Susquehanna Shale Hills Critical Zone Observatory

All Hands Meeting Agenda and Abstract Volume

The Pennsylvania State University

University Park, PA

May 2017

SSHCZO All Hands 2017 Agenda

<u>Wednesday, May 10th</u>

Arrival of out of town participants

4:00pm – 5:00pm Poster Session Set-up (217 EES Suites)

6:00pm – Dinner Sue and Emily

<u>Thursday, May11th</u> ALL **HANDS MEETING - 117 EES Building**

8:00am – 8:15am – Welcome and Introductions to SSHCZO. Talks are to be 10 -12 minutes followed by 5-7 minute Q/A session and 1 minute speaker switchover

8:20am – 8:40am – Synthesis Talk of Renewal Ideas and CZO next research questions

8:45am – 9:30am – ***<u>Opening Poster Session</u>***

- **Geophysical Techniques for Revealing Subsurface Structure and Processes in the Critical Zone (Guo et al.)**
- **Integrating geomorphological and time-lapse geophysical techniques to characterize hydrogeologic properties within shale and sandstone catchments at the Susquehanna Shale Hills Critical Zone Observatory, Pennsylvania, USA (Mount et al.)**
- **Concentration-Discharge Relations and End-Members Analysis in a Model Catchment for Shale Hills (Kakuturu et al.)**
- **Using leaf-on and leaf-off airborne LiDAR to understand spatial patterns of tree and shrub biomass in a deciduous forest (Brubaker et al.)**
- **Shallow critical zone architecture of a headwater sandstone catchment quantified using near-surface geophysics (DiBiase et al.)**
- **Nitrogen Balance of the Shale Hills CZO (Weitzman & Kaye)**
- **Monitoring, Collecting, and Analyzing Water Quality Data of Stream in Central Pennsylvania (TeenShale Participants)**
- **Instrumentation at SSHCZO (Forsythe)**
- **Catchment-scale Lateral Flow Analysis and Hydropedologic Functional Units (Miller et al.)**
- **Forest dynamics and the carbon budget in the Shale Hills watershed (Reed & He)**
- **Reading the Regolith at Garner Run: Geomorphic history, chemical weathering and hydrogeology (Marcon, Del Vecchio, and Hoagland)**
- **Water budgets and downstream chemistry trends in the Shaver's Creek Watershed (Hoagland, Xiao, Wayman, and Kim)**
- **Comparing the critical zone at Garner Run and Shale Hills (Szink, Marcon, Tang, Del Vecchio, Kim, and Kaye)**

- **Water transport in the <u>S</u>oil <u>P</u>lant <u>A</u>tmosphere <u>C</u>ontinuum (SPAC) (Szink, Miller, He, Davis, and Eissenstat)**

9:35am – 9:50am – Team H1 – **Boulder fields and a long-lived critical zone** (Denn & Bierman - Will be Zoom presentation)

9:50am – 9:55am – Discussion of H1

9:55am – 10:10am – Team H1 – **A record of coupled hillslope and channel response to Pleistocene periglacial erosion in a sandstone headwater valley, central Pennsylvania** (Del Vecchio et al.)

10:10am – 10:15am – Discussion of H1

10:15am – 10:30am – Team H2 – **Comparing the soil gas chemistry of shale and sandstone in the Susquehanna Shale Hills Critical Zone Observatory** (Kim et al.)

10:30am – 10:35 am – Discussion of H2

10:35am – 10:50am – Team H3 – **Root Ecology at the Susquehanna Shale Hills Critical Zone Observatory** (Szink et al.)

10:50am – 10:55am – Discussion of H3

10:55am – 11:10am – Team H4 – **Comparing preferential flow and soil moisture dynamics in two catchments of contrasting lithology** (Tang et al.)

11:10am – 11:15am – Discussion of H4

11:20am – 12:00pm – ***Posters, Break, and Field Trip Preparations***

12:00pm – 3:00pm – Field Trip with Emily Elliott to Cole Farm, meet in EES Building parking lot – sandwiches and water will be provided for RSVP participants. Not all team members are required to participate; however, one from each Hypothesis team is required.

4:00pm – 5:00pm – Featured Seminar by Emily Elliott, Associate Professor at University of Pittsburgh, will present "Exploring <u>AIR-WATER-ECOSYSTEM</u> interactions of reactive nitrogen using stable isotope geochemistry" in ***114 EES Building***

6:30pm – Dinner – Elliott, J. Kaye, J. Weitzman, and others

Friday, May 12th **ALL HANDS MEETING - 117 EES Building**

8:00am – 9:00am – ***Opening Poster Session***

9:05am – 9:20am – Team H5 – **Understanding hydrologic control on regolith formation at the hillslope scale** (Xiao et al.)

9:20am – 9:25am – Discussion H5

9:25am – 9:40am – Team H6 – **Modeling water and solute transport in a watershed with diverse landuses and lithologies** (Wayman)

9:40am – 9:45am – Discussion H6

9:45am – 10:00am – Team H7 – **Understanding C distribution in complex terrain with observations and model** (He et al.)

10:00am – 10:05am – Discussion of H7

10:05am – 10:20am – Team H8 – **What should we measure? – Testing parameter transferability from Shale Hills to Garner Run** (Xiao et al.)

10:20am –10:25am – Discussion of H8

10:25am – 10:40am – Team H9 – **Iron cycling within Garner Run** (Marcon et al.)

10:40am – 10:45am – Discussion of H9

10:45am – 11:30 am – ***Break and Posters***

11:30am – 12:30pm – Brainstorming for Renewal

12:30 – 1:00pm – Feedback from Emily Elliott – Observations of the SSHCZO

1:00pm – 2:00pm ***Lunch and Discussions and Posters – 2217 EES Building***

2:00pm – 2:20pm – Collaborations and Outreach Opportunities (Potter, McClain, & Wentzel with SCEC)

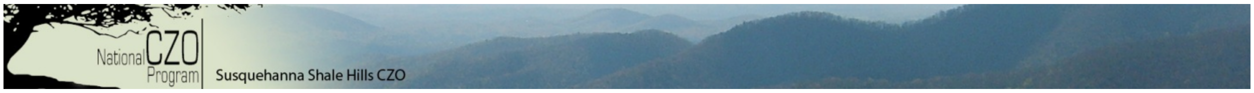
2:20pm – 2:30pm – Discussion of collaborations – Next steps

2:30pm – 3:30pm – ***Break and Posters***

3:30pm – 5:00pm – Renewal Discussions – CZO Science Opportunity (pop-ups welcome?)

Facilitator – Ken Davis; Notes – Sue Brantley

6:00pm – Happy Valley Brewing Company – for Social and Happys



The 9 original hypotheses

H1 - ***Feedbacks among frost shattering, weathering reactions, and the evolution of topography have resulted in an asymmetric distribution of fractures that in turn controls the observed differences in fluid flow in the subsurface between the sun-facing and shaded sides of catchments within Shale Hills and much of the Susquehanna River Basin.*** *(DiBiase, Kirby, Bierman, Singha, Brantley, Lin)*

H2 – ***The distribution of weathering reactions across a landscape can be described as a function of biotic and abiotic production and consumption of acids (CO_2, DOC) and O_2.*** *(Kaye, Brantley, Eissenstat, Li)*

H3 – ***Trees with deeper roots (oaks) are associated with less frequent tree throw, slower hillslope erosion rates, fewer vertical macropores, faster weathering at depth, and deeper regolith than trees with shallower roots (maples).*** *(Eissenstat, Davis, Kaye, Brantley)*

H4 – ***Macropores are important in controlling fluid flow and chemistry in soils derived from various lithologies, but the nature and effects of these macropores differ significantly among shale, calcareous shale, and sandstone.*** *(Lin, Duffy, Eissenstat, Davis)*

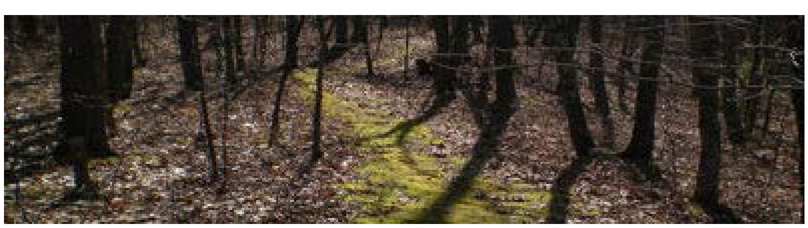
H5 – ***Greater evapotranspiration on the sunny, north side of Shale Hills means that less water recharges to the stream, explaining why Mg and other cations are less depleted in the regolith on the north compared to the south hillslopes.*** *(Li, Brantley, Kaye, Shi)*

H6 - ***Ions that are released quickly from ion exchange sites (Mg, Na, K) throughout the catchment demonstrate chemostatic behavior (~constant concentration in the stream), whereas Fe, Mn, and DOC concentrations vary with changes in watershed-stream connectivity.*** *(Russo, Brantley, Li, Kaye, Shi)*

