Preview of Award 1331726 - annual Project Report

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Using the Susquehanna - Shale Hills CZO to Project from the Geological Past to the Anthropocene Future
PD/PI Name:

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- Tess A Russo, Co-Principal Investigator

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Accomplishments

*** What are the major goals of the project?**

We are developing models to use in earthcasting the CZ. Over short timescales and large spatial extents, we use an atmosphere-land surface model that couples meteorological and ecological processes with hydrological and biogeochemical processes in regolith by parameterizing i) depth to bedrock; ii) permeability; iii) water uptake by roots; iv) distribution of fractures and macropores. Over long timescales and smaller spatial extents, we are developing models that predict these regolith characteristics. Both the land-atmosphere and the regolith models describe changes in water, energy, sediment, and solute (WESS) fluxes, but from 10^{-3} y (water) to 10^{6} y (regolith). For the sedimentary rocks underlying our CZO, we use these models to explore how the geological past has impacted the structure of regolith, and, in turn, how this structure contributes toward controlling today's fluxes.

Our group is structured into 9 teams, identified by 9 driving hypotheses, as described below.

H1 Team Goal: The H1 team is testing the following hypothesis while developing as complete a dataset as possible that allows understanding of fracture distributions, using measurements of cosmogenics to assess erosion rates; using boreholes, field observations, and geophysics for sandstone and shale lithologies in the Shavers Creek watershed and surrounding relevant sites: H1. ***Feedbacks among frost shattering, weathering reactions, and the evolution of topography have resulted in an asymmetric distribution of fractures that in turn controls the observed differences in fluid flow in the subsurface between the sun-facing and shaded sides of catchments within Shale Hills and much of the Susquehanna River Basin.*** *(Kirby, Bierman, DiBiase, West, Denn, Brantley, Lin)*

This team lost K. Singha in year one because she moved to Colorado School of Mines. Roman DiBiase, new faculty in geomorphology at Penn State, has joined the team. In addition, postdoc Brian Clarke did not produce any papers from his year and a half project on geophysical work; therefore, post-doctoral associate N. West has joined the team to finish the geophysical work. During this year, West has continued the work started by Brian Clarke. Al Denn (MS candidate, UVM) has joined the team and collected over 60 samples for cosmogenic isotope analysis.

H2 Team Goal: This team will test the following hypothesis while developing as complete a dataset as possible that allows understanding of the distribution of soil gases, soil moisture, and organic acids and their effects on weathering of regolith in the Shavers Creek watershed: H2. ***The distribution of weathering reactions across a landscape can be described as a function of biotic and abiotic production and consumption of acids (CO_2, DOC) and O_2.*** *(Kaye, Brantley, Eissenstat, Li)*

H3 Team Goal: Team H3 will test the following hypothesis while developing as complete a dataset as possible that allows understanding of the distribution of tree roots and their effects on water cycling, weathering, fungal distribution, macropores, erosion, and tree throw in the Shavers Creek watershed: H3. ***Trees with deeper roots (oaks) are associated with less frequent tree throw, slower hillslope erosion rates, fewer vertical macropores, faster weathering at depth, and deeper regolith than trees with shallower roots (maples).*** *(Eissenstat, Davis, Kaye, Brantley)*

H4 Team Goal: This team will test the following hypothesis while developing as complete a dataset as possible that allows understanding of the distribution of regolith and macropores in regolith and their controls on fluid flow among the lithologies within the Shavers Creek watershed. H4. ***Macropores are important in controlling fluid flow and chemistry in soils derived from various lithologies, but the nature and effects of these macropores differ significantly among shale, calcareous shale, and sandstone.*** *(Lin, Duffy, Eissenstat, Davis)*

H5 Team Goal: Team H5 will test the following hypothesis while developing as complete a dataset as possible that allows understanding of the controls on regolith chemistry and mineralogy using a reactive transport model developed for simulation of regolith formation: H5. ***Greater evapotranspiration on the sunny, north side of Shale Hills means that less water recharges to the stream, explaining why Mg and other cations are less depleted in the regolith on the north compared to the south hillslopes.*** *(Li, Brantley, Kaye, Russo)* Mike Gooseff left Penn State. Tess Russo joined Penn State and is now part of the CZO team. Russo has replaced Gooseff and taken his place on this team.

H6 Team Goal: Team H6 will test the following hypothesis while developing as complete a dataset as possible that allows understanding of the controls on solute concentrations in stream waters of subcatchments within the Shavers Creek watershed, using a reactive transport modelling approach: H6. ***Ions that are released quickly from ion exchange sites (Mg, Na, K) throughout the catchment demonstrate chemostatic behavior (~constant concentration in the stream), whereas Fe, Mn, and DOC concentrations vary with changes in watershed-stream connectivity.*** *(Russo, Brantley, Li, Kaye, Shi, Duffy)* Mike Gooseff left Penn State. Tess Russo joined Penn State and is now part of the CZO team. Russo has replaced Gooseff as the lead for this hypothesis team.

H7 Team Goal: This team will test the following hypothesis while developing as complete a dataset as possible that allows understanding of the fluxes of carbon and water in the Shavers Creek watershed using PIHM modelling: H7. ***Land-atmosphere fluxes of carbon (C) and water, ground-water hydrology, and ecosystem change are coupled processes at time scales of months to decades. This coupling varies with the lithology and land use and position on the hillslope***. *(Davis, Shi, Eissenstat, Duffy, Lin, Kaye)*

H8 Team Goal: The H8 team will test the following hypothesis while developing as complete a dataset as possible that allows multi-scale modelling to project physical processes from Shale Hills to Shavers Creek, to Young Woman's creek, to Snake Creek: H8. ***Co-located, intensive, relocatable measurements of soil moisture, tree sap flux, sapwood area, LAI, ground water depth, temperature, ^{18}O and D/H along with a 4-component radiometer, laser precipitation monitor and landscape-level soil moisture (COSMOS) can be assimilated within a multi-scale distributed modeling framework to project physical processes from Shale Hills to Shavers Creek to Young Woman's Creek and Snake Creek watersheds.*** *(Shi, Duffy, Davis, Eissenstat, Lin, Duffy)* Chris Duffy has indicated he would like to have minimal involvement with the CZO other than with respect to PIHM modelling. Instead, Yuning Shi, who has been involved in the CZO since its inception and now works part time on the project, is leading the H8 team in collaboration with Li Li. In addition, despite repeated attempts, the CZO has found it hard to interact easily or efficiently with Joe Graney (Univ of Binghamton), who is working at Snake

Creek. Given these two factors, the CZO team will most likely not model the Snake Creek watershed. C. Duffy has completed a model for the YWC watershed.

