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Consortium of Universities for the Advancement of Hydrologic Science, Inc.

Fourth Biennial Symposium on Water Science and Engieneering

July 28-30, 2014
National Conservation Training Center
Shepherdstown, WV

Water across the Critical Zone: Scaling from Local to Global Hydrology

Table of Contents

Table of Contents 2
Agenda 4
Plenary abstracts 6
Keynote Lecture: Jay Famiglietti 6
Water Cycle Change and the Human Fingerprint on the Water Landscape of the 21st Century: Observations from a Decade of GRACE 6

Reds Wolman Lecture: Charles J. Vörösmarty 6
Rivers in the Anthropocene: The Rise and Fall of the Water Engineer? 6

Eagleson Lecture: Ying Fan Reinfelder 7
Groundwater in the Critical Zone: From Column to Planet 7

Community Service Awards 7
Session Abstracts 8
Critical zone evolution: legacy influences on contemporary processes 8
Li Li: When water meets rock: controls of chemical weathering across scales 8

Bill Dietrich: Critical zone evolution legacy: what happened matters to what happens 9

James Kirchner 11

Water sustainability, climate, and human dimensions 11
Stephanie Pincetl: Urban Water Sustainability: What do we not know? 11

Alberto Montanari: Hydrological change: towards a theoretical framework for assessment and attribution 12

Ecohydrology 13
Holly Barnard: Ecohydrology of Forested Catchments: investigations of transpiration, growth and subsurface hydrology 13

Oliver Chadwick: The Role of Critical Zone Ecohydrology in Developing and Evolving Spatial and Temporal Chemical Structure in Terrestrial Ecosystems 13

Alexandra Ponette-González: Heterogeneous hydrologic and biogeochemical responses to land change in the high-elevation humid tropics 14

Hydroclimatology 15
Tara Troy: Scale in Flooding: The role of drainage area, heavy precipitation, and model resolution 15

Gabriele Villarini: North Atlantic Tropical Cyclones and U.S. Flooding 15

Upmanu Lall: Hydroclimatology: A unifying global perspective for floods and droughts 16

Scaling in Hydrology 17

Jennifer Adam: Climate Model Bias and Land Surface Heterogeneity: Two Factors that Impact the Usefulness of Earth System Models for Natural Resource Management 17

Markus Weiler: Observing and predicting temporal and spatial scaling of runoff generation processes at various scales 18

Daniel Moore 19

Deep and shallow flow system interactions 20

Bayani Cardenas: The relevance and scales of interactions between surface and subsurface flow systems 20

W. Payton Gardner: Looking for the Bottom of the Active Zone – Investigating the Magnitude and the Implications of Deep Groundwater Interaction with Shallow Systems 20

Daniella Rempe: Runoff in the deep critical zone: the role of weathered, fractured bedrock in mediating water availability 21

Advances in Community Modeling 22

Mukesh Kumar: Community Hydrologic Models for Analyses, Discovery, Prediction and Mitigation: An Evolving Paradigm 22

Ben Mirus: Code Development and Concept Development: Opportunities for Progress and Synergy 23

Instrumentation enabled science: advances and frontiers 24

Marty Briggs: Surface geophysical methods for evaluating stream habitat and the resilience of aquatic systems to climate warming 24

Matt Cohen: The Sensor Revolution: Insights on Nutrient Dynamics in Large River Ecosystems 24

Burke J. Minsley: Hydrogeophysics at the watershed scale using airborne electromagnetics 25

Comunity Workshops 26

Advances in Environmental Data Management for the Research Community 26

Community Modeling discussion (half-session) 26

DTS and Drones: CTEMPs Instrumentation Workshop 27

Exploring Sino-US Collaboration in Critical Zone Science 27

HydroShare Community Workshop (half-session) 28

The Landscape Evolution Observatory: a community research facility for large-scale controlled experimentation in hydrology (Peter Troch) 28

Poster Index 29

Acknowledgements 35

Agenda

CUAHSI 2014 Biennial Colloquium

Fourth Biennial Colloquium on Hydrologic Science and Engineering
July 28-30, 2014 || National Conservation Training Center, Shepherdstown, WV

"Water across the Critical Zone: Scaling from Local to Global Hydrology"

Sunday, July 27, 2014

8:30 PM - 9:30 PM	Welcome Reception	Roosevelt Room

Monday, July 28, 2014

8:30 AM - 8:45 AM	Opening Remarks: Roger Wakimoto, NSF	Auditorium
8:45 AM - 9:45 AM	Keynote Lecture: Jay Famiglietti	Auditorium
9:45 – 10:00 AM	Break	
10:00 AM - 12:00 PM	Critical zone evolution: legacy influences on contemporary processes Session Chairs: Cliff Riebe, Erkan Istanbulluoglu Speakers: Li Li, Bill Dietrich, Jim Kirchner	151 Inst West
10:00 AM - 12:00 PM	Water sustainability, climate, and human dimensions Session Chairs: Terri Hogue, Praveen Kumar Speakers: Stephanie Pincetl, Josh Newell, Alberto Montanari	Auditorium
2:00 PM - 5:00 PM	Poster Session	Gymnasium
3:00 PM - 3:30 PM	Poster Session Break	Gymnasium
7:00 PM - 9:00 PM	Ecohydrology Session Chairs: Paul Brooks, Drew Guswa Speakers: Holly Barnard, Oliver Chadwick, Alexandra Ponette-González	Auditorium
7:00 PM - 9:00 PM	Hydroclimatology Session Chairs: Witold Krajewski, Ana Barros Speakers: Tara Troy, Gabriele Villarini, Upmanu Lall	151 Inst West

Tuesday, July 29, 2014

8:45 AM - 9:00 AM	Opening Remarks, Rick Hooper, CUAHSI	Auditorium
9:00 AM - 9:45 PM	Reds Wolman Lecture: Charles Vorosmarty	Auditorium
9:45 – 10:00 AM	Break	

10:00 AM - 12:00 PM	Scaling in Hydrology Session Chairs: Christina Tague, Roy Sidle Speakers: Jennifer Adam, Markus Weiler, R. Daniel Moore	Auditorium
10:00 AM - 12:00 PM	Deep and shallow flow system interactions Session Chairs: David Genereux, Gordon Grant Speakers: Bayani Cardenas, W. Payton Gardner, Daniella Rempe	151 Inst West
Education & Outreach Sessions		
1:30 PM - 2:30 PM	Pathfinder Pop-Up Talks	201 Inst East
2:30 PM – 2:45 PM	Break	
2:45 PM - 3:45 PM	Using WDC Services for Place-Based Education	201 Inst East
4:00 PM - 5:00 PM	Let's Talk About Water - Hosting an LTAW event	201 Inst East
Water Data Center Sessions		
2:00 PM - 4:00 PM	Training: Water Data Center	151 Inst W
3:00 – 3:15 PM	Break	
4:00 PM - 5:00 PM	Community Discussion on Water Informatics	151 Inst W
5:30 PM - 6:45 PM	BBQ Banquet	Patio (outside Dining Hall)
7:00 PM - 9:00 PM	Awards & Film Screening: Chasing Ice	Auditorium

Wednesday, July 30, 2014

8:45 AM - 9:00 AM	Observations on the Colloquium: Tom Torgersen, NSF	Auditorium
9:00 AM - 9:45 AM	Eagleson Lecture: Ying Fan Reinfelder	Auditorium
10:00 AM - 12:00 PM	Advances in Community Modeling Session Chairs: Reed Maxwell, Chris Duffy Speakers: Mukesh Kumar, Ben Mirus, Dave Gochis	151 Inst West
10:00 AM - 12:00 PM	Instrumentation enabled science: advances and frontiers Session Chairs: Kamini Singha, Brian Pellerin Speakers: Marty Briggs, Matt Cohen, Burke Minsley	Auditorium
Community Workshops		
2:00 PM - 5:00 PM	Advances in Environmental Data Management for the Research Community	109 Inst East
2:00 PM - 5:00 PM	Communicating Science with AAAS	201 Instr East
2:00 PM - 3:30 PM	Community Modeling discussion (half-session)	105 Inst East
2:00 PM - 5:00 PM	DTS and Drones: CTEMPs Instrumentation Workshop	151 Inst East
2:00 PM - 5:00 PM	Exploring Sino-US Collaboration in Critical Zone Science	103 Inst East
3:30 PM - 5:00 PM	HydroShare Community Workshop (half-session)	105 Inst East
3:30 PM - 5:00 PM	The Landscape Evolution Observatory: a community research facility (half-session)	101 Inst East
8:00 PM - 9:30 PM	Campfire	

Meal times

Breakfast: 6:30- 9:00 a.m. Hot food until 8:30 a.m.
Lunch: 11:30- 1:30 p.m. Hot food until 1:00 p.m.
Dinner: 5:30-7:30 p.m. Hot food until 7:00 p.m.

Plenary abstracts

Keynote Lecture: Jay Famiglietti

Water Cycle Change and the Human Fingerprint on the Water Landscape of the 21st Century: Observations from a Decade of GRACE

Jay Famiglietti
Jet Propulsion Laboratory, California Institute of Technology
Earth System Science, University of California, Irvine

Over the last decade, satellite observations of Earth's water cycle from NASA's GRACE (Gravity Recovery and Climate Experiment) mission, have provided an unprecedented view of global hydrological change and freshwater availability. Since its launch, the mission has helped to confirm that precipitation, evaporation and continental discharge rates are increasing, that the mid-latitudes are drying while the high and low latitudes are moistening, and that the hydrologic extremes of flooding and drought are becoming even more extreme. Importantly, GRACE has exposed the human fingerprint of water management practices such as groundwater use and reservoir storage, which raises many important issues for climate, water, food and economic security. Moreover, the GRACE mission has enabled us to peer beneath Earth's surface and characterize the worldwide depletion of groundwater aquifers, raising significant concerns about the potential for heightened conflict over transboundary water resources. In this talk I review the basics of how the GRACE mission observes terrestrial and global hydrology, what new information the mission has provided since its launch in 2002, and the implications for the future of water availability and sustainable water resources management.

Reds Wolman Lecture: Charles J. Vörösmarty

Rivers in the Anthropocene: The Rise and Fall of the Water Engineer?

Charles J. Vörösmarty[1,2]
1 CUNY Environmental CrossRoads Initiative, City University of New York
2 Civil Engineering Dept., The City College of New York

Fresh water underpins countless benefits to society and is pivotal to the success of the food and energy sectors, industry and commerce, and the expanding urban domain. It as well provides essential cultural, recreational, and aesthetic values. Water also plays a critical role in the maintenance of ecosystem services and biodiversity. Recent analyses of water systems across the planet, summarized using high resolution, geospatial indicator maps of rivers, demonstrate that a wide array of stressors combine to produce a pattern of worldwide threat to much of the fresh water resource base that sustains human water supply as well as to aquatic biodiversity. A pervasive, globally-significant pattern of management is evident in the contemporary setting, through which impairment accumulates as a function of wealth, but is then remedied by costly, after-the-fact technological investments. This strategy of treating symptoms while leaving unabated the underlying causes is practiced widely across rich countries, but it strands poor nations and much of the world's aquatic lifeforms at high levels of vulnerability. The seeds of such an approach to water management are hardly new and are evident throughout human history.

This lecture will explore the implications of these global realities and will focus on the role of 21st century engineering in contributing to the growing water crisis or in stimulating innovation for more effective stewardship of our water resource systems.

Eagleson Lecture: Ying Fan Reinfelder

Groundwater in the Critical Zone: From Column to Planet

Although we have an intuitive understanding of what groundwater does in the critical zone at the scales of a column (atmosphere-plant-soil-bedrock), along a topo-sequence (ridge to valley), and across a small watershed (e.g., ~ 3rd order streams and floodplains), this talk examines how relevant groundwater is to river-basin, continent and global-scale patterns and processes. Through global observation syntheses, conceptual and numerical models, this talk suggests that groundwater influence is far more globally prevalent than previously thought, it forms an environmental gradient not fully captured by climate, and it profoundly shapes the critical zone at continental to planetary scales. Four examples illustrate these ideas: (1) global distribution of wetlands, gallery forests and desert oases as ecological refugia, (2) dry-season evapotranspiration in the Amazon, (3) patterns in plant rooting depth from topo-sequence to global scales, and (4) continental weathering and planetary change. More importantly, these examples reveal critical disciplinary, scale and data gaps that prevent us from translating what we learn at CZO scales to what we attempt to predict at the planetary scale.

Community Service Awards

In recognition of his outstanding vision and leadership in education and interdisciplinary research in hydrologic science, CUAHSI Presents **David Freyberg** with this token of our gratitude at the CUAHSI 4th Biennial Symposium, July, 2014

In recognition of his outstanding vision and leadership in the development of critical zone science and contributions to cyberinfrastructure, CUAHSI Presents **Anthony Aufdenkampe** with this token of our gratitude at the CUAHSI 4th Biennial Symposium, July, 2014

Session Abstracts

Critical zone evolution: legacy influences on contemporary processes

Speakers: Li Li, Bill Dietrich, Jim Kirchner
Session Chair: Cliff Riebe, Erkan Istanbulluoglu

Understanding the chemical, physical, and biological processes that modify the critical zone (or "CZ") is important across a diverse range of problems, from assessing soil and water sustainability over human lifetimes, to quantifying feedbacks between climate, weathering, and tectonics over geologic timescales. The evolution of the CZ ultimately influences as well as reflects the processes that modify it. For example, chemical alteration and physical disruption, which drive weathering at depth, also generate storage space and flowpaths for water in the subsurface, thus modulating the hydrology and biogeochemistry of watersheds. Meanwhile, geomorphic transport phenomenon gradually change landforms, altering the distribution of energy and water across landscapes. In this session, presenters will address the duality of drivers and factors affected by CZ evolution in a series of talks on he role of water in CZ evolution and the influence of the CZ evolution on runoff sources, flowpaths, and water age.

Li Li: When water meets rock: controls of chemical weathering across scales

Li Li

Dept. Energy and Mineral Engineering, Penn State University

Water-rock interactions play a pivotal role in the formation and response of the critical zone to natural and anthropogenic perturbations. The extent of interactions is dictated by an array of factors including the total amount of reacting minerals, water flow that flushes out dissolved reaction products, and spatial patterns that regulate water distribution. With the ubiquitous occurrence of spatial heterogeneities and the unique topographic characteristics at different scales, it is important to understand and quantify how they control chemical weathering in the critical zone. In this talk I will share our work along this line across spatial scales from columns (centimeters) to the watershed scale (kilometers).

At the column scale of 10 - 20 centimeters, we use flow-through experiments and reactive transport modeling to understand how the spatial patterns of magnesite govern dissolution rates under a variety of flow velocity and permeability contrast conditions. Columns were packed with the same total mass of magnesite (10%) distributed in quartz sand in different spatial patterns. The spatial patterns vary from the uniformly-distributed mixture of magnesite and quartz in the "Mixed" column to the "zoned" columns where magnesite grains are distributed in 3, 2, or 1 zones, oriented either in the direction parallel (flow-parallel) or transverse (flow-transverse) to the main flow direction. We found that under sufficiently low flow condition, the reactions reach equilibrium and the spatial patterns do not matter. Under high flow regimes (>0.4 m/d), dissolution rates can be more than an order of magnitude lower than those from the corresponding Mixed column when magnesite is distributed in a low permeability zone in the flow-parallel direction. Dissolution rates are highest when the spatial pattern maximizes the water flow through the reactive magnesite zones. The effective surface area Ae quantitatively measures the actively-dissolving magnesite and varies by more than 4 orders of magnitude, although the BET surface area in all columns is the same. This corresponds to the same range of observed variation in dissolution rates under the tested flow-through conditions.

Modeling of the regolith formation in Marcellus Shale formation over geological time scale (104 yrs) and over a

length scale of 1.2 meters indicates that the measured surface area has be lowered by more than 2 orders of magnitude in order to reproduce the observed pore water chemistry and soil profile, indicating limited water and rock contact revealed by the column-scale experiments.
At the watershed scale (km), we use the Susquehanna-Shale Hills Critical Zone Observatory (SSHCZO) as a natural laboratory to explore water-rock interactions using a newly developed model, RT-FLUX-PIHM, which couples a subsurface reactive transport module (RT) with the watershed hydrological and land-surface model (FLUX-PIHM). With constraints from observations of soil profile and pore water and stream water chemistry, this tool enables mechanistic and integrative understanding on the topological, hydrological, and climatic controls of chemical weathering at the water shed scale.

Bill Dietrich: Critical zone evolution legacy: what happened matters to what happens

William E. Dietrich and Daniella M. Rempe, UC Berkeley

The critical zone extends to varying depths across landscapes and the material properties developed in this zone may directly influence surface runoff, solutes and gas fluxes, rock moisture, vegetation, and erosion processes. Three examples illustrate the importance of critical zone evolution. First, slow deep weathering in granitic rocks can lead to a kind of hydrogeomorphic inversion of processes (Figure 1). The near-surface, most strongly weathered bedrock may lose nearly all bedrock structure and form a clayrich, relatively low conductivity layer that can induce Horton overland flow. A deeper sandy saprolite may form beneath this layer that has relatively high conductivity, contains groundwater, and, when breached by erosion processes, produce a progressive seepage erosion, that leads to gullying, landsliding and complex colluvial deposition episodes. Even with deep weathering, bedrock fractures may dictate groundwater flow paths and thus channel orientations. Second, in other cases, the deeper bedrock consists of conductive fractures bordered by blocks of essentially unweathered bedrock (Figure 2). These fractures can be significant sources of groundwater and characterize the so-called hard rock aquifer case. Typically the bedrock is plutonic or metamorphic rock (including shale). As in the previous case, a shallow, strongly weathered bedrock layer may direct storm runoff to channels, while recharge to the fractures leads to head gradients that provide flow to and influence the solute chemistry of streams. Such conditions are found widely and it has been argued that the deep conductive fractures are a result of weathering, and hence lie near the bottom of the critical zone. The third example arises where active bedrock uplift and channel incision leads to hillslopes underlain by a tapered subsurface critical zone that thins from hillslope divide to channel (Figure 3). In this case, the depth to a low-conductivity fresh bedrock can be fairly shallow and all runoff can occur via perched groundwater flow in the weathered bedrock. This water may exfiltrate along fractures, contributing to saturation overland flow and landslide inducing pore pressures. Solute evolution in these runoff waters dictate stream chemistry and rock moisture in the weathered bedrock zone may provide critical water for seasonally water-stressed vegetation. In this simplest of the three cases, the lower boundary of the critical zone, i.e. the transition to fresh bedrock, which we label Zb may be controlled by the slow drainage of the emerging saturated fresh bedrock. A coupled hillslope erosion model for the topographic surface and groundwater flow model for the saturated fresh bedrock predict the observed thickening of the weathered zone towards the divide. This analytical model has 7 measureable parameters and can be tested from a drill hole at the divide, hydraulic characterization of the materials, and determination of channel incision rates and surface transport rates. The relationship between Zb and surface topography will be influenced by temporal variability in climate, channel incision

rates, lithologic change with depth, and chemical weathering products (e.g. ferricrete). Nonetheless, the proposed simple model for Zb may give a useful estimate, especially when considering adding the weathered bedrock zone to hydrological and climate models that need to account for the moisture dynamics therein.

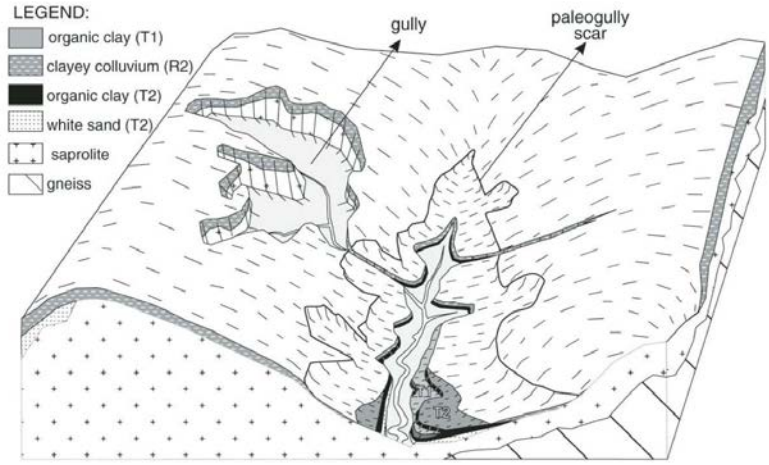

Figure 10. Schematic diagram of typical headwater hollow, which represents a paleogully, filled up by upper Quaternary sediments (T2/R2 and T1). The channel incision cuts the less erodible sediments (organic clays and colluvial soils) and reaches the more erodible gneiss saprolite. The further natural convergence of underground and surface water towards the hollows leads to the development of a new gully. Where the saprolite is thinner (right), deep gullies do not develop.

Figure 1: Bacellar et al., Earth Surface Processes and Landforms, 2005

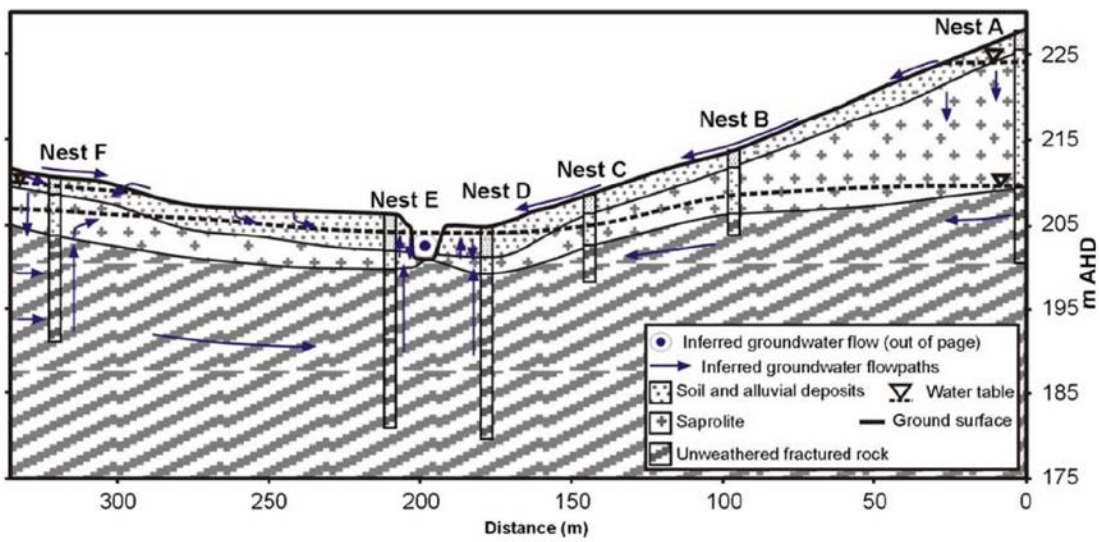

Figure 2. Banks et al., Hydrogeology Journal, 2009

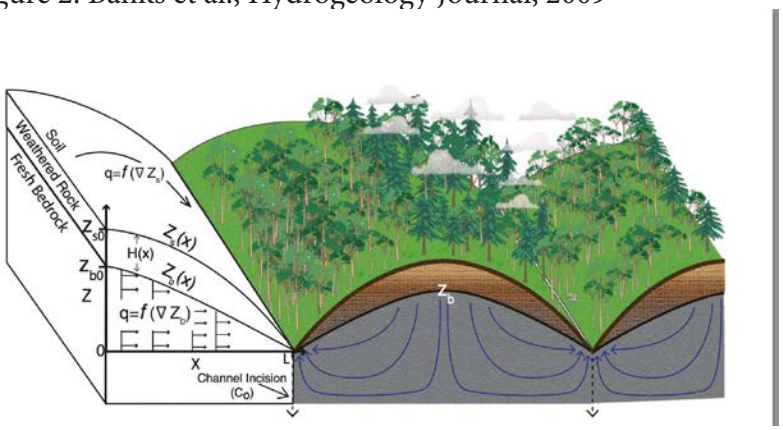

Figure 3. Rempe and Dietrich, Proc. National Academy of Sciences, 2014

Legacy effects of the critical zone: dispersive transport at the hillslope scale, catchment travel-time distributions, non-self-averaging, and their implications for water quality trend detection

James Kirchner

Dept. of Environmental System Sciences, ETH Zurich, Switzerland
Swiss Federal Research Institute WSL, Zurich, Switzerland

The critical zone is characterized by preferential flow, strong conductivity gradients, and heterogeneity on all scales. These critical zone properties lead directly to the strongly skewed, nearly scale-free travel time distributions that characterize many catchments. These distributions, in turn, give rise to fractal scaling in stream chemistry across diverse solutes and wide ranges of time scales.

These water quality time series share a broad-band universal 1/f spectral signature, and are not self-averaging: that is, averages taken over longer and longer time periods do not converge to stable means. Such time series defy the Central Limit Theorem and the standard regimen of statistical tests that are based on it. Statistically "significant" trends arise much more frequently, on all time scales, than one would expect from conventional statistics. These same trends are also poor predictors of future trends – much poorer than one would expect from their calculated uncertainties – and having more data makes these problems worse. Implications of these findings for trend analysis and change detection will be discussed.

Water sustainability, climate, and human dimensions

Speakers: Stephanie Pincetl, Josh Newell, Alberto Montanari
Session Chair: Terri Hogue, Praveen Kumar

Stephanie Pincetl: Urban Water Sustainability: What do we not know?

Stephanie Pincetl, Founding Director California Center for Sustainable Communities, Institute of the Environment and Sustainability, UCLA

In the arid West of the United States, and in California in particular, water development has been local, historically accreted, opaque and largely unregulated. Faced with a severe drought and likely substantial climate impacts on water availability over time, this system is anachronistic. This presentation shows the baffling complexity of water delivery and distribution and ground water management in Los Angeles County and suggests initial further areas for research and reform.

