By comparing the robustness of a given model in the observation space as well as in the management space, the need of additional data for calibration is assessed.

H11I-06 1135h

Hydrogeological characterization of sedimentary rocks with numerical inversion using steady-state hydraulic head data

Kazumasa Ito[1] (510-486-6985; KIto@lbl.gov)

Kenzi Karasaki[1] (kkarasaki@lbl.gov)

[1]Lawrence Berkeley National Laboratory, One Cyclotron Road MS:90-1116, Berkeley, CA 94720, United States

In the hydrogeological characterization of sedimentary rocks, hydraulic properties of fault and cap rock structures are important factors. Although, the certainty of a hydrogeological model depends on the amount of geological or hydrogeological data, mainly obtained from boreholes, it is indispensable to make a preliminary model from a small amount of data obtained in the early stage of field investigation, and improve the details of the model as the number of observations increases. In sedimentary rocks, several aquifers often have different hydraulic heads, caused by various reasons such as surface topography, long-term change of sea level, or cap rock structures that were not explicitly observed during geological investigations in boreholes. In this study, we used the steady-state hydraulic head distribution obtained in the pressure monitoring (or the water level monitoring) during the drilling of boreholes as the observed data, and applied numerical inversion code iTOUGH2 to construct alternative hydrogeological models for the Horonobe underground research laboratory site of Japan Nuclear Cycle Development Institute. We applied random sampling for the coverage of an assumed cap rock, and two models for the hydrogeological structure of faults in the study area. The following are the main results of this study. 1. It is necessary to assume a low permeability cap rock structure that was not clearly observed in boreholes, to reconstruct the deep high-pressure zone as a characteristic hydraulic feature in this site. 2. The numerical inversion with random sampling of cap rock shows that if the cap rock coverage is larger than 75%, the observed hydraulic head profile can be reproduced. 3. The hydrogeological structure of the fault dominates the vertical groundwater flow in the vicinity of the fault. 4. The hydraulic head profile of the deeper zone is controlled by the hydrogeological structure of a steep fault in this area. Thus, the increase of hydraulic head in the deeper zone, and numerical inversion can determine the hydrogeological structure of the fault. From these results, numerical inversion using the steady state head distribution has proven to be a useful method to construct a preliminary but quantitative hydrogeological model from a small amount of data obtained in the early investigation stage.

H11I-07 1150h

Parameter estimation via risk-based optimization

Daniel M Tartakovsky[1] (dmt@lanl.gov)

Markus Berndt[1] (berndt@lanl.gov)

[1]Theoretical Division, Los Alamos National Laboratory, Group T-7, MS B284, Los Alamos National Laboratory, Los Alamos, NM 87545

Most hydrologic systems are inherently heterogeneous and are characterized by parameters that can be sampled at a few selected locations. Yet, numerical simulations of system behavior require that the system parameters be specified at every point of a computational domain. Traditionally, this is done by means of statistical interpolation schemes, such as kriging, that produce the system parameter fields that are much smoother than their true counterparts. This yields predictions of the system states that provide little, if any, insight into the likelihood of a system failure (the so-called rare events). This problem arises in a variety of applications that range from flood prediction, to contaminant transport in groundwater, to oil and gas extraction or water supply. To resolve this issue, we present a new paradigm for parameter estimation. It is based on risk-based optimization, thus providing decision-makers with best and worst case scenarios of the system behavior.

H11I-08 1205h

A Coupled Zonation-Kriging Method for Parameter Structure Identification in Groundwater Modeling: A Case Study of a Seawater Intrusion Problem, the Alamitos Barrier in Southern California Coastal Plain

Frank T-C. Tsai[1] ((225) 578-4246; ftsai@lsu.edu)

Youn Sim[3] ((626) 458-6137; ysim@ladpw.org)

William W-G. Yeh[2] ((310) 825-2300; williamy@ucla.edu)

[1]Louisiana State University, Civil and Environmental Engineering Dept. 3507 CEBA, Baton Rouge, LA 70803

[2]University of California, Los Angeles, Civil and Environmental Engineering Dept. 5731 Boulder Hall, Los Angeles, CA 90095

