fold. We converted the size-count to size-weight distribution using log-normal functions between two consecutive size groups. When used to calculate the median and the standard deviation of the distribution, the method yielded a more stable approach than two alternative calculations.

H61C-0821 0830h INVITED POSTER

Design Considerations for Continental-Scale Water-Quality Networks

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The U.S. Geological Survey recently completed the redesign of two continental-scale networks, the National Stream Quality Accounting Network (NASQAN) and the Hydrologic Benchmark Network (HBN). In both cases, although the original networks provided useful data, the networks failed to achieve as much as was originally hoped when they were implemented approximately 30 years ago (NASQAN) and 40 years ago (HBN). Although both networks focused on water quality, the lessons from these networks are applicable to the network of research watersheds currently under consideration.

The most important lesson was that network objectives must be stated with sufficient precision to define the intended interpretation and analysis of data collected by the network. For example, many monitoring networks have the objectives to determine the status of a resource and the trend in that status. These generic objectives were too imprecise to determine the NASQAN and HBN network design: how are the data going to define the status? For NASQAN, we decided that estimation of the annual load of selected water-quality constituents was our central objective because it permitted us to determine the source, transport, and delivery of constituents using the principle of conservation of mass. Once this objective was specified, the details on network design fell into place. Sampling strategy, sampling methods, and minimum sampling frequency could be determined, which, in turn, determined the cost of operating stations. Methods and quality-assurance plans could be specified to meet this objective, as well as the requisite data-handling system. When combined with the budget, these elements defined the maximum number of stations that could be operated. In general, resource constraints will require iterating between defining objectives and determining whether environmentally meaningful data that meet those objectives can be collected within budget. Often, objectives will have to be redefined to meet the budgetary constraints.

The second lesson to be drawn from the operation of long-term networks like NASQAN and HBN is the need for on-going data interpretation to be integral to the program. Such interpretation will determine whether the data truly meet the objectives of the network and if any adjustment to the network operation is required. Such interpretation maintains the vitality of the network and ensures the continued merits of its operation.

H61C-0822 0830h INVITED POSTER

Modeling and Monitoring Soil Erosion, Sediment Movement, and Sediment Storage in the United States

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The U.S. has in place the National Resources Inventory (NRI), a large and efficient system for collecting data for prediction of soil erosion using the Universal Soil Loss Equation (USLE). What seems required now is a worldwide verification scheme, with network design, that would account for earth-mass fluxes in sample stream basins chosen to be representative of global climatic zones and hydrogeomorphic systems. Each sample basin would terminate in a reservoir that stores water and sediment and thus permits the calculation of sediment yield. Stream channels and valleys, as well as sample upland areas, would be monitored by surveys and cosmogenic tracers. Ideally, streamflow and sediment transport in each basin would be monitored, at least just upstream of the reservoir. Such a scheme would not only allow for verification of the USLE or related technologies under different conditions on an areal basis, but it would allow powerful insights into sediment movement and storage and associated fluvial processes.

URL: http://www.geog.ucla.edu/

H61D MCC: 105 Saturday 0830h

Drought Analysis and Prediction I

(joint with A, GC)

Presiding: **J Valdes,** University of Arizona**; J Salas,** Colorado State University

H61D-01 0830h INVITED

The Evolution of 20th Century Drought Monitoring Tools Leading to a 21st Century North America Drought Monitor

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The monitoring and analysis of drought have long suffered from the lack of an adequate definition of the phenomenon. As a result, drought indices have slowly evolved during the last two centuries from simplistic approaches based on some measure of rainfall deficiency or streamflow, to more complex problem-specific models. The incorporation of evapotranspiration as a measure of water demand by C. Warren Thornthwaite led to the landmark development in 1965 by Wayne Palmer of a water budget-based drought index that is still widely used. The 20th Century concluded with the development of the Drought Monitor tool, which incorporates Palmer's index and several other indices to provide a universal assessment of drought conditions across the entire United States. The 21st Century is seeing the coordinated operational monitoring of drought on a continental scale as experts from Mexico, Canada, and the United States develop the North America Drought Monitor.