Extending urban metabolism: A political industrial ecology of water supply for the city of Los Angeles

This paper draws on theory and method from urban political ecology and industrial ecology to examine Los Angeles's water supply metabolism, which sprawls for thousands of miles in geographically diverse directions, via a complicated infrastructure system of pumping plants, pipelines, dams, and aqueducts. First, we infuse spatiality into traditional life cycle assessment (LCA) by combining it with GIS to model the emissions burden of the city's

supply sources. The results reveal that the energy footprint varies widely depending on the source. Water from the Sacramento Delta is the most energy intensive, while water from the Los Angeles Aqueduct (LAA) is the least. The energy required to convey the water far outweighs treatment and distribution phases. This spatially-explicit LCA also reveals the contingency of LCA studies, as the results are fundamentally shaped by decisions about system boundaries, emissions factors, and other building blocks in the LCA process. Second, through historical analysis and interviews, we explore how Los Angeles's water supply metabolism reflects historical circumstances as well as strategic new paradigms to secure water resources and build more resilient infrastructures to climate change. We illsutrate how a focus on low emission supply sources are problematized by legacies of social and environmental injustices and tradeoffs between maintaining reliable water supplies and mitigating carbon emissions. By revealing the spatiality of material and energy flows as well as the heterogeneous properties that structure metabolisms, combining approaches in industrial ecology and urban political ecology moves beyond the 'black boxed' input–output methodologies that undergird the carbon footprint calculus and the discourses that emerge from them.

Keywords: urban political ecology, industrial ecology, life cycle assessment, urban metabolism, carbon footprints, water resources

Alberto Montanari: Hydrological change: towards a theoretical framework for assessment and attribution

Alberto Montanari, University of Bologna – Italy, alberto.montanari@unibo.it

Environmental change is a reason of relevant concerns as it is occurring at an unprecedented pace and might increase natural hazards. Moreover, it is deemed to imply a reduced representativity of past experience and data on extreme hydroclimatic events. Consequently, calls are being issued for improving its understanding and interpretation and its connection with society, through the study of the two-way interaction between environment and humans. The awareness of the importance of the research themes related to change, in connection with evolving societal systems, recently lead the International Association of Hydrological Sciences (IAHS) to focus on these topics during the Scientific Decade 2013-2022, by launching the Panta Rhei research initiative (www.iahs.info/pantarhei). In an attempt to provide a unified scheme for the simulation of changing behaviors of hydrological systems, a theoretical framework for stationary and non-stationary modeling is presented. The main triggers for hydrological change are reviewed, their impact on the long term properties of the inherent system are analyzed and a theoretical solution is proposed for their representation. I propose a stochastic approach which is general, and allows a comprehensive treatment of uncertainty.

Ecohydrology

Speakers: Holly Barnard, Oliver Chadwick, Alexandra Ponette-González
Session Chair:Paul Brooks, Drew Guswa

This session will focus on the interactions and feedbacks between water both as a driver of critical zone evolution and as a consequence of critical zone structure and function. In addition to revealing fundamental ecohydrologic processes across a range of spatial and temporal scales, an understanding of these interactions is required for the valuation of ecosystem services and adaptation to climate change. Our three speakers bring expertise and backgrounds in tropical and montane hydrology, fog-vegetation interactions, soil formation, and the use of stable isotopes to reveal soil-vegetation-water interactions. The talks and subsequent conversation will integrate knowledge across disciplines and perspectives, and we look forward to an engaged discussion.

Holly Barnard: Ecohydrology of Forested Catchments: investigations of transpiration, growth and subsurface hydrology

Holly R. Barnard[1]

1Institute for Arctic and Alpine Research, Department of Geography, University of Colorado, Boulder, CO 80303, USA *holly.barnard@colorado.edu

Processes operating in the hydrosphere, geosphere, and biosphere interact at multiple scales to determine the structure, function, and health of terrestrial ecosystems. Although over the past 65 years, numerous studies have examined soil hydrologic processes, vegetation function, and micro-climate independently; investigating the feedbacks among these core areas has only recently become a research priority. Fundamental questions of forests' effect on the hydrologic cycle remain unanswered: At what depth do trees access soil moisture? To what extent does transpiration affect streamflow? How does complex terrain influence the feedbacks between hydrology and ecology? Detailed process-based studies that explore the interface between tree physiological function and watershed flowpaths, flow sources, and residence times are just now being attempted. These studies are fundamental to how the subsurface reservoir is viewed by hydrologists where our residence time models, hydrograph separation models, and distributed watershed models assume the subsurface is well mixed. This talk presents new information on the links between forests, soil water, and streamflow in a critical zone context.

Oliver Chadwick: The Role of Critical Zone Ecohydrology in Developing and Evolving Spatial and Temporal Chemical Structure in Terrestrial Ecosystems

Oliver Chadwick, Department of Geography, University of California, Santa Barbara

The capacity of soil and terrestrial ecosystems to withstand perturbations, whether driven by climate, land use change, or spread of invasive species, depends on its chemical composition and physical state. The Hawaiian Islands provide an excellent natural lab for understanding changes in hydrology, geochemistry, and ecosystem processes. The most important features are: a) increasing volcano age with distance from the hotspot, b) asymmetric rainfall distribution imposed by the northeasterly trade winds and orographic processes, creating wet windward sides and dry leeward sides, c) an impoverished vegetation assemblage characterized by the same species existing in strongly varying climate and soil conditions, and d) the ability to hold topography relatively constant over long time scales by sampling on volcanic shield remnants that are preserved even on the oldest high island, Kauai. These diverse conditions allow us to observe ecosystem functioning across a surprisingly broad range of soil

chemical states. We mapped the distribution of chemical/physical buffering systems in a time-climate context and show them to be bounded by strong thresholds. The dynamic interplay between stable, well buffered soil process domains and thresholds is a strong determinant of ecosystems composition and function and their response to forcing from global change, particularly as it affects water balance.

In terrestrial ecosystems, edaphic processes are often mediated by availability of water and its flux into and through soils. Water influences soil processes in several ways: it supports biological production, hence proton-donor, electron-donor and complexing-ligand production; it determines the advective removal of dissolution products, and it can promote anoxia leading microorganisms to utilize alternative electron acceptors. As a consequence climate patterns strongly influence global distribution of soil, although within region variability is governed by other factors such as landscape age, parent material and human land use. Soil properties can vary greatly among climate regions, variation which is guided by the functioning of a suite of chemical processes that tend to maintain chemical status quo. This soil "buffering" involves acid-base reactions as minerals weather and oxidation-reduction reactions that are driven by microbial respiration. At the planetary scale, soil pH provides a reasonable indicator of process domains and varies from about 3.5 to10, globally, although most soils lie between about 4.5 and 8.5. Those that are above 7.5 are strongly buffered by the carbonate system, those that are characterized by neutral pH (7.5-6) are buffered by release of non-hydrolyzing cations from primary minerals and colloid surfaces, and those that are <6 are buffered by hydrolytic aluminum on colloidal surfaces. Alkali and alkaline (with the exception of limestone parent material) soils are usually associated with arid and semiarid conditions, neutral pH soils with young soils in both dry and wet environments and acid soils with wet environments. Furthermore acid soils often have lost much of their easily weatherable primary minerals and their soluble (plant nutrient) ions, and thus much of their ability to buffer against acidity introduced by biological respiration and its products. Acid soils are closer to thermodynamic equilibrium with their near-surface environment and are less vulnerable to change compared with soils that contain a substantial supply of weatherable minerals (young soils) or carbonate minerals (dry soils).

Existing soil process domains determine ecosystem patterns across regional to global landscapes and guide human land-use decisions as we demonstrate using archeological evidence for prehistoric Polynesian agricultural systems. The impact on soil process domains of changing seasonal and annual rainfall and evapotranspiration patterns associated with climate change depends on how current pedogenic thresholds manifest across the landscape. We expect that humid soils subjected to drying should undergo less change than arid or semi-arid soils subjected to wetter seasonal conditions. Land-use changes can drive differential responses depending on changing chemistry and porosity. Collectively these factors provide the framework that may allow us to predict and map soil sensitivity to global change and climate change in particular.

Alexandra Ponette-González: Heterogeneous hydrologic and biogeochemical responses to land change in the high-elevation humid tropics

Ponette-González, A.G., E. Marín-Spiotta, K.A. Brauman, K.A. Farley, K.C. Weathers, and K.R. Young

In the high-elevation humid tropics, human- and climate-driven land transitions can have a disproportionate impact on water resources through effects on hydrologic flux and nutrient transport. We reviewed the influence of four common land transitions in montane (≥1000 m) Latin America (including the Caribbean) and Hawaii––forest-to-grassland conversion, coffee agroforest-to-nonforest conversion, tree plantation establishment on nonforest land, and recent glacier retreat––on throughfall, evapotranspiration, runoff and associated nitrate fluxes. Drawing from studies conducted primarily in temperate highlands, we predicted land-transition effects on the direction of change in water and nitrate fluxes and then compared our predictions with data assembled from recent (~50% published since 2008) empirical, paired land-use studies. Our synthesis reveals heterogeneous, and in some cases, unexpected responses to land change. Recent findings show that in montane tropical LAC and Hawaii, conversion

of forest to established grassland frequently results in negligible increases in surface runoff and that tree plantation establishment on nonforest land may have a greater relative impact on water cycling than deforestation. Our review also indicates that forest-to-grassland conversion frequently results in lower nitrate loss. These findings contrast with land use/land cover and water relationships derived from temperate research and highlight instances when principles developed in temperate highlands should not underpin payments for watershed services programs in the high-altitude tropics. Finally, we identify gaps in our current understanding of tropical land-change impacts on water resources at high altitudes and highlight research needs to improve management of tropical montane watersheds.

Hydroclimatology

Speakers: Tara Troy, Gabriele Villarini, Upmanu Lall
Session Chair: Witold Krajewski, Ana Barros

Tara Troy: Scale in Flooding: The role of drainage area, heavy precipitation, and model resolution

Tara J. Troy1, Naresh Devineni2, Carlos Lima3, and Upmanu Lall4

Floods are costly natural disasters, causing significant loss of life and destruction of property. Understanding how floods will change with climate in the coming decades is therefore of considerable interest. Existing studies largely focus on changes in precipitation extremes and assume that this extends to floods. However, it is unclear that an increase in more intense precipitation automatically translates into an increase in flooding. For example, large-scale floods are not the result of extreme 1-day rainfall. Rather it is the long-term precipitation dynamics combined with basin characteristics that dictate the relationship between heavy rainfall and flood events. This study tackles two open questions that need to be explored to understand the appropriate approach to projections of future flooding. First, we must understand how basin size influences the relationship between basin rainfall and the resulting floods. To tackle this question, we use historical precipitation and streamflow records for 165 basins in the Ohio River. This informs what variables must be considered when examining how changes in precipitation extremes may translate into flood events. Second, many studies analyzing the response of hydrologic systems to climate change involve downscaling climate information and feeding it through a hydrologic model. This raises questions of the appropriate resolution for accurate flood modeling. In order to understand the effect spatial and temporal resolution have on modeled flooding, we performed model experiments with the Variable Infiltration Capacity (VIC) model. These experimental results can inform future studies that seek to understand how flood regimes will change with climate.

Affiliations
1 Civil & Environmental Engineering, Lehigh University, Bethlehem, PA (tara.troy@lehigh.edu)
2 Civil & Environmental Engineering, City College of New York, New York, NY
3 Civil Engineering, University of Brasilia, Brasilia, Brazil
4 Earth & Environmental Engineering, Columbia University, New York, NY

Gabriele Villarini: North Atlantic Tropical Cyclones and U.S. Flooding

Gabriele Villarini
IIHR-Hydroscience & Engineering, The University of Iowa, Iowa City, Iowa, USA

Riverine flooding associated with North Atlantic tropical cyclones (TCs) is responsible for large societal and economic impacts. The effects of TC flooding are not limited to the coastal regions, but affect large areas away from

the coast, and often away from the center of the storm. Despite these important repercussions, inland TC flooding has received relatively little attention in the scientific literature, although there has been growing media attention following Hurricanes Irene (2011) and Sandy (2012). Based on discharge data from 1981 to 2011, a climatological view of inland flooding associated with TCs is provided, leveraging on the wealth of discharge measurements collected, archived, and disseminated by the U.S. Geological Survey (USGS). Florida and the eastern seaboard of the United States (from South Carolina to Maine and Vermont) are the areas that are the most susceptible to TC flooding, with typical TC flood events that are two to six times larger than the local 10-year flood peak, causing major flooding. A secondary swath of extensive TC-induced flooding in the central United States is also identified. These results indicate that flooding from TCs is not solely a coastal phenomenon, but affects much larger areas of the United States, as far inland as Illinois, Wisconsin and Michigan. Moreover, the dependence of the frequency and magnitude of TC flood events on large scale climate indices (the North Atlantic Oscillation and the El Niño-Southern Oscillation phenomenon) is highlighted, suggesting potential sources of extended-range predictability.

Upmanu Lall: Hydroclimatology: A unifying global perspective for floods and droughts

Upmanu Lall, Dept. of Earth & Environmental Engineering, Columbia Water Center, & International Research Institute for Climate and Society, Columbia University

Traditionally, hydrologists treated floods and droughts as random, and potentially unpredictable events and developed sophisticated statistical algorithms to characterize their local and regional frequency and intensity of occurrence. The development of the field of hydroclimatology since the 1980s has informed us as to the space and time organization of such events and as to their potential predictability in different parts of the world. Consequently, the global nature of such phenomena is now clear, even as their future projection under a changing climate continues to be a challenge. In this talk, I intend to review some open challenges and opportunities for hydroclimatology from a scientific perspective and link them to their potential contribution to address key societal and engineering challenges. This personal perspective is presented to solicit feedback and discussion as to possible community efforts that could be developed to improve our end to end understanding of hydroclimatic extremes.

Scaling in Hydrology

Speakers: Jennifer Adam, Markus Weiler, R. Daniel Moore
Session Chair: Christina Tague, Roy Sidle

Jennifer Adam: Climate Model Bias and Land Surface Heterogeneity: Two Factors that Impact the Usefulness of Earth System Models for Natural Resource Management

J.C. Adam1, C.L. Tague2, M.L. Liu1, E. Garcia2, K. Rajagopalan1, S. H. Chung1, X. Jiang3, J. Harrison4, T. Nergui1, A. Guenther1,5, C. Miller4, J. Reyes1, J. Choate2, E.P. Salathé6, C.O. Stöckle1
1Washington State University, Pullman, WA, USA
2University of California, Santa Barbara, CA, USA
3National Center for Atmospheric Research, Boulder, CO, USA
4Washington State University, Vancouver, WA, USA
5Pacific Northwest National Laboratory, Richland, WA, USA
6University of Washington, Bothell, WA, USA

As managers of agricultural and natural resources are confronted with uncertainties in global change impacts, the complexities associated with the interconnected cycling of nitrogen, carbon, and water present daunting management challenges. Existing models may provide detailed information on specific sub-systems (e.g., land, air, water, and humans) while few of them can capture the overall interconnections among these sub-systems. An increasing awareness of the unintended consequences of management decisions resulting from these interconnectedness, however, necessitates coupled Earth system models (EaSMs). With a focus on the U.S. Pacific Northwest (PNW), BioEarth is an EaSM currently in development that explores the interactions between coupled Carbon:Nitrogen:Water (C:N:H2O) dynamics and resource management actions at the regional scale. Capturing coupled biogeochemical processes within EaSMs like BioEarth is important for exploring the response of the land surface to changes in climate, management, and other global change phenomenon; information that is important for shaping decisions that promote sustainable use of natural resources. However, for a variety of reasons, this response may not be realistic. We explore two factors that impact the usability of information generated using EaSMs, each of which are described below: 1) climate model bias, particularly in tightly-coupled land-atmosphere frameworks, and 2) spatial heterogeneity of the landscape, including the role of lateral connectivity.

Climate Model Bias. Regional climate change impact (CCI) studies have widely involved downscaling and bias-correcting (BC) Global Climate Model (GCM)-projected climate for driving land surface models. However, BC may cause uncertainties in projecting hydrologic and biogeochemical responses to future climate due to the impaired spatiotemporal covariance of climate variables and a breakdown of physical conservation principles. Using a variety of models that comprise the BioEarth framework, we quantify the impact of BC on simulated climate-driven changes in water variables (evapotranspiration (ET); runoff; snow water equivalent (SWE); and water demand for irrigation), crop yield, biogenic volatile organic compounds (BVOC), nitric oxide (NO) emissions, and dissolved inorganic nitrogen (DIN) export over the PNW region. We also quantify the impacts on net primary production (NPP) over a small watershed in the region (HJ Andrews). Two climate data series are generated, with bias-correction (BC) and without bias-correction (NBC). Impact models are then applied to estimate hydrologic and biogeochemical responses to both BC and NBC meteorological datasets. These impact models include a macro-scale hydrologic model (VIC), a coupled cropping system model (VIC-CropSyst), an ecohydrologic model (RHESSys), a biogenic emissions model (MEGAN), and a nutrient export model (Global-NEWS). Results demonstrate that the BC and NBC climate data provide consistent estimates of the climate-driven changes in water fluxes (ET, runoff, and water demand), VOCs (isoprene and monoterpenes) and NO emissions, mean crop yield, and river DIN export over the PNW domain. However, significant differences rise from projected SWE, crop yield from dry lands, and HJ Andrews's

ET between BC and NBC data. Even though BC post-processing has no significant impacts on most of the studied variables when taking PNW as a whole, their effects have large spatial variations and some local areas are substantially influenced. In addition, there are months during which BC and NBC postprocessing produces significant differences in projected changes, such as summer runoff. Factorcontrolled simulations indicate that BC post-processing of precipitation and temperature both substantially contribute to these differences at regional scales. We conclude that there are trade-offs between using BC climate data for offline CCI studies versus directly modeled climate data. These tradeoffs should be considered when designing integrated modeling frameworks for specific applications; e.g., BC may be more important when considering impacts on reservoir operations in mountainous watersheds than when investigating impacts on biogenic emissions and air quality, for which VOCs are a primary indicator.

Spatial Heterogeneity. Many EaSM frameworks do not adequately represent landscape-scale (~200 m) spatial heterogeneity that influences land surface response, as relatively coarse resolution simulations (~10 km) are necessitated by both data and computational limitations. Spatial heterogeneity in a landscape arises due to spatial differences in underlying soil and vegetation properties that control moisture, energy and nutrient fluxes; as well as differences that arise due to spatially-organized connections that may drive a hydrologic or biogeochemical response by the land surface. While many land surface models used in EaSM frameworks capture the first type of heterogeneity, few account for the influence of lateral connectivity on land surface processes. This type of connectivity can be important when considering soil moisture and nutrient redistribution; the spread of fire, pests, and invasive species; etc. The RHESSys model is utilized by BioEarth to enable a "bottom-up" approach that preserves fine spatial-scale sensitivities and lateral connectivity that may be important for coupled C:N:H2O dynamics over larger scales. RHESSys is a distributed eco-hydrologic model that was originally developed to run at relatively fine but computationally intensive spatial resolutions (< 400 m) over small catchments. For larger-scale simulations, RHESSys is being adapted for BioEarth to allow for coarser resolutions (or "patch" sizes) by incorporating within-patch heterogeneity through non-spatial elements; i.e., we combine aspatial approaches used in many macro-scale land surface models with explicit hydrologic routing approaches used in catchment-scale models. We argue that this approach will be substantially more efficient but will still allow users to represent differences that arise due to lateral connectivity and spatial heterogeneity in watershed hydrology and ecosystem dynamics. Therefore, the objective of this study is to investigate the role of finer-scale heterogeneity in determining large scale, aggregate watershed response, in terms of C:N:H20 dynamics, to meteorological and management-related perturbations. We note that fine-scale heterogeneity is important when it leads to significant non-linear responses to environmental stresses. We selected several different locations varying in climate and biomes to examine the sensitivity of C:N:H2O dynamics to climate and management changes, as well as to using different methods of capturing spatial heterogeneity. Results from this work will be used to develop strategies to account for heterogeneity in the BioEarth framework.

Markus Weiler: Observing and predicting temporal and spatial scaling of runoff generation processes at various scales

Markus Weiler, Hannes Leistert, Andreas Steinbrich, Ralf Loritz

Runoff generation processes are the key to understand and predict watershed dynamics and runoff behaviour under current as well as under changing conditions. A variety of approaches have been developed to observe these processes at the plot scale (e.g. infiltration and sprinkling experiments), the hillslope scale (soil moisture and piezometer networks and trenching) and the watershed scale (hydrograph separation with baseflow separation or stable isotopes and natural tracers). However, predicting the major runoff generation mechanisms (infiltration excess, saturation excess, subsurface flow and deep percolation) without detailed observation at the various spatial

scales in a watershed is still a challenge, but a prerequisite to track water flow pathways and residence times and to make adequate prediction for hydrological extremes. Methods have been developed to map dominant runoff generation processes in the field and with digital maps, however, these methods are often static and do not consider the temporal dynamics of runoff generation processes frequently observed with the various experimental approaches. The recently developed parsimonious uncalibrated rainfall-runoff model RoGeR may provide a way forward bridge the gap between across spatial scales in ungauged watersheds. The model incorporates high-resolution GIS data (1m resolution DEM, land-use, impervious surfaces), hydro-geological and pedological data as well as information about the effect of macropores, cracks and other preferential flow pathways on runoff generation processes with a comprehensive knowledge base from various field observations and experiments. The model was applied to over 6500 meso-scale watershed in the State of Baden-Württemberg in Germany and 15 gauged watersheds were selected for detailed model evaluation. The evaluation was done with field-mapping of runoff generation processes for direct comparison with the simulated pattern of runoff processes for different types of precipitation (high intensity and short duration / low intensity and long duration) and benchmarking of several observed floods in these watersheds. The simulated patterns were analysed in more detail to gain a better understanding of the initial conditions (soil moisture) and different precipitation events and to derive scaling relationships. In addition, we also tested the performance of RoGeR using hillslope sprinkling experiments on a variety of soil and landuse. Finally, a detailed analysis of runoff ratio distribution for over 60 watersheds was performed to empirically determine the dominating factors that influence the runoff ratio in these watersheds. The empirical factors were than compared to the factors that are sensitive in the RoGeR model to evaluate if the model and hence the predicted runoff generation processes match the observed patterns. The model RoGeR is different from many other model approaches not only with respect to spatial resolution and model calibration, but in particular by incorporating a detailed understanding of hydrological processes, obtained from many experimental studies on runoff generation at the plot, hillslope and watershed scale worldwide.

Daniel Moore

Meteorological conditions exert a strong control on processes associated with hydrology and ecology. A typical set of variables required for physically based analysis and modelling includes precipitation, air temperature, humidity, wind speed and solar radiation. Given the increasing focus on applying models and analyses over heterogeneous catchments, landscapes or even at a global scale, there is a growing need to develop accurate methods for generating spatially distributed meteorological fields at a range of spatial scales and temporal resolution. A number of gridded products, such as ClimateWNA and the North American Regional Re-analysis, are currently available at regional to global scales that can be considered to represent “ambient”meteorological conditions. The applicability of these fields in any given situation can be limited by temporal resolution, temporal extent, the available variables in the product and the accuracy of the gridded fields. Furthermore, these fields require adjustment to account for the effects of slope, aspect, vegetation cover, elevation and boundary layer processes. In this presentation, I explore some of the issues associated with generating spatially distributed meteorological fields with a specific focus on their use in modelling surface energy exchanges associated with snow and ice melt, and stream thermal dynamics.

Deep and shallow flow system interactions

Speakers: Bayani Cardenas, W. Payton Gardner, Daniella Rempe
Session Chair: David Genereux, Gordon Grant

Bayani Cardenas: The relevance and scales of interactions between surface and subsurface flow systems

M. Bayani Cardenas plus many, many co-authors

Surface water bodies, such as rivers, wetlands, lakes and the coastal ocean, and groundwater are interconnected. Their interactions mediate many processes within the critical zone of Earth's surface that are relevant for ecosystems but also for societal problems.

At the regional scale, the character of flow systems from recharge to discharge zones, which oftentimes coincide with surface water bodies, determines the age and residence time of groundwater in regional aquifers. This is relevant because age is a metric for renewability of aquifers. If an aquifer has mostly young water, this suggests a high rate of replenishment and is therefore good for exploitation. The downside of this is that an aquifer with young water has high vulnerability for contamination from the surface. I will illustrate some ideas and preliminary results of on-going work on how we are applying concepts of regional groundwater flows to develop a global groundwater renewability map.

At local but nested scales, the hyporheic zone, the shallow transition zone between rivers and aquifers, has been shown to play a major role in determining watershed-scale water quality. That is, biogeochemical reactions occurring at this interface may integrate to affect the chemistry of both surface and subsurface water at much larger if not regional scales. Here, I will discuss ideas and results that span the pore to continental scales. At each scale, reactive transport models and residence time distribution analyses show the development of redox/biogeochemical zonation largely in part due to broad residence time distributions. A ubiquitous result from analyses across scales is that the hyporheic zone, or even more broadly the groundwater-surface water interface, is a hotspot. One that is perhaps at once unique to but prevalent within the critical zone.

Lastly, I will show how we analyzed hyporheic exchange at local scales (a few river channel widths) across the entire Mississippi River basin using distributed data. The maps illustrate the extent of hyporheic exchange. Further, the analysis shows that practically every drop of water that is drained through the river network has flowed through the hyporheic zone. Since the hyporheic zone is a hotspot for potentially beneficial reactions, such as denitrification, this begs the question - why is there a dead zone in the Gulf of Mexico? Why does so much nitrate make it downstream? Our analysis shows that hyporheic zones within the parafluvial zone or river banks may have insufficient residence times to denitrify most of the nitrate. Hence, the system is prone to becoming overwhelmed with addition of nitrate.

Despite recent lessons, open questions and exciting directions remain. This presentation concludes with questions motivated by results from recent studies such as those that will be illustrated.