[3]LA County Dept. of Public Works, Water Resources Division, 900 S. Fremont Ave, Alhambra, CA 91803

In this research, we propose a coupled zonation-kriging method for parameter heterogeneity characterization as well as parameter structure identification. With a set of distinct point measurements over a field, on one hand, a zonation structure for the field can be created based on a Voronoi tessellation method. Each Voronoi cell contains one sampled point and has the corresponding measured value. On the other hand, a kriging method can be used to characterize a continuous parameter distribution. In this study, we only use local information for the kriging method to estimate the parameter value at an unsampled site. First, we apply Voronoi tessellation and Delaunay triangulation to define a set of natural neighbors among the sampled points for an unsampled site. Each site has its unique natural neighbors. Then the kriging method uses the local information provided from these natural neighbors for the estimation. This is called the natural neighbor kriging (NNK) method. We combine the zonation method and the NNK method together as one parameterization method by introducing a set of weighting coefficients to the measurement points. The zonation-NNK method unifies zonation and kriging methods and generates a distribution between a pure zone structure and a continuous structure over a set of weighting coefficients. It shows greater flexibility in manipulating spatial distribution and spatial optimization. When a non-smooth field is investigated, the zonation-NNK outperforms all other parameterization schemes. For the inverse problem, we identify parameter heterogeneity with the zonation-NNK method by seeking the optimal weighting coefficients while minimizing the fitting residual of observations. We demonstrate the developed methodology by a case study of the Alamitos barrier for the seawater intrusion problem in Southern California Coastal Plain. The unknown distributed parameter is the hydraulic conductivity of five aquifers. We adopted the FEMWATER as a model to simulate the density-dependent coupled flow and transport in the coastal aquifers. For the given set of head and salinity concentration observations, we have identified the hydraulic conductivity field in three dimensions.

H12A MCC: Level 2 Monday 1330h

Model Calibration, Parameter Nonuniqueness, and Predictive Uncertainty Associated With Flow and Transport in Variably Saturated Media Posters

Presiding: **J A Tindall,** U.S. Geological Survey**; M J Friedel,** U.S. Geological Survey

H12A-0957 1330h POSTER

Inverse Calibration of the Dual-Permeability Model MACRO: Theoretical Analysis and Application to Microlysimeter Experiments.

Stephanie Roulier[1] (46-18-67-11-62; Stephanie.Roulier@mv.slu.se)

Nicholas Jarvis[1] (Nicholas.Jarvis@mv.slu.se)

[1]Dept. of Soil Sciences, Swedish University of Agricultural Sciences, Box 7014, Uppsala 75007, Sweden

Macropore flow is a key factor for determining chemical transport in unsaturated soils, but the description of the complex processes involved in macropore flow requires several parameters that cannot be easily measured. Inverse modeling procedures are increasingly used for model calibration, because they are objective and reproducible. But this is only true when the problem is well-posed: an ill-posed problem leads to parameter nonuniqueness, and thus contributes to poor model performance, like error and/or uncertainty in model predictions. Factors linked to nonuniqueness are most often related to sensitivity issues and/or correlation among two or several parameters. This study focused on the use of inverse techniques to estimate parameters controlling macropore flow, transport, and transformation processes in the dual porosity/dual-permeability model of water flow and solute transport MACRO. MACRO was used together with the inverse modeling package SUFI. The Bayesian (global) approach followed by SUFI is stable, converging, and robust. Moreover, the procedure also predicts a posterior uncertainty domain for the estimated parameters. A theoretical study was carried out to test the inverse modeling tool SUFI/MACRO. Generated "dummy" data set were used for this purpose, representing transient leaching experiment for tracers and reactive solutes in small soil columns (20 cm height). General issues related to inverse modeling such as internal correlation and sensitivity were investigated, with the help of response surface analysis, as well as the influence of the choice of the goal function used in the inverse procedure. Attention was also focused on the most appropriate experimental design necessary for a reliable parameter estimation. The procedure was then applied to real data, obtained from tracer leaching experiments carried out on microlysimeters. Based on calculated model efficiencies, MACRO/SUFI gave good predictions of water movement and tracer transport. This is an encouraging first step prior to application against real data on reactive transport.

