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The availability of remotely-sensed precipitation data from radars and satellites is increasing. These observing platforms could potentially improve substantially on information available from rain gauges because of their ability to provide expanded spatial and temporal coverage. However, the quality of these new and emerging data sets needs to be examined before they are used operationally in hydrologic forecasting models. In this research, we investigate the errors in streamflow simulation when remotely-sensed precipitation estimates are used as forcing for a hydrological model. We apply a fully distributed hydrologic model to Juniata River Basin in Pennsylvania (catchment area 8687 km2) using several types of precipitation inputs including gage only, radar only, satellite only and multi sensor products such as merged gauge-radar and merged gauge-satellite. The radar estimates used in this study are hourly Digital Precipitation Arrays from the WSR-88D while the satellite estimates are hourly Hydroestimator products produced by the National Environmental Satellite, Data and Information Service. The differences between each of these products will be quantified, and streamflow errors propagated through the system will be identified.

H31A-26 0830h POSTER

Assessment of Satellite Rainfall Error Propagation in Land Surface Hydrologic Variables

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Precipitation is the most important component of a mixture of hydrologic variables and is critical to the study of water and energy cycle. In this research we study the propagation of precipitation retrieval uncertainty in the simulation of hydrologic variables and fluxes (soil moisture, runoff, latent heat etc) for different satellite retrievals, different spatial grid scales, and for varing vegetation cover. We explore three satellite rain retrievals: one based on IR-only data, a second based on combined PM and IR rain product, and a third based on a combined MW-IR and lightning data; and three spatial grid resolutions: 0.25, 0.5 and 1.0 degree. This investigation is facilitated by NCAR's offline Community Land Model (CLM) forced with in situ met data from Oklahoma Mesonet and high-resolution (0.1-degree /hourly) rain gauge-calibrated WSR-88D radar based precipitation fields. In turn, radar rainfall is replaced by the three satellite rain estimates at coarser resolution (0.25, 0.5 & 1-degree) to determine their impact on model predictions. A fundamental assumption made in this study is that CLM can adequately represent the physical land surface processes.

H31A-27 0830h POSTER

Including Model Input Uncertainty In Hydrologic Modeling

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Several methods have been developed in hydrologic modeling to estimate prediction uncertainty resulting from imprecise model parametric settings. It is realized, however, that additional sources of uncertainty may be present in model inputs (i.e., the precipitation estimates), the model structure, and in the observations of streamflow. An ensemble approach is developed in this study to estimate the total prediction uncertainty of streamflow for three events impacting the Blue River Basin in Oklahoma. The QPE SUMS precipitation algorithm produces as many as nine different estimates, each of which is derived from ground-based radar, infrared satellite data, rain gauges, or combinations. The diversity of sensors used to generate the rainfall estimates provides for the creation of a rainfall probability distribution function, which is believed to encompass the "true" rainfall. All rainfall estimates are input to the Vflo hydrologic model which employs three sensitive parameters. A combined ensemble is produced from the different rainfall estimates combined with model parameter perturbations. It is shown how simulation bounds derived from the combined input-parameter ensembles encompass observations for the cases studied. Consideration of uncertainty in the model inputs is essential for hydrologic predictions cast in a probabilistic framework.

H31B CC: 220 C-E Wednesday 0830h

Coupling Microbial Activity, Water Flow, and Solute Transport in the Subsurface II Posters *(joint with B)*

Presiding: **J E Smith,** McMaster University**; M Rockhold,** Pacific Northwest National Laboratory

H31B-01 0830h POSTER

The Presence and Dynamics of Entrapped Biogenic Gas Bubbles in Peat I: Biogeochemical Implications

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Production and emission of peat gas has attracted great interest since substantial amounts of methane (CH_4) are emitted to the atmosphere from peat soils. Many studies indicate supersaturation of methane in peat water indicating a high potential for gas bubble formation. However, observations of bubbles in peat are often only qualitatively described, and as such knowledge of the dynamics of entrapped gas bubbles in peat is still greatly limited. Using field measurements at a poor fen in central Québec, we investigated variations in production and volume of gas during the growing seasons of 2002 and 2003. Measurements made with TDR and subsurface gas collectors revealed that gas volume varied throughout the growing season. There was also a short-term temporal variability related to hydrostatic and barometric pressure changes as well as a great spatial variability. Gas collected from bubbles revealed the presence of CH_4. However, its concentration also experienced spatio-temporal variability. The presence of these bubbles has important biogeochemical implications including the development of enhanced localized CH_4 diffusive gradients, alteration of local flow paths affecting substrate delivery, and the potential episodic release of CH_4 via ebullition events. These interactions must be included in peatland models to accurately describe the hydrology and greenhouse gas emissions from these ecosystems.