W. Payton Gardner: Looking for the Bottom of the Active Zone – Investigating the Magnitude and the Implications of Deep Groundwater Interaction with Shallow Systems

W. Payton Gardner and Bill W. Arnold
Sandia National Laboratories
Albuquerque, NM, USA

The location and amount of discharge from deeply-sourced, regional groundwater systems has important implications for a large number of practical problems in Earth science including: migration of deeply sourced contaminants, proper management of water resources at the watershed scale and prediction of hydroecological response to prolonged climatic shifts. Most current studies either explicitly ignore the role of deep groundwater discharge in shallow alluvial systems, or use methods for estimating groundwater discharge that are incapable of identifying very old, deeply-sourced groundwater circulation. In this talk I will use environmental tracers including 3He, 4He and 222Rn to show that deep, regional groundwater is active in a variety of surface water systems around the world. We have evidence that groundwater with apparent age in excess of 1000 years comprises up to 10-100% of the total groundwater discharge in large river systems at the ~100 km reach scale. Our evidence indicates that over a range of geologic, climatic and hydrologic systems, regional groundwater plays an important role in shallow alluvial systems. Finally, I will discuss the importance of understanding the magnitude of deep groundwater velocity and the bottom of the active circulation zone in the context of disposal of nuclear waste in mined repositories and deep boreholes.

Daniella Rempe: Runoff in the deep critical zone: the role of weathered, fractured bedrock in mediating water availability

Authors: Daniella M. Rempe1, William E. Dietrich1, Rohit Salve2, and Jasper Oshun1
1 University of California, Berkeley, Berkeley, CA
2 Lawrence Berkeley National Laboratory, Berkeley, CA

There is a growing body of research that suggests that weathered, fractured bedrock underlying hilly and mountainous landscapes is an important source of moisture to vegetation and influences runoff and landsliding processes. However, we have few direct observations about the storage, transport, and chemical evolution of water in the weathered fractured bedrock zone underlying hillslopes. This is due in part to the challenges associated with making measurements in bedrock and also to the common assumption that the permeability contrast at the soil-bedrock boundary limits water movement on hillslopes to the soil layer. As landscapes are uplifted and eroded, fresh, nearly impermeable bedrock is converted to porous and permeable weathered bedrock through physical and chemical weathering. Here we present observations from the Eel River Critical Zone Observatory in Northern California that reveal the dynamics of runoff through the weathered bedrock, deep in the critical zone and, importantly, document significant rock moisture change in response to storms, seasonal drainage, and transpiration demand by specific tree species (Figure 1). The 4000 m2 hillslope study site is mantled with thin soils which overlie a thick (4-25 m) zone of weathered, fractured argillite that thickens towards the divide. Over seven years of continuous monitoring demonstrate that all runoff passes through the soil and into the weathered bedrock. Groundwater perches on the underlying fresh bedrock during the wet winters and provides baseflow to Elder Creek, a tributary of the South Fork Eel River, as it drains during the dry summers. Groundwater response may be strongly driven by film flow along fractures networked to a near-surface saprolite. Repeat neutron probe profiles down 9 wells demonstrate that individual rainstorms can increase the weathered bedrock moisture content by greater than 180 mm, and that in the current year up to 30% of the 1000 mm of seasonal rainfall is stored in the weathered bedrock zone as rock moisture. Stable isotope (dD and d18O) analysis of weathered bedrock, groundwater, soil, vegetation and rain demonstrate that the dominant conifer species, Douglas Fir, (Pseudostuga menziesii), relies primarily on rock moisture whereas adjacent hardwoods (e.g. Interior live oak Quercus wislizeni) exploit soil moisture. Collectively, our observations demonstrate that the deep critical zone, that which lies below the soil, is a dynamic reservoir of unsaturated water (rock moisture) and saturated groundwater. The rock moisture sustains vegetation, may provide slow recharge to the groundwater, which in turn, sustains river ecosystem baseflow in this seasonally dry environment.

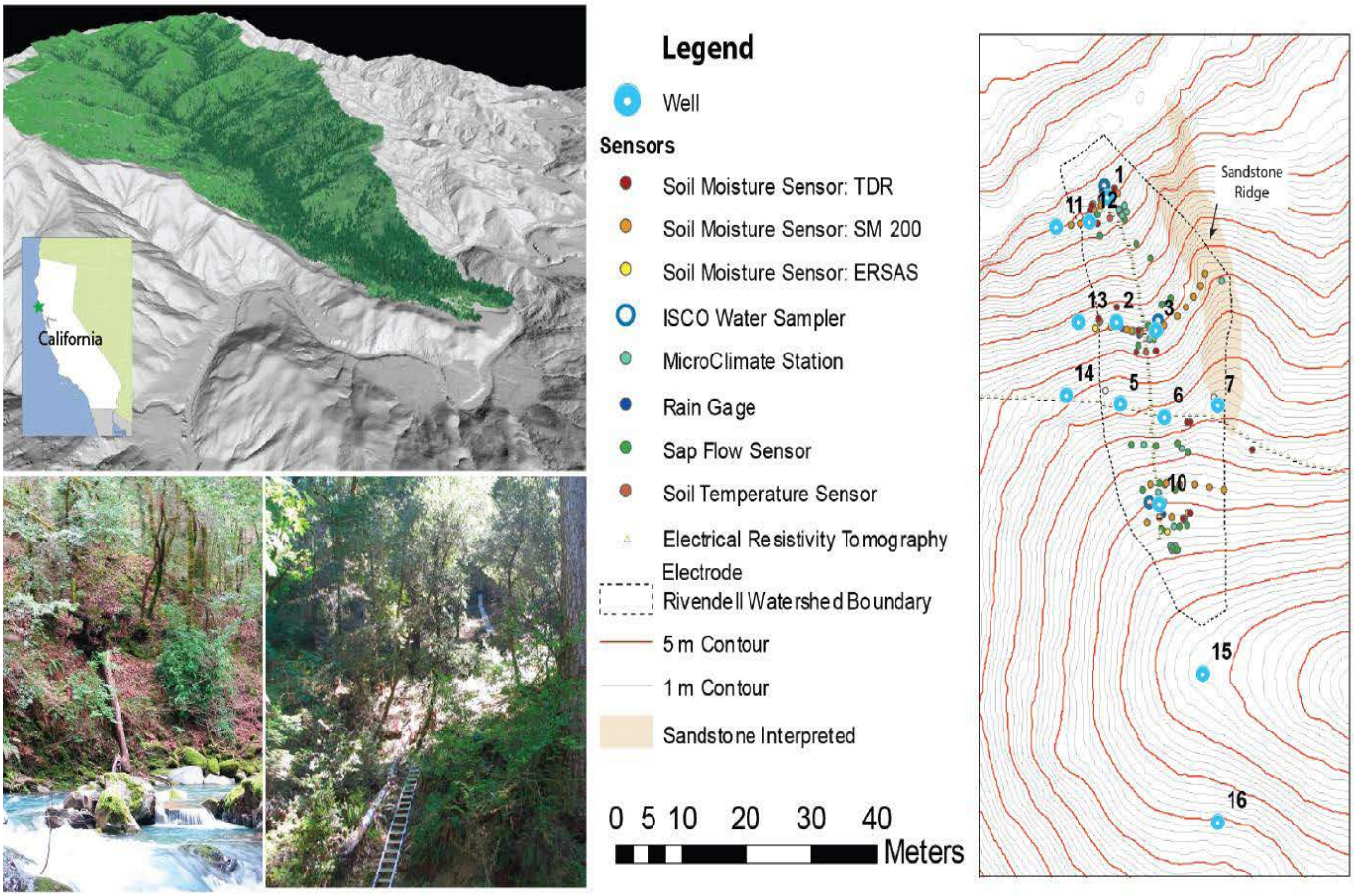

Figure 1: Location and map of the Eel River Critical Zone Observatory Rivendell field site within the Elder Creek watershed in Northern California.

Advances in Community Modeling

Speakers: Mukesh Kumar, Ben Mirus, Martyn Clark
Session Chair: Reed Maxwell, Chris Duffy

Mukesh Kumar: Community Hydrologic Models for Analyses, Discovery, Prediction and Mitigation: An Evolving Paradigm

Mukesh Kumar, Nicholas School of Environment, Duke University

Prediction of hydrologic responses and identification of mitigation strategies generally require detailed elucidation of process interactions in both space and time. Here we present a strategy for simulating water cycle processes at watershed and river basin scales, that couples physics, numerics, data and computation. The strategy involves use of a state-of-the-art numerical solver and multi-processor clusters for computational efficiency, a flexible code structure to support different approximations and number of processes, and a tightly coupled GIS that facilitates seamless flow of data between data-management systems and hydrologic models. The framework encourages fast prototyping of new model simulations and allows independent-yet-connected development paths by domain scientists in the field of solvers, domain decomposition, visualization, and critical-zone processes. The framework

has been applied from hill-slope (10-100m) to catchment (100-1000m) to synoptic scales (>100km), to analyze, discover and predict hydrologic responses, and also for identifying potential risk mitigation strategies.

Ben Mirus: Code Development and Concept Development: Opportunities for Progress and Synergy

Ben Mirus, Department of Geological Sciences, University of North Carolina at Chapel Hill

High resolution applications of distributed hydrologic models are playing a central role in addressing several grand challenges related to climate and land-use change, land-atmospheric coupling, forecasting extreme-events, and assessment of water resources. However, hydrologic modeling itself faces many grand challenges related to computational efficiency, parameter estimation, data integration, and process representation. To address these combined challenges, the Community Hydrologic Modeling Platform (CHyMP) initiative has established a revised blueprint for digitally simulated hydrologic modeling in the era of super computers and big data. Designed to broadly advance quantitative characterization of the hydrologic cycle, CHyMP involves two crucial, but often diverging themes: (1) model testing and code development, and (2) model applications and concept development. The contrast between the technical skills and creative insights needed to advance these two themes has previously led to a divisive view of modelers versus model users. However, a more inclusive outlook is integral to supporting the CHyMP vision for a sophisticated, modular modeling platform that will provide the scientific community and society with open access to advanced simulations and visualizations. Cooperation will be necessary to address several of the primary objectives outlined by CHyMP, notably: (1) seamless access of parameter data into simulations at different scales, (2) calibration of models based on observations of hydrologic fluxes or state variables, (3) modification of functions and coupling processes to address new observations or discoveries, and (4) access for non-specialists to state of the art simulations. With these challenges in mind, this presentation will focus on developing a mutual understanding between code developer and concept developer about the benefits and drawbacks of the many underlying assumptions used in current modeling platforms and applications, from simplified processes conceptualization to novel numerical tricks. This will include examples from a variety of data/model integration studies focused on parameter estimation and process characterization to highlight areas where a community effort is needed to advance the predictive capabilities of CHyMP and ensure consistency across model applications.

Instrumentation enabled science: advances and frontiers

Speakers: Marty Briggs, Matt Cohen, Burke Minsley
Session Chair: Kamini Singha, Brian Pellerin

Marty Briggs: Surface geophysical methods for evaluating stream habitat and the resilience of aquatic systems to climate warming

The temperature, availability and movement of surface water and shallow groundwater are changing. Variations in shallow permafrost affect arctic lake water budgets, and sea-level rise may disrupt limited fresh groundwater resources on low Pacific islands. Closer to home, groundwater upwelling to streams creates unique habitat by influencing stream water quality and temperature. The relative stability of groundwater temperature buffers biota against seasonal and extreme weather events; therefore upwelling-induced thermal refugia will become increasingly important as climate warms. The evaluation and management of surface water, groundwater, and obligate biota as intimately connected resources necessitates novel applications of traditional research methods and field development of emerging methods. To illustrate these concepts, we will explore comprehensive geophysical/thermal/hydrodynamic data recently collected in the upper Delaware River in an effort to inform management of the endangered dwarf wedgemussel (Alasmidonta heterodon). We will then travel to Palmyra Atoll in the Central Pacific where surface-geophysical and borehole monitoring techniques have been integrated to begin a long-term record of fresh groundwater response to change. Finally, geophysical observations from a field site in central Alaska are interpreted with numerical modeling to determine why new permafrost may be forming around shrinking lake systems in a region where general thaw is expected. This collection of studies from around the globe illustrates the broad applicability of surface geophysical methods to describe shallow aquifer water quality and fluid exchange dynamics across the critical zone.

Matt Cohen: The Sensor Revolution: Insights on Nutrient Dynamics in Large River Ecosystems

Matthew Cohen1, Courtney Reijo1, Bobby Hensley1, James Heffernan3, Sean King4

Understanding and managing nutrient enrichment is a grand challenge in watershed science, and predicting when and how aquatic ecosystems will respond to nutrient enrichment is a grand challenge in ecosystem science. Sensors are enabling a revolution in both areas by providing measurements at temporal resolutions (e.g., sub-hourly) compatible with hydrologic and ecosystem processes. In this talk, we present four new inferences about river ecosystems based on high resolution measurements of solute chemistry. First, using high resolution time series of nitrate and dissolved oxygen, we present a method to measure pathway specific reach-scale N retention, and explore the coupled element cycling implied by the sensor-derived signal in rivers with both constant and tidally-varying discharge. Second, by adding high resolution measurements of phosphate to the suite of analytes, we evaluate pathway specific P retention, and implications for plant uptake timing and hyporheic exchange. Third, we alter the reference frame from Eulerian to Lagrangian to explore longitudinal solute patterns, from which we extract both nitrogen uptake rates and evaluate ecosystem uptake kinetics. Finally, we present a sensor-enabled investigation of nutrient and metabolic process scaling in river systems where we compare point-scale (using benthic chambers) and reach-scale measurements. Like all technologically enabled advances, the new signals from these in situ nutrient sensors spawn new questions, and this talk will close with hypotheses generated from signal behaviors unexplained by current ecosystem theory.

1- School of Forest Resources and Conservation, University of Florida, Gainesville FL, USA

2- Nicholas School of the Environment, Duke University, Durham NC, USA
3- Southwest Florida Water Management District, Brooksville FL, USA

Figure (next page): Recent advances in watershed and aquatic ecosystem science are being enabled by new nutrient sensors (A), which provide high temporal resolution time series from which ecosystem processes can be extracted. Examples include diel variation in dissolved oxygen and nitrate in response to solar forcing (B; Heffernan and Cohen 2010), and the convolution of diel and tidal signals in freshwater tidally-varying rivers (C; Hensley et al. in review). Additional solutes provide additional insights. The addition of phosphate yields a diel signal (D; Cohen et al. 2013) that is out of phase with photosynthesis and is derived from the combined action of plant uptake and calcite co-precipitation. Altering the reference frame so that the sensor samples at high spatial rather than temporal resolution yields clear longitudinal profiles (E; Hensley et al. in press) from which retention hotspots can be discerned, and spatial controls on nutrient uptake enumerated. Finally, sensors enable comparisons of nutrient dynamics across scales, with novel methods for assessing point-scale uptake (F; Reijo et al. in preparation) and assessing patterns of spatial and temporal variation.

Burke J. Minsley: Hydrogeophysics at the watershed scale using airborne electromagnetics

Model structural uncertainty can lead to significant errors in hydrologic simulations. Imperfect knowledge of aquifer geometry and connectivity between hydrogeologic units can result in erroneous estimates of the extent and magnitude of hydrologic responses to climatic and anthropogenic forcing. A key challenge for making improved groundwater management decisions is to accurately delineate hydrogeological structures over watershed scales with sufficient resolution to capture small-scale, yet hydrologically important, features.

Borehole observations and ground-based geophysical measurements, although useful, cannot characterize model structure over large-scale modeling domains with sufficient detail. Much as LIDAR and other remote sensing technologies have transformed the way in which we interpret the geomorphological processes that have shaped Earth's surface, airborne electromagnetic (AEM) surveys have become an invaluable tool for extending our view into the subsurface, imaging geological and hydrological features from tens to hundreds of meters below ground. AEM surveys provide densely sampled data over large areas (hundreds to thousands of square kilometers) that cannot be covered using ground-based methods, particularly in remote locations. AEM data are therefore uniquely suited to hydrogeophysical studies at the watershed scale where groundwater management decisions require detailed knowledge of subsurface aquifer geometry and properties.

I will describe the AEM method and present results of recent studies that illustrate the value of airborne geophysics in hydrological applications. Two of the main challenges to integrating AEM data in groundwater models include (1) quantifying uncertainty in geophysical estimates, and (2) understanding the relationship between measured geophysical properties and hydrologic properties of interest. To address these challenges, I will discuss the development of new Bayesian and geostatistical algorithms being used to better quantify geophysical parameter uncertainty, to probabilistically estimate the location of geological interfaces and lithological units, and to integrate geophysical, geological, and hydrologic data to make improved estimates of hydrologic variables.

Comunity Workshops

Advances in Environmental Data Management for the Research Community

Organizer: Yoram Rubin, UC Berkeley

This workshop will focus on a solution for geospatial data management called myObservatory (see myobservatory.org). The event includes a presentation and hands-on demonstrations.. Participants should bring their own laptop and connect to NCTC wi-fi for online participation.

The vision that defines myObservatory is our wish to provide our users with a platform that combines analytical tools with the rigorous needs of managing scientific research, while providing a superb user experience. As scientists, we know first-hand the importance of quality assurance and data curation, the ability to maintain confidentiality and secured access, and maintaining simplicity in managing and visualizing data. We also wanted to create a platform that is not subordinated to any particular vendor. To meet these goals, myObservatory is built from the bottom up with industry-standard open-source software tools. Some of its features include:

- web-based data entry, analysis, display, management, sharing, and reporting
- data visualization and analysis tools
- customized suite of science modules (e.g., data interpolation, contouring, flow vector computation, etc.)
- automated custom data validation and data curation
- automated alerts on set trigger points of environmental variables
- differentiated access control
- complete, continuous monitoring solution available (integrated data management with sensors and telecom hardware)
- linked with external public data providers (i.e., federal and state agencies) providing access to outside environmental data
- seamless desktop-smartphone connectivity
- Accredited by CUAHSI for data-harvesting

Communicating Science with AAAS

Led by Jeanne Braha, AAAS

Scientists and engineers often find that they need to discuss complicated scientific findings in a clear, concise manner with members of the public. The AAAS Communicating Science workshops developed by the Center for Public Engagement with Science and Technology are specifically designed to address the needs of scientists and engineers in communicating scientific information to those outside their immediate field.The ability to convey complex concepts effectively can help scientists successfully engage in a variety of public and professional interactions, including conducting media interviews, writing grant proposals, discussing ideas with students, testifying before Congress, or participating in a public forum.

Community Modeling discussion (half-session)

NSF has recently funded CUAHSI to begin a community-level effort to accelerate the improvement of hydrological process representation in the context of earth system modeling that will integrate our community's best understanding of water storages, fluxes and flowpaths across scales. This will require a broad effort to entrain the best data, scientific understanding, process models and software development practices.

The goal for the funded period (an initial pilot project of 2 year duration) is to lay out the steps forward, including the design of a community process to develop/benchmark/maintain/improve community hydrologic models and the frameworks in which they reside. This pilot project is an important opportunity - It represents an opportunity for the community to express and demonstrate to NSF what is needed in terms of true community resources and infrastructure.

In the proposal stage, we suggested that the working group focus on the NCAR Community Land Model (CLM) as a starting framework for two main reasons; i) to establish collaboration with NCAR, and ii) to allow members of the hydrologic sciences community to contribute to earth system modeling more directly. While we all recognize that there are important distinctive aspects of hydrology that require multi-scale thinking and approaches, there is still a need for the hydrology community as a whole to ensure that hydrology is well-represented in large scale models used by other communities (e.g. like CLM), while still advancing our science and understanding through other modeling endeavors (e.g. integrated models). Alternative paths may emerge as the working group begins to develop a blue print, and is the reason that CUAHSI needs your input.

This half-day open working session will discuss developing a work plan and to identify interested working group members. The primary task of the working group is to provide scientific and programmatic advice to the development of a "community process" for benchmarking community models and frameworks. Part of this pilot exercise is to explore the structure and activities that would need to be in place to support communities coalescing around different types of models; the ultimate goal is to support several different groups with the same "blueprint" for infrastructure/resources and community framework for each group.

DTS and Drones: CTEMPs Instrumentation Workshop

Organizer: Scott Tyler, University of Nevada-Reno

Environmental sensing is undergoing a revolution in sensor design, cost and accessibility. This workshop will describe and discuss two evolving sensing systems, DTS and UAS a.k.a.drones. Distributed temperature sensing (DTS) represents a significant step up in spatial and temporal resolution of environmental temperatures. This workshop will first provide a basic introduction to DTS along with some recent examples of advanced uses along with opportunities for hands-on use of an ultra high resolution DTS. Autonomous vehicles, in particular aircraft represent another wide open area for hydrologists to sense their environment. While not yet as accessible as DTS, it is clear that UAS systems will be integrated into our sensing suite. We will cover the basics of UAS operation with a focus on the current regulatory environment and finish with an open discussion of possible applications and designs of UAS systems for hydrologic research. The workshop will be modular, with DTS taking the first hour, and UAS discussions in the last hour. Participants are encouraged to drop in and bring their ideas!

Exploring Sino-US Collaboration in Critical Zone Science

Organizers: Paul Brooks, University of Arizona; Chunmiao Zheng, Peking University; Rick Hooper, CUAHSI

Many parallels exist between the US and China that make comparative study of critical zone processes compelling:

- Both countries are at continental scale with large rivers that integrate CZ processes across a broad range of parent material, vegetation, and climate
- Both countries have large water-limited regions where mountain precipitation heavily supplements midstream and downstream water resources
- Both countries are experiencing conflicts in water allocation among competing uses that are being exacerbated by climate change and variability
- Both countries are investing in long-term observatory infrastructure, notably the Heihe program in China and the CZO, LTER, NEON and other networks in the US

This workshop will explore how Chinese and American scientists can collaborate on these and other topics, identify existing barriers to collaboration, and generate recommendations on how to mitigate these barriers joint research. Results from this workshop will be reported to an upcoming joint meeting of the US and Chinese National Science Foundations to be held in the fall of 2014.

HydroShare Community Workshop (half-session)

Led by David Tarboton, Utah State University

Hydroshare is a web based collaborative system being developed for the sharing of hydrologic data and models. The goal of HydroShare is to enable scientists to easily discover and access data and models, retrieve them to their desktop or perform analyses in a distributed computing environment that may include grid, cloud or high performance computing model instances as necessary. They will then be able to publish outcomes (data, results or models) back to the system, sharing with whom they choose and use the system as a platform for collaboration. HydroShare will also support formal publication of data and models.

This workshop will present the vision and roadmap for the development of HydroShare and introduce the beta version (http://beta.hydroshare.org). HydroShare is at an early stage of development and we seek input from the CUAHSI community about capability and needs for future development.

Schedule

- Introduction to HydroShare. David Tarboton (15 min)
- Demonstration of HydroShare beta release. Dan Ames and Jeff Heard (15 min)
- Model Sharing. Jon Goodall (10 min)
- 4.SWATShare. Adnan Rajib (10 min)
- Participating in the development of HydroShare. Ray Idaszak and Jeff Heard (10 min)
- Audience discussion of needs and opportunities related to HydroShare development. (30 min)

The Landscape Evolution Observatory: a community research facility for large-scale controlled experimentation in hydrology (Peter Troch)

Field and laboratory experimentation has been critical in advancing hydrological science (from Darcy's column experiment in Dijon to the covered Gårdsjön catchment in Sweden). While it is relatively easy to control small-scale experiments in the laboratory, a major challenge to experimental work in the field is the inability to manipulate experimental variables. Moreover, at the large scale (e.g. hillslope scale) it is often impossible to monitor multiple physical, chemical and biological response variables at high spatial and temporal resolution. There is thus a need for research facilities that allow controlled experimentation at sufficiently large scale and with sufficiently dense sensor networks that interactions of processes controlling the landscape response can be observed under different initial and boundary conditions. Ideally such controlled experimentation could also be replicated to quantify variability that exists within experimental units receiving different manipulations. Our community has invested in such research facilities (e.g. St. Anthony Falls Laboratory at the University of Minnesota or the Landscape Evolution Observatory at the University of Arizona). This workshop will offer a forum to exchange ideas on how the broader critical zone community can engage in experimentation at the Landscape Evolution Observatory (LEO). We'll start with a brief introduction of the LEO, followed by a round table discussion of the opportunities and challenges related to operating this facility for the community.

Poster Index

Posters are available for veiwing throughout the duration of the conference
*Indicates student presenter

General

1 *Ball, Ashley – Johns Hopkins University

Applied time-varying transit time distributions for understanding hyporheic exchange

2 *Bandy, Ashley – University of Kentucky; 2012 Pathfinder Fellow

Mobility of *Escherichia coli* as compared to traditional tracers in karst aquifers, Kentucky, USA

3 Cole, Joshua – University of Maryland, Baltimore County

Design and implementation of tailored online services for hydrologic data management

4 Demir, Ibrahim – University of Iowa

Interactive web-based hydrological simulation system as an education platform

5 *Jarden, Kimberly – Kent State University

Assessing impacts of green infrastructure at the watershed scale for suburban streets in Parma, Ohio

6 Kelleher, Christa – Duke University; 2010 Pathfinder Fellow

Reality check: Assessing internal catchment behavior to reduce uncertainty in complex, distributed models

7 *Pelak, Norman – Duke University

Theoretical considerations for stochastic soil moisture dynamics and the optimal design of soil moisture sensor networks

8 Rajib, Mohammad Adnan – Perdue University

RWater: A cyber-enabled data-driven tool for enhancing hydrology education

9 *Seybold, Erin – Duke University

The role of hydrologic connectivity in mediating stream metabolism and carbon dynamics across space and time

10 Shmagin, Boris – San Diego State University

Hydrology: Modeling an uncertainty

11 *Soltanian, Reza – Wright State University

Linking hierarchical stratal architecture to reactive plume spreading in the Lagrangian-based transport models

Critical Zone Evolution – Legacy Influence on Contemporary Processes

12 *Birch, Andrew – North Carolina State University

Evaluating wastewater export to local streams from a forested-municipal wastewater land application facility

13 *Mallard, John – Duke University

Field to forecast: Leveraging wireless environmental sensor networks to facilitate real-time hydrologic prediction

Critical Zone Science – Research from the Shale Hills/ Cristina River Basin REU/RET

14 *Beaulieu, Olivia – University of Massachusetts Amherst; Penn State REU

Soil saturated hydraulic conductivity and its spatial variability in the Shale Hills Critical Zone Observatory

15 *Kim, Christine – Temple University; Penn State REU

Comparing carbon stocks in the O horizon of shale and sandstone watersheds according to topographic position and ecosystem characteristics

16 *Fisher, Jess – Brown University; Penn State REU

Lithologic and land-use controls on solute concentration-discharge behavior in the Susquehanna Shale Hills Critical Observatory (SSHCZO)

17 Hess, Melissa – Conestoga Valley Middle School; Stroud Water Research Center RET

Applications of environmental DNA in a middle school classroom

18 *Hostetler, Bryce – Bethel College; Penn State REU Program

Optimization of qPCR techniques to determine environmental DNA transport in stream systems

19 *Johnson, Quincey – Hobart and William Smith Colleges; Penn State REU

Comparing vegetation across topographic positions in two watersheds at the Susquehanna Shale Hills Critical Zone Observatory

20 *Kubina, Dylan – Penn State University; Penn State REU

A floristic survey of Pingo scars in central Pennsylvania

21 Longwell, Paul – Hollidaysburg Area High School; Stroud Water Research Center RET
Monitoring temperate forest soil moisture dynamics using ground-penetrating radar

22 *Lunn, Eric – University of Delaware; Penn State REU

Impact of mineral weathering and organic matter on soil water retention

23 *Mark, Sam – Bates College; Stroud Water Research Center REU

Fine-grained channel margin deposits form by recirculating flow downstream of woody debris in a laboratory flume

24 *Schmid, Kimberly – Pennsylvania State University; Penn State REU

Predicting the presence of headwater wetland depressions, Valley and Ridge Physiographic Province, central Pennsylvania

25 *Schoenstein, Jennifer – University of Delaware; Stroud Water Research Center REU

Thermal dynamics and transient storage in a spring-fed forested headwater stream, Southeastern PA, USA

26 *Thayer, Abigail – Ohio Northern University; Stroud Water Research Center REU

Evaluation of an in situ UV-Vis spectrophotometer for high frequency measurements of dissolved organic carbon and nitrate concentrations

27 *Vrijmoet, Meike – Bennington College; Penn State REU

Does root morphology and architecture reflect aboveground species composition?