H7 - ***Land-atmosphere fluxes of carbon (C)and water, ground-water hydrology, and ecosystem change are coupled processes at time scales of months to decades. This coupling varies with the lithology and land use and position on the hillslope****. (Davis, Shi, Eissenstat, Duffy, Lin, Kaye)*

H8 - ***Co-located, intensive, relocatable measurements of soil moisture, tree sap flux, sapwood area, LAI, ground water depth, temperature, ^{18}O and D/H along with a 4-component radiometer, laser precipitation monitor and landscape-level soil moisture (COSMOS) can be assimilated within a multi-scale distributed modeling framework to project physical processes from Shale Hills to Shavers Creek to YWC and Snake Creek watersheds.*** *(Shi, Duffy, Davis, Eissenstat, Lin)*

H9 - ***Increasing atmospheric CO_2 in the future will cause higher temperatures and faster weathering of clays in the catchment, increasing streamwater solute loads.*** *(Brantley, Godderis, Li, Duffy, Davis)*



The Susquehanna Shale Hills Critical Zone Observatory

hosts Dr. Emily Elliott, Associate Professor of Geology & Planetary Science, University of Pittsburgh for the 2017 All Hands Meeting

Dr. Elliott will present **"Exploring** AIR-WATER-ECOSYSTEM **interactions of reactive nitrogen using stable isotope geochemistry**" in 114 EES Building @ 4:00pm on Thursday, May 11th

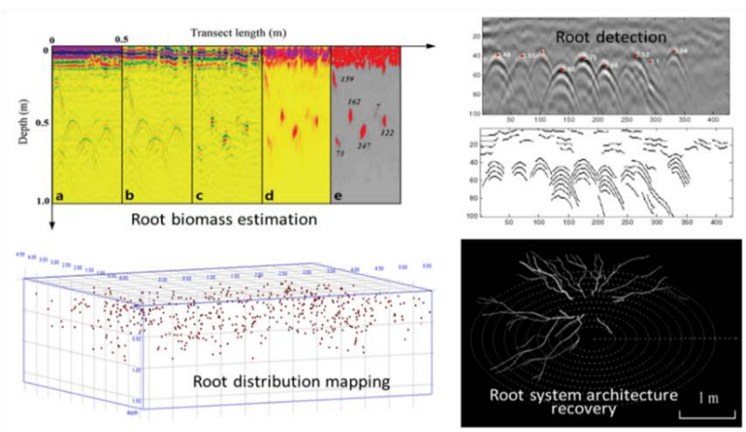
Abstract:

Nitrogen (N) distributions in the Earth's atmospheric, terrestrial and aquatic systems are tightly coupled with human activities. Although N is an essential building block of life, in excess nitrogen is a major factor in the degradation of air and water quality with important implications for ecosystem and human health. This presentation will demonstrate the utility of using stable isotope N biogeochemistry to address key challenges at the heart of the water-ecosystem-society nexus. I will describe several examples of our work that examine the coupled relationships between human activities on N distributions and dynamics in urban, forested, and agricultural systems. Together, this body of work ultimately aims to determine how best to manage inputs of N to protect ecosystem and human health, water and air quality.

Geophysical Techniques for Revealing Subsurface Structure and Processes in the Critical Zone

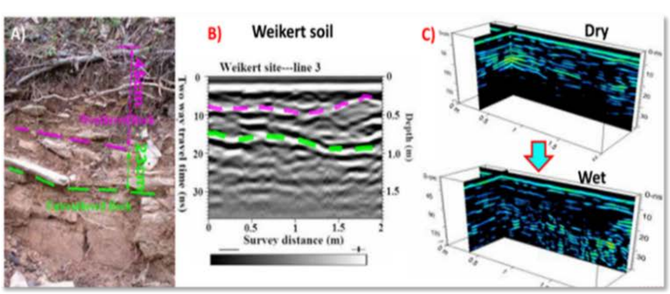
Li Guo[1], Henry Lin[1], Jonathan E. Nyquist[2]
[1]The Pennsylvania State University, University Park, Pennsylvania, USA
[2]Temple University, Philadelphia, Pennsylvania, USA

Abstract: Insights into subsurface structure and processes, including soil depth, soil layering, soil-bedrock interface, root system, subsurface flow pathways, and dynamic changes in water, salts, and other elements belowground can significantly enhance the understanding of Critical Zone functions and services. Traditional sampling and observation methods have encountered challenges for gaining such insights as many of them are costly, time consuming, and even infeasible especially when spatial scale involved is large or when temporal dimension involved requires repeated measurements. Geophysical methods provide an alternative or complement to traditional techniques to characterize spatial heterogeneity and temporal dynamics in the subsurface. Using ground-penetrating radar, we have been able to successfully delineate soil-bedrock interface and soil layering patterns, estimate coarse root biomass, reconstruct root system architecture, monitor soil water dynamics, and detect subsurface preferential flow networks. In addition, we have applied time-lapse electromagnetic induction surveys to reveal the drying and wetting cycles at the catchment scale and identify potential pathways of subsurface flow. We have also used electrical resistivity tomography to monitor fast infiltration process after introducing water into soils. Recent advances in thermal imaging create opportunities to map the network of surface runoff and subsurface lateral flow. Our results highlight the promising potential of geophysical techniques as a minimally invasive, repeatable, and scalable approach to explore subsurface structure and processes in the Critical Zone across multiple spatial-temporal scales.

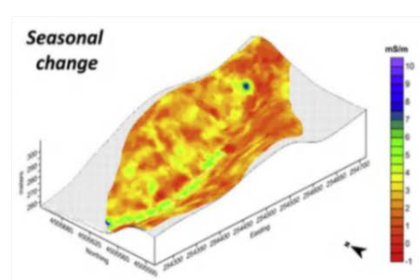


GPR-based root detection and quantification

Thermal imaging of subsurface flow



GPR-based soil architecture detection and soil water monitoring



EMI-based soil wetness monitoring

Integrating geomorphological and time-lapse geophysical techniques to characterize hydrogeologic properties within shale and sandstone catchments at the Susquehanna Shale Hills Critical Zone Observatory, Pennsylvania, USA

Gregory J. Mount[1], Roman DiBiase[2], Xavier Comas[3], Joanmarie Del Vecchio[2]
Li Guo[4], Jorden Hayes[5], Brandon Forsythe[6], Susan Brantley[7]
[1]Department of Geosciences, Indiana University of Pennsylvania, Indiana, PA 15705
[2]Department of Geosciences, Penn State University, University Park, PA 16802
[3]Department of Geosciences, Florida Atlantic University, Boca Raton, FL 33431
[4]Department of Ecosystem Science and Management, Penn State University, University Park, PA 16802
[5]Department of Earth Sciences, Dickinson College, Carlisle, PA 17103
[6]Susquehanna Shale Hills Critical Zone Observatory, Penn State University, University Park, PA 16802
[7]Earth and Environmental Systems Institute, Penn State University, University Park, PA 16802

Heterogeneities in the structure and composition of the surface and near subsurface create difficulties in the modeling of seasonally varying hydrologic processes occurring throughout the critical zone. At the catchment scale, characterization of the architecture and material properties of the critical zone through direct measures over varying timescales presents significant challenges, often relying on sparse observations to understand geomorphologically complex areas. Here we use a diverse suite of geophysical tools to characterize the critical zone architecture and gain understanding of the link between geomorphological and hydrological processes at two first order catchments with distinct lithologies; Garner Run underlain by sandstone and Shale Hills underlain with shale, within the Susquehanna Shale Hills Critical Zone Observatory. High resolution airborne LiDAR topography coupled with physical mapping of surficial geomorphology was used to identify patterns of relict periglacial deposits, landforms and surficial conditions at large spatial scales. In addition, near-surface electromagnetic techniques were used both as: 1) discrete surveys to image and characterize the subsurface composition and structure at sub-meter resolution; and 2) time-lapse surveys to investigate changes in the hydrologic regime within the catchment, through areas of enhanced recharge and shallow transmission. Our results show an agreement between inferred surficial and subsurface processes, and highlight structural and aspect-dependent controls on weathering zone thickness and associated hydrologic processes. The multidisciplinary approach presented here therefore shows potential for quickly and efficiently developing critical zone structure models that reveal the linkage between potential surface and subsurface hydrogeologic and geomorphologic controls on landscape evolution.