H12A-0958 1330h POSTER

Multiscale Heterogeneity and Solute Transport Model Parameter Uncertainty Study for a Fractured Low-Level Nuclear Waste Disposal Site in the Eastern United States

Jin-Ping Jack Gwo[1] (jgwo@umbc.edu)

Philip M. Jardine[2] (jardinepm@ornl.gov)

[1]University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, United States

[2]Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831, United States

The objective of this research is to determine multiscale fluid and solute transport parameters in support of a site characterization effort at the Waste Area Grouping 5 (WAG 5) at ORNL (Oak Ridge National Laboratory) in eastern Tennessee, USA. The study site is located within the top 10 m of the subsurface, in which groundwater flow dynamics is influenced by both infiltration and recharge events. The soil and rock formations are macroporous and/or highly fractured at WAG 5. A natural gradient, multiple tracer injection experiment (bromide, helium and neon), was conducted to quantify the solute transport and mass transfer processes in the highly fractured shale bedrock. The field site is intensively instrumented with arrays of drive point and multi-level sampling wells. Field observations of hydraulic head and bromide solute movement dynamics are used in this study to calibrate a two-pore-domain, fracture-matrix flow and non-reactive solute transport model. We use a nested Latin hypercube (NLH) sampling technique to determine the near-optimal combinations of model parameters. As a result of the sampling technique, empirical probability distributions of model parameters are derived. Heterogeneity in two scales, field and matrix block, are quantified in terms of field scale distribution of hydraulic and solute transport properties and fracture spacing between matrix blocks. Uncertainties arising from tracer source density effect are also addressed through model prediction uncertainty analysis. It is also concluded that NLH is a relatively effective optimization technique, often capable of locating the near-optimal combination of model parameters in a few iterations.

H12A-0959 1330h POSTER

Soil Hydraulic Property Uniqueness as Determined From Inverse Modeling Using Surface Temperature : the Role of Soil Type

Ethan D Gutmann[1] (303-492-5051; gutmann@colorado.edu)

Eric Small[1] (303-735-5033; Eric.Small@colorado.edu)

[1]University of Colorado, Department of Geological Sciences University of Colorado Campus Box 399, Boulder, CO 80309-0399, United States

Knowledge of the spatial distribution of soil hydraulic properties (SHPs) is critical for a broad range of earth system problems, from predicting the hydrologic implications of climate variability to understanding how land cover and land use change modify water, energy, and carbon cycling at the earth's land surface. SHPs strongly control how water and energy flow through soils, and therefore influence infiltration at the soil surface, redistribution of water within the soil column, and the loss of water from soil via evaporation and transpiration. Soil hydraulic properties define two fundamental relationships: (1) the water characteristic function or water retention curve, which describes how the water content of soil varies with the potential of the medium; and (2) the unsaturated conductivity curve of the medium, which shows how conductivity varies with water content. We have developed a method to determine SHPs from remotely sensed surface temperature (T_S) via inverse modeling. Model simulations of T_S are compared to observed values. If the observed and modeled values do not match, the SHPs are modified, and the forward model run is repeated. This process continues until the observed and modeled T_S values are minimized. This method uniquely determines the SHP for some soil types, but is much less accurate for others. We will discuss the limitations of this method with respect to soil type. We present an example based partially on applying the inverse procedure to forward model output for bare soil. We used a modified version of the NOAH land surface model with observed weather forcing data and a variety of soil types. The Ts output from these forward model runs were used as input to the MOSCEM-UA inverse modeling framework. The accuracy with which the inverse procedure is able to determine the soil hydraulic properties is controlled in part by the original soil type itself. For example, when one assumes a 1K RMS sensor error, the van Genuchten "n" parameter for silt can only be determined to fall within a range of values from 1.2 to 3, but for sand it can be determined to fall between 3 and 3.5. Additionally, certain parameters are easier to estimate then others, the van Genuchten "alpha" parameter is less identifiable than the "n" parameter for instance.

