

the current sampling frequency is sufficient (or redundant) at monitoring locations; and give estimates of uncertainty at spatial locations of interest.

H31B-05 0830h POSTER

Transport and Retention of *E. coli* in Saturated Well-Structured Soil.

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Manure is a source of several bacterial pathogens that can potentially contribute to surface and ground water contamination. We hypothesized that manure could enhance bacteria survival, and manure particulates could compete for soil adsorption sites and serve as carriers. Colloid transport in soil is affected by soil structure and flow velocity, because only the pathways formed by large pores can serve as conduits for colloidal particles. Therefore, transport of manure-borne bacteria should be affected by flow velocity. To test these two hypotheses, column experiments were conducted with Tyler silt loam soil. Undisturbed 20-cm soil columns from the A horizon were subjected to saturation. A pulse of 4% filtered bovine manure solution containing *E. coli* bacteria and KCl was passed through columns, preceded and followed by deionized water infiltration at 9 degrees C during 10 days. Volumes of the pulses ranged from 1.27 to 1.35 column pore volume. *E. coli* concentrations, chloride content and turbidity were measured in influent and in effluent. After the experiment, columns were cut into 2-cm layers to enumerate viable bacteria in pore solution and bacteria attached to the soil, and to measure bulk density and water content. Complementary batch experiments were carried out to measure attachment of *E. coli* to soil in presence of various amounts of manure Attachment of *E. coli* to soil was much smaller in presence of manure, and decreased with the increase in manure contents. The attachment isotherm was linear without manure, and convex in presence of manure. Maximum bacteria concentrations in leachate were observed before the first pore volume of soil solution has been displaced with the influent. Maximum breakthrough chloride concentrations were observed after the one pore volume of influent passed the column. Effluent turbidity peaked and then stabilized at low levels. Bacteria content in soils varied within two orders of magnitude after the breakthrough experiment. From 1% to 3% of the total applied bacteria were found in pore solution, and from 5% to 18% were attached to soil particles. Individual columns had different average water flow velocities ranging from 2.3 to 9.3 cm/day. *E. coli* and manure transport was similar at low velocity during the whole experiment. At high flow rates, the *E. coli* transport was similar to the chloride transport until 0.5 volume of the pore solution was replaced with the influent, and was retarded after that. An increase in flow velocity caused larger cumulative breakthrough per unit of the influent pore volume. Bacteria and manure breakthrough curves had much longer tails compared with chloride. The *E. coli* attachment to soil in the fast-flow columns was similar to that in the batch experiment with 4% manure content. Attachment in the batch experiments with 0% and 2% manure bracketed the attachment observed in the slow-flow columns. Overall, slow manure transport and high concentration in pore solution decreased attachment to soil and increased survival of *E. coli*. Increase in flow velocity decreased attachment and entrapment of manure and bacteria in pore space. Variability in flow velocity and its effect on *E. coli* and manure transport were probably caused by different macroporosity in individual columns of the same soil.

H31C CC: 220 C-E Wednesday 0830h

Groundwater and Climate Change II Posters

Presiding: D M Allen, Simon Fraser University; G van der Kamp, National Water Research Institute

H31C-01 0830h POSTER

Climate Change and Groundwater in the Northern Prairies of North America

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The semi-arid climate of the glaciated northern plains of North America results in limited water resources for human activities and for sustaining the aquatic ecology of surface waters. The region is almost entirely covered by clay-rich glacial deposits and thus significant groundwater flow is limited to sand and gravel aquifers and to the weathered and highly fractured clay and glacial till within 10 m of the ground surface. Observation well records for the region indicate that the response of groundwater levels to climatic variability over the last 40 years can be classified according to aquifer type, ranging from relatively sensitive unconfined aquifers and shallow fractured glacial till to deep confined aquifers that have very little sensitivity to climate variation. Long-term hydrometric records for lakes and streams indicate that in the decades prior to about 1920 base flow in streams was greater than at present, suggesting that groundwater levels were also considerably higher. Groundwater flow through the fractured active layer near the ground surface may have been much stronger than it is now. It is not clear as yet to what extent climate variation or land-use changes were the key factor in the long-term hydrologic changes during the twentieth century. Hydrologic modeling studies of the region are on-going in an attempt to simulate the response of both surface and groundwater to climatic variability and to identify the sensitivity of surface and ground water resources to climate change.