28 Yeckley, Mark – Glendale Junior-Senior High School; Penn State RET

Dendrology, forest ecology, and data analysis in the STEM-centered classroom

Deep and Shallow Flow System Interactions

29 *Baker, Stuart – Kent State University
Development of hyporheic exchange and nutrient uptake following stream restoration

30 *Brown, Krista – Kent State University

After the dam comes out: groundwater-stream interactions and water quality impacts of former reservoir sites

31 Gomez-Velez, Jesus – United States Geological Survey

Modeling hyporheic exchange fluxes across river networks

32 Michael, Holly – University of Delaware

Geologic and hydrodynamic effects on shallow groundwater-surface water exchange and chemical fluxes to an estuary

33 Tian, Yong – Peking University
An integrated modeling approach to understanding the complex water cycle in large inland basins

34 *Zimmer, Margaret – Duke University

The role of groundwater and stream network dynamics in baseflow and stormflow generation

Water Sustainability, Climate, and Human Dimensions

35 Barnes, Michael – University of Maryland, Baltimore County
High-resolution coupled groundwater-surface water-land surface modeling incorporating urban land cover data in PARFLOW.CLM

36 Bhaskar, Aditi – University of Maryland, Baltimore County

Urban watershed storage and streamflow generation

37 *Jasechko, Scott – University of New Mexico; 2012 Pathfinder Fellow

The isotopic fingerprint of global groundwater resources

38 Jefferson, Anne – Kent State University

Stormwater control measures modify event-based stream temperature dynamics in urbanized headwaters

39 *Lindner, Garth – University of Maryland, Baltimore County

Propagation of flood waves through urban channels and riparian zones

40 *MacLeod, Sarah – Dalhousie University

Increasing aluminium concentrations in Southwest Nova Scotia Canada rivers from 1980 to present

41 Ward, Adam – Indiana University

Product-to-parent reversion of Trenbolone: Stream-hyporheic spiraling increases ecosystem exposure and environmental persistence

42 Welty, Claire – University of Maryland, Baltimore County

Analysis of water isotope content of precipitation and stream samples in the Baltimore Ecosystem Study LTER

Hydroclimatology

43 *Beamer, Jordan – Oregon State University; 2013 Pathfinder Fellow

Improving glacier and snow melt runoff simulations in an operational hydrologic model: Prince William Sound, Alaska

44 *Eggett, Leighia – West Virginia University

Effect of climate change on hydrologic regime of Canaan Valley and the Upper Blackwater River Watershed in West Virginia

45 *Volk, John – University of Nevada Reno

Potential effects of a warming climate on water resources within the Lehman and Baker Creek Drainages, Great Basin National Park, Nevada

46 Zhang, Aijing – Peking University
Modeling the hydrological response to climate change in the Heihe River Basin, northwest China

Ecohydrology

47 *Allen, Scott – Louisiana State University

A process-based model of tree growth responses to hydrology in a forested wetland

48 Buskirk, Brendan – United States Geological Survey

Hydrologic and ecological alterations of urban headwaters: relative influence of in-channel and watershed best management practices (BMPs)

49 *Chen, Xiaoli – University of California Santa Barbara

Modeling nitrate exporting patterns during storm events for a semi-arid mountain watershed

50 *Gaffney, Rowan – University of Nevada Reno

Hydrologic Impacts of Forest Thinning in the Hat Creek and Burney Creek Basins

51 Hausner, Mark – Desert Research Institute

Assessing desert ecohydrologic habitat suitability under varying management and climate scenarios

52 Johnston, Carol – South Dakota State University

Plumbing the landscape: beavers optimize dam sites

53 *Kaiser, Kendra – Duke University

Watershed scale soil biogeochemistry and greenhouse gas fluxes: Space-time dynamics, patterns, and interrelationships of CO2, CH4, and N2O

54 *Reyes, Julian – Washington State University

Eco-hydrologic modeling of rangelands: Evaluating a new carbon allocation approach and incorporating grazing impacts on ecosystem processes

55 *Nippgen, Fabian – Duke University/ Montana State University

The effect of precipitation variability on rainfall-runoff response and storage in steep headwater catchments

56 *Roche, Kevin – Northwestern University; 2013 Pathfinder Fellow

Biofilm complexity controls fine particle dynamics in streams

57 *Scaife, Charles – University of North Carolina Chapel Hill

Long-term variability of threshold runoff response in forested watersheds

58 *Shifflett, Dawn – North Carolina State University

A catchment-scale study evaluating the influence of waste water irrigation on the hydrologic balance

59 *Singh, Nitin – North Carolina State University

Space-time variability of headwater streamflow in the Southern Appalachians

60 *Son, Kyongho – University of California, Santa Barbara

Effect of soil parameter uncertainty on assessing climate change projection in two small Sierra Nevada watersheds

61 *Yao, Yingying – Peking University

A study of spatiotemporal patterns of vegetation in a groundwater dependent ecosystem, Heihe River Basin, northwest China

62 *Young, David – West Virginia University

Catchment streamflow response to climate change conditioned by historic alterations of land-use: forest harvest, succession, and stand conversion

Instrumentation enabled science: advances and frontiers

63 *Liu, Chuankun – Peking University- Analysis of Groundwater-Lake Interaction by Distributed Temperature Sensing in Badain Jaran Desert, Northwest China

64 Pellerin, Brian – United States Geological Survey

Mississippi River Nitrate Dynamics from Drought to Flood Revealed by High Frequency Measurements

65 Sawyer, Audrey – Ohio State University

Insights into hydrogeochemical dynamics in a floodplain aquifer during Hurricane Sandy from multiple sensor technologies

Scaling in hydrology

66 *Allen, George – University of North Carolina Chapel Hill

Scaling river width and surface area from continental river networks to first-order streams

67 *Feng, Dongmei – Northeastern University

Variation in freshwater input to the Eastern US coastal ecosystem

68 Shen, Chaopeng – Penn State University

Temporal evolution of soil moisture statistical fractal: seasonal and rainfall dynamics

69 Stewart, Ryan – Virginia Tech

Soil-water interactions in shrink-swell clays: measurements and models across scales

70 *Zhao, Yuanhao – Northeastern University

Investigating runoff behavior using remote sensed data and modeling in the Ohio River Basin

Poster Abstracts are arranged in aphabetical order (A-Z) by last name, from page 37.

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Scaling river width and surface area from continental river networks to first-order streams

George H Allen, Tamlin M Pavelsky
Department of Geological Sciences at the University of North Carolina at Chapel Hill, Chapel Hill, NC

Rivers are hotspots for carbon dioxide emission to the atmosphere. The surface area of rivers is a primary control on carbon dioxide efflux and is used to estimate global evasion rates. Current evaluations of river surface area rely on: 1) downstream hydraulic geometry (DHG), which relates river width to upstream drainage area; 2) extrapolation of river width and length from large to small river basins using Horton ratios; and 3) empirical relationships between climate and percentage water cover. Here we use the Landsat-derived North American River Width (NARWidth) dataset to directly quantify the surface area of all North American rivers wider than 100 m. We then use the strong statistical relationship between river width and surface area to estimate the total surface area of rivers wider than 1 m. Using this conservative width threshold, we find that the total mean river surface area of North America is ~138k km^2, a value ~30% greater than previous estimates with consequences for air-water gas exchange estimates.

A process-based model of tree growth responses to hydrology in a forested wetland

Scott Allen[a]*

Richard Keim[a]

[a]School of Renewable Natural Resources, Louisiana State University, Baton Rouge LA

Tree rings provide both a useful hydrologic proxy and an indicator of environmental controls over growth. Generally, annual radial growth increments are compared to numerous environmental variables (i.e., monthly / yearly / seasonal precipitation, water level, temperature, etc.) via simple correlations, multiple regressions, or other linear statistical procedures. In water limited environments, typically growth is positively correlated with precipitation and water levels, and negatively correlated with temperature. Similar patterns have been observed in wetland environments, but the reason is unclear. Statistical correlative analysis does not capture the true controls over growth and neglects complex behavior. Accordingly, recent work has demonstrated that a process-based model accounting for the water budget and ecophysiological responses is a better predictor of radial growth than conventional approaches. A modeling approach may be particularly useful in a wetland environment where both flood stress and drought stress limit growth. In this study, we developed a process-based model specific to wetland environments for predicting tree radial growth. This model tracks a simple water budget, accounting for the interaction of weather variables with water table depth and flood duration for both current and antecedent conditions. The model is parameterized using radial growth chronologies for baldcypress from multiple sites within Atchafalaya Basin, Louisiana. These sites vary in hydrology and connectivity to major channels. Our objectives are: (1) to determine if such a model better explains annual growth variations, (2) to use the parameterization process as a tool for exploring controls over growth in a wetland environment. We will present (1) an analysis of the modeling efficiency compared to conventional methods, and (2) variations between site-specific parameterizations which indicate how controls over growth vary between sites. This work is important for both reconstructing past hydrologic conditions and predicting growth responses to a changing hydrologic environment.

Applied time-varying transit time distributions for understanding hyporheic exchange

Ashley Ball[1]*, Ciaran Harman[1], and Adam Ward[2]
[1]Department of Geography and Environmental Engineering, Johns Hopkins University, Baltimore, MD, USA
[2]Department of Earth & Environmental Sciences, University of Iowa, Iowa City, IA, USA

Abstract. The hyporheic zone has long been recognized as important in nutrient cycling, in controlling stream temperature changes, and for stream ecology. However, there is still a lot to learn about how these zones exchange water, mass, and energy. Transit time distributions (TTD) have been used to study in-stream transport and exchange with the hyporheic zone by quantifying the probability of water (and of dissolved material) taking time T to traverse the stream reach control volume. However, many of the studies assume this distribution is time-invariant, despite the time-variability of the streamflow. Others assume that the hyporheic zone is a 'randomly sampled' store with a fixed volume or exchange rate. Here we present a formulation for a time-variable TTD that relaxes both of these assumptions and only requires a few parameters. This approach does not assume that hyporheic and dead-zone storage is fixed or invariant, and allows for these stores to be sampled in less idealized ways. Instead, probability distributions of storage called Ω functions are used to describe how the off-stream storage is sampled in the outflow. Here the Ω function approach will be used to describe hyporheic exchange during diurnal fluctuations in streamflow in a gaining reach of the H.J. Andrews Experimental Forest. The breakthrough curves of salt slugs injected four hours apart over a 28-hour period show a systematic variation in transit time distribution. The corresponding time-variation in the Ω function can be related to changes in in-stream storage and hyporheic zone mobilization under varying flow conditions.

Mobility of *Escherichia coli* as compared to traditional tracers in karst aquifers, Kentucky, USA

A. Bandy (University of Kentucky)*, K. Cook (USDA-ARS), S. A. Macko (University of Virginia), and A. Fryar (University of Kentucky)

Bacterial contamination of karst aquifers is a large concern across the globe. Currently, bacterial transport in karst aquifers is not well understood. Groundwater tracers typically used in karst systems include fluorescent dyes and latex microspheres, but these tracers cannot accurately mimic the transport behaviors of bacteria and other potential pathogens, and therefore are not good proxies for risk assessment involving microorganisms. Lack of filtration combined with turbulent flow conditions make areas with karst aquifers more prone to pathogen contamination than clastic aquifers. This study examines the movement and attenuation of two serotypes of *Escherichia coli* (*E. coli*) with differing attachment efficiencies compared to traditional tracers (Rhodamine WT dye and 1-µm diameter microspheres). Study sites include epikarst above Cave Springs Cavern near Bowling Green, KY, and a karst aquifer that emerges at Royal Spring in Georgetown, KY.

E. coli grown in media enriched in either stable isotope tracer containing ^{13}C or ^{15}N will be injected into the karst area of interest (an augered hole to the top of epikarst or a swallet into the aquifer conduit) along with dye and microspheres. Water samples will be collected at the appropriate outlet location (waterfall within the cave or Royal Spring) and analyzed for tracers. Quantification of *E. coli* will be performed through molecular methods (qPCR) and isotope analysis on an IRMS (Isotope Ratio Mass Spectrometer). Preliminary findings suggest that the two methods may be complementary, having limitations across the range of isotopically enriched bacteria or number of gene copies they can detect.

Based on prior research, it was hypothesized that dyes, microspheres, and bacteria tracers will show differential transport times in the Cane Run/Royal Spring basin under normal flow conditions, with microorganisms arriving at the spring prior to microspheres or conservative dyes. For the epikarst trace above Cave Spring Caverns, the *E. coli* isolate that exhibits higher attachment efficiency in saturated granular columns is expected to have higher attenuation and emerge from the epikarst after the isolate that exhibits lower attachment efficiency. These two types of *E. coli* will have different transport times than microspheres or dyes and may take many storm events before they are flushed through the epikarst, with dye emerging from the epikarst prior to particulate tracers.

High-resolution coupled groundwater-surface water-land surface modeling incorporating urban land cover data in PARFLOW.CLM

Michael L. Barnes[1*], Elvis Andino[1,2], Claire Welty[1,2], and Andrew J. Miller[1,3]

[1]Center for Urban Environmental Research and Education; [2]Department of Chemical Biochemical and Environmental Engineering; [3]Department of Geography and Environmental Systems; University of Maryland Baltimore County, Baltimore MD 21250; *mlbarnes@umbc.edu.

As part of ongoing research on urban water sustainability in the Baltimore region, we are applying PARFLOW.CLM to six headwater catchments (order 1 sq km) spanning a gradient of urbanization to evaluate the effects of development pattern and stormwater management practices on the groundwater flow system. Two contrasting sites among our six study areas are discussed in this presentation. The Kevsway subwatershed is characterized by high-density impervious cover, business parks and townhome subdivisions served by public water and sewer, whereas Sunnydale contains low density suburban development served by wells and septic systems. We have set up PARFLOW.CLM models of each subwatershed domain with a horizontal computational resolution of 10 m and a vertical resolution of 1 m using high-resolution data on topography, land cover and subsurface properties. We utilize a high-resolution (0.6-m) land cover dataset derived from LIDAR and orthoimageryto represent variation in land surface model properties across the model domain. Our previous work used this dataset to distinguish impervious from pervious surfaces and mapped the hydrogeologic properties of the surface layer accordingly. Here, use of the land cover classification dataset is extended to parameterization of the CLM land surface model coupled to ParFlow. Each model surface cell (10m x 10m) is assigned an IGBP land cover classification and mapped to the IGBP land cover parameterization. Spin-up for each model is conducted using primary forcing data from NLDAS2 and an hourly time step. This provides a method for comparing the 2D spatial variability of ET and land surface forcing across different development types and landcover distributions. Variation of surface pressure, ET, and subsurface storage in each model resulting from the spatially-explicit representation of landcover types and the differences in ET and recharge are evident. Impervious cover in the Kevsway subwatershed, covering ~50% of the landscape, blocks recharge in CLM, limiting recharge to zones with grass or deciduous forest landcover types. This creates areas of focused recharge under these zones. Grass and deciduous forest zones respond differently to climate forcings, with differences in ET reflected in model surface cell pressures. The Sunnydale subwatershed has much higher forest cover and lower impervious cover, with different spatial patterns of recharge and ET and no major subsidy from imported water, causing potentially significant differences in the relative magnitude of different components of the water balance as well as differences in flowpaths, subsurface storage volume and residence times. During spin-up, the wetting front in the unsaturated zone and saprolite beneath pervious zones advances more rapidly than under impervious land cover type. Modeling differences in land surface forcing using CLM at the grid scale with high-resolution land cover information helps improve the representation of the ET component of the water balance, and the resultant variability in infiltration beneath land cover types.

Improving Glacier and Snow Melt Runoff Simulations in an Operational Hydrologic Model: Prince William Sound, Alaska

Jordan P. Beamer (School of Civil and Construction Engineering at Oregon State University)

ABSTRACT: In Prince William Sound (PWS), Alaska, there is a pressing need for accurate estimates of the spatial and temporal variations in coastal freshwater discharge (FWD). FWD into PWS originates from streamflow due to rainfall, annual snowmelt, and changes in stored glacier mass. *Neal et al.* (2010) estimated FWD from the PWS area of 95 km^3 yr^{-1} of which km^3 yr^{-1} (60%) was derived from runoff and volume loss from glaciers. FWD from glacier melt and volume loss is a significant contributor to sea level rise, and PWS is located in a region witnessing the largest glacier mass losses in the world (*Gardner et al.,* 2013). The remote and heavily glaciered PWS watershed is under sampled for weather data with a large bias towards coastal, low elevation areas. This makes accurate characterization of hydrological components, such as precipitation and streamflow, extremely challenging. As part of my PhD work, I seek to advance the state of knowledge of FWD and glacier mass balance in PWS by adapting and validating an integrated modeling suite of physically-based, distributed weather, energy-balance snow/ice melt, and runoff-routing models to the PWS drainage. SnowModel (Liston and Elder, 2006), driven with 100-m topography and land cover and gridded reanalysis weather data, computes seasonal snow evolution, surface mass balance, and runoff derived from snow and ice melt. HydroFlow (Liston and Mernild, 2012) routes the SnowModel runoff to coincident catchment outlets. Using funding from the CUAHSI fellowship, I traveled to Fairbanks Alaska to work with Dr. Anthony Arendt and the Glaciers group at the Geophysical Institute. Modeling efforts were focused on several smaller catchments located within PWS watershed, each with a gaged glaciated and non-glaciated catchments, along with measurements of snow depth transects (from ground penetrating radar) and weather data from high elevation stations. Uncertainty in the model input/output was reduced by verifying model forcing with weather variables at high altitude weather stations, comparison of modeled end-of-winter snow accumulation with GPR measurements made along glacier midline, modeled glacier ice melt with ablation stake data and results of temperature index modeling, simulated runoff with observations from glaciated and non-glaciated watersheds. A direct link and knowledge exchange was formed between the modeling group at OSU and the field measurements/validation instrument team at UAF which included a modeling short course and a seminar involving researchers in the glaciology and oceanography departments.

Soil Saturated Hydraulic Conductivity and Its Spatial Variability in the Shale Hills Critical Zone Observatory

Olivia Beaulieu[1]*, Jianbin Lai[2], Henry Lin[3]

1. University of Massachusetts Amherst; 2. Institute of Geographic Science and Natural Resources Research, CAS; 3. Department of Ecosystem Science and Management, The Pennsylvania State University

There have been observations that show water movement in soils at the Shale Hills Critical Zone Observatory to be considerable due to macropores and fractures produced during soil formation and rock weathering. Hydrologic models often fail to accurately reproduce soil moisture dynamics and hillslope water movement in complex terrains with diverse soil types and landform units. The objectives of this study are two-fold: 1) to determine field soil hydraulic conductivity throughout the Shale Hills; and 2) to figure out the spatial variability of soil hydraulic conductivity and its relationship with soil-landscape features (e.g., slope and hillslope position). Using a double-ring infiltrometer, the infiltration rate under falling head conditions is used to determine soil saturated hydraulic conductivity (K_s). Three sets of infiltration, located close together, were taken at each of fourteen sites distributed across the Shale Hills (at the ridge, mid-slope, and valley floor along both north- and south-facing slopes and in both swale and planar hillslopes). The results show that soil saturated hydraulic conductivity at the Shale Hills was highly variable. In general, for each site, the variation of K_s measurements was higher at the upper slope than at the lower slope. The K_s was found to be of greatest at the ridge and decreased downward along the hillslope. The average K_s at the ridge was four to five times of those in the valley. However, no significant difference of K_s was observed between the north- and south-facing slopes.

Title

Urban watershed storage and streamflow generation

Authors

Bhaskar, Aditi S. - Department of Chemical, Biochemical and Environmental Engineering and Center for Urban Environmental Research and Education, University of Maryland, Baltimore County

Welty, Claire - Department of Chemical, Biochemical and Environmental Engineering and Center for Urban Environmental Research and Education, University of Maryland, Baltimore County

Abstract (500 word max)

Subsurface storage as a regulator of streamflow was investigated as an explanation for the large proportion of pre-event water observed in urban streams during storm events. We used multiple methods of inquiry to explore the relationship between pre-event water proportion, subsurface storage, and streamflow under storm conditions. First, we applied chemical hydrograph separation to specific conductance data collected in nested urban watersheds in Baltimore, Maryland. Second, we used a three-dimensional groundwater-surface water flow and transport model to simulate an idealized urban hillslope. We used this idealized hillslope model to simulate chemical hydrograph separation. Lastly, we employed simple dynamical systems analysis to derive the relationship between subsurface storage and streamflow for three Baltimore watersheds along an urban-to-rural gradient. We found that rainfall depth was the primary control on pre-event water proportion in both field observations and hillslope numerical experiments. Field observations showed that antecedent baseflow did not affect pre-event water proportion or stormflow volumetric discharge. Hillslope model results showed that the relationship between streamflow and subsurface storage was clockwise hysteretic. Streamflow in the most urbanized of three watersheds exhibited the largest sensitivity to changes in storage.

Title: Evaluating Wastewater Export to Local Streams From A Forested-Municipal Wastewater Land-Application Facility.

Birch A.L., Nichols E.G., Emanuel R.E.

Land application of wastewater to managed forests is an important treatment and disposal practice for municipal wastewater, however; little research has been done evaluating the contribution of wastewater from these facilities to the local hydrology. This study uses stable isotope analysis of hydrogen (2H) and oxygen (18O)(Picarro Model L2120i), chloride concentrations (Hach Digital Titrator Model 16900), specific conductance (YSI Model Professional Series Plus) and physical hydrology to examine the contribution of irrigated wastewater to local groundwater and stream systems. On a 2,000 ha site in Jacksonville, NC, preliminary data shows higher chloride concentrations and consistently more positive isotopic signatures in wastewater lagoons than precipitation, reference surface waters and ground waters which provides a source signature to track it's transport. To study the wastewater's export pathway, hill slope well transects have been installed connecting the sites upland loblolly pine forest recharge zones, where irrigation takes place, with the lowland riparian cypress wetlands where it is discharged. These wells are sampled biweekly and are equipped with Odyssey Capacitance Water Level Loggers to observe the irrigation's effect on groundwater level and composition. Preliminary data shows evidence of the wastewater's chemical and isotopic signature contributing to the composition of shallow groundwater up to the edge of the floodplain, and a rising water table during periods of irrigation. Additionally, the surface waters draining the site have been gauged and sampled biweekly at the watershed outlet, an irrigated catchment, and a non-irrigated catchment to evaluate the influence of groundwater discharge of irrigated wastewater on surface water flow.

Title: After the dam comes out: groundwater-stream interactions and water quality impacts of former reservoir sites

Author: Krista Brown – Kent State University

Over that past decade, dam removals have become increasingly popular, as many dams near the end of their life expectancy. With an increasing number of anticipated dam removals coming in the near future this study aims to develop an understanding of groundwater-stream interactions and water quality in former reservoir sites after dam removals have occurred. Low head dams (~2 m) were removed in 2009 from Plum Creek in Kent, Portage County, Ohio and on Kelsey Creek in Cuyahoga Falls, Summit County, Ohio. Kelsey Creek reservoir has been unaltered since the dam removal and consists of a stream channel flowing through riparian-wetland environments, while Plum Creek reservoir underwent channel restoration in 2011. At Kelsey Creek, 20 piezometers and 3 wells were installed in the stream and riparian areas. Pressure transducers were also deployed in each well and stream from November 20, 2013 to January 5, 2014. Hydraulic conductivity was calculated using the Hvorslev method. Since October 2013, hydraulic heads have been recorded semi-weekly and water samples have been taken in the wells and stream. Water quality is being evaluated with field-measured pH, temperature, specific conductance, and dissolved oxygen, and ion chromatography of chloride, bromide, nitrate and phosphate concentrations. Plum Creek is being used to understand the water quality effects of channel restoration at former reservoir sites.

At Kelsey Creek, hydraulic conductivity ranges four magnitudes, from 10^{-3} to 10^{-6} m/s, but wells near the channel, in an off-channel wetland, and on an adjacent hillslope respond similarly during high flow events. However, the well closest to the stream shows substantial variability in specific conductance, indicating bidirectional groundwater-stream exchange. Despite the wetlands and presumed greater groundwater-stream exchange in the unrestored Kelsey Creek, stream water quality is similar to the restored Plum Creek site. This suggests that the water quality measures considered here should not determine whether to restore channels within former reservoir sites. Findings from this research may be applicable when considering options for future dam removal sites.

