

moving waters in storage zones results in delayed downstream transport of solutes, relative to what would be predicted from velocity measurements in the main flow zone. The transient storage concept is useful particularly for understanding the fate and transport of contaminants in streams, such as nutrients and metals, because solutes transported into storage zones come in close contact with reactive substrates such as sediment, periphyton, and macrophyte leaves. Delayed transport and characterization of transient storage zones can be quantified with solute tracer injections and modeling. Many of the widely used stream transport models that consider transient storage, such as the OTIS-P model (Runkel, *USGS WRIR 98-4018*, 1998), use only a single storage zone (i.e., linear reservoir with exponential residence time distribution) to account for transient storage. Choi et al. (*WRR*, 36:1511, 2000) showed that a model with two independent storage zones improved the characterization of transient storage in systems having both slow and fast exchange zones while retaining an appropriate level of model simplicity. We modified the OTIS-P model to include the option of simulating transport by allowing for exchange with two independent storage zones. The new model package, called OTIS-2Stor, also incorporates new options for weighting tracer concentration measurements while estimating the parameters of the model using the same non-linear least squares regression routine that is included in OTIS-P. Our experiences in headwater channels of Indiana and in the Florida Everglades demonstrate that, if used in conjunction with high quality tracer data sets, the OTIS-2Stor model package can reliably identify the sizes and fluid residence times of two storage zones in complex natural channels and wetland environments.

H13B-06 1445h INVITED

Watershed Residence Time and the Role of Topography

Kevin J. McGuire¹ (541-737-4149; kevin.mcguire@oregonstate.edu); Jeff J. McDonnell¹ (jeff.mcdonnell@oregonstate.edu); Markus Weiler² (markus.weiler@ubc.ca); Carol Kendall³ (ckendall@usgs.gov); Brian L. McGlynn⁴ (bmcglynn@montana.edu); Jeff M. Welker⁵ (jwelker@nrel.colostate.edu); Jan Seibert⁶ (jan.seibert@ma.slu.se)

¹Department of Forest Engineering, 215 Peavy Hall Oregon State University, Corvallis, OR 97331, United States

²Department of Forest Resources Management, 2037-2424 Main Mall University of British Columbia, Vancouver, BC V6T 1Z4, Canada

³US Geological Survey, McKelvey Building 15, Room 1241 345 Middlefield Road, MS 434, Menlo Park, CA 94025, United States

⁴Land Resources & Environmental Sciences, 826 Leon Johnson Hall Montana State University, Bozeman, MT 59717, United States

⁵Natural Resource Ecology Laboratory, NESB, B250 Colorado State University, Fort Collins, CO 80523, United States

⁶Department of Environmental Assessment, Swedish University of Agricultural Sciences, Uppsala, Sweden

In the past few decades, tracers have provided some of the most important insights into hydrological processes; from definition of groundwater and surface water age, to hydrograph source components, to descriptions of water flow pathways at the watershed scale. The age, or residence time of water is an integrated descriptor of watershed hydrology, revealing information about the storage, flow pathways and source of water in a single measure. Residence time offers a linkage to water quality, since the contact time in the subsurface largely controls stream chemical composition. While there has been tremendous recent interest in residence time estimation to characterize watersheds, there are relatively few studies that have quantified residence time at the watershed scale, and fewer still that have extended those results beyond single watersheds to larger landscape scales. We examined topographic controls on residence time for seven watersheds that range in basin area from 10 ha to 6200 ha and represent diverse geologic and geomorphic conditions in the western Cascade Mountains of Oregon. We found that baseflow mean residence time, estimated using stable isotope tracers, ranged from 0.8 to 3.6 years. Like in our previous work in other watersheds, there was no relationship with basin area. We then developed relationships between mean residence time and simple watershed terrain indices and found that mean residence time is highly correlated ($r = 0.96$) to the flow path distance and gradient. This illustrates that landscape organization (i.e., topography), as opposed to watershed size controls transport. Results from this study may provide a framework for describing scale invariant transport across climatic and geologic conditions, whereby the internal form and structure of the basin defines the first order control on baseflow residence time. These findings may present new opportunities for watershed classification and regionalization based on seemingly simple internal topographic descriptors.

