Annual Report for Period: 11/2011 - 10/2012
Submitted on: 11/13/2012
Principal Investigator: Duffy, Christopher J.
Award ID: 0725019
Organization: PA St U University Park
Submitted By:
Duffy, Christopher - Principal Investigator
Title:
CZO: Susquehanna/Shale Hills Critical Zone Observatory

Project Participants

Senior Personnel

Name: Duffy, Christopher
Worked for more than 160 Hours: Yes
Contribution to Project:
Stable Isotope and Computational Hydrology

Name: Slingerland, Rudy
Worked for more than 160 Hours: Yes
Contribution to Project:
Geomorphology

Name: Brantley, Susan
Worked for more than 160 Hours: Yes
Contribution to Project:
Geochemistry

Name: Singha, Kamini
Worked for more than 160 Hours: Yes
Contribution to Project:
Hydrogeophysics

Name: Nyquist, Jonathan
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Davis, Kenneth
Worked for more than 160 Hours: Yes
Contribution to Project:
Meteorology

Name: Eissenstat, David
Worked for more than 160 Hours: Yes
Contribution to Project:
Plant Ecology

Name: Kaye, Jason
Worked for more than 160 Hours: No
Contribution to Project:
Soil Science

Name: Kirby, Eric
Worked for more than 160 Hours: Yes
Contribution to Project:
Geomorphology

Name: Lin, Henry
Worked for more than 160 Hours: Yes
Contribution to Project:
Soil Science

Name: Miller, Douglas
Worked for more than 160 Hours: Yes
Contribution to Project:
Informatics

Name: Reed, Patrick
Worked for more than 160 Hours: Yes
Contribution to Project:
Computational Hydrology, Cyberinfrastructure

Name: Salvage, Karen
Worked for more than 160 Hours: Yes
Contribution to Project:
Groundwater Geochemical Modeling

Name: Dressler, Kevin
Worked for more than 160 Hours: Yes
Contribution to Project:
Snow Hydrology, Hydrologic Modeling, Site and Project Management

Name: Fletcher, Raymond
Worked for more than 160 Hours: Yes
Contribution to Project:
Geochemistry

Name: White, Timothy
Worked for more than 160 Hours: Yes
Contribution to Project:
Geology, Liaison to Transect Participants, Project Management

Name: April, Richard
Worked for more than 160 Hours: Yes
Contribution to Project:
Transect Participant

Name: Harbor, David
Worked for more than 160 Hours: Yes
Contribution to Project:
Transect Participant

Name: Mathur, Ryan
Worked for more than 160 Hours: Yes
Contribution to Project:
Transect Participant

Name: Teferi, Tsegaye
Worked for more than 160 Hours: Yes
Contribution to Project:
Transect Participant

Name: Santos, Hernan
Worked for more than 160 Hours: Yes

Contribution to Project:
Transect Participant

Name: Boyer, Elizabeth
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Tuttle, Michelle
Worked for more than 160 Hours: No
Contribution to Project:
USGS Scientist

Name: Lichtner, Peter
Worked for more than 160 Hours: No
Contribution to Project:
Los Alamos National Lab Scientist

Name: Goldhaber, Marty
Worked for more than 160 Hours: No
Contribution to Project:
Geochemistry

Name: Steefel, Carl
Worked for more than 160 Hours: No
Contribution to Project:
USGS scientist

Name: Lehnert, Kirsten
Worked for more than 160 Hours: No
Contribution to Project:
Geochemistry Informatics

Name: Miller, Tom
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Fedo, Chris
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Name: Jin, Lixin
Worked for more than 160 Hours: Yes
Contribution to Project:
Leads geochemistry field experiment

Name: Graham, Chris
Worked for more than 160 Hours: Yes
Contribution to Project:
Leads Hydropedology field experiment

Graduate Student

Undergraduate Student

Technician, Programmer

Other Participant

Name: Cherrey, Kelly
Worked for more than 160 Hours: Yes
Contribution to Project:
In charge of installing sensors and communications

Name: Williams, Jennifer
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Duffy, Colin
Worked for more than 160 Hours: Yes
Contribution to Project:

Research Experience for Undergraduates

Organizational Partners

CZEN: The Critical Zone Environmental Ne

CUAHSI: The CUAHSI Hydrologic Informati

GfG Geoinformatics for Geochemistry pro

Crossbow Technologies Inc.
Crossbow Technologies Inc. (http://www.xbow.com/eKo/) has been instrumental in helping us plan for a new direction at the Shale Hills CZO allows 2-way communication and control for all sensors in a high resolution adaptive sensor array. Seed money has also been made available to test the Crossbow system by the Penn State Institute for CyberScience (ICS) and Penn State Institutes for Energy & the Environment.

Other Collaborators or Contacts

Crossbow Technologies Inc. (http://www.xbow.com/Eko/) has been instrumental in helping us plan for a new direction at the Shale Hills CZO that will ultimately allow 2-way communication and control for all sensors in a high resolution adaptive sensor array. More information on this will be presented next year but seed money has been made available to test the design by the Penn State Institute for CyberScience (ICS) and Penn State Institutes for Energy & the Environment.

Activities and Findings

Research and Education Activities:
see attached file

Findings:
see attached file under activities

Training and Development:

Opportunities for Training, Development, and Mentoring

Graduate Students: CZO-funded or from contributing research* (completion date)

Name: Anderson, Colin, B.S. Candidate Environmental Systems Engineering
Name: Andrews, Danielle, (2011) PhD Soil Science
Name: Baldwin, Doug, (2011) M.S. Soil Science
Name: Bazilevskaya, Katya, Post-Doc, Geosciences
Name: Bhatt, Gopal, (2010) PhD Civil and Environmental Engineering
Name: Bhattacharyya, Amrita, PhD Soil Science
Name: Bingham, Nina, B.S. Candidate, Geosciences
Name: Brubaker, Kristen, (2011) PhD Ecology
Name: Burger, Will, M.S. student Soil Sciences
Name: Carone, Alex, (2012) B.S. Geosciences
Name: Carter, Megan, M.S. Candidate, Geosciences
Name: Chattopadhyay, Pallavi, Post-Doc, Geosciences
Name: Dere, Ashlee, PhD Candidate Geosciences
Name: Fuller, Robert, PhD Geosciences
Name: Gaines, Katie, PhD Candidate Ecology
Name: Graham, Chris, Post-Doc, Soil Science
Name: Guo, Li, PhD student Soil Science
Name: Herndon, Beth, PhD Candidate Geoscience
Name: Holleran, Molly (2011) B.S. Geosciences
Name: Hopkins, Isaac, M.S. student Soil Sciences
Name: Holmes, George, (2011) M.S. Civil and Environmental Engineering
Name: Johnson, Mitch, M.S. Geosciences
Name: Kramer, Ryan, B.S. Candidate Meteorology
Name: Kumar, Mukesh*, PhD (2009) Civil and Environmental Engineering
Name: Kuntz, Brad, (2010) M.S. Geosciences
Name: Leidel, Lauren, B.S. Candidate Environmental Systems Engineering
Name: Li, Wenfang, (2009) M.S. Civil and Environmental Engineering
Name: Li, Shuangcai*, (2008) PhD Civil and Environmental Engineering
Name: Lichtner, Derek, B.S. Candidate Geology, Temple University
Name: Mann, Elizabeth, (2012) B.S. Geology, Washington & Lee University
Name: Mercuri, Matthew, M.S. Candidate, Temple University
Name: Moscatello,Tony, B.S. Candidate Geosciences
Name: Naithani, Kusum, Post-Doc Ecology
Name: Shi, Yuning, (2012) PhD Meteorology
Name: Slim, Mirna, PhD Candidate, MIT
Name: Smith, Lauren, M.S. Candidate Ecology
Name: Takagi,Ken, (2009) MS Soil science
Name: Twiest, Burkely, B.S/M.S. Candidate Meteorology
Name: West, Nicole, PhD Candidate Geosciences
Name: Williams, Marisol, B.S. Candidate Environmental Systems Engineering
Name: Wubbles, Jane, (2010) M.S. Horticulture
Name: Yesavage, Tiffany, PhD Candidate Geosciences
Name: Yu, Xuan, PhD Civil & Environmental Engineering
Name: Zhang, Jun, (2011) PhD Soil science
Name: Zhang, Yu, PhD student Geosciences
Name: Zhao, Ying, Post-Doc, Soil Sciences

? The Shale Hills CZO has been used as a field laboratory for Soils 405/Geosci 405 Hydropedology class every fall semester. A number of field trips with students have been made to this catchment.
? Jonathan Nyquist, Chairperson and Professor, Earth & Environmental Science, Temple University, Philadelphia, PA, along with his undergraduate student Derek Lichtner, came to work with my group in July 2012 at the Shale Hills. We used a suite of geophysical tools

(mainly GPR and ERT) to conduct some innovative studies of subsurface hydrology and hydrogeophysics.

? Summer 2011 REU program including field visits with sample and data collection at SSHO-affiliated shale climosequence study sites in NY, PA, VA, TN and AL
? Research advisor to E. Mann senior thesis, Washington and Lee U., Bioturbation of forested shale soils by tree throw in the Appalachian Mountains
? Ongoing oversight of research activities by PSU rising senior Lauren Leidel

Ashlee Dere (PSU graduate student) was trained to use the GC at Princeton University.

Lin Ma (Geoscience, Penn State) measured U disequilibrium isotopes on Shale Hills samples at the Univ of Strasbourg with Francois Chabaux. Beth Herndon (Penn State) learned to run mesocosm experiments at Univ of Sheffield. Jennifer Williams and Ashlee Dere (Penn State) visited Plynlimon, Wales, a shale site that will become part of our satellite sites.

George Holmes (MS CEE Dept. Penn State) participated in the International CZO Experience. The experience started in Vienna, Austria with two weeks visiting scientists at the IAEA (International Atomic Energy Agency). The first week was spent at a short course demonstrating how to operate a Los Gatos Research Liquid Water Stable Isotope Analyzer. The second week was spent working with Brent Newman on the GNIR (Global Network of Isotopes in Rivers) database. The database was made public this year and Brent is encouraging publishing papers using the data. He also spent time with Tomas Vitvar and Luis Araguas concerning the Shale Hills CZO. The next spent three weeks were in Zurich, Switzerland working with Manfred Staehli at WSL (Swiss Federal Institute for Forest, Snow and Landscape Research). Where he was able to talk with many scientists about the Shale Hills CZO, and I also was able to discuss related projects like the BigLink Damma Glacial Forefield and the Cottbus Watershed in Germany. At WSL he gave a presentation that outlined all three CZO projects with focus on Shale Hills. He was able to visit the Damma Glacier Forefield and see the set up of the instrumentation, and I was also part of a trip to the Rietholzbach research catchment. The final week was spent in Davos, Switzerland at the Goldschmidt Conference with many talks related to the Shale Hills CZO.

Undergraduate Students working on the Shale Hills CZO:

Nick Kaiser , Geosciences PSU
Jose Morales , Geosciences, Univ of Puerto Rico
Kristen Jurinko, Soil Science Dept.PSU
Shaquandra Wilson, Geoscience Univ of W Alabama
Terryl Daniels, Geosciences, PSU
Valentina Prado Geosciences, PSU
Mitchell Johnson, Geosciences, PSU
Tamika Shannon, Geosciences, PSU
Maurice Dukes, Geosciences, PSU
Nate Wysocki, Geosciences, PSU
Nathan Barber, Geosciences, PSU
Ahmad Yusof, Geosciences, PSU
Erica Folio, Geosciences, PSU

Example Research Experience for Undergraduates:

Name: Jurinko, Kristen
Contribution to Project: REU at Penn State University Soil Science Dept, Summer 09. See Hydropedology findings for a description of this research.

Name: Nick Kaiser
REU at Penn State University Soil Science Dept, Summer 09

Nick Kaiser's summer REU project focused on the measurement of soil respiration in the Shale Hills catchment. He was mentored by Dr. Jason Kaye, Dr. Lixin Jin (postdoc), and Danielle Andrews (graduate student). Over the summer, Nick tested hypotheses regarding relationships among soil CO2 concentrations, soil respiration, and soil microclimate. He made weekly trips to the field site where he used soil

access tubes to sample soil gas from multiple depths. At the same locations he measured soil moisture using at TDR probe, and surface soil respiration using a portable infrared gas analyzer and soil cover (a chamber used to capture CO2 diffusing out of the soil). Using Fick's law of diffusion he predicted soil CO2 flux throughout the profile and compared these values to soil moisture, soil temperature, and surface soil flux measured with the soil cover. His work has led to important insights on the role of soil water in controlling gas diffusion, and has inspired the possible use of simple gas access syringes for cheap, highly replicated measurements of soil respiration. At the end of the summer, Nick attended the Ecological Society of America meeting in Albuquerque where he was exposed to a wide array of carbon cycling talks that provide context for his work at Shale Hills. Nick is now a senior at Gannon University in northwestern PA where he is double-majoring in math and chemistry.

Name: Jose Morales
Contribution to Project: Jose Morales (Univ of Puerto Rico, Hispanic American) measured metal contents of vegetation in leaves at Shale Hills.

Name: Shaquandra Wilson
Contribution to Project: Shaquandra Wilson (Univ of W Alabama, African American) developed a new membrane for use in root boxes to image enzyme production around roots.

Name: Jose Valentina Prado
Contribution to Project: (see Geophysics)

Name: Mitchell Johnson
Contribution to Project: (see Geophysics)

Name: Tamika Shannon
Contribution to Project: (see Geophysics)

Name: Maurice Dukes
Contribution to Project: (see Geophysics)

Name: Nate Wysocki
Contribution to Project: (see Geophysics)

Name: Maurice Dukes
Contribution to Project: (see Geophysics)

Name: Nathan Barber
Contribution to Project: (see Geophysics)

Name: Ahmad Yusof
Contribution to Project: (see Geophysics)

Name: Erica Folio
Contribution to Project: (see Geophysics)

Name: Dernier, Gabrielle, REU Hydrology. Rose Hulman College. Carried out hydraulic tests on 20 wells at Shale Hills and compiled a report showing the mean distribution of hydraulic conductivity with depth for the watershed. This critical to modeling study.

Outreach Activities:

Outreach Activities for the Shale Hills CZO

1. STEM Field School: The State College Area School District, SCASD, has formed a summer STEM Academy, a new initiative that uses field and experiential instructional techniques to engage our students in STEM areas. The goal of this Academy was to improve the middle school to high school transition by engaging students early in their high school career with academic experiences of the highest caliber. Incoming first year high school students along with pre-service and master

teachers learned how to measure and monitor soil moisture, collect GPS data, install a weather station, and observe the hydrologic cycle through rain and groundwater
simulation systems. Data collected from school premises will be compared to data streaming from the catchment to develop STEM curriculum modules, thus engaging students in relevant,
project-based collaborative research.

2. PIHM Workshop: As part of our Critical Zone cross-site activities, the Shale Hills CZO helo a workshop August 2-4, 2010 titled: Multiscale Modeling Using the Penn State Integrated Hydrologic Modeling System (PIHM). PIHM is multi-process, multi-scale hydrologic modeling tool, where the physical processes are fully coupled using the semi-discrete finite volume method (http://www.pihm.psu.edu). This workshop provided hands-on experience in using PIHM for modeling watershed dynamics. Participants learned to use a customized GIS interface to PIHM (called PIHMgis) for i) automated ingestion of model parameters from national databases, ii)
conditional domain decomposition of the model domain, iii) performed multistate simulations and calibration and iv) visualized model results. A goal of the workshop was to stimulate crosssite
CZO modeling activities. The Departments of Anthropology and Civil and Environmental Engineering hosted Jaime J. Carrera-Hern?ndez, PhD, Professor of Applied Geosciences at Instituto Potosino de
Investigaci?n Cient?fica y Tecnol?gica (IPICyT) in San Luis Potos?, M?xico on August 4, 2010. Dr. Carrera's nterests are in the analysis of the impact that human activities have on the hydrological cycle and on the development of tools to analyze water management policies. He is also interested in the use of remotely sensed imagery for the development of physically-based,distributed hydrogeological modeling along with the use of Relational Databases for the efficient
development of these models, as exemplified in the Basin of Mexico Hydrogeological Database (BMHDB). Carrera has applied some of these tools to estimate potential aquifer recharge in the Basin of Mexico and to analyze the impact that urban growth has had on aquifer recharge.

3. CZO Field School: The Shale Hills CZO is a research and teaching platform open to the academic community that supports general environmental education especially as it relates to environmental information, modeling and earth systems infrastructure. The inaugural field school was offered May 31 - June 9 and attracted 16 participants
(undergraduate to post-doc) from 9 countries. During the two week school, the junior scientists experienced field techniques, instrumentation set-up and deployment, as well as modeling and
database utilization. The data and models generated at Shale Hills and the surrounding region are widely used in the classroom by CZO scientists and grad students as well as non-CZO researchers through the real-time capability. To date, several of the international participants have begun collaborative research projects initiated during the school.

CZO REU Summer Field School brought together 7 undergraduates from collaborating institutions. This summer, the CZO Field School adds a new dimension with two weeks of field work followed by one week of data analysis. Undergraduate participation includes two students from the University of Puerto Rico Mayaguez, one student from Alabama A&M Univ., one from University of Tennessee, one from Washington & Lee University, one from Juniata College and one from Penn State. Field work, organized by Dr. Tim White and Ashlee Dere (PhD Candidate), will complete research at the CZO Shale Transect sites in New York, Virginia, Tennessee and Alabama. Work will include sampling and digging soil pits on hillslopes, GPR transects, shale fracture density and tree throw measurements.

4. Shale Satellite Sites: Ashlee Dere (Geoscience, Penn State) and her advisors, Tim White and Sue Brantley, are working to understand the influence of climate on rates of shale weathering and rates of soil formation by investigating a series of soils on shale from Wales
to New York to Puerto Rico. Each of these 'satellite sites' is
run with a partner institution and many of these are primarily
undergraduate-serving institutions. This work thus provides
opportunities for faculty and students at other institutions to
interact with scientists from Penn State. Students from each
satellite institution spent two weeks this past summer (2010) at
PSU learning about Shale Hills and the instrumentation used in
the catchment. Those students were taught how to set-up and collect data from a weather station as well as how to describe soils and collect samples. Ashlee and Nicole West (Geoscience, Penn State) have visited almost all the sites to date, working with students and faculty at the corresponding institutions.

5. This summer (2010), nine undergraduate students took a special class Geosc 497A: The Hydrogeophysics Field Experience with Dr. Kamini Singha from May 18 to June 5. Four students were from Penn State, and five came from Historically Black Universities: three
students attended from Jackson State University in MS and one each from Fort Valley State University in GA and Elizabeth City State University in NC. These students combined field experimentation, data analysis, and numerical modeling with in-class instruction during the three-week program to develop hypotheses regarding the processes controlling solute transport. The Shale Hills Critical Zone Observatory was the 'home base' for this field camp. Environmental consultants, government employees, and small companies will be coming through the field

camp to demonstrate hydrogeophysical field equipment and highlight jobs in environmental fields. Graduates from this program were be able to: (1) apply their knowledge of mathematics, science, and engineering to real field problems, (2) conduct experiments, and analyze and interpret data, (3) function in multidisciplinary teams, and (4) communicate their scientific data and analyses effectively.

The 3rd Annual Hydrogeophysics Field Camp hosted nine undergraduates this summer (2011). The 3rd annual hydrogeophysics field camp, offered by Dr. Kamini Singha, has come to completion. Nine undergraduate participants, from rising sophomores to rising seniors, spent three weeks collecting a wide range of data from the CZO and nearby Lake Perez. New data included images from the optical televiewer and gamma logs, GPR, pumping/slug tests and electrical resistivity measurements. Using COMSOL, a multiphysics software designed for analysis and visualization, the students built numerical models and learned the intricacies of field data interpretation.