HYDROLOGIC AND ECOLOGICAL ALTERATIONS OF URBAN HEADWATERS: RELATIVE INFLUENCE OF IN-CHANNEL AND WATERSHED BEST MANAGEMENT PRACTICES (BMPs)

B. Buskirk[1], J. Harvey[1], L. Larsen[1], J. Choi[1], K. Skalak[1], C. Ferreira[2], A. Walker[1], A. Benthem[1], J. Singh[1], S. Hoyos[2]

[1]U.S. Geological Survey, Reston, VA; [2]George Mason University, VA

Headwater streams in urbanizing watersheds are some of the nation's most impaired aquatic ecosystems. The effectiveness of different management strategies in these systems is not well understood. We investigated mechanisms of stream impairment in two neighboring urban watersheds: one with only watershed BMPs (e.g., stormwater retention ponds) and the other with only in-channel BMPs (e.g., engineering structures such as rock cross vanes). The in-channel BMP watershed had higher peak flows and nominally greater sediment yield, but lower fine sediment concentration in the streambed. The results are consistent with hydraulic modeling and sediment source tracking data suggesting greater hydraulic shear stress on the bed in the in-channel BMP stream. Stream metabolism, a measure of aquatic ecosystem, also differed, with levels of aquatic community respiration in the streambed being substantially lower and at unhealthy levels in the in-channel BMP stream. The role of related drivers such as carbon quality and nutrient availability is still being investigated. Nonetheless there is ample evidence to conclude that different management actions can drastically influence fine sediment dynamics and stream ecology of urban watersheds.

Modeling Nitrate Exporting Patterns during Storm Events for a Semi-arid mountain watershed

Xiaoli Chen, Naomi Tague, Janet Choate

Abstract: In steep semi-arid areas like coastal Southern California, most nitrate export occurs during storm events. Observed data from the Santa Barbara Long Term Ecological Research site shows that concentration and concentration-discharge relationships vary both throughout storm events and seasonally. Nitrate sources can be inferred from these data by comparing the arriving time of the nitrate concentration peak and that of the stream flow peak. For example, for small storm events in September or October after the long sever summer drought, nitrate concentration peak several hours earlier than stream flow peak, and may indicates the nitrate flux is from near-stream riparian areas. In contrast, storm events in the winter or early spring after a series of precipitation events tend to produce the nitrate concentration peaks several hours later than the stream flow peak, and indicates the nitrate flux is from hydrologically connected upslopes area. To model these dynamics, hydrologic models must be able to capture temporal shifts in hydrologically connected source areas as well as seasonal shifts in nitrogen availability associated with ecosystem biogeochemical cycling. We assess the ability of Regional Hydro-Ecologic Simulation System (RHESSys), to reproduce the seasonal/multi-yearly nitrate's export patterns and compare the success of different model implementations. Specifically we compare a new developed hourly time-step implementation versus a daily time-step model and a model implementation where lateral routing is based on the "fill and spill" hypothesis versus the more traditional approach based on subsurface transmissivity functions. Results highlight the importance of both the hourly time-step and the threshold based response of a "fill and spill" connectivity model.

Design and implementation of tailored online services for hydrologic data management

Joshua Cole[1] and Claire Welty[1,2]

[1]UMBC, Center for Urban Environmental Research and Education, Baltimore, MD 21250
[2]UMBC, Department of Chemical, Biochemical and Environmental Engineering, Baltimore, MD 21250

As part of ongoing efforts to streamline quality control and data dissemination tasks, we have developed new web applications to augment our existing end-to-end system of data collection, telemetry, storage, QA/QC, and archiving. We aim to provide high-quality and high-resolution datasets to UMBC researchers and the water science community. To meet this goal, we have developed web-enabled data visualization and download for the community and online editing capabilities for UMBC researchers. These services are interoperable with an edited version of CUAHSI's Observation Data Model (ODM) database schema. The data visualization and download web portal affords the viewing of multiple variables in graph and table forms across multiple sites with a user-friendly interface. Metadata are also available for each monitoring site, and the data are available to download in standard formats (CSV, JSON). The web editing application offers researchers the ability to select and edit data from an ODM database by date range. When a user submits a data selection to the application the selected data are shown on a graph and table. Using either checkboxes or a date range formulas, values, or data quality codes may be applied to a subset of the selected data. Formula or data value changes are viewed on the graph and table alongside the original values before being committed to the database. Both sites offer individual or group logins, and data request validation. These services are illustrated using precipitation data collected as part of the BES LTER and eddy covariance data collected on the UMBC campus. We demonstrate the sites, data workflow, and how QA/QC protocols are applied. The web application code, written primarily in asp.net, is available upon request.

Interactive Web-based Hydrological Simulation System as an Education Platform

Ibrahim Demir, Iowa Flood Center, IIHR – Hydroscience & Engineering, University of Iowa, Iowa City, Iowa, USA, Ibrahim-demir@uiowa.edu

Recent developments in web technologies make it easy to manage and visualize large data sets with general public. Novel visualization techniques and dynamic user interfaces allow users to create realistic environments, and interact with data to gain insight from simulations and environmental observations. The hydrological simulation system is a web-based 3D interactive simulation environment to simulate hydrological processes with real world data. The simulation systems provides a visually striking platform with realistic terrain information, and water simulation. Students can create and modify predefined scenarios, control environmental parameters, and evaluate mitigation techniques. The web-based simulation system provides an environment for students to learn about the hydrological processes, flooding, flood damage, and effects of development and human activity in the floodplain. The system utilizes latest web technologies and graphical processing unit (GPU) for water simulation and object collisions in the floodplain. The system provides various scenarios customized to fit the age and education level of the users. The platform provides cutting edge visualization techniques, supports virtual reality and augmented reality modes, and gesture based interaction. This presentation provides an overview of the web-based simulation system, and demonstrates the capabilities of the system for various flooding scenarios.

Effect of Climate Change on Hydrologic Regime of Canaan Valley and the Upper Blackwater River Watershed in West Virginia

Leighia Eggett[1], Nicolas Zegre[1], Eungul Lee[2]

[1]Division of Forestry and Natural Resources, West Virginia University
[2]Division of Geography, West Virginia University

Wetlands are an important element in hydrologic systems and have many important ecological functions. The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) asserts that climate change will cause many interconnected stresses on wetlands through shifts in ecosystem function by modifying hydrology, biogeochemical cycles, and altering community distribution and interactions. This study focuses on the importance of headwater wetlands on downstream resilience in a changing climate by characterizing past climate conditions within the upper Blackwater River Watershed in relation to hydrologic regime. Historical climate affect was statistically assessed using linear regression and correlation analysis from Grid Analysis and Display System (GrADS) output on mean air temperature and precipitation. Hydrometric data was used with climate data to analyze correlations between climate and hydrologic regime from 1950-2005.

Elevations of 3000^{+} feet in Canaan Valley cause the upper Blackwater River Watershed to resemble colder climates at higher latitudes, with cold wet winters and warmer summers. Average seasonal temperatures are increasing in the upper Blackwater River Watershed, especially in the autumn season. Temperature is positively correlated to streamflow both annually and seasonally. The area precipitation is also increasing, predominantly in the autumn season. Annual precipitation and streamflow have a significant positive correlation, at α=0.10. This positive correlation is supported by a composite difference of about 22 millimeters more precipitation falling in maximum streamflow years than minimum streamflow years. Stronger positive correlations occur in winter (DJF) and summer (JJA) than spring (MAM) and autumn (SON) between precipitation and streamflow, with only SON significant at α=0.10.

As urbanization increases with the installation of Corridor H and increases in ecotourism to the area, conservation of wetlands remains important to downstream hydrology of the Blackwater River. Urbanization decreases infiltration due to impervious surfaces which cause higher peak runoff into area streams to occur. The presence of an extensive riparian zone allows for limited hydrologic connectivity of urbanized area impacts. Nonetheless, as precipitation intensity is expected to rise, so too will the hydrologic connectivity due to inadequate infiltration of previous saturated wetlands. As the available storage capacity is decreased and precipitation intensity increased, streamflow will rise as a direct result. Best management practices can be recommended and implemented to mitigate potential impacts of climatic variables on the hydrologic regime of rivers with headwater wetlands.

Variation in freshwater input to the Eastern US coastal ecosystem

Dongmei Feng[1*], Yeosang Yoon[1], Edward Beighley[1], Randall Hughes[2], and David Kimbro[2]
[1] Civil and Environmental Engineering, Northeastern University
[2] Marine Science Center, Northeastern University
[*] Corresponding Author, Email:feng.do@husky.neu.edu

Abstract: *Phragmites* is one of the most invasive plants in North American wetlands. Although its spread in coastal marshes has been linked by independent studies to urbanization, eutrophication, and salinity change, there is good evidence that these factors may interactively determine invasion success and in turn, the ecosystem services provided by marshes. We hypothesize that the invasion of *Phragmites* is linked to changes in freshwater inputs due to climate and/or land use change. In this study, we focus on quantifying changes in freshwater input to the coastal zone along the eastern U.S. Hydrologic modeling, remote sensing and field measurements are combined to: (a) quantify freshwater inputs to coastal marshes along the eastern U.S. for the period 1978 to current; and (b) quantify the relative contributions of freshwater sources (i.e., surface, shallow soils and groundwater). The Hillslope River Routing (HRR) model is used to simulate hourly streamflow from all watersheds east of the Mississippi River draining to the Atlantic Ocean. The modeling effort utilizes satellite precipitation (2002-current, 3-hr, ~25 km grid, TRMM 3B42v7), land surface temperature and vegetation measures (2002-current monthly, ~5 km grid, various MODIS products). To account for land cover change, land cover data form 1992, 2001, 2006, 2010 and time varying population statics are merged to estimate annual land cover characteristics for each sub-catchment within the study region. Static datasets for soils and ground elevations are used. Daily U.S. Geological Survey streamflow data from major river outlets along the coastline are used for model assessment. We explore the use of environmental tracers – such as silica, electronic conductivity, and end member mixing methods for the identification of the sources of freshwater input.

Lithologic and Land-use Controls on Solute Concentration-Discharge Behavior in the Susquehanna Shale Hills Critical Observatory (SSHCZO)

Fisher J*[1], Sullivan PL[2], Neal A[2], Brantley SL[2]

1 Geological Sciences Department, Brown University, Providence, RI

2 Earth and Environmental Systems Institute, The Pennsylvania State University, University Park, PA

The integration of climate, weathering, and biological processes across the critical zone is conveyed in stream water solute concentrations and fluxes. Solute concentrations can vary differently with stream discharge so that in some cases solutes are enriched, diluted, or chemostatic. Enrichment and dilution describe streams whose solute concentrations change with discharge, while chemostasis describes stream chemical environments in which solute concentrations remain relatively constant despite variations in discharge. As concentration-discharge behaviors vary between catchments of differing lithology, land use, and vegetation cover, the underlying control on stream water solute behavior remains elusive. To examine variation in concentration-discharge relationships, stream grab samples were collected monthly to bimonthly and discharge was measured at five sites within the Shavers Creek watershed. This watershed is the focus of the new SSHCZO. Two monolithologic (shale and sandstone) first-order streams were examined to elucidate the influence of lithology on concentration-discharge behavior. Additionally, three sites along the main channel of Shavers Creek were used to study the influence of land-use on this behavior. The data provides evidence of increased nutrient loading (nitrate and sulfate) when approaching the outlet, which is concurrent with an increase in agricultural land-use. Furthermore, correlations between Mg and Ca with Si exhibit the transition from a shale to carbonate setting. Mg and Ca also dilute in response to increasing discharge while silica remains relatively chemostatic. This suggests that under low-flow conditions, stream water is recharged largely from carbonate sources while under high-flow conditions, water interacting with Si-rich sandstone becomes increasingly important to stream chemistry. These results support the need to integrate the geologic setting into hydrogeochemical models in order to accurately predict the anthropogenic impact on stream water quality.

Hydrologic Impacts of Forest Thinning in the Hat Creek and Burney Creek Basins

Rowan Gaffney[1], Scott W. Tyler[1], Shawn Wheelock[2], Gordon Grant[3], Cara Nadler[1], Chris Sladek[1], Dave Young[4], Matt Staudacher[5] and Paula Adkins[1]

1. Department of Geological Sciences and Engineering
   University of Nevada
   Reno, Nevada, USA
2. swheelock@fs.fed.us
   Lassen National Forest
   Fall River Mills, CA 96028
   530-336-334, cell: 520-820-2737
3. Forestry Sciences Laboratory 280
   USDA Forest Service
   Pacific Northwest Research Station
   3200 SW Jefferson Way
   Corvallis, OR 97331
4. daveyoung@fs.fed.us
   North Zone Soil Scientist
   Redding, CA 96002
   530-226-2545
5. mstaudacher@fs.fed.us
   Shasta-Trinity National Forest
   Redding, CA 96002
   530-226-2526

Forest management practices are commonly employed to improve forest health and decrease the risk of fire but the effects on forest hydrology are not well understood. To reduce the risk of fire, regions experiencing prolonged droughts and higher temperatures are generally inclined to increase active forest management while simultaneously experiencing increased stress on the water resources. Therefore, it is vital to better understand and quantify the relationship between forest management practices and forest hydrology. Of particularly interest to water resources is the effect on snow pack accumulation and melt timing. To quantify this relationship in the snow-dominated northern Sierra/southern Cascades, four sites in Lassen National Forest were chosen in 2013 to study the effect of two of the most common management practices, forest thinning and group selection as part of a Comprehensive Forest Landscape Restoration Program (CFLRP). Each site was equipped with traditional hydraulic and meteorological sensors to measure soil moisture, soil temperature, radiation, wind speed, precipitation, and barometric pressure. In addition, fiber-optic sensing was installed to evaluate the evolution of snow storage in a high spatial and temporal resolution.

During the 2013/2014 winter, the Sierras and California experienced a significant drought including a near-absence of continuous snow cover. Results from this first season of instrumentation shows little difference in throughfall from the treatments as expected due to the dominance of rain rather than snow. Preliminary soil moisture monitoring indicates more rapid wetting at depth in the most disturbed sites, however this may be due to soil disturbance rather than forest management.

Modeling Hyporheic Exchange Fluxes Across River Networks

Jesus D. Gomez-Velez and Judson W. Harvey

U.S. Geological Survey, 430 National Center, Reston, VA 20192, USA

Hyporheic exchange occurs in rivers, streams, wetlands, lakes, estuaries, and nearshore and shelf submarine areas throughout the world, wherever surface waters are in contact with permeable sediments. The spatial and temporal scales of exchange range across six orders of magnitude, i.e. from millimeters to kilometers and from seconds to decades. Even though controls on hyporheic flow vary across a broad continuum of hydrologic and geomorphic settings, there is consistency in the mechanisms and predictable regimes based on well-established theory. Yet, the ability to predict hyporheic exchange across these disparate environments is limited by available fluvial, geomorphic, and hydrogeologic data as well as tools to analyze and interpolate the data for estimating hyporheic exchange flows across river networks. We discuss advancements in geomorphic characterization and application of a parsimonious model for multi-scale hyporheic exchange based on relatively widely available information about discharge and grain size.

Assessing desert ecohydrologic habitat suitability under varying management and climate scenarios

Mark B. Hausner, Division of Hydrologic Sciences, Desert Research Institute, Las Vegas, Nevada
Kevin P. Wilson, Pahrump Field Office, Death Valley National Park
D. Bailey Gaines, Pahrump Field Office, Death Valley National Park
Francisco Suárez, Department of Hydraulic and Environmental Engineering, Pontificia Universidad Católica de Chile
G. Gary Scoppettone, Western Fisheries Research Center, USGS (emeritus)
Scott W. Tyler, Department of Geological Sciences and Engineering, University of Nevada Reno

Abstract

Aquatic ecosystems of North American deserts are frequently very restricted in area, and tend to harbor very specialized species endemic to their restricted habitats. Small changes in environmental conditions of these specialized forms may jeopardize their persistence. A notable example of endemic and specialized species which may have been influenced by slight changes in its habitat is the Devils Hole pupfish (*Cyprinodon diabolis*). In this study we combine computational fluid dynamic (CFD) modeling with a conceptual ecological model to examine the simultaneous impacts of changes in the water level and the ambient climate of Devils Hole. The CFD model predicts water temperatures as a response to climate and water level, and the ecological model is used to determine the timing of tipping points that encourage or suppress the annual recruitment of *C. diabolis*. The influence of water level on peak temperatures in Devils Hole (and therefore on the likelihood of survival for *C. diabolis*) is an order of magnitude greater than the influence of climate change. The combination of interdisciplinary modeling approaches offers a method to quantify and compare the suitability of habitat under a range of management and climate scenarios.

Applications of Environmental DNA in a Middle School Classroom

Melissa Hess* (RET), Bryce Hostetler (REU), Laura Borecki and Dr. William Eldridge
Stroud Water Research Center, Avondale, PA and
University of Delaware

The use of DNA in forensics has been glamorized by television and movies, and students of all levels are excited and engaged when asked to solve crimes using forensic evidence. Recently scientists have been able to use environmental DNA (eDNA) to monitor for the genetic presence of aquatic organisms. eDNA can be used to indicate the presence of local species, invasive, endangered, and/or species that are not accessible through visual surveys. Students in the middle school setting will use eDNA as a medium to increase STEM (Science, Technology, Engineering and Mathematics) education in a Life Science classroom. The purpose of the activities are to engage young learners using real scientific data, so they may be more apt to participate in STEM related subjects in future years. The students will analyze pictures of a gel to identify invasive, endangered and local species in a waterway. Students will use the base pairs of organisms to predict their evolutionary relationship.

Optimization of qPCR techniques to determine environmental DNA transport in stream systems

Bryce Hostetler* (REU), Melissa Hess (RET), Laura Borecki and Dr. William Eldridge
Stroud Water Research Center, Avondale, PA and
University of Delaware

Environmental DNA (eDNA) surveillance is an increasingly popular tool for detecting aquatic organisms that does not require visual surveys. In many studies this process has shown to be successful at indicating the presence of specific species. PCR primers were previously developed to amplify small fragments of DNA from several species of freshwater mussels including *Margaritifera margaritifera, Elliptio complanata,* and *Pyganodon cataracta* over short distances in a small stream setting. However, there is still a limited understanding of how eDNA moves through streams and water systems. It has yet to be determined how far eDNA can be detected from the source of DNA and how the concentration of eDNA changes over distance. One method to help answer this question of concentration change is quantitative PCR (qPCR). qPCR is highly sensitive (detection of 1 copy per uL is possible) and can be used to quantify the amount of eDNA present. This in turn will allow us to track the change in concentration over distance from the source material.

In this study, we developed a SYBR green real-time qPCR method to detect DNA from freshwater mussels in samples of surface water. First, qPCR must be optimized to reduce the likelihood of false positive detection due to primer dimers or non-specific binding. We developed qPCR standards for both *Elliptio complanata* and *Pyganodon cataracta.* We optimized by testing various template concentrations (1 uL template without dilution, 1:10 and 1:100 dilutions), annealing temperatures (60-70° C) and $MgCl_2$ (1 mM and 1.5 mM $MgCl_2$) and ran the PCR process in both the presence and absence of BSA. It was indicated that a 1:10 dilution of template DNA, a 65° C annealing temperature, 1 mM $MgCl_2$ and the presence of BSA are all optimal PCR conditions.

A second concern is false negatives—where eDNA is not detected in water samples that are known to contain mussel DNA. False negatives are most likely caused by low concentrations of eDNA. eDNA concentration will decrease downstream from the source due to a combination of physical, chemical and biological processes. To evaluate eDNA transport in streams we conducted a series of experiments in which we planted mussels in artificial (outdoor flumes) or natural (a small stream) settings. In all experiments we allowed enough time for eDNA particles to equilibrate downstream and then took water samples at various distances from the mussels. eDNA concentration at these various distances was determined by qPCR which allowed us to determine the settling rate of eDNA particles and better understand how these particles are transported in aquatic systems.

Abstract:

Assessing impacts of green infrastructure at the watershed scale for suburban streets in Parma, Ohio.

Kimm Jarden[1*], Anne Jefferson[1], Jennifer Griesser[2], Derek Schafer[3]

(Kent State University, Department of Geology[1], Cleveland Metroparks[2], West Creek Conservancy[3])

High levels of impervious surfaces in urban environments can lead to greater levels of runoff from storm events and overwhelm storm sewer systems. Disconnecting impervious surfaces from storm water systems and redirecting the flow to decentralized green infrastructure treatments can help lessen the detrimental effects on watersheds. The West Creek Watershed is a 36 km^2 subwatershed of the Cuyahoga River that contains ~35% impervious surface. We seek to evaluate the hydrologic impacts and pollution reduction of street scale investments using green infrastructure best management practices (BMPs), such as rain gardens, bioretention, and rain barrels. Before-after-control-impact design will pair two streets with 0.001-0.002 ha. lots and two streets with 0.005-0.0075 ha. lots. Flow meters have been installed to measure total discharge, velocity, and stage pre– and post-construction. Runoff data has been preliminarily analyzed to determine if peak discharge for large (> 10 mm) and small (<10 mm) storm events has been reduced after installation of BMPs on the street with 0.001-0.002 ha. lots. Initial results show that the peak flows have not been reduced for most storm events on the street with the green infrastructure. However, several larger events show that peak flows have been reduced on the treatment street and need to be further investigated to determine what conditions led to flow reductions from these storms but not other events. Initial analysis of total flow volume for each event, pre- and post-construction, show that total volume has increased on the street with green infrastructure treatments. Possible explanation for the increase on flow volume could be attributed to under drains from bioretention creating a more connected flow path to the storm drain or an upstream leak in the control street storm drain. Each scenario will be investigated further to confirm results. Further research will include analysis of the total effect of street-scale BMPs on storm hydrograph characteristics including, hydrograph regression behavior and lag time.

The isotopic fingerprint of global groundwater resources

Scott Jasechko [1,*] and Tom Gleeson [2]
Email: sjasechk@ucalgary.ca

[1] Department of Earth and Planetary Sciences, University of New Mexico, New Mexico, U.S.A.
[2] Department of Civil Engineering, McGill University, Montreal, Quebec, Canada
* Now at Department of Geography, University of Calgary, Calgary, Alberta, Canada

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Groundwater nourishes life by sustaining one-third of all human water consumption, which supplies 30% of the human population with drinking water and delivers 40% of global cropland irrigation. Current assessments of continental-scale groundwater resources draw primarily upon just two unique tools: (i) satellite-based gravimetric measurements of groundwater depletion (i.e., GRACE) and (ii) global-scale hydrological models (e.g., PCR-GLOBWB, WaterGAP). We have developed a third tool as a complement to these two existing approaches: (iii) a global compilation and analysis of chemical tracers measured in Earth's groundwaters. In this presentation the results of three unique and global-scale studies are presented on the basis of the compiled groundwater data. First, a suite of groundwater age tracers are applied to quantify the global volumes of recently recharged "renewable groundwater" vs. "fossil groundwater," with broad implications for sustainable water management and agriculture. Second, the seasonality of groundwater recharge is mapped at 54 locations spanning a variety of biomes on the basis of isotopic differences between groundwater and precipitation. A pronounced seasonality in the efficiency of groundwater recharge is revealed, suggesting that a unit change in wet-season or winter hydrological processes will be more important to groundwater recharge than the same unit change in dry-season or summer hydrological processes. Third, the chemistry of "ice age groundwaters" (i.e., groundwaters that recharged during the last ice age, when Canada and northern Europe were covered by multiple kilometers of ice) at 65 globally-distributed locations indicates that the natural warming of Earth's climate over the past 20,000 years induced significant, large-scale hydrological changes, with important ramifications for predicting the impacts of human-induced climate warming on fresh water resources. This presentation concludes by presenting future visions and opportunities, such as integration with global hydrological models or isotope-enabled general circulation models. The lack of data in some regions can help to target future hydrochemical fieldwork such that a truly global hydrogeochemical dataset can be realized in the future.

Stormwater control measures modify event-based stream temperature dynamics in urbanized headwaters

Grace Garner[1], Anne Jefferson[2*], Sara McMillan[3], Colin Bell[4] and David M. Hannah[1]

[1]School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK.

[2]Department of Geology, Kent State University, Kent, OH, 44240, USA

[3]Department of Civil and Environmental Engineering, University of North Carolina at Charlotte, Charlotte, NC, 28223, USA

[4]Department of Infrastructure and Environmental System, University of North Carolina at Charlotte, Charlotte, NC, 28223, USA

*presenting author

Urbanization is a widespread and growing cause of hydrological changes and ecological impairment in headwater streams. Stream temperature is an important control on physical, chemical and ecological processes, and is an often neglected water quality variable, such that the effects of urban land use and stormwater management on stream temperature are poorly constrained. Our work aims to identify the influence of stormwater control measures (SCMs) of differing design and location within the watershed on the event-based temperature response of urban streams to precipitation in the North Carolina Piedmont, in order to improve prediction and management of urban impacts. Stream temperature was measured within SCMs, and upstream and downstream of them in two streams between June and September 2012 and 2013. Approximately 60 precipitation events occurred during that period. To unambiguously identify temperature increases resulting from precipitation, surges were identified as a rise in water temperature of ≥0.2°C between the hours of 15:30 and 5:30, when the diurnal temperature cycle is either decreasing or static on days without precipitation. Surges up to 5°C were identified in response to precipitation events, with surges occurring both upstream and downstream of the SCM under some conditions. Surges were also recorded within the SCMs, confirming that temperature surges are the result of heated urban runoff. Classification tree modeling was used to evaluate the influence of hydrometeorological drivers on the generation and magnitude of temperature surges. In both streams, event precipitation, antecedent precipitation, and air temperature range were identified as the drivers of whether or not a surge was observed and how large the surge was, though the order and thresholds of these variables differed between the two sites. In a stream with an off-line, pond SCM, the presence

of the pond in the lower 10% of the watershed did not affect the magnitude of temperature surges within the stream, but the pond itself had a wider range of surge magnitudes than did the stream. In a watershed with a large in-line pond, and a downstream contributing wetland SCM receiving flow from 40% of the watershed, the wetland increased both the frequency and magnitude of temperature surges observed in the stream. Our results suggest dynamic hydrometeorological conditions, SCM design, and position within a watershed all influence whether stormwater management reduces or enhances temperature surges observed within urban headwater streams, and that these factors should be considered in the recommendations for urban stormwater management systems.