H9 Team Goal: The H9 team will first use WITCH as a model to earthcast weathering into the future, and will then develop and begin to use the entire suite of PIHM models to simulate CZ processes into the future while testing hypotheses including the following: H9. ***Increasing atmospheric CO_2 in the future will cause higher temperatures and faster weathering of clays in the catchment, increasing streamwater solute loads.*** *(Brantley, Godderis, Li, Duffy, Davis, Shi)* Pam Sullivan was a postdoctoral student working on this project and she started a position at University of Kansas during the last year. She will be first author of the WITCH paper, though completion of this paper has been slowed because she started her faculty position at KS.

* What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?

Major Activities:

The H1 team did fieldwork in the Hickory Run boulder field, Young Woman's Creek, and Shavers Creek to collect samples for cosmogenic isotope analysis that will be used to understand better base level and climatic controls on rock weathering. Team member R. DiBiase also recruited a new graduate student for Fall 2015.

The H2 team: 1) recruited a new graduate student (Lillian Hill), 2) tested and installed pore fluid monitoring equipment in one shale and one sandstone catchment, 3) synthesized results from a study of roots within rock fractures, 3) submitted one paper on soil CO_2, and 4) continued to monitor soil pCO_2, O_2, and N_2O in a shale catchment.

The H3 team: 1) recruited a new, under-represented graduate student (Ismail Szink) to begin Aug 2015, 2) began assessing vertical root distribution at the shale and sandstone sites, and 3) submitted 2 papers, one on tree effective rooting depth for water uptake and the other on water residence time in vegetation.

The H4 team 1) published 5 papers related to the Shale Hills catchment (see list below), 2) continued soil moisture and GPR data collection at Shale Hills, 3) collected DTS and infiltrometer data in Shale Hills, and 4) collected GPR data in the Garner Run catchment.

H5. The H5 team 1) developed code for RT-FLUX-PIHM that models hydrological and geochemical processes coupled at the watershed scale, and 2) is writing a manuscript on RT-FLUX-PIHM, which will be submitted to Water Resources Research in a couple of weeks.

The H6 team 1) continued stream chemistry data collection at Garner Run and along the main branch of Shavers Creek, 2) deployed a stilling well and weir at Garner Run for

measuring discharge, and 3) deployed a distributed temperature sensor (DTS) and conducted a tracer injection test at Garner Run.

The H7 team 1) helped to maintain the eddy covariance flux data stream at Shale Hills, 2) assembled a variety of Shale Hills carbon stock and flux observations, 3) tested the ability of the Biome-BGC model to simulate Shale Hills carbon stocks and fluxes, and 4) began to couple Biome-BGC with the Flux-PIHM modeling system.

The H8 team 1) recruited a new graduate student (Dacheng Xiao), 2) submitted a paper describing the data assimilation experiment at the Shale Hills watershed, and 3) implemented the suite of PIHM models at Garner Run and performed uncalibrated land surface hydrologic simulations.

H9. The H9 team 1) published a paper describing the suite of PIHM (and other) models that the CZO is developing in order to understand how to model and earthcast the CZ, 2) made progress on a paper describing earthcasting using the WITCH model, and 3) started developing a paper describing the measurements at the CZO.

Specific Objectives:

H1. The objective is to use cosmogenic nuclides to understand the influence of climate and base level change on the rate at which rock weathers and regolith forms in the context of the CZO. This team is also working to provide soil distribution information for the team.

H2. The main objective was to install a suite of pore chemistry monitoring devices along catenas, in one shale and one sandstone catchment. This included testing and calibrating soil O_2 and CO_2 sensors that are new to the team.

H3. Lack of a graduate student in the 1st year limited the team's objectives to mapping roots along the catena of the sandstone catchment.

H4. The team took a more integrated approach to investigating regolith and macropores through a combined geophysical, hydrological, and modeling approach.

H5. In response to a comment from the 2014 SSHCZO All-Hands meeting, the team has focused on using RT-FLUX-PIHM to understand key controls of watershed dynamics for the non-reactive tracer Cl^- and the reactive tracer Mg^{++}. In response to a comment on the difference between watershed science and CZO science, the team has started to develop the conceptual framework for Regolith-Flux-PIHM, which will aim to simulate the hydrology-geochemistry-geomorphology coupling over geological time scales, with more detailed representation of the subsurface than in the current PIHM framework.

H6. This team expanded stream chemistry and flow measurements to the new sandstone catchment and along the main branch of Shavers Creek.

H7. The team focused on testing the response of the carbon stocks and fluxes in the Biome-BGC ecosystem biogeochemistry model to the variability in soil temperature and moisture conditions within the Shale Hills watershed.

H8. This team identified the need to use the intermediate scale COSMOS soil moisture sensor to calibrate and evaluate land surface hydrologic models in small watersheds, instead of using point soil moisture measurements.

H9. During the 2014 SSHCZO All-Hands meeting, this team identified a need to coordinate overall modelling activities; in response, the CZO team produced a paper describing the suite of PIHM models.

Significant Results:

H1. Frost cracking models suggest that the depth and magnitude of subsurface fractures are not aspect-dependent at Shale Hills; however, comparing shallow seismic surveys to previously measured creep efficiencies implies that once fractured, bedrock materials are quickly converted to regolith and transported via frost heave on south-facing slopes.

H2. Pore water chemistry observation sites along catenas in one shale and one sandstone catchment were installed and sampling commenced.

H3. Root maps are being produced for the sandstone catchment and will be compared to the shale catchment.

H4. The team published a paper on the innovative use of time-lapsed GPR to reveal subsurface lateral flow in hillslopes, and another paper on the role of macropores and multi-resolution soil survey datasets for distributed surface-subsurface flow modeling.

H5. The team has developed a manuscript describing RT-FLUX-PIHM that is ready to be submitted in 2 weeks. The team is also developing a users' manual for the model.

H6. This team has collected stream chemistry and streambed exchange data from Garner Run and is preparing a manuscript for submission.

H7. Varying soil conditions affect the BIOME-BGC-modeled carbon stocks in ways that are similar to observations at Shale Hills, but the simulated amplitude is lower than the observed change in carbon stock across the watershed.

H8. This team submitted a paper describing the data assimilation experiment at the Shale Hills watershed.

H9. This team published a paper that describes the suite of PIHM models and furthered its work on the WITCH earthcasting model and a new paper describing all the measurements at the CZO.