By placing the development of these drought indices into a historical perspective, this paper will provide a better understanding of the complex Palmer Index and of the nature of measuring drought in general. Drought patterns over the United States during the last 100 years will be illustrated using several of these indices.

H61D-02 0845h INVITED

Stochastic Modeling of La Niña Influence on Meteorological Droughts in the South Cone of America

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The objective of this work is to characterize and to establish quantitative relations between the properties of meteorological droughts in the geographic scope of the South Cone of America and the extreme phases of ENOS. From the quantitative point of view it also of interest to be appraised the existence of non linearities and effects of temporary phase angle between both phenomena. Stochastic models were used to relate the temporary structure of dependency between the field of Standardized Anomalies of the Sea Surface Temperature, SST, fields in the Pacific Ocean, and fields of monthly values of the Standardized Precipitation Index in those continental regions of South America, to the south of the Tropic of Capricorn, where the homogenous influence of ENOS has been previously identified, particularly La Niña events related with the occurrence of droughts.

Transfer Function and NARMAX models were applied to model relationships between both phenomena, applied to all the phantom of both phenomena as a first approach. This sample that are no significant differences between both types of modeling, linear and non linear. In addition, since evidence exists of which the extreme events La Niña are associate with the occurrence of meteorological droughts in this region, with the intention of modeling the nonlinear relation presents between both types of events, these same models are applied in a threshold scheme, considering the percentile of the main component of the SST that identifies conditions of La Niña, like indicating variable. The modeling indicates that while these models applied to the whole set of the variables allow to explain not more of the 0.10 of the variance of the first main component of the monthly precipitation field in the analyzed continental zones, get to explain more of the 0.50 of her if they are applied as much considering only conditions of the colder extreme phase, corresponding to La Niña, like exogenous variable in the Transfer Function like in NARMAX models, and without significant differences among them are detected.

H61D-03 0900h

Characterizing the Recurrence of Hydrologic Droughts

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Characterizing periods of deficit and drought has been an important aspect in planning and management of water resources systems for many decades. An extreme drought is a complex phenomenon that evolves through time and space in a random fashion. It may be characterized by its initiation, duration, severity (magnitude or intensity), spatial extent, and termination. These characteristics may be determined by comparing the water supply time series versus the corresponding water demand series in the area of consideration. Because the water supply quantities such as rainfall and streamflow are stochastic variables the ensuing drought characteristics are random and must be described in probabilistic terms. Let us consider a periodic stochastic water supply and a variable water demand series. A drought event is defined as a succession of consecutive periods (run) in which the water supply remains below the water demand. Thus, the drought length L (negative run length) is the number of consecutive time intervals (seasons) in which the water supply remains below the water demand, preceded and followed by (at least one season where) the water supply is equal or greater than the demand. Likewise, the difference between the water demand and the supply at time t is the magnitude of the deficit at time t so that the accumulated deficit D (drought magnitude) is the sum of the deficits over the drought duration L. In the study reported herein, the probability density functions (pdf) of drought length and drought magnitude and their low order moments are derived assuming that the underlying water supply series after is clipped by a constant or periodic water demand results in a periodic dependent binary series that is represented by a periodic two-state Markov chain. The derived pdfs allow estimating the occurrence probabilities of droughts of a given length where either the drought begins in a given season or regardless of the initial season. In addition, the return periods of droughts (based on length and magnitude) are determined. The applicability of the drought formulations is illustrated using several series of precipitation and streamflow in Sicily, Italy and Colorado, USA. The results obtained show an excellent agreement between the observed and theoretical results. In conclusion, the proposed methods appear to be a useful addition for drought analysis and characterization using stochastic methods.