Comparing Vegetation Across Topographic Positions in Two Watersheds at the Susquehanna Shale Hills Critical Zone Observatory

Quincey Johnson*- Hobart and William Smith Colleges
Kristen Brubaker- Hobart and William Smith Colleges
Margot Kaye- The Pennsylvania State University

The Susquehanna Shale Hills Critical Zone Observatory in the Ridge and Valley province of central Pennsylvania includes two watersheds with distinct bedrock: one shale and one sandstone. Both watersheds contain second growth mixed deciduous forests approximately 100 years old. Our objective was to compare basal area, tree density, and species richness across three topographic positions (toe slope, mid slope, and ridge top) at both watersheds. In addition, we assessed how the rockiness of the catchments affects each of these metrics. We hypothesized that basal area and species richness will decrease from the toe slope to the ridge top, while density will increase. Toe slopes generally have deeper soils than ridge tops, suggesting greater nutrient availability and water holding capacity, leading to greater tree growth and basal area. We anticipate species richness to decrease with topographic position because fewer species can tolerate stressful ridge top conditions. We also hypothesized that species richness and basal area will decline as the percentage rockiness increases, because greater rockiness limits soil available for trees to grow. Our hypotheses were tested with field data collected along 10-m wide belt transects following the contour at toe slope, midslope, and ridge top landscape positions of the two watersheds. Transect length at the shale site ranged from 150-200 meters, while the transects on the sandstone site ranged from 675-1000 m. All trees >10 cm diameter at breast height were measured for diameter, identified to species, and mapped. Rock presence or absence was recorded every 1 meter along the transects. Our hypotheses were tested by calculating basal area, tree density, and species richness and comparing values based on topographic position and % rockiness. Six hundred five trees representing 21 species were sampled at the shale site and 1447 trees representing 16 species were sampled at the sandstone site. At the shale site, basal area increased from approximately 13 m^2/ha the ridge top to approximately 46 m^2/ha at the toe slope position. Tree density ranged from 512 trees/ha to 575 trees/ha across all topographic positions. At the sandstone site, basal area remained relatively constant across topographic positions at approximately 25 m^2/ha. Tree density ranged from 385 m^2/ha at the ridge top position to 608 m^2/ha at the toe slope.

PLUMBING THE LANDSCAPE: BEAVERS OPTIMIZE DAM SITES

Victor W. Garrett and Carol A. Johnston*
South Dakota State University

The beaver (*Castor canadensis*) is an ecosystem engineer that alters surface water flow by its pond building. The pre-Columbian beaver population was nearly extirpated from northern Minnesota due to over-trapping, but recovered during the latter half of the 20th century. The objective of this study was to determine how the mean area of beaver ponds and their catchments changed over time as beavers expanded throughout Voyageurs National Park during their recovery period. For each of 870 beaver dams, historical aerial photos (1927-1990) were used to document date of initial establishment (i.e., pond cohort), and digital elevation data were used to calculate area of local catchment (i.e., adjacent lands draining into the pond) and area of network catchment (i.e., all lands upstream to the headwaters draining into the pond). The earliest cohorts (years 1927 & 1940) had the largest impoundment areas (mean = 7.4 ha), the largest local catchments (mean = 43 ha), and the largest network catchments (~500 ha). Cohorts established in 1961 or later had significantly smaller impoundments (mean = 2.7 ha), local catchments (mean = 11 ha), and network catchments (~50 ha). We conclude that as beavers expand into new territory, they dam hydrologically optimal stream locations first, leaving less desirable locations (smaller local and network catchments) for subsequent colonizers.

Title: Watershed scale soil biogeochemistry and greenhouse gas fluxes: Space-time dynamics, patterns, and interrelationships of CO_2, CH_4, and N_2O

Authors: K.E. Kaiser, B.L. McGlynn, J.E Dore, E.C. Seybold, D. A. Riveros-Iregui, R.E. Emanuel, T.E. Lorenzo

Large uncertainties regarding climate-terrestrial greenhouse gas (GHG) feedbacks exist, especially in mountainous regions. This is partially due to the complex relationships that exist between hydrology, soil physics, and soil biology. Complex terrain provides an ideal laboratory to gain improved understanding of the spatial patterns, temporal dynamics, and drivers of trace gas efflux rates, requisite to constraining current GHG budgets and future scenarios. We measured soil GHG concentrations and fluxes across a full range of landscape positions to examine the relationships between environmental variables, hydrologic dynamics, and GHG production and consumption. This research builds on previous carbon cycle research at the USFS Tenderfoot Creek Experimental Forest, Little Belt Mountains, Montana that highlighted the relationships between landscape position, induced by topographic redistribution of water, and seasonal CO_2 efflux. In this study, we measured soil gas well profiles of CO_2, CH_4, N_2O concentrations, and surface CO_2, N_2O, and CH_4 fluxes into and out of the soil and observed: 1) Soil CO_2 efflux varied as a function of landscape position and soil water redistribution. Seasonally, CO_2 efflux increased until mid-July and decreased slowly throughout the rest of the growing season, following the decline in soil moisture and temperature. 2) Throughout the growing season, upland areas of the watershed were CH_4 sinks while most riparian sites were CH_4 sources. The source/sink spatial boundary shifted in time with watershed wetness state. Despite the strong riparian CH_4 source, the spatially weighted strength of the hillslope CH_4 sink was ~13 times greater than the riparian source. 3) We also observed transient N_2O efflux associated with transitional areas between CH4 sources and sinks. Preliminary results suggest that the strength of CO_2 and CH_4 sources and sinks are mediated by water availability, which is typically a function of landscape scale water redistribution. We further examined the fine temporal scale patterns in soil CO_2 efflux across a subset of wet to dry landscape positions and quantified the plot scale heterogeneity in volumetric water content and CO_2 efflux. We seek to highlight and understand the temporal evolution of spatial patterns in CO_2 efflux, N_2O efflux, and CH_4 efflux and influx across the Upper Stringer Creek watershed with the goal of linking our network of ground-based observations to eddy-covariance derived estimates of landscape scale CO_2 and CH_4 balances.

Reality check: Assessing internal catchment behavior to reduce uncertainty in complex, distributed models

C Kelleher, B McGlynn, T Wagener

Complex, distributed models can be a double edged sword. They allow us to investigate the intricacies of complex hydrologic behavior in space and time, including impacts from changes to land use and climate. At the same time, they are also plagued by equifinality due to the high number of input parameters. There are typically many parameter sets that fit the hydrograph (and occasionally other observations) equally well. Therefore, a range of modeled internal catchment behavior can produce equally strong fits to the hydrograph. The information content of the hydrograph alone is often insufficient to reduce this equifinality. However, the typically ignored internal catchment processes can be used to refine behavioral parameter sets. Here, we illustrate how widely internal catchment behavior can vary across equally well-performing parameter sets. We introduce a framework of diagnostics that can help refine the selection of a best-fit parameter sets for complex models that takes into account not only fitting to the hydrograph but also the representation of dominant catchment processes and states including storage, dominant flow pathways, and water table connectivity through time. Ultimately, we seek to improve catchment representation of complex processes through effective use of often-ignored outputs provided by distributed models, ensuring a more holistic selection of parameter set to represent a range of catchment behavior.

Title: Comparing carbon stocks in the O horizon of shale and sandstone watersheds according to topographic position and ecosystem characteristics

Authors: Christine Kim (REU, Temple University) and Jason Kaye (Shale Hills Critical Zone Observatory, Pennsylvania State University Department of Ecosystem Sciences and Management)

Abstract:
Understanding the global carbon cycle is critical for predicting potential feedbacks between ecosystems and climate change. Soils contain most of the C in Earth's Critical Zone and are intricately tied to biotic, atmospheric, and hydrologic forces that further influence climate change
and the C cycle. Soil organic (O) horizons are a large and dynamic pool of C in forests. We compared organic horizons between the Susquehanna Shale Hills (shale bedrock) watershed and the Leading Ridge/Tussey Mountain (sandstone bedrock) watershed in South central PA for their organic C content. We collected samples within a 30 cm diameter ring every 25 m along transects across the ridgetop, midslope, and toeslope positions of the two watersheds. Other data such as tree species, diameter, and spacing; coarse woody debris content; understory plant composition; and landscape rockiness were also collected. With these data we will address the following questions: 1) Does C stored in the O horizon differ between the shale and sandstone watersheds or vary among ridgetop, midslope and toeslope positions? And, 2) Which ecosystem characteristics are correlated with variance in O horizon C storage? With these data we expect gain insight into variation in O horizon C that may ultimately improve our ability to predict the role of this C pool in the global C cycle.

A Floristic Survey of Pingo Scars in Central Pennsylvania

Dylan Kubina* and Sarah Chamberlain

REU

Abstract

Pingo scars are unique vernal pool wetlands that are evidence of large frozen mounds (pingos) that date back to the Pleistocene Era. The groundwater fed water basins range from 2 to 9m deep and formed approximately 13,000 years ago during the Periglacial Period. The scars resulted when 5m ice mounds split the overburden and melted due to the warming climate. The resulting basin was approximately the same size and shape of the mound. The three areas part of the present study are boggy, containing flora such as Sphagnum moss and a variety of sedges. Extensive research has been done on the geology and soils of these systems but Pingo scar flora is largely unknown and undocumented. The current study surveyed the Pingo scars in the Halfway Run Natural Areas and two other areas in Central Pennsylvania: Mohn Mills in Mifflinburg and Chestnut Springs in Milroy. The floristic survey will provide a more complete picture of these unique geological features. Surveys will consist of meandering through each Pingo . Plants will be recorded and for each plant identified, a voucher specimen or photograph will be collected. Plant surveys have begun in June and will continue until August. Nomenclature will follow Rhoads and Block (2007). Once the final list is complete, floristic quality will be assessed using the Floristic Quality Index. The information will be provided to Halfway Run Natural Area and also submitted in manuscript form to a peer-reviewed journal. Potential journals include the *Journal of the Torrey Botanical Society* and *Bartonia*. In addition to the manuscript, the project will provide an opportunity to learn plant identification in-situ, particularly hard to identify graminoids (grasses, sedges, and rushes), as well as how to collect and preserve plants.

Propagation of flood waves through urban channels and riparian zones

Lindner and Miller - UMBC

Urban streams are often flashy and are considered to have elevated probability of flooding compare to rural systems. However channel incision and enlargement increases cross-sectional area and conveyance, reducing the probability of overbank flow. Urban infrastructure, particularly where there are constrictions owing to culverts at road crossings, may influence flow hydraulics by causing backwater effects as well as downstream acceleration. One key question is how the morphology of the riparian zone and associated infrastructure affects propagation of flood waves. Another is whether stream restoration, which is an increasingly common response to channel incision and widening, has the capacity to alter or attenuate the flood wave as provided by highly impervious upstream source areas.

In this study, field-measured topographic data, flow records from nested stream gages, and a 2-d depth-averaged hydraulic model (TUFLOW) are used to characterize floodwave propagation in two urban streams. The first stream (DR5; 1.6 km^2; 45.9% impervious; 2.9% of drainage area controlled by stormwater management) is most responsive to high-intensity short-duration convective storms. The channel is highly degraded with little to no riparian zone and is scheduled for restoration in 2015. Using stream flow records from 4 stream gages bounding the study domain to calibrate the model, we explore the potential for a headwater stream restoration to mitigate the impacts of upstream development through attenuation of the hydrograph. In addition to the existing conditions, 3 restoration scenarios are modeled. Preliminary results indicate little to no attenuation in this stream reach under existing conditions or under the planned design scenario. Additional modeling scenarios assess whether there is any feasible design that can provide attenuation for the flood peaks that are characteristic of this watershed.

To provide insight into the role of natural channel and floodplain geometries in controlling floodwave attenuation, we investigate a second stream (HB; 4.7 km^2; ~20% impervious; 46.5% of drainage area controlled by stormwater management) with a large, connected riparian zone and a muted runoff signal. Three stream gages with drainage areas of 2.2 km^2, 3.9 km^2, and 4.7 km^2 are nested within the HB domain. Short-duration high-intensity thunderstorms rarely produce flooding in this watershed, and overbank flows are produced almost exclusively by longer-duration storms of moderate to high intensity. The gages and modeling results show that the hydrographs experience almost pure translation with little or no attenuation downstream because of large runoff volumes that overwhelm floodplain storage capacity.

Finally, we test whether broad riparian corridors can attenuate the short-duration large-peak flows seen in flashy urban watersheds. This is accomplished by routing hydrographs from two flashy urban watersheds (DR4 and DR5) through the HB domain. Preliminary results suggest that even broad, connected riparian zones do not cause significant attenuation of a flashy urban hydrologic signal along the length of the modeling domain. This research provides valuable insight for understanding how flood waters move through

urban channels and riparian zones, and has implications for the stormwater management and stream restoration communities.

Analysis of Groundwater-Lake Interaction by Distributed Temperature Sensing in Badain Jaran Desert, Northwest China

Chuankun Liu[1], Jie Liu[1], Aijing Zhang[1], Xi Li[1], Yuxiang Sun[1], Zan Sun[1], Chunmiao Zheng[1,2]

[1]Center for Water Research, Peking University, Beijing, China

[2]Department of Geological Sciences, University of Alabama, Tuscaloosa, Alabama

The Badain Jaran Desert is the third largest desert of China within the Alxa Plateau in northwest China with a total area of 49,200 km^2. With an average annual precipitation less than 60 mm and the potential evapotranspiration rate exceeding 2000 mm, Badain Jaran is extremely arid with little vegetation. Yet, there are a total of 72 perennial lakes scattered throughout the desert sustaining a unique desert-lake ecosystem. Previous studies have investigated the origin and sources of water for these lakes. According to some geochemical and stable isotope analyses, shallow groundwater, likely from precipitation during early and middle Holocene, is recharging lakes. However, limited by rough natural conditions, direct hydrogeological measurements in those desert lakes are still lacking. This study applied the distributed temperature sensing (DTS) technique to continuously measure, in high resolution, temperature variations in one of the desert lakes – Badain Lake. The Badain Lake is located in the southeast part of the Badain Jaran Desert consisting of two adjacent twin lakes, salty one on the west side and fresh one on the east side. In summer time the surface water temperature is higher than the groundwater temperature in both day and night, and the temperature difference makes temperature a robust tracer for analyzing the patterns of interaction between the lake and groundwater. DTS was applied to measure temperatures on the lake bed during a period of seven days in August 2013, covering almost the entire bed of the eastern Badain Lake with an area of 18,400 m^2. Since temperature may be influenced by various unpredictable and temporary factors, it is important to eliminate other factors that affected the lake temperature such as solar radiation and vertical temperature stratification, and to identify a time window in which the temperature variations of the lake water were mainly determined by the groundwater discharge. A 3-hour time window at night was identified during which the maximum temperature difference between air and water was 0.2℃ and the vertical temperature gradient was less than 0.4℃/meter. It is reasonable to consider the groundwater discharge as the dominant factor that determines the distribution of the lake bed temperature within this time window. The results of the DTS study show that the lake bed temperature near the eastern and southeastern lakeshores of the eastern Badain Lake is colder than the average, indicating that this area is the main groundwater discharge area. In the northwestern lakeshore adjacent to a sand dune, a weak cold abnormal area was identified, indicating that the sand dune might recharge the lake by channeling the precipitation toward the lake. The contribution from the sand dune, however, appeared to be much less than the recharge from groundwater near the eastern and southeastern lakeshores. Based on the mass balance analysis, the groundwater discharges into the eastern Badain Lake was estimated to be at a rate of almost 200 m^3/day, the evaporation rate about 126 m^3/day, and the rate of lake water leakage into the aquifer approximately 98 m^3/day over the study period. Correspondingly, the rate of lake storage decrease was about 22 m^3/day during the study period. This study provides the first direct measurement and quantitative analysis of groundwater discharge into a lake in the Badain

Jaran Desert and contributes to the better understanding of a unique dessert-lake ecosystem.

Title: Monitoring Temperate Forest Soil Moisture Dynamics using Ground-Penetrating Radar

Authors:
Paul Longwell* (Hollidaysburg Area High School)
Dr. Xihong Cui (Beijing Normal University)
Dr. Henry Lin (The Pennsylvania State University)

Abstract:
Although ground-penetrating radar (GPR) technology has been in use for over thirty years, its potential for evaluating soil moisture dynamics is still being fully realized. The objective of this project was to collect GPR data over a period of several weeks from a defined test site located in a swale within the Shale Hills Critical Zone Observatory in the Pennsylvania's Stone Valley. The layout of the test site formed a rectangular grid which was divided into thirteen horizontal lanes. A 500-Mhz bistatic set of GPR transducers was configured with a wheel-mounted odometer and pulled at a slow steady rate across each lane resulting in a repeatable procedure for collecting data of the grid lines. The resulting time-lapsed GPR data was imported to a software program designed for processing and interpretation of reflection and transmission data. Data was processed to remove background noise and other signal disturbances while augmenting subsurface soil features. The result was a set of graphical representations of the soil subsurface features and soil moisture changes. This data set was also referenced to soil moisture levels recorded using a time domain reflectometry (TDR) probe. To provide a diverse set of data, measurements with both instruments were made following periods of varying precipitation levels. Distinguishing features of GPR imagery data that could be associated with varying levels of soil moisture changes were identified.

Impact of Mineral Weathering and Organic Matter on Soil Water Retention

Eric Lunn[1*], Fang Tan[1], Paul Imhoff[2], Holly Michael[1,2],
[1]Department of Geological Sciences, University of Delaware, Newark, DE 19716
[2]Department of Civil and Environmental Engineering, University of Delaware, Newark, DE 19716

Water retention of soils and rock in the unsaturated zone is important for predicting flow and solute transport through the subsurface and likely affects mineral weathering. We are evaluating the effects of 1) weathering and 2) organic matter on soil water retention. A WP4C Dewpoint Potentiameter (Decagon Devices, Inc., Pullman, WA) is used to measure the water retention behavior of soil and sapprolite samples from ground surface to 100 cm depth at Laurel Preserve in West Chester, PA. The data from the WP4C are used to derive the -1.5 MPa to -300 MPa section of the water retention curve. We hypothesize that soil from shallower depths will retain more water than soil from deeper depths due to higher surface area resulting from a greater extent of weathering near the surface compared to sapprolite at deeper depth. Specific surface area (SSA) can be predicted by regression analysis using water retention curves. Samples are separated into two identical sets from the same depths, and organic matter removal pretreatment is used for one set. This is done to observe whether the presence of organic matter in soils reduces the SSA for mineral weathering to occur and therefore the ability of samples to retain water. We hypothesize that the organic matter removal treatment could reduce the water adsorption ability to certain degrees, especially for shallow depths which contain high organic matter content.

Increasing aluminium concentrations in Southwest Nova Scotia Canada rivers from 1980 to present

Jeff Minichiello (1), Shannon Sterling (1), Sarah Ambrose (1), and Tom Clair (2)

(1) Dalhousie University, Earth Sciences, Halifax, Nova Scotia, Canada (shannon.sterling@dal.ca)
(2) Wood Buffalo Environmental Association, Fort McMurray, Alberta, Canada (tclair@wbea.org)

Elevated aluminium levels in rivers is known to be toxic for aquatic species, in particular Salmo *salar*; however it was only recently aluminium has been identified as a potential threat to Salmo *salar* populations in South Western Nova Scotia, Canada (SWNS) (Dennis and Clair 2012). Previously, it was thought SWNS rivers contained enough DOC to render the aluminium in rivers inactive. A key remaining question is whether aluminium levels are declining following atmospheric pollution reductions. Here we make a first assessment of long term (1980-2011) aluminium concentration trends in three watersheds located in SWNS, as measured by weekly grab samples. Our results show that total aluminium levels have significantly increased from 1980-2011 in all three sites. Estimates of ionic aluminium levels indicate that the ionic aluminium concentrations frequently exceed the threshold for the level of aquatic health determined by the European Inland Fisheries Advisory Commission (Howells et al. 1990). Data also indicates that calcium levels have yet to recover even with declining concentrations of riverine sulfate. This new knowledge that aluminium is at toxic levels and is worsening will have implications for policy on acidification mitigation in SWNS; this is an urgent issue as the local salmon population numbers currently are declining to near extirpation levels.

Field to Forecast: Leveraging Wireless Environmental Sensor Networks to Facilitate Real-Time Hydrologic Prediction

John Mallard –Duke University

Forecasting hydrologic dynamics in streams and rivers is a well-recognized challenge that has been addressed via a variety of existing predictive methods utilizing watershed models, past hydrographs, or regionalized hydrologic behavior. Hydrologic response, however, is both spatially and temporally dynamic: the response to a given unit of precipitation will often vary strongly as a function of past conditions. Therefore, incorporating non-stationary behavior in modeling efforts could yield enhanced predicative ability critical to providing forecasts that are useful within the relatively short time-scales of, for example, extreme hydrologic events. Models that can ingest real-time information on system state variables (e.g. soil moisture and streamflow) to characterize prior states through time could capitalize on enhanced "field to forecast" capabilities provided by wireless sensor and communication networks. Here we propose an observational network that leverages wireless sensors within the Calhoun Critical Zone Observatory (CCZO) to evaluate the effectiveness of multi-input, real-time hydrologic forecasting systems as part of the larger CCZO research program. This portion of the larger project focuses on watershed observation sensor networks, elucidating runoff generation processes, and developing parsimonious hydrological models and forecasting tools.

Fine-Grained Channel Margin Deposits Form by Recirculating Flow Downstream of Woody Debris in a Laboratory Flume

Sam Mark*, Bridget O'Neill, Dr. James Pizzuto, Dr. Katherine Skalak, Dr. Peter Wilcock

Fine-grained channel margin (FGCM) deposits are significant reservoirs of fine-grained sediments (and adsorbed pollutants), which form when suspended sediments are trapped in the lees of large woody debris (LWD) near the banks of gravel-bedded rivers. We determined how FGCM deposits form through experiments in a 15-meter long by .6-meter wide, adjustable slope, recirculating flume with a fixed pebble bed. Two LWD obstructions were placed along opposite walls 3.7 meters apart. LWD was simulated using wooden dowels (20 cm long, 2 cm diameter) with wire-mesh to represent upstream-facing rootwads. We documented the effects of LWD on the flow before adding 31 kg of very fine-grained (0.125 mm) sand; the run continued until FGCM deposits were fully formed. Upstream of the LWD, flow was 6.9 cm deep, with a mean velocity of .42 m/s, a Froude number of .51, and a Shields number of .059 (typical for gravel-bed rivers). A Rouse number of 6.39 indicates well-developed suspended sediment transport. While small amounts of sediment carried in suspension washed through gaps in the rootwad, the majority of sediment in FGCM deposits recirculates around LWD in eddy currents. Recirculating flow produced upstream migrating dunes upstream of the reattachment point, where eddying slowed current velocity to .04 m/s in the recirculation zone. Downstream of the reattachment point, dunes migrate downstream with the current. In these experiments, FGCM deposits formed as a result of recirculation currents imposed by LWD, similar to reattachment bars documented in bedrock canyon rivers partially obstructed by debouching debris fans.

Geologic and hydrodynamic effects on shallow groundwater-surface water exchange and chemical fluxes to an estuary

Audrey H. Sawyer[1,2], Kevin Kroeger[3], Olesya Lazareva[4], Kyle Crespo[5], Clara .S. Chan[1], Thomas Stieglitz[6], and Holly A. Michael[1,5*]

[1]Department of Geological Sciences, University of Delaware, Newark, DE, USA
[2]Department of Earth and Environmental Sciences, University of Kentucky, Lexington, KY USA
[3]USGS Woods Hole Coastal & Marine Science Center, Woods Hole, Massachusetts
[4]Delaware Environmental Institute, University of Delaware, Newark, DE, USA
[5]Department of Civil and Environmental Engineering, University of Delaware, Newark, DE, USA
[6]Europole Mer, Institut Universitaire Européen de la Mer, Plouzané, France

ABSTRACT

Fluxes of nutrients and other chemicals from aquifers to coastal waters can have adverse impacts on ecosystems. While solute concentrations may change along groundwater flowpaths toward the sea, they can also be modulated near the point of discharge in the shallow benthic zone below the sediment-water interface. This benthic reactivity depends on the supply of reactants from both groundwater and surface water and the duration of contact in the mixing zone. These factors are closely tied to physical processes: fluxes from above and below as well as mixing and residence time in the benthic zone. We characterized heterogeneity in benthic exchange and associated solutes in Indian River Bay, DE (USA), which is impacted by severe eutrophication. High-resolution measurements from a hand resistivity probe, groundwater sampling, and measurements of biogeochemical parameters in transects across paleovalley and interfluve features within the estuary were used to characterize stratigraphic effects on both the nature of the physical exchange processes and solute concentrations and fluxes. In the interfluve, fresh groundwater discharge was focused and rapid, and nitrogen transport was largely conservative. Across the peat-filled paleovalley, fresh discharge was low and saltwater exchange was deep. The long residence times promoted sulfate reduction and ammonium production. Iron-rich fresh groundwater discharged diffusely around the paleovalley feature, with significant saltwater exchange. In this zone ammonium was produced in shallow sediments and fluxes to the surface water were large. By modifying patterns of groundwater flow, discharge, and mixing between fresh groundwater and saline surface water, hydrodynamics and stratigraphic features influence the geochemistry in the subsurface and near the sediment-water interface, affecting rates and patterns of geochemical fluxes to coastal waters.

Title: The effect of precipitation variability on rainfall-runoff response and storage in steep headwater catchments

Author: Fabian Nippgen - Duke University/ Montana State University

Topography, active layer depths, and climate have long been recognized as first order controls on hydrologic response. However, the legacy effect of previous hydroclimatic conditions on the runoff response of a watershed has received less attention. Using >20 years of precipitation (P) and runoff (Q) data from the Coweeta Hydrologic Laboratory in southwestern North Carolina we seek to elucidate how precipitation variability affects the water balance of five watersheds with different vegetation types (coniferous and vegetation), aspects, and precipitation magnitudes. We quantified the effect of watershed memory (i.e. the degree of influence of past precipitation) for time scales ranging from monthly to seasonal to annual. We determined that on a monthly time scale the precipitation of the previous 6-7 months exerts a strong influence on the runoff ratio of a given month. The strong memory effect was also evident at seasonal and annual time scales, where the precipitation of the previous season/year was more correlated with runoff ratios than the current season/year's precipitation. We calculated annual watershed storage and determined that is was correlated with the residuals of a regression between annual P and annual Q, partially explaining observed variability in annual runoff. We found that the previous year’s final storage explained much of the variability of the next year’s P-Q residuals for the watersheds with deep soils. However, for a particularly steep watershed with shallower soils, storage did not have a significant effect on annual runoff variability.