Key outcomes or Other achievements:

The CZO produced seven big results this year. 1) The CZO showed that frost cracking is not aspect-dependent at Shale Hills; however, once fractured, bedrock materials are quickly converted to regolith and transported via frost heave on south-facing slopes. 2) The team showed that time-lapsed GPR is a new and innovative technique that can reveal subsurface lateral flow in hillslopes, and that can be used for distributed surface-subsurface flow modeling (featured as a cover story in WRR Dec. 2014 issue). 3) The team produced a coupled land surface-atmosphere model that incorporates a module to complete geochemical reactive transport modelling (RT-FLUX-PIHM…this may be the first such model available). 4) The team discovered that BIOME-BGC can adequately model carbon stocks in SSHCZO although the amplitude of changes are lower than observed. 5) The CZO produced a paper that described how the Critical Zone can be modelled – this is the first description of a "total CZ" model (or, more accurately, a suite of models). 6) The CZO team contributed to running Teen Shale Network, a very successful outreach program that is teaching high school students about shales and shale gas development. 7) The CZO worked with a data sonification team and produced a sonification of watershed data.

* What opportunities for training and professional development has the project provided?

H1. UVM MS graduate student, Al Denn (co-advised by P. Bierman and E. Kirby), was mentored by the rest of the team in the application of cosmogenic nuclide data to problems in surface earth science and assisted by the team in learning field sampling protocols. N. West (post-doc) participated in the National CZO All-Hands meeting, presented three invited presentations, and is currently learning new geophysical field techniques.

H2. One graduate student, Lillian Hill (co-advised by J. Kaye and D. Eissenstat) has been trained in datalogger programming and soil pore chemistry sampling by manual collection and automated sensors. One REU student was trained to establish sampling transects and quantify soil organic horizon carbon storage. Several other postdocs, graduate students, and undergraduates were trained to sample pore fluid chemistry. An undergraduate honors student (Bret Turner) completed his thesis by developing an in situ gas diffusivity probe that was installed in one shale catchment. One Geosciences undergraduate student (Reese Davis) dug soil pits and ground samples after completing an undergraduate senior thesis at the CZO in 2014.

H3. One PhD student successfully defended her thesis, Katie Gaines (co-advised by D. Eissenstat and M. Kaye) on water use by trees in Shale Hills. One REU student was trained in root biology and developed research examining the relationship between root morphology and aboveground tree species composition. One undergraduate was trained in identifying and quantifying mycorrhizal colonization of roots. A postdoc working on this part of the project started a faculty position at St Louis University.

H4. A REU student and a RET teacher have been trained to use GPR and an infiltrometer.

H5. The project supported Li to attend the CSDMS annual meeting (May 26-28, 2015) to facilitate CZO-CSDMS interactions. Graduate student Chen Bao (co-advised by L. Li and S. Brantley) has been offered a student travel grant from CSDMS organizing committee. The modellers in this team have benefitted from monthly SSHCZO seminars and cross-disciplinary discussions.

H6. The PI (Russo) and a post-doc (Kim) were able to attend the CZO All-Hands meeting in California in Sept. 2014, and a new graduate student B. Hoagland (co-advised by T. Russo and S. Brantley) has been trained in collecting and analyzing stream samples, as well as learning Matlab for DTS analysis. Two undergraduates (Pederson, Brazil) have been working as field assistants to the watershed coordinator. Hoagland, Kim, Russo, and Neal all visited John Cherry and Beth Parker at Univ of Guelph to learn how to use new drilling technologies.

H7. The team leader (Davis) and grad student (He) attended the CZO All-Hands meeting in California in September, 2014, and He formed a Ph.D. committee including two co-advisors (Davis, Eissenstat) from the CZO team.

H8. A graduate student Dacheng Xiao (co-advised by L. Li and Y. Shi) was trained to run PIHM, and use PIHMgis to generate PIHM input. Xiao also learned the data assimilation method and the PIHM code. Xiao is co advised by Yuning Shi and Li Li.

H9. Several graduate students learned to run PIHM as part of this project. One postdoc learned to use WITCH. The postdoc is now on the faculty at Univ of Kansas.

The CZO hosted its Annual All Hands meeting on May 11-12, 2015. 45 people attended, including our outside speaker and Executive Committee member, Dorothy Merritts (Franklin and Marshall Univ.). All CZO participants had the opportunity to attend talks, peruse posters, and attend the field trip with the entire team and with Merritts.

CZO Director Brantley taught Geosc 413W, an upperclass Geosciences class as a project working at the CZO. CZO team members DiBiase and Russo both participated.

The Penn State CZO seminar series for the 2014-2015 academic year included the following presentations: Director Brantley presented “The State of the CZO” on Sept 19th; Postdoctoral Scholar Kim presented “Water chemistry evolution through the critical zone revealed by parallel hydrochemistry observations” on Oct 17th; PhD Candidate Bao presented “Development of an Integrated Hydrochemical Model RT-Flux-PIHM: what have we learned?” on Nov 7th; PI Kaye presented “Forests and the Critical Zone: Known Knowns and Known Unknowns” on Dec 5th; PhD Candidate Zhang presented “A Next Generation Landscape Evolution Model with Applications to the Shale Hills CZO” on Feb 13th; and team presentations of “Garner Run Updates” on March 20th and of “Trees in the CZO” on April 10th.

The CZO hosted two outside visitors, Dr. Whendee Silver, Dept. of Environmental Science, Policy and Management, UC Berkeley, who presented “Pumping Iron: How Redox Dynamics

Drive Biogeochemical Cycling in Tropical Forest Soils" on Sept 4th and Dr. Fabio Reis, Professor of Physics, from the Physics Institue, Universidade Federal Fluminense, Niteroi, Brazil who presented "Some Applications of Stochastic Lattice Models to Growth and Dissolution Processes" on Nov 20th

Watershed coordinators Andy Neal and Brandon Forsythe mentored all team members in field equipment and usage. On May 28th, the full team worked with Forsythe and the Penn State Forester for identification, marking, and geolocation of all PI instrumentation in the CZO.

The CZO cyberspecialist Dan Arthur conducted training and demonstrations with small groups of investigators over a period of approximately 2 months (9/12/14, 10/31/14,11/04/14, and 11/17/14), and an update was presented at the most recent All-Hands meeting (5/12/15). He also assisted former watershed specialist Andrew Neal in training graduate student and postdoc field team in methods of collecting data from dataloggers in the field and how to use a private Box.com repository for turning over collected data to him. Despite specifics of the proposed web site format being revised, the training also covered how to find CZO data, both in general and specifically, regardless of final web page format.

* How have the results been disseminated to communities of interest?

H1. Frost cracking models and borehole observations at Shale Hills will be contributed to a cross-CZO Deep Critical Zone Salon scheduled for June, 2015. Two members of the H1 CZO team are leading this workshop (West, Brantley). Team members gave talks on campus and at other venues.

H2. The H2 team leader (J. Kaye) has been participating in the Organic Chemistry Cross CZO Working group to disseminate and learn CZO approaches. Team members gave talks on campus and at other venues.

