these water quality changes or their ecological impacts. A field study was conducted in the Powder River Basin, WY to document changes in solute composition within stream channels below discharge points of CBM water. Particular emphasis was placed on nitrogen and nitrogen cycling processes. Concentration ranges in discharge water were: DOC, 200-350 μM; alkalinity, 40-50 meq/L; specific conductance, 3.3-4.0 mS/cm; ammonium, 350-400 μM; and pH, 7.2-7.3. Ammonium concentrations decreased with transport distance via nitrification, with subsequent increases in nitrite and nitrate. Within a single discharge channel, nitrite concentrations increased with travel distance, peaking at $>$100 μM at 100-200 m, but also exhibited a strong diel pattern that was inversely related to incident light. Nitrite production/consumption processes differed significantly within in-stream incubation chambers, depending upon location relative to the CBM discharge point and time of day. In the main channel, subject to several CBM discharge points, diel nitrite concentrations were more constant at a fixed station, but did increase with distance downstream. Main channel total inorganic nitrogen remained relatively constant ($\sim$400 μM N) with distance ($>$5 km), suggesting little net nitrogen removal. The results of this study suggest that CBM discharge can serve as a significant source of dissolved nitrogen to western watersheds, with oxidative processes resulting in nitrate and nitrite concentrations greatly in excess of current drinking water limits.

H32G-07 1730h

Characterizing Hydrologic Properties of Coal Beds From the Powder River Basin, Southeastern Montana, by Analysis of Geophysical Well Logs

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As part of a study designed to evaluate the potential for coal-bed methane development in the Powder River Basin of southeastern Montana, six wells were drilled through Paleocene coal beds of the Fort Union Formation along a 31-km transect within the Tongue River drainage basin. Sets of geophysical logs were recorded in these wells, cores were collected, and a complementary aquifer test was conducted at one site across an isolated 4.6-m thick coal seam. Natural gamma and electrical resistivity logs were highly effective in distinguishing individual coal beds. Sonic velocities computed from full-waveform logs were combined with rock densities determined from cores to estimate aquifer storage and results are in reasonable agreement with the value derived from the aquifer test. Televiewer logs, both acoustic and optical, provided magnetically oriented images of the borehole walls. Inspection of these digital projections and comparison with coal cores infer a face cleat orientation of approximately N33°E, in close alignment with regional lineament patterns and the northeast trend of the nearby Tongue River. Further analysis of these televiewer data reveals two primary sets of shallow-dipping features, presumably bedding planes, that are interspersed throughout the rocks and that strike east-west and north-south. These orthogonal directions are aligned with the principal axes of the contemporary stress field in this physiographic province as inferred from a nearby 1984 earthquake. The aquifer test consisted of pumping one of these wells for nine hours and monitoring water levels in three nearby observation wells. The drawdown ellipse generated during this test delineates a horizontal anisotropy ratio of 2.1, with the principal transmissivity tensor aligned N88°E and oblique to cleat orientation. Thus, interpretation of this aquifer test within the context of local structural and tectonic conditions indicates that transmissivity anisotropy in coals at this site is controlled by bedding configuration and perhaps a mechanical response to contemporary stresses rather than solely by cleat geometry.

H32G-08 1745h

Transmissivity Anisotropy in a Bounded Coal-Bed Aquifer in the Powder River Basin, Southeastern Montana Determined by Aquifer Test Analysis