H12A-0960 1330h POSTER

First-Order Sensitivity Analysis of the Variation in Temperature History at Yucca Mountain due to Thermal-hydrologic Parameter Uncertainty

Lee Glascoe[1] (925-423-2922; glascoe@llnl.gov); Gwen Loosmore[1] (925-423-0214; loosmore1@llnl.gov); Thomas Buscheck[1] (buscheck1@llnl.gov); Yunwei Sun[1] (sun4@llnl.gov); James Gansemer[1] (gansemer1@llnl.gov); Kenrick Lee[1] (lee23@llnl.gov)

[1]Lawrence Livermore National Laboratory, PO Box 808, L-646, Livermore, CA 94550, United States

Sensitivity analysis can be used for both uncertainty quantification and model simplification. Presented here is a thermal-hydrologic example with a first-order sensitivity analysis addressing the response of temperature to uncertainty in heat-transfer and hydrologic parameters. The Multi-Scale Thermal-Hydrologic Model (MSTHM) employs LLNL's Non-isothermal Unsaturated/saturated Flow and Transport (NUFT) code to simulate mountain and drift-scale heat transfer and hydrology for the proposed waste repository at Yucca Mountain. For MSTHM predictions of thermal-hydrologic conditions within the emplacement drifts and in the adjoining host rock, the key uncertain parameters include thermal-conductivity and percolation flux. Discussed here is a first-order sensitivity analysis of temperature response to the uncertainty of these two parameters. To address the impact of percolation-flux uncertainty, MSTHM simulations are run for three (mean, upper-bound, and lower-bound) infiltration-flux cases; to address the impact of thermal-conductivity uncertainty, MSTHM simulations are run for three (mean, +1 standard deviation, -1 standard deviation) cases. The sensitivity analysis anticipates the combined impact of thermal-conductivity and percolation uncertainty for the temperature response. MSTHM simulation illustrates that the first-order approach yields accurate prediction; the prediction is more accurate for perturbations in thermal-conductivity than for perturbations in percolation flux. It is anticipated that contours of predictive accuracy could be determined by such a sensitivity analysis as both parameters are monotonic with respect to temperature. Such contours of predictive accuracy may be useful in reducing the overall number of simulations necessary for bracketing the effect of parameter uncertainty. This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

H12A-0961 1330h POSTER

Calibration and inverse modelling of multicomponent reactive transport in single and dual porosity media

Javier Samper[1] (34981167000; jsc@iccp.udc.es); Ana Maria Fernandez[2]; Liange Zheng[1] (zheng@iccp.udc.es); Luis Montenegro[1]; Pedro Rivas[2]; Zhenxue Dai[3]

[1]Universidad de La Coruña, Campus de Elviña s/n, Coruña E-15192, Spain

[2]CIEMAT, Av Complutense 22, Madrid E-28040, Spain

[3]Wright State University, Dept of geological Sciences, Dayton, OH 45435, United States

The inverse methodology developped by Dai and Samper (2003) is applied to the interpretation of a long-term permeation test performed on a sample of nearly-saturated FEBEX compacted bentonite. Hydrogeochemical modelling of porewaters indicate that the main geochemical processes controlling the chemistry of the bentonite are: acid-base reactions, aqueous complexation, cation exchange, dissolution/ex-solution of CO2 and dissolution and precipitation of highly soluble minerals such as calcite, dolomite, chalcedony and gypsum/anhydrite. All these processes are assumed to take place under equilibrium conditions. The initial saline porewater of the bentonite is flushed with a fresh water with a chemical composition typical of granite formation. Water flux and chemical data of effluent waters were measured during the experiment. Direct and inverse modelling of this experiment has been carried out using the code CORE (Samper et al., 2000). WE address the uncertainties in mobile and immobile porosities as well as on the underlying geochemical conceptual model. Models of chloride breakthrough curves indicate that bentonite exhibits a double porosity behavior. The model reproduces the trends of measured data except for bicarbonate and pH which are affected by uncertainties in the evolution of CO2(g) pressures.

