unique, powerful tool for scientific discoverythe extreme cost of groundwater modeling continues to limit its use. This occurs primarily because the modeling paradigm that has been employed for decades limits our ability to take full advantage of recent developments in computer, communication, graphic, and visualization technologies. In this presentation we introduce an innovative and sophisticated computational environment for groundwater modeling that promises to eliminate the current bottleneck and greatly expand the utility of computational tools for scientific discovery related to groundwater. Based on a set of efficient and robust computational algorithms, the new software system, called Interactive Groundwater (IGW), allows simulating complex flow and transport in aquifers subject to both systematic and "randomly" varying stresses and geological and chemical heterogeneity. Adopting a new paradigm, IGW eliminates a major bottleneck inherent in the traditional fragmented modeling technologies and enables real-time modeling, real-time visualization, real-time analysis, and real-time presentation. IGW functions as a "numerical laboratory" in which a researcher can freely explore in real-time: creating visually an aquifer of desired configurations, interactively imposing desired stresses, and then immediately investigating and visualizing the geology and the processes of flow and contaminant transport and transformation. A modeler can pause to edit at any time and interact on-line with any aspects (e.g., conceptual and numerical representation, boundary conditions, model solvers, and ways of visualization and analysis) of the integrated modeling process; he/she can initiate or stop, whenever needed, particle tracking, plume modeling, subscale modeling, cross-sectional modeling, stochastic modeling, monitoring, and mass balance analyses. IGW continually provides and displays results that are intelligently processed, organized, overlaid, and displayed. It seamlessly and dynamically merges heterogeneous geo-spatial data into graphical images - integrating related data to reveal the complex interplay among the geology, hydrology and chemistry across multiple spatial and time scales. This unprecedented capability in real-time modeling, steering, integration, analysis, and visualization transforms the way we model and profoundly expands the utility of groundwater model as a tool for research, education, and professional investigation related to groundwater.

URL: http://www.egr.msu.edu/~lishug/igw

H22F-06 1455h

A generalized hierarchical paradigm for modeling and visualizing complex groundwater systems across-multiple spatial scales

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We present in this paper a generalized hierarchical framework for modeling and visualizing complex groundwater systems across multiple spatial scales. A large-scale regional system is converted into a cascade of nested subsystems that are modeled sequentially with finer and finer resolution over a smaller and smaller domain. Higher levels are used to simulate larger scale dynamics whereas nested lower levels are used to simulate faster and smaller-scale processes. The upper level exerts constraints (e.g., as boundary conditions) to the lower level, whereas the rapid dynamics at lower level are aggregated (scaled up) and only manifest as aggregated effective values, providing initiating conditions to the upper. The subsystems at the same level interact with each other through their "parent" or "grand parent", etc. We implement the generalized hierarchical modeling paradigm in a sophisticated object-oriented, interactive software environment, called Interactive Groundwater. The system is designed such that a modeler can initiate on-line, interactively, and graphically an arbitrary number of submodels, submodels in a submodel, or most generally, a hierarchy of dynamically linked models and visualize in real-time multi-scale flow and transport. This generalized hierarchical paradigm eliminates the infamous "curse of dimensionality" in large-scale modeling and allows characterizing complex groundwater systems with unprecedented resolution and efficiency. At the meeting, we will demonstrate live the innovative software environment and the power of real-time hierarchical groundwater modeling.

URL: http://www.egr.msu.edu/~lishug/igw

H22F-07 1510h

Geostatistical Modeling of Uncertainty Attached to the Spatial Distribution of Arsenic in Groundwater of Southeast Michigan

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Assessment of the health risks associated with exposure to elevated levels of arsenic in drinking water has become the subject of considerable interest and some controversy in both regulatory and public health communities. The objective of this research is to explore the factors that have contributed to the observed geographic co-clustering in bladder cancer mortality and arsenic concentrations in drinking water in Michigan. A corner stone is the building of a probabilistic space-time model of arsenic concentrations, accounting for information collected at private residential wells and the hydrogeochemistry of the area. Because of the small changes in concentration observed in time, the study has focused on the spatial variability of arsenic, which can be considerable over very short distances. Various geostatistical techniques, based either on lognormal or indicator transforms of the data to accommodate the highly skewed distribution, have been compared using a cross validation procedure. The most promising approach involves a soft indicator coding of arsenic measurements, which allows one to account for data below the detection limit and the magnitude of measurement errors. Prior probabilities of exceeding various arsenic thresholds are also derived from secondary information, such as type of bedrock and surficial material, well casing depth, using logistic regression. Both well and secondary data are combined using kriging, leading to a non-parametric assessment of the uncertainty attached to arsenic concentration at each node of a 500m grid. This geostatistical model can be used to map either the expected arsenic concentration, the probability that it exceeds any giventhreshold, or the variance of the prediction indicating where supplementary information should be collected. The accuracy and precision of these local probability distributions is assessed using cross validation.