6. Lehigh University Professor Frank Pazzaglia brought his class geology to visit the Shale Hills CZO on March 28th ,2009. Professor Daniel Bain also brought his Groundwater Geology Class Visit from the University of Pittsburgh on April 3rd, 2009. The field trips were lead by Kevin Dressler. The students received an overview of the
Critical Zone Observatory project and a field guide to accompany the day's activities. The group covered topics both in the water laboratory in the field. The following demonstrations were provided to the students in ~1 hr discussions:

1) O18 and H2 Isotopes using the Los Gatos Laser Isotope Analyzer (by George Holmes ? MS Student in Engineering)
2)Geology of the region and Shale Hills specifically (by Timothy White ? Senior Research Associate)
3)Tour of Shale Hills Infrastructure including data retrieval, communications, wireless network and overall hydrological experimental design (by Kevin Dressler ? Research Associate Penn State Institutes of Energy and Environment)
4)Geophysical techniques and execution of a well log exercise (by Brad Kuntz ? MS Student in Geosciences)
5) Soil Pit and Soil Moisture experimental design and data collection techniques (by Danielle Andrews ? PhD Student in Soil Sciences)
6) Geochemistry experimental design, current results and collection of Lysimeter and ISCO Data (by Lixin Jin ? Postdoctoral Scholar in Geosciences)
7) Ecophysiology of Tree Species in the Shale Hills Catchment. Overview of speciation by landscape position and design of Sap Flow experiments (by Jane Wubbels ? Graduate student in Horticulture)

7. Penn State University Graduate Course in Surface Water Hydrology (CE561) ? April 21st ? April 30: As their final project, members of this graduate class were tasked with developing a method to develop water budgets. The Concept was as follows:

The Shale Hills Watershed has been a testbed for hydrologic studies since the 1970's. The State of Pennsylvania is interested in using Shale Hills as a prototype for developing water budgets across the state that will allow improved management of surface and groundwater supplies at other sites. That is they need a 'method' to develop water budgets that you would recommend. The 'water budget' generally be categorized as having 3 components:
1) data analysis (climate, soils, stream, vegetation, groundwater);
2) hydrologic conceptualization and characterization;
3) modeling-simulation-forecasting. In class we have discussed a range of issues and tools that can be applied to developing improved water budgets. The final product is a report that develops this prototype for the State.

Note that generally the State DEP is interested in 3 water issues: drought/flood/supply.

Kevin Dressler supervised 4 class periods regarding this project and led the group on a field trip to the site to illuminate both the current Critical Zone project and the previous studies done at the site in the 1970's.

8. International: Lin Ma (Penn State) measured U disequilibrium isotopes on Shale Hills samples at the Univ of Strasbourg with Francois Chabaux. Beth Herndon (Penn State) learned to run mesocosm experiments at Univ of Sheffield. Jennifer Williams and Ashlee Dere (Penn State) visited Plynlimon, Wales, a shale site that will become part of our satellite sites. S Riggins (Univ of CO, Boulder) visited the British Geological Survey. As a graduate student working on the Shale Hills Critical Zone Observatory I was able to travel to both Austria and Switzerland for a total of six weeks. While in both countries I was able to create a relationship with scientists working on projects similar to the Shale Hills CZO, and I was able to further my knowledge on many aspects of the critical zone.

George Holmes (MS CEE Dept. Penn State) participated in the International CZO Experience. The experience started in Vienna, Austria with two weeks visiting scientists at the IAEA (International Atomic Energy Agency). The first week was spent at a short course demonstrating how to operate a Los Gatos Research Liquid Water Stable Isotope Analyzer. The second week was spent working with Brent Newman on the GNIR (Global Network of Isotopes in Rivers) database. The database was made public this year and Brent is encouraging publishing papers using the data. He also spent time with Tomas Vitvar and Luis Araguas concerning the Shale Hills CZO. The next spent three weeks were in Zurich, Switzerland working with Manfred Staehli at WSL (Swiss Federal Institute for Forest, Snow and Landscape Research). Where he was able to talk with many scientists about the Shale Hills CZO, and I also was able to discuss related projects like the BigLink Damma Glacial Forefield and the Cottbus Watershed in Germany. At WSL he gave a presentation that outlined all three CZO projects with focus on Shale Hills. He was able to visit the Damma Glacier Forefield and see the set up of the instrumentation, and I was also part of a trip to the Rietholzbach research catchment. The final week was spent in Davos, Switzerland at
the Goldschmidt Conference with many talks related to the Shale Hills CZO.

9. Craig Rasmussen (Arizona CZO) and Susan Brantley led six Webinars with three to 12 participants in each to discuss how to compare soil chemistry developed on granitic protolith as a function of climate variables. Rasmussen is developing this study into a publication to be submitted in 2009-2010 with co-authors from the CZEN and seminar
group. Alex Blum (Boulder CZO) was involved. The approach being developed will be used for the shale satellite sites.

10. Sue Brantley teamed with international colleagues (Francois Chabaux, Yves Godderis, Mohammed Rafi Sayyed) to convene a special session entitled 'Rates and mechanisms on erosion and weathering processes: from experiments to models' at the Goldschmidt 2009 meeting in Davos, Switzerland. The session included 28 talks and 28 posters.

11. Heather Buss (USGS) and Lixin Jin have organized a special session entitled 'Water in the Critical Zone: Major Elements, Trace Elements, and Isotopes as Biogeochemical Tracers' for the AGU 2009 meeting in San Francisco, CA.

12. Data and technology are being shared with colleagues in research across Penn State colleges and universities associated with the project, as well as operational state and federal agencies (e.g. NOAA Mid-Atlantic River Forecast Center, Susquehanna River Basin Commission, USGS, USDA, EPA).

13. Collaboration is occurring with the Shaver's Creek Environmental Center to share ournew wireless communication system. The tower installed for this research project is now providing internet services to the entire Penn State Forest. The system is allowing the center to create a virtual classroom for K-12 education on their site, several hundred meters away from Shale Hills CZO.

14. Transect site CZO Partners: measurements, data management and integration

An all hands meeting was held for the transect participants last year and a 2nd meeting in Sept. of 2009. At the meeting all PIs for the transect sites (see Fig 4) and for the main Penn State site were present to discuss plans for the first year including logistics, instrumentation, and site specific issues. The main result was a field plan for selecting sites for instrumentation and approval of both core activities and instrumentation to be placed at each site along transect.

It was determined that the transect site PIs would take and record data locally. Afterward a copy will be transferred to the core data set held at Penn State University and maintained.

From the meeting it was determined that the first year main focus should be development of the regional shale transect; and assessment of parent material heterogeneity as a control on soil type. Both are ongoing.

Shale transect development still remains in the early phase of site selection. Rich April, Colgate has visited numerous sites in the greater central New York region. His most recent foray led to the identification of the most suitable site visited thus far: close to Colgate with site access on Rose Hill equivalent shale, but with a surficial geology dominated by till. Timothy White will visit this site in the coming month or so.

Ryan Mathur, Juniata, has been very active over the past few summers in his pursuit of Marcellus Shale studies. Timothy White has visited a suitable site with Ryan, Lixin Jin, Jennifer Williams, and Ryan's undergraduate student, in May, which they subsequently cored and have been working on this summer. Another site may eventually be chosen for instrumentation to better mimic the slope and aspect of the Shale Hills drainage basin.

Teferi Tsegaye, Alabama A&M, has delegated the site selection activity to a geologist and soil scientist on his staff. Tim White has communicated with them several times. They have collected the requisite geologic and soil maps and are in the process of dentifying a site in

northeastern Alabama.

Larry McKay is working on recruiting a PhD student, his desired strategy for moving his shale transect site forward. October will be the month in which his transect site will be selected. David Harbor, Washington and Lee, will work together with Timothy White this fall to locate a site. Timothy White has contacted two faculty members at University of Puerto Rico Mayaguez and a prospective graduate student there to determine interest/feasibility of their transect site. From previous visits and field work he has pinpointed a few sites to discuss with the group.

The assessment of Rose Hill Shale heterogeneity has progressed nicely as an offshoot of Poonam Giri's (recent BS Geosciences graduate, soon-to-be MS student, Geosciences) senior thesis overseen by Tim White. Her senior thesis involved a geochemical study of an excellent Rose Hill Shale outcrop near Allenport, PA. The total carbonate profile aided in delineation of four geochemical/lithologic facies in the formation and consequently guidance in sampling of soils developed on each facies. Soil cores were taken from ridgetop and slope locations in each of three facies. Distinct soil profiles were identified over each facies. This summer Poonam has sampled the fourth facies at Allenport. In addition, she sampled a bedrock section near Reedsville, PA, at the base of the Rose Hill Shale that overlaps with the Allenport section thus providing 100% coverage of the formation. She sampled ridgetop and slope soils at the Reedsville site. Furthermore, an ore bank and an undisturbed soil profile near Greenwood Furnace State Park were sampled. This focuses on determining whether recent pedogenesis on the ore bank can be differentiated from the nearby undisturbed soil, thus providing some insight into the rate of soil formation on the Rose Hill Shale. Analyses of the summer samples are ongoing.

15. Katie Gaines participated in the USA Science and Engineering Festival in Washington, D.C., in April 2012 at the CZO booth sharing information on CZO research and activities with the children and educators in attendance.
Three undergraduate students participated in CZO field research, supervised by Katie Gaines and Tom Adams. Rachel Hoh (Community, Environment, and Development major) and Michael Schneider (Horticulture major) worked to climb trees, construct sap flow probes, and assist with other aspects of a tree water use study. Rachel and Michael were partially supported with CZO funds. Cody Barnyak (Environmental Resource Management major), collected soil cores and measureds soil moisture using time domain reflectometry and will complete an independent study with the Eissenstat lab this fall. Cody's project will focus on investigating the relationship between soil water isotopes and soil volumetric water content across the Shale Hills catchment.

16. A diverse group of students from Penn State and two historically black colleges (Jackson State University and Fort Valley State University) participated in a 3-week research experience at the Penn State campus from mid-May to early June. The students conducted tracer, slug, and pump tests, collected ground-penetrating radar and electrical resistivity data, and learned to use wellbore logging tools such as the optical televiewer and spectral gamma logs. They also analyzed and interpreted data, which included creating numerical models of water flow and solute transport using Comsol Multiphysics to extrapolate their field findings to other systems. The field portion of the class was held at the Shale Hills Critical Zone Observatory near the Penn State Campus. Information on the program is available at www.geosc.psu.edu/hydrocamp.

17. REU included participation of students from University of Puerto Rico-Mayaguez and Alabama A&M University; separate field visit and collaborative field work with students from UPRM in January 2011.

18. Nicole West led experiences that involved outreach and engagement of both undergraduates and secondary school students. During summer 2010 ? 2012 this involved participation for 1-2 days in the Hydrogeophysics Field Experience for Undergraduates (http://www3.geosc.psu.edu/hydrocamp/) run by K. Singha. During the Spring of 2011, Nicole also led a trip through the Women in Science and Engineering Day Camp for 10th, 11th, and 12th Grade Girls. Finally, she also participated in the International Critical Zone Observatory Field School during Summer 2010 which brought in graduate students from other countries to learn techniques and instrumentation applied to Critical Zone science.

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Web/Internet Site

URL(s):

http://www.czo.psu.edu/

Description:

Our new Shale Hills-Susquehanna Critical Zone Observatory website was implemented recently. We are still working on content but the site is up and running and fully linked to the National CZO page. The website will host all Shale Hills data and provides an overview of CZO science activities.

Other Specific Products

Product Type:

Software (or netware)

Product Description:

We are developing community models for integrated hydrologic modeling a data handling for modeling. These are known as the Penn State Integrated Hydrologic Model PIHM and PIHM_GIS

Sharing Information:

The software is available as open source projects Source Forge

http://sourceforge.net/projects/pihmmodel/

http://sourceforge.net/projects/pihmgis/

Product Type:

Software (or netware)

Product Description:

During 2009 the Hydrology group completed a multi-platform watershed modeling software platform called PIHM_GIS. The software allows the user to build a distributed watershed model from basic GIS layers for topography, soils, vegetation, geology, and climate inputs.

Sharing Information:

The Penn State modeling team has also posted its software PIHM and PIHM_GIS, to the CSDMS website: http://csdms.colorado.edu/wiki/Models

Product Type:

Data or databases

Product Description:

RTH_NET has been completely upgraded by Kelly Cherrey to provide real time hydrologic and weather data at Shale Hills for CZO scientists and is being utilized by the CUAHSI-WATERS community.

Sharing Information:

http://www.rthnet.psu.edu/

Product Type:

Data or databases

Product Description:

SAP_NET is a new network established this year by Dave Eisenstat and a team of scientists from Oregon State University with support for networking and power by Kelly Cherrey to measure sapflow (transpiration) along a tree transect at Shale Hills.

eKo_NET is a new network established this year by Colin Duffy and a team of Penn State researchers to measure groundwater level/temperature/electrical conductance, soil moisture/tension/temperature/electrical conductance, and snow depth. The Crossbow adaptive Sensor Net technology is used for this array.

LPM is a our new disdrometer or Laser Precipitation Monitor.

ISO_NET is a network of stable isotope monitoring of precipitation events (up to 8, 4-hourly integrated water samples) automatically collected. An ISCO auto-sampler for streamflow at the outlet collected daily, 2 ISCO auto-samplers for shallow groundwater collected daily, 6 soil moisture lysimeter sites sampled on a weekly basis, and 14 new observations wells drilled into the weathered shale sampled on a weekly basis.

Sharing Information:

RTH_NET, SAP_NET, and LPM are in ?flat-file? format while eKo_net is a SGQL database. Basic meta-data and permissions is also provided. http://cataract01.cee.psu.edu/czo/
The ?flat file? site is meant to be a simple service for all users to access raw data from Shale Hills.

eKo.net data is in a SQL database format http://cataract01.cee.psu.edu/czo/eko/

Product Type:

DVD

Product Description:

A set of 3 DVD for The 1st International Conference on Hydropedology held July 28-31, at Penn State Univ. in University Park, PA.

Sharing Information:

Available from Prof Henry Lin

Product Type:

Data or databases

Product Description:

A relational database, CZchemDB, which contains soil data collected at the SSHCZO as well as additional soil data, legacy and other CZO's.

Sharing Information:

The database is available on the SSHCZO website. We currently include 21 investigators from 11 institutions representing 46 different field locations, one of which is international (Plynlimon, Wales, UK). Two CZO's, Luquillo and Jemez River Basin - Santa Catalina Mountains CZO, have contributed data. Total contributions thus far represent 255 cores collected, 2237 samples analyzed which produced 33,142 data values. We have 10 additional template contributions to add to the database but are waiting on modifications for EarthChem compatibility.

Contributions

Contributions within Discipline:

The Shale Hills CZO provides a multi-disciplinary framework for the study of regolith development and function in the critical zone. The Geochemistry group has developed a model for shale weathering at SSHO. We have assessed the geochemical reactions that are occurring and we have used uranium disequilibrium isotopes to estimate the residence time of regolith. We have discovered that Mn atmospheric deposition to SSHO is significant and that this deposition may be common in industrialized countries. Ecology team has developed a model code to predict a spatial map of LAI. We selected regions of low (red), intermediate (orange) and high (yellow) LAI to study the inter- and intra-specific differences in maximum light use efficiency (REU Project: John) and leaf structure (REU Project: Shelly) of plants living in different light environments. We are in the process of conducting a vegetation survey of the watershed to coincide with a LiDAR flight of the CZO which is scheduled to take place in mid to late July. We have selected 40 plots, of 15m radius each, in deciduous, conifer, and mixed forest areas, as well as wetland meadow and grassland sites. In each forest plot we counted the number of trees and measured tree height and diameter at breast height (DBH). For the wetland meadow and grassland sites we identified the predominant plant species. Within one week of the LiDAR flight (tentatively scheduled for 7/14/2010 and 7/15/2010), we will measure LAI and canopy closure at each plot and vegetation height at the grassland and meadow sites. The data we collect during the vegetation survey will allow us to ground truth the land cover and LAI data collected during the LiDAR flight. From our sapflow study characteristics of stem hydraulic architecture in some genera (Pinus) was linked to soil moisture distribution in central Pennsylvania, but not in other genera (Carya and Quercus)

Hydrology Land Surface Modeling Team: The CZO data (time series, geospatial, open source modeling) are being provided to the community through SourceForge http://sourceforge.net/projects/pihmmodel/ and http://sourceforge.net/projects/pihmgis/ . During 2009 the Hydrology group completed a multi-platform watershed modeling software platform called PIHM_GIS. The software allows the user to build a distributed watershed model from basic GIS layers for topography, soils, vegetation, geology, and climate inputs. Physically-based distributed models seek to simulate state variables in space and time while using heterogeneous input data for climate, land use, topography and hydrogeology. In the process of incorporating several physical data layers in a hydrologic model requires intensive effort in data gathering, development as well as topology definitions. Traditionally Geographic Information System (GIS) has been used for data management, data analysis and visualization. Joint use and development of sophisticated numerical models and commercial GIS systems poses challenges that result from proprietary data structures, platform dependence, inflexibility in their data models and non-dynamic data-interaction with pluggable software components. Alternatively this tool presents an open-source, platform independent, extensible and 'tightly-coupled' integrated GIS interface to Penn State Integrated Hydrologic Model (PIHM) called PIHMgis. The tight coupling between the GIS and the model is achieved by developing the PIHMgis data-model to promote minimum data redundancy and optimal retrievability. Minimum data redundancy and optimal retrievability are facilitated through carefully designed data-model classes, relationships and integrity constraints. Two papers have been published (Kumar, Bhatt, and Duffy, 2009a,b) and a monograph is being written to describe the software for classroom, research, and operational watershed modeling. The first generation of PIHM and PIHM_GIS focus on distributed hydrologic modeling. However, in years 3 and 4 solute, and sediment transport will be added. By year 5 we hope to have the geochemical model implemented. The figure below shows how PIHM_GIS uses hypsometry to constrain the unstructured numerical grid along lines of constant elevation for the Little Juniata watershed, and an example for the PIHM_GIS interface.

An important flux that is not included in most other models is the negative recharge or upward flux from the water table. It appears to be at least 5% on an annual basis. This flux is basically the capillary rise from the water table that occurs as the soil moisture dries due to plant water usage. Yuning Shi working with Ken Davis has implemented a new land surface scheme in PIHM and at Shale Hills is comparing the model latent heat flux (net evapotranspiration or ET) to the eddy flux measurements for latent heat and sensible heat flux. Yuning is finding that groundwater may have a significant affect on the land surface energy fluxes, especially for shallow water table settings. This is important since most land surface models do not include this effect.

Geomorphology Team have discovered that the valley bottom regolith/alluvium represents a polygenetic deposit that appears to contain relict post-glacial-maximum material. 10Be concentrations appear to increase downslope, consistent with soil transport. Lidar-imaged subtle pits and mounds are prevalent and exhibit an approximate spacing of 5 m and are interpreted to be a result of tree-throw. Using meteoric 10Be measurements at SSHO, we have estimated that the residence time of soils on the southern ridge top is ~10-11 ky, while soils further downslope have greater inventories consistent with slow rates of downslope creep. Sediment cores collected from the valley fill at SSHO suggest the presence of buried hillslope colluvium along the southern side of the valley floor. The combination of stratigraphic observations and 10Be residences suggest that regolith presently mantling ridgetops has formed over at least the Holocene, whereas colluvium and soils toward the valley floor are inferred to be older, perhaps even relict from glacial times in the Late Pleistocene.

Hydrogeophysics Team has carried out preliminary modeling of the soil cores at Shale Hills with simple dual-domain mass transfer models indicate that the fraction of immobile porosity in the aquifer is larger in the shale than in the soil derived from that shale, which has important implications to estimating age of water. Interestingly, it appears mass transfer rates only vary slightly throughout the geologic section, indicating that the diffusive length scale does not vary significantly. These results are only preliminary, however, and will be compared to results based on CTRW modeling.

Hydropedology Team: The time-lapse GPR radargrams revealed the general infiltration wetting front and preferential flow pattern that were significantly different between different types of soils and hillslopes within the CZO, which were then confirmed by simulation modeling results. Time-lapsed GPR is proved as a useful methodology for improved understanding of hydrologic connectivity in the subsurface, which facilitates the formulation and test of different conceptualizations of subsurface network modeling.
We have found that preferential flow occurs across the Shale Hills CZO. Ridge and hillslope sites are controlled by initial soil moisture (preferential flow occurs more often when the soil is dry) and during the late summer. Swale and valley sites, while more likely when the soil is dry, are more sensitive to the internal storm precipitation intensity dynamics. Preferential flow occurs at these sites when storms are long, with an extended prewetting, followed by a large spike in precipitation intensity. These findings will help in determining the locations and timing of preferential flow in steep, forested environments.
An important goal of watershed modeling effort at Shale Hills has been to evaluate all terms in the water budget, including the separation of transpiration by plants and evaporation, estimation of recharge to groundwater and the fraction of streamflow due to surface runoff and groundwater baseflow. The figure in FIndings illustrates the calculated water budget from PIHM using a simulation for 2009.