Concentration-Discharge Relations and End-Members Analysis in a Model Catchment for Shale Hills

Sruthi Kakuturu[1], Zhang Cai[1], Li, Li[2]

1: Environmental Systems Engineering, Pennsylvania State University; 2: Department of Civil and Environmental Engineering, Pennsylvania State University

The goal of this research is to characterize concentration (C) – discharge (Q) relations for the species F^-, Br^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, Mg^{2+}, Ca^{2+}, K^+, pH and Dissolved Organic Carbon (DOC) in a model catchment of Shale Hills. Understanding CQ relationships are important for estimating solute and contaminant loads to rivers and streams and ultimately to the ocean. This work also enables understanding of two overarching concepts: Flow Paths and End Members of chemicals. This experiment was performed in a physical model catchment (approximately 40 x 80 cm in area) resembling the real watershed Susquehanna Shale Hills Critical Zone Observatory (SSHCZO, 0.08 km^2). The model catchment was 3D printed using the elevation and topographical data of SSHCZO. Soils from SSHCZO was packed to a depth of 2-3 cm. Sprinkling experiments were conducted to simulate large rainfall events (image shown below). The discharge from the model catchment was collected and analyzed to quantify water quantity and chemical composition. The advantage of the model approach is that although soils are from a real watershed, the processes are not affected by ecological and microbiological processes at the watershed. The stream discharge primarily comes from two end members: rain fall with new water composition C_{new} and soil water C_{old}. Three patterns of end member contribution were characterized. F^- fell into Type A species, where rainfall is the dominant end-member and soil buffers the discharge load by retaining these species. Br^- and NO_3^- fell into Type B species, where discharge load is similar to input load, therefore soil is neither dissolving nor retaining these species. Cl^-, Ca^{2+}, K^+, Na^+, Mg^{2+} and SO_4^{2-} all fell into Type C species, where soil was the significant end member, and the soil gradually leached out these stored species during rainfall events with concentrations much larger than the rainfall input. Hysteresis patterns roughly show that F^- mimicked chemodynamic behavior. Br^-, Cl^-, Ca^{2+}, K^+ show dilution behavior. Na^+, Mg^{2+} and pH show chemostatic behavior. And NO_3^-, SO_4^{2-} and DOC show crisscross CQ patterns that are in essence, chemostatic. These patterns together suggest that C_{old} is larger than C_{new} for the most part, meaning the discharge load synchronizes itself with soil water composition. Time along each Run has the influence of connecting pores so that old water contribution can increase over the course of a precipitation event. Insights gained here will facilitate grouping of different behaviors of chemicals from different sources and predict solute loads and water quality in aquatic systems.

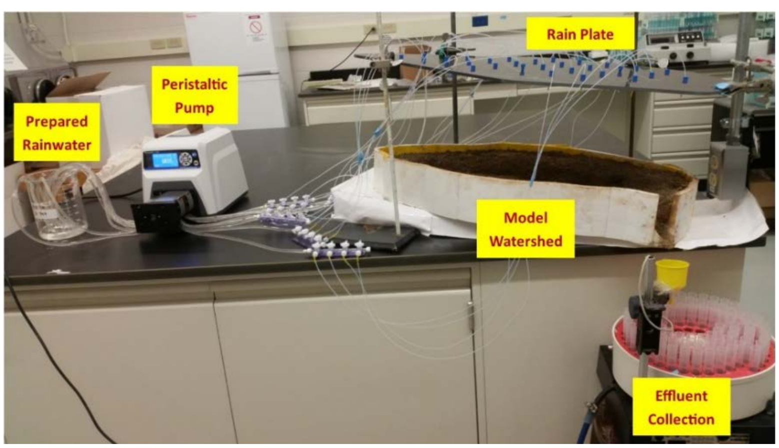


Figure 1. Model Catchment of Shale Hills.

Using leaf-on and leaf-off airborne LiDAR to understand spatial patterns of tree and shrub biomass in a deciduous forest

Kristen M. Brubaker[1,], Quincey K. Johnson[1] and Margot W. Kaye[2]

[1] Hobart and William Smith Colleges;
[2] Pennsylvania State University; mwk12@psu.edu

Abstract: Understanding patterns of aboveground carbon storage across forest types is increasingly important as managers adapt to the threats of global change. Although airborne LiDAR has been used extensively to model aboveground biomass, it has not been used to understand the difference between tree and shrub biomass in closed canopy forests. We compared the fine-scale aboveground biomass in two watersheds; one watershed was underlain by sandstone bedrock and the other by shale. We measured tree and shrubs across three topographic positions for both watersheds, and calculated biomass in each. Using random forest, we modeled shrub and tree biomass across both watersheds, using a combination of leaf-on and leaf-off LiDAR point cloud metrics and topographic metrics. We found that there is an inverse relationship between tree biomass and shrub biomass across sites, and that LiDAR can be used to model these relationships across a broader, watershed scale. We also found differences in the ratio of biomass in trees versus shrubs between watersheds.

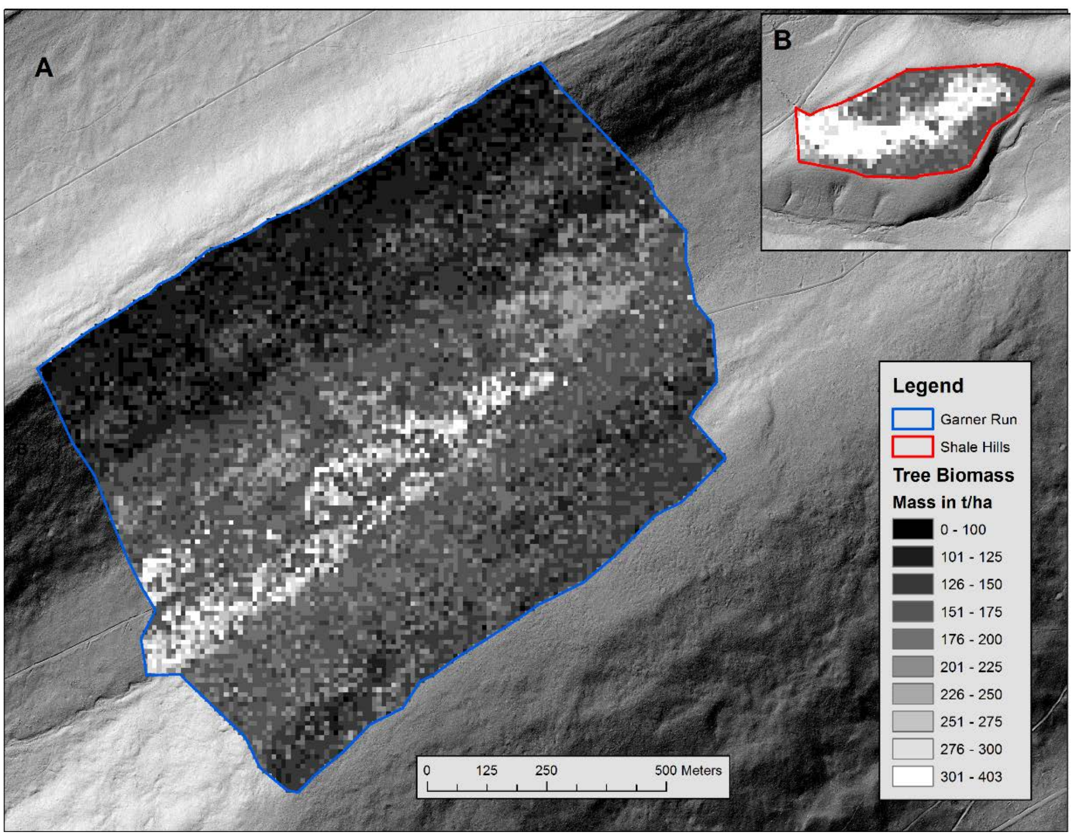


Figure 1. Modeled values of tree biomass in tons/ha for both Garner Run (A) and Shale Hills (B) watersheds.

Shallow critical zone architecture of a headwater sandstone catchment quantified using near-surface geophysics

Roman A. DiBiase[1, 2], Joanmarie Del Vecchio[1], Gregory J. Mount[3], Jorden L. Hayes[4], Xavier Comas[5], Li Guo[6], Henry Lin[6], Fardous Zarif[7], Brandon Forsythe[2], Susan L. Brantley[1,2]

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[7]*Department of Earth and Environmental Sciences, Rutgers University, Newark, New Jersey, USA 07102*

The composition and structure of Earth's surface and shallow subsurface control the flux of water, solutes, and sediment from hillslopes into rivers. Additionally, bedrock weathering profiles and the stratigraphy of soil and colluvium preserve a record of past surface processes. However, landscapes often exhibit heterogeneity in critical zone architecture that is difficult to capture with remote sensing and costly to characterize through direct measurement in soil pits or drill cores. Here we present results from a multifaceted approach to quantifying spatial variability in critical zone architecture using a suite of geophysical surveys. We focus on Garner Run, a first order sandstone catchment in the Susquehanna Shale Hills Critical Zone Observatory situated in the valley and ridge province of central Pennsylvania, 80 km southwest of the last glacial maximum ice limit. Geomorphic mapping of Garner Run indicates pervasive modification by Pleistocene periglacial surface processes, but the extent to which these processes are recorded in weathering profiles and colluvial deposits is unclear. Through the use of shallow geophysical techniques, including cross-valley transects of seismic refraction, multiple frequency ground-penetrating radar (GPR), and electrical resistivity tomography (ERT), we image spatial patterns in subsurface architecture at a range of scales (10-1,000 m horizontal; 1-10 m depth), and high spatial resolution (cm). By using diverse subsurface methods, we highlight structural (dip-slope) and aspect controls on weathering zone thickness, as well as spatial variations in the depth of colluvium that are consistent with surficial observations. Additionally, our results are consistent with and leverage geologic interpretations based on a 10 m drill core across the entire catchment, and serving as a template for studying modern critical zone processes.