H31C-02 0830h POSTER

Analysis and Modeling of Low-Frequency Runoff Oscillations within Hydrologic Similarity Regions of Colorado River Basin

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This study proposes to apply "hydrologic similarity regions" (Winter et al, 2001, AWRA, 37, 335-349) as a strategy for modeling climate and landuse effects on runoff across the Colorado River Basin. A "Hydrologic Similarity Region" can be defined for our purposes, as a qualitative measure of the spatial scale over which climate, hydrogeology, and land surface processes are unique or independent in some sense. 50 to 80 years of monthly average precipitation, temperature and streamflow records from stations distributed from the upper Green river to the Gulf of California formed the database of the work. The research demonstrates: (i) a signal processing strategy for interpretation of historical precipitation, temperature and runoff in the Colorado River Basin for the purpose of detecting low-frequency (annual to decadal) climate or landuse trends and oscillations, (ii) a method for comparing time scales and response functions of hydrologic similarity regions and quantifies the response using a dynamic hydrologic model, (iii) the optimal estimation of model parameters based on historical rainfall-runoff time series. The results show that HLRs provide a useful conceptual framework for large-scale, low-dimensional dynamic modeling (Duffy, 1996, WRR, 32(8), 2421-2434). Comparison of model and reconstructed phase-plane plots for precipitation, evapotranspiration and runoff illustrate the impact of long term climate on terrestrial hydrology within the major physiographic regions of the Colorado River Basin. Sensitivity of the runoff response to model parameters, climate, and physiographic conditions are presented in terms of dimensionless groups.

H31C-03 0830h POSTER

Paleodrainage Networks Recharging the Nubian Aquifer Dakhla and Kufra Sub-Basins Revealed From SIR-C and SRTM Data

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The Nubian Aquifer system of northeast Africa is one of the world's largest potable groundwater reserves. Because it occurs in one of the world's driest climates, understanding its history and behavior has both scientific and practical importance. The sparse settlement of the huge (2x10⁶ km²) area underlain by this aquifer, and the limited resources of the nations in which it occurs, result in a situation where knowledge of its origin and history is incomplete. We defined the paleodrainage channels across the entire aquifer using Shuttle Radar Topography Mission data (SRTM) and ARC/INFO watershed delineation routines. The SRTM-based streams, which are now partially covered by sand sheets and dunes, were validated by comparison to stream distribution inferred from co-registered Space-borne Imaging Radar-C/Synthetic Aperture Radar (SIR-C) data. A good correspondence between the SRTM-derived channels and the SIR-C derived channels is evident. Results indicate that there are two major paleodrainage patterns: the first extends in a NE direction from the highlands of NW Sudan towards the Kharga oasis in Egypt and feeds the underlying Nubian Aquifer Dakhla sub-basin. The second trends N-S from the highlands of northern Chad along the eastern borders of Libya and feeds the underlying Nubian Aquifer Kufra sub-basin. We postulate that extensive recharge of the underlying Nubian aquifer must have occurred beneath the paleodrainage networks during previous wet climatic periods since the Nubian sandstone crops out across major sectors of the entire area covered by the delineated watersheds. The autochthonous recharge is supported by the presence of surrounding highlands that are largely formed of basement uplifts suggesting that these sub-basins are probably largely disconnected. This suggestion is further corroborated by the progressive increase in ages of Nubian Aquifer groundwater in the Dakhla sub-basin along the hydraulic gradient (from SW to NE). For example, the youngest ³⁶Cl age (~50 kyr) was obtained from East Uweinat and the oldest ⁸¹Kr age (~1million yr) was obtained from Bauti-1 (Bahariya).



H31C-04 0830h POSTER

Large-Scale Integrated Hydrologic Modeling: Response of the Susquehanna River Basin to 99-Year Climate Forcing