H61D-04 0915h

Stochastic modelling of regime changes

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Graphical and numerical techniques exist to represent the duration, magnitude, and intensity not only of droughts, but of any climatic episode. We present here statistical decision and limit methodologies for quantifying regime shifts through their duration and magnitude. Duration is defined as the number of consecutive values above (or below) a reference level, and magnitude is the sum of all values for any given duration. Assuming that a regime shift can occur every year, independently of prior years, we naturally obtain a class of standard waiting time distributions (waiting times for the regime shift). Because magnitude can be expressed as a random sum of N random variables (where N is duration), its probability distribution is evaluated using limit theory for random sums. Here we analyze a reconstructed time series of the Pacific Decadal Oscillation (PDO), explicitly describe the probability distributions, and estimate their parameters from the PDO data obtaining a reasonably good fit. Our stochastic approach to modeling duration and magnitude of multi-annual events (such as droughts) enables the computation of statistical significance for those episodes, and provides a rigorous solution to deciding whether two droughts are significantly different from one another.

H61D-05 0930h

Drought in Central and Southwest Asia: La Nina, the warm pool, and Indian Ocean precipitation

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Severe drought from 1998-2001, in combination with the effects of protracted socio-political disruption, led to widespread famine affecting over 60 million people in Central and Southwest (CSW) Asia. Here we document both a regional and a large-scale mode of climate variability that, together, suggest a possible forcing mechanism for the drought. During the boreal cold season, an inverse relationship exists between precipitation anomalies in the eastern Indian Ocean and CSW Asia. Suppression of precipitation over CSW Asia is consistent with interaction between local synoptic storms and wave energy generated by enhanced tropical rainfall in the eastern Indian Ocean. This regional out-of-phase precipitation relationship is related to large-scale climate variability through a subset of El Nino-Southern Oscillation (ENSO) events characterized by an enhanced signal in the warm pool region of the western Pacific Ocean. Both the prolonged duration of the 1998-2001 cold phase ENSO (La Nina) event and unusually warm ocean waters in the western Pacific appear to contribute to the severity of the drought.

URL: http://iri.columbia.edu/outreach/publication/irireport/SWAsia/

H61D-06 0945h

Global Teleconnections between Climate Indices and the Palmer Drought Index

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The current U.S. Seasonal Drought Outlook as prepared by NOAAs Climate Prediction Center uses a combination of forecast tools to indicate likely improvement, intensification, or persistence of large-scale drought areas over the following season. In order to improve the accuracy of the forecasts and gain a better understanding of the possible causes of drought, correlations between the Palmer Drought Index (PDI) and various climate indices and oscillations have been calculated. The correlations are carried out for U.S. climate regions and states. The climate indices include SST anomalies for the common ENSO regions in the Pacific and numerous additional oceanic areas outside of the tropical Pacific. Assorted atmospheric indices were examined, including tropospheric indices such as the NAO, AO, and SOI and stratospheric indices such as the QBO. Solar indices were also examined. Coincident correlations were calculated in addition to correlations for various lead times. The results show that a variety of oceanic, atmospheric, and solar indices are statistically related to the PDI, many at lead times of several months, suggesting their potential use as forecast tools.