Shale Transect Team: Initial results show soil depth increases as a function of temperature, with shallow (~30 cm) profiles in Wales and Pennsylvania varying up to 630 cm deep in Puerto Rico. Depletion profiles of Na, a proxy for feldspar dissolution, are less than 20 % depleted at the surface in Wales and Pennsylvania, 50-60% depleted in Virginia and Tennessee, and 100% depleted at the surface in Puerto Rico. Using estimated soil residence times, apparent activation energies for Na depletion were calculated using different assumptions to range from 15-19 kcal mol-1, values that are slightly higher than those reported for Na plagioclase dissolution in the laboratory.

Contributions to Other Disciplines:

Collaboration with the Chesapeake Bay Research Consortium has fostered relationships with the ocean community. The Shale Hills CZO site was a recommended site in the Mid-Atlantic NEON RFI. The Chesapeake Community Modeling Program is also an important partner for our modeling effort and PI Duffy serves on the Steering Committee.

The Community Surface Dynamics Modeling System (CSDMS) deals with the ever-changing, dynamic interface between lithosphere, hydrosphere, cryosphere, and atmosphere. CSDMS is a diverse community of experts promoting the modeling of earth surface processes by developing, supporting, and disseminating integrated software modules that predict the erosion, transport, and deposition of sediment and solutes in landscapes and their sedimentary basins. CSDMS produces protocols for community-generated, continuously evolving, open software, distributes software tools and models, and provides cyber-infrastructure to promote the quantitative modeling of earth surface processes. The Penn State modeling team has also posted its software PIHM and PIHM_GIS, to the CSDMS website: http://csdms.colorado.edu/wiki/Models

We are developing a close relationship with the Delaware CZO team as they have adopted our model (PIHM) and we are actively sharing ideas and strategies that will move the watershed modeling science forward and more closely couple models to CZO data.

Contributions to Human Resource Development:

Cohorts in education levels of undergraduate, graduate, and post-doc are being trained in field, laboratory and modeling studies regarding hydrologic science. The CZO has engaged a variety of institutions in this regard including universities and undergraduate colleges directly associated with the project. The CZO has also provided many site visits to investigators from universities, the interested public, the National Science Foundation, the National Resource

Conservation Service (USDA), US Geological Survey, and various state agencies and non-profit groups.

Chris Duffy is interacting with the State College Area School District (SCASD), regional STEM Professional Development Center, coordinating filed trips for students (18-19 Aug) to the Shale Hills CZO. Colin Duffy is constructing a weather station for the high school and he and Chris Graham are providing field seminars on the use of environmental sensors as part of the STEM program.

An REU summer field school was conducted from June 5 ??? June 25 in which seven undergraduates, representing Penn State, Juniata College, Washington and Lee University, University of Tennessee, Alabama A&M University and the University of Puerto Rico ??? Mayaguez, participated in two weeks of field work followed by one week of laboratory work and data processing.

Contributions to Resources for Research and Education:

The Shale Hills CZO is a research and teaching platform open to the academic community that supports general environmental education especially as it relates to environmental information, modeling and earth systems infrastructure. The data and models generated at Shale Hills and the surrounding region are widely used in the classroom by CZO scientists and grad students as well as non-CZO researchers through the real-time capability.

A number of CZO investigators participated in CZO Summer School led by Tim White May 31-June 9. The Field school participants carried out a full range of CZO activities which is currently being written up by Tim.

Contributions Beyond Science and Engineering:

The Shale Hills-Susquehanna CZO is developing a new generation of models and experimental observations that will eventually be implemented in operational models to forecast drought, flood, water supply and water quality for a fully coupled approach to surface and groundwater systems. The contribution of our sediment and geochemical-weathering research is fundamental to predicting how to manage land and water resources within the Chesapeake bay and watershed, as well as similar locations around the world.

Conference Proceedings

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Conference

2012 Annual Reporting for SSHCZO

Discipline (Please choose team and list current team members): ***Hydroclimatology Team,***

Personnel: Kenneth J. Davis (PI), Christopher Duffy, (Co-PI), Fuqing Zhang (collaborator), Yuning Shi (Ph.D.), Xuan Yu (Ph.D. Candidate), Burkely Twiest (B.S/M.S. Candidate), Ryan Kramer (B.S. candidate)

Research Progress and Significant Findings:

Climate and Hydrometeorology: Research in this area has focused on investigation of explicit subsurface-landsurface-atmosphere interactions using a fully coupled groundwater-land surface modeling system optimized to match the array of hydrometeorological observations collected within the Shale Hills watershed. The model is referred to as flux-PIHM and it has been optimized using observations of soil moisture, groundwater level, latent and sensible heat flux, and watershed discharge. We have developed an Ensemble Kalman filter data assimilation system that estimates model parameter values and their uncertainties. The system has been used to identify the observations that are most critical to assimilate to ensure optimal model performance, and to identify parameter interactions in the modeling system. The system has been successfully applied to Shale Hills observations, resulting in an automated model-data fusion system that provides model performance the equals or exceeds the "hand-tuned" model, provides quantitative parameter uncertainties, and is much more efficient than manual tuning of the model.

The group is also testing and deploying a micronet of meteorological sensors that will be used to study subcanopy meteorological conditions within the watershed. Progress to date has focused on development and testing of network instrumentation.

Training/Development:

Yuning Shi, Ph.D., Meteorology, graduated August, 2012.

Burkely Twiest, M.S./B.S. candidate, Meteorology, scheduled to graduate 2014.

Ryan Kramer, B.S. Meteorology, Honors thesis on Shale Hills CZO research, scheduled to graduate 2013.

Outreach Activities (broadening participation of under-represented / under-served groups):

Presentations:

Davis, K.J., Model-data syntheses to improve simulation of the atmospheric boundary layer, Urban and Rural Meteorology Workshop, Jeju Island, S. Korea, 27-29 August, 2012

Shi, Y., K. J. Davis, F. Zhang, and C. J. Duffy, 2012: Parameter estimation of a physically-based land surface hydrologic model using the ensemble Kalman filter. AGU Fall Meeting, San Francisco, CA. (abstract submitted)

Twiest, B, K. J. Davis, C. Duffy, C. Duffy, 2012: Establishing a Micronetwork at the Shale Hills Critical Zone Observatory, Annual Meeting of the American Meteorological Society.

Shi, Y., K. J. Davis, C. J. Duffy, and X. Yu, 2011: A Watershed Scale Groundwater-Land-Surface Model. Poster, 25th Conference on Hydrology, Seattle, WA. American Meteorological Society.

Publications:

Shi, Y., 2012: Development of a land surface hydrologic modeling and data assimilation system for the study of subsurface-land surface interaction. Ph.D. dissertation, the Pennsylvania State University, 214pp.

Shi, Y., K. J. Davis, C. J. Duffy, and X. Yu, 2012: Development of a coupled land surface hydrologic model and evaluation at a critical zone observatory. *J. Hydrometeor*. (in prep.)

2012 Annual Reporting for SSHCZO

Discipline (Please choose team and list current team members): ***Soils and Weathering Geochemistry,***

Personnel: Susan Brantley (PI), Katya Bazilevskaya (Post-doc), Elizabeth Herndon (PhD. Candidate), Ashlee Dere (PhD. Candidate), Tiffany Yesavage (PhD. Candidate), Megan Carter (M.S. Candidate), Alex Carone (B.S. graduate), Nina Bingham (B.S. Candidate)

Research Progress and Significant Findings:

We discovered that the Mn flux out of the Susquehanna River Basin over the last several decades can be predicted based on the Shale Hills data (Herndon, E. PhD Thesis).

We discovered that the Fe released from Shale hills is isotopically heavy – distinct from most of the world rivers (Yesavage, T., paper submitted to Geochimica).

We observed that weathering advance is faster on shale in southern climates than in northern climates, and that this trend is best explained as a temperature effect (Dere, A., paper submitted to Geochimica).

Training/Development:

Mentored three Senior Theses in Geosciences for Spring 2012: Alex Carone, Erika Frey, Jenny Kissel

- Insight into the weathering of the Marcellus Shale through Sulfur and Carbon Analyses (A. Carone)
- Rate of Manganese Release from Soil Components Interacting with Rainwater and Litter Leachate (E. Frey)
- Examining the role of trees in manganese cycling though soil (J. Kissel)

Outreach Activities (broadening participation of under-represented / under-served groups):

Conference Abstracts:

L. Jin; D.M. Andrews; G. Holmes; C. Duffy; H. Lin; S.L. Brantley; *Controls of mineralogy and hydrology on weathering fluxes in the Susquehanna Shale Hills Critical Zone Observatory*. Fall Meeting of the American Geophysical Union, San Francisco, CA, USA, Dec 04-09, 2011.

E. Herndon and S.L. Brantley; *Movement of manganese contamination through the Critical Zone*. 9th International Symposium Geochemistry of the Earth's Surface (GES-9), Boulder, CO, USA, June 03-07, 2011.

Lixin Jin, Susan L. Brantley. *Soil chemistry and shale weathering on a hillslope influenced by convergent hydrologic flow regime at the Susquehanna/Shale Hills Critical Zone Observatory.* 9th International Symposium Geochemistry of the Earth's Surface (GES-9), Boulder, CO, USA, June 03-07, 2011.

Lin Ma, Lixin Jin, Susan L. Brantley. *Geochemical behaviors of different element groups during shale weathering at the Susquehanna/Shale Hills Critical Zone Observatory.* 9th International Symposium Geochemistry of the Earth's Surface (GES-9), Boulder, CO, USA, June 03-07, 2011.

Xianzeng Niu, Kerstin A. Lehnert, Jennifer Williams, Susan L. Brantley. *CZChemDB and EarthChem: Advancing management and access of critical zone geochemical data.* 9th International Symposium Geochemistry of the Earth's Surface (GES-9), Boulder, CO, USA, June 03-07, 2011.

ASHLEE L. DERE, BRIAN REYNOLDS, TIMOTHY S. WHITE AND SUSAN L. BRANTLEY; *A comparison of shale weathering rates inferred from catchment solute mass balance versus soil profile chemistry at Plynlimon, Wales.* The 22nd V.M. Goldschmidt Conference, Montreal, QC, CA, June 24-29, 2012.

SUSAN BRANTLEY, HEATHER BUSS, MARJORIE SCHULZ; (Invited) *Back to the Future: The Art of Weathering*. The 22nd V.M. Goldschmidt Conference, Montreal, QC, CA, June 24-29, 2012.

ELIZABETH M. HERNDON, JAMES KUBICKI, SUSAN L. BRANTLEY; *Micro- to macro-scale investigations of manganese in soil-plant systems*. The 22nd V.M. Goldschmidt Conference, Montreal, QC, CA, June 24-29, 2012.

N. Bingham, S.L. Brantley; *Modeling Soil Addition Profiles of Carbon, Nitrogen, Lead and Manganese across a Climate Gradient*. ASA, CSSA and SSSA Annual Meeting, Cincinnati, OH, USA, October 21-24, 2012.

Publications:

Dere, A. L., White T. S., April R. H., Reynolds B., Miller T. E., Knapp E. P., McKay L. D. and Brantley S. L. (2012) Climate dependence of feldspar weathering along a latitudinal gradient. *Geochim. Cosmochim. Acta.* Submitted.

Carone, A (2012) *Insight into the weathering of the Marcellus Shale through Sulfur and Carbon Analyses.* Bachelor of Science, Pennsylvania State University, p. 72.

Herndon, E (2012) *Biogeochemistry of manganese contamination at the Shale Hills CZO*, Doctor of Philosophy, Pennsylvania State University.

Mathur, R., Jin, L., Prush, V., Paul, J., Ebersole, C., Fornadel, A., Williams, J.Z., and Brantley, S.L. (2012) Insights into the weathering of black shale: Cu isotopes and concentrations in the Marcellus Formation shale, Huntingdon County, Pennsylvania (U.S.A.). *Chemical Geology* 304–305:175–184, doi: 10.1016/j.chemgeo.2012.02.015.

Lin Ma, Lixin Jin, Susan L. Brantley. (2011) How mineralogy and slope aspect affect REE release and fractionation during shale weathering in the Susquehanna/Shale Hills Critical Zone Observatory. *Chemical Geology* 290:31–49, doi:10.1016/j.chemgeo.2011.08.013.

Jin, L., Andrews, D.M., Holmes, G.H., Lin, H., and Brantley, S.L. (2011) Opening the "Black Box": Water Chemistry Reveals Hydrological Controls on Weathering in the Susquehanna Shale Hills Critical Zone Observatory. *Vadose Zone Journal* 10:928-942, doi:10.2136/vzj2010.0133.

Andrews, D.M., H. Lin, Q. Zhu, L. Jin, S.L. Brantley. (2011) Hot Spots and Hot Moments of Dissolved Organic Carbon Export and Soil Organic Carbon Storage in the Shale Hills Critical Zone Observatory. *Vadose Zone Journal* 10:943-954, doi:10.2136/vzj2010.0149.

Xianzeng Niu, Kerstin A. Lehnert, Jennifer Williams, Susan L. Brantley. (2011) CZChemDB and EarthChem: Advancing management and access of critical zone geochemical data. *Applied Geochemistry* 26:S108–S111, doi:10.1016/j.apgeochem.2011.03.042

Lin Ma, Lixin Jin, Susan L. Brantley. (2011) Geochemical behaviors of different element groups during shale weathering at the Susquehanna/Shale Hills Critical Zone Observatory. *Applied Geochemistry* 26:S89–S93, doi:10.1016/j.apgeochem.2011.03.038.

Lixin Jin, Susan L. Brantley. (2011) Soil chemistry and shale weathering on a hillslope influenced by convergent hydrologic flow regime at the Susquehanna/Shale Hills Critical Zone Observatory. *Applied Geochemistry* 26:S51–S56, doi:10.1016/j.apgeochem.2011.03.027.

Elizabeth M. Herndon, Susan L. Brantley. (2011) Movement of manganese contamination through the Critical Zone. *Applied Geochemistry* 26:S40–S43, doi:10.1016/j.apgeochem.2011.03.024.

2012 Annual Reporting for SSHCZO

Discipline (Please choose team and list current team members): ***Ecology Team***

Personnel: David Eissenstat (co-PI), F.S. Meinzer, Kusum Naithani (Post-Doc), Katie Gaines (PhD. Candidate, Ecology), Lauren Smith (M.S. Candidate, Ecology), Margot Kaye (co-I), Elizabeth Boyer (co-I), and Tom Adams (technical assistant), Kristen Brubaker (PhD conferred December 2011, Assistant Professor of Environmental Studies at Hobart and William Smith Colleges).

Research Progress and Significant Findings:

Ecological Research: In this study patterns of tree water use and water availability across the watershed influence trees at the physiological, community and evolutionary time scales; and how a temperate forest affects water, energy and weathering rates. Up-looking LAI (Leaf Area Index) carried out at about 40 locations across Shale Hills. In parallel during the last two summer seasons sapflow campaigns were carried out with Penn State and Oregon State scientists along transects and including different tree species to evaluate the tree water use. These studies demonstrate that dynamics of summer drought on tree canopy growth is a function of tree species. For example, ring porous species like oaks can recover sap flux and leaf area index much more readily after drought than diffuse porous species such as maples. There is also evidence based on natural abundance of oxygen and hydrogen isotopes that oaks can access deeper soil moisture than maples. The ecology-hydropedology teams have also established important new relationships between soil moisture and tree water use during a severe drought in 2010. These results (weekly LAI) are currently being used by the PIHM modeling team to constrain the transpiration prediction in the model.

Training/Development:

David Eissenstat and Katie Gaines attended the CZO Lidar Acquisition Initiative and Workshop on December 4, 2011 at the University of California at Berkeley.

Outreach Activities (broadening participation of under-represented / under-served groups):

Katie Gaines participated in the USA Science and Engineering Festival in Washington, D.C., in April 2012 at the CZO booth sharing information on CZO research and activities with the children and educators in attendance.

Three undergraduate students participated in CZO field research, supervised by Katie Gaines and Tom Adams. Rachel Hoh (Community, Environment, and Development major) and Michael Schneider (Horticulture major) worked to climb trees, construct sap flow probes, and assist with other aspects of a tree water use study. Rachel and Michael were partially supported with CZO funds. Cody Barnyak (Environmental Resource Management major), collected soil cores and measureds soil moisture using

time domain reflectometry and will complete an independent study with the Eissenstat lab this fall. Cody's project will focus on investigating the relationship between soil water isotopes and soil volumetric water content across the Shale Hills catchment.

Conference Abstracts:

Feb 2012 Kristen M. Brubaker and Elizabeth W. Boyer. AGU Chapman Conference on Remote Sensing of the Terrestrial Water Cycle, Kona, HI. *Multi-scale lidar greatly improve characterization of forested headwater streams in central Pennsylvania.* (poster)

Most current hydrographic data used in Geographic Information Systems (GIS) have been derived by digitizing blue line streams from USGS topographic maps or by modeling streams using traditional digital elevations models (DEMs) in GIS. Both methods produce stream models that lack detail and accuracy, particularly in headwater streams. In addition to channel network delineation, another hydrologic attribute that is of interest to hydrologists, modelers, and ecologists, is topographic index (TI) as measured by the formula $\ln(\alpha/\tan\beta)$. This metric and its distribution is an important component to the hydrologic model TOPMODEL and other hydrologic models, but is also used extensively to represent soil moisture in fields of ecology, forestry, and soil science.

Newly available lidar data available statewide in Pennsylvania can produce DEMs with an accuracy and resolution that far exceed previously available elevation data. In this study, streams were modeled using lidar-derived DEMs of 1 m, 3 m, and 10 m resolutions using existing GIS software programs and compared to both actual streams and streams modeled using a 10 meter National Elevation Dataset (NED) DEM. Results showed that the most accurate stream locations could be modeled using a lidar-derived DEM thinned to 3m resolution or smoothed using a mean smoothing filter. Also, when a 10 m resolution lidar-derived DEM was compared to the NED 10 m resolution DEM, the streams delineated with the 10 m lidar data were significantly better than those modeled with the 10 m NED data, showing that significant improvement in accuracy can be achieved with no increase in data storage. When topographic index was modeled with multiple resolutions of lidar-derived DEMs, the spatial and statistical distributions were both very different, with finer resolution DEMs not accurately modeling areas of high TI. Additionally, depending on the flow accumulation algorithm used, there were differences in the change in statistical resolution with response to initial DEM resolution.

July 2011 Kristen M. Brubaker and Elizabeth W. Boyer. Gordon Research Conference for Catchment Science, Bates College, ME. *LiDAR imagery improves classification of forest function in the Ridge and Valley physiographic province of Pennsylvania.* (poster)

Technology is changing the way scientists see the landscape, with new data providing accuracy never before available. Scientists in many fields are looking for concise, effective methods to predict vegetation by classifying landscapes based on digital elevation model-derived terrain metrics such as slope, aspect, curvature and topographic indices. With newly available lidar-derived elevation data, the accuracy and resolution of is greatly improved but scale is so dramatically different that new approaches should be used to classify topographic features. By identifying lidar-derived patterns of curvature, major

gradients impacting vegetation in a catchment including water accumulation, soil characteristics and nutrient availability can be summarized into compact metrics. We applied this approach in the Ridge and Valley region of central Pennsylvania, in the broader basin encompassing the Shale Hills Critical Zone Observatory. The forest vegetation communities here have recolonized after disturbances from multiple stressors over the last century, including deforestation, charcoal burning, gypsy moth defoliation, atmospheric deposition, forest management, and wind-throw events. By classifying the watershed into four dominant recurring landforms using patterns of lidar-derived curvature data, dominant vegetation communities and forest structures were successfully predicted and confirmed using multivariate statistical methods. These methods are useful for comparing and classifying watersheds, and considering resilience of vegetation to disturbance.

Publications:

Johnson, D. M., McCulloh, K. A., Meinzer, F. C., Woodruff, D. R., and Eissenstat, D. M., (2011) Hydraulic patterns and safety margins, from stem to stomata, in three eastern US tree species. *Tree Physiology* 31:659-68, doi:10.1093/treephys/tpr050.

Meinzer, F.C., D.R. Woodruff, D.M. Eissenstat, H.S. Lin, T. Adams, K.A. McCulloh. (2011). Above- and belowground controls on water use by trees of different wood types in an eastern United States deciduous forest. Tree Physiology (In review).

Naithani, K.J., Baldwin, D., Gaines, K., Lin, H., Eissenstat, D.M. (2012) Spatial distribution of tree species governs the spatio-temporal interaction of leaf area index and soil moisture across a landscape. *Ecology Letters* (In review)

2012 Annual Reporting for SSHCZO

Discipline (Please choose team and list current team members): ***Biogeochemistry Team***

Personnel: Jason Kaye (PI),

Research Progress and Significant Findings:

Soil Biogeochemistry: This research has focused on quantification of soil respiration rates and investigation of how water movement/storage and soil texture lead to variability in soil-atmosphere CO2 exchange.