Nitrogen Balance of the Shale Hills CZO

Julie N. Weitzman[1,*] and Jason P. Kaye[1]

[1]*The Pennsylvania State University, Department of Ecosystem Science and Management, 116 ASI Building, University Park, PA 16802, USA*

[*]*Current affiliations: CUNY Advanced Research Center, 85 St. Nicholas Terrace, 5th Floor New York, NY 10031, USA & Cary Institute of Ecosystem Studies, Box AB, 2801 Sharon Turnpike, Millbrook, NY 12545, USA*

Capacity N saturation, which results when N retention in the plants and soils of an ecosystem is negligible (i.e. inputs = outputs), tends to occur in response to elevated inputs of atmospheric N. Many measurements taken in forest ecosystems of the northeastern United States have been proposed as indicator symptoms of N saturation. One such way to assess an ecosystem's N saturation status is to determine the balance between its inputs and outputs of inorganic N (i.e. low retention of inorganic N). Thus, we constructed an N budget for the Shale Hills CZO – an acidic, forested, first-order catchment in central Pennsylvania, known to receive elevated N depositional inputs – in order to characterize its N saturation status. Inputs and outputs of N to the watershed were evaluated using soil, soil gas, and soil pore water data collected from this study, as well as utilizing available Shale Hills CZO datasets and other literature-based values. Watershed N accumulation or loss was determined by subtracting N outputs from N inputs, while internal N cycling processes were measured to identify possible N retention pathways in the watershed.

An estimate of the N budget for the Shale Hills CZO revealed that despite a long-term record of elevated atmospheric deposition, inputs of N still exceed outputs by ~4.3 kg N ha^{-1} yr^{-1}. This represents a retention of ~54% of the watershed's N inputs, which suggests the Shale Hills CZO is still far from N-saturated. A high estimate of plant N uptake (18.3 kg N ha^{-1} yr^{-1}) and a thin organic layer (~2-3cm) suggests that most N is being retained via net uptake into forest biomass, as opposed to accumulating in the soil. Therefore, the soil is likely either being "mined" for N to meet N plant needs, or there is an unmeasured N input that further contributes to N needs. Overall, the N budget at the Shale Hills CZO indicates that demand for available N is high within the watershed, which implies continued competition for N among plants, microbes, and physical stabilization processes within the soils.

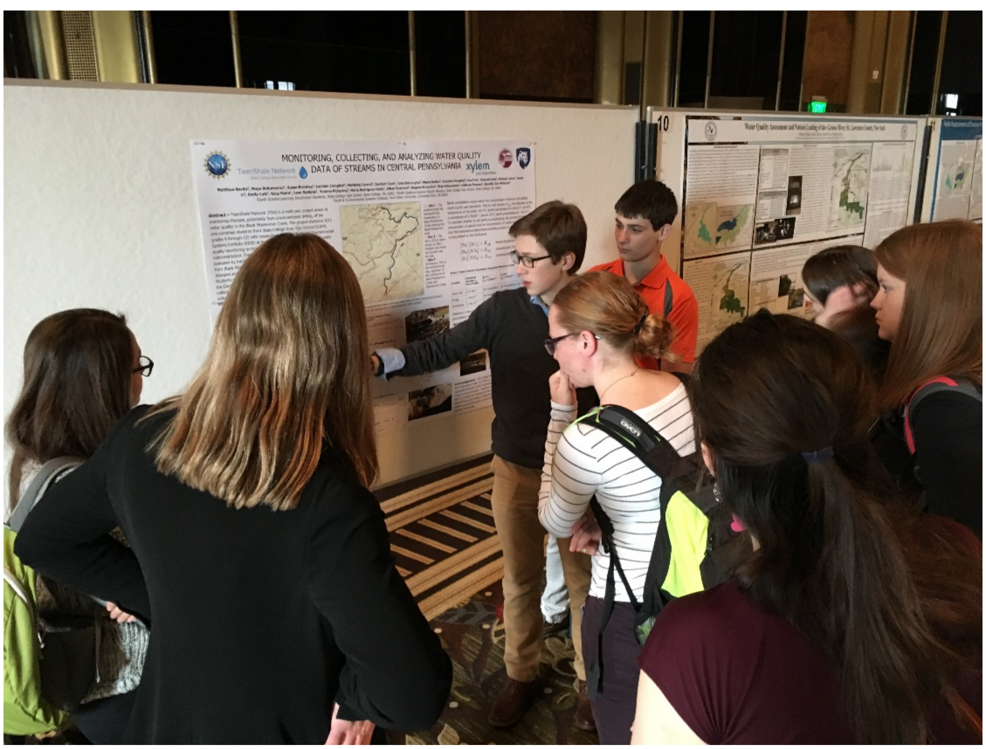
MONITORING, COLLECTING, AND ANALYZING WATER QUALITY DATA OF STREAMS IN CENTRAL PENNSYLVANIA

Matthew Bardo[2], Maya Bokunewicz[1], Susan Brantley[3], Lachlan Campbell[1], Matthew Carroll[3], Zachiah Cook[1], John Donoughe[2], Maria Duiker[1], Brandon Forsythe[3], Ava Fritz[1], Hannah Good[1], Kristen Lenze[1], Aaron Li[1], Emily Lieb[1], Kacy Mann[1], Lena Nyblade[1], Yvonne Pickering[2], Maria Rodriguez Hertz[1], Ethan Rowland[1], Eugene Ruocchio[2], Bryn Schoonover[1], Kathryn Thomas[1], Jennifer Zan Williams[3]

[1]Earth Science Learning Enrichment Students, State College High School, State College, PA 16801;
[2]Earth Systems Science Faculty Mentors, State College High School, State College, PA 16801;
[3]Earth & Environmental Systems Institute, Penn State University, University Park, PA 16802

Abstract – TeenShale Network (TSN) is a multi-year project aimed at monitoring changes, potentially from unconventional drilling, of the water quality in the Black Moshannon Creek. The project started in 2013 and combines students from State College Area High School (SCAHS, grades 9 through 12) with researchers from the Earth and Environmental Systems Institute (EESI) at Penn State University. Students learn water quality monitoring techniques through use of a variety of instrumentation. These measurements are collected on full day field trips overseen by members of EESI and SCAHS faculty. The water samples from Black Moshannon are processed by the LIME (Laboratory for Isotopes and Metals in the Environment) facilities at Penn State. Students examine changes in water quality and compare it to data from the Centre County Pennsylvania Senior Environmental Corps (CCPaSEC) collected at Beech Creek. TeenShale Network will continue to monitor, collect, and analyze water quality data of streams in Central Pennsylvania for the foreseeable future.

Poster presentation by high school student research group – TeenShale



Instrumentation at SSHCZO Poster

Brandon Forsythe

Earth & Environmental Systems Institute, Penn State University

Instrumentation for SSHCZO is continuing to move forward. New sensor system structure was developed in Shale Hills to stream more data directly to the CZO database. Sap-flow, dendrometer bands, leaf litter traps, and leaf area index measurements were completed at Shale Hills and Garner Run Sandstone sites. An agricultural site, Cole Farm, is starting to be developed and instrumented. Flux tower instruments will be installed between two fields. Four pits will be dug and instrumented with soil moisture sensors, soil gas tubes, and TDR Waveguides with lysimeters near during the Spring 2017. Shavers Creek that passes through the farm was instrumented in Fall 2016 for stream depth, water temperature, and electrical conductivity. Cole Farm also contains a spring, three wells, and a pond that will be sampled. These sensors and our future data collection regime will be presented.

Catchment-scale Lateral Flow Analysis and Hydropedologic Functional Units

Melissa Miller[1], Henry Lin[1], Elizabeth Boyer[1], Tess Russo[2]

[1]Department of Ecosystem Science and Management
[2]Department of Geosciences
The Pennsylvania State University, University Park, PA

Poster Abstract:

In humid forests, shallow subsurface flow through soils contributes significant amounts of water to streams. Often that water movement occurs as lateral flow, whereby water moves through the subsurface along various layer boundaries, such as soil horizon boundaries and the soil-bedrock interface, and/or macropores of various kinds. While this process is well understood conceptually, it is insufficiently quantified using actual field monitoring data and have not been linked to soil-landscape units. We propose a method to employ data collected from a catchment-scale soil moisture sensor network at the Susquehanna Shale Hills Critical Zone Observatory to describe lateral flow paths and to develop Hydropedologic Functional Units (HFUs) based on the frequency and timing of lateral flow resulting from satiated conditions. Further, modeling of HFUs using widely accessible and inexpensive data, including topographic indices and soil properties, in a tiered approach can lead to a better understanding of the controls on water flow and create potential for modeling less densely monitored catchments. The tiered modeling approach will allow us to determine how much and what form of data is needed to achieve accurate predictions. Improved and parsimonious characterization of water flow through complex soils will advance watershed and flood prediction models, many of which currently rely on the assumption of soil homogeneity.