H3. A workshop focusing on "Exploring Four Critical Puzzles about Trees, Water and Soil: A Vison for Research" has been planned, to take place in State College, 9-11 September 2015. This work involves other CZO investigators, as well as scientists not directly involved in the CZO network. Questions to be explored include how trees affect and are affected by subsurface water, stream chemistry and flow, and soil formation and hillslope evolution and lithology. One expected outcome of the workshop is the production of a vision paper that will summarize what is known about these questions, what important hypotheses still need to be addressed and what would be the approaches to address these hypotheses over the next five years. Recently completed PhD student Katie Gaines will be one of the featured speakers at the workshop. Team members gave talks on campus and at other venues.

H4. One of this team's publications was featured in the Soil Science Society of America web site in March 2015 as an outreach story for the International Year of Soils celebration. Team leader Lin is also involved at the IML CZO and Germany's TERENO project: he was even featured in Germany's TERENO Newsletter for his CZO involvements. Team members gave talks on campus and at other venues.

H5. The team (Li and graduate student Chen Bao) has been actively advocating the use of models to understand general principles across CZOs as well as in the identification of key specifics particular to individual CZOs. The team, together with Russo and Hoagland (H6 team), is actively involved in a Cross-CZO C-Q relationship workshop. Li is also developing an online reactive transport modeling (RTM) course that can potentially be used to teach graduate students across CZOs. To the best of the team's knowledge, this is the first RTM online course, which has the potential for teaching the next generation of scientist RTM tools for CZO work. Li also organized an RTM workshop (together with Kate Maher and Alexis Navarre-Sitchler) on expanding the use of RTM in biogeochemical sciences. A white paper has been submitted to NSF GG program and a vision manuscript is in development, targeted for submission in July 2015.

H6. Team members gave talks on campus and at other venues.

H7. Team members gave talks on campus and at other venues.

H8. Team members gave talks on campus and at other venues.

H9. Team leader Brantley helped to organize and run a workshop in December 2014 at AGU to promote international efforts to fund critical zone science worldwide. An article about that effort is being published in EOS this month. The workshop was entitled "International Critical Zone Observatory Initiative," Hotel Palomar, San Francisco, December 13-14, 2014; included about 20 participants from around the world

Seed grants: The CZO advertised a seed grant competition. Three proposals were received. The SSHCZO awarded a seed grant of $20,000 to Kristen Brubaker (Assistant Professor at Hobart and William Smith Colleges) for measuring above ground carbon storage across the sub-watersheds in Shavers Creek.

CZO director Brantley gave the following invited talks about CZO work:

"Drilling to Explore the Transformation of Bedrock into Soil in the Deep Critical Zone," invited Roscoe Ellis seminar, Kansas State University, Manhattan, KS, October 16, 2014

"Exploring the Transformation of Bedrock into Soil in the Deep Critical Zone," Invited technical lecture, **11th Annual Noel Potter Lectures**, The Department of Earth Sciences, Dickinson College, Carlisle, PA, November 18, 2014

"CZ-Tope: Using Measurements of Multiple Isotopes in One Setting to Understand Critical Zone Processes Occurring over Different Timescales (invited)" Invited talk at the American Geophysical Union Fall Meeting, San Francisco, CA, December 15, 2014.

"Developing a Paradigm to Measure and Model the Form and Function of the Critical Zone," (**Keynote Lecture**) American Geophysical Union Fall Meeting, San Francisco, CA, December 16, 2014.

Brantley presented to attendees at the “Town Hall: Critical Zone Observatories, Past, Present, Future,” American Geophysical Union Fall Meeting, San Francisco, CA, December 16, 2014.

Brantley will present the invited talk, “Weathering and Surface Processes” as part of the series of Goldschmidt 25th Anniversary Talks at the Goldschmidt Conference in August 2015.

J. Williams gave invited presentation to the Centre County Pennsylvania Senior Environmental Corp on March 11, 2015 "SSHCZO, TeenShale Network and Water Quality Monitoring of Black Moshannon Creek: Past, Present, and Coming Soon" at their monthly membership meeting.

TeenShale Network students wrote a student byline article in the Centre Daily Times “Focus on Research: Hands-on project monitors water quality” which was published online June 8th: http://www.centredaily.com/2015/06/08/4782850_focus-on-research-hands-on-project.html?rh=1

* What do you plan to do during the next reporting period to accomplish the goals?

During the next reporting period, the CZO plans to choose and begin to instrument the agricultural subcatchment on calcareous shale.

H1. In the next year, the team will process the samples collected for cosmogenic nuclide analysis, and Denn will begin data analysis in addition to presenting her work to date at the National GSA meeting in Baltimore, MD, in Fall 2015. Postdoc West is writing up her work as 1 or 2 papers for submission for publication. Dibiase will mentor a new graduate student to begin to understand and investigate soil distribution in the CZO.

H2. Having just established pore chemistry monitoring catenas, the H2 team will emphasize sampling those sites to build a two-year record of differences in pore chemistry between the shale and sandstone catchments. This team will also make progress in concert with team H3 on publishing one paper describing roots within rock fractures.

H3. The team will contribute to one paper describing roots within rock fractures. The team will also begin assessing tree species composition of roots in relation to soil depth along the catenas in sandstone and shale.

H4. At least three papers are planned and in progress for publication in the next reporting period: one on catchment stratification in relation to soil moisture variability, one on DTS data, and one on infiltrometer data.

H5. The team plans to use RT-FLUX-PIHM to explore the role of key parameters, including climatic conditions, watershed storage capacity, lithology, and topography, in controlling the C-Q relationship of reactive cations and non-reactive tracers. The team will also move forward in development of the Regolith-Flux-PIHM.

H6. This team will publish a paper combining the thermal and chemistry data to locate and characterize groundwater inflow to the Garner Run study area. The team will also install observation wells along the catena and stream at Garner Run and continue to collect stream concentration-discharge data.

H7. The team will publish the results of the BIOME-BGC test at Shale Hills, investigate how to improve model performance via parameter optimization and/or process modifications, and test the coupled Flux-PIHM-BGC modeling system at the watershed.

H8. A COSMOS sensor will be installed at Garner Run. Data assimilation experiments using the COSMOS soil moisture measurements will be performed to be compared to using point soil moisture measurements for Flux-PIHM model state and parameter estimation.

H9. This team will publish a paper identifying what measurements are needed to understand the CZ and will publish a paper that directly tests the H9 hypothesis using WITCH.