H12A-0962 1330h POSTER

Capillary-Physics Mechanism of Elastic-Wave Mobilization of Residual Oil

Igor A Beresnev[1] (515-294-7529; beresnev@iastate.edu)

Wayne D Pennington[2] (906-487-3573; wayne@mtu.edu)

Roger M Turpening[2] (906-487-1756; roger@mtu.edu)

[1]Department of Geological and Atmospheric Sciences, Iowa State University, 253 Science I, Ames, IA 50011-3212, United States

[2]Department of Geological Engineering and Sciences, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931, United States

Much attention has been given to the possibility of vibratory mobilization of residual oil as a method of enhanced recovery. The common features of the relevant applications have nonetheless been inconsistency in the results of field tests and the lack of understanding of a physical mechanism that would explain variable experiences. Such a mechanism can be found in the physics of capillary trapping of oil ganglia, driven through the pore channels by an external pressure gradient. Entrapping of ganglia occurs due to the capillary pressure building on the downstream meniscus entering a narrow pore throat. The resulting internal-pressure imbalance acts against the external gradient, which needs to exceed a certain threshold to carry the ganglion through. The ganglion flow thus exhibits the properties of the Bingham (yield-stress) flow, not the Darcy flow. The application of vibrations is equivalent to the addition of an oscillatory forcing to the constant gradient. When this extra forcing acts along the gradient, an instant "unplugging" occurs, while, when the vibration reverses direction, the flow is plugged. This asymmetry results in an average non-zero flow over one period of vibration, which explains the mobilization effect. The minimum-amplitude and maximum-frequency thresholds apply for the mobilization to occur. When the vibration amplitude exceeds a certain "saturation" level, the flow returns to the Darcy regime. The criterion of the mobilization of a particular ganglion involves the parameters of both the medium (pore geometry, interfacial and wetting properties, fluid viscosity) and the oscillatory field (amplitude and frequency). The medium parameters vary widely under natural conditions. It follows that an elastic wave with a given amplitude and frequency will *always* produce a certain mobilization effect, mobilizing some ganglia and leaving others intact. The exact macroscopic effect is hard to predict, as it will represent a response of the populations of ganglia with unknown parameter distributions. The variability of responses to vibratory stimulation should thus be expected.

H12A-0963 1330h POSTER

Effect of Heterogeneity Structure on Estimation Uncertainty for a Calibrated Seepage Model

Stefan Finsterle[1] (1-510-486-5205)

Teamrat A Ghezzehei[1] (1-510-486-5688; TAGhezzehei@lbl.gov)

[1]Earth Science Division, Lawrence Berkeley National Lab, One Cyclotron Rd., MS 90R1116, Berkeley, CA 94720-8126, United States

Dripping of water into underground openings is significantly affected by the heterogeneity of the geologic formation. Calibration of numerical models against field seepage data is a method for estimating effective, seepage-related properties of the geologic formation surrounding the openings. The van Genuchten a parameter is considered the primary seepage-related parameter of a three-dimensional, heterogeneous (with respect to permeability) continuum model. Each seepage data set is obtained from a certain test bed that can be considered one realization from a number of statistically similar geologic systems. The lack of knowledge regarding the details of this specific realization makes the inversely determined a parameter estimate uncertain. This uncertainty is analyzed by performing multiple inversions of the same data set using different realizations of the underlying heterogeneous permeability field, which generates a probabilistic distribution of the estimated a parameter. Knowledge of how the heterogeneity structure affects the estimation uncertainty is very important, because permeability data are usually sparse and multiple inversions are computationally intensive. The objective of this study was to analyze how the geostatistical parameters of the permeability field affect the distribution of the estimated a parameter. We calibrated a seepage model with a circular tunnel against synthetic seepage data, assuming uniform percolation flux at the upper end. Inversions were performed for wide ranges of geostatistical parameter values. This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, Division of Chemical Sciences, Geosciences, & Biosciences, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

H12A-0964 1330h POSTER

Thermohydrological Conceptual Model Evaluation Using Laboratory- and Field-Scale Heater Tests

Ronald T Green[1] (210-522-5305; rgreen@swri.edu)

Scott Painter[1] (210-522-3348; spainter@swri.edu)

Beth Fratesi[2] (662-347-1688)

[1]Center for Nuclear Waste Regulatory Analyses, Southwest Research Institute 6220 Culebra, San Antonio, TX 78238, United States