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Extensive installation of well fields to develop coal-bed methane in the Powder River Basin has resulted in large environmental impacts due to discharge of the co-produced water to drainage channels and reservoirs, and to surface disruptions caused by construction of drill pads and gas and water pipelines. These impacts can be reduced by optimizing well spacing based on knowledge of hydraulic properties and boundaries of the coal bed aquifers, including the commonly observed transmissivity anisotropy oriented with face cleat structure. A multiple-well aquifer test was conducted of a 7.6-m thick coal bed located in southeast Montana to determine the magnitude and orientation of the transmissivity tensor, the storage coefficient, and possible aquifer boundaries. Results of the test appear ideal for determining aquifer anisotropy, as the slopes of the semilog time-drawdown curves are nearly identical and the zero-drawdown intercepts are significantly different. The maximum transmissivity, trending N88° E, is 20 m^2/d and the minimum transmissivity 9 m^2/d, defining an anisotropy ratio of 2.1. The effective or geometric mean transmissivity, the value that would be determined from a single-well test, is 13 m^2/d. The corresponding value of hydraulic conductivity is about 2 m/d, which is somewhat larger than most published values for Powder River Basin coal-bed aquifers. Specific storage of the unit is $4X10^{-6}$/m, which is smaller than most published values for Powder River Basin coal beds. The principal anisotropy tensor direction is not aligned with the face cleats, which is dominantly oriented N33° E, as determined from geophysical well logs, but instead is oriented with another fracture set and with dominant east-west tectonic compression. The aquifer test results also indicate the presence of an impermeable or low-permeability boundary. Image well theory, adapted through scale transformation for application to an anisotropic aquifer, indicates that the boundary is likely located about 400 m to the northeast of the production well, and has a strike to the ENE. Results of this test demonstrate that multiple-well aquifer tests can provide hydrologic information not otherwise available to implement optimum spacing and orientation of coal bed methane development wells.

H32H MCC: 3020 Wednesday 1600h

Ecohydrological and Geochemical Processes at the Hillslope and Watershed Scales II *(joint with B)*

Presiding: **M H Nachabe,** University of South Florida; **M C Boufadel,** Temple University; **B D Newman,** Los Alamos National Laboratory; **D Mackay,** State University of New York at Buffalo

H32H-01 1600h INVITED

Hydrology Role in Sustaining Ecological Functions in the Everglades; an Experimental Approach.

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The Everglades ecosystem, the largest subtropical wetland in the United States, has been historically altered to achieve numerous goals such as flood protection, water supply, restoration, conservation, enhancement of specific emergent vegetation types, maintenance or restoration of landscape habitats, and enhancing waterfowl habitat. This "River of Grass" consists of several topographic landscape features (ridges, sloughs, and tree islands), supports a unique variety of plants and wildlife, and provides water resources for both agricultural and urban needs. The South Florida Water Management District and the US Army Corps of Engineers are currently conducting an integrated large-scale effort to restore this ecosystem to a more natural condition. A major part of the ongoing restoration effort is to re-establish the Everglades hydrology by controlling both flow and marsh water levels. The South Florida Water Management District, in collaboration with the A.R.M. Loxahatchee Wildlife Refuge and researchers from several academic institutions, has modified two existing impoundments to replicate the Everglades landscape. The Loxahatchee Impoundment Landscape Assessment (LILA) is designed to assess the impact of seasonal changes in water level and pulsing on wading bird foraging, the significance of flow for the creation and persistence of ridge and slough topography, and to evaluate techniques for restoring tree islands. This project utilizes a scaled-down version of the Everglades landscape to measure responses of wildlife, tree islands, and ridges and sloughs to hydrologic manipulations. Specifically, this study examines the effects of a highly-pulsed (event) pattern of water discharge on wildlife, ridge and slough, and tree island components of the natural system as compared to effects of sustained discharge. LILA provides the opportunity to quantitatively link hydrologic regimes with biological performance measures in a scientifically sound manner that allows for replication and provides information more rapidly than observational studies in the natural system. The main goal of the research program in LILA is to define hydrologic regimes that sustain a healthy Everglades ecosystem. Results of this research program will contribute to supporting routine water management operations and establishing quantitative targets for the Comprehensive Everglades Restoration Project (CERP) Performance Measures. This research program will help develop and recommend options for hydrologic operation of the Everglades, particularly during flood events, when the flexibility to move water through the system is critical. Our discussion is focused on the effects of sediment transport and water velocities on marsh topography, habitat diversity, and their role in sustaining certain ecological functions in the Everglades.