Forest dynamics and the carbon budget in the Shale Hills watershed

Warren Reed[1], and Yuting He[2]

[1]*Department of Ecosystem Science and Management and the Intercollege Graduate Degree Program in Ecology, The Pennsylvania State University, University Park, PA, 16802*
[2]*Department of Meteorology and Atmospheric Science, The Pennsylvania State University, University Park, PA, 16802*

Tracking forest dynamics and quantifying the forest carbon (C) budget is crucial to account for the strength of a forest's potential to act as source/sink of atmospheric CO_2 and understand a major portion of the terrestrial C cycle. The ecosystem within the Shale Hills CZO is characterized by a +110 year old oak-mixed hardwood forest where trees are monitored and mapped at high resolution. Up until this point the forest growing within the CZO watershed has been sampled three times between 2008 to 2016. Forest carbon dynamics in ecosystems generally operate at much greater temporal scales when compared to many of the other ecosystem components measured on a higher frequency (e.g. soil respiration measurement on an hourly basis). Therefore, tree inventory data surveyed every four years provides unique and valuable information on forest dynamics which is often impossible to get directly from higher frequency measurements (due to data loss, etc.).

Despite the relative stability of the forest, dynamic processes do occur such as tree mortality and changes in the rate or location of net primary productivity (NPP). We mapped the existing data collected that has measured these dynamics to visually represent forest change in the Shale Hills CZO. Additionally, we generated maps of topography such as elevation, soil depth, and slope, as well as model (Flux-PHIM-BGC) simulated solar radiation, soil temperature and soil moisture to visually explore factors that could contribute to the patterns of live carbon and tree mortality within the watershed. Higher forest productivity seems to be correlated with wetter soils and higher solar radiation (valley floor and swales); while tree mortality seems to spread randomly across the watershed. Oak and pine species at this point have experienced most of the mortality (69% of dead trees), but overall stand composition is unlikely to shift as a result due to the dominance of oaks and relative rarity of pines.

To better understand the carbon storages and flows in the forested watershed, we created a diagrammatic carbon budget based on various works conducted at Shale Hills. Net ecosystem productivity (NEP) seems to be high for a mature forest based on this C budget estimation (~450 gC/m2/yr), probably due to large uncertainties in estimating soil heterotrophic respiration. Soil respiration data collected from soil chambers can be helpful to reduce the uncertainties and thus improve the C budget estimation. Tower-based estimation of NEP also has large uncertainties due to topography and stable atmospheric conditions at night times and winter times. This poster brought together different carbon components of the ecosystem and highlighted the need to better quantify C flux data especially in complex terrain.

Reading the Regolith at Garner Run: Geomorphic history, chemical weathering and hydrogeology

Virginia Marcon, Joanmarie Del Vecchio and Beth Hoagland

The Garner Run subcatchment at the SSHCZO bears a critical zone that exhibits heterogeneity in both space and time. In this presentation, we synthesize water, rock, and soil chemistry in the context of chemical weathering processes. We combine surface and subsurface mapping with hydrologic data to interpret modern hillslope hydrology and solute transport. We also contextualize rock and soil properties within a framework of site-specific geomorphic and climatic history.

The structure of the Garner Run catchment is governed by the structural folding of the underlying sandstone bedrock geology. Further, the physical and chemical properties of the regolith at Garner Run are products of both temperate and periglacial climate processes. We quantify the impacts of past climate fluctuations on bedrock erosion, sediment transport and regolith weathering. We also explore how past processes shape the present water flowpaths and the transport of solutes from the hillslopes to the stream. We compare these two datasets in order to understand the timescales over which critical zone architecture integrates these processes. Evidence of periglacial-driven mass wasting of soil and rock is corroborated by differences in the chemical weathering profiles on the ridgetop and in the valley floor. Further, we find that solute storage in the valley is modulated by groundwater flow and an active hyporheic zone within the periglacial valley fill, as well as the presence of clay minerals. The clay in the Garner Run hillslope soils and sediments could have been derived from dust inputs as observed in other montane catchments, from retention of residual material from the previously overlying shale formations that weathered away, or from clay-rich interbeds in the Tuscarora Formation. We conclude by highlighting unanswered questions and future directions of study at Garner Run, including geochemical interpretations of cored material.

Water budgets and downstream chemistry trends in the Shaver's Creek Watershed

Beth Hoagland, Dacheng Xiao, Callum Wayman, and Hyojin Kim

The migration of water throughout a catchment is a fundamental control on the concentration, form, and location of solutes and nutrients that are essential to life in the critical zone. In this study, we plotted out the water balance for three watersheds – Shale Hills, Garner Run, and Shaver's Creek – in the Shale Hills Critical Zone Observatory (SSHCZO). The water balance curves showed that the water surplus and the ground store depletion varied seasonally. In addition, we calculated the water budget for Shale Hills and Garner Run constrained by raw and quality controlled datasets from the SSHCZO website and model reanalysis data, including precipitation, discharge, soil moisture, groundwater levels, and evapotranspiration. Whereafter, the soil moisture measured by the Ground HOG and the COSMOS at Shale Hills and Garner Run were compared to evaluate the behavior of the COSMOS and to reflect the heterogeneous effects on soil moisture. The COSMOS measurements in general follow the trend of Ground HOG measurements, which means the COSMOS reasonably responds to hydrologic processes. Further, we evaluated how stream chemistry responds to changes in streamflow using concentration-discharge (CQ) relationships, where stream solute concentrations can remain constant with changes in discharge ("chemostatic"), increase with increasing discharge ("flushing"), or decrease with increasing discharge ("dilution"). We found CQ relationships differed depending on catchment characteristics. For example, the CQ relationship for calcium exhibits flushing-driven behavior at Garner Run, dilution-driven behavior at Shale Hills, and chemostatic behavior at the outlet of Shaver's Creek. We conclude that the water budget and water chemistry in each catchment is influenced by differences in stream order, drainage area, bedrock lithology, and land cover.

Comparing the critical zone at Garner Run and Shale Hills

Ismaiel Szink[1,2,] Virginia Marcon[3], Qicheng Tang[1], Joanmarie Del Vecchio[3], Hyojin Kim[3], Jason Kaye[1,2]

[1]Department of Ecosystem Science and Management, Penn State; [2]IGDP in Ecology, Penn State; [3]Department of Geoscience, Penn State

The Susquehanna/Shale Hills Critical Zone Observatory (SSHCZO) is located in the Valley and Ridge physiographic province of the Appalachian Mountains in central Pennsylvania. SSHCZO research focuses on two monolithic zero-order catchments, Shall Hills and Garner Run. The goal if this project to evaluate the difference between the two catchments based on slope, aspect, and lithology. Shale Hills is almost completely underlain by the Rose Hill Shale, an olive-pink to grayish-buff clay shale with interbedded layers of siltstone and hematite-rich sandstone. Garner Run is underlain by the Tuscarora Sandstone a silica-cemented, quartz arenite with minor interbedded shales and siltstone. The Garner Run catchment has characteristically steeper slopes compared to Shale Hills as result of lithology variations, which in turn influences water flow and residence time.

Soil gas, soil moisture, and soil chemistry were collected from each site along the ridge top, midslope, and valley floor positions on the south planar slopes, and midslope position for the north planar slopes. Additionally, root distribution and leaf litter were collected at similar positions in each watershed.

Variations in soil CO_2 and O_2 concentrations can provide insight on processes that occur in the shallow subsurface. When O_2 is compared to CO_2 concentrations, we expect the values to plot along a -1.39 slope when the main processes occurring in soil are diffusion and respiration. When the values deviate from this line, other process such as redox reactions or partitioning of CO_2 into aqueous and gaseous phases are occurring. At Garner Run, these values often fall above the -1.39 slope, indicative of drier soils. This is corroborated with soil moisture data. At Shale Hills, these values often fall below the -1.39 slope, which is indicative of interactions of O_2 with redox sensitive elements such as iron.

Soil moisture content in the valley floor is higher than the upslope measurements at Shale Hills. However, soils moisture values are similar across all sites at Garner Run. We hypothesize these differences can be explained by differences in lithology between the two sites: Shale Hills has higher clay content and therefore, the soils can hold more moisture. We can also see these differences in soil moisture content by evaluating changes in the biological world. For example, the primary zone of root activity is deeper at Garner Run as compared to Shale Hills. We also found that leaf senescence occurs earlier in the season at Garner Run as compared to Shale Hills and earlier along the north planar slopes as compared to the south planar slopes at each site. Additionally, soil moisture content is the highest in winter when primary production is essentially zero.