Field work: We (Tiffany Yasavage, Lin Ma, Lixin Jin) collected gas, water and soil samples for two seasons (fall: October of 2011 and spring: April of 2012)

(1) Collect soil gas samples at different depths at three sites along a hillslope (ridge top, mid-slope and valley floor). Gas samples were collected through existing soil gas samplers and injected into pre-evacuated vials, one during the growing season, and the other during the winter. Soil gas CO_2 concentrations and its C isotope ratios will be measured.
(2) Sample the organic matter in the O-horizon of the soil profiles, and measure soil organic C concentrations as well as C isotopes.
(3) Collect soil water samples at different depths at three sites along the same hillslope as the soil gas samples, ground water at several locations within the catchment, and first order stream water in the Shale Hills catchment, and analyze dissolved inorganic carbon concentrations and C isotope compositions.

Conference Abstracts:

AGU abstract for fall 2012 meeting:

Session: Tracing Earth Surface and Critical Zone Processes Using Innovative Isotopic Approaches

Drawdown of atmospheric CO_2 by gray shale weathering: insights from carbon, sulphur, and oxygen isotope systematics in the Susquehanna Shale Hills Critical Zone Observatory

Lixin Jin[1], Nives Ogrinc[2], Tiffany Yesavage[3], Jason Kaye[4], and Susan L. Brantley[3]

1. Department of Geological Sciences, University of Texas at El Paso, El Paso, TX, USA
2. Department of Environmental Sciences, Jozef Stefan Institute, Ljubljana, Slovenia
3. Department of Geosciences, Pennsylvania State University, State College, PA, USA
4. Department of Crop and Soil Sciences, Pennsylvania State University, State College, PA, USA

Shales, covering 25% of land surface, are an important lithology in linking the CO_2 drawdown and continental silicate weathering on the global scale. In this study, we aim to evaluate the potentials of shale weathering to consume CO_2 by investigating the elemental chemistry as well as stable isotopes (C, S and O) along the water flow paths in the well-studied Susquehanna Shale Hills Critical Zone Observatory

(SSHO). We also try to determine the potentials of releasing CO_2 by quantifying the relative importance of sulfuric acid in carbonate dissolution and the decomposition rates of ancient organic matter.

At SSHO, shallow soils are dominated by clay dissolution, and soil waters are low in dissolved inorganic carbon (DIC) concentrations controlled by equilibrium with soil pCO_2. Here CO_2 is produced primarily by oxidative decomposition of soil organic matter, and its concentrations vary seasonally and spatially. Ankerite, present in the Rose Hills bedrock, is depleted in soils and only remains at greater depths. Weathering of ankerite contributes to much higher concentrations of DIC and divalent cations (Ca and Mg) in groundwaters, but groundwater chemistry evolves to different extents with respect to ankerite saturation because the depths to ankerite weathering fronts vary due to heterogeneity of the Rose Hill shales and landscape position. Consistently, the $\delta^{13}C_{DIC}$ ratios of these groundwaters are indicative of mixing between DIC from ankerite and soil CO_2 endmembers. Hydrologically, the first-order stream is contributed by different proportions of groundwater and shallow soil waters as observed by major elemental chemistry, [DIC] and $\delta^{13}C_{DIC}$ ratio of stream waters.

In addition to reacting with carbonic acid , shale can also react with sulfuric acid. The strong acidity derives from oxidative dissolution of pyrite at SSHO. Similar to ankerite, pyrite, at trace levels, is depleted from soils and is only present close to the ankerite weathering front at depth. Additionally, Pennsylvania receives high rates of acid deposition, loading significant amounts of sulfuric acid at the land surface. Thus at SSHO, the dissolution of the carbonate mineral ankerite by sulfuric acid may release CO_2, instead of consuming CO_2, and may be important in the mass balance of inorganic carbon. We collected preliminary S/O isotope data to evalute the sources of sulfuric acid and quantify its involvement in shale weathering.

The global inventory of organic carbon in sedimentary rocks such as shales is greater than all the other surface reservoirs combined. Although most of the ancient organic matter is relatively refractory, it may still be altered at Earth's surface, which is important in the atmospheric CO_2 and O_2 levels on global scales. Our ongoing investigation is also focused on the degradation rates of this ancient organic matter during shale weathering and its contribution to CO_2 mass balance using C isotope analyses.

2012 Annual Reporting for SSHCZO

Discipline (Please choose team and list current team members): ***Hydrogeophysics Team***

Kamini Singha, co-I
Pallavi Chattopadhyay, postdoc
Tony Moscatello, undergrad
Marisol Williams, undergrad
Colin Anderson, undergrad
Matthew Mercuri, MS student, Temple University
Mirna Slim, PhD student, MIT
Rob Jacob, collaborator, Bucknell University
Laura Toran, collaborator, Temple University
Taylor Perron, collaborator, MIT

Research Progress:

2012

This year, we explored fracture patterns within the Susquehanna-Shale Hills Critical Zone Observatory, and considered how they may be influenced by weathering, rock structure, and stress via two steps: field observations of variable fracture orientation within the site, with implications for the spatial variability of structural control on hydrologic processes; and 2-D numerical modeling of topographic stresses, with implications for spatial variability in permeability. The interaction of gravitational and tectonic stresses with land-surface topography affects the stress field in the subsurface. Theoretical calculations indicate that topographic stresses in some landscapes may be large enough to fracture rocks, which could influence slope stability, erosion rates, and bedrock hydrologic properties. Previous studies have calculated stresses for simplified topographic profiles, predicted fracture modes and orientations, and compared these predictions with general observations of regional fracture modes and orientations. Yet there have been few direct comparisons of predicted topographic stresses and observed fractures at specific field sites. We use a numerical model to calculate the stresses induced by measured topographic profiles and specified far-field tectonic stress, and compare the calculated stress field with fractures observed in shallow boreholes. The model uses a boundary element method to calculate the stress distribution beneath an arbitrary topographic profile.

2011

Last year we completed a suite of borehole logging in wells at the Shale Hills Critical Zone Observatory, including (1) spectral gamma, which measures gamma rays emitted by isotopes of the uranium decay series, the thorium decay series, and potassium-40; (2) caliper, which measures the borehole diameter to locate broken and fractured zone; (3) fluid resistivity, which measures the total dissolved solids in the water column (4) fluid temperature; (5) heat-pulse flowmeter, which indicates the rate and direction of vertical flow within a borehole; and (6) optical televiewer, which provides a continuous, oriented, true-color 360^{o} image of the borehole wall. These data, as well as slug and pump tests to estimate the effective transmissivity of subsurface at this site, were used to determine where to conduct a sodium chloride tracer test in the shale saprolite. We additionally collected soil cores from a continuous hole that extended through the soil profile to quantify also how solute transport behavior changes with depth and weathering. We modeled a series of tracer tests in the soil columns and a field-scale tracer test using fracture flow models to compare with mobile-immobile domain models.

Significant Findings:

Based on outcrop analysis and numerical modeling of stresses, we suggest that the appropriate structural model for the watershed is steeply dipping strata with meter- to decimeter-scale folds superimposed, including a superimposed fold at the mouth of the watershed that creates more gently dipping strata. These settings would control fluid flow differently, especially within the context of the imposed stress field. When applied to topographic profiles extracted from a laser altimetry map of the SHCZO, the topographic stress model predicts considerable differences in depth profiles of stresses beneath ridgelines and valley floors. Using a representative value for the friction angle of shale, we calculate the minimum cohesion required to prevent shear failure, C_{min}, as a proxy for the potential for fracturing or reactivation of existing fractures. We compare depth profiles of C_{min} with structural analyses of image logs from four boreholes located on the valley floor, and find that fracture abundance declines sharply with depth in the uppermost 10 m of the boreholes, consistent with the modeled profile of C_{min}. In contrast, C_{min} increases with depth below ridgetops, suggesting that future analyses of ridgetop wells should observe a different trend in fracture abundance if topographic effects are indeed important. Thus, the present results support the hypothesis that topography can influence subsurface rock fracture patterns, and provide a basis for further observational tests.

The stress model also predicts a higher density of new or reactivated fractures beneath the valley bottom than beneath the ridgelines, which may in turn accelerate weathering within the valley, potentially driving a positive feedback that enhances the growth of valley relief. Continuum models describing fracturing may be appropriate for modeling flow, and that stress models may be used to help categorize zones of higher and lower permeability within similar watershed settings. Even if topographic stresses do not cause new fractures, they could activate and cause displacement on old fractures, making the rocks easier to erode and increasing the permeability. Calculated stress fields are consistent with field observations, which show significant fracturing at shallow depths within the valley, and predict a lower density of fractures at ridgetops.

2011

From the data collected at the SHCZO, we can make the following conclusions: there is substantial variability in the quality of the shale above 6-7 m, after which the shale becomes more homogeneous and less fractured. Pump and slug test indicate a hydraulic conductivity of the shale material on the order of 10-6 m/s. Many of the bedding plane partings seen in the optical televiewer data are not flowing, as indicated from heat-pulse flowmeter data, and hydraulic conductivity and porosity are as low as 10^{-15} m/s and 0.035, respectively, in the unfractured shale bedrock. Hydraulic conductivity and porosity of the shallow soils are notably higher, around 10^{-5} m/s and 0.45, respectively. Bromide breakthrough curves from the SHCZO demonstrate significant tailing in soil cores and field tracer experiments, which do not fit classical advection-dispersion processes. To quantify the behavior, numerical simulation of solute transport is carried out with both a mobile-immobile (MIM) model and a continuous-time random walk (CTRW) approach. 1-D MIM modeling results yield low mass transfer rates (<1/d) coupled with large immobile domains. MIM modeling results also suggest that immobile porosity is a combination of soil texture, fractures, and porosity development on shale fragments. 1-D CTRW results yield a parameter set indicative of a transport regime that is consistently non-Fickian within the soil profile and bedrock. These modeling results confirm the important role of preferential flow paths, fractures, mass transfer between more- and less-mobile fluid domains, and advances the need to incorporate a continuum of mass transfer rates to more accurately quantify transport behavior

within the SHCZO, as well as estimating age of water, a fundamental variable of interest to geochemists working at this site. The field-scale tracer test conducted at the soil/shale interface also shows non-Fickian behavior and the expected long tailing.

The borehole logs and fracture flow modeling both show reduced fracture spacing with depth. There is improved fit in the tail of the breakthrough using fracture flow models, but also indications that the fracture network may be nested (both large and small scale fractures).

Training/Development:

Brad Kuntz received in MS in 2011 with research at this site. Matthew Mercuri, an MS student from Temple University, is actively conducting research on site. A new postdoc, Pallavi Chattopadhyay is being supported by this grant, as well as three undergraduates.

Outreach Activities (broadening participation of under-represented / under-served groups):

A diverse group of students from Penn State and two historically black colleges (Jackson State University and Fort Valley State University) participated in a 3-week research experience at the Penn State campus from mid-May to early June. The students conducted tracer, slug, and pump tests, collected ground-penetrating radar and electrical resistivity data, and learned to use wellbore logging tools such as the optical televiewer and spectral gamma logs. They also analyzed and interpreted data, which included creating numerical models of water flow and solute transport using Comsol Multiphysics to extrapolate their field findings to other systems. The field portion of the class was held at the Shale Hills Critical Zone Observatory near the Penn State Campus. Information on the program is available at www.geosc.psu.edu/hydrocamp .

Conference Abstracts (*student author):

Singha, K. (2011). Development of a summer field-based hydrogeology research experience for undergraduates. EOS Trans. 92(53) AGU Fall Meet. Suppl. Abstract ED43B-0554.

Slim, M.*, Perron, T., Martel, S., and Singha, K. (2011). Influence of Topographic Stress on Rock Fracture: a Numerical Model for Arbitrary Surface Topography and Comparison with Borehole Observations. EOS Trans. 92(53) AGU Fall Meet. Suppl. Abstract EP23C-751.

Mercuri, M.*, Toran, L., Nyquist, J., Kuntz, B.*, and Singha, K. (2011). Using Groundwater Models to Understand the Effects of Fractures on the Transport of Solutes at the Shale Hills Critical Zone Observatory. National Annual Meeting of the Geological Society of America, Oct. 9-12, 2011, Minneapolis, MN: GSA Abstracts with Programs.

Kuntz, B.* and Singha, K. (2009). Solute transport in shale and shale-derived soils at the Shale Hills CZO. EOS Trans. AGU 90(52), Fall Meet. Suppl. Abstract. H33H-0985.

Publications (*student author):

Slim, M.*, Perron, J.T., Martel, S., Singha, K. (submitted). Influence of topographic stress on rock fracture: A numerical model for arbitrary surface topography and comparisons with borehole observations. Submitted to *Earth Surface Processes and Landforms*.

Singha, K., White, T., Perron, J.T. (submitted). Fracture Patterns and Their Relations to Groundwater Flow within the Shale Hills Critical Zone Observatory. Submitted to *Earth Surface Processes and Landforms*.

Kuntz, B.*, Rubin, S., Berkowitz, B., and Singha, K. (2011). Quantifying Solute Transport Behavior at the Shale Hills Critical Zone Observatory. *Vadose Zone Journal*, 10, doi:10.2136/vzj2010.0130, 15 p.

2012 Annual Reporting for SSHCZO

Discipline (Please choose team and list current team members): ***Geomorphology Team***

Personnel: Eric Kirby (PI), Rudy Slingerland (I), Nicole West (PhD. Candidate), Yu Zhang (PhD. Student)

Research Progress and Significant Findings:

Regolith evolution: We have expended significant effort to measure the rates of both regolith production and downslope transport on hillslopes within the SSHO. We have analyzed a total of 87 samples of meteoric ^{10}Be distributed across two hillslopes with opposite topographic aspect. Collectively our results reveal the following: 1) meteoric ^{10}Be appears to be largely sequestered in the clay-rich, upper most portions of the regolith (< ~1 m depth), 2) ^{10}Be concentrations decrease with depth, consistent with addition via surface delivery, 3) ^{10}Be inventories increase downslope, from ridgetop to valley floor positions, consistent with downslope transport. Collectively, these observations suggest to us that meteoric ^{10}Be in the SSHO can be utilized as a tracer of downslope transport (West et al., 2011; in review).

Exploiting a simple conservation of mass, the increase in meteoric ^{10}Be inventories can be used to determine rates of hillslope transport. These results suggest that 1) residence times for regolith at the ridgecrest positions in the SSHO are ~10 ka, and that 2) downslope flux appears to depend on both the topographic gradient and the depth of mobile regolith (West et al., in review). Interestingly, our results also suggest that the efficiency of hillslope transport is greater on the northern (south-facing) hillslope, an asymmetry that demands further exploration and will be the subject of ongoing studies.

Finally, comparison of these results with regolith production rates determined from the application of U-series isotopes (Ma et al., 2010; in review) suggest that 1) residence timescales are similar between the two systems and that 2) fluxes of regolith production via weathering are approximately balanced by downslope transport near the ridgecrests (West et al., in review). Further, exploration of possible scenarios with a simple model of hillslope evolution imply that response timescales to a perturbation in this landscape are expected to be long, on the order of ~1 Ma, and thus the catchment is not likely in a steady-state (Ma et al., in review).

Landscape Evolution & Sediment Transport: To understand the feedbacks between regolith transport, thickness, and weathering in the SHO, we have characterized the rates of erosion throughout the watershed and are attempting to relate these to distributions of hillslope topography and regolith thickness through a landscape evolution model. The model is based on a set of equations derived during the course of this research that describe the 3-D time-dependent evolution of the ground elevation and thickness of the regolith as functions of rock weathering, rock uplift, and hillslope sediment transport processes. The hillslope transport processes are subdivided into a lateral volumetric regolith flux that involves a number of sediment transport processes: 1) creep mechanisms, as for example by cryoturbation (freeze-thaw) and wetting and drying; 2) slow bulk down-slope sliding such as solifluction; 3) plant root decay; 4) tree throw; and 5) asymmetric bioturbation by various animals, and surface sediment transport flux by

overland flow. In addition, the model includes all of the hydrologic processes presently in PIHM (see final report by Duffy).

Training/Development:

Outreach Activities (broadening participation of under-represented / under-served groups):

Nicole West led experiences that involved outreach and engagement of both undergraduates and secondary school students. During summer 2010 – 2012 this involved participation for 1-2 days in the Hydrogeophysics Field Experience for Undergraduates (http://www3.geosc.psu.edu/hydrocamp/) run by K. Singha. During the Spring of 2011, Nicole also led a trip through the Women in Science and Engineering Day Camp for 10^{th}, 11^{th}, and 12^{th} Grade Girls. Finally, she also participated in the International Critical Zone Observatory Field School during Summer 2010 which brought in graduate students from other countries to learn techniques and instrumentation applied to Critical Zone science.

Conference Abstracts:

N. West; E. Kirby; P.R. Bierman; D.H. Rood; *Constraints on regolith formation and erosion rates at the Susquehanna Shale Hills Critical Zone Observatory, PA, determined using meteoric ^{10}Be*. Fall Meeting of the American Geophysical Union, San Francisco, CA, USA, December 04-09, 2011.

West, N., Kirby, E., Bierman, P.R., Rood, D.H.; *Using meteoric ^{10}Be to estimate soil residence times and erosion rates at the Susquehanna Shale Hills Critical Zone Observatory, PA*. European Science Foundation Research Conference on Cosmogenic Nuclides, Obergurgl, Austria, 3-8 August, 2011.

Nicole West, Eric Kirby, Paul Bierman, Dylan Rood. *Preliminary estimates of regolith generation and mobility in the Susquehanna Shale Hills Critical Zone Observatory, Pennsylvania, using meteoric ^{10}Be.* 9th International Symposium Geochemistry of the Earth's Surface (GES-9), Boulder, CO, USA, June 03-07, 2011.

West, N., Kirby, E., Slingerland, R., Ma, L., Jin, L., Brantley, S.; *Spatial variability in soil residence times in the Susquehanna Shale Hills Critical Zone Observatory, PA: Insights from multiple isotopic systems*. NSF National Critical Zone Observatory Program All Hands Meeting, Biosphere 2, Oracle, AZ, 9-12 May, 2011.

West, N., Kirby, E., Bierman, P., Rood, D., 2010, *Using meteoric ^{10}Be to track soil erosion and transport within a forested watershed, Susquehanna Shale Hills Critical Zone Observatory, PA*. Abstract EP43A-0747 presented at 2010 Fall Meeting, AGU, San Francisco Calif., 13-17 Dec.

Publications:

Nicole West, Eric Kirby, Paul Bierman, Dylan Rood (2011), Preliminary estimates of regolith generation and mobility in the Susquehanna Shale Hills Critical Zone Observatory, Pennsylvania, using meteoric ^{10}Be. *Applied Geochemistry* 26:S146–S148, doi:10.1016/j.apgeochem.2011.03.053.

Manuscripts submitted:

West, N., Kirby, E., Bierman, P., Slingerland, R.S., Ma, L., Brantley, S., and Rood, D., in review, Regolith transport on hillslopes in the Susquehanna Shale Hills Critical Zone Observatory inferred from meteoric ^{10}Be. *Journal of Geophysical Research, Earth Surface*

Ma, L., Chabaux, F., West, N., Kirby, E., Jin, L., and Brantley, S., in review, Regolith production and erosion in the Susquehanna Shale Hills Critical Zone Observatory, Part 1: Insights from U-series isotopes: *Journal of Geophysical Research, Earth Surface*

2012 Annual Reporting for SSHCZO

Choose your Discipline: Hydropedology

Participants:

- Henry Lin (PI), Professor of Hydropedology/Soil Hydrology
- Ying Zhao, Postdoc
- Li Guo, PhD student
- Will Burger, Master student
- Isaac Hopkins, Master student

Research Progress and Significant Findings:

- We have made important progress on macropore flow characterization using the X-ray tomography, ground-penetrating radar, and in situ monitoring. We have identified and proved flow in fractured shale bedrocks. The ground-penetrating radar in the soil-over-shale profile is able to see subtle moisture changes that are being used to re-conceptualize the macroporous flow dynamics in the field. Subsurface preferential flow pathways and patterns were confirmed and visualized through time-lapsed GPR investigations, which showed contrasts between shallow and deep soils. We have demonstrated the potential of geophysical tools in easing the technological bottleneck of subsurface investigation and closing data gaps at the intermediate scales.
- We have been able to fundamentally characterize the spatial-temporal patterns of soil moisture. We also carried out an intensive survey of in-situ soil hydraulic characteristics and are now able to predict the water holding and soil hydraulic properties across the watershed. These data are being used in the PIHM watershed modeling. Controls on the catchment's soil moisture spatial organization at the near-surface (< 0.3 m) change seasonally between evapotranspiration and topography; at intermediate depths (0.3 to 0.7 m) the soil moisture organization is controlled significantly by lateral subsurface flow; and the organization at deeper depths (> 0.7 m) becomes more temporally persistent and is primarily a function of both topography and soil depth.
- We have developed a toolbox called Hydropedograph for comprehensive and streamlined analysis of automatic soil moisture monitoring datasets, which allows the revealing of soil and hydrologic information in efficient and visually appealing ways. Such information will provide a valuable foundation for improving hydrologic models and their predictions as well as biogeochemical hot spots and hot moments as dictated by soil hydrologic conditions.
- We have stratified the entire catchment into five Hydropedological Functional Units (HFUs) based comprehensive datasets (LIDAR terrain attributes, soil and depth to bedrock maps, soil properties, soil moisture storages, soil water retention parameters, and others). These units reflect soil moisture storage and hydrologic processes, and will

significantly facilitate the modeling and future data collections in the Shale Hills CZO and other similar watersheds.