H22F-08 1525h

3D Geological Mapping : a Pioneering Tool for Underground Water Management

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Modern geology needs accurate representation of underground volumes. Because 3D geological mapping was so far based on the interpretation of expensive 2D and 3D seismic surveys, it has not been much used in water exploration and exploitation. We present a pioneering way to generate accurate and efficient 3D geological maps using already existing and inexpensive data sets, in a context of fresh water management in the Beirut watershed (Lebanon). Our approach is based only on surface information coming from a published geological map, remotely sensed data, and a Digital Elevation Model (DEM). In order to generate the 3D geological map, we used a 3D geological modeler (EarthVision developed by Dynamic Graphics Inc.) that combines and extrapolates the surface information into a coherent 3D data set, to represent volumes. Once the 3D map has been calculated, graphical representations allow the user to examine it from various directions, slice it to generate cross-sections, or disassemble it to examine individual geological units. Such 3D geological map is a powerful tool to understand both the regional geological settings and the local relationships between faults, horizons and topographic surface. A major advantage of our 3D map is that it offers the possibility to attribute rock properties to each geological volume unit. In order to illustrate how ground water reserves can be quantified, we simulate the porosity of one water reservoir leading to the calculation of rock pore volume. We also calculated a cellular grid in conjunction with the porosity model that quantifies the water circulation within the reservoir. These results are of major significance when planning future wells or for any water and reserve management tasks. Any other underground resources could also be described by such a 3D geologic model. This methodology can be applied to other parts of the world, using the same kind of input geological map, complemented with field and remote sensed data when needed and available.

H22G MCC: 3022 Tuesday 1340h

Hydrologic Flow Near the Earth's Surface I

Presiding: **D A DiCarlo,** USDA Agricultural Research Service**; D Barry,** University of Edinburgh

H22G-01 1345h INVITED

The Poisson-Boltzmann Equation as a Dynamical System

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The Poisson-Boltzmann equation is a nonlinear ordinary differential equation that provides a rather accurate model for the behavior of the diffuse ion swarm near charged colloidal particles suspended in dilute aqueous media. Analytical solutions of this equation are known only for planar charged surfaces (e.g. layer type clay minerals), but an iterative method of approximate solution suggested by J.-Y. Parlange in 1972 has enjoyed widespread application to both cylindrical (e.g. polyanions) and spherical (e.g. metal oxides) charged surfaces. Since the Poisson-Boltzmann equation is a special case of a generic nonlinear ordinary differential equation whose other realizations include well known mathematical models in astrophysics, nuclear engineering, and theoretical ecology, progress in the analytical solution of the Poisson-Boltzmann equation also contributes to the elucidation of its mathematical siblings. In this paper we show that the Poisson-Boltzmann equation can be derived from a Lagrangian variational principle and that it can be put into one-to-one correspondence with a Hamiltonian dynamical system. This correspondence opens the door to utilizing the vast array of mathematical results available in Lagrangian and Hamiltonian dynamics. For example, Noether's theorem can be applied to find first integrals and an exact Hamilton-Jacoby equation can be constructed, the solution of which is tantamount to solving the Poisson-Boltzmann equation. This latter avenue is explored for planar, cylindrical, and spherical geometries emphasizing the utility of the Parlange approximation scheme.