H61D-07 1020h INVITED

North American Drought and Wetness Reconstructed From Long Tree-Ring Records

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Extremes of drought and wetness in North America have great impacts on human and natural systems. Yet, because such hydrometeorological events are by definition rare, there may be only one realization of them in the relatively short instrumental climate records of the 20th century, e.g. the northern Great Plains "Dust Bowl" drought of the 1930s. Thus, such rare events are difficult to model, either statistically or mechanistically, using instrumental data alone. In addition, it is impossible to know how unbiased the instrumental data are in expressing the full range of natural hydroclimatic variability prior to the 20th century, especially given the impact of greenhouse gases on current climate. This limitation can be greatly ameliorated through the reconstruction of past hydroclimatic variability from centuries-long, moisture-sensitive, annual tree-ring records. To this end, a 154-point, 2x3 degree grid of summer Palmer Drought Severity Index (PDSI) reconstructions has been developed for the coterminous USA. These reconstructions, which extend back to AD 1700 at all locations, have been used in several studies of hydroclimatic variability over the USA, including those related to ENSO forcing of drought and wetness in the American Southwest. A longer subset of these drought reconstructions, extending back to AD 1200, has also revealed the occurrence of a "megadrought" in the late-16th century that may have propagated northward from Mexico to the American Southwest and eastward to the southeastern USA. This drought appears to have been the most severe such event of the past ca. 800 years over temperate North America. In order to provide a more complete space-time history of past drought and wetness, especially that related to especially severe events like the "megadrought", the drought reconstruction grid has now been expanded to cover most of North America, including a significant portion of Canada and all of Mexico. This new 297-point, 2.5x2.5 degree grid, coupled with a substantially improved network of long tree-ring chronologies, provides a more geographically complete history of drought and wetness over North America covering the past 500-800 years in most regions. The properties of this new grid of PDSI reconstructions are described, including the space-time evolution of the 16th century "megadrought" and changes in natural hydroclimatic variability prior to AD 1600. Regional differences in drought and wetness are also described through the use of rotated EOF analysis and the spectral properties of those hydroclimatic regions are compared.

H61D-08 1035h

Bivariate Drought Recurrence Analysis Using Paleoclimatic Records

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Droughts are natural phenomenon during which the moisture availability is below the normal conditions. Usually droughts are mainly characterized by their durations and severities. However most of the drought recurrence analyses study those characteristics separately due to the shortness of historic records. Valuable sources of information, that complement the historical records, are the tree ring reconstructions of droughts. An approach to adapt and include dendrochronology reconstructions combined with historical records to characterize droughts is presented. The proposed approach uses the stochastic structure of the residuals of paleo reconstructions to generate equally-likely representations of past drought events. This information allows further drought recurrence analyses. For those cases, a general methodology to evaluate the frequency and risk of the occurrence of droughts is presented using a bivariate drought characterization. The theory of runs is applied to model drought recurrence as an alternating renewal process, describing droughts simultaneously in terms of their durations and severities. The procedure was applied in an analysis of droughts in Texas climatic division 5. Bivariate and univariate analyses were compared. The application shows the advantages of bivariate analyses using tree ring reconstructions in drought characterization.

H61D-09 1050h INVITED

Long-Term Drought Characteristics from Dendrochronological Streamflow Reconstructions East and West of the Continental Divide

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Colorado, along with much of the intermountain western United States, has experienced severe drought conditions in 2002. The drought, preceded by several years of below-average snowpack, has resulted in statewide projected water-year streamflows that are lower than any other year in the instrumental record. If the 2002 drought continues, it may exceed the overall severity of the 1950s drought, until now the drought of record, and the recurrence interval of this 2002 extreme drought will need to be established. The instrumental record is too short for this task, but extended records of streamflow, reconstructed from tree rings, will allow an assessment of the recurrence of this extreme drought in the context of 300 to 700 years of hydroclimatic variability.

In this study we analyze tree-ring reconstructions of annual streamflow for gages east and west of the Continental Divide for drought characteristics. East of the Divide, a composite Front Range streamflow record for Middle Boulder, South Boulder, and Clear Creek is used (1685-1987), while west of the Divide, a reconstruction of the Blue River (1539-1999) is used. Drought is evaluated by ranking both records and examining the years in which flow falls below the 50th percentile. Duration, intensity and magnitude are calculated for droughts in both records, which are then compared to assess differences east and west of the Divide. Persistent droughts are shared in both watersheds during some periods (e.g., the late 1680s, early 1700s, and the late1840s), while other episodes droughts are not (e.g., 1730s and 1750s droughts occurred only in the Blue R. watershed, and the 1690s and 1880s primarily in the Front Range watershed). The distribution of single extreme years of drought and longer multiple-year droughts are inspected to assess the representativeness of the period of instrumental record, including 2002, in the context of past centuries. For single extreme years, reconstruction results suggest that streamflow for 2002 is one of the lowest 5 years in the 400-year Blue River, and likely the lowest year of flow in the 300-year Front Range streamflow record. Sequences of drought years are also examined to characterize different onset and ending patterns surrounding droughts. In particular, the sequence of three years of somewhat below average conditions that lead to the 2002 drought is examined. No clear analogues of this pattern are evident, but sequences of a mix of slightly below average to moderate drought leading up to a severe drought year are evident in both reconstructions.