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This research focuses on large scale (10,000-100,000 sq. km) simulation of regional water budgets using digital data sets and a fully-coupled integrated (surface/subsurface) hydrologic model for the Susquehanna River basin (SRB). The main objectives in this effort are to develop an appropriate and consistent data model for the SRB, delineate groundwater basins, assess the dominant modes and spatial scales affecting the SRB, and estimate the dominant hydrologic response of relatively un-gaged sub-basins. The data model primarily consists of 1) a 99-year climate and vegetation history from PRISM and VEMAP, 2) land surface parameters from various EPA, NRCS, and USGS reports and data sets, and 3) hydrogeology from various state geologic surveys and reports. MODHMS (MODFLOW Hydrologic Modeling System) is a fully-coupled integrated hydrologic model that simulates 3-D variably saturated subsurface flow (Richard's equation), 1-D channel flow and 2-D surface runoff (diffusion wave approximation), canopy interception and evapotranspiration, and offers robust solutions to the governing equations for coupled surface/subsurface flow. The first step in this approach uses a steady-state simulation to estimate regional recharge, to delineate groundwater basins within

each river basin, and to assess the validity of the hydro-logic landscape concept. The long term climate history is then used to drive a transient simulation that will be used to study the effect of seasonal, inter-annual, and decadal climate patterns and land use on the persistence of wet and dry cycles in soil moisture, on recharge, and on the regional water budget as a whole.

H31C-05 0830h POSTER

Regional Groundwater Modeling for Source-Area Delineation and Recharge Estimation From Long Term Climate Forcing

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This research is developing a 3D groundwater model of the Spring creek and Spruce creek drainage basins in central Pennsylvania. The purpose of the model is to evaluate the source-area for drinking water supplies, rates of areal and focused recharge and the long-term effect of seasonal, annual and decadal climate variations on recharge and groundwater levels. A solid body model is developed to represent the hydrostratigraphy from borehole data and geologic cross-sections. The hydrostratigraphic model allows parameterization of the 3D model using GIS (Geographical Information System) tools and the GMS groundwater modeling system. Other necessary software includes the HUF package, Modflow and Modpath. At this time we have developed a GIS data-model for climatic inputs and parameters including topography, geology, precipitation, and evapotranspiration. The data-model is fully compatible with the physical model. Preliminary results for a simple 2 layer model simulation shows the importance of terrain and hydrostratigraphy on the simulated flow field. At present the model is being used to determine the distribution of residence time or travel time from all points within the basin to the outlet using Modpath. The poster will show estimated rates of recharge over the basin. The model is used to predict the subsurface groundwater divide between the Spring creek and Spruce creek basins. In this case we show that the topographic divide and groundwater divide are not coincident.

H31C-06 0830h POSTER

Evapotranspiration from Wetland Pond Complexes in the Western Boreal Forest, Alberta, Canada

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Wetlands on the Canadian Western Boreal Plain account for as much as 50 % of the landscape and provide one of the most important waterfowl habitats in North America as well as representing a significant regional water resource and carbon pool. In this sub-humid region potential evapotranspiration (PET) exceeds precipitation in most years and consequently these wetland complexes are very vulnerable to any climate change that may alter patterns of precipitation and evapotranspiration. The permanence of these wetland and pond systems depends on the underlying glacial deposits, topography and evapotranspiration. Flow within these wetland pond catchments is from the pond to the hill-slope for most of the time and small changes in precipitation can result in a dramatic change in runoff. Increased climatic variability (natural or anthropogenic) will likely influence the duration of drought cycles. However, whether or not, or for how long these ponds may dry completely remains unknown. Thus, it is essential to understand the ecological and physiographic factors within these complexes that control evapotranspiration, and how these are influenced by large scale climate and climate cycles. This paper investigates not only open water evaporation from the ponds, but also the role of ET from the surrounding riparian peatlands, and illustrates how the evaporative regimes from these units and their linkages with the ponds are significant to the permanence of these water bodies.

H31C-07 0830h POSTER

Assessing the Impacts of Land Use Change and Increased Precipitation on Streamflow

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Increased precipitation, one aspect of climate change, has been documented in many parts of the United States and may lead to increased streamflow and flood frequency. Urbanization can also increase streamflow by elevating runoff levels through the addition of impervious surfaces. Increased precipitation and urbanization have occurred simultaneously in many areas, necessitating the quantification and separation of their impacts in order to advance our understanding of changing flood frequencies and magnitudes. This study is an examination of the relative impacts of combined changes in precipitation events and land use on flooding in small watersheds. Watersheds selected for analysis are distributed throughout the climate regions of the United States. Each has over 50 years of precipitation and streamflow data, a distinct land use, and an area less than 100 km². Watershed selection is based on these criteria, with streamflow and precipitation trend analysis to be conducted after site selection is complete. Quantitative examination of upstream land use change in conjunction with precipitation change will constrain the factors influencing streamflow and flooding. By analyzing spatial and temporal trends in precipitation and streamflow for climatically-varied watersheds, this study will improve our understanding of process interactions in a complex environmental system responding to climate change.