H32H-02 1615h INVITED

Solute Transport and Surface-Subsurface Exchange in the Everglades Characterized by a Tracer Release in Surface Water

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Solute tracer injections into flowing surface water are useful to characterize water velocity, dispersive mixing, and biogeochemical reactions that result from processes such as solute exchange between surface water and sediment porewater. Presently, there are few data or guidelines to understand transport processes in the Everglades. Our tracer study was conducted in central Shark Slough, Everglades National Park (25°38' 31.2" N, 80°43' 20.4" W) at an experimental flume facility. The flume consists of 4 side-by-side channels enclosing wetland vegetation in open-ended flow-ways (3-m by 100-m) that are subject to ambient flow conditions. The injection was conducted in one channel that, at the time of the experiment, had 60-cm of surface water and a typical assemblage of Everglades' slough vegetation, including rooted macrophytes (mainly *Eleocharis sp.*), and a well-developed layer (15-cm) of periphyton-coated vegetation (mainly *Utricularia sp.*) below the water surface. A constant-rate injection of sodium bromide (NaBr) was conducted for 22 hours by dividing the flow between four horizontally oriented soaker hoses that were evenly spaced in the water column. At a distance of 6.8 m downstream of the injection, small-volume (10 to 20-ml) water samples were collected on regular intervals for 48 hrs by withdrawing them by suction from 1/8-inch tubes deployed throughout the water column and in the peat sediment to a depth of 30-cm. Transport was characterized by adjusting the parameters of the USGS model OTIS (One-dimensional Transport with Inflow and Storage). Mean velocity of surface water during the experiment was 0.63 cm/s, longitudinal dispersion was 5 x 10^{-5} m^2/s, and fluid residence times in two storage zones, where local mixing but no appreciable downstream transport occurred, were 1 hr (in periphyton-dominated floating vegetation)and 24 hrs in peat porewater), respectively. We conclude that storage-exchange affects solute transport in the Everglades by decreasing the mean water velocity and increasing the time available for biogeochemical processing of non-conservative solutes.

URL: http://water.usgs.gov/nrp/jharvey/site/index.html

H32H-03 1630h

Observations and Modeling of Soil Water Storage in Variable Saturation Zones

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Variable saturation zones occur in shallow water table environments due to the small storage capacity in the soil profile, or the Soil Water Storage Capacity (SWSC). The SWSC is the depth of water required to raise a shallow water table to the land surface. The

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health of natural and constructed wetland systems depends on the hydroperiod, or the duration of continuous saturation, of the variable saturation zones in the systems. The concept of SWSC is fundamental to hydroperiod development and other hydrologic processes, including surface runoff by saturation excess and estimation of the length of the overland flow plane. Initial conditions, such as the pre-storm soil moisture profile and depth to water table, are critical when predicting runoff in these areas. In this study, we monitored the water table and the soil moisture at different depths in a shallow Floridian sand profile. The relatively high resolution of soil moisture with depth allowed simultaneous observations of encapsulated air and SWSC above a shallow water table. The objectives of this study were 1) to introduce an equation for SWSC as a function of depth to the water table, 2) to assess the influences of the capillary fringe and encapsulated air on SWSC, and 3) to test and validate the concept of SWSC with field data. The main finding is that the profile soil water storage can be expressed as a polynomial function of the depth to water table. The parameters of this function can be derived from the soil hydraulic and physical characteristics. Encapsulated air reduced the available soil storage and resulted in a rapid rise in the water table. Soil storage results including and excluding air are compared as a function of water table depth. Ignoring encapsulated air below the water table may result in significant overestimation of profile water storage.