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H61D-10 1105h

A Realtime Drought Monitoring System for the USA

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The impacts of drought affect agriculture, water resources and societal well-being. The costs to society are in the billions of dollars annually in the USA, and despite efforts to alleviate the impacts through, for example, irrigation and water transfers, areas of the USA are becoming more susceptible to drought. Timely determination of the current level of drought, in hydrological, agricultural or societal terms, may aid the decision making process in reducing the impacts of drought. To this end, we use products from the Land Data Assmimilation System (LDAS) to develop a drought monitoring system that can be used in near realtime to provide indices of current drought level. The LDAS generates hourly land surface water and energy states and fluxes including soil moisture for the USA at 1/8 degree resolution. The data are generated in near realtime by forcing land surface models with meteorological forcings derived from a combination of gauge and remotely sensed sources. The LDAS has been applied retrospectively back to 1950 and this is used to construct probability distributions of monthly average soil moisture. The relative position of realtime soil moisture fields within the historic distribution provides a measure of drought in relation to the long term behaviour, at high resolution over the whole USA. The soil moisture data are available as a vertical distribution over the top 2m of the soil and so the level of drought may be determined for a variety of applications, for example, agricultural or water resources. Drought indices are normalised to the local climate, enabling the level of drought to be assessed in relation to other regions. We show examples of historic and recent droughts.

H61D-11 1120h

Drought Prediction Site Specific and Regional up to Three Years in Advance

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Dynamic Predictables has developed proprietary software that analyzes and predicts future climatic behavior based on past data. The programs employ both a regional thermodynamic model together with a unique predictive algorithm to achieve a high degree of prediction accuracy up to 36 months. The thermodynamic model was developed initially to explain the results of a study on global circulation models done at SUNY-Stony Brook by S. Hameed, R.G. Currie, and H. LaGrone (Int. Jour. Climatology, 15, pp.852-871, 1995). The authors pointed out that on a time scale of 2-70 months the spectrum of sea level pressure is dominated by the harmonics and subharmonics of the seasonal cycle and their combination tones. These oscillations are fundamental to an understanding of climatic variations on a sub-regional to continental basis. The oscillatory nature of these variations allows them to be used as broad based climate predictors. In addition, they can be subtracted from the data to yield residuals. The residuals are then analyzed to determine components that are predictable. The program then combines both the thermodynamic model results (the primary predictive model) with those from the residual data (the secondary model) to yield an estimate of the future behavior of the climatic variable. Spatial resolution is site specific or aggregated regional based upon appropriate length (45 years or more monthly data) and reasonable quality weather observation records. Most climate analysis has been based on monthly time-step data, but time scales on the order of days can be used. Oregon Climate Division 1 (Coastal) precipitation provides an example relating DynaPreds method to natures observed elements in the early 2000s. The predictions leading dynamic factors are the strong seasonal in the primary model combined with high secondary model contributions from planet Earth's Chandler Wobble (near 15 months) and what has been called the Quasi-Triennial Oscillation (QTO, near 36 months) in equatorial regions. Examples of regional aggregate and site-specific predictions previously made blind forward and publicly available (AASC Annual Meetings 1998-2002) will be shown. Certain climate dynamics features relevant to extrema prediction and specifically drought prediction will then be discussed. Time steps presented will be monthly. Climate variables examined are mean temperature and accumulated precipitation. NINO3 SST, interior continental and marine/continental transition area examples will be shown. http://www.dynamicpredictables.com