H14A CC: 520 A Monday 1530h

Merging Soil Physics With Geophysics and Remote Sensing: Spatial and Temporal Variations in Shallow Soil Processes and Properties

Presiding: R M Holt, University of Mississippi; C J Hickey, University of Mississippi; B Mohanty, Texas A&M University

H14A-01 1530h

Soil Variability Measurements Via Acoustic to Seismic Coupling

Wheeler B Howard¹ (wbhoward@olemiss.edu)

Craig J Hickey¹ (chickey@olemiss.edu)

David A DiCarlo² (ddicarlo@msa-oxford.ars.usda.gov)

Fred E Rhoton² (frhoton@npa.ars.usda.gov)

James M Sabatier¹ (sabatier@olemiss.edu)

¹National Center for Physical Acoustics, 1 Coliseum Dr, University, MS 38677, United States

²USDA-ARS National Sedimentation Laboratory, 598 McElroy Dr, Oxford, MS 38655, United States

We use acoustic to seismic (A/S) coupling to study soil variability at the field scale with particular attention on delineating the depth to the fragipan, a shallow high strength layer which has important consequences for soil productivity. Acoustic waves from a loudspeaker are used to excite the ground in the form of seismic energy. These seismic waves (recorded by a geophone at the air-earth interface) contain information, via reflected waves, about the underlying subsurface layer boundaries. In theory, seismic resonances can be set up between the soil and the onset of the fragipan, a soil layer with very high strength and low water conductivity. By recording the A/S coupling versus frequency at many points within an agricultural field, we show how these resonance compare to actual measurements of the fragipan depth, and discuss how this technique can be used to quickly measure fragipan depth.

H14A-02 1545h

Impact of Soil Hydraulic Parameter Distributions on Upscaling for Steady State Flow in Heterogeneous Soils

Jianting Zhu¹ (979-458-4651; jzhu@cora.tamu.edu)

Binayak P. Mohanty¹ (979-458-4421; bmohanty@tamu.edu)

¹Texas A&M University, Department of Biological and Agricultural Engineering, College Station, TX 77843-2117, United States

In this study, we investigate effective soil hydraulic parameter averaging schemes for steady state flow in heterogeneous soils. Our focus is on the impact of hydraulic parameter distributions and domain scales on the effective hydraulic parameters. "Effective" soil hydraulic parameters of the heterogeneous soil formation are obtained by conceptualizing the soil as an equivalent homogeneous medium. It requires that the "effective" homogeneous soil will discharge the same ensemble-mean surface flux. Using Gardner's unsaturated hydraulic conductivity model, we derive the effective value for the parameter α . Skewness is found to be important in determining the averaging schemes. Negative skewness greatly enhances heterogeneity effects, which make the optimal averaging schemes for the α parameter deviate more from the arithmetic mean. Scale impact on the averaging schemes is more significant as the fractal dimension increases.

H14A-03 1600h

Radiometric Sensitivity to Soil Moisture at 1.4 GHz Through a Corn Crop at Maximum Biomass

Brian K. Hornbuckle¹ (515 294 9868; bkh@iastate.edu)

Anthony W. England² (england@umich.edu)

¹Iowa State University of Science and Technology, 3007 Agronomy Hall 100 Osborn Drive, Ames, IA 50011-1010, United States

²The University of Michigan, 4234A EECS Building 1301 Beal Avenue, Ann Arbor, MI 48109-2122, United States