H32H-04 1645h

Hydrologic Controls on Everglades Landscape Form and Function: Physical, Chemical and Biotic Interactions

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In the Florida Everglades, the natural landscape has evolved over thousands of years to sustain a delicately balanced ecosystem. The annual cycle of wetting and drying controls a variety of chemical, biological and physical processes. Human developments have interrupted this annual cycle by causing changes in water levels that lead to changes in hydroperiod . Relatively small changes in water level cause major shifts in hydroperiod, initiating a cascade of changes that drastically shift the ecosystem out of balance. Soil oxidation, soil formation and shifts in vegetation lead to changes in water chemistry, soil type and habitat value. Losses of soil result in losses in water storage, amplifying the effects of drainage. Keystone species that shape or maintain the landscape are eliminated as habitat value decreases, leading to further degradation of the landforms. To restore Everglades hydrology and ecology, it is necessary to restore the landscape form and function. Restoration of water levels does not necessarily coincide with restoration of hydroperiods, since in many cases soil loss or gain has changed the form of the landscape. Soils that are destroyed by fire in a matter of hours may take decades to rebuild. Sloughs that were maintained by flow and biotic activity have filled in, causing changes in vegetation and increased resistance to flow. To understand restoration it is necessary to identify the critical links between biotic and abiotic communities. Knowledge of current and past responses to hydrologic change can be used to formulate individual metrics that characterize the response of soils, vegetation and fauna to changes in water levels. These individual metrics can be combined and "calibrated" using current and historical soil and vegetation data to produce landscape performance measures. These performance measures are formulated in terms of hydroperiod return frequency to account for inter-annual variability. Application of these performance measures to hydrologic model output allows for quantification of the predicted spatial extent of a given landscape type.

H32H-05 1700h

Hydrological and Biogeochemical Connectivity Between Uplands, Vernal Pools, and Streams, Great Central Valley, California

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Vernal pools are depressional wetlands that are inundated for portions of the wet season, then drain and dry in the late wet and early dry seasons. During portions of the wet season, surface water often flows out of vernal pools to down-gradient aquatic systems such as streams. A common conceptual model of vernal pool hydrology is that vernal pools fill largely due to direct precipitation and drain and dry largely due to evapotranspiration. However, this conceptual model may be largely incorrect for vernal pools occurring on duripans, perhaps the most common type of vernal pool in the Great Central Valley, California. In this presentation, we will present evidence that suggests that vernal pools occurring on duripans are integral surface water components of seasonal, perched surface water and groundwater flow systems, and that the hydrogeological characteristics of these seasonal, perched surface water and groundwater flow systems play important roles in determining biogeochemical function. Groundwater is recharged by annual rainfall, perches on the duripan, and flows down gradient toward a seasonal stream. Groundwater flows through the vernal pools, with groundwater discharge occurring at the up-gradient end of the vernal pools and groundwater recharge occurring at the down-gradient end of the vernal pools. Surface water also flows through the vernal pools, with surface water flowing out of the lowest vernal pool through an outlet swale to a seasonal stream. However, groundwater discharge occurs along the length of the outlet swale, and surface water discharged to the seasonal stream is largely upland groundwater discharge rather than vernal pool surface water discharge. At the pool scale, the biogeochemical functions of individual vernal pools are easily quantified since it is clear that nitrate and, presumably, phosphate are uptaken and that dissolved organic carbon is produced. However, at the catchment scale, the biogeochemical functions of individual vernal pools are not easily quantified since it is equally clear that surface water discharged to the seasonal stream is largely upland groundwater discharge rather than vernal pool surface water discharge.