URL: http://www.dynamicpredictables.com

H61D-12 1135h

Using Satellites to Monitor Surface Wetness

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A land surface wetness product is derived from the Special Sensor Microwave Imager (SSMI), which flies on a polar orbiting satellite with global coverage. The frequencies observed by the Special Sensor Microwave Imager are sensitive to liquid water near the earth's surface. The surface wetness can originate from multiple sources (i.e. precipitation, snow melt, irrigation). In conjunction with the Department of Agriculture we seek to establish the utility of the wetness product for real time monitoring of crop conditions around the world, and demonstrate the benefit of actual SSMI observations over modeled or interpolated analyses. We provide numerous examples showing how SSMI observations provide a more realistic spatial structure in areas where surface observations are limited. Moreover, due to the sparcity of in situ observations in many rural and poor areas of developing counties extreme events are frequently undetected. Consequently, by using the SSMI to observe the true spatial distribution of water near the surface in near real time, there can be timely action to mitigate the spread of water borne diseases and famine. In addition, we demonstrate that the surface wetness product has a strong correspondence with the upper level soil moisture at many locations. By analyzing the wetness values over an extended period, one can usually determine its association with deeper soil moisture (e.g., it was excessively wet two weeks ago; therefore, deep soil moisture is probably abundant, although it appears that the surface has dried out). This product is unique and the talk demonstrates the value of the SSMI observations to enhance monitoring activity, to validate global circulation model, and/or be assimilated into energy or water budget balances.

The relationship between brightness temperatures at different frequencies is used to dynamically derive the amount of liquid water in each SSM/I observation; i.e., there are no static apriori assumptions in the computation of the wetness values. They are derived at 1/3 degree resolution, and are calibrated and validated using independent high resolution in situ observations. A 15 year climatology (1988 to 2002) serves as the base period for monthly and weekly anomalies. The wetness product is based on a standardized cumulative probability gamma function with values from zero to one hundred percent. The standardization procedure accounts for variation in surface features around a region (i.e., forest, lakes, farm land, mountains), time of year (i.e., wet versus dry season), and soil type (i.e., clay versus sandy soil).

URL: http://www.ncdc.noaa.gov/ssmi.html

H61E MCC: 120 Saturday 0830h

Twenty-Two Years of Stochastic Groundwater Hydrology I

Presiding: **V Tidwell,** Sandia National Laboratories**; R Holt,** University of Mississippi

H61E-01 0835h

Solute Transport in Heterogeneous Formations of Bimodal Conductivity Distribution

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Transport of a conservative solute takes place in a formation made up from a matrix of conductivity K_0 and porosity ϑ_0 and inclusions of properties K, ϑ. For given inclusions shape, the system is characterized by the two parameters $\kappa = K/K_0$ and the inclusions volume fraction n. In the past, approximate solutions of the flow and transport problems were obtained under the limit of low variability, i.e. $\kappa - 1 \ll 1$, and arbitrary n. The present study aims at solving the problem under the opposite limit of a dilute system, i.e. $n \ll 1$ and arbitrary κ. We are particularly interested in elongated inclusions (high length/thickness ratio) of high permeability contrast to the matrix. Such configurations are related to applications in which lenses or cracks are present in a medium of highly different conductivity. The basic procedure was developed by Eames, I., and J.W. Bush, [Longitudinal dispersion by bodies fixed in a potential flow, *Proc. R. Soc. Lond. A.*, 455, 3665-3686, 1999]. In the present study we extend the approach to inclusions of arbitrary porosity and elliptical shape, characterized by the parameter e, the ratio between the small and large axes, with emphasis on $e \ll 1$. We present the analytical solution of the flow problem and the procedure, requiring two quadratures, to calculate the macrodispersivity. Analytical solutions are obtained for two particular limits: $\kappa \ll 1$ and $\kappa \simeq 1$. The latter is compared with the limit $n \ll 1$ of small conductivity variance solutions.