[2]University of South Florida, Dept of Geology 4202 E. Fowler Ave, Tampa, FL 33620, United States

Coupled heat and mass transfer observations and measurements from heater tests conducted at two scales, laboratory and field, provide a basis to evaluate thermohydrological conceptual models. The U.S. Department of Energy is conducting a long-term drift-scale heater test (DST) as part of a comprehensive evaluation of a proposed geologic high-level nuclear waste repository at Yucca Mountain, Nevada. Laboratory-scale heater tests conducted at CNWRA provide results of similar heat and mass transfer processes, but at a different scale. Comparison of results from tests at different scales provides an opportunity to examine different conceptual models for matrix-fracture interactions expected at the proposed repository. Conceptual models used for heat and mass transfer between the fractures and matrix are evaluated because they have been found to have a profound effect on simulations of thermohydrological processes. In addition, the effects of selected property (i.e., matrix and fracture permeability, thermal conductivity, and the air-entry pressure) values are evaluated in terms of their importance to the evolution of temperature and saturation in the simulations. The multiphase simulator, MULTIFLO, was used to perform the conceptual model evaluations. Simulated temperature and fracture saturation were used to compare the ability of the conceptual models to replicate the laboratory- and field-scale results and the importance of the property values assigned to key parameters in the numerical models. This abstract is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

H12A-0965 1330h POSTER

Percolation- and Effective Medium-Based Models of Unsaturated Hydraulic Conductivity

Robert P. Ewing[1] (515-294-7856; ewing@iastate.edu)

Allen G Hunt[2] (301-871-5373; allenghunt@msn.com)

[1]Department of Agronomy Iowa State University, Department of Agronomy Iowa State University, Ames, IA 50011-1010, United States

[2]CIRES University of Colorado, Department of Agronomy Iowa State University, Ames, IA 50011-1010

The unsaturated hydraulic conductivity function K(S) is of fundamental importance in understanding and predicting flow in the vadose zone. However, time and cost constraints typically require hydrologists to estimate K(S) rather than measuring it. Existing K(S) models are empirical; in this work we develop new theoretical models based upon percolation theory and effective medium theory. Percolation- and effective-medium-based theories have been recognized for over 25 years in the physics of transport in disordered systems as the premier means to "upscale" transport properties, i.e. to calculate system transport parameters from the variability at smaller scales. Percolation theory has recently been used to derive pressure-saturation curves, solute and gas diffusion, and the K(S) of probabilistic fractal porous media, and the results have given excellent agreement with experiment. An advantage of percolation theory vis-a-vis effective medium theory is the possibility to isolate effects of pore-sizes and the topology of the connections of pores on transport phenomena. The disadvantage of this procedure is that it can require treating different ranges of parameters, such as the moisture content, differently. The attractive aspect of effective-medium theory is its ability to handle all contributions to the physics simultaneously. We compare effective-medium and percolation theories using a model porous medium in which the pore radii are power-law distributed. In both theoretical treatments we observe a cross-over from critical pore-size dominated hydraulic conductivity at relatively large moisture contents to the dominance of the topological connections of the wetted pore space at moisture contents near the critical value for percolation.

H12A-0966 1330h POSTER

ENHANCED REMEDIATION OF TOLUENE IN THE VADOSE ZONE VIA A NITRATE-RICH NUTRIENT SOLUTION: FIELD STUDY

James A Tindall[1] (303.236.5005; jtindall@usgs.gov)

Michael J Friedel[1] (303.236.4882 x288; mfriedel@usgs.gov)

[1]U.S. Geological Survey, MS 413, Box 25046 Federal Center, Denver, CO 80225-0046, United States