Water transport in the Soil Plant Atmosphere Continuum (SPAC)

Ismaiel Szink[1, 3], Melissa Miller[1], Yuting He[2], Kenneth Davis[2], David Eissenstat[1, 3]

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Abstract:

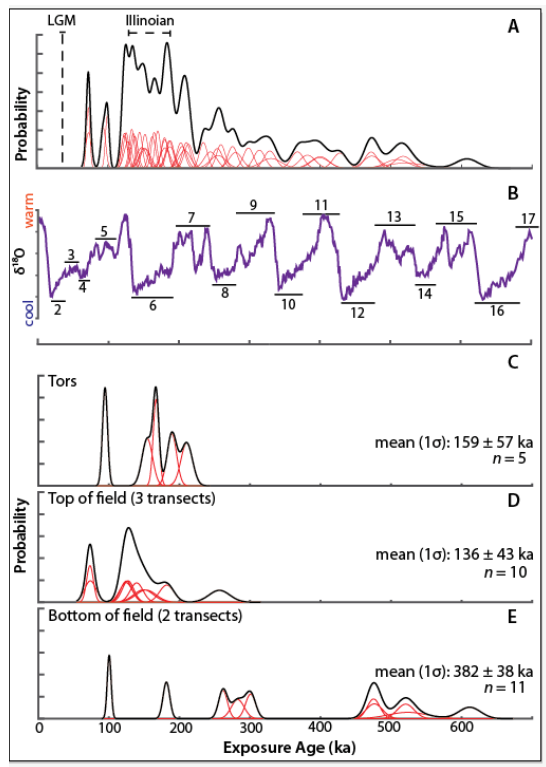
Water is one of the key components that connect soil, plants, and the atmosphere, therefore characterizing the water transport along this continuum (SPAC) is key to understanding the interactions between biotic and abiotic ecosystem components. By analyzing different water components of the SPAC: precipitation, soil moisture, sap flux, and evapotranspiration (ET) using data collected at the Shale Hills Critical Zone Observatory, temporal patterns in water movement throughout the critical zone can be explored. These patterns describe the dynamic nature of the interactions among biotic and abiotic components of the ecosystem, while providing important insights into the drivers of various critical zone processes and fluxes. Both sap flow activity measured from individual trees and ET measured from above the whole forest canopy slow down when soil becomes drier over the course of the growing season, and there are good temporal correlations between these two water fluxes. Temporal patterns reveal that the effects of precipitation on sap flux and ET vary seasonally, suggesting that the dynamics among precipitation, soil moisture, sap flux and ET depend on the annual cycle in leaf growth of the trees. For example, in the early summer when soil water availability is still high, precipitation event has no effect on sap flux or ET; but in the late summer when soils are dry, precipitation will increase sap flux activity and ET. Interdisciplinary work within the context of the soil-plant-atmosphere continuum can provide important insights to describe the complex interactions between biotic and abiotic ecosystem components.

Boulder fields and a long-lived critical zone

Alison Denn and Paul Bierman, Geology Department, University of Vermont

Periglacial boulder fields are found throughout the world; yet, it is not known whether most date to the Last Glacial Maximum (~26 ka), or whether they are older. These low-gradient expanses of fractured rock are thought to form or at least become active during glacial periods, when areas near ice margins are intensely modified by freeze-thaw cycles that move sediment downslope, creating distinctive landforms. As part of our CZO research, we used *in-situ* cosmogenic ^{10}Be and ^{26}Al to estimate age and infer process at one of the largest boulder fields in North America. Hickory Run, in central Pennsylvania, is a 550 m long by 150 m wide nearly flat expanse of clasts and boulders, some of which are more than 10 m long.

We find that ^{10}Be concentrations (n=52) increase downfield and are spatially autocorrelated. Boulder lithology, size, and position do not correlate with ^{10}Be concentration. All boulders have at least 70 ka of exposure; none have recent exposure ages. Most ages fall between 130 and 200 ka and are consistent with initial exposure during marine isotope stage 6. Fourteen boulders have >300 ka of exposure; the longest exposure duration is 600 ka. Measurement of samples from the top and bottom of a boulder and three clasts beneath it demonstrates that rocks in the field move over time and that variations in ^{10}Be concentration are not only the result of in-situ weathering. Measured $^{26}Al/^{10}Be$ ratios (n = 23) suggest that boulders have remained near the surface and have been buried for less time than they were exposed.



Probability density of 10-Be exposure ages from Hickory Run Boulder Field along with marine oxygen isotope curve (stages marked by number).

The isotopic data demonstrate that Hickory Run, and likely many other boulder fields are ancient, multigenerational features that have persisted over many glacial-interglacial cycles. These findings add nuance to the conventional view of periglaciation as a force that 'wiped the slate clean'; rather, in upland areas with resistant lithologies, we show that the landscape was reworked, but not reset by repeated periglaciation. The critical zone in the central Appalachians preserves the "memory" of at least several glacial/interglacial cycles complicating climatic interpretation of landforms but opening up opportunities for deciphering what may be a landscape archive of response to climatic change.

A record of coupled hillslope and channel response to Pleistocene periglacial erosion in a sandstone headwater valley, central Pennsylvania

J. Del Vecchio[1], R. DiBiase[1,2], A. Denn[3], P. Bierman[3]
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South of the Last Glacial Maximum ice extent, the landscape in central Valley and Ridge physiogaphic province of Appalachia preserves soils and thick colluvial deposits that retain information about how the landscape responded to changes in Quaternary climate. The topography shows extensive evidence of relict periglacial landscape modification, suggesting vigorous sediment production and transport in climates colder than modern conditions and highlighting the need to identify the mechanics and rates of climate-modulated erosion. Here, we pair geomorphic mapping with *in situ* cosmogenic ^{10}Be and ^{26}Al measurements to estimate erosion rates and residence time of colluvium in Garner Run, a 1 km^2 sandstone headwater valley containing relict Pleistocene periglacial features including solifluction lobes, block fields and thick valley fill. Distribution of lobes and blockfields implies an aspect dependence of periglacial processes consistent with regional morphologic observations. ^{10}Be concentrations in stream sediment, soils, and amalgamated surface boulders are similar, and indicate slow erosion rates (6 m/My) over the past 50-100 kyr. When paired with estimates of colluvial valley fill volume constrained by coring, topographic analysis, and shallow geophysics, we find that episodic accumulation, occurring in two pulses ~300 kya and <100 kya, is equivalent to the long-term sediment production from bedrock lowering. This implies that erosion rates measured within regional ridgelines and basins reflects the integration of slow temperate climate processes and relatively rapid periglacial processes. Thus, in landscapes with slow erosion rates, the critical zone integrates the physical and chemical effects of Quaternary climate cycles, which is important for interpreting modern hillslope hydrology and pedogenesis. We show that sedimentary records in slowly-eroding headwater valleys present future opportunities to directly examine climate-modulated hillslope processes. This work also highlights a future direction of critical zone science in employing multidisciplinary and multiscale methods to inform models of critical zone architecture.

Comparing the soil gas chemistry of shale and sandstone in the Susquehanna Shale Hills Critical Zone Observatory

Hyojin Kim[1], Lillian Hill[2], Susan Brantley[1], and Jason Kaye[2]

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Carbon dioxide (CO_2) and O_2 are important reactants in weathering reactions. Their concentrations in the critical zone are controlled by both abiotic and biotic processes. Therefore, identifying the underlying controls for the dynamics of the soil gas chemistry may improve our understanding of the roles of living organisms on the evolution of the critical zone. Although paired observations of CO_2 and O_2 provide useful insights into studying the controlling biotic processes for soil gas chemistry, they have rarely been monitored together. In this study, we documented the concentrations of CO_2 (pCO_2) and O_2 (pO_2) gas along with soil moisture in three soil layers at a weekly interval in the Susquehanna-Shale Hills Critical Zone Observatory, PA. We carried out this study in two sites underlain by different lithologies—shale and sandstone—to investigate the roles of the physical and chemical properties of bedrock on controlling the gas chemistry.

In the Shale Hills catchment, which is the shale site, as the growing season started, pCO_2 increased and pO_2 decreased from the ambient levels roughly at a $\Delta pO_2/\Delta CO_2 = -1/1$ ratio. The concentration of CO_2 was highest (up to 2% in the valley floor position) and that of O_2 was lowest (down to 17% in the same position) during the late spring (May-June) and then they evolved closely back to the ambient levels for the rest of the growing season. During this period, the $\Delta pO_2/\Delta CO_2$ ratio was around -1. At the beginning of the rainy autumn (Oct.-Nov.), pO_2 slightly decreased while pCO_2 did not change, which resulted in the $\Delta pO_2/\Delta CO_2$ ratio to be significantly lower than -1. In the Garner Run catchment, which is the sandstone site, similar to Shale Hills, pCO_2 increased and pO_2 decreased as the growing season proceeds. The highest pCO_2 and lowest pO_2 were recorded in May. However, unlike Shale Hills, the soil gas chemistry remained at these levels (pCO_2 = 2% and pO_2 = 18% in the valley floor position) until the late summer (Aug.-Sept.) and then by the end of the growing season the soil gas started evolving back to the ambient level until the winter season. The $\Delta pO_2/\Delta CO_2$ of Garner Run was around -1 year-round.