Supporting Files

	Filename	Description	Uploaded By	Uploaded On
(Download)	Inter_CZO_activities 2015.pdf	This document summarizes the inter-CZO activities the team is engaging this reporting period.	Susan Brantley	06/09/2015
(Download)	Noteworthy Nuggets 2015.pdf	This document describes particularly interesting or noteworthy activities, or interesting figures with captions.	Susan Brantley	06/09/2015

Products

Books

Book Chapters

- Yu, X., C. J. Duffy, J. Kaye, W. T. Crow, G. Bhatt, and Y. Shi (2015). Reanalysis of water and carbon cycle models at a critical zone observatory. *Remote Sensing of the Terrestrial Water Cycle* Venkat Lakshmi. American Geophysical Union. Washington, D.C.. . Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

Conference Papers and Presentations

- S.L. Brantley (2014). *(Invited) CZ-Tope: Using Measurements of Multiple Isotopes in One Setting to Understand Critical Zone Processes Occurring over Different Timescales*. AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Susan Brantley (2014). *(Invited) Developing a Paradigm to Measure and Model the Form and Function of the Critical Zone*. AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Yuning Shi • Kenneth Davis • Fuqing Zhang • Christopher Duffy • Xuan Yu (2014). *(Invited) Towards Improved High-Resolution Land Surface Hydrologic Reanalysis Using a Physically-Based Hydrologic Model and Data Assimilation*. AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- West, N., Kirby, E. (2014). *Aspect-dependent regolith flux revealed by meteoric 10Be*. 2014 Geological Society of America National Meeting. Vancouver, BC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Molly Cain • Tess Russo • Pamela Sullivan • Andrew Neal (2014). *Elucidating the effects of dam restoration on hydrologic patterns in streams and tributaries*. AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Yuning Shi • Kenneth Davis • David Eissenstat • Jason Kaye • Christopher Duffy • Xuan Yu • Yuting He (2014). *Exploring the Influence of Topography on Belowground C Processes Using a Coupled Hydrologic-Biogeochemical Model*. AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Louis Derry • Katherine Meek • Jed Sparks (2014). *Ge/Si, Ca/Sr and 87Sr/86Sr tracers of biogeochemical sources and cycling of Si and Ca at the Shale Hills CZO*. AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- S.L. Brantley (2014). *How Deep is the Critical Zone: A Scientific Question with Potential Impact For Decision-makers in Areas of Shale-Gas Development and Hydraulic Fracturing*. AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- West, N., Kirby, E., (2015). *Invited: Hillslope processes and topographic adjustment to rock-type and aspect in the central Appalachians*. Pardee Symposium, 2015 GSA National Meeting. Baltimore, MA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes
- West, N., Kirby, E., Bierman, P. (2014). *Invited: Hillslope response to differences in aspect-related microclimate*. 2014 Fall Meeting, AGU. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- West, N., Kirby, E., Brantley, S. (2015). *Invited: Microclimate controls on weathering and erosion in a temperate forest, 2015 Goldschmidt Conference*. 2015 Goldschmidt Conference. Prague, CZ. Status = ACCEPTED; Acknowledgement of Federal Support = Yes
- Bao, C., Li, L., Shi, Y., Duffy, C., and Brantley, S. L. (2015). *RT-Flux-PIHM: A Coupled hydrological, land Surface, and reactive transport Model.*. CSDMS annual meeting. Boulder, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Katie Gaines • Frederick Meinzer • Christopher Duffy • Evan Thomas • David Eissenstat (2014). *Rapid Water Uptake and Limited Storage Capacity at Height of Growing Season in Four Temperate Tree Species in a Central Pennsylvania Catchment*.

AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Timothy White and Ashlee Dere (2014). *Rates of tree throw in Appalachian shale landscapes*. AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Clarke, B.A., Kirby, E., Burbank, D.W., West, N. (2014). *Shallow seismic tomography to characterize patterns of near-surface weathering and the mobile-immobile regolith transition: implications for the erodibility and morphology of hillslopes*. 2014 Fall Meeting, AGU. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Lixin Jin • Lin Ma • Ashlee Dere • Tim White • Susan Brantley (2014). *Systematic Investigation of REE Mobility and Fractionation During Continental Shale Weathering Along a Climate Gradient*. AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Pamela Sullivan • Scott Hynek • Kamini Singha • Tim White • Xin Gu • Christopher Duffy • Susan Brantley (2014). *The Interplay of Regolith Evolution and Watershed Hydrodynamics on Shale Weathering Fluxes*. AGU 2014 Fall Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Inventions

Journals

- A. M. L. Kraepiel • A. L. Dere • E. M. Herndon • S. L. Brantley (2015). Natural and anthropogenic processes contributing to metal enrichment in surface soils of central Pennsylvania. *Biogeochemistry*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10533-015-0068-5
- Ashlee L. Dere, Timothy S. White, Richard April, Lauren Leidel, Nina Bingham and Susan L. Brantley (2015). Investigating the role of climate in shale weathering across a latitudinal climosequence. *Soil Science Society of America*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Brantley, S. L., W. E. Dietrich, and S. Banwart (2015). An international initiative for science in the critical zone. *Eos*. 96 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No ; DOI: 10.1029/2015EO031111.
- Carter, M., B.J. Gaudet, D.R. Stauffer, T.S. White, S.L. Brantley (2015). Using soil records with atmospheric dispersion modeling to investigate the effects of clean air regulations on 60 years of manganese deposition in Marietta, Ohio (USA). *Science of the Total Environment*. 515-516 49. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.scitotenv.2015.01.015.
- Duffy, C., Shi, Y., Davis, K., Slingerland, R., Li, L., Sullivan, P.L., Godderis, Y., Brantley, S.L. (2014). Designing a suite of models to explore critical zone function.. *Procedia Earth and Planetary Science*. 10 7. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.proeps.2014.08.003