Title:
Theoretical considerations for stochastic soil moisture dynamics and the optimal design of soil moisture sensor networks

Authors and Affiliations:
Norman Pelak[1,*], Mark Bartlett[1], John Albertson[1], Paolo Barbano[2], Amilcare Porporato[1]
[1]*Department of Civil and Environmental Engineering, Duke University*
[2]*Department of Mathematics, Duke University*

Abstract:
The complexity of space-time dynamics of soil moisture resulting from hydrometerological forcing and topographic variability poses great challenges for the design of soil moisture sensor networks. Motivated by the recent emphasis on critical zone monitoring and the development of new affordable sensor capabilities, we present preliminary theoretical results regarding the optimal design of soil moisture sensor networks providing optimal compromises between the need to obtain representative soil moisture data and physical and budget constraints that invariably limit the location, type, and number of sensors that can be deployed.
The new approach for optimal sensor placement uses ‘quality’ measures based on information theory. A minimalist stochastic model of space-time soil moisture dynamics within a watershed (parameterized on local slope, aspect, and contributing area and forced by stochastic rainfall conditions) is used to generate a reference space-time soil moisture field. Different statistical and information theory measures are then used to quantify the distance between such fields and hypothetical point measurements of soil moisture distributions in different locations. We calculate the relative entropy between the distributions for each point in the watershed. The configurations of sensors which minimize different optimality criteria are discussed for a case study based on the Holcomb branch of the Calhoun CZO.

Title: Mississippi River Nitrate Dynamics from Drought to Flood Revealed by High Frequency Measurements

Author: Brian Pellerin – United States Geological Survey

Accurately quantifying nitrate (NO_3^-) loading to the Gulf of Mexico is important for predicting summer hypoxia and establishing targets for nutrient reductions in the Mississippi River basin. We used an ultraviolet NO_3^- sensor to measure high-frequency concentrations and loads near the mouth of the Mississippi River over a two year period that included an extreme summer drought (2012) and spring flooding (2013). Seasonality in NO_3^- concentrations and loads was observed, with considerable variability in concentration-discharge relationships within and between years. Anomalously high daily NO_3^- loads (relative to discharge) were observed in the wet spring after the drought, consistent with a large flush of stored NO_3^- from soil. Monthly NO_3^- loads from measured sensor data and modeled (regression-based) techniques differed by -40 to +53%, particularly during the spring months critical to the formation of summer hypoxia. While challenges inherent in predicting the size of the hypoxic zone in years with climatic disturbances in the Gulf will likely not be alleviated by improving riverine NO_3^- loads, high frequency NO_3^- measurements provide a number of benefits for understanding nutrient transport to the Gulf of Mexico, particularly given projected increases in the magnitude and frequency of extreme events within the Mississippi River basin.

RWater: A Cyber-enabled Data-driven Tool for Enhancing Hydrology Education

Mohammad Adnan Rajib (1), Venkatesh Merwade (2)
(1): Graduate Research Assistant, Lyles School of Civil Engineering, Purdue University, West Lafayette, IN 47907, USA; Email: adnanrajib@purdue.edu
(2): Associate Professor, Lyles School of Civil Engineering, Purdue University, West Lafayette, IN 47907, USA; Email: vmerwade@purdue.edu

Enhancing students' analytical ability of interpreting complex hydrologic processes from limited classroom environment has been a subject of long-standing research. From this perspective, a new internet-based educational tool, called RWater, is developed using Purdue University's HUBzero technology. The current version of RWater interface includes the following three elements: (i) coding workspace, (ii) visualization window, and (iii) instruction modules, providing a self-contained learning environment that instructors and students can use from any location and/or device. Following real-time hydrologic data-driven modules, students can write small scripts in R to create visualizations identifying the effect of rainfall distribution and watershed characteristics on streamflow response, seasonal characteristics of hydrologic cycle, and investigate the impacts of landuse change on streamflow. Each module contains relevant definitions, instructions on data extraction and coding, as well as conceptual questions based on the possible visualizations which the students would create. In order to assess its suitability in real time classroom atmosphere and to evaluate learners' perception over its utility, the current version of RWater is tested under two different settings: (i) with high school students in a limited week long training program, and (ii) with middle and high school teachers in a two-day workshop mode. The evaluation survey results from these programs suggest that the RWater has potential to improve students' understanding on various cause-and-effect relationships in natural water cycle, leading towards effective dissemination of hydrology education at K-12 level.

Eco-hydrologic modeling of rangelands: Evaluating a new carbon allocation approach and incorporating grazing impacts on ecosystem processes

J.J. Reyes (1)*, C.L. Tague (2), J.S. Choate (2), J.C. Adam (1)

(1) Department of Civil and Environmental Engineering, Washington State University
(2) Bren School of Environmental Science and Management, University of California Santa Barbara

More than half of U.S. rangelands are impacted by invasive species and cost the economy $137 billion annually in lost or damaged ecosystem productivity and restoration efforts. Maintaining the health of our rangelands is vital to support important ecosystem goods and services like grazing and production areas for forage. However, rangelands are vulnerable to both changes in climate and human management. These complex and interacting changes may result in reduced water quality, decreased range productivity, or declines in livestock numbers. The overarching objective of this study is to quantify the resilience, i.e., the ability of these human-natural systems to handle disturbances and maintain their basic identity and essential functions, under changing management and climate conditions in rangelands. Ultimately, the goal is to provide information on interactions between management activities, climate and productivity to inform sustainable rangeland management. One of the prerequisites to providing useful information is evaluating model estimates of rangeland productivity and, if needed, improving the model. The specific objectives of this paper are to develop, parameterize, and evaluate a new carbon allocation scheme for grasses and introduce mechanisms that capture feedbacks related to grazing impacts on ecosystem processes.

The Regional Hydro-ecologic Simulation System (RHESSys) is a process-based, watershed-scale model that simulates hydrology and biogeochemical cycling with dynamic soil and vegetation modules. Climate, soil, vegetation, and management effects within the watershed are represented in a unique, nested landscape hierarchy to account for heterogeneity and the lateral movement of water and nutrients. We developed a new carbon allocation algorithm for partitioning net primary productivity (NPP) between roots and leaves for grasses. The 'hybrid' approach incorporates both resource-based limitation and growth-based allocation. We evaluated this new allocation scheme at the point-scale at a variety of rangeland sites in the shortgrass steppe, tallgrass prairie, desert grassland, mixed prairie, and cold desert biomes. Aboveground biomass, belowground biomass, and leaf area index were metrics for evaluation. The hybrid approach was compared against existing allocation schemes currently used in RHESSys. We found that the hybrid approach best approximates the high root:shoot ratios observed in these grasses. The hybrid approach represented a balance between preferential partitioning due to environmental conditions and age-related growth, both of which suited simulation of grass growth well as compared to use of other allocation schemes. Additionally, we conducted an analysis on the impact of these different allocation strategies on ecosystem water use and potential vulnerability to drought. We have also incorporated grazing impacts on the landscape such as biomass removal and soil structure changes. We found that parameters governing the daily to annual allocation of NPP and fractional storage of carbohydrates dictate recovery of grasses to defoliation. Future work will involve parameterization of algorithms related to reproduction and seed germination, as well as grazing impacts on soil.

Title: Biofilm Complexity Controls Fine Particle Dynamics in Streams

Coauthors: K. R. Roche*, W.R. Hunter, J.D. Drummond, T.J. Battin, F. Boano, and A.I. Packman

Most models of riverine eco-hydrology and biogeochemistry rely upon bulk parameterization of fluxes. However, the transport and retention of carbon and nutrients in headwater streams is strongly influenced by biofilms (surface-attached microbial communities). Mechanistic understanding of the interactions between streambed biofilms and nutrient dynamics is lacking.

Here we present experimental results linking microscale observations of biofilm community structure to the deposition and resuspension of clay-sized mineral particles in streams. Biofilms were grown in identical 3 m recirculating flumes over periods of 14-50 days. Fluorescent particles were introduced to each flume, and their deposition was traced over 30 minutes. Particle resuspension from the biofilms was then observed under an increased stream flow, mimicking a flood event. We quantified particle fluxes using flow cytometry and epifluorescence microscopy. We directly observed particle adhesion to the biofilm using a confocal laser scanning microscope. 3-D Optical Coherence Tomography was used to determine biofilm roughness, areal coverage and void space in each flume. These measurements allow us to link biofilm complexity to particle retention during both baseflow and floodflow. The results suggest that increased biofilm complexity favors deposition and retention of fine particles in streams.

Insights into hydrogeochemical dynamics in a floodplain aquifer during Hurricane Sandy from multiple sensor technologies

A.H. Sawyer[1,2]*, L.A. Kaplan[3,4], O. Lazareva[4], H.A. Michael[1,5]
[1] Department of Geological Sciences, University of Delaware, Newark, DE 19716
[2] Now at School of Earth Sciences, The Ohio State University, Columbus, OH 43210
[3] Stroud Water Research Center, Avondale, PA 19311
[4] University of Delaware Environmental Institute, Newark, DE 19716
[5]Department of Civil and Environmental Engineering, University of Delaware, Newark, DE 19716

Storms dominate solute export budgets from catchments and drive hydrogeochemical changes in the near-stream environment. We captured near-stream hydrogeochemical dynamics during an intense storm (Hurricane Sandy, October 2012), by instrumenting a riparian-hyporheic zone transect of White Clay Creek in the Christina River Basin Critical Zone Observatory with pressure transducers, redox probes, and pore water samplers. In the floodplain aquifer, preferential vertical flow paths such as macropores facilitated rapid infiltration early in the storm. Water table rose quickly and promoted continuous groundwater discharge to the stream. Floodplain-hillslope topography controlled post-storm aquifer drainage rates, as the broad, western floodplain aquifer drained more slowly than the narrow, eastern floodplain aquifer adjacent to a steep hillslope. These changes in groundwater flow drove heterogeneous geochemical responses in the floodplain aquifer and hyporheic zone. Vertical infiltration in the floodplain and hyporheic exchange in the streambed increased DOC and oxygen delivery to microbially active sediments, which may have enhanced respiration. Resulting geochemical perturbations persisted from days to weeks after the storm. Our observations suggest that groundwater-borne solute delivery to streams during storms depends on unique interactions of vertical infiltration along preferential pathways, perturbations to groundwater geochemistry, and topographically controlled drainage rates.

Long-term variability of threshold runoff response in forested watersheds

Charles I. Scaife[1,2,*] and Lawrence E. Band[1,2]
[1]*Department of Geography, University of North Carolina, Chapel Hill, NC*
[2]*Institute for the Environment, University of North Carolina, Chapel Hill, NC*
[*]*Presenter*

Commentary within the hydrologic sciences has called for a broader understanding of catchment behavior that is both scalable and versatile across landscapes. This means shifting scientific paradigms away from intra-catchment heterogeneities towards broader hydrologic principles. To address this, research has focused on emergent behavior as a surrogate for what McDonnell et al. (2007) calls catchment "functional traits", for example connectivity. In several studies, connectivity has manifested as threshold behavior in runoff relationships. Because connectivity is difficult to measure directly, it is implied from soil moisture states, precipitation, and/or shallow groundwater. These threshold relationships between runoff and its inputs have been well defined in other studies, however they may not be static in time. Instead, runoff relationships may exhibit non-unique behavior that varies seasonally and annually. This temporal variance may be linked to several factors. The goal of this research is to focus on characterizing runoff relationships and explore why they change over time. Our approach creates and recreates relationships observed in other studies. For example, we use an antecedent precipitation index (API) and an antecedent soil moisture index (ASI) to characterize how hillslope wetness drives runoff from short to long timescales. This requires also understanding the effects of long-term rainfall patterns (i.e. dry versus wet years) on threshold behavior. Our study site is situated in watersheds 14 and 18 (WS14 and WS18, respectively) of the Coweeta Hydrologic Laboratory in the Southern Appalachian Mountains of North Carolina. Long-term discharge data has been collected in both sites since the 1930s. To compliment this, three long-term soil moisture plots have been measuring hourly soil moisture using time-domain reflectometry (TDR) in WS18 since 1999. Also, 18 soil moisture plots (all; synoptically measured, 3; with concomitant TDR) have been sampled in WS14 from 2011-2013. Synoptic and logged shallow groundwater data are also available in WS14 and they're collocated with nine of the downslope soil moisture plots. Lastly, we'll use two rain gages located near our study watersheds to characterize rainfall patterns. Two results have emerged from this study: (1) strong phenologically-driven changes in runoff with respect to soil moisture and shallow groundwater and (2) high inter-annual variability in antecedent soil moisture and baseflow. We hypothesize a semi-preferred state system dominated by vegetation where threshold behavior changes between states of the system. Under leaf-off conditions there is less ET and greater lateral redistribution allowing the hillslope to transmit water more quickly. During the growing season, this lateral redistribution is interrupted by plant water uptake henceforth altering our runoff relationship between the two states. We also suggest that high inter-annual variability between soil moisture and baseflow will be linked to precipitation. The effects of a wet versus dry year will alter the sensitivity of discharge to changes in soil moisture. Ultimately, this research will expand on our knowledge of runoff behavior and how it changes with time. Characterizing what controls them will be important for thinking about long-term emergent behavior in other climates and landscapes.

Predicting the presence of headwater wetland depressions, Valley and Ridge Physiographic Province, central Pennsylvania

Kimberly Schmid*, Rob Brooks, Tim White, The Pennsylvania State University

This project involves the development of a conceptual model of the formation of wetland depressions in headwater saddles on shale. The model considers paleoenvironmental landscape changes that probably occurred during the Pleistocene Epoch, and may provide a tool for predicting the location of these important features in otherwise obscure landscape positions. The project includes an assessment of the presence or absence of wetland depressions in headwater saddles on shale to determine the effectiveness of using field observations as a predictive tool.

Wetland depressions are elliptical shaped basins that are typically isolated -- they have no surface water connections to any other bodies of water. They are often filled only in the spring and early summer, thus may be called vernal pools. These types of pools are important breeding habitats for a broad range of flora and fauna. In our experience, the wetlands described here are distinct and unique features of the central Pennsylvania landscape that most often have not been recognized in the National Wetland Inventory. This lack of recognition presents a challenge to land managers and any effort to conserve these important wetland habitats. Their headwater position emphasizes the need to protect them to maintain water quality at downstream locations.

The focus of field efforts during this REU field season is on two sites previously known to the research team: Chestnut Springs in the Rothrock State Forest (SF) and Mohn Mills in Bald Eagle SF. At each site at least two soil pits were dug on the flanks of the wetland, described using standard field soil descriptive methods, and sampled in 10-centimeter increments for geochemical analyses. Cores were augured into wetland sediments and described and sampled in the field. Ground-penetrating radar surveys were performed to elucidate the internal stratigraphy of the soils and sediments and to determine a depth to bedrock. Samples were returned to Penn State laboratories where they were air dried, and then prepared by standard methods for major oxide and trace element geochemical analyses.

A similar stratigraphy was observed in all of the soil pits: a boulder/cobble layer exists at depth, overlain by fine-grained material (sand and clay) that encompasses the majority of the soil column. Boulders and cobbles are also visible at the soil surface and are associated with widespread talus deposits visible throughout the central Appalachian Mountains. Where water was encountered, it occurred within the deep boulder zone. In the vernal pool cores, the uppermost lithology consisted of fine organic material overlying clay. A layer of rock was encountered in the vernal pool core at Chestnut Spring.

A swath of the central Pennsylvania Valley and Ridge province known to contain wetland depressions in headwater saddles on shale was evaluated using LiDAR imagery and topographic maps, and our ongoing assessment indicates that 100% of them contain wetland depressions.

Thermal Dynamics and Transient Storage in a Spring-fed Forested Headwater Stream, Southeastern PA, USA

Jennifer Schoenstein*, Dr. Melinda Daniels, Sarmistha Chatterjee, Jennie Matkov
Stroud Water Research Center, 970 Spencer Road, Avondale, PA 19311

Stream water temperature is a vital control on stream ecosystem function. Groundwater inputs and hyporheic exchange can substantially influence headwater stream temperature and hydrologic regimes. The relatively stable temperature of groundwater contributions produces distinct thermal habitats, controls nutrient cycling, and influences water quality and quantity. Various techniques are available to measure groundwater flow into a stream, such as thermal sensing and the use of conservative tracers. In this study, we examined both the thermal and transient storage dynamics of a stream by using distributed temperature sensing (DTS) technology and a conservative salt tracer. These two methods were used at Spring Brook, a first order spring-fed stream and the Christina River Basin-CZO's forest end-member, located within the Brandywine Conservancy's Laurels preserve. This study determined the points of hyporheic flow in Spring Brook using the DTS system and then evaluated if geomorphic structures (such as debris and log dams) were affecting the stream thermally through forcing of hyporheic exchange. A chloride tracer release was also conducted in Spring Brook to provide rate of transport and transient storage, both of which are altered by stream-groundwater exchange and surface transient storage caused by debris in the channel. Understanding these processes in a headwater stream is important for addressing the capability of the stream to transform nutrients and to maintain a suitable temperature range for native organisms.

Title : The role of hydrologic connectivity in mediating stream metabolism and carbon dynamics across space and time

Author: Erin Seybold – Duke University

In mountainous catchments, landscape hydrologic connectivity is seasonally and spatially dynamic and strongly influences dissolved organic carbon transport to streams. This seasonal variation in hydrologic connectivity and lateral delivery of carbon to streams may influence magnitudes of stream metabolism, nutrient uptake, and downstream transport. We seek new understanding of watershed hydro-biogeochemical dynamics, with a focus on carbon transport from snowmelt through summer baseflow. To assess stream carbon export patterns, we paired real time fDOM observations in headwater stream reaches with watershed outlet monitoring in two contrasting watersheds in the Tenderfoot Creek Experimental Forest of central Montana. We couple these measurements with hydrologic measurements of hillslope connectivity to assess transport mechanisms, and nutrient uptake kinetic experiments to quantify the retention and transport of carbon through headwater streams. Previous research at this site has generated a detailed understanding of the dynamic, seasonal nature of hillslope hydrologic connectivity and the changing fraction of the watershed actively contributing to streamflow. Here, we seek to interpret carbon transport and processing dynamics in this context across contrasting watersheds.

Temporal evolution of soil moisture statistical fractal: seasonal and rainfall dynamics

Chaopeng Shen and Xinye Ji
Department of Civil and Environmental Engineering
The Pennsylvania State University, University Park, PA 16802, USA
e-mail: cshen@engr.psu.edu; xzj102@psu.edu

William J. Riley
Earth Science Division
Lawrence Berkeley National Lab, Berkeley, CA 94720, USA
e-mail: wjriley@lbl.gov

Abstract

Soil moisture statistical multi-fractal has the potential to play a key role in multi-scale hydrologic modeling. The fractal was first discussed two decades ago, but little is known about how it evolves in time in response to climatic forcings. In this study we used a physically-based surface-subsurface process model (PAWS+CLM) to examine the patterns and drivers of fractal temporal evolution in two U.S. Midwest basins. The fractal scaling exponents (τ) display complex hysteresis and are not monotone functions of mean or variance of the moisture field. The scaling exponents are found to relate negatively to basin water storage, producing a dominant seasonal mode, suggesting a more organized pattern in wetter seasons. Storm events induce hysteretic excursion loops that can be divided into three phases: (a) wetting, (b) re-organization-dominated, and (c) dry-down-dominated. We show prototypical rainfall-induced excursion loops in seasonal water withdrawing and storing limbs. Scaling exponents during dry-down periods are found to be approximately parallel linear functions of basin water storage. The hysteresis is shown to be due to in-homogeneous wetting and basin-wide self-organization of moisture. The reorganization has a steady component, but is more prominent immediately after rainfall, yielding a re-organization-dominated phase. Grid resolution has a mild influence on the results. Overall, our results suggest that coherent patterns in the response of spatial scaling exponents to climate forcings exist and a dynamical system approach may be considered to predict its temporal evolution.

Title: Hydrology: Modeling an uncertainty
Author: Boris Shmagin – San Diego State University

Vit Klemeš (1932-2010) wrote: “The unsatisfactory state of hydrology is … the result of the dichotomy between the theoretical recognition of hydrology as a science in its own right and the practical impossibility of studying it as a primary discipline, but only as an appendage of hydraulic engineering, geography, geology, etc. …” (1986) and “… the consequence of the fact that, in the absence of hydrology as a full-fledged science, engineers themselves had to supply the hydrological inputs they needed and they did so by constructing simple empirical models from the data - after all, it was not their business to do 'scientific hydrology'”(1999). These were last century articles; the recent publication, “Joint Editorial – On the Future of Journal Publications in Hydrology” in five international hydrological journals shows the presence of a similar situation now.

Two topics considered in the presentation are Logic and Ontology, to present Hydrology in a wider multi-disciplinary picture.

The scientific research in Hydrology takes place in a system: object – researcher – data – model – stakeholder, a system having straight and feedback connections. The object of study in Hydrology is a watershed, taking in consideration 3D, time, and landscape properties.

The Cybernetic Model of Watershed (CMOW), developed on the base of Joseph Krcho’s (1978) work on system analysis of Geospheres, complies with the requirements of Logic for a full, formal, and developed description of domain(s), model(s) and the identity of the objects of study and models in use. CMOW is a conceptual model for the formal presentation of regional variability in natural and modernized landscapes and the formulation research goal and tasks. The use of Statistical Learning in V. Vapnik’s (1982) original version provides quantification for CMOW and a basis for the following steps of modeling. Logic in the conceptualization of research, quantification of uncertainty in modeling, formalization of language for results representation, and education brings a “full-fledged” Hydrology in the family of natural sciences as an equal member.

The Ontology of Hydrology includes: (1) a tacit interaction with a watershed as the evolutionally developed initiation of study in hydrology and as the definitive difference on this matter between a hydrologist and an engineer; (2) a consideration of the uncertainty of any study as a property of a system (defined as a researcher – a modeler – a stakeholder) during the extraction, formulation & communication of the knowledge about the watershed; (3) the formal scaled description (including cartographical) of a natural object as a time spatial and multi-dimensional fuzzy system; (4) a limitless opportunity to extract specific research tasks from one and apply ways and methods to solve them on the other; (5) an integration during particular study of all empirical data on the conditions and a behavior for the analysis of a watershed; (6) the regional “landscape specific” time and space approach for the verification of research results; (7) the use of math models as tools to extract, structures of representation, and communicative media for the obtained knowledge & the uncertainty of this knowledge.

Space-time Variability of Headwater Streamflow in the Southern Appalachians

Singh NK[1]*, Emanuel RE[1], McGlynn BL[2]

[1]Forestry and Environmental Resources, North Carolina State University, Raleigh NC 27695, US
[2]Division of Earth and Ocean Sciences, Nicholas School of the Environment, Duke University, Durham, NC, 27708 US

How hillslope shape and structure affect the spatial and temporal variability of streamflow is a key question in catchment hydrology. In particular, the role of hillslope structure and arrangement in modulating the longitudinal variability of streamflow in first-order headwater catchments is poorly understood. Here we assess the spatio-temporal distribution of streamflow under baseflow condition in small headwater catchments that are characterized by different topography and vegetation. We studied the relationship between hillslope structure and baseflow along a series of first-order streams using a combination of in-stream water isotope sampling, stream gauging, and geospatial analysis. We studied two pairs of small (< 15 ha) forested catchments at the Coweeta Hydrologic Laboratory (CHL), an LTER site in the southern Appalachian Mountains. The catchments comprise different combinations of aspect (north and south) and vegetation type (deciduous and evergreen), and they contain hillslopes ranging in size from ~ 10^3 m^2 to ~10^4 m^2. We collected water isotope (^{18}O and ^{2}H) samples (i) at 50 m intervals along first-order streams in each catchment, (ii) from shallow groundwater wells on hillslopes within each catchment, and (iii) from rain gauges distributed across CHL. We collected samples monthly from June 2011 until October 2013 and analyzed them for ^{18}O and ^{2}H using laser spectrometry. During the same period, we conducted three dilution stream gauging campaigns to measure longitudinal changes in discharge at different baseflow states along streams in each catchment. We developed discharge versus contributing area relationships for each stream and combined these with continuous flow measurements at the outlets to estimate lateral inflows from hillslopes during the entire study period. We used a simple mass balance approach to estimate the isotopic composition of lateral inflows from observed isotopic composition of stream water immediately upstream and downstream of each hillslope. These methods allowed us to produce time series of lateral inflows and their isotopic composition for hillslopes in each of the four catchments.

Our results indicate high spatial and temporal variability in observed stream isotope composition, and high spatial and temporal variability in both the estimated magnitude of lateral inflows and their estimated isotopic composition. We observed a strong positive relationship between stream delta^{18}O and stream contributing area, which may result from complex interactions between precipitation and other water pools at time-scales longer than one month. We observed a positive relationship between the temporal variability of lateral inflows and the size of an individual hillslope, which may result from the capacity of relatively large hillslopes to produce a wide range of runoff with varying seasons and flow states. This research is a step forward gaining new insights into the linkages between the structure and arrangement of hillslopes in forested catchments and the nature of baseflow in these systems.