It is generally assumed that brightness at 1.4 GHz is usefully sensitive to soil moisture only up to a certain level of canopy biomass. We have found that this is not true for a corn canopy. We accomplished this by analyzing time-series measurements of 1.4 GHz brightness, soil moisture, and relevant micrometeorology, all of high temporal resolution, made on the plot-scale for a corn canopy at maximum biomass. Our approach was unique: remote sensing studies typically replicate satellite measurements, in which discrete measurements are made at isolated points in time. Our method of integrating nearly continuous observations of brightness, micrometeorology, and soil state revealed how these variables change together as a result of their interdependencies. This method can be used to identify subtle physical processes that might otherwise be hard to find, much like using the context of a sentence to decipher an unknown word as opposed to only examining the word itself. One of the notable features of our experiment was our measurement of surface soil moisture. Buried TDR instruments, calibrated in-situ with periodic, hand-held impedance probe measurements, produced continuous observations of 0-3 cm and 3-6 cm soil water content. The impedance probe measurements themselves were calibrated with gravimetric samples and bulk density measurements. Two different temperature corrections were applied to the TDR measurements. Each method fit the data well and it was impossible to determine the true temperature correction. Both temperature corrections were considered in the final analysis. We found that there is useful radiometric sensitivity to soil moisture at 1.4 GHz through a corn canopy of vegetation column density 8 kg m⁻² (water column density of 6.3 kg m⁻²). The magnitude of the measured sensitivity of horizontally-polarized brightness temperature to the 0-3 cm volumetric soil water content was at least 1.5 K per 0.01 m³ m⁻³, and could have been as high as 2.5 K per 0.01 m³ m⁻³. Vertically-polarized brightness temperature was 0.5 K per 0.01 m³ m⁻³ less sensitive than horizontally-polarized brightness temperature. A widely-used radiative transfer model underestimated this soil moisture sensitivity at horizontal polarization by over 1 K per 0.01 m³ m⁻³. We hypothesize this is because the water in a corn canopy is concentrated in stems and ears and not spread evenly over the canopy volume as assumed by the model, and as it effectively is in vegetation with electrically small components like grass. Enhanced backscatter from such scattering canopies has been observed in radar experiments. There may be a similar effect in radiometry. It is also possible that this "backscatter effect" could itself be enhanced when the vegetation canopy constituents are wet, and hence more reflective, when intercepted precipitation or dew is present. Given an appropriate emission model that correctly accounts for the differences in transparency between corn and grass-like canopies and/or an enhancement of soil moisture sensitivity through volume scattering, it appears that there will be practical sensitivity to soil moisture through corn (and most, if not all row crops) throughout the growing season.

URL: <http://www.public.iastate.edu/~bkh/>

H14A-04 1615h

The Use of Multispectral Imagery to Detect Variations in Soil Moisture Associated Shallow Soil Slumps

Joel S. Kuzmaul¹ (662-915-7499; kuzmaul@olemiss.edu)

Jessica A. Neuner² (909-793-2853; jneuner@esri.com)

A. K. M. Azad Hossain¹ (662-915-6540; akhossai@olemiss.edu)

Gregory L. Eason¹ (662-915-5995; geason@olemiss.edu)

¹University of Mississippi, Department of Geology and Geological Engineering, University, MS 38677, United States

²ESRI, 380 New York Street, Redlands, CA 92373, United States

Spatial variations in soil moisture have previously been linked to the process of soil aging and can contribute to mass wasting in slopes rich in clay. We use remote sensing imagery to assess variation in soil moisture. Our investigation includes compacted clay soils of the levees along the Mississippi River maintained by the Mississippi Levee Board. Shallow soil slumps are associated with aging of levee soils composed of clay of high plasticity. Continued exposure to seasonal fluctuations in groundwater conditions has contributed to this aging process, causing the soils to become increasingly fissured and stiff. This aging process also alters the moisture retention characteristics of the soil, providing a property contrast that we identified using multispectral imagery. Airborne multispectral imagery was collected along sites with limited vegetation cover (almost bare soil) along with direct measurements of soil water