H31B-02 0830h POSTER

The Presence and Dynamics of Entrapped Biogenic Gas Bubbles in Peat II: Hydrological Implications

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In peat soils, the influence of hydrology on biological processes has been recognized widely as the water table determines redox and wetness conditions and water flow paths are critical for delivery of substrate and nutrients. On the other hand, biological activity may also change the hydrological conditions significantly. In peat, the gas production (CH_4, CO_2) of decomposing bacteria causes formation of bubbles. These have a great potential to change peat hydraulic properties, compressibility and pore-water pressure distribution and hence change gradients and flow paths as well as affect the peat stress and compression. Using field measurements at a poor shallow fen in central Québec we explore the hydrological implications of bubble volume dynamics in peat. The temporal variation of hydraulic conductivity, measured with piezometers, showed good correlation with gas content at those locations where highest gas content was found, but less at other places, indicating that the clogging effect of bubbles varies and may be of different nature in different types of peat. Bubbles both clogging pores and building up pressure as they grow caused great variations of pore-water pressure in localized zones. These zones may deflect flows driven by dominating flow paths to an extent that depends on how large the zones grow. As peat soils are highly compressible, they shrink and swell because of changes in water pressure and peat buoyancy and presence of bubbles and excess pressure zones therefore complicates the description of the hydrology and traditional methods and models are therefore far from satisfactory.

H31B-03 0830h POSTER

Spatial trends of potential denitrification below the root zone in an agricultural setting, San Joaquin Valley, California, USA

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Contamination of groundwater by nitrate is a major problem worldwide. Under anaerobic conditions in the subsurface, reduction of nitrate to nitrogen gas via denitrification may mitigate the problem. Denitrification has been studied extensively in the shallow subsurface, but few studies have been done to examine the potential for denitrification below the root zone. In this study, we examined spatial trends in potential denitrification rates in the sub-root unsaturated and saturated zones. Sediment samples were collected from bore holes located in the San Joaquin Valley near Merced, California. Samples were analyzed for potential denitrification rates using acetylene block enzyme assays. Maximum denitrification rates, microbial growth, and lag coefficients were calculated by calibrating a numerical model of microbial growth and substrate consumption to the experimental data. The rate coefficients were compared to hydrologic regime, depth, grain size, and organic carbon content of the sediment samples. Preliminary results show complex spatial trends in potential denitrification rates. In samples taken from near the water table and near the ground surface, rates were comparable. In the unsaturated zone and deep saturated zone, rates were orders of magnitude lower. Variability between sites and hydrologic regimes could be explained in part by abundance of organic carbon. We speculate that limitations on microbial growth and transport by sediment properties and hydrologic regime also control the ability of subsurface microbial communities to carry out denitrification.

H31B-04 0830h POSTER

Data sufficiency analysis and assessment of uncertainty before and after detection of a leachate plume from a municipal landfill

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Groundwater contamination from municipal landfill leachate consisting of halogenated volatile organic compounds and petroleum byproducts in northeastern New York State was delineated between 1993 and 1995 and has been undergoing remediation since 1998. Elevated concentrations of leachate indicators (i.e. BOD5, TSS, chloride, and Specific Conductance) were identified in several downgradient monitoring wells as early as 1986. This case study involves a statistical power analysis for the landfill's detection and monitoring wells for two distinct time periods: (1) prior to plume delineation with limited data, and (2) post construction of monitoring wells and examination of additional exploratory borings. Traditional multivariate and geostatistical techniques (cokriging) were combined with a sufficiency analysis and uncertainty assessment to evaluate the importance of multiple data types at monitoring well locations. We address whether a sufficient number of monitoring locations existed to determine, within a particular confidence interval, that a regulatory concentration was not exceeded at specified spatial locations; whether

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 to1.35 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 ($2x10^6$ km^2) 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 Lybia 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 autochtonous 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 ^{36}Cl age (~50 kyr) was obtained from East Uweinat and the oldest ^{81}Kr age (~1million yr) was obtained from Bauti-1 (Baharyia).

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 subbasins. 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