- Gaines KP, FC Meinzer, CJ Duffy, EM Thomas, DM Eissenstat (2015). Rapid tree water transport and residence times in a Pennsylvania catchment.. *Ecohydrology*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
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- Guo, L., J. Chen, and H.S. Lin (2014). Subsurface Lateral Flow Network on a Hillslope Revealed by Time-lapse Ground Penetrating Radar.. *Water Resource Research*. 50 9127. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2013WR014603
- Hasenmueller, E.A., Jin, L., Stinchcomb, G.E., Lin, H., Brantley, S.L., Kaye, J.P. (2015). Topographic controls on the depth distribution of soil CO2 in a small temperate watershed.. *Applied Geochemistry, in revision. Moderate revisions requested prior to publication.*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Herndon E.M., Jin L., Andrews D.M., Eissenstat D.M., and Brantley S.L. (2015). Importance of vegetation for manganese cycling in temperate forested watersheds.. *Global Biogeochemical Cycles*. 29 (2), 160. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2014GB004858
- Herndon EM, Dere AL, Sullivan PL, Norris D, Reynolds B, and Brantley SL (2015). Landscape heterogeneity drives contrasting concentration-discharge relationships in shale headwater catchments.. *Hydrology and Earth Systems Science Discussions*.. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Herndon, E.M., C.E. Martínez, S.L. Brantley (2014). Spectroscopic (XANES/XRF) characterization of contaminant manganese cycling in a temperate watershed. *Biogeochemistry*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10533-014-0018-7
- Jin, L., N. Ogrinc, T. Yesavage, E. Hasenmueller, L. Ma, P. Sullivan, J. Kaye, C. Duffy, and S. Brantley (2014). The CO2 consumption potential of gray shale weathering: insights from the evolution of carbon isotopes in the Susquehanna Shale Hills critical zone observatory.. *Geochimica et Cosmochimica Acta*. 142 260. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.gca.2014.07.006
- Lin Ma*, Jasper Konter, Elizabeth Herndon, Lixin Jin, Grit Steinhoefel, Diego Sanchez, Susan Brantley (2014). Quantifying an early signature of the industrial revolution from lead concentrations and isotopes in soils of Pennsylvania, USA. *Anthropocene*. 7 16. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.ancene.2014.12.003
- Lin Ma, Fang-Zhen Teng, Lixin Jin, Shan Ke, Wei Yang, Hai-Ou Gu, Susan L. Brantley (2015). Magnesium isotope fractionation during shale weathering in the Shale Hills Critical Zone Observatory: Accumulation of light Mg isotopes in soils by clay mineral transformation. *Chemical Geology*. 397 37. Status = PUBLISHED;

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- Liu, H., and H.S. Lin. (2015). Temporal and spatial patterns of preferential flow occurrence in the Shale Hills catchment: From pedon to catchment scales.. *Soil Science Society of America Journal*. 79 360. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/sssaj2014.08.0330
- Mirna Slim, J. Taylor Perron, Stephen J. Martel and Kamini Singha (2014). Topographic stress and rock fracture: a two dimensional numerical model for arbitrary topography and preliminary comparison with borehole observations. *EARTH SURFACE PROCESSES AND LANDFORMS*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/esp.3646
- Noireaux J., Gaillardet J., Sullivan P.L., Brantley S.L. (2014). Boron isotope fractionation in soils at Shale Hills CZO. *Procedia Earth and Planetary Science*. 10 218. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.proeps.2014.08.024
- Shi, Y., B. C. Baldwin, K. J. Davis, X. Yu, C. J. Duffy, and H. Lin (2015). Simulating high resolution soil moisture patterns in the Shale Hills watershed using a land surface hydrologic model.. *Hydrological Processes*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Shi, Y., K. J. Davis, F. Zhang and C. J. Duffy, and X. Yu (2015). Parameter estimation of a physically-based land surface hydrologic model using an ensemble Kalman filter: A multivariate real-data experiment. *Advances in Water Resources*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- X. Z. Niu, J. Z. Williams, D. Miller, K. Lehnert, B. Bills, and S. L. Brantley (2014). An Ontology Driven Relational Geochemical Database for the Earth's Critical Zone: CZchemDB. *Journal of Environmental Informatics*. 23 (2), 10. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.3808/jei.201400266
- Yu, H., P. Yang, and H.S. Lin. (2015). Spatiotemporal patterns of soil matric potential in the Shale Hills Critical Zone Observatory.. *Vadose Zone J.*. . Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/vzj2014.11.0167
- Yu, X., C. Duffy, D. Baldwin, and H.S. Lin (2014). The role of macropores and multi-resolution soil survey datasets for distributed surface-subsurface flow modeling. *Journal of Hydrology*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.jhydrol.2014.02.055
- Zhang, J., H.S. Lin, and J. Doolittle (2014). Soil layering and preferential flow impacts on seasonal changes of GPR signals in two contrasting soils.. *Geoderma*. 213 560. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.geoderma.2013.08.035

Licenses

Other Products

- *Databases.*

Dan Arthur, the CZO cyberspecialist, imported existing CZO data into locally-hosted MS SQL Server database, linked to local CZO data portal web site (http://www.czo.psu.edu/data_overview.html). Instrument map on this site was updated to include new field areas and associated instrumentation. PHP scripts were written to download data via web from this database (e.g., http://www.czo.psu.edu/data_surfflux.html). Recordings of all seminars have been archived and made publicly viewable on the website (https://criticalzone.org/shale-hills/news/story/susquehanna-shale-hills-czo-videos/).

Dan Arthur, the CZO cyberspecialist uploaded new and/or updated datasets of the following: Land/Atmosphere Fluxes, LPM Disdrometer, Sap Flow, Fiber-Optic Distributed Temperature Sensor, Bedrock Elevation, Tree Fall Data, Above-Ground Tree Biomass, Soil Gas and Porewater Concentrations, Raw Seismic Refraction and Surface Wave Analyses, Discharge and Water Chemistry, Surface and Groundwater Chemistry, Tree Isotope Chemistry, Model Input Soil Parameters, and Shale Transect Meteorology. These new datasets, as well as pre-existing ones, are accessible via http://criticalzone.org/shale-hills/data/datasets and http://www.czo.psu.edu/data_overview.html. Time series and other datasets have been imported into locally-hosted SQL Server database, and access pages (e.g., http://www.czo.psu.edu/data_surfflux.html) are currently being rolled out.

Two complete datasets were submitted to EarthChem Library for DOI and archival purposes: Susquehanna Shale Hills Litter and Dendroband Data (doi:10.1594/IEDA/100517) and Susquehanna Shale Hills Critical Zone Observatory Tree Survey (2012 updates) (doi:10.1594/IEDA/100516).

- *Physical Collections.*

  The CZO maintains a physical archive of solid and aqueous samples. Solid samples have been registerd with SESAR and available to the public upon request. This reporting period, 863 new samples from the CZO were registered and archived with ISGNs. To date, the public archive houses 4339 rock, soil, and leaf litter samples.

Other Publications

Patents

Technologies or Techniques

- H1. MS candidate Denn has developed a stratified sampling strategy for understanding better spatial differences in duration of weathering for blockfields.

H2. An undergraduate honors student adapted (from a version published in the literature) and tested in the lab a new probe for measuring soil diffusivity. Probes were deployed in a shale catchment and monitoring will commence this spring.

H3. Nothing to report.

H4. Guo et al. (2014) developed an innovative time-lapsed GPR technique to investigate subsurface lateral flow in the Shale Hills hillslope.

H5. RT-Flux-PIHM has been developed by adding a reactive transport module to Flux-PIHM. The module enables detailed hydrological and geochemical process coupling at the watershed scale, for understanding chemical weathering, as well as watershed dynamics such as C-Q relationship, at time scales of months and years.