content. Moderate correlations, with correlation coefficients ranging from -0.62 to -0.80, were found between soil moisture and both the red and infrared reflectance bands of the imagery. Strong correlations, with correlation coefficients of 0.88 and 0.90, were found between soil moisture and the imagery indices known as simple ratio and Normalized Difference Vegetation Index (NDVI). Spaceborne multispectral imagery (IKONOS) was used in more heavily vegetated sites to detect variations in moisture content using Tasseled Cap transformation and imagery classification algorithms. We use this algorithm to provide a map of relative moisture content across the levee surface. We demonstrate how detecting variations in soil moisture is useful in detecting shallow surficial slides using both airborne and spaceborne multispectral images along with image processing tools.

H14A-05 1630h

Predicting Soil Moisture Dynamics and Crop Yield Using Electrical Geophysical Methods

David Lesmes¹ (301-903-2368; lesmes@gwu.edu)

David Wertz²

Timothy Gish³

Wayne Dulaney³

¹The George Washington University, Department of Earth and Environmental Sciences 2029 G St. NW, Washington, DC 20052, United States

²Boston College, Department of Geology and Geophysics, Chestnut Hill, MA 02467, United States

³USDA-ARS Hydrology Laboratory, BARC-West, 10300 Baltimore Ave., Beltsville, MD 20705, United States

Our research at the USDA's Agricultural Research Center (OPE3 field site) located in Beltsville, MD is motivated by the need to develop efficient and non-invasive methods for characterizing the soil properties that control soil moisture dynamics and crop yield. Soil moisture dynamics are controlled by hydraulic conductivity and soil water retention rate, which in turn are controlled by the soil texture (sand and clay content). In this study, we use time-domain reflectometry (TDR) and ground-penetrating radar (GPR) to measure the spatial and temporal variability in soil moisture on an experimental corn field. Electromagnetic induction (EM) and induced polarization (IP) measurements are observed to be highly correlated with soil texture, and can therefore be used to make high-resolution soil texture maps. We have found that the correlation of crop yield with the geophysically derived soil texture maps depends on the overall soil water availability. For example, the crop yield is positively correlated with clay content in 1999 (drought year), but is negatively correlated with clay content in 2000 (wet year). This ground based geophysical methodology provides a framework for the prediction of soil moisture dynamics and its effects on crop yield, and may allow for the optimization of fertilizer and pesticide applications so as to minimize non-point source pollution.

URL: <http://hydrolab.arsusda.gov/ope3/>

H14A-06 1645h

Surface Electrical Conductivity Prediction by Soil Moisture and Electromagnetic Mapping Techniques: Implication for Landmine Detection Technologies

John Katsube¹ (1-613-995-5239;

jkatsube@NRCan.gc.ca); Heather McNairn²

(mcnairnh@agr.gc.ca); Pierre K Keating¹

(PKeating@NRCan.gc.ca); Yoga Das³

(Yoga.Das@drdc-rddc.gc.ca); Larry Dyke¹

(LDyke@NRCan.gc.ca); Mel E Best⁴; Vern

Singhroy⁵; Shauna Connell-Madore¹

(1-613-943-8886; sconnell@NRCan.gc.ca); James

Hunter¹ (JHunter@NRCan.gc.ca); Rod Klassen¹

(klassen@NRCan.gc.ca); Ron Dilabio¹

(RDilabio@NRCan.gc.ca); Andrew Moore¹

(AMoore@NRCan.gc.ca)

¹Geological Survey of Canada, 601 Booth Street, Ottawa, ON K1A 0E8, Canada

²Agriculture and Agri-food Canada, K. W. Neatby Building, 960 Carling Avenue, Ottawa, ON K1A 0C6, Canada

³Defense R&D Canada Suffield, P.O. Box 4000, Station Main, Medicine Hat, AB T1A 8K6, Canada

⁴Bemex Consulting International, 5288 Cordova Bay Road, Victoria, BC V8Y 2L4, Canada

