatory assessment needs to address potential future conditions, predictive groundwater modeling has been used to help provide the necessary information. A case study of a proposed mine in northern Wisconsin is the focus of this discussion. In this project, both the applicant and the state regulatory agency review team recognized that substantial uncertainty would remain in model output even after conducting detailed analyses of sizeable project data sets to develop reasonable model inputs and completion of a rigorous calibration and an extensive sensitivity analysis. As a consequence, the modeling work and associated impact assessments submitted by the applicant addressed uncertainty by incorporating two scenarios: an expected case and a worst case. The agency review team, however, concluded that the level of uncertainty was so great in this situation, and the results of such importance to the impact assessment and permitting processes, that a more extensive approach to addressing uncertainty was necessary to ensure a technically defensible product. In response, the state's review team completed a number of detailed analyses of the project area information and the applicant's 3D MODFLOW regional flow model. These included: development of a 2D analytic-element model (GFLOW) to evaluate the submitted MODFLOW model boundary conditions and recharge rates; completion of Monte Carlo analyses to assess lake outlet flow and lakebed hydraulic conductivity; calculation of GFLOW-UCODE confidence intervals for prediction of mine pumping rates and associated reductions in stream baseflow; and the development of detailed analyses of project-site historical pump tests using both the regional and inset models. Numerous sensitivity analyses were performed after completing updates to the submitted model, allowing the review team to identify and evaluate the most sensitive parameters. This work on model uncertainty provided the review team's "reasonable" range for model inputs, which in turn provided two end-member scenarios that established high and low estimates of the reasonable range of project effects on the groundwater system for use in the regulatory process. The concept of reasonable ranges of model inputs and outputs was also subsequently used in the review team's work on the solute transport models submitted by the applicant to assess groundwater chemistry impacts from the proposed mine and waste facilities. This approach provides a means for communicating uncertainty to both the public and regulatory decision-makers. Moreover, it underscores the uncertainty inherent in simplified numerical representations of complex, real-world systems.

H12G-03 1410h

JUPITER Project - Joint Universal Parameter IdenTification and Evaluation of Reliability

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The JUPITER (Joint Universal Parameter IdenTification and Evaluation of Reliability) project builds on the technology of two widely used codes for sensitivity analysis, data assessment, calibration, and uncertainty analysis of environmental models: PEST and UCODE. These programs are universal in that they can be applied to any computer model; and both have very flexible methods for interacting with application models through ASCII files. Their combination in an Application Programming Interface (API) will yield a full-featured, well-designed, flexible, stable, modular, thoroughly documented foundation for advancing the technology incorporated in UCODE and PEST. Phase 1 of the project is development of the JUPITER API, which will include (1) conventions for program input and output and internal data production and consumption, and (2) subroutines that support commonly used calculations and manipulations, to facilitate use of the API by many researchers in the field. Phase 2 is development of the first applications of the JUPITER API, J_UCODE, J_PEST, and J_MMRI, where J_MMRI is an alternative conceptual model evaluation tool for ranking and weighting models to facilitate multi-model inference. Applications developed using the JUPITER API will provide the opportunity for users to readily: (1) experiment with a number of techniques for generating conceptual models (e.g. geostatistical methods, geologic process modeling, upscaling); (2) compare alternative parameter-estimation algorithms (for example, the algorithms in J_PEST and J_UCODE); (3) "mine" results from various conceptual models for model evaluation, ranking and multi-model inferential analysis, as well as use these results to evolve the conceptual model (e.g. unreasonable parameter-value estimates provide clues to hydrogeologic structure; residual bias provides clues to conceptual model error); and (4) assess data needs to improve the calibration in light of the predictions.

H12G-04 1425h

A Novel Approach to Modeling of Hydrogeologic Systems Using Fuzzy Differential Equations

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The many simultaneously occurring processes in unsaturated-saturated heterogeneous soils and fractured rocks can cause field observations to become imprecise and incomplete. Consequently, the results of predictions using deterministic and stochastic mathematical models are often uncertain, vague or "fuzzy." One of the alternative approaches to modeling hydrogeologic systems is the application of a fuzzy-systems approach, which is already widely used in such fields as engineering, physics, chemistry, and biology. After presenting a hydrogeologic system as a fuzzy system, the author presents a fuzzy form of Darcy's equation. Based on this equation, second-order fuzzy partial differential equations of the elliptic type (analogous to the Laplace equation) and the parabolic type (analogous to the Richards equation) are derived. These equations are then approximated as fuzzy-difference equations and solved using the basic principles of fuzzy arithmetic. The solutions for the fuzzy-difference equations take the form of fuzzy membership functions for each observation point (node). The author gives examples of the solutions of these equations for flow in unsaturated and saturated media and then compares them with those obtained using deterministic and stochastic methods.