H31D CC: 220 C-E Wednesday 0830h

Percolation and Related Processes in Porous Media Posters (joint with NG)

Presiding: R P Ewing, Iowa State University; P R King, Imperial College London

H31D-01 0830h INVITED POSTER

Hydraulic Properties of Unsaturated Porous Media From Percolation Theory

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Percolation theory can be used to calculate transport properties in disordered media, such as solute diffusion and the hydraulic conductivity. Experiments have shown that diffusion of solutes in porous media vanishes linearly as threshold moisture content is approached. An empirical relationship gives the threshold moisture content as approximately the square root of the surface area to volume ratio of the medium. The first relationship demonstrates the relevance of percolation theory in its continuum application (non-zero transport in a given phase requires phase continuity), while the second can be shown to be based on the validity of a fractal description of the medium. Percolation-type scaling behavior of the unsaturated hydraulic conductivity is not observed; in fact critical path analysis from percolation theory using the threshold moisture content for the critical moisture content for percolation gives the hydraulic conductivity in agreement with experiment. However, cross-over from the validity of critical path analysis to the percolation scaling regime is accompanied by a rapid change in the slope of the conductivity, leading to rapid increases in experimental equilibration times, failure to observe equilibrium pressure-saturation relations, and excess water in the medium for a given tension. These effects confound interpretation of experiments, but unification within a percolation perspective allows quantitative predictions of both the equilibrium and non-equilibrium behavior.

H31D-02 0830h INVITED POSTER

Network Models of Pore Structure and Percolation Theory Concepts for Modelling Capillary Pressure Curves and Relative Permeability Characteristics.

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Network models of pore structure using percolation theory concepts were developed at the University of Waterloo by Chatzis and Dullien since 1976. At present, the modeling of pore structure, capillary and transport phenomena in porous media using network models that incorporate percolation theory concepts is commonly performed by many researchers world-wide. A key feature in the use of network models is assign pore structure data for pore throats to the bonds of a lattice and pore structure data for the pore bodies to the sites of the lattice. The manner in which the pore structure data are assigned to the bonds and to the sites of a lattice is very critical in determining the pore space accessibility to the non-wetting phase, the capillary pressure characteristics and the two phase flow properties of network models, which in turn are utilized for the prediction of capillary pressure curves and relative permeability curves. There is a plethora of publications where bond percolation type of analysis is being performed with no special attention given on pore size and the corresponding pore volume assigned to a particular pore size in the network model. An attempt is made to clarify this contentious issue in the literature. Another equally important issue is that of percolation threshold probability and how the spatial variation of distributing pore structure information affects the pore space accessibility and two-phase flow characteristics of such network models. Examples of results obtained in our research group over the past 20 years along with that of others in literature will be also presented and discussed.

H31D-03 0830h POSTER

Diffusion Iso-Surfaces and Correlation Lengths in Low-Connectivity Structured Rock

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Diffusive exchange between flowing fractures and the tuff matrix is hypothesized to be a major retardant in the migration of radionuclides from the proposed nuclear waste repository at Yucca Mountain, NV. Studies and simulations to date have assumed that the tuff matrix can be treated as a homogeneous, low-diffusivity medium. However, a recent study by Hu and Ewing showed that the tuff porespace is only slightly above the percolation threshold, meaning that diffusion scales with distance up to the percolation correlation length X_c . Knowing this length could substantially improve predictions of diffusive retardation. This length X_c in a structured medium is presumably $X_c = X_0 (\Theta - \Theta_c)^{\nu}$, where X_0 is the correlation length of the medium's structure, Θ is volume wetness, the subscript c denotes the critical volume for percolation, and ν is the length exponent from percolation theory. Using random walk simulations on low-connectivity structured lattices, we evaluate our hypothesis that the correlation length can be given as the length at which diffusion iso-surfaces change from fractal to non-fractal.

H31E CC: 520 A Wednesday 0830h

Advances in Understanding the Global Water Cycle I

Presiding: J Entin, NASA Headquarters; R Avissar, Duke University; R G Lawford, International GEWEX Project Office International GEWEX Project Office

H31E-01 0835h

Emerging Opportunities in Synergistic Water Cycle Research

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