⁵Canada Centre for Remote Sensing, 588 Booth Street, Ottawa, ON K1A 0Y7, Canada

Electrical conductivity (EC) can be a source of significant signal interference in landmine detection, implying that there is a necessity for soil EC prediction in order to carry out safe demining operations in landmine affected countries in the world. A fundamental study on soil EC mechanisms and their relationship to moisture content has been carried out in order to increase the soil EC prediction accuracy when using data from various sensors, such as remote sensing, airborne and surficial electromagnetic (EM) methods. Results indicate that soil moisture consists of free water filling pore spaces and bound water which forms adsorbed water layers on the grain surfaces. The response of these two water phases to drying rates and EC are very different, to the extent that a moist clay poor soil may have low EC but a dry clay rich soil may have higher EC. This is a result of not only the bound water layers being a significant source of EC, but of the capillary component of the free water reacting differently to the different grain-sizes of the soil. The capillary water forms important electrical conductive bridges between the adsorbed water layers on the grains that constitute the soil. This implies that information on soil texture, mineralogy and their distribution are required for accurate EC prediction. Whereas information on these soil characteristics may be acquired by remote sensing and soil maps, soil moisture content is likely to vary from the time of data acquisition to that of demining operations, implying methods to predict these changes are required. In addition, soil type inhomogeneity, such as vertical and horizontal variation can also be a source of inaccuracies in moisture and EC predictions. However, these investigations also indicate that a wide band electrical frequency signal may have the possibility of providing information on, not only metallic mineral content, but on pore space, clay mineral type and water content. In addition, applications of airborne and surficial electromagnetic (EM) systems with varied frequency bands and coil configurations have the possibility of adding considerable information to the remote sensing data and overcoming many of their limitations. This paper reports the research progress being made in these areas. These results have also implications on the effect of geological factors on soil mechanical property predictions.

H21A CC: 220 C-E Tuesday 0830h

Isotope Tracing of Water and Carbon Cycling Processes in Large River Basins III Posters (joint with B)

Presiding: K Telmer, University of Victoria; N L Miller, Lawrence Berkeley National Laboratory

H21A-01 0830h POSTER

A first synoptic water-isotope survey of the Yangtze River

Baohong Lu¹ (519-888-4567 x7232; lubaohong@hotmail.com)

Thomas WD Edwards¹ (519-888-4567 x3236; twdewar@uwaterloo.ca)

¹University of Waterloo, Department of Earth Sciences 200 University Ave. West, Waterloo, ON N2L 3G1, Canada

Variations in the oxygen- and hydrogen-isotope composition of water sampled along the main stem of the Yangtze River during a two-week campaign in January 2003 reveal systematic patterns that strongly reflect the over-riding influence of regional precipitation isotope fields. Secondary signals deriving from influx of evaporatively enriched waters from several major reservoirs along the system are also apparent. This first isotopic "snapshot" of the Yangtze River provides a key baseline for analysis of seasonal and interannual changes emerging from ongoing monitoring at selected stations, as well as affording a basis for isotope-mass balance analysis in combination with hydrometric and climatological data.

H21A-02 0830h POSTER

Assessing the Amazon Basin Circulation with Stable Water Isotopes

Kendal McGuffie¹ (kendal.mcguffie@uts.edu.au)

Ann Henderson-Sellers² (ahssec@ansto.gov.au)

¹Department of Applied Physics, University of Technology Sydney, Broadway, NSW 2007, Australia