H6. Team H6 worked with the sc::ann units to measure stream chemistry. This new instrumentation must be calibrated and the team will be calibrating the instrument during summer 2015.

H7. Flux-PIHM-BGC, a modeling system that includes coupled carbon, nitrogen and water cycles, is in development.

H8. The suite of PIHM models received a major update to provide more user-friendly input formats. The code has been made available via the GitHub web repository for better group collaboration and management.

H9. Yves Godderis taught Sue Brantley and Pam Sullivan how to cascade models together to earthcast weathering into a future with higher CO_2.

Thesis/Dissertations

- Smith, Lauren A. *Above ground Carbon Distribution across a temperate watershed (Master of Science, Ecology)*. (2013). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- Arvy Adira. *Assessing the Subsurface Geology of Garner Run Through the Relationship Between Seismic Velocity and Layer Density (Senior Thesis, Geosciences)*. (2015). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- Megan Carter. *EXPLORING A 60-YEAR RECORD OF MANGANESE DEPOSITION IN MARIETTA OHIO USING SOIL CHEMISTRY AND ATMOSPHERIC DISPERSION MODELING (Master of Science, Geosciences)*. (2014). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- Molly R Cain. *Elucidating the Effects of Reservoir Filling on Watershed Hydrodynamics and Shallow Groundwater Chemistry in a Previously Impounded Lake (Senior Thesis, Geosciences)*. (2015). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- Katie P. Gaines. *FOREST ECOHYDROLOGY IN A CENTRAL PENNSYLVANIA CATCHMENT: A STABLE ISOTOPE APPROACH (PhD Dissertation, Ecology)*. (2015). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- Matthew Kenney. *Isotopic data sonification: Shale Hills Critical Zone Observatory (Master of Fine Arts, Arts and Architecture)*. (2015). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- Yu, Xuan. *Modeling, parameter optimization, and ecohydrologic assessment of watershed systems (Ph.D. Dissertation, Civil and Environmental Engineering)*. (2014). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- Ashlee L. D. Dere. *SHALE WEATHERING ACROSS A LATITUDINAL CLIMOSEQUENCE (PhD Dissertation, Geosciences)*. (2014). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- Eric Wang. *Seismic Refraction for Subsurface Analysis of Garner Run (Senior Thesis, Geosciences)*. (2015). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- Twiest, Burkely L.. *Spatial and temporal evolution of the nocturnal surface layer in a small, steep watershed (Master of Science, Meteorology)*. (2014). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- Sara Macdonald. *Thick soil formation on Orthoquartzite since the Wisconsinan in Huntingdon County (Senior Thesis, Geosciences)*. (2015). The Pennsylvania State University. Acknowledgement of Federal Support = Yes
- West, Nicole. *Topographic Fingerprints of Hillslope Erosion in the Central Appalachians Revealed by Meteoric Beryllium-10 (PhD Dissertation, Geosciences)*. (2014). The Pennsylvania State University. Acknowledgement of Federal Support = Yes

Websites

- *PSU modeling: MM-PIHM*
  https://github.com/PSUmodeling/MM-PIHM

A GitHub page has been developed for the suite of PIHM models (https://github.com/PSUmodeling/MM-PIHM). This is currently a private repository but will be open to the public soon.

- *SSHCZO DATA SITE*
  http://www.czo.psu.edu/data_agreement.html

  This is the local PSU website where data collected from the CZO is shared publicly or privately. It is also the portal to access the local database.

- *UVM Cosmogenic Nuclide Laboratory*
  http://www.uvm.edu/cosmolab/

  UVM MS candidate Denn is developing a web site (at http://www.uvm.edu/cosmolab/) that will present the team's sampling results to the public.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Brantley, Susan	PD/PI	1
Davis, Kenneth	Co PD/PI	1
Eissenstat, David	Co PD/PI	1
Li, Li	Co PD/PI	1
Russo, Tess	Co PD/PI	1
Bierman, Paul	Co-Investigator	1
DiBiase, Roman	Co-Investigator	1
Kaye, Jason	Co-Investigator	1
Kirby, Eric	Co-Investigator	1
Lin, Henry	Co-Investigator	1
Singha, Kamini	Co-Investigator	0
Clarke, Brian	Postdoctoral (scholar, fellow or other postdoctoral position)	0
Hasenmueller, Elizabeth	Postdoctoral (scholar, fellow or other postdoctoral position)	0
Karwan, Diana	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Sullivan, Pamela	Postdoctoral (scholar, fellow or other postdoctoral position)	0
West, Nicole	Postdoctoral (scholar, fellow or other	12

Name	Most Senior Project Role	Nearest Person Month Worked
	postdoctoral position)	
Neal, Andrew	Staff Scientist (doctoral level)	5
Shi, Yuning	Staff Scientist (doctoral level)	12
Bao, Chen	Graduate Student (research assistant)	12
Denn, Alison	Graduate Student (research assistant)	12
Dere, Ashlee	Graduate Student (research assistant)	0
Gaines, Katie	Graduate Student (research assistant)	8
He, Yuting	Graduate Student (research assistant)	12
Hill, Lillian	Graduate Student (research assistant)	12
Hoagland, Beth	Graduate Student (research assistant)	12
Hopkins, Isaac	Graduate Student (research assistant)	0
Weitzman, Julie	Graduate Student (research assistant)	12
Xiao, Dacheng	Graduate Student (research assistant)	12
Zhang, Yu	Graduate Student (research assistant)	12
Arthur, Dan	Non-Student Research Assistant	12
Forsythe, Brandon	Non-Student Research Assistant	8
Williams, Jennifer	Non-Student Research Assistant	12

Full details of individuals who have worked on the project:

Susan L Brantley
Email: brantley@essc.psu.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: PI, Exec Committee Chair

Funding Support: Penn State and NSF

International Collaboration: No
International Travel: No

Kenneth J Davis
Email: kjd10@psu.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Co-I, Exec Committee member, Coordinator of Mobile Array

Funding Support: Penn State and NSF

International Collaboration: No
International Travel: No

David M Eissenstat
Email: dme9@psu.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Co-I, Exec Committee member, Coordinator of Sensor Network

Funding Support: Penn State and NSF

International Collaboration: No
International Travel: No

Li Li
Email: lili@eme.psu.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Co-I, Exec Committee member (rotating), in charge of reactive transport modelling

Funding Support: Penn State and NSF

International Collaboration: No
International Travel: No

Tess A Russo
Email: russo@psu.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Co-I, Coordinator of Seed Grant Program,

Funding Support: Penn State

International Collaboration: No
International Travel: No

Paul Bierman
Email: pbierman@uvm.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Geomorphologist/Geochemist - works on Hypothesis 1