H32H-06 1715h

Nutrient Flux from Mediterranean Coastal Streams: Carpinteria Valley, California

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Along the southern California coast, near Santa Barbara, California, we are measuring nutrient export from specific land uses and developing a model to predict nutrient export at a watershed scale. The area is characterized by a Mediterranean-like climate and short steep catchments producing flashy runoff. The six land uses include chaparral, avocado orchards, greenhouse agriculture, open-field nurseries, and residential and commercial development. Sampling sites are located on defined drainages or storm drains that collect runoff from relatively homogeneous areas representing each land use. Stream water samples are taken once a week during the rainy season, every two weeks during the dry season and every one to four hours during storms. Samples are analyzed for ammonium, nitrate, phosphate, total dissolved nitrogen and particulate nitrogen and phosphorus. Intensive sampling at the thirteen sites of the study was conducted throughout Water Year (WY) 2002 and 2003. We determine discharge from measurements of stage derived from pressure transducers at all sampling sites. This information is then converted to flux at a high temporal resolution. Wet and dry season sampling has shown that nitrate baseflow concentrations vary over three orders of magnitude, from a few micromoles per liter in undeveloped catchments, to a few 100 mol/L in agricultural and urban watersheds, to 1000 mol/L where intensive "greenhouse" agriculture dominates. Nitrate loading ranged from a few moles per hectare per storm at undeveloped and residential sites to hundreds at the greenhouse site. Phosphate concentrations show a similar, but smaller, variation from 1 to 100 mol/L, although the loading is comparable at 1-100 moles/ha-storm. Stormflow concentrations fluctuate with the storm hydrograph: phosphate increases with flow, while nitrate typically decreases due to dilution from runoff probably from impervious surfaces. Nitrate export patterns indicate a marked difference between land use type (1, 10, 100 g ha-1mm-1 for undisturbed, urban, and greenhouse sites respectively) and show little variance storm to storm during WY2002 and WY2003. The phosphate export pattern with successive storms is not as clear. Cumulative rainfall and/or runoff/rainfall ratios for nitrate and phosphate show promise as variables to simulate the magnitude of nutrient export for individual storms in non-monitored catchments.

H32H-07 1730h

NONLINEAR DYNAMICS OF SOIL MOISTURE AND MINERAL NITROGEN

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We investigate the behavior of simple dynamical systems describing the temporal dynamics of soil moisture, plant growth, soil organic matter, and mineral nitrogen. The equilibrium condition of the deterministic system are analyzed as a function of the climate, soil, and vegetation parameters, along with the possible bifurcations of the system to regimes of periodic or aperiodic oscillations. Particular attention is devoted to the soil moisture control on the dynamics of plant uptake of nitrogen and water and to the role of the delay in litter incorporation into the soil and its subsequent mineralization. A preliminary analysis of the system dynamics under conditions of stochastic environmental fluctuation (rainfall in particular) is also presented.

H32H-08 1745h

Evaluating Ecological Effects in a Semi-arid Aquatic System Using Three Lines of Evidence

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One mission of Los Alamos National Laboratory has been to develop explosives, machine explosive charges, and test explosive components for the United States nuclear weapons program. Effluents containing high explosives and metals from machining and photographic facilities were discharged to Canon de Valle for forty years at rates up to ten million gallons per year, making up as much as half of the canyon's flow. Discharges to the canyon were discontinued in 1996. Canon de Valle has an interrupted stream that supports an herbaceous ground cover and a multi-layer canopy of conifers, oak and aspen. An ecological screening assessment and problem formulation identified barium, cadmium, copper, manganese and silver as metals of potential ecological concern for the aquatic system in the canyon. Additionally, potential impacts associated with high explosives in the aquatic system are unknown because aquatic community screening values are not available. Two field studies were designed and implemented to assess the adverse effects in the canyon's aquatic system. The first field study consisted of benthic macroinvertebrate surveys that were conducted in Canon de Valle and three reference streams. The survey was then repeated in Canon de Valle four years later to assess trends in the benthic macro-invertebrate community. The second field study consisted of toxicity testing with it Chironomus tentans using three locations in the Canon de Valle and one location in a reference canyon. Two rounds of toxicity testing were conducted. Each round was supported with sediment and water sampling at each location for contaminant analysis. The data from the contaminant analysis of water and sediments will be presented along with the results of the benthic macro-invertebrate surveys and the toxicity tests. An example of identifying the contaminants associated with reduced survival in a toxicity test will presented, the utility of benthic macro-invertebrate community metrics as indicators of adverse ecological effects will be discussed, and the relative importance of these three lines of evidence for assessing adverse effects in the canyon's aquatic system will be discussed.