- Taking a holistic and evolutionary view, we have synthesized three general principles of soil change and pedogenesis in time and space (especially time). First, the principle of conservation plus evolution provides the reconciliation of fast and slow changes in multiphase soil systems. Second, the principle of dissipation plus organization explains the simultaneous occurrence of soil matrix and soil structure during pedogenesis. Third, the principle space plus time highlights the fundamental differences and intimate links between time and space. Both time and space share the common characteristics of preferentiality and threshold that govern soil functions and soil evolution. The three principles offer useful perspectives that can guide the modeling and prediction of soil change and pedogenesis.

Training/Development:

- The Shale Hills CZO has been used as a field laboratory for Soils 405/Geosci 405 Hydropedology class every fall semester. A number of field trips with students have been made to this catchment.
- Jonathan Nyquist, Chairperson and Professor, Earth & Environmental Science, Temple University, Philadelphia, PA, along with his undergraduate student Derek Lichtner, came to work with my group in July 2012 at the Shale Hills. We used a suite of geophysical tools (mainly GPR and ERT) to conduct some innovative studies of subsurface hydrology and hydrogeophysics.

Conference Abstracts:

1. Lin, H., and J. Zhang. 2011 Subsurface Lateral Flow and Hillslope Hydrologic Connectivity in the Shale Hills Critical Zone Observatory (Invited). Fall Meeting of the American Geophysical Union, San Francisco, CA, USA, December 04-09, 2011.
2. Lin, H., J. Zhang, and J.A. Doolittle. 2011. Seasonal GPR Signal Changes in Two Contrasting Soils in the Shale Hills Catchment (Invited). Fall Meeting of the American Geophysical Union, San Francisco, CA, USA, December 04-09, 2011.
3. Lin, H. 2012. Complex Soil Systems and Hydropedology: Bridging Time, Space and Systems (Invited). 2nd International Conference on Hydropedology, Leipzig, Germany, July 22-27, 2012.
4. Lin, H. 2012. Three principles and a mosaic theory of water flow in real-world soils. 2nd International Conference on Hydropedology, Leipzig, Germany, July 22-27, 2012.
5. Graham, C., and H. Lin. 2012. The Hydropedograph toolbox. 2nd International Conference on Hydropedology, Leipzig, Germany, July 22-27, 2012.

6. Thomas, E., G. Holmes, H. Lin, and C. Duffy. 2012. Spatial and Temporal Patterns of Stable Isotopes in Soil and Ground Water at the Shale Hills Critical Zone Observatory. 2nd International Conference on Hydropedology, Leipzig, Germany, July 22-27, 2012.
7. Lin, H. 2012. Looking beneath the surface for sustainability: Future of soil science in the new era (invited keynote). 12th National Congress of Chinese Soil Science Society. August 21-22, 2012, Chengdu, China.

Publications:

1. Takagi, K. and H.S. Lin. 2012. Changing controls of soil moisture spatial organization in the Shale Hills Catchment. Geoderma 173-174:289-302.
2. Lin, H.S. 2011. Three principles of soil change and pedogenesis in time and space. Soil Science Society of America Journal 75:2049–2070, doi:10.2136/sssaj2011.0130.
3. Zhao, Y., J. Tang, C. Graham, Q. Zhu, K. Takagi, and H.S. Lin. 2012. Hydropedology in the Ridge and Valley: Soil Moisture Patterns and Preferential Flow Dynamics in Two Contrasting Landscapes. In H. Lin (Editor) Hydropedology: Synergistic Integration of Soil Science and Hydrology. Elsevier. p. 381-412.
4. Doolittle, J., Q. Zhu, J. Zhang, L. Guo, and H.S. Lin. 2012. Geophysical Investigations of Soil-Landscape Architecture and Its Impacts on Subsurface Flow. In H. Lin (Editor) Hydropedology: Synergistic Integration of Soil Science and Hydrology. Elsevier. p. 413-448.
5. Guo, Li, J. Chen, X. Cui, B. Fan, and H. Lin. 2012. Application of Ground Penetrating Radar for Coarse Root Detection and Quantification: A Review. Plant and Soil (in press), DOI: 10.1007/s11104-012-1455-5.
6. Zhang, J., H.S. Lin, and J. Doolittle. 2012. Subsurface Lateral Flow as Revealed by Combined Ground Penetrating Radar and Real-Time Soil Moisture Monitoring. Hydrological Processes (in revision).
7. Zhang, J., H.S. Lin, and J. Doolittle. 2012. Soil Layering and Preferential Flow Impacts on Seasonal Changes of GPR Signals in Two Contrasting Soils. Geoderma (in review)
8. Meinzer, R., D. R. Woodruff, D. M. Eissenstat, H. S. Lin, T. Adams, K. A. McCulloh. 2012. Above- and belowground controls on water use by trees of different wood types in an eastern United States deciduous forest. Tree Physiology (in review)
9. Naithani, K.J., D. Baldwin, K. Gaines, H. Lin, D.M. Eissenstat. Xxxx. Spatial distribution of tree species governs the spatio-temporal interaction of leaf area and soil moisture across a landscape. Ecology Letter (to be submitted)
10. Baldwin, D., and H. Lin. Xxxx. Catchment-Scale Soil Water Retention Characteristics in the Shale Hills Catchment. Journal of Hydrology (to be submitted)
11. Baldwin, D., K. Naithani, and H. Lin. Xxxx. Hydropedological functional units: a novel and accurate catchment-scale characterization of soil hydrology. Journal of Hydrology (to be submitted)
12. Graham, C., and H. Lin. 2012. The Hydropedograph toolbox. Journal of Hydrology (to be submitted)

2012 Annual Reporting for SSHCZO

Discipline (Please choose team and list current team members): ***Shale Transect Team***

Research Progress:

• Oversight and participation in field study of tree throw in SSHO catchment, anticipated completion of field work = September 2012

• also see conference abstracts

Training/Development:

• Summer 2011 REU program including field visits with sample and data collection at SSHO-affiliated shale climosequence study sites in NY, PA, VA, TN and AL

• Research advisor to E. Mann senior thesis, Washington and Lee U., Bioturbation of forested shale soils by tree throw in the Appalachian Mountains

• Ongoing oversight of research activities by PSU rising senior Lauren Leidel

Outreach Activities (broadening participation of under-represented / under-served groups):

• see training: REU included participation of students from University of Puerto Rico-Mayaguez and Alabama A&M University; separate field visit and collaborative field work with students from UPRM in January 2011

Conference Abstracts:

Dere, A.L., Leidel, L., and White, T., 2011, Shale weathering on slopes across a latitudinal climosequence, AGU abstract B33G-0547,

Mann, E.A., Downey, K., Dere, A.L., and White, T., 2011, Bioturbation of forested shale soils by tree throw in the Appalachian Mountains, AGU Abstract B33G-0548.

Anderson et al., 2012, An international initiative for Critical Zone Observatories (CZ)) and research along global environmental gradients, Eurosoil 2012

Dere, A., Reynolds, B., White, T., and Brantley, S., 2012, A comparison of shale weathering rates inferred from catchment fluxes versus soil chemistry at Plynlimon, Wales, Goldschmidt

Publications:

Dere, A. L., White T. S., April R. H., Reynolds B., Miller T. E., Knapp E. P., McKay L. D. and Brantley S. L. (2012) Climate dependence of feldspar weathering along a latitudinal gradient. *Geochim. Cosmochim. Acta.* Submitted.

2012 Annual Reporting for SSHCZO

Discipline (Please choose team and list current team members): ***Collaborating Research Team***

Anne Kraepiel, Princeton University
Ashlee Dere, Penn State University
Beth Herndon, Penn State University
Susan L. Brantley, Penn State University

Research Progress:

In September 2011, we began experiments at the Susquehanna Shale Hills Observatory (SSHO) CZO with PI Sue Brantley and graduate student Ashlee Dere. We collected the organic layer at three valley floor sites within the watershed that correspond to sites where soil chemistry was measured by Jin et al., 2010 (north swale valley floor (NSVF), north planar valley floor (NPVF), and south planar valley floor (SPVF)). In the laboratory, the organic soil from each sampling site was homogenized and 4 different treatments were added to 20 g of organic soil in glass jars to test for metal limitation: water, water + Mo, water + sucrose, and water + sucrose + Mo. (Sucrose was added as a carbon source to stimulate N_2 fixation activity in the soil community.) Each treatment was repeated four times.

Nitrogen fixation activity was determined by incubating the samples with acetylene for 8 hrs and measuring the production of ethylene over time (measurements at 0 hrs, 4 hrs and 8 hrs). Ethylene concentrations in the incubation jars over time were measured by Ashlee Dere on the GC at Princeton University in October 2011. The main goal of this field effort was to set up the experimental protocol in the Brantley lab to be prepared to repeat the field work in the summer of 2012. The experiment was repeated in July 2012 using samples collected from the same sampling sites previously studied and with four treatments all including a carbon source (sucrose): C, Mo+C, V+C, and Fe+C. Headspace samples collected during this second experiment were also measured on the GC at Princeton University in July 2012.

In addition to the incubation studies of N_2 fixation, we have also been collaborating with Ashlee Dere and Beth Herndon, both graduate students working with Sue Brantley, on the cycling of Mo and V in soils and in leaves at SSHO.

Significant Findings:

Results of the incubations experiments completed in the fall of 2011 showed no production of ethylene from any of the four treatments, suggesting N fixation was not occurring during the fall. Preliminary results of the study completed in July 2012 shows that N fixation is in fact

measurable at all three footslope sites studied at SSHO, but there appears to be no treatment effect on N fixation.

The depth profiles of Mo and V concentrations in SSHO soils, which were measured at Penn State, show that Mo is enriched in the upper soil layer (Fig. 1). While some of the soil profiles also show enrichment for V in the top soil layers, it is not as marked or as systematic. There are two competing hypotheses to account for the higher concentrations of Mo in the top soil layers:

1- Tree leaves are enriched in Mo and are a source of Mo to the top soil layers as they fall on the ground.
2- High Mo concentrations in the top soil layers are the result of anthropogenic atmospheric inputs as Mo is present in ppm concentrations in coal and is enriched on the fine particles of ash. Indeed, previous work by the Brantley group (Herndon et al., 2011) has shown atmospheric industrial inputs originating from major steel and industrial centers in Pennsylvania over the past century are responsible for the high manganese concentrations measured in SSHO soils.

We also measured Mo and V in tree leaves collected at the SSHO in June, July, August and September 2011. The concentrations of Mo and V measured in the leaves were much lower than in soil layers (Table 1). Canopy leaves are thus not a source of Mo to the soil, and the high Mo concentrations measured in the top soil layers are likely to originate from anthropogenic inputs, as is the case for Mn.

Training/Development:

Ashlee Dere (PSU graduate student) was trained to use the GC at Princeton University.

Outreach Activities (broadening participation of under-represented / under-served groups):

NA

Conference Abstracts:

NA

Publications:

In prep

Collaborating Institution Progress Report 2011-12

Monitoring time-lapse changes in soil moisture during artificial infiltration with geophysical methods

Derek Lichtner, Jonathan Nyquist, Laura Toran, Li Guo, and Henry Lin
Temple University and Penn State University

Artificial infiltration experiments were conducted at the Shale Hills Critical Zone Observatory monitored with various geophysical methods to improve knowledge of the hydrological processes in the near surface soils during infiltration. The geophysical methods included time-lapse electrical resistivity tomography (ERT) and ground wave ground-penetrating radar (GPR). In addition to acquiring standard 2D radargrams, two GPR techniques known to respond directly to water content were tested: mapping changes in the direct transmitter to receiver ground wave velocity, and changes amplitude of the reflection off of the surface measured by elevating the antennae. These methods were assessed for their ability to observe changes in soil moisture content during infiltration at a small, 1 m by 3 m survey plot on a forested hillslope in Weikert series soil. Artificial infiltration events consisted of the addition of 26.5 or 53 L (7 or 14 gal) of water at constant head to a 1 m long, ~10 cm deep trench situated 20 cm upslope of the survey plot, promoting subsurface flow. Hilbert-transformed time lapse GPR images revealed significant increases in signal amplitude due to increased water content (Figure A). In addition, small-scale heterogeneity of moisture distribution showed consistent patterns in pre-infiltration radargrams, surface reflection amplitude maps, and ERT profiles. The calculation of volumetric water contents from the GPR methods was problematic owing to difficult calibrating measurements. Qualitatively, the time-lapse images showed rapid infiltration, with moisture increases observed immediately after infiltration as far as 80 cm downslope. Within 15 minutes the geophysical signatures of infiltration decreased, with a majority of measurements within 20-40% of pre-infiltration values after 1 hour. Additionally, the infiltration of a second pulse of water suggested interflow pathways corresponding to already wetted flow paths and microtopography. The microtopography was assessed using travel time of the surface reflection GPR from a platform at an average elevation of 0.7 m above the ground to map centimeter-scale changes in topography. Conductivity (ERT), ground wave arrival time, and surface reflection amplitude all indicated changes in soil moisture that were useful in characterizing the soil's heterogeneity, rapid infiltration, and flow path variability.

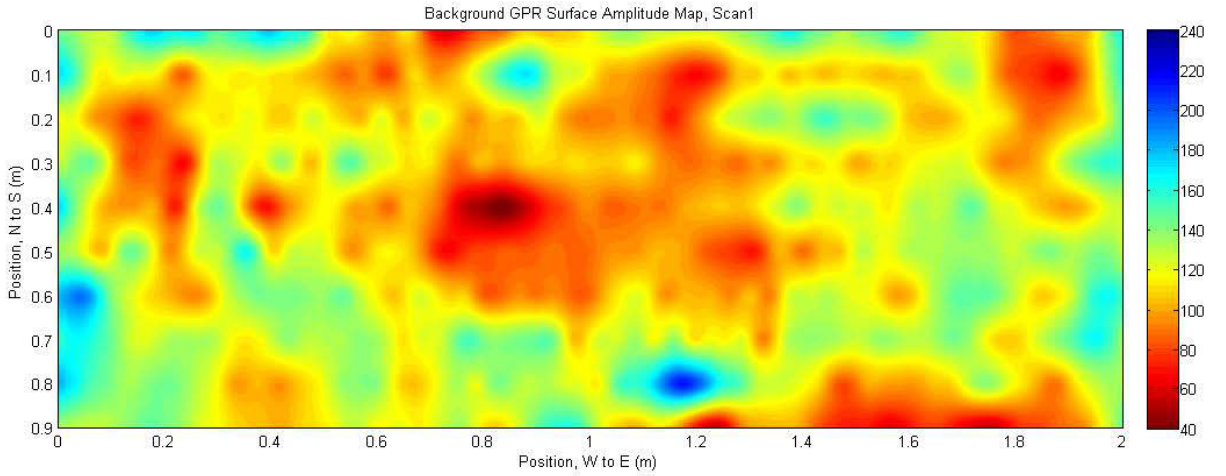

Figure A: Background surface reflectance GPR before the test. Amplitude scale (units arbitrary to show full color scale) is related to moisture content (not quantitative for this survey) such that red and yellow colors are drier areas and blue and green are wetter areas.

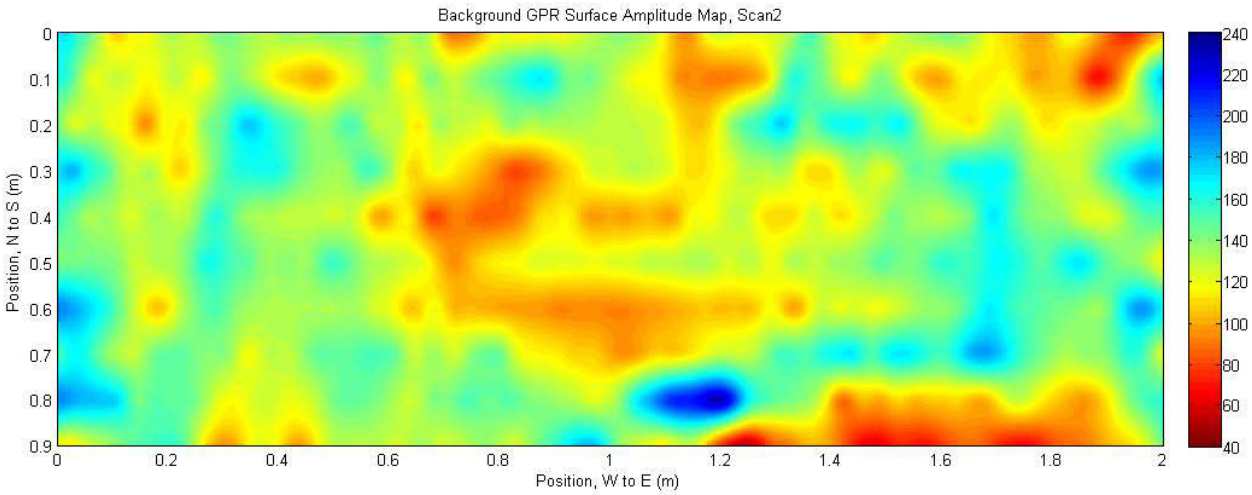

Figure B: Survey immediately after infiltration of 26.5 L of water. Moisture increased throughout, shown by reds fading except in the SE corner.

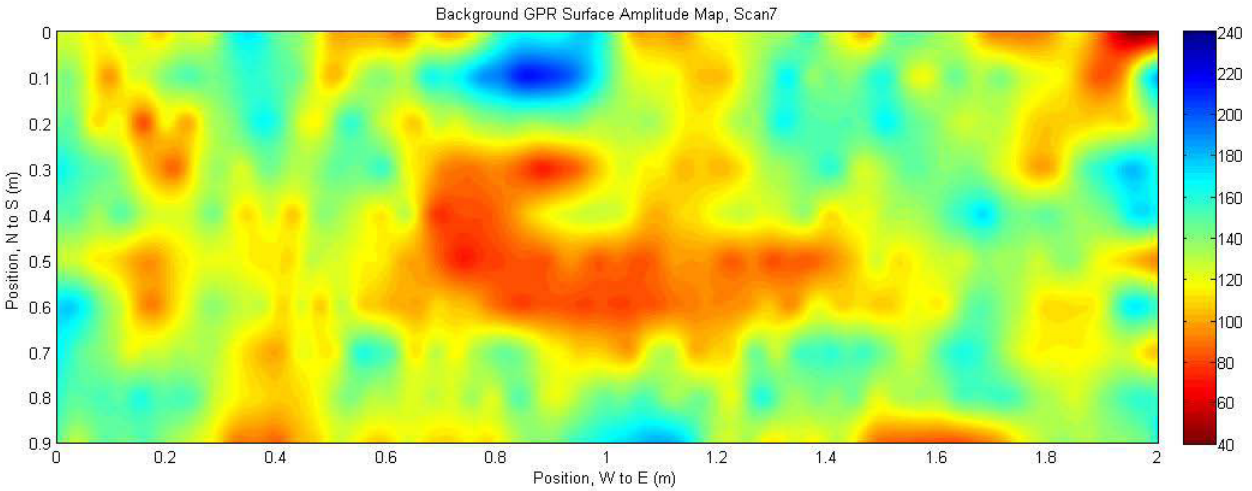

Figure C: Survey immediately after the second infiltration of 53 L. Moisture increased in the SE corner after the second infiltration, a low point in the microtopography, but otherwise the overall pattern was similar to prior survey.