The objective of this study was to test the effectiveness of nitrate-rich nutrient solutions and hydrogen peroxide (H202) to enhance in-situ microbial remediation of toluene. Three sand filled plots (2 m2 surface area and 1.5 meters deep) were tested in three phases (each phase lasting approximately 2 weeks). During each phase, toluene (21.6 mol as an emulsion in 50L of water) was applied uniformly via sprinkler irrigation. Passive remediation was allowed to occur during the first (control) phase. A nutrient solution (modified Hoagland), concentrated in 40L of water, was tested during the second phase. The final phase involved addition of 230 moles of H202 in 50L of water to increase the available oxygen needed for aerobic biodegradation. During the first phase, toluene concentrations in soil gas were reduced from 120 ppm to 25 ppm in 14 days. After the addition of nutrients during the second phase, concentrations were reduced from 90 ppm to about 8 ppm within 14 days, and for the third phase (H202), toluene concentrations were about 1 ppm after only five days. Initial results suggest that this method could be an effective means of remediating a contaminated site, directly after a BTEX spill, without the intrusiveness and high cost of other abatement technologies such as bioventing and soil vapor extraction. However, further tests need to be completed to determine the effect of each of the BTEX components.

URL: http://www.agu.org

H12B MCC: Level 2 Monday 1330h

Surface Water Hydrology and Water Resources Posters *(joint with NG)*

Presiding: **J M Jacobs,** University of New Hampshire**; C H Luce,** USDA Forest Service

H12B-0967 1330h POSTER

The Application of Censored Regression Models in Low Streamflow Analyses

Chuck Kroll[1] (315 470-6699; cnkroll@esf.edu)

Joana Luz[2] (jgluz@ufba.br)

[1]Environmental Resources Engineering, SUNY College of Environmental Science and Forestry, 1 Forestry Drive, Syracuse, NY 13210, United States

[2]Instituto de Geociencias, Universidade Federal da Bahia, Rua Barao de Geremoabo, Salvador 40170-290, Brazil

Estimation of low streamflow statistics at gauged and ungauged river sites is often a daunting task. This process is further confounded by the presence of intermittent streamflows, where streamflow is sometimes reported as zero, within a region. Streamflows recorded as zero may be zero, or may be less than the measurement detection limit. Such data is often referred to as censored data. Numerous methods have been developed to characterize intermittent streamflow series. Logit regression has been proposed to develop regional models of the probability annual lowflows series (such as 7-day lowflows) are zero. In addition, Tobit regression, a method of regression that allows for censored dependent variables, has been proposed for lowflow regional regression models in regions where the lowflow statistic of interest estimated as zero at some sites in the region. While these methods have been proposed, their use in practice has been limited. Here a delete-one jackknife simulation is presented to examine the performance of Logit and Tobit models of 7-day annual minimum flows in 6 USGS water resource regions in the United States. For the Logit model, an assessment is made of whether sites are correctly classified as having at least 10% of 7-day annual lowflows equal to zero. In such a situation, the 7-day, 10-year lowflow (Q710), a commonly employed low streamflow statistic, would be reported as zero. For the Tobit model, a comparison is made between results from the Tobit model, and from performing either ordinary least squares (OLS) or principal component regression (PCR) after the zero sites are dropped from the analysis. Initial results for the Logit model indicate this method to have a high probability of correctly classifying sites into groups with Q710s as zero and non-zero. Initial results also indicate the Tobit model produces better results than PCR and OLS when more than 5% of the sites in the region have Q710 values calculated as zero.

H12B-0968 1330h POSTER

Bivariate Drought Characterization Using Nonparametric Approaches

Tae-Woong Kim[1] (520-626-1205; taek@email.arizona.edu)

Juan B Valdes[1] (520-621-6564; jvaldes@u.arizona.edu)

Chulsang Yoo[2] (82-2-3290-3321; envchul@korea.ac.kr)

F Javier Aparicio[3] (52 -777-320-8671; japaricio@tlaloc.imta.mx)

[1]The University of Arizona and SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas), Dept. of Civil Engineering, Tucson, AZ 85721-0072, United States

[2]Korea University, Dept. of Civil and Environmental Engineering, Seoul 136-701, Korea, Republic of

[3]Mexican Institute of Water Technology, Paseo Cuauhnahuac 8532, Jiuttepec, Mor 62550, Mexico