Title:

Linking hierarchical stratal architecture to reactive plume spreading in the Lagrangian-based transport models

Reza Soltanian[1,*], Robert Ritzi[1], Chaocheng Huang[2] , Zhenxue Dai[3]

[1]Department of Earth and Environmental Sciences, Wright State University, Dayton, OH 45435, United States

[2]Department of Mathematics and Statistic, Wright State Univeristy, 3640 Colonel Glenn Hwy, Dayton, OH 45435-0001

[3] EES-16, Earth and Environmental Sciences Division, Los Alamos National Laboratory, Mailstop T003, Los Alamos, NM 87545

Abstract

We present new Lagrangian-based theories which link the time-dependent effective retardation factor and also particle displacement variance of reactive solute spreading undergoing linear sorption to hierarchical sedimentary architecture. The formulations are based on a hierarchical expression of the spatial covariance of log permeability, $Y = \ln(k)$, log sorption distribution coefficient, $\Xi = \ln(K_d)$, and their cross-covariance. The covariance expressions represent a two level hierarchy of stratal facies types with a corresponding hierarchy of each attribute's subpopulations. The covariances are a linear sum of terms corresponding to the probability of transitioning across stratal facies types of different scales, and these terms are directly related to quantifiable physical attributes of the hierarchical sedimentary architecture. The developed models avoid the fitting sample bivariate statistics to define the model parameters. The new transport models are also a linear sum of terms, with different integral scales defined by the hierarchy of

cross-transition probabilities and computed from the proportions and length statistics of the stratal facies types. The model allows the study of the contribution of each term to the effective retardation factor and composite particle displacement variance of reactive solute and thus the study of how the hierarchical stratal architecture influences reactive plume spreading. A data set collected at the well-documented Borden research site were used in order to evaluate the transport model. The data set allowed us to determine how the stratal architecture quantified at the Borden site, at different scales, controlled the particle displacement variance of perchloroethylene (PCE) plume observed in the original natural gradient tracer test. The transport model represents the field-measured retardation factor and particle displacement variance that occurred in the natural gradient tracer test well. The contributions by strata at each scale of stratal hierarchy to the particle displacement variance of PCE plume were analyzed. The results reveal that the majority of the particle displacement variance of PCE plume at the Borden site is controlled by the proportions, and the mean and variance in length of larger-scale strata of medium sand (M) and strata of fine sand and silt (FZ). Smaller-scale strata types occurring within the larger-scale facies have a smaller contribution to than larger scale facies types of M and FZ. The analysis also showed that time-dependent effective retardation factor can be explained by the proportions, and the mean and variance of both smaller-scale and larger-scale strata observed at the Borden site. Furthermore, we found that the spatial variability of Ξ and consequently retardation factor has the main contribution to time dependent effective retardation factor. The contribution from the cross-correlation between Y and Ξ to the time dependent retardation factor is not significant.

Effect of soil parameter uncertainty on assessing climate change projection in two small Sierra Nevada watersheds

Kyongho Son[1] and Christina Tague[1]

1:Bren School of Environmental Science & Management, University of California Santa Barbara, CA

Abstract

The importance of soil parameter uncertainty in hydrologic modeling is generally well understood, but its effect is not well studied in climate change impact analysis, especially for Sierra Nevada watersheds in California. Many previous climate change impact studies in Sierra Nevada watersheds focused on large basin scales (>100km^2) that are relevant for regional water management. Estimates of the impact of climate change on hydrology however are also needed for lower order catchments that are the focus of forest management practices and stream restoration projects. This paper aims to assess the impact of soil parameter uncertainty on the estimation of ecohydrologic response to inter-annual climate variation and climate warming in two low-order watersheds, located in Sierra National Forest, California. We compared model streamflow accuracy and the sensitivity of model estimates (streamflow, evapotranspiration (ET) and net primary productivity (NPP)) to soil parameter uncertainty in a transient snow watershed (TSW) and a snow-dominated watershed (SDW). In addition, we compared the variation of ecohydrologic responses to soil parameter uncertainty with the magnitude of ecohydrologic responses to moderate climate

warming. The Regional Hydro-Ecologic Simulation System (RHESSys) and Generalized Likelihood Uncertainty Estimation (GLUE) were used to quantify the predictive uncertainty of model estimates. Our results showed that the model estimates for TSW had higher predictive uncertainty for streamflow, ET and NPP than those for SDW. At annual time scales, drier years have the highest sensitivity of annual streamflow estimates to soil parameter uncertainty in both watersheds, and intermediate years have highest sensitivity of annual ET and NPP estimates to soil parameter uncertainty in both watersheds. At monthly time scales, the effect of inter-annual climate variability on estimated monthly streamflow, ET and NPP in spring and winter was more significant than the effect of soil parameter uncertainty. However, the effect of soil parameter uncertainty and inter-annual climate variability on the variation of estimated monthly streamflow, ET and NPP was equally important in summer period. The effect of soil parameter uncertainty on estimating annual ecohydrologic variables was often greater than climate warming effects, and the soil parameter uncertainty effect became greater in drier years. The results emphasized the importance of soil parameter uncertainty in capturing the ecohydrologic responses, particularly in dry years and during the summer.

Title: *Soil-water interactions in shrink-swell clays: measurements and models across scales*

Author: Ryan Stewart – Virginia Tech

Shrink-swell clay soils are found all over the globe, with up to 350 million hectares being classified as either *Vertisols* or *vertic* intergrades. Shrink-swell clay soils are characterized by crack networks that form as the soil dries. When open, these cracks can exert significant influence on hydrological processes. This study, which took place in the *Secano Interior* region of South-Central Chile, uses a diverse and innovative dataset to quantify soil-water interactions across scales. These measurements were then utilized to develop a new, parsimonious model that integrates the behavior of individual clods with plot- and catchment-scale processes such as infiltration and overland flow. Even though the model was developed for *vertic* soils, it potentially can be applied to other clayey soils in order to better describe common processes such as infiltration, preferential flow, and nutrient transport.

Title: Development of hyporheic exchange and nutrient uptake following stream restoration

Author: Stuart Baker – Kent State University

Stream restoration is a multi-million dollar industry in Ohio, with major goals of improving water quality and degraded habitat. Yet restoration often falls short of significant improvements in water quality and biodiversity. It is thus important to improve the theory and practice of stream restoration in order to achieve greater benefits per dollar spent, yet there are limited data and understanding of the physical and biogeochemical responses to restoration that constrain the potential for water quality and ecological improvements. Hyporheic exchange, the flow of water into and out of the streambed, is an important stream process that serves critical roles in naturally functioning streams, allowing for stream water to participate with the substrate in various processes. Hyporheic flowpaths can be altered by the transport of fine sediment through the stream bed and are thus susceptible to changes in sediment regime and hydraulics, as well as the changes wrought by construction of a restoration project. The goal of this research is to determine the effectiveness of restoration in enhancing hyporheic flow and associated biogeochemical processes to improve water quality. Preliminary results from Kelsey Creek, OH, a second-order stream restored in August 2013, show a decrease in average hydraulic conductivity but an increase in heterogeneity from pre-restoration (geometric mean 8.47×10^{-5} m/s, range 1.18×10^{-6}-1.19×10^{-3}) to post-restoration (geometric mean 4.41×10^{-5} m/s, range 2.67×10^{-5}-3.05×10^{-4}) in piezometer nests through large constructed riffle structures. These piezometers also indicate dominance of downwelling throughout riffle structures with only isolated locations of upwelling. Transient storage and hyporheic exchange will be measured with resazurin injections for comparison between pre-restoration and post-restoration, and nutrient injections of NH_4Cl at time points following the restoration will compare the nitrogen uptake rates of the restored reach to an unrestored reach downstream. Additional sites are planned for study to include restoration projects of different ages to examine the development of hyporheic exchange and biogeochemistry after completion of restoration projects.

Evaluation of an in situ UV-Vis spectrophotometer for high frequency measurements of dissolved organic carbon and nitrate concentrations

Thayer, Abigail G.[1]*, Kaplan, Louis A. [2], Aufdenkampe, Anthony K.[2]
(1) Ohio Northern University, (2) Stroud Water Research Center

There exist several critical indicators of water quality in streams and watersheds, including dissolved organic carbon (DOC) and nitrate. We used an in situ UV-Vis spectrophotometer in White Clay Creek, Christina River Basin CZO, to capture fluctuations in these parameters at a high frequency. The instrument, an s::can spectro::lyser, acquires in situ measurements of a full UV-Vis spectrum and utilizes a built-in algorithm to determine DOC and nitrate, compensating for turbidity and other interfering species. Three s::can probes were installed at one site in White Clay Creek, and were programmed to take continuous measurements at four minute time intervals. Discrete samples were collected from this location during both baseflow and storms, and were analyzed for DOC, nitrate, and total suspended solids. The s::can had a precision of 0.05 mg/L for both DOC and nitrate, and consistently exceeded concentrations in laboratory measurements of DOC and nitrate. Cleaning the sampling window after a two week period caused the s::can measurement of DOC to decrease by approximately fifteen percent, but did not affect nitrate measurements. Despite these issues, the s::can correlated with laboratory values, $R^2 = 0.95$ and 0.86 for DOC and nitrate, respectively. The s::can captured dynamics that exist on a diel basis as well as storms. DOC concentrations exhibited a recurring peak at approximately 1700 and a trough at 0500. Nitrate concentrations showed an inverse pattern to DOC. During periods of high rainfall, DOC concentrations significantly increased, while nitrate decreased. Comparisons of s::can and laboratory measurements will be used to evaluate the validity of the built-in algorithm, and multiple linear regression models will then be used to derive a more accurate site-specific calibration of the s::can.

An integrated modeling approach to understanding the complex water cycle in large inland basins

Yong Tian *, Yi Zheng, Chunmiao Zheng, Jie Liu, Yingying Yao, Aijing Zhang, Bin Wu
Center for Water Research, Peking University, Beijing 100871, China

Abstract: The water cycle in inland river basins often features substantial surface water-groundwater interaction and is sensitive to climate change and human activities. A systematical understanding of the water cycle is critical to the sustainable use of the scarce water resources, but it is difficult to achieve for large basins with limited hydrological observations. An integrated surface water-groundwater (SW-GW) model could help fuse the limited observations such that the systematical understanding might be attained. The Heihe River Basin (HRB) is the second largest inland river basin in China. It is a semi-arid region with extensive agriculture in its oasis, typical of northwest China. Although many studies have been conducted on this basin and various types of hydrological data have been collected, a coherent understanding of its water cycle is yet to be formed. In this study, GSFLOW, a USGS model coupling PRMS and MODFLOW, was improved and applied to the HRB. The model is grid-based for both its surface and subsurface domains. The integrated model assimilated multiple types of data including groundwater levels at monitoring wells, streamflow at gaging stations, and evapotranspiration (ET) derived from remote sensing data. The calibrated model was able to adequately reproduce the observed hydrological variables. The integrated model was then used to assess the potential response of the water cycle to both climate change and human activities, as well as the effectiveness of the current restoration practice. Overall, this study demonstrates an approach by which the characteristics and dynamics of the water cycle in large inland river basins can be systematically evaluated.

Keywords: surface water-groundwater interaction; water cycle; inland river basin; GSFLOW; integrated modeling; Heihe River Basin

Potential Effects of a Warming Climate on Water Resources within the Lehman and Baker Creek Drainages, Great Basin National Park, Nevada

John Volk*, David Prudic

Warming trends in near surface air temperature across the South-Western U.S. have been observed over the last century and are projected to continue over the 21st century. This warming shift is directly related to decreased snowpack and earlier snowmelt in mountainous basins throughout the West. Predictions of future precipitation in the South-West are much more uncertain amongst global climate models. In this study the objective was to quantitatively predict the impacts of projected warming to water resources in the Lehman and Baker Creek drainages, located in the Snake Range in the Great Basin National Park, NV. To accomplish this, a distributed parameter, Precipitation-Runoff Modeling System (PRMS) watershed model was developed and calibrated for both basins. Calibration and validation periods showed total errors between 0.6 and 12%. The model was forced by statistically downscaled and bias-corrected daily projections from the National Center for Atmospheric Research-Community Climate System Model 4.0 for four representative concentration pathways (greenhouse gas concentration trajectories). A thirty-year record of historical precipitation was repeated three times, and PRMS projections were conducted for the period 2009-2098 (water years). Results from the thirty-year periods (2009-2038, 2039-2068, 2069-2098) were compared such that volumes and variations in precipitation were identical and changes could be directly related to temperature variations. The study area was sensitive to small increases in temperature; results include shifts to earlier snowmelt timing for most scenarios from May to April with an increase in winter runoff. For a temperature rise of 5.5 °F by the end of the century, mean annual streamflow reductions exceed 10%, also a significant decrease in peak snowpack and May runoff was observed. Reduced snowpack and earlier snowmelt affected the snow-dominated study area by reducing soil moisture and evaporation-transpiration in July and August.

Title: Does Root Morphology and Architecture reflection Aboveground Species Composition?

Authors and affiliates: Mieke Vrijmoet*, Dr. David Eissenstat, Penn State University

Abstract: Distribution, function, and interaction of tree roots in a forest ecosystem remains among the most poorly understood branches of forest ecology. Belowground resource acquisition and competition strongly influence plant performance and subsequently forest composition. Further, root architecture and morphology may vary with soil traits. Among these many factors, which are predictors of belowground architecture, and to what extent is aboveground species composition reflective of belowground morphology? I documented root morphology and architecture traits of roots from the O-Horizon of soil collected as part of a vegetation survey at the Susquehanna-Shale Hills Critical Zone Observatory. Root morphological traits such as root diameter, root length density, tip density, and specific root length were measured and compared among sites of varying species composition, tree density, and rock content. This study should help test whether aboveground species composition, tree density and rock content can be used to predict belowground root architectures, density and morphology.

Product-to-parent reversion of Trenbolone: Stream-hyporheic spiraling increases ecosystem exposure and environmental persistence

Adam S. Ward[1, 2, *]
David M Cwiertny[3]
Edward P. Kolodziej[4]
Colleen C. Brehm[3]

1 –School of Public and Environmental Affairs, Indiana University, Bloomington, IN 47405. USA.

2 –Department of Earth & Environmental Sciences, The University of Iowa, Iowa City, IA 52242. USA.

3 – Department of Civil & Environmental Engineering, The University of Iowa, Iowa City, IA 52242. USA.

4 – Department of Civil & Environmental Engineering, The University of Nevada - Reno, Reno, VN 89557. USA.

The product-to-parent reversion of trenbolone acetate (TBA), a steroidal growth promoter used widely in beef cattle, was recently discovered to occur in environmental waters. The rapid forward reaction is by direct photolysis, with the much slower reversible reaction occurring during periods of darkness. The objective of this study is to quantify the effect of this newly discovered diurnal reversion cycle on TBA metabolite concentrations and total bioactivity exposure in stream systems. Here, we demonstrate increased persistence of TBA metabolites in the stream and hyporheic zone due to the reversion process, increasing peak and mean bioactivity exposure to bioactive compounds along a stream. The perpetually dark hyporheic zone acts as a dynamic source and sink characteristics for in-stream trenbolone. Relative to the no reversion case, mean in-stream trenbolone concentrations are increased by 40% in systems experiencing hyporheic reversion, which acts as a net steroid source to the stream. A regulatory framework for compounds undergoing product-to-parent reversion should consider total exposure to bioactive compounds, which vary in space and time, and with the relative bioactivity of products and parents. We extend our modeling framework to consider mixture bioactivity for other emerging contaminants, and demonstrate several metrics that can be used to quantify persistence and exposure to metastable products exhibiting reversion or other reversible reactions influencing total system bioactivity.

Analysis of water isotope content of precipitation and stream samples in the Baltimore Ecosystem Study LTER

Claire Welty[1,2] and John Kemper[1]

[1]Center for Urban Environmental Research and Education; [2]Department of Chemical, Biochemical, and Environmental Engineering, UMBC, Baltimore MD 21250

Isotopic analysis of precipitation samples in the Baltimore region collected since January 2013 has revealed significant seasonal and inter-storm variability in d18O and d2H content. Analysis of weekly stream grab samples from Baltimore Ecosystem Study (BES) LTER stream stations during the same period of time shows that the stream isotopic signatures are dampened and lagged compared to the precipitation signal. The observed temporal patterns in precipitation and stream isotopic contents provide an opportunity to evaluate mean watershed transit times using standard mathematical methods. The stream sampling strategy allows for comparison of mean transit times among similarly-sized watersheds as well as among nested watersheds across a gradient of land use, ranging from forested to remnant agricultural, suburban, and urban.

An initial bounding analysis using sine wave fitting functions applied to the precipitation and stream data yields mean watershed transit times of the BES watersheds ranging from 15 to 40 days, ordered by watershed areas ranging from 0.4 sq km to 171 sq km. The mean stream isotopic signature becomes enriched as water flows from small, forested headwater catchments to the urban outlet. Mean transit times of similarly-sized watersheds are nearly identical across a gradient of urbanization (5%, 18%, 45 % impervious surface area). For a nested set of subwatersheds ranging from 1 to 14 sq km within the highly urban watershed (all 45% -50% impervious), the mean isotopic signature is much more greatly enriched that all other BES study watersheds of all sizes (0.4 to 171 sq km), and the calculated mean transit times (~30 days) appear to be invariant with watershed size in this set of urban subwatersheds. This behavior is likely due to anthropogenic perturbations associated with leaking water and sewer pipes, which can confound the transit time analysis owing to sources other than precipitation contributing to the observed stream isotopic contents.

A study of spatiotemporal patterns of vegetation in a groundwater dependent ecosystem, Heihe River Basin, northwest China

Yingying Yao[1], Chunmiao Zheng[1], Wenjie Fan[2], Ye Zhong[1], Jie Liu[1], Yi Zheng[1]
[1]*Center for Water Research, Peking University, Beijing, China*
[2]*School of Earth and Space Sciences, Peking University, Beijing, China*

Abstract

In arid regions, natural vegetation is mainly distributed along river corridors or centered in the areas where groundwater maintains an appropriate depth for plant growth. The distribution of groundwater depth impacts the vegetation pattern on the catchment scale. This study explores the relationship between the spatiotemporal patterns of vegetation and groundwater dynamics in the Heihe River Basin (HRB), northwest China. The HRB is the second largest inland river basin in China and typical of ecohydrological conditions in northwest China. As the water consumption in the middle HRB increased to support irrigated agriculture and oases, the lower HRB has encountered a series of ecological problems, such as vegetation degradation and desertification, over the past 50 years. Previous studies in the HRB have shown a notable correlation between the vegetation status and water table depth. When the water table depth declined from 1 to 5m below the land surface, the vegetation coverage has been shown to decrease from 80% to 10%. The leaf area index (LAI) is a critical biophysical variable that describes the canopy geometric structures and growth conditions. In this study, LAIs from High Resolution Imaging Spectroradiometer HJ-CCD and MODIS on 30-day interval at 30 m resolution and 8-day interval at 1 km resolution are used to investigate vegetation patterns for the lower HRB during 2000～2010. The distribution and evolution of LAI values are compared with measured water table depths and simulated groundwater level changes to ascertain the spatiotemporal relationship between the vegetation patterns and groundwater dynamics. The effect of water management policy on vegetation health in the lower HRB is also evaluated. This study discusses these issues in the context of the HRB, but the method combining remote sensing and groundwater modeling and the insights about the responses of vegetation patterns to groundwater dynamics have important implication for other arid watersheds.

Key words: Heihe River Basin, LAI, groundwater level, vegetation

Dendrology, forest ecology, and data analysis in the STEM-centered classroom

Author:

*Mark Yeckley, Glendale School District

Abstract:

The students of rural Pennsylvania have a unique opportunity to use Pennsylvania State Parks and public forests to enrich their education(s) in the areas of environmental science and ecology. The middle school students have the opportunity to be part of a 2-module curricular STEM (Science Technology Engineering Mathematics) program while also meeting several environment and ecology state standards.

Module 1 will primarily consist of hands-on fieldwork including, but not limited to, developing the following skills; reading and interpreting topographic maps, tree identification, tree tagging and record keeping, metric system measurements, o-horizon sampling, course woody debris measurements and using compasses for navigational and orienteering purposes.

Module 2 will consist of data entry of measurements/observations taken in the field, construction of graphs, and graphic/data analysis. This module has the potential to create a long-term monitoring system in which students can access previously collected data in future projects.

Students will also have several experiences working with the DCNR park rangers from the Prince Gallitzin State Park allowing them to further develop their outdoor skills.

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Catchment streamflow response to climate change conditioned by historic alterations of land-use: forest harvest, succession, and stand conversion

David Young*[1], Dr. Nicolas Zegre[1], Dr. Pamela Edwards[2]

1. West Virginia University, Davis College of Forestry and Natural Resources.
2. U.S. Forest Service, Northern Research Station: Fernow Experimental Forest

When assessing the effects of climate change on streamflow it is customary to select pristine watersheds, free of confounding perturbations from land cover and land use change. Therefore the majority of knowledge is based on a minority of catchments covered by undisturbed mature forests. In well instrumented research sites such as the Fernow Experimental Forest, the complex history of plant succession across experimental disturbance regimes is known, as is climate forcing variables such as precipitation and temperature. Therefore, streamflow can be used to assess the hydrologic response to climate change conditioned by historic alterations of land-use change. We employ a Budyko framework, a means of accounting for water and energy balance to quantify the relative contributions of climate and land cover changes on annual streamflow between two time periods spanning 1951-2011. Results are interpreted within and between catchments with careful consideration to differences in landform and historic paired catchment study results. Based on this analysis, land-use, forest succession, and climate change-variability are differentially impacting streamflow. These results describes the importance of understanding how climate variability and/or landscape disturbance can mask or enhance the effects of climate change.

Modeling the hydrological response to climate change in the Heihe River Basin, northwest China

Aijing Zhang[1], Chunmiao Zheng[1, 2*], Yi Zheng[1], Jiu Liu[1]

1 Center for Water Research, College of Engineering, Peking University, Beijing, China

2 Department of Geological Sciences, University of Alabama, Tuscaloosa, Alabama

ABSTRACT

Located deep in the hinterland of Eurasia, the Heihe River Basin (HRB) is an arid inland river basin in northwest China where the hydrologic regime responds sensitively to climate change. From the headwater region to terminal lakes, the HRB can be roughly divided into three sections, i.e., the upstream Qilian Mountains, the midstream oases and the downstream Gobi Desert. Runoff generated in the upstream mountainous terrains, dominated by climate variations, is the critical water resource for the whole river basin. With increasing intensification of climate change, there is an urgent need to understand future changes of water resources and water-related disasters to provide support for regional water management in an arid inland river basin such as the HRB. This study investigates the potential impact of climate change on hydrologic processes in the upper HRB for the future period of 2021~2160. Downscaled temperature and precipitation projections from eight General Circulation Models (GCMs) under two emission scenarios (Representative Concentration Pathways: RCP4.5 and RCP8.5) are adopted to drive a commonly used flow model, Soil Water Assessment Tool (SWAT), for the upper HRB. The impacts of climate change on the total runoff and its components are quantified based on the future climate scenario analysis and the results of SWAT simulation. This work will further enhance our understanding of the complex interactions between future climate and watershed hydrology and the implications for water resources management in the HRB and similar arid inland river basins.

Keywords: Heihe River Basin, Climate change, GCMs, Statistical downscaling, SWAT model

Investigating runoff behavior using remote sensed data and modeling in the Ohio River Basin

Yuanhao Zhao[1]*, Yeosang Yoon[1], Edward Beighley[1], Tamlin Pavelsky[2], Hyongki Lee[3]

[1]Department of Civil and Environmental Engineering, Northeastern University
[2]Department of Geological Sciences, University of North Carolina, Chapel Hill
[3]Department of Civil and Environmental Engineering, University of Houston
*Corresponding Author, zhao.yua@husky.neu.edu

Abstract:

The hydrologic community has made significant advancements in our predictive understanding of the hydrologic cycle at continental to global scales. Still, there is need for improving model performance at the local scale (i.e., individual river reaches) to evaluate potential impacts of climate variability or landscape disturbances on water availability, ecosystem services and flood/drought risk. Specifically, the assessment of local water resources and related systems (e.g., ecological and biogeochemical cycles) requires predictive capabilities for flood events not achievable in many current Earth System models. Here, we investigate a new event-focused hydrologic modeling approach applicable at continental to global scales. A case study in the Ohio River Basin (0.5M sq km) is presented. Driven by TRMM precipitation (3B42v7), MODIS evapotranspiration (MOD16A2), MODIS land cover (MCD12C1), AMSR-E snow water equivalent, LandSat based river widths, and SRTM digital elevation data (v4.1), the Hillslope River Routing (HRR) hydrologic model is used to estimate daily streamflow throughout the Ohio River Basin for the period 2004-2012. To generate runoff, a coefficient (α) based is used approach, where runoff is α times precipitation. The generated runoff is then routed with HRR to simulate event hydrographs. In our approach, the runoff coefficient varies in space and time with the maximum value based on land cover type, and the time varying values based on a relationship with relative soil moisture. The maximum value and form of the soil moisture relationship are determined by calibrating the model to the measured USGS gauge 03303280 Note that, this gauge is the second most downstream gauge on the Ohio River and located upstream of the highly regulated Tennessee River. Three soil moisture functions are evaluated: linear, logarithmic and power. The results show that the power function provides the best agreement to gauge data. For example, maximum Nash Sutcliffe Efficiency was nearly 0.7 for the power function compared to 0.5 and 0.3 for the linear and logarithmic relationships, respectively. Results are presented to show how each relationship impacts event hydrographs over a range of initial soil moisture conditions. Using the calibrated model, model performance is analyzed over a range of drainage areas to investigate hydrologic scaling behavior.

Title: The role of groundwater and stream network dynamics in baseflow and stormflow generation
Author: Margaret Zimmer – Duke University

Catchment hydrology of the Piedmont region of the United States has been relatively understudied as compared to steep mountain terrain with shallow soils. However, the deep, highly weathered soils, gentle relief, and dynamic hydro-climatology of the Piedmont provide outstanding opportunities to gain new understanding about increasingly recognized challenges in the hydrological sciences, including the interplay of antecedent conditions and rainfall intensity that mediate shallow and deep flowpath partitioning, ephemeral stream network expansion and contraction, and resulting baseflow and stormflow generation. Here, we investigate how overland, shallow soil, and deep subsurface flow across landscape positions manifest in observed baseflow and stormflow generation and the dynamics of dissolved organic carbon, turbidity, and electrical conductivity. Our research in Duke Forest, North Carolina seeks to elucidate the interrelationships between the space-time dynamics of runoff generation processes and observed biogeochemical behavior in this deeply weathered, low relief landscape, to provide new insight into processes widely active but less easily identified and quantified elsewhere.