The theoretical results are further applied to three types of media: horizontal lenses submerged in a homogeneous matrix, sparse cracks of random orientation in a matrix of contrasting permeability and channels of high permeability at the surface of a homogeneous medium. These discrete features are modeled as sparse elliptical inclusions of arbitrary conductivity. The longitudinal macrodispersivity is determined as function of the parameters characterizing the medium: the conductivity ratio κ, the anisotropy ratio of the ellipses e, the porosity ratio ϑ/ϑ_0 and the volume fraction $n \ll 1$ or the fracture number per unit volume. Unlike existing stochastic continuum solutions that are first-order in the logconductivity variance, the model developed here applies for an arbitrary permeability variance. This is of great advantage in media with high conductivity contrasts between the matrix and the inclusions. Simple results are obtained for inclusions of low conductivity, that lead to high macrodispersivity values that are underpredicted by the first-order continuum approach. In contrast, the presence of thin and highly conductive cracks leads to a finite longitudinal macrodispersivity that depends mainly on their length and the number density. An attempt is made to compare the present approach with the numerical simulations from the literature. This work includes material from [Dagan, G. and S. C. Lessoff, Solute transport in heterogeneous formations of bimodal conductivity distribution 1. Theory *Water Resour. Res.*, 37, 465-472, 2001] and [Lessoff, S. C. and G. Dagan Solute transport in heterogeneous formations of bimodal conductivity distribution 2. Applications, *Water Resour. Res.*, 37, 473-480, 2001]

H61E-02 0850h

Non-Unique Transmissivity Field Calibration and Predictive Transport Modeling

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Recent work with stochastic inverse modeling techniques has led to the development of efficient algorithms for the construction of transmissivity (T) fields conditioned to measurements of T and head. Small numbers of calibration targets and correlation between model parameters in these inverse solutions can lead to a relatively large region in parameter space that will produce a near optimal calibration of the T field to measured heads. Most applications of these inverse techniques have not considered the effects of non-unique calibration on subsequent predictions made with the T-fields. Use of these T fields in predictive contaminant transport modeling must take into account the non-uniqueness of the T field calibration. A recently developed "predictive estimation" technique is presented and employed to create T fields that are conditioned to observed heads and measured T values while maximizing the conservatism of the associated predictive contaminant transport model. Predictive estimation employs confidence and prediction intervals calculated simultaneously on the flow and transport models respectively. In an example problem, the distribution of advective transport results created with the predictive estimation technique is compared to the distribution of results created under traditional T field optimization where model non-uniqueness is not considered. The predictive estimation technique produces results with significantly shorter travel times relative to traditional techniques while maintaining near optimal calibration. Additionally, predictive estimation produces more accurate estimates of the fastest travel times.

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A Quarter Century of Uncertainty in the Aqueous Underground

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During the past 25 years we have seen a dramatic change in the way researchers quantify the flow of underground water and the migration of associated contaminants in which the inherent ambiguity of predictions is characterized probabilistically . The vigor and intensity of this stochastic revolution is reflected in the thousands of research articles, dozens of scientific meetings, scores of computer codes, several books, and many millions of dollars of research grants that have focused on such issues. The need for stochastic approaches derives fundamentally from the complex natural spatial and temporal variability of subsurface hydrologic systems and the very limited nature of the observations available to characterize the properties and processes involved at pertinent application scales. From an applied perspective, realistic quantification of the uncertainty in model results is required if such predictions are to form a basis for sound decisions. There have been major advances in theoretical and computational methodology, but the impact of these new methods and results in practical applications has been limited. Some of the key accomplishments and remaining challenges in this area are summarized in the context of contaminant transport analysis applied to the issue of radioactive waste disposal. Here predictions over periods of thousands to millions of years and scales of tens of kilometers are sought and a probabilistic regulatory framework is imposed. The needs for more pragmatic research approaches that will address applied issues, and for candor regarding the limitations of quantitative uncertainty assessments of model predictions are emphasized.