Droughts cause significant damages both in natural environment and human society, especially, in a transboundary region, where sustainable water use and water right are one of main issues among countries and communities during droughts. Nonparametric approaches allow more flexibility in practice by better approximating the characteristics of the probability distribution of the records. This paper presents new development in nonparametric methods in which, using a kernel density estimator, a nonparametric random generation is proposed for synthetic generation of hydrologic time series. Based on the nonparametric probability density function estimator, comprehensive approaches for evaluation of drought characteristics at a site and over a region are presented. The nonparametric method using a kernel density estimator easily extends to the estimation of a drought probability density function in two dimensions. Based on the synthetically generated data from the nonparametric distribution, a methodology is introduced for estimating the bivariate characteristics of droughts. The proposed approach was applied to a catchment in the Lower Rio Bravo/Grande and the results compared satisfactory with several parametric approaches.

H12B-0969 1330h POSTER

Assessing Hydrologic Similarity of Watersheds by Analyzing Geometric Patterns in Streamflow Time Series

Ramesh Teegavarapu[1] ((859) 257 1302; ramesh@engr.uky.edu)

Anil Tangirala[1] (aktang@uky.edu)

Lindell Ormsbee[1] (lormsbee@engr.uky.edu)

[1]University of Kentucky, 161 Oliver Raymond Hall Departmet of Civil Engineering, Lexington, KY 40506, United States

The concept of hydrologic similarity has been used in the past in the field of watershed hydrology to identify points or units in watersheds to assess their similar responses for a specific rainfall event. The similarity idea has also helped in identifying hydrologic response units (HRU) and improved representation of hydrologic processes in distributed hydrologic models. In the present study hydrologic similarity at a watershed scale is evaluated by using observed hydrologic time series data. The process involves exploring patterns in data time series and is almost similar to pattern recognition task in which a specific structure is searched in data items or observations. The motivation for evaluating these patterns is derived from the fact that observed data carry information either about the process generating them or the phenomenon they represent. Therefore the main objective of this study is to explore the possibility of establishing similarity in the hydrologic response of the watersheds based on geometrical patterns identified from observed streamflow time series. If the distribution of geometric patterns is similar, then a hydrologic similarity can be assumed as the response of the watershed is reflected in the observed streamflow values. Once a hydrologic similarity between any two watersheds is established using the similarity in the geometric patterns, then one or more of the several watershed physical properties (landuse, soils or topography) can be used to confirm the hypothesized similarity. The concept of establishing hydrological similarity using streamflow time series is tested by analyzing historical streamflow data from several USGS gaging stations in the state of Kentucky. The streamflow data is processed using a data-sorting program developed specifically for analyzing geometric patterns. Digital Elevation Models (DEMs) are used to delineate watersheds using the location of the gaging stations as outlets of the watersheds. Similarity in Land use/Land cover information is used as one of tests to confirm the possible existence of hydrologic similarity. If hydrological similarity is established based on the patterns in streamflow time series, transferability of streamflow prediction approaches can be evaluated.

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Ensemble Streamflow Forecast Verification: Putting Research Into Practice

Kristie J Franz[1] (949-824-5333; franzk@uci.edu); Soroosh Sorooshian[1]; Edwin Welles[2]; David Brandon[3]; Scott Townsend[4]; Luiz Teixeira[4]

[1]University of California, Irvine, Civil and Environmental Engineering, E/4130 Engineering Gateway, Irvine, CA 92697, United States

[2]National Weather Service, Hydrology Lab, 1325 East-West Hwy, Silver Spring, MD 20910, United States

[3]National Weather Service, Colorado Basin River Forecast Center, 2242 W. North Temple, Salt Lake City, UT 84116, United States

[4]Riverside Technology, Inc., 2290 E. Prospect Rd Ste. 1, Fort Collins, CO 80525, United States

The application of probabilistic forecast evaluation methods to synthetic hindcasts was demonstrated in a previous study. The goal of this initial research was to assess the potential for using specific verification methods for National Weather Service Ensemble Streamflow Predictions (NWS ESP). Results from this work indicated that the measures studied (ranked probability skill score, discrimination, and reliability) provided a comprehensive evaluation of forecast characteristics. However, it remained unclear whether the statistics could be put into practical application. The second phase and current phase of this study highlights the problems, issues, and obstacles that come to light