H22G-02 1405h

Improving the Dupuit-Forchheimer Approximation for Free Surface Flow in an Unconfined Aquifer

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The classical Dupuit-Forchheimer (DF) approximation for groundwater free surface flow in an unconfined aquifer assumes that the vertical component of the seepage velocity is zero. This assumption is expected to be least accurate when there is non-zero accretion at the free surface. The DF approximation leads to a nonlinear diffusion equation satisfied by the height of the free surface. The general principles of integral methods used by Yves Parlange are to assume some simple approximate shape for some unknown function, and then to choose the parameters of this function to satisfy some known integral relation of the flow system. The DF approximation is improved by assuming that the vertical velocity component is zero at the impermeable horizontal base, and increases linearly to its unknown value at the free surface. The well known Guirinsky potential which depends only on the free surface height

corresponds to the DF assumptions. Youngs used an integral relation to define a new potential which depends on the free surface height and also on the vertical velocity component, and which for steady flow satisfies a Poisson equation in the horizontal coordinates. We use the assumption of linear variation of vertical velocity to calculate an approximation to the Youngs potential. In some simple flow systems such as the classical dam problem this leads to a simple differential equation for the free surface height, which can be solved numerically. In some cases simple explicit approximations can be found for quantities of interest, such as the maximum free surface height between drainage ditches.

H22G-03 1420h

Approximate Similarity Solutions to the Boussinesq and the Porous Medium Equations.

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The Boussinesq equation models unconfined groundwater flow under the Dupuit assumpion that the equipotential lines are vertical, making the flowlines horizontal. For certain classes of initial and boundary conditions it is possible to reduce problem to a nonlinear ODE and construct approximate analytical solutions. We extend the approach of Lockington, Parlange, Parlange, and Selker (2000) that constructed quadratic approximate similarity solution for the power-law head boundary condition at the inlet. Our new cubic approximation as the original quadratic approximation preserves the scaling properties of the problem, but it produces much better results. Also, we extend this approach to other types of boundary conditions. Discussed method is rather general and we apply it to the porous medium equation that describes the laminar flow of the polytropic gas through porous media.

H22G-04 1435h

Analytical Solutions Of The Degenerate Diffusion Equation

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Certain nonlinear diffusion equations of degenerate parabolic type display a finite speed of propagation of disturbances. This mathematical behavior can be used to describe a wide range of nonlinear phenomena such as the penetration distance of a thermal layer, the boundary of a reaction zone, or a wetting front unsaturated soil moisture flow. However there are two main-difficulties in obtaining solutions to problems of this class. One is that the location of the interface is not known a priori and must be discovered during the analysis. The other is the fact that the differential equation is singular in the neighborhood of the interface. The solution technique developed and presented in this work overcomes these difficulties by extracting a local solution of the differential equation in the neighborhood of the diffusing front. One profound result is the discovery that the velocity of the front is entirely controlled by the first term of the spectral series expansion. Also, by capturing the critical behavior of the solution in the region of the singularity and incorporating the behavior as a dominant factor, the series expansion is provided a means for very rapid convergence. The versatility of the solution technique is demonstrated by solving various boundary value problems covering a broad range of interest and the solutions are tested against previously published results.

H22G-05 1450h

Operator Fractional Motion: Permeability Fields with Anisotropic Long Range Dependence and the Effect on Plume Growth

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Anisotropy in the dependence structure of hydraulic conductivity K is typically handled by a dilation of one or more physical coordinates. However, aquifer K measurements usually have completely different scaling behaviour in the horizontal versus vertical directions. Mandelbrot's original definition of fractional motion is based on fractional-order differentiation or integration of a stable noise, which in a discrete setting can be represented by a field of iid random numbers with any distribution. In one-dimension, fractional integration or differentiation of the noise is handled in Fourier space by division by $p(ik)^A + q(-ik)^A$, where $A = H + 1/2$ is the scaling exponent (H is the Hurst coefficient) and p and q represent the relative weight on forward versus backward integration. The influence of large values may have directional dependence, i.e., the occurrence of K structures may be causal. A subset of this is isotropic, $p = q = 1/2$, leading to the familiar division by $|k|^A$. For multidimensional self-similarity, the exponent A is replaced by a matrix $\mathbf{A}$. Furthermore, the weighting of the directional integrals is described by a random measure (the mixing measure) on the unit sphere. The result is an Operator Fractional Motion (OFM) that has, what is called in hydrologic applications, "Generalized Scale Invariance." The utility of the OFM is that 1) similarity of extreme K values may be restricted to a small set of directions, as one might expect in fractured rock or fluvial depositional environments (such as braided streams), and 2) the scaling matrix A has unique eigenvalues that describe the scaling (e.g., the Hurst coefficients) in any direction. The eigenvectors of A need not be orthogonal. For sedimentary deposits, we might expect that the K field is positively correlated in the horizontal direction, but anticorrelated in the vertical. It has been suggested that a plume's continuously non-Fickian growth rate can be predicted by measuring H (therefore A) in the direction of transport. We generate synthetic K fields with identical statistical properties in the direction of transport, but different values of A in the transverse direction. The growth of plumes in these fields strongly depends on the scaling properties of the K field in the transverse direction. Low values of transverse A lead to plumes that quickly become quite Fickian.