These observations imply two interesting findings: (1) the lower pCO_2 (and higher pO_2) in Shale Hills during the summer relative to those of Garner Run suggest lower biological activities in Shale Hills; (2) the values of Garner Run's $\Delta pO_2/\Delta CO_2$ are consistent with the dominance of aerobic respiration while seasonally changing $\Delta pO_2/\Delta CO_2$ (-3 to -1) in Shale Hills is consistent with other types of respiration becoming dominant, particularly during the wet season (winter). We hypothesize that either nutrients or water are more limited in Shale Hills than in Garner Run, explaining the lower biological activity in the dry summer.

We are also considering other explanations. For example, the elevations of the Garner Run sites are much higher than those of Shale Hills; therefore, nutrient inputs via wet and dry deposition may be higher in Garner Run. In addition, roots are found at deeper depths in Garner Run compared to those of Shale Hills; therefore, trees may be able to access groundwater more easily. This might explain why trees and microbial communities can remain active in this site during the summer, resulting in high pCO_2 and low pO_2. The clay-rich nature of Shale Hills may develop spatially heterogeneous micro-sites in which processes other than aerobic respiration may become dominant. Garner Run, in contrast, is quartz-rich; therefore, such micro-sites are less likely to be developed and air and gas may be quickly transported. Thus, aerobic respiration may be dominant year-round. Loss of dissolved CO_2 in rain may also explain some discrepancies in the $\Delta pO_2/\Delta CO_2$ ratios.

Root Ecology at the Susquehanna Shale Hills Critical Zone Observatory

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Root positioning in soil is an important factor in understanding erosion rates, organic matter decomposition, weathering, soil respiration, and regolith depth in soils. Researching tree physiological processes can increase the current understanding of ecosystem functions.

(1) Observations at sandstone lithology sites found root distributions of ~25% at depths of 20-40 cm, compared to ~15% in shale. DNA extraction and fragment amplification techniques (Barcoding) have discovered that this may be due to niche partitioning. At Garner Run a greater proportion of the roots from the top 20 cm of soil were found to be from herbaceous species when compared to Shale Hills. This may be the cause of deeper rooting distribution at the 20-40 cm range.

(2) Nitrogen concentration in leaves can vary based on the function and placement of the leaf, as well as nitrogen availability to the whole tree. By determining carbon to nitrogen ratios (C:N) in live leaves we can determine how available nitrogen might be to trees throughout the catchment. Preliminary observations have found an increase in C:N in leaves of trees of the same species across an elevation gradient. However, this trend is not common for all tree species, and further study will determine additional factors contributing to variation in C:N.

(3) Roots are the primary drivers of soil respiration either directly or indirectly through microbial stimulation. Topography may be playing an important role in root production and turnover. However, topography is rarely used in spatial assessments of soil respiration. Through bi-weekly minirhizotron measurements of root growth and death the dynamic variation in root production can be determined across a topographically diverse landscape.

(4) Decomposition of detritus material is largely performed by a varied group of microorganisms collectively called the microbiota. The identity of these microorganisms is largely dependent on local environmental conditions. Living roots can have a dramatic effect on these local environmental conditions and create what is known as the rhizosphere around them. Research is currently being performed to determine the effect of living roots on the decomposition of wood.

Comparing preferential flow and soil moisture dynamics in two catchments of contrasting lithology

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Lithology can strongly influence preferential flow and soil moisture. We compare soil moisture and preferential flow in two small catchments of contrasting lithology: a shale site (Shale Hills) and a sandstone site (Garner Run). Besides the lithological difference, these two sites also differ in hillslope morphology, soil type, and tree species. In this research, we use temporal and spatial variation in soil moisture to characterize the occurrence of preferential flow and soil moisture storage. Soil moisture probes (Stevens HydraProbe) were installed at 10, 20, and 40 cm for each site (called “Ground HOG”). We first analyze the frequency of preferential flow events for 8 Ground HOG sites based on soil moisture response time at the three depths. We then calculate soil water storage for each Ground HOG site, and check the fluctuation levels for different sensors to test the potential role of preferential flow in influencing soil moisture dynamics across different seasons. Lastly we examine soil moisture time series and its ‘*sensitivity*’ and ‘*memory*’ for each Ground HOG site, including how accurately it responds to each precipitation event and how fast it recovers to its original condition after each rainfall event has passed. Our preliminary results show significant difference in soil moisture dynamics between the two contrasting catchments. For example, at the Shale Hills, the North mid-slope site had a preferential flow frequency of more than 30%, while at the Garner Run, the North mid-slope site had less than 10% preferential flow frequency. For soil water storage, the Shale Hills showed an overall higher soil moisture content (around 25%) as compared to the Garner Run (around 18%), which was attributed to different soil types in the two contracting catchments. Moreover, the Shale Hills showed a lower ‘*sensitivity*’ and higher ‘*memory*’ level as compared to the Garner Run, which was attributed to both soil type and root water uptake. Our future work will test different types of models (e.g., multiple-layer model, network-based model, and agent-based model) to better capture complex soil-water-vegetation dynamics and processes in the two contrasting catchments.

Understanding hydrologic control on regolith formation at the hillslope scale

Dacheng Xiao, Li Li, Susan Brantley

Chemical weathering processes transform rock to soil and determine soil texture, bedrock depth, and other hydrological properties. In Shale Hills, field evidences have indicated that the regolith depth, hydrologic processes, and chemical depletion are different at two different aspects (Clarke et al., 2013; Ma et al., 2013; Shi et al., 2014). We hypothesize that the hydrologic processes control regolith formation depth. We test this hypothesis by developing a two-dimensional hillslope model of regolith formation using mineral composition and hydrologic characterizations and observation at Shale Hills. In general, understanding on regolith formation at the hillslope or watershed scales are limited.

A 2D hillslope domain was set to simulate the hydrologic, chemistry and regolith processes considering both north and south aspects. There are two layers in the domain: fractured bedrock layers and bedrock layers. The slope aspects and depth of the fractured layer were set up based on observations. Minerals include quartz, illite, chlorite, calcite, goethite, and pyrite. We implement two different ET/P ratios in the two aspects, which turns out to drive different velocity fields however keep similar regolith layer depth. Start from currently condition for a long term. The aspect with larger flow recharge velocity to the deep ground water and stream enhance chemical weathering and leads to, deeper regolith depth and steeper slope. Future numerical experiments will explore the impacts of the water/gas saturation conditions and climate change pattern on regolith formation at the hillslope scale.

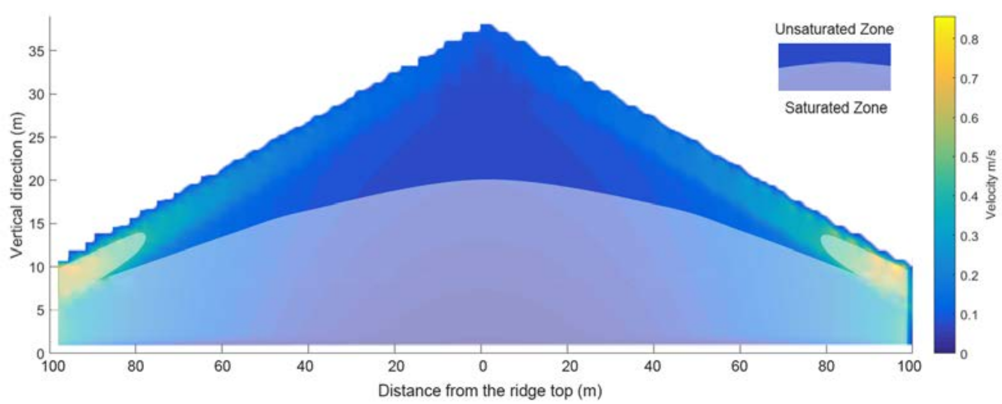

Figure 1. The velocity field and saturation condition of developed regolith formation model under current condition in the basic scenario with symmetric flow condition.