²ANSTO Environment, PMB 1, Menai, NSW 2234, Australia

The isotopic abundances of Oxygen-18 ($\delta^{18}\text{O}$) and Deuterium (δD) over the Amazon are used to constrain

simulations of the water cycle in this, the largest river basin in the world. Tracking the two stable but rare isotopes of water ($^1\text{HD}^{16}\text{O}$ and $^1\text{H}_2^{18}\text{O}$) makes it possible to trace Amazonian regional evaporative and condensation processes. This offers isotopic constraints on regional to global-scale atmospheric moisture budgets. Based on data in the Global Network on Isotopes in Precipitation (GNIP) database, we analyse the simulation of the land surface hydrology and water cycling. Temporal changes between 1965 and 2000 in stable water isotopic signatures in the Amazon have been used to evaluate global climate model (GCM) predictions revealing notable anomalies. For example, the differences in the wet season deuterium excess between Belem and Manaus are consistent with recent GCM simulations only if there has been a relative increase in evaporation from non-fractionating water sources over this period. Despite earlier predictions that land-use change signals would be found, late twentieth century data reveal no significant change in dry season isotopic characteristics. On the other hand, more recent isotopic data do show trends at stations in the Andes, where as much as 88% of the rainfall is thought to be derived from recycled moisture. At Izoabamba the wet season depletions are enhanced (greater depletion) and the dry season ones decreased (less depletion). At Bogota only the wet months show statistically significant changes - also an enhancement. More depletion in the wet months is consistent with reductions in non-fractionating recycling such as through transpiration and in full re- evaporation of canopy-intercepted rainfall. These data might be linked to deforestation impacts. Results of GCM and simpler model simulations of the Amazon suggest that the recent stable isotope record is consistent with the predicted effects of forest removal, perhaps combined with greenhouse warming. At a minimum, large-scale simulations of South American climate ought to be tested against these isotopic data in any validation effort. Specific caveats our conclusions include: (i) monthly isotope data only are available in GNIP and hence analysed; (ii) the statistically significant seasonal changes reported might be related to, or even exaggerated by, El Niño-Southern Oscillation (ENSO) events or other climatic variations that modify the Walker circulation and Inter-Tropical Convergence Zone (ITCZ) position and hence affect the moisture climatology of the Amazon; (iii) no information on fluxes from simulated open water as a surface type in the Amazon GCM experiments has been considered; (iv) the selected models are failing to correctly simulate the relative components of transpiration and re-evaporated canopy interception in the Amazon dry season; and (v) no isotope tracking in the Amazon deforestation simulations was reviewed, because none is yet available. These shortcomings deserve further work.

H21A-03 0830h POSTER

Stable Isotope Hydrology of Walnut River Watershed, Kansas, The U.S.A.

Madhav V Machavaram (510-486-5026; mvmachavaram@lbl.gov)

Mark E. Conrad (510-486-6141; msconrad@lbl.gov)

Norman L. Miller (510-486-2374; nlmiller@lbl.gov)

The isotope hydrology of a stream at any time primarily reflects the source components, which contribute to its discharge. Precipitation events influence the stream discharge during shorter times where as the ground and soil waters determine the long term effects. While the presence of surface water bodies affect the hydrological response of a stream, the extent of evapotranspirational process influences the stream hydrology by contributing to the atmospheric moisture and subsequent precipitation. Thus, to understand the regional hydrology it is important to investigate the relative contribution of various hydrologic components and processes through which water cycling occurs in that region. Such studies not only aid in regional hydrological studies but also compliment the efforts to identify global scale hydrological process. Such an effort is made - as a part of the Department of Energy's Water Cycle Pilot Study (WCPS) - to study the water cycling through various hydrologic compartments by using stable isotope variations in the Walnut River basin located in the southern Great Plains region of the United States. Apart from event-based precipitation, samples were collected quarterly from streams, ponds, ground water, soil and atmospheric vapor. The isotope values in precipitation and atmospheric vapor samples indicate a significant contribution of the locally evapotranspired moisture content to precipitation. A temperature dependent seasonal isotopic contrast in precipitation is reflected in the major tributaries of the Walnut river system where as the isotopic composition of smaller streams is governed by the recharge source and the extent of evaporation. The surface water bodies with their high rate of evaporation have a distinct isotopic composition from that of ground water and precipitation and were useful in estimating the relative contributions of these components during precipitation events. An isotopic mass-balance model to estimate relative contribution of various sources is presented together with a discussion on isotope climate relationship.