H22G-06 1505h INVITED

Land-Atmosphere Exchange Over Complex Terrain

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We study turbulent boundary layer flow over surfaces with varying roughness scales. The goal is to use LES results to formulate effective boundary conditions in terms of an effective roughness height and blending height. The LES are implemented with the dynamic Smagorinsky model based on the Germano identity. To account for geometric complexities associated with surface heterogeneity and its effects on the subgrid scales, the Lagrangian dynamic SGS model is implemented. A systematic array of simulations of flow over patches of differing roughness is performed, covering a range of patch length scales and surface roughness values. The simulated mean velocity profiles are analyzed to identify the height of the blending layer and to measure effective roughness lengths. We propose a simple expression for effective surface roughness and blending height knowing local surface patch roughness values and their lengths. Predictions of the model agree well with the LES results.

H22G-07 1525h

Integrated Modeling of Infiltration, Evapotranspiration, Recharge, Subsurface Flow, Surface Runoff, and River Flow with First Principle, Physics-based Approaches

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Over the past 30 years, progress in the development of physics-based models for individual processes of infiltration, evapotranspiration, recharge, moisture redistribution in vadose zone, groundwater flow, surface runoff, and river flow has been remarkable. However, these individual processes are continuously and dynamically coupled over various spatial and temporal scales. In the past, each individual process was often investigated assuming other coupling and influencing processes were a priori. For example, to model overland flow (surface runoff), it was often implicitly assumed that the infiltration was known and the feedback from groundwater flow and river flow were not explicitly enforced. Integrated approaches to modeling coupled processes have gained momentum recently. Many integrated models have achieved the coupling via external or internal linkage of individual process-level models. As a result, these models often have to introduce undue empiricism. This paper presents the development of an integrated numerical model of the aforementioned processes. A rigorous coupling of these hydrological processes is achieved with the first principle approach by imposing the continuity of volumetric fluxes and state variables. In this integrated model, any process between two media is the natural consequence of interaction and feedback between processes occurring in the media. For example, infiltration and recharge are spatially and temporally varied and are the consequence of interacting flow processes on the land surface (overland) and in the subsurface media and rivers. Numerical implementations of the theoretical coupling are thoroughly discussed. Several example problems will be used to demonstrate theoretical and application aspects of this model. Key Words: Infiltration, Evapotranspiration, Recharge, Surface Runoff, Groundwater Flow, River Flow, Numerical Model

H22H MCC: 3024 Tuesday 1600h

Early Results From NASA's EOS Aqua Spacecraft Mission II *(joint with A, OS)*

Presiding: **S M Graham,** NASA Goddard Space Flight Center**; R Spencer,** University of Alabama in Huntsville

H22H-01 1600h INVITED

Observation of Sea Surface Temperature by two Microwave Radiometers; AMSR and AMSR-E

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In 2002, two passive microwave radiometers (MR) were launched successfully into the space. One is the Advanced Microwave Scanning Radiometer-E (AMSR-E) aboard AQUA of the National Aeronautics and Space Administration (NASA), and the other is the AMSR aboard the Advanced Earth Observation Satellite-II (ADEOS-II) of the National Space Development Agency of Japan (NASDA). AMSR/AMSR-E have low frequencies, such as 6 and 10 GHz, and one of new parameters derived from those frequencies is the sea surface temperature (SST). MR have a merit to observe geophysical parameters through clouds, and AMSR/AMSR-E also can observe SST through clouds. We can trace continuously the oceanic eddies in the Kuroshio Extension region, from 5 day averaged SST images. On the other hand, MR have a demerit of low spatial resolution. The spatial resolution of instantaneous SST of AMSR or AMSR-E is an order of 50 Km. But, AMSR/AMSR-E take SST samples with 10Km interval. We can see finer structure than 50Km, by composing two sensors data during several days. We will validate composed SST, by using the infrared data of Global Imager (GLI) aboard the ADEOS-II.