2012 Annual Reporting for SSHCZO

Discipline (Please choose team and list current team members): ***Hydroinformatics Team and Isotope Hydrology Team***

Personnel: Chris Duffy (PI), G. Bhatt (PhD. 2012), Evan Thomas (M.S. Candidate), Xuan Yu (PhD. Candidate), Yu Zhang (PhD. Candidate), Lorne Leonard (PhD. Candidate), George Holmes (M.S. 2010), Ryan Jones (B.S. Candidate), Colin Duffy (technical staff)

Research Progress and Significant Findings:

Stable Isotope Hydrology: The stable isotope network has carried out a comprehensive measurement campaign to determine space-time stable isotope signatures for 18O and D2H in all stores of the watershed and to elucidate fluid pathways and time scales from source to sink. The hydrology, ecology and geochemistry team have all participated in the sampling effort. The measurement system collected and processed nearly 6000 water samples over the last 3 years including: 6 hourly precipitation, daily stream samples, daily groundwater samples at 2 sites, and weekly to bi-weekly soil water and observation well water samples. The fundamental results of 3 years of investigation have allowed a new interpretation of the "old water- new water" paradox (Kirchner, 2003, Hyd. Proc. 17, 871–874) that experimentally demonstrates the seasonal and event mixing patterns of hillslope waters that explain the phenomena. Recharge predominantly occurs in the cold or non-growing season with a unique isotopic signature of snowmelt and winter precipitation, while summer precipitation is almost completely utilized by the vegetation except during very heavy rain events. The controlling transport mechanism relies on the macropore-matrix threshold property of the soil. During summer soil moisture is low and well below the macropore flow threshold, making all water held in the soil matrix available to plants. In the cold season plants are inactive and soil moisture accumulate in the soil matrix eventually reaching the threshold to allow fast infiltration below the root zone and flow accumulation and flow downslope. Fluctuations in the water table exert a strong control on soil moisture and stable isotope ratios below 1-1.5 m. Within the zone of seasonal water table fluctuation, infiltrating water mixes with laterally flowing water from the upper hillsopes. The zone of water level fluctuation is important to the seasonal flushing of 18O and D2H, where 18O and D2H accumulates during the summer months and is flushed during the late winter and spring when recharge is high and the shallow water table is high. We note that this concept of seasonal flushing of solutes from the lower soil was proposed experimentally for the evolution of sulfate at the nearby Leading Ridge watershed by Lynch and Corbett (WRR, 25, 1989) and incorporated in a model for concentration-discharge of sulfate by Duffy and Cusumano (WRR, 34, 1998). Holmes (MS, 2010) in his MS thesis has further tested this conceptual model for 18O and D2H at Shale Hills and a paper is in development that uses the Shale Hills data to resolve a conceptual model of the site flow system. Thomas (M.S. 2012) has carried out a detailed analysis of the soil profile with a paper to be submitted to the Vadose Zone Journal, Dec. 2012. An interesting result of Thomas's work is that 18O and D2H in the soil profile are also strongly influenced by seasonality, and the soil profiles of 18O and D2H appear to mimic the thermal soil profile.

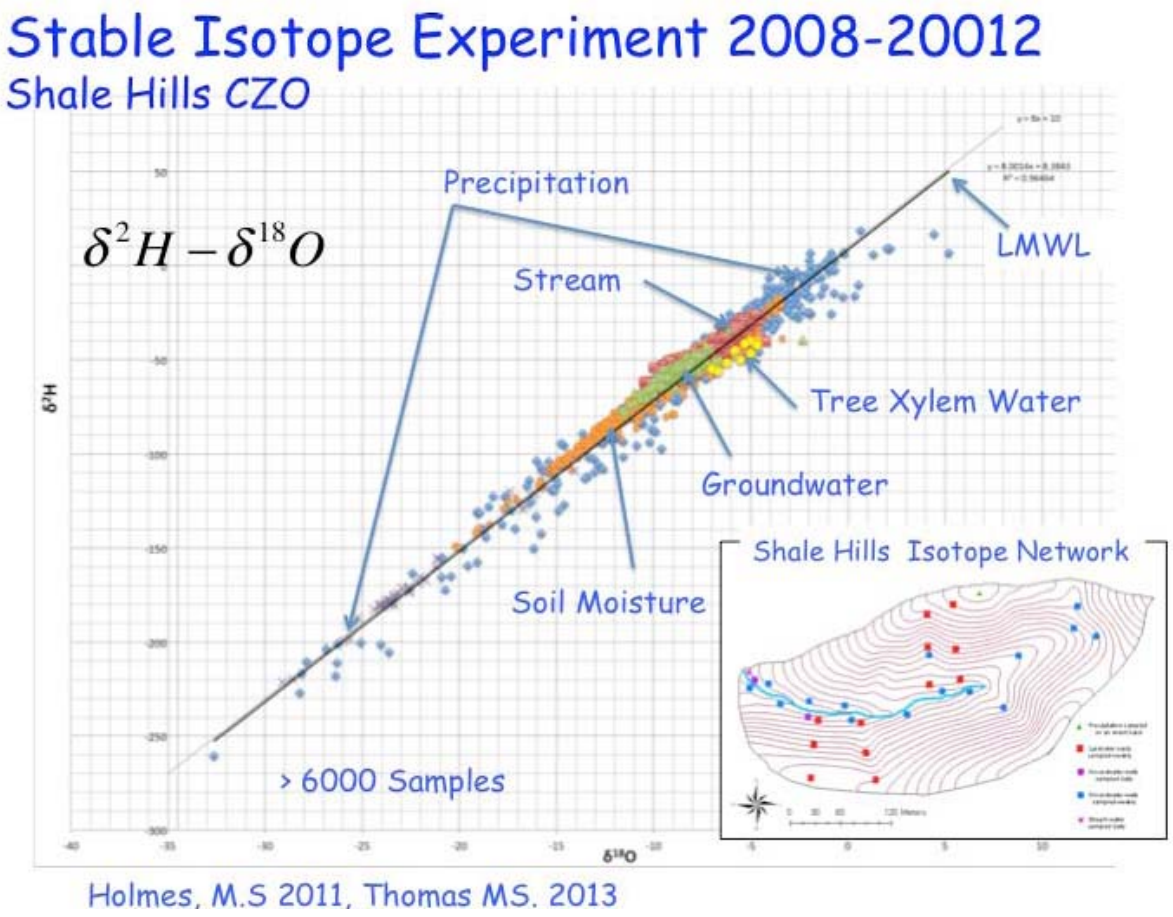

Figure 1. Stable isotope ratios for precipitation, soil water, groundwater and stream water at the Shale Hills catchment.

Catchment Hydrology and Transport Modeling: Over the last 4 years hydrologic and transport modeling has developed along both theoretical and experimental lines. We briefly review the progress made over the last 5 years.

Xuan Yu (PhD candidate 2013) has developed a Shale Hills catchment simulation that focuses on the hyporheic zone and the spatially distributed exchange of surface water and groundwater. This relationship is complex function of channel-hillslope terrain and climate conditions. For example during extreme rainfall events from tropical storms during the late summer and fall, the ephemeral stream that drains the Shale Hills catchment is dry and the water table within the hyporheic zone (near channel saturated zone) is well below the land surface. The previous growing season creates a large soil moisture deficit and a relatively deep water table in the hyporheic zone. Under these conditions it takes a very large precipitation event to produce runoff. On the other hand during the late winter and early spring, the lack of evapotranspiration, melting of snow and frost creates a high water table condition in the hyporheic zone which can in turn produce very large runoff events. Thus seasonal differences in the water table-stream stage relation serves as an important control on the magnitude of hyporheic surface-groundwater exchanges. Figure 2 illustrates pre- and post storm Hyporheic Flow Exchange for a 2009 rain event. A paper Yu, Bhatt and Duffy is in preparation for submission in Dec. 2012.

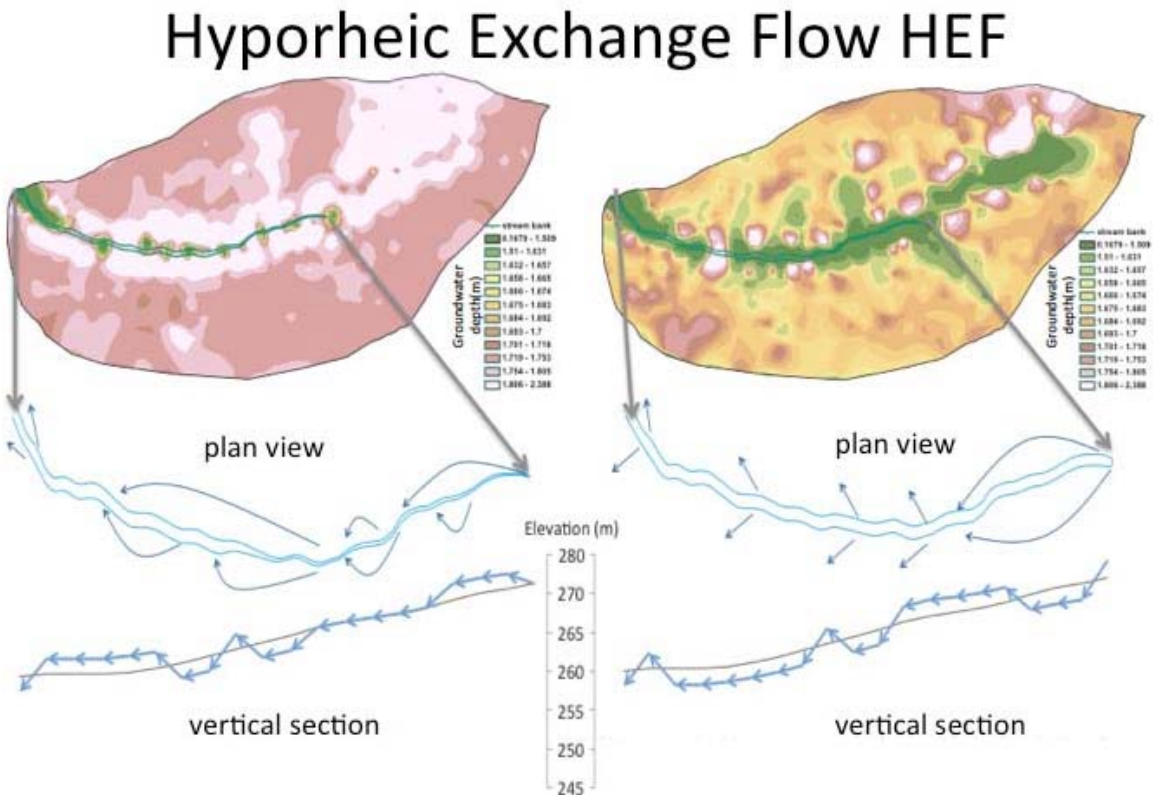

Fig. 2. Simulated spatial distribution in hyporheic surface-groundwater dynamics at Shale Hills before (left) and after (right) a precipitation event in 2009 showing the complex spatial pattern of flow direction within the hyporheic zone.

Xuan Yu (PhD candidate 2013) has also developed a multi-scale calibration strategy for our distributed catchment model PIHM (The Penn State Integrated Hydrologic Model), which supports the use of national data products for topography, soils, vegetation, hydrogeology and climate/weather. The method, referred to as CMA (Covariance Matrix Adaptation) evolution strategy, is used to optimize the parameters linked to the processes with fast hydrologic response (e.g. precipitation events), followed by optimization of parameters associated with seasonal hydrological processes (evaporation/transpiration/snowmelt). The calibration strategy was used for parameter estimation for the numerical simulation for 3 watersheds in central PA: the Susquehanna-Shale Hills Critical Zone Observatory (SSHCZO); Young Womans Creek watershed (YWC); and Little Juniata River watershed (LJR). These watersheds are located in Central Pennsylvania, USA and vary dramatically in the drainage area (Figure 3). One of the objectives was to examine the use of national data products as initial- or a-priori parameter estimates for scaling up from small scale testbeds such as Shale Hills to larger catchments. A paper has been submitted to Computers in Geoscience (under review Nov. 2012).

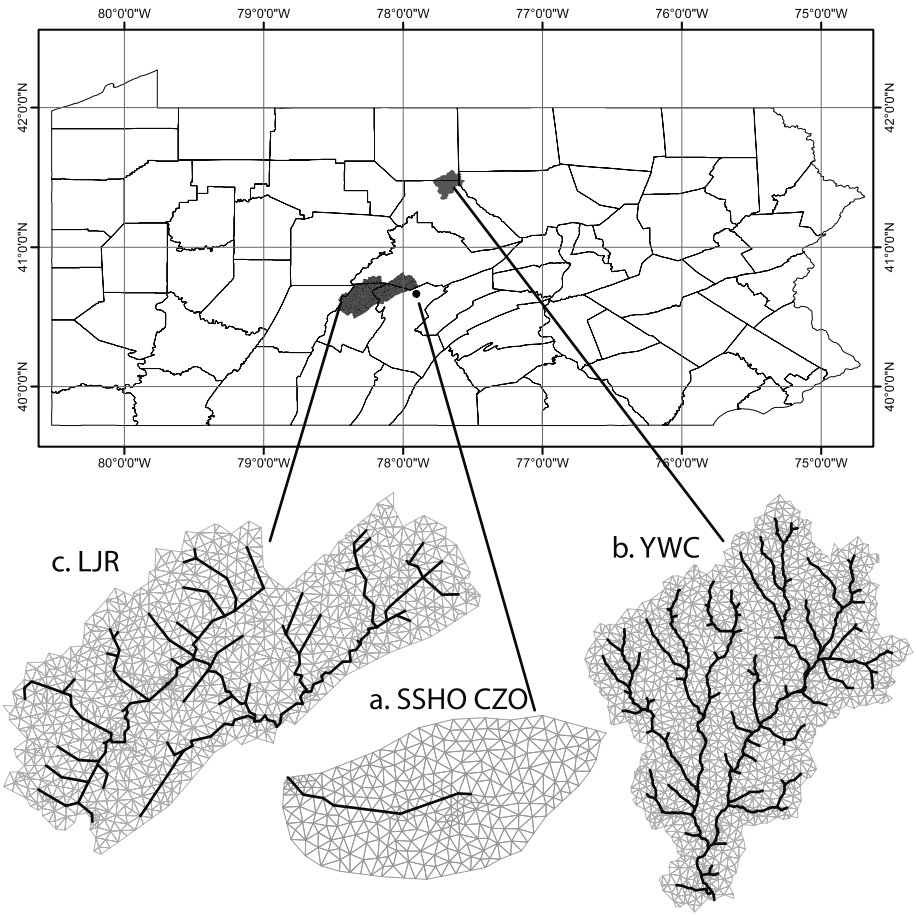

Figure 3 Watersheds used for testing and scaling up the calibration strategy from small-scale testbeds to larger scale catchments with all cases using national geospatial data. A) Shale Hills CZO, b) Young Woman's Creek, c) Little Juniata River basin.

PI Duffy authored a paper describing a new theory for modeling the dynamic age of solutes and isotopes in watersheds (Duffy, Hyd. Proc. 24, 2010). In this context "age" is defined as the time since the water parcel carrying an environmental tracer entered the system as precipitation. The paper first examines the theoretical basis for "age" models of environmental tracers and how dynamic flow and transport processes affect the estimated age dynamics. Solutions for the age of watershed runoff are presented for storm events, seasonal and stochastic tracer inputs. Several theoretical and practical issues are presented: (1) The low-order moments of the age distribution function are sufficient to construct a dynamical system for the mean age and concentration under steady or transient flow conditions. (2) Solutions to the coupled system of equations for flow, concentration and age show that 'age' of solutes stored within the watershed or leaving the watershed is a dynamic process which depends on flow variations as well as the solute or tracer dynamics. (3) Intermittency of wetting and drying cycles leads to an apparent increase in the tracer age in proportional to the duration of the 'dry' phase. (4) The question of how mobile/immobile flow may affect the age of solutes is examined by including a low permeable, passive store that relaxes the well-mixed assumption. (5). A spatially distributed advective and dispersive transport solution for age evolution over a simple 1-D hillslope is developed to demonstrate the age theory for a distributed source

of water and tracer, and the solution is shown to have very similar input–output behaviour when compared to the volume-average model for comparable parameters.

Gopal Bhatt (PhD in October 2012) made a contribution to CZO modeling. Bhatt's dissertation research includes a modeling study of 175 km^2 Shaver Creek watershed, which includes the Shale Hills site. The study conducted a 30 year downscaling of NLDAS-2 climate reanalysis data (NOAA). In this study, the impacts of global climate change on the Shaver's Creek watershed were assessed. Multiple climate model simulations for the past, present, and future periods over the Susquehanna-Shale Hills region were used from the Phase 3 of the Coupled Model Intercomparison Project (IPCC), World Climate Research Programme (WCRP). These results were collected and analyzed by Ray Najjar.

Shavers Creek is located in Centre and Huntingdon Counties, PA, in the Ridge and Valley eco-region [Figure 4] and surrounds the Shale hills Critical Zone Observatory. Shavers Creek flows south into the Juniata River and is part of the Susquehanna River Basin and the Chesapeake Bay Watershed. Catchment elevations in the 163 sq. km. watershed range from 192 to 710 meters above the mean sea level [Figure 4 (a)]. The land use in the valleys of the watershed is mixed primarily with farming and small towns with significant amounts of forests that cover the run along the ridges. Land-use in the Ridge and Valley region is a mixture of forested and agricultural lands. Typically, the land-use in this region has forests on the ridges and agricultural and developed lands in the valley floors. According to Myers et al. (2000) approximately 64% of the region is forested, 30% agricultural, and 5% is developed, which accounts for small towns and roadways. Very limited area in the region can be truly considered as undisturbed because most of the Ridge and Valley areas have experienced anthropogenic disturbances due to logging all across Pennsylvania in the early 20^{th} century [Whitney, 1990]. According to National Land Cover Database (NLCD) 2006 [Fry et al., 2011] major land cover types in Shaver's Creek watershed are deciduous forest (103 sq. km.), pasture/hay (21 sq. km.), cultivated crops (13 sq. km.), evergreen forest (11 sq. km.), developed open space (7 sq. km.), and mixed forest (6 sq. km.) [Figure5].

Analysis of the long-term variability in hydroclimatic responses across the landscape reveals the complex coupling between hydrologic processes and competing relationship between changes in precipitation and temperature projections by IPCC. Figures 6 (a) – (b) show the water-budget of the entire watershed corresponding to historical and IPCC scenario simulations. Water-budgets have been shown as percentages of net precipitations. Although, all the water-budget components have increased during the 'scenario' in terms of magnitude, their relative contributions as the percentage of net precipitation is non-linear and complex. It revels the interdependence of changes in the magnitude and temporal distribution of climate conditions to the hydrologic properties of the watershed and prevailing antecedent hydrologic conditions.

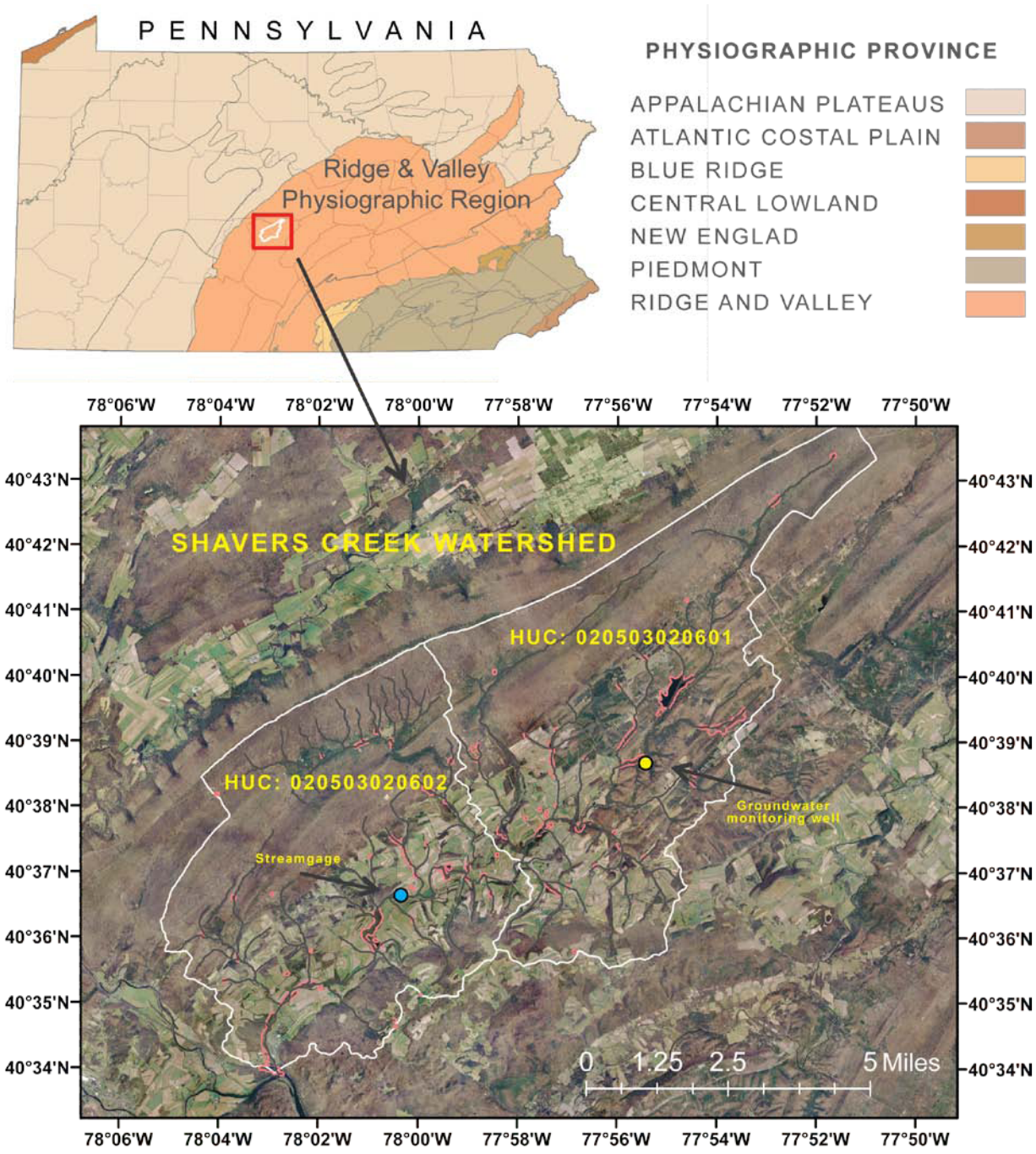

Figure 4: Shaver's Creek watershed in the Ridge and Valley eco-region Center and Huntingdon counties, PA. The study watershed (163 sq. km) comprise of two level 12 Hydrologic Unit Codes.