Funding Support: University of Vermont and NSF

International Collaboration: No
International Travel: No

Roman DiBiase
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Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Coordinator of geomorphological soils analysis

Funding Support: Penn State and NSF

International Collaboration: No
International Travel: No

Jason Kaye
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Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Soil Biogeochemist - works on Hypotheses 2, 3, 5, and 6

Funding Support: Penn State and NSF

International Collaboration: No
International Travel: No

Eric Kirby
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Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Geomorphologist - works on Hypothesis 1

Funding Support: unknown

International Collaboration: No
International Travel: No

Henry Lin
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Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Hydorpedologist - works on Hypotheses 1, 4, 7, and 8

Funding Support: Penn State and NSF

International Collaboration: No

International Travel: No

Kamini Singha
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Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Hydrogeologist - works on Hypothesis 1

Funding Support: unknown

International Collaboration: No
International Travel: No

Brian Clarke
Email: bac43@psu.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 0

Contribution to the Project: Geomorphologist - worked on Hypothesis 1

Funding Support: unknown

International Collaboration: No
International Travel: No

Elizabeth Hasenmueller
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Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 0

Contribution to the Project: Hydrochemist - works on Hypothesis 2

Funding Support: Washington University at St. Louis

International Collaboration: No
International Travel: No

Diana Karwan
Email: dlkarwan@umn.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 1

Contribution to the Project: Cross-CZO Post-doctoral Fellow

Funding Support: NSF

International Collaboration: No
International Travel: No

Pamela Sullivan
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Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 0

Contribution to the Project: Hydrochemist - works on Hypotheses 6 and 9

Funding Support: Kansas University

International Collaboration: No
International Travel: No

Nicole West
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Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 12

Contribution to the Project: geomorphologist - works on Hypothesis 1

Funding Support: CZO

International Collaboration: No
International Travel: No

Andrew Neal
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Most Senior Project Role: Staff Scientist (doctoral level)
Nearest Person Month Worked: 5

Contribution to the Project: Watershed Specialist

Funding Support: CZO

International Collaboration: No
International Travel: No

Yuning Shi
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Most Senior Project Role: Staff Scientist (doctoral level)
Nearest Person Month Worked: 12

Contribution to the Project: Hydrologist - works on Hypothesis 7 and 8

Funding Support: CZO

International Collaboration: No
International Travel: No

Chen Bao

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Nearest Person Month Worked: 12

Contribution to the Project: works on Hypothesis 5

Funding Support: CZO

International Collaboration: No
International Travel: No

Alison Denn
Email: adenn@uvm.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: contributing to H1

Funding Support: CZO

International Collaboration: No
International Travel: No

Ashlee Dere
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Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: shale weathering along transect sites

Funding Support: University of Nebraska

International Collaboration: No
International Travel: No

Katie Gaines
Email: kpgaines@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 8

Contribution to the Project: works on tree physiology

Funding Support: CZO

International Collaboration: No
International Travel: No

Yuting He
Email: yzh120@psu.edu

Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: works on PIHM and Biome-BGC

Funding Support: CZO

International Collaboration: No
International Travel: No

Lillian Hill
Email: lzh157@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: contributing to H2

Funding Support: NSF

International Collaboration: No
International Travel: No

Beth Hoagland
Email: neh137@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: contributing to H6

Funding Support: CZO

International Collaboration: No
International Travel: No

Isaac Hopkins
Email: ieh105@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: works on Hypothesis 4

Funding Support: unknown

International Collaboration: No
International Travel: No

Julie Weitzman
Email: jnw142@psu.edu
Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 12

Contribution to the Project: works on Hypothesis 2

Funding Support: CZO and NSF

International Collaboration: No
International Travel: No

Dacheng Xiao
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Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: contributing to H8

Funding Support: CZO

International Collaboration: No
International Travel: No

Yu Zhang
Email: yzz130@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: works on PIHM-sed

Funding Support: CZO

International Collaboration: No
International Travel: No

Dan Arthur
Email: dka12@psu.edu
Most Senior Project Role: Non-Student Research Assistant
Nearest Person Month Worked: 12

Contribution to the Project: Data Manager / Cyberspecialist

Funding Support: CZO

International Collaboration: No
International Travel: No

Brandon Forsythe
Email: brf11@psu.edu
Most Senior Project Role: Non-Student Research Assistant

Nearest Person Month Worked: 8

Contribution to the Project: watershed coordinator

Funding Support: CZO

International Collaboration: No
International Travel: No

Jennifer Williams
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Most Senior Project Role: Non-Student Research Assistant
Nearest Person Month Worked: 12

Contribution to the Project: Program, Outreach, and Sample Coordinator

Funding Support: CZO

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
Beijing Normal University	Academic Institution	Beijing, China
Brown University	Academic Institution	Providence, RI
State College Area School District	School or School Systems	State College, PA
Technical Univ. of Munich	Academic Institution	Munich, Germany
Temple University	Academic Institution	Philadelphia, PA
UMass-Amherst	Academic Institution	Amherst, MA
USDA Forest Service	State or Local Government	Corvallis, OR.
USDA-NRCS-NSSC	State or Local Government	Newtown Square, PA
Univ of Kansas	Academic Institution	Lawrence, Kansas
University of Guelph, Canada	Academic Institution	Guelph, ON, Canada
University of Texas @ El Paso	Academic Institution	El Paso, TX
University of Toulouse, France	Academic Institution	Toulouse, France
CTEMPS	Academic Institution	University of Nevada, Reno
Chinese Academy of Sciences	Academic Institution	Beijing, China
Colgate University	Academic Institution	Hamilton, NY
Hollidaysburg Area High School	School or School Systems	Hollidaysburg, PA
Ninxia University	Academic Institution	Ningxia, China
Oregon State University	Academic Institution	Corvallis, Oregon

Name	Type of Partner Organization	Location
Princeton University	Academic Institution	Princeton, NJ
Saint Louis University	Academic Institution	Saint Louis, MO

Full details of organizations that have been involved as partners:

Beijing Normal University

Organization Type: Academic Institution
Organization Location: Beijing, China

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Brown University

Organization Type: Academic Institution
Organization Location: Providence, RI

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

CTEMPS

Organization Type: Academic Institution
Organization Location: University of Nevada, Reno

Partner's Contribution to the Project:
Facilities
Collaborative Research

More Detail on Partner and Contribution:

Chinese Academy of Sciences

Organization Type: Academic Institution
Organization Location: Beijing, China

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Colgate University

Organization Type: Academic Institution
Organization Location: Hamilton, NY

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Hollidaysburg Area High School

Organization Type: School or School Systems
Organization Location: Hollidaysburg, PA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Ninxia University

Organization Type: Academic Institution
Organization Location: Ningxia, China

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Oregon State University