Modeling water and solute transport in a watershed with diverse landuses and lithologies

Callum Wayman
Ph.D. Student, Pre-comps

Advisor: Tess Russo

Tess Russo
Sue Brantley
Li Li
Brandon Forsythe
Beth Hoagland

Developing simulations of water and nutrient transport that accurately reflect field observations is difficult in areas with complex subsurface heterogeneity. However, there is a need for watershed-scale nutrient and water transport models in watersheds containing varied lithology and landuses. RT-Flux-PIHM will be used to simulate water and solute transport within the Shaver's Creek watershed in central PA. RT-Flux-PIHM is a 3D numerical model that integrates a reactive transport (RT) module into a combined land surface and shallow groundwater/surface water model. As part of the Susquehanna Shale Hills Critical Zone Observatory project, we have collected geochemical and hydrological data from several subcatchments and four monitoring sites on the main stem of Shaver's Creek. The modeling platform capabilities will be applied and evaluated first within a small catchment on agriculturally developed land. Following successful simulation, the model will be expanded to encompass the Shaver's Creek watershed (163 km^2), which includes both agricultural and forested land-types, and multiple lithologies. The primary inputs for both models include soil parameters, vegetation parameters, and meteorological forcing time series data. Calibration data will include measured stream discharge and nutrient concentration time series records, and remote sensing data for evapotranspiration (ET) rates across the watershed. Initially, Landsat 7 and 8 thermal imagery will be used to estimate ET, but other products may be used in the future if there is a call for data that Landsat cannot provide. Developing these models is important because they will improve our understanding of the effects of land development and bedrock geology on fluid and solute transport. Agriculturally developed land has distinctly different soil and land cover properties from those found in forested landscapes. This type of model could be applied in other watersheds to understand how changing land use could affect the physical hydrology and well as the geochemistry of those watersheds.

Understanding C distribution in complex terrain with observations and model

Yuting He, Kenneth Davis, Yuning Shi, Dave Eissenstat, Jason Kaye

Terrestrial carbon (C) cycle remains the least constrained component in the global C cycle, partly due to the difficulty in quantifying C distributions in complex terrain. Bringing together the intense observations at Susquehanna Shale Hills Critical Zone Observatory (SSHCZO) and a spatially distributed, coupled water-carbon-nitrogen model Flux-PIHM-BGC, could help us understand the factors and processes that control the terrestrial C cycle in complex terrain. Our preliminary results showed that the model could simulate the average C stocks well in the watershed with only a few parameters calibrated, but tends to underestimate the spatial variabilities compared to observations. The discrepancies between model and observations could be attributed to three main sources: 1) model input data (forcing data, e.g. meteorological data, soil moisture, soil depth, soil texture); 2) model parameters; 3) model structure (e.g. missing or misrepresented model processes). To diminish the differences between modeled and observed C distribution, we are designing a sensitivity study, varying both the model input data and model parameters to learn what observations are most important to improve simulation of the watershed carbon cycle. Some parameters are measurable (e.g. C:N of leaves, litter); while others cannot be easily measured (e.g. allocation parameters), but might be important to certain state variables (e.g. vegetation C pool) and therefore can be inferred from these state variables. Our next step will be to incorporate the observations into the model and to make better simulations/predictions of the watershed C cycle. This study will direct us to the key measurements to observe in order to upscale simulation of the carbon cycle to a larger domain. It may also highlight the importance of some missing model processes if the model is unable to match the range of observed watershed properties.

What should we measure? -- Testing parameter transferability from Shale Hills to Garner Run

Dacheng Xiao, Yuning Shi, Li Li

Field measurements are important to understand fluxes of water, energy, sediments, and solutes in the Critical Zone however are expensive in time, money, and labor. This study aims to assess the transferability of hydrological parameters from an intensively-measured watershed to another with sparse data, therefore providing insights of what needs to be measured. We focused on two monolithological, forested watersheds under similar climate and vegetation conditions in central Pennsylvania: the Shale-based Shale Hills watershed (SSH, 0.08 km^2) and the sandstone-based Garner Run watershed (GR, 1.34 km^2). We compared the hydrological processes in those two watersheds integrating national datasets, field measurements, and a physics-based land surface hydrologic model Flux-PIHM.

We firstly tested the transferability of calibration coefficients of SSH from previous studies to GR without using any *in situ* measurements at GR. We found that although the direct use of SSH calibration coefficients can coarsely reflect the annual change and average level of hydrologic variables, the model cannot sufficiently capture discharges in GR. Only after calibrating soil hydrological parameters with the uncertainty-based Hornberger-Spear-Young algorithm and the Latin Hypercube Sampling method, discharge prediction at GR improves. The parameter values suggest that compared to SSH, GR soil has larger pore diameter, larger water storage (i.e., larger porosity), lower water retention capacity, shallower soil layer depth, and larger preferential flow. The Van Genuchten beta and porosity are the most sensitive among all parameters, which should be measured in the field. A field measured boulder map helps decrease the parameter uncertainty and yield a better spatial distribution of hydrologic variables. In the future, this model-data synthesis framework will be implemented in upscaling to the Shavers Creek watershed with the multi-lithology condition.

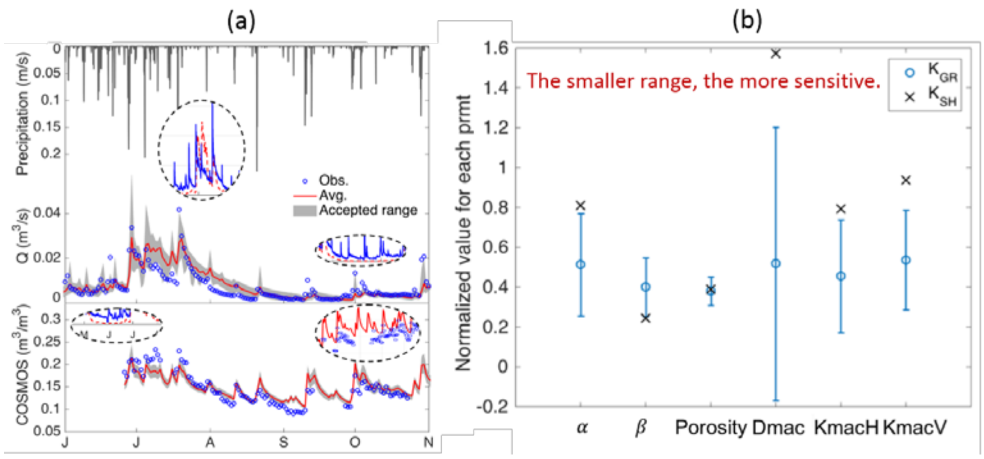

Figure 1 a) Prediction of daily discharge and areal averaged SM in the top 10 cm after uncertainty-based calibration with satisfied evaluation statistics. The curves in dish circle represent the major difference in transferability test. b) Normalized parameter value comparison between transforming from the Shale Hills to the Garner Run. The bar of each parameter represents the range of value in different accepted runs. The van Genuchten β and porosity are most sensitive parameters.

Iron cycling within Garner Run

Virginia Marcon, Beth Hoagland, Xin Gu and Susan Brantley

Small suspended particles (SPMs) and colloids (<1 μm) are transported through the subsurface and are important for the overall evolution of the critical zone. SPMs are small enough to move through pore spaces and have a slow settling rate, which allows this material to remain suspended in solution for long periods of time. These particles contribute to the distribution of solutes and sediment in a watershed and impact the geochemical behavior of elements. They can transport elements through the system at concentrations not available in the dissolved phase and can provide a source of nutrients to a watershed.

In this study, we focus on SPM cycling in a headwater catchment, Garner Run, which overlies quartz arenite bedrock, known as the Tuscarora Formation. The catchment is characterized by periglacial features such as boulder fields, solifluction lobes, and landslides, all of which influence physical and chemical weathering processes, as well as the flow of water through the catchment. Despite the insoluble nature of the bedrock, thick soils (>1 m) enriched in K, Mg, and Fe have developed on the hillslopes and in the valley. Weathering of the stratigraphically younger formations, such as the Castanea member (the upper Tuscarora with interbedded shales) and the Rose Hill Shale Formation, contribute to nutrients (e.g. Ca, Mg, and Fe) to the watershed. Additionally, aeolian deposits could influence soil chemistry, as seen in other catchments.

High concentrations of iron in groundwater, iron precipitates in deep groundwater, and iron-staining on quartz-rich boulders recovered from drill cores (HV-1) indicate potential transport of iron particles through quartz-rich colluvium. Water chemistry in the HV-1 well is stratified with depth. In particular, iron concentrations (measured in samples that pass 0.45μm filter) vary by 100s of μmol/l: values near the surface are 0.1 μmol/l and values 9 m below the surface are 276 ± 44 μmol/l. Further downstream, additional wells (HV-2 and HV-3) were drilled approximately 1.5 m from the stream channel. Core pieces recovered during drilling where completely red and contain high total iron concentrations (< 50 wt% Fe_2O_3). Core pieces closest to the surface (0-0.8 m) are depleted in iron compared to the deeper core pieces. This depletion could be explained by groundwater-surface water interactions within the hyporheic zone along the stream channel. As water interacts with iron-rich boulders in the shallow subsurface, iron is removed from the rock and exported from the catchment via the stream.