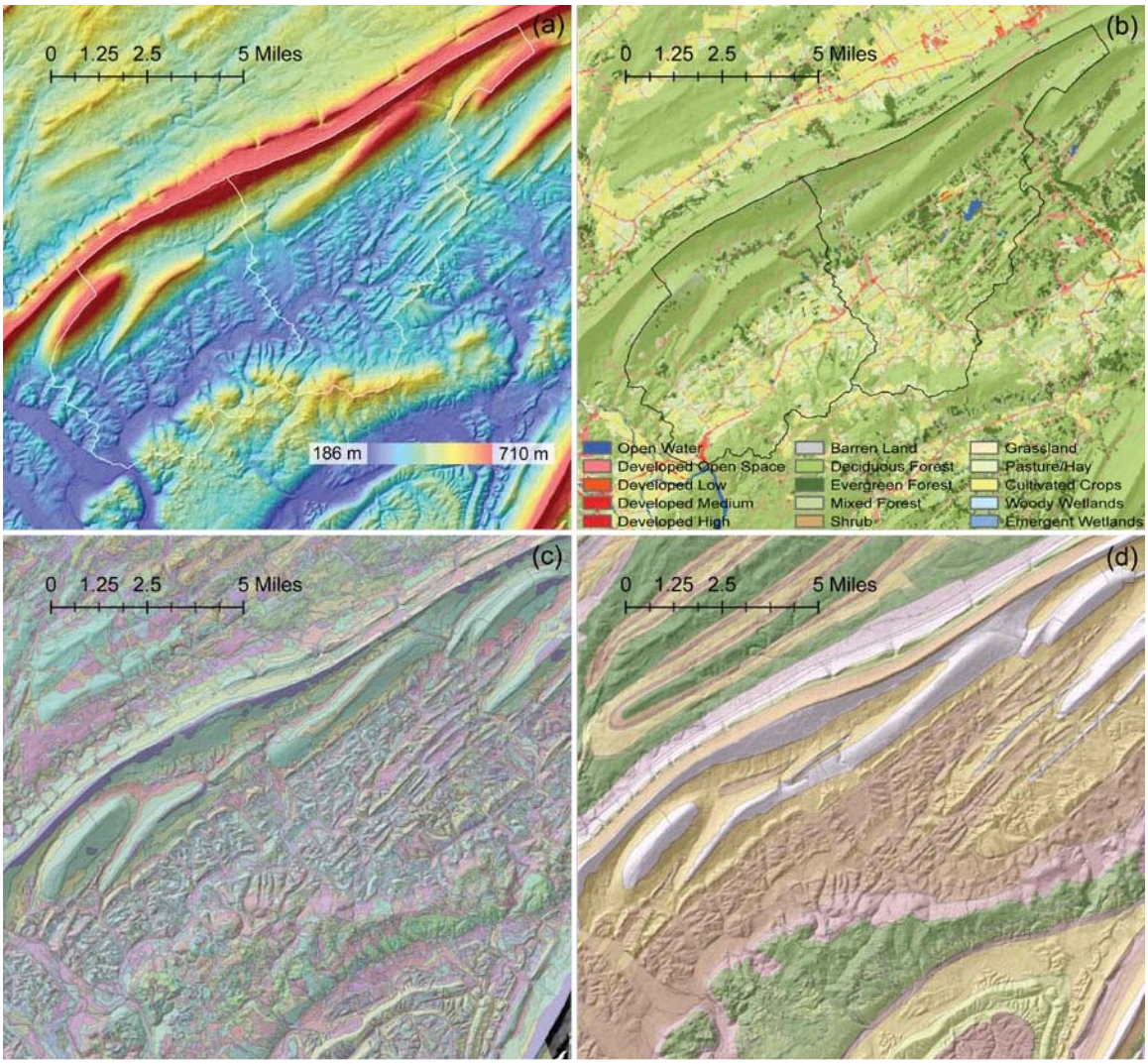

Figure 5: Geospatial data products used in the development of physics based distributed hydrologic model application. (a) 10-m (1/3 arc second) USGS Digital elevation model (DEM) data of the study watershed. (b) National Land Cover Database (NLCD) 2006 land cover / use of the region. (c) Soil Survey Geographic (SSURGO2) soil cover classification of the watershed. (d) Spatial variability in the underlying geology.

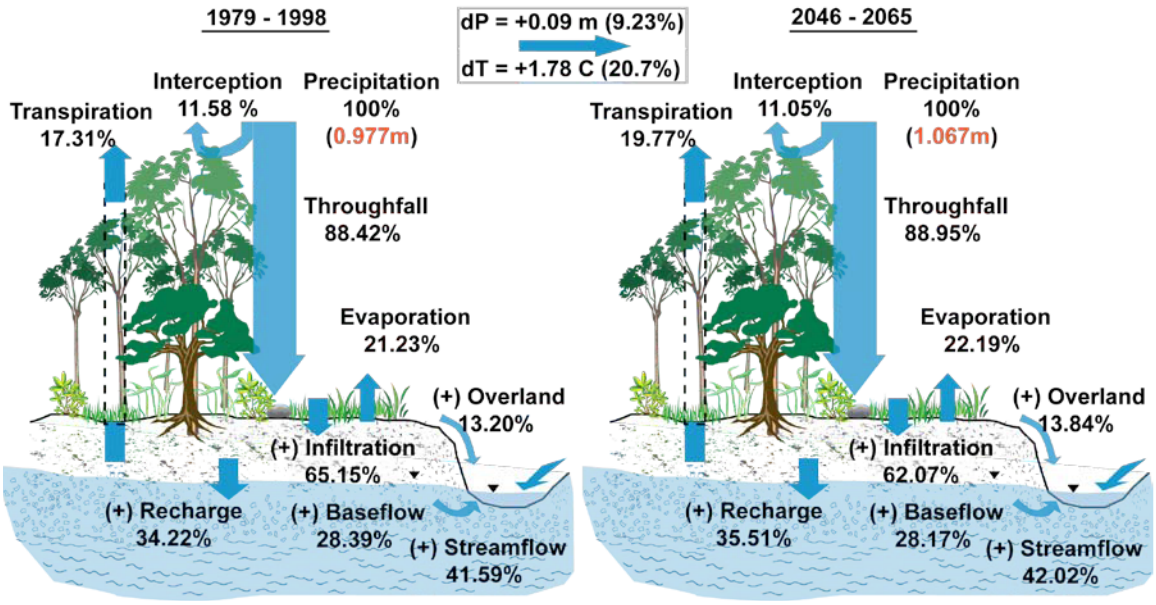

Figure 6: Water-budget components of the Shaver Creek watershed as a percentage of total precipitation during respective simulation periods (i.e. 1979-1990 and 2046-2065). According to IPCC A2 emission scenario projections '2046-2065' is 9.23% wetter and 20.7% warmer on average over the two decades in the Susquehanna River Basin compared to '1979-1990'.

Wireless Sensor Network (WSN). Research concerning the use of research-grade digital sensors in a WSN at Shale Hills is coming to completion. We have designed and built a basic system with modest support from PSIEE, ICS, NSF-CZO and NOAA based on the Libellium Wasp-mote WSN for low-power wireless support of sensor nodes for large arrays of multi-state digital sensing. A board was designed and software implemented that will support research grade digital SDI-12 sensors for pressure, moisture, wind, temperature, electrical conductance, relative humidity, infra-red skin temperature and acoustic snow depth sensors. The WSN is fully integrated with standard Campbell Scientific data loggers and standard CSI radio communications. The boards have been tested and the first batch is being manufactured for delivery in late Nov. 2012. Our first operational field deployment of the array will be for a groundwater level, soil moisture, electrical conductance and temperature with 2-way web access and sensor control at Shale Hills. The WSN will form the basis for a "relocatable array" we have proposed for the CZO scale-up during the next 5 years of the research. The boards and WSN were designed and implemented by Colin Duffy (CZO staff Tech) and Joe Portelli (design engineer, SEDTAPP program College of Engineering).

Training/Development:

Reactive Transport Modelling, Chania, Crete, 16th to 19th July 2012. More than 50 graduate students and faculty form around the world participated in the workshop. The Penn State team of Duffy, Bhatt and Yu gave a 2 day hands on introduction to using PIHM for modeling flow and transport processes.

Outreach Activities (cross-site research and broadening participation of under-represented groups):

PIHM model development team, the SoilTrEC cross-site modeling team. Working with Tim White, SoilTrEC scientists, Daniel Moraetis and Nikos Nikolaidis we have implemented catchment models for the White mountains in western Crete under an European Commission funded effort to support international CZO's. Under the same project we have completed a model of the Lysina catchment in the Czech republic working with Pavel Kram and Anna Lamacova. A draft paper is in preparation. We are also working with Stefano Bernasconi Damma and Maria Andrianaki to develop a catchment model for the Damma glacier in Switzerland. We are in the early stages of developing a model for the Plynlimon catchment, Wales and the Fuchsenbigl CZO in Austria.

Conference Abstracts:

C. Duffy; L.N. Leonard; L. Giles; G. Bhatt; X. Yu; *The Virtual Watershed Observatory: Cyberinfrastructure for Model-Data Integration and Access* (Invited) Fall Meeting of the American Geophysical Union. San Francisco, CA, USA. December 04-09, 2011.

G. Bhatt; X. Yu; C. Duffy; A. Kemanian; M. Kumar; L.N. Leonard; *'Age' of water: A physics based, fully coupled, distributed model for watershed assessment.* Fall Meeting of the American Geophysical Union. San Francisco, CA, USA. December 04-09, 2011.

C. Duffy; X. Yu; G. Bhatt; M. Kumar; *Wetlands Response to Climate Change across Susquehanna River Basin*. Fall Meeting of the American Geophysical Union. San Francisco, CA, USA. December 04-09, 2011.

X. Yu; C. Duffy; G. Bhatt; M. Kumar; *Hyporheic Zone Study at Susquehanna/Shale Hills Critical Zone Observatory.* Fall Meeting of the American Geophysical Union. San Francisco, CA, USA. December 04-09, 2011.

Publications:

Shuangcai Li and Christopher J. Duffy. 2011. Fully coupled approach to modeling shallow water flow, sediment transport, and bed evolution in rivers. *WATER RESOURCES RESEARCH* VOL. 47, W03508, doi:10.1029/2010WR009751.

Holmes III, G.H., Usings δ^2H AND δ^{18}O To Determine The Flowpaths and Timescales of Water at the Susquehanna Shale Hills Critical Zone Observatory, Master of Science, Pennsylvania State University, p. 70.

Duffy, C.J., Y. Gil, E. Deelman, S. Marru, M. Pierce, I. Demir, G. Weiner, 2012, Designing a Road Map for Geoscience Workflows, EOS, TRANSACTIONS AMERICAN GEOPHYSICAL UNION, VOL. 93, NO. 24, PAGE 225, 2012doi:10.1029/2012EO240002

Banwart, S. S. M. Bernasconi, J. BloemW. Blum, Miguel Brandao, S. Brantley, F. Chabaux, C. Duffy, P. Kram, G. Lair, L. Lundin, N. Nikolaidis, M. Novak, P. Panagos, K. V. Ragnarsdor, B. Reynolds, S. Rousseva, P. de Ruiter, P. van Gaans, W. van Riemsdijk, T. White, B. Zhang2011, Vadose Zone Journal, Soil Processes and Functions in Critical Zone Observatories: Hypotheses and Experimental Design. 10:974–987. doi:10.2136/vzj2010.0136

Shuangcai Li, Christopher J. Duffy , Fully-Coupled Modeling of Shallow Water Flow and Pollutant Transport on Unstructured Grids Original Research Article El Sevier, Procedia Environmental Sciences, Volume 13, 2012, Pages 2098-2121

Christopher Duffy, Lorne Leonard, Gopal Bhatt, Xuan Yu and Lee Giles, 2011, Title: Watershed Reanalysis Towards a National Strategy for Model-Data Integration, 2011 Seventh IEEE International Conference on e-Science, 5-8 December 2011 Stockholm, Sweden. L. O'Conner Ed. IEEE Computer Society, DOI 10.1109/eScienceW.2011.32, pp. 61-65

Catchment Outreach Activities **Annual Report 2012**

3rd Quarter 2011:

- STEM academy with State College High rising freshmen, mid-August

4th Quarter 2011:

- Alex Carone, undergrad, is sampling the Marcellus sites with Jennifer and Katya
- Jennifer sampled the bulk density at Marcellus site
- We had the geomorphology class (GEOSC 340) collect hillslope profile and soil depth data (9/24/2011) along the north ridge/slope of SSHO.
- Soils 405/Geosc 405 (Hydropedology) class visited the SSHO twice (at the beginning and the end of the fall semester) to learn and investigate the landscape-soil-hydrology-ecology relationships (Henry Lin)
- Hosted a visiting scholar from the Chinese Academy of Sciences (Dr. Jialiang Tang) and involved this scholar in the hydropedology research in the SSHO (Henry Lin).
- Jason Kaye will host the Fall Biogeochem Field Trip to the catchment on October 15th.

1st Quarter 2012:

- Diana Karwan, Post-doctoral Research Scholar Stroud Water Research Center, successfully acquired cross-site CZO funding to characterize sources of suspended sediment at SSHCZO.

2nd Quarter 2012:

- ***Geosc 483*** will be making gravity, resistivity and seismic measurements along 3 subparallel profiles starting near the stream by Kamini's wells and heading up the slope to the north.
- ***Biology*** – PSU Altoona scientists, Jim Julian and Bradley Ross, along with Susan Yetter (PSU Geography, UPark) will be expanding investigations within the SSHO catchment to include biodiversity assessments of marco-biology along the lysimeter transects, total ornithological assessment, and a stream macroinvertebrate assessment, respectively. Work began the week of May 21st and continues until completed.
- ***Geophysics*** – Dr. Laura Toran, Dr. Jon Nyquist, and Derek Lichtner (Temple University faculty and undergraduate student) have begun a summer research project in conjunction with Henry Lin. Lichtner is currently visiting the catchment for an introduction and to work with Kamini's undergraduate hydrogeophysics field workshop. Nyquist will visit the CZO June 12-14 to work

with Henry Lin and Jim Doolittle to familiarize himself with the field site and begin the GPR field work. Lichtner, who recently was awarded the David C. Bartel Scholarship from SEG for geophysics undergrads, will be in the catchment beginning July 15 for a couple of weeks to learn GPR techniques and complete the GPR survey.

- ***Annual CZO Seminar Series*** – The CZO hosts Ron Amundson, Director for the Division of Ecosystems Science University of California – Berkeley. Dr. Amundson will present "Hillslope Soils and Life" from 4:00 - 5:00pm on April 12th in 22 Deike Building. On Friday, a field trip to the CZO and beyond will leave campus at 11:30am and return late in the afternoon.

3rd Quarter 2012:

- Continued GPR surveys by Dr. Jon Nyquist, and Derek Lichtner (Temple University faculty and undergraduate student) beginning July 15th.
- Continued leaf-litter surveys along lysimeter transects for macrofauna by Jim Julian, PSU Altoona Biologist.
- Received proposal for research by PhD student Christopher Fernandez and advisor Dr. Roger Kiode, Intercollege Graduate Program in Ecology, PSU University Park.
- Received proposal for research by PhD Candidate Christine Rollinson and advisor Dr. Magot Kaye, Intercollege Graduate Program in Ecology, PSU University Park.

In the Press **September 2012**

August 30, 2012 – International Innovation Publishes August Edition with Special Focus on US Critical Zone Program

The European magazine, International Innovation Environment, published bi-annually, focused the August issue on "How science must lead the way to a healthier planet." Within this edition, the Special Focus Section introduces readers to the concepts behind the Critical Zone Observatory National Program followed by interviews and overviews from each of the Principal Investigators and their CZOs, respectively. To read the articles, just click here!

August 27, 2012 – CZO PhD Candidate Ashlee Dere wins award at Goldschmidt 2012

It is with great pleasure we announce that Ashlee Dere, PhD Candidate Geosciences, has been awarded Winner of the poster and oral presentation competition at Goldschmidt 2012 in Montreal, QC, CA. Dere's presentation entitled "A comparison of shale weathering rates inferred from catchment solute mass balance versus soil profile chemistry at Plynlimon, Wales" was delivered in the "Dynamics of Continental Weathering" Session during 22nd V. M. Goldschmidt Conference. 24 - 29 June.

July 19, 2012 – CZO PI takes Penn State Hydrologic Model to Chania, Crete

In a four day workshop focused on reactive transport modeling, PI Chris Duffy and his research group teach the finer points of the Penn State Integrated Hydrologic Modeling System (PIHM) to 40 student-researchers. During the workshop, students were introduced to the unique aspects of PIHM. Hands on training sessions allowed the participants to work through the processing steps, one by one, using data from the Shale Hills CZO as well as the much larger Young Womans Creek watershed. The development of these two model applications creates the tools necessary to model a watershed of any size.

June 4, 2012 – Collaborating Undergrad Awarded Society of Exploration Geophysicists Scholarship

Derek Lichtner, undergraduate at Temple University, has recently been awarded the David C. Bartel Scholarship from SEG. Lichtner has participated in the Summer 2012 Hydrogeophysics Field Workshop hosted by Kamini Singha, PSU Professor of Geosciences, and will begin his summer research project in the catchment July 15th.

May 29, 2012 – PSU Altoona Biologists and Temple University Geophysicists join the catchment

Dr. Jonathan Nyquist and undergraduate student, Derek Lichtner, both of Temple University, have begun a summer research project in conjunction with Dr. Henry Lin to collect Ground Penetrating Radar (GPR) surveys across the catchment. PSU Altoona biologists, Dr. Jim Julian and Brad Ross, along with Susan Yetter, PSU Riparia, are conducting marco-biological

assessments along the lysimeter transects, total ornithological assessment catchment-wide, and a stream macroinvertebrate assessment, respectively.

May 16, 2012 – NSF Investment in SSHCZO Leads in New Directions

Our "Planet at a Crossroads," a National Science Foundation SEES (Science, Engineering and Education for Sustainability) Discovery Article, has just been released. The SEES project is designed to advance science, engineering, and education to inform the societal actions needed for environmental and economic sustainability and sustainable human well-being. Specifically, the SSHCZO research has improved our interpretation of the chemistry and flow of groundwater in shale and has direct application to assist with the development of new resources for energy while maintaining healthy ecosystems. To read the collection of articles, just click the link.

May 14, 2012 – The catchment hosts members of Penn State satellite campuses, Mont Alto and Altoona

Students from PSU Mont Alto Forestry Academy, one of the first forestry schools in the nation, were given an overview of the CZO, past and present, last Friday while touring the Penn State forestlands as part of the "Forest Technology" curriculum. Twelve students along with faculty members, Dr. Elizabeth Brantley and Craig Houghton were in attendance. In addition, Dr. Jim Julian, PSU Altoona Biologist, and colleagues will begin macroinvertebrate and stream assessments late this week.