H12G-05 1440h

Uncertainty and Sensitivity Analysis for Basic Transport Parameters at the Horonobe Site, Hokkaido, Japan

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Incorporating results from a previously developed finite element model from the Hazama Corporation, an uncertainty and parameter sensitivity analysis was conducted using site-specific data from Horonobe, Japan. Latin Hypercube Sampling (LHS) is used to draw random parameter values from the site-specific measured, or approximated, physicochemical uncertainty distributions. Using pathlengths and groundwater velocities extracted from the currently available three-dimensional, finite element flow and particle tracking model for Horonobe, breakthrough curves for multiple realizations were calculated with the semi-analytical, one-dimensional, multirate transport code, STAMMT–L. A stepwise linear regression analysis using the 5, 50, and 95% breakthrough times as the dependent variables and LHS sampled site physicochemical parameters as the independent variables was used to perform a sensitivity analysis. Results indicate that the distribution coefficients and hydraulic conductivities are the parameters responsible for most of the variation among simulated breakthrough times. This suggests that researchers and data collectors at the Horonobe site should focus on accurately assessing these parameters and quantifying their uncertainty.

H12G-06 1455h

Backward-in-time Modeling to Identify Sources of Reactive Solutes in Groundwater Using Probabilities Conditioned on Concentration Measurements

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When contamination is observed in an aquifer, the source of contamination is often unknown. We present an approach that can be used to identify sources of contamination based on the observed distribution (spatial, temporal, or both) of the contaminant plume. Using backward-in-time advection dispersion theory, we first obtain a backward location probability distribution that describes the possible prior positions of the contamination. This distribution is independent of the measured concentrations of the contaminant. Next, we condition the probability distribution on the measured concentrations, resulting in an improvement in the accuracy and a reduction in the variance of the backward location probability distribution. We illustrate the approach for a reactive solute (first-order decay), and demonstrate its applicability for identifying possible source locations of a trichloroethylene plume at the Massachusetts Military Reservation.

H12G-07 1510h

MAXIMUM LIKELIHOOD BAYESIAN AVERAGING OF SPATIAL VARIABILITY MODELS IN UNSATURATED FRACTURED TUFF

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Hydrologic analyses typically rely on a single conceptual-mathematical model. Yet hydrologic environments are open and complex, rendering them prone to multiple interpretations and mathematical descriptions. Adopting only one of these may lead to statistical bias and underestimation of uncertainty. Bayesian Model Averaging (BMA) [Hoeting et al., 1999] provides an optimal way to combine the predictions of several competing models and to assess their joint predictive uncertainty. However, it tends to be computationally demanding and relies heavily on prior information about model parameters. Neuman [2003] proposed a Maximum Likelihood version (MLBMA) of BMA to render it computationally feasible and to allow dealing with cases where reliable prior information is lacking. We apply MLBMA to seven alternative variogram models of log air permeability data from single-hole pneumatic injection tests in six boreholes at the Apache Leap Research Site (ALRS) in central Arizona. Unbiased ML estimates of variogram and drift parameters are obtained using Adjoint State Maximum Likelihood Cross Validation [Samper and Neuman, 1989a] in conjunction with Universal Kriging and Generalized Least Squares. Standard information criteria provide an ambiguous ranking of the models, which does not justify selecting one of them and discarding all others as is commonly done in practice. Instead, we eliminate some of the models based on their negligibly small posterior probabilities and use the rest to project the measured log permeabilities by kriging onto a rock volume containing the six boreholes. We then average these four projections, and associated kriging variances, using the posterior probability of each model as weight. Next, we cross-validate the results by eliminating from consideration all data from one borehole at a time, repeating the above process, and comparing the predictive capability of MLBMA with that of each individual model. Finally, we use the individual and MLBMA model results to predict pressure variations with time obtained independently through cross-hole pneumatic injection tests at the ALRS. We find that MLBMA is superior to any individual geostatistical model of log permeability among those we consider at the ALRS.

H12G-08 1525h

Transport of Surface-Active Solutes in a Heterogeneous Vadose Zone: Dealing With Limited Data Collection

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Realistic modeling of the non-steady state transport of surface-active compounds through unsaturated heterogeneous soils requires representation of the spatial variability in the relationships of soil moisture retention and the unsaturated hydraulic conductivity. In the case of limited resources for site characterization, the question arises as to what type of data to collect and how to best represent these relationships at locations where data are lacking. This study investigates the impact on surface-active solute transport predictions of the collection: 1) of different types of data, air-water retention curves or saturated hydraulic conductivities, 2) at different locations, and 3) of different ways of describing the spatial variability of the data: similar media scaling, Leverett scaling and a categorical-continuous method based on the pore-size distribution index. Based on a series of geostatistically-conditioned realizations, simulations of groundwater flow and contaminant transport were generated utilizing subsets of the soil property measurements from the Las Cruces trench site and compared to simulations utilizing the entire set of soil property measurements from that site. Since preliminary simulations showed that the results were influenced by the flux rate at the land surface, the degree of uncertainty under different infiltration rates was also assessed.

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H12H MCC: 3020 Monday 1340h

Hydrogeophysics: Characterization and Monitoring of Soil Properties and Processes in the Laboratory I *(joint with NG, MR)*

Presiding: **L Slater,** Rutgers University**; E Atekwana,** University of Missouri-Rolla

H12H-01 1340h

Effect of Hydrocarbon Biodegradation on the Low-Frequency Electrical Properties of Unconsolidated Sediments

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