April 12th – 13th, Ron Amundson, UC – Berkley, visits PSU and CZO for Annual Seminar Series

The CZO in conjunction with the Department of Crop and Soils, Department of Geosciences and the Earth and Environmental Systems Institute hosts Ron Amundson, Director for the Division of Ecosystems Science University of California – Berkeley. Dr. Amundson will present "Hillslope Soils and Life" from 4:00 - 5:00pm on April 12th in 22 Deike Building. On Friday, a field trip to the CZO and beyond will leave campus at 11:30am and return late in the afternoon. All are welcome!

March 21, 2012 – CZO to join PHENOCAM - An ecosystem phenology web camera network

Dr. Andrew Richardson (http://www.oeb.harvard.edu/faculty/richardson/) has provided a high resolution video camera (StarDot NetCam SC Megapixel Hybrid IP Camera) that is mounted at the eddy flux tower at the Shale Hills CZO. This camera monitors changes in phenology (leaf emergence and fall leaf senescence are basic examples) and snow cover with greater temporal resolution than is logistically feasible for individual observers. This camera also helps support a student initiated project to monitor phenology in central PA (*PennPhen*, www.sites.google.com/site/psuphenology), contributes data to a larger network of camera based phenology observations (http://phenocam.sr.unh.edu/), and provides data that supports ongoing projects at the CZO.

March 15, 2012 – The Penn State Environmental Geophysics class (Geosc 483) goes to the catchment

The Geosc 483 geophysics course, taught by Dr. Andrew Nyblade, will begin work in the catchment today for hands on experience using geophysical techniques. Students will be making gravity, resistivity and seismic measurements along three profiles from the stream northward up slope. Common applications for the techniques include estimating depth to bedrock and the water table, as well as identifying faults and fracture zones, and delineation of geologic boundaries.

December 21, 2011 – January edition of CSA News features the Critical Zone and Observatories

CSA News magazine, published for members of American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, features cover story Investigating the Earth's Critical Zone in the January 2012 issue. Interviews with Co-PI's Susan Brantley and Henry Lin illustrate the need for Critical Zone science and observatories, specifically. As observatories are established on a global scale (in Europe, China and Australia), the hopes of a new soil science grow. To read the entire article, click the link above.

December 16, 2011 – Cross CZO research proposal awarded to study sediment transport mechanisms

The call for cross-CZO / cross-disciplinary research proposals was successfully answered by Dr. Diana Karwan, Post-Doctoral Fellow at the Christina River Basin CZO in Delaware. Her research will apply sediment-fingerprinting techniques developed at the Christina CZO to test hypotheses within the Susquehanna Shale Hills CZO. Cross site comparisons of watershed materials will enable quantification of watershed suspended load, more fully evaluate the watershed budget for weathering products (e.g. iron and aluminum), and provide data on which sediment transport models can be built. Congrats Dr. Karwan and welcome to the catchment!

December 12, 2011 – NSF article highlights new research project stemming from SSHCZO

Progress in Critical Zone research at the Susquehanna Shale Hills CZO has provided "a better interpretation of the chemistry and flow of groundwater in shale," says Enriqueta Barrera, program director in NSF's Division of Earth Sciences. Moving forward with a grant from NSF's Science, Engineering and Education for Sustainability (SEES) Research Coordination Networks (RCN) activity, CZO Co-PI Susan Brantley is developing a Marcellus Shale Research Network. To read the entire story, click here: NSF Discovery Article.

November 1, 2011 – *Science Nation* video features Shale Hills Critical Zone Observatory

Resources like water can be taken for granted until changes in supply are observed. As global warming accelerates, some areas experience increases in rainfall while others experience longer or more severe drought. Researchers at Penn State are "Following the Water" to better understand these conditions. To do so, they are tracking the flow of water from rain and snow

through the rock, soil and plants. To view the Science Nation video, click here: "Want to Understand Dought? Follow the Water!"

October 11, 2011 – CUAHSI to feature Earth Observatories in this year's cyberseminar series

This academic year (2011-2012), CUAHSI (Consortium of Universities for the Advancement of Hydrologic Science, Inc) will focus their cyberseminar series on "Earth Observatories for Interdisciplinary Science: Reports from Critical Zone Observatories and Water, Sustainability and Climate Studies." The fall lineup includes Suzanne Anderson (Boulder Creek CZO), Jon Chorover (Jemez-Catalina CZO), Chris Duffy (Shale Hills CZO), and Mike Goulden (Southern-Sierra CZO) with the remaining 2 CZOs featured in the spring. For details on how to attend the online seminars click here: Fall 2011 Cyberseminars.

October 4, 2011 – Collaborator from Princeton University begins field research in the catchment

Anne Kraepiel, of Princeton University, visited the SSHCZO last week to begin a laboratory incubation experiment measuring nitrogen fixation rates in the watershed. Tree leaves were collected from three sites on the valley floor and incubated with four different nutrient treatments. Results from the experiment will be used to calculate rates of bacterial nitrogen fixation. Future work will include measurements of Mo concentrations to better understand the role Mo and other metals, such as V and Fe, play in the biogeochemical cycling of N in temperate forest ecosystems.

September 28, 2011 – CZO PI featured in flood forecasting article for Research | Penn State

Do we predict floods well? This question and several others were asked of Chris Duffy, Professor of Civil Engineering. His response, several factors go into forecasting and computer models need data. In light of the recent flooding of our Susquehanna River, Duffy states "we will not improve flood and drought prediction in the U.S. until we begin to look beyond the stream and include measurements that tell us about the state of the entire watershed." To read the entire article, click here: Research | Penn State.

September 1, 2011 – Special Section of Vadose Zone Journal focuses on CZO research

As Critical Zone science takes root in the array of disciplines comprised in Earth science and initial observatory results become available, a special section of the Vadose Zone Journal has been published to highlight current and future research efforts. In this edition, contributions to hydrology, biogeochemistry and the interplay between both hydrology and biogeochemistry are reviewed. A total of 14 manuscripts were selected to illustrate advances in the study of the near-surface terrestrial environment. The Table of Contents is available here: Vadose Zone Journal.

July 6, 2011 – Deployment of Non-Invasive Soil Moisture Instrumentation a Success

Postdoctoral Research Associate Dr. Trenton Franz, Department of Hydrology and Water Resources at the University of Arizona, has successfully installed the COSMOS probe at Shale Hills. The probe consists of two gas filled chambers and a datalogger, which count and record the number of cosmic-ray neutrons, respectively. Neutrons counted over a period of time are correlated to the volumetric water content over a 700 m diameter circle and 10-70 cm of soil. Our instrument is number 39 of the initial 50 to be deployed across the continental United States, with all real-time data freely available to the public to view and download at http://cosmos.hwr.arizona.edu/Probes/probemap.php.

June 4, 2011 – Nine Undergraduates Complete the 3rd Annual Hydrogeophysics Field Camp

The 3rd annual hydrogeophysics field camp, offered by Dr. Kamini Singha, has come to completion. Nine undergraduate participants, from rising sophomores to rising seniors, spent three weeks collecting a wide range of data from the CZO and nearby Lake Perez. New data included images from the optical televiewer and gamma logs, GPR, pumping/slug tests and electrical resistivity measurements. Using COMSOL, a multiphysics software designed for analysis and visualization, the students built numerical models and learned the intricacies of field data interpretation.

June 1, 2011 – CZO REU Summer Field School Brings 7 Undergraduates from Collaborating Institutions

This summer, the CZO Field School adds a new dimension with two weeks of field work followed by one week of data analysis. Undergraduate participation includes two students from the University of Puerto Rico Mayaguez, one student from Alabama A&M Univ., one from University of Tennessee, one from Washington & Lee University, one from Juniata College and one from Penn State. Field work, organized by Dr. Tim White and Ashlee Dere (PhD Candidate), will complete research at the CZO Shale Transect sites in New York, Virginia, Tennessee and Alabama. Work will include sampling and digging soil pits on hillslopes, GPR transects, shale fracture density and tree throw measurements.

May 16, 2011 - National CZO All Hands Meeting hosted by University of AZ takes place at the Biosphere 2

Team members from each of the 6 national CZO's gathered at the Biosphere 2 to share research progress and develop new directions for cross CZO research. The program included 2 full days of oral and poster presentations in addition to a tour of the Santa Catalina Mountains including stops at Soldier Canyon, Mt. Bigelow eddy covariance tower and Marshall Gulch catchment experiments. Created as a model for Biosphere 1, our Earth, the Biosphere 2 was an ideal locale to host scientists who study the zone where rock meets life, The Critical Zone. To learn more about Biosphere 2.....click here.

March 21, 2011 - The COsmic-ray Soil Moisture Observing System (COSMOS) is coming to the catchment

A non-invasive, intermediate scale soil moisture measurement network consisting initially of 50 probes is upscaling to 500 probes distributed across the contiguous USA. Recent research progress has determined soil moisture can be inferred from measurements of cosmic-ray neutrons that are generated within soil and emitted back to the atmosphere. Probe deployment is targeted for summer 2011 with the real-time data available to for the public to view.

February 22, 2011 - The passing of Kelly Cherrey has touched the SSHCZO community

It is with sadness yet great appreciation we pay tribute to one of our own, Kelly Cherrey. Cherrey worked tirelessly to build the communication and backbone physical structure at the Shale Hills watershed. He made things work and work well, which is an art unto itself. Through his work, the CZO team gained reliability in data and communication that we are using and building on today. We are grateful for all of the hard work Kelly contributed mostly on his own and to our benefit, for which we say - Thank you. You left this Earth much too soon and it enlightens all of us of how very precious every life is. For words most fitting by Alfred Lord Tennyson.....click here.

December 20, 2010 - Environmental DNA from SSHCZO soil to be analyzed in international study

The DNA Sequencing Research Group (DSRG) of the Association of Biomolecular Resource Facilities (ABRF), an international group of scientists from 140 core laboratories, is conducting a comparison of high-throughput parallel sequencing technologies on selected environmental DNA samples. On the recommendation of Mary Ann Bruns, PSU Associate Professor of Crop and Soil Sciences, soil DNA from the SSHCZO (Rushtown series, A/A2 horizons) will be included in the study. According to Bruns, the wealth of soil biogeochemical data collected at the CZO site adds value to the "metagenome" information obtained by DSRG. Provision of key soils information is consistent with the mission of the Genomics Standards Consortium for international DNA sequence databases. The Bruns lab will obtain DNA using two different soil extraction methods. Deb Grove, Director of the Huck Institutes of Life Sciences Genomics Core Facility at Penn State, will be involved in high-throughput sequencing of two "pools" of environmental DNA-small subunit ribosomal RNA genes and shotgun metagenome fragments. Results will be presented at 2011 ABRF meeting Feb 19 in San Antonio, TX.

December 13, 2010 - Paper highlights manganese contamination in soils

Elizabeth Herndon, PhD candidate in Geosciences, and co-authors have determined that iron furnaces in operation during the 1700s and 1800s may have left toxic levels of manganese in Pennsylvania soils. Researchers identified the manganese enrichment after sampling various sites within the Susquehanna Shale Hills CZO. By examining soil chemistry from around the world, the team concluded the increased manganese levels were the result of industrialization. For the full story, visit: Penn State Live - SciTech or NSF News.

November 11, 2010 - Best Paper Award for 2010 SSSA Forest, Range and Wildland Soils Session

Danielle Andrews, PhD candidate in Crop and Soil Science, was recognized for her research accomplishments at this year's Soil Science Society of America annual meeting in Long Beach, CA. Her paper entitled "*The Carbon Story at the Shale Hills Critical Zone Observatory*" was selected as the best paper in Session 328: Soil Carbon Dynamics. Her accomplishment will be rewarded with a certificate from the Soil Science Society of America in the S7 Business Meeting at next years SSSA Meeting in San Antonio, TX.

October 25, 2010 - Shale Hills CZO featured article in Research|PennState

Members of the University Research Magazine Association and the National Association of Science Writers focused a September article on the Critical Zone, specifically Shale Hills. Weekly features, designed to inform and inspire the University community, highlight current research by telling the story. Interviews with Dr. Chris Duffy and Dr. Susan Brantley shed light on the various research questions posed by different disciplines and how the watershed has sparked interest from other Penn State researchers. For the complete article, visit Research|Penn State or download the pdf Critical Zone.

October 8, 2010 - CZO hosts students and faculty from University of Pittsburgh

The Pitt Chapter of IAHR, the International Association of Hydro-Environment Engineering and Research, spent a day in the catchment visiting with Professor Christopher J. Duffy, Civil and Environmental Engineering, about ongoing research projects, instrumentation and technology. This student group has specific interests in research with engineering applications. Although the engineers focus is primarily water resources and sediment transport, forward progress suggests the interactions of river and coastal hydraulics, risk analysis, energy, environment, disaster prevention, and industrial processes must be taken into consideration when addressing future societal needs. Students are seeking to expand their knowledge base through interactions from neighboring disciplines, with Shale Hills an ideal laboratory for collaborative projects.

August 10, 2010 - State College Area School District teams with PSU for STEM studies

The SCASD has formed a summer STEM Academy, a new initiative that uses field and experiential instructional techniques to engage our students in STEM areas. The goal of this Academy is to improve the middle school to high school transition by engaging students early in their high school career with academic experiences of the highest caliber. Incoming first year high school students along with pre-service and master teachers will learn how to measure and monitor soil moisture, collect GPS data, install a weather station, and observe the hydrologic cycle through rain and groundwater simulation systems. Data collected from school premises will be compared to data streaming from the catchment to develop STEM curriculum modules, thus engaging students in relevant, project-based collaborative research.

August 9, 2010 - PI's from CZO organizing AGU session on hydrologic processes

As scientists from all over the world converge in San Francisco, CA this fall for the annual meeting of the American Geophysical Union, PI's from Penn State (Chris Graham, Kevin Dressler, and Chris Duffy) will convene a hydrology session "The Role of Isotope Networks in

Environmental Observatories." This session is envisioned as bringing together researchers who are using stable isotope measurements (water, carbon and other isotopes) in the fields of surface hydrology, ecohydrology, tree physiology and groundwater hydrology. It is of special interest to anyone who is working at some of the hydrological observatory networks (such as CZO, LTER, NEON etc…). Abstracts for presentations are now being accepted on topics ranging from determining flow patterns and flow rates to the design and implementation of isotope networks. Additional session details can be found at 2010 AGU Fall Meeting. Search for session H84.

August 2, 2010 - Sanders Seminar Series hosts Jaime J. Carrera-Hernández, PhD

The Departments of Anthropology and Civil and Environmental Engineering will host Jaime J. Carrera-Hernández, PhD, Professor of Applied Geosciences at Instituto Potosino de Investigación Científica y Tecnológica (IPICyT) in San Luis Potosí, México on August 4, 2010. Dr. Carrera is interested in the analysis of the impact that human activities have on the hydrological cycle and on the development of tools to analyze water management policies. He is also interested in the use of remotely sensed imagery for the development of physically-based, distributed hydrogeological modeling along with the use of Relational Databases for the efficient development of these models, as exemplified in the Basin of Mexico Hydrogeological Database (BMHDB). Carrera has applied some of these tools to estimate potential aquifer recharge in the Basin of Mexico and to analyze the impact that urban growth has had on aquifer recharge.

July 26, 2010 - Airborne LiDAR survey completed for Susquehanna Watershed

Last week, NCALM, NSF's National Center for Airborne Laser Mapping completed an airborne laser mapping flight over the Susquehanna/Shale Hills Critical Zone Observatory. The area flown was ~200 km^2 for the purpose of a leaf-on survey of the Shaver Creek watershed which includes the Shale Hills catchment. The goal of the survey is to identify tree species distribution, leaf area and abundance over the watershed. Extensive ground-based validation sites were surveyed during the campaign in conjunction with LiDAR survey. This most recent fly-over will provide high-resolution imagery at the 0.5 m scale. Data collected from this flight will be available for use in conjunction with maps of the regional geology, soils, instrumentation site surveys and PASDA (the Pennsylvania Spatial Data Access). An interactive version is currently under development with accessibility from this website in the future.

June 29, 2010 - Multiscale Modeling Workshop will be hosted by Shale Hills CZO

As part of our Critical Zone cross-site activities, the Shale Hills CZO will be holding a workshop August 2-4, 2010 titled: Multiscale Modeling Using the Penn State Integrated Hydrologic Modeling System (PIHM). PIHM is multi-process, multi-scale hydrologic modeling tool, where the physical processes are fully coupled using the semi-discrete finite volume method (http://www.pihm.psu.edu). This workshop will provide hands-on experience in using PIHM for modeling watershed dynamics. Participants will learn to use a customized GIS interface to PIHM (called PIHMgis) for *i*) automated ingestion of model parameters from national databases, *ii*) conditional domain decomposition of the model domain, *iii*) performing multistate simulations and calibration and *iv*) visualization of model results. A goal of the workshop is to stimulate cross-site CZO modeling activities.

June 1, 2010 – 1st CZO Field School Brings 16 Participants from 14 Institutions across 9 Countries

The first week of a two week field school opened on Monday with 16 participants, including both undergraduates and graduates/post-docs. Field school attendees will experience a range of activities such as: discussions of Critical Zone science, SSHO and CZO modeling, laboratory tours, regional geology, field instrumentation and GIS applications. Each of the disciplines with active projects in the catchment will provide hands-on activities to introduce and train the junior scientists. The overarching goal of the school is to develop a new international interdisciplinary cadre of Critical Zone scientists.

May 25, 2010 - Collaborations with outside institutions to begin Spring 2011

Princeton scientists, Dr. Francois Morel and Dr. Anne Kraepiel, will collaborate at Shale Hills to advance our understanding of nitrogen fixation in the laboratory and the catchment. The fertility of ecosystems is often limited by the amount and availability of nitrogen. PI's will investigate how aerobic soil bacteria acquire metals and how the kinetics of that reaction limit N2 fixation in terrestrial systems.

April 16, 2010 - Hydrogeophysics Field Camp Returns for 2nd year

This summer, nine undergraduate students will be taking Geosc 397A: The Hydrogeophysics Field Experience with Dr. Kamini Singha from May 17 to June 4. Four students will be from Penn State, two from Jackson State University in MS and three from Fort Valley State University in GA. These students will combine field experimentation, data analysis, and numerical modeling with in-class instruction during the three-week program to develop and test hypotheses regarding the processes controlling solute transport. The Shale Hills Critical Zone Observatory near Shaver's Creek Environmental Center is the "home base" for this field camp due to its proximity to the Penn State campus and its facilities.

Environmental consultants, government employees, and researchers from small companies will be coming through the field camp to demonstrate hydrogeophysical field equipment and highlight jobs in environmental fields. The students will learn basics of pumping tests, tracer tests, and slug tests as well as have exposure to geophysical techniques such as electrical resistivity, wireline logging, and ground-penetrating radar. Any students, staff, or faculty, interested in hydrology or environmental science are welcome to attend field demonstrations if they are interested; please contact Kamini Singha at kxs55@psu.edu.

April 1, 2010 - Terrestrial LIDAR Comes to the Catchment

PI's Eric Kirby and Rudy Slingerland and PhD student, Nicole West, hosted A.J. Herrs (University of Kansas) from March 21st – 23rd to conduct high-resolution imaging of micro-topography along hillslopes within the Shale Hills CZO catchment. Herrs used a terrestrial, tripod-mounted LiDAR (Light Detection and Ranging) to scan the topography of the catchment from multiple points; geodetically referenced prisms and reflectors were used to tie multiple scans into a single image. Measurements from the ground-based LiDAR are collected at much

finer resolution (decimeter scale) than airborne LiDAR (approximately 1.5 meter). This resolution will enable the researchers to characterize pit-and-mound topography characteristic of soil mixing by tree-throw.

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Meinzer, F.C., D.R. Woodruff, D.M. Eissenstat, H.S. Lin, T. Adams, K.A. McCulloh. Above- and belowground controls on water use by trees of different wood types in an eastern United States deciduous forest. *In review, Tree Physiology*

Naithani, K.J., Baldwin, D., Gaines, K., Lin, H., Eissenstat, D.M. Spatial distribution of tree species governs the spatio-temporal interaction of leaf area index and soil moisture across a landscape. *In review, Ecology Letters*

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Holmes III, G.H., Usings δ^2H AND $\delta^{18}O$ To Determine The Flowpaths and Timescales of Water at the Susquehanna Shale Hills Critical Zone Observatory, Master of Science, Pennsylvania State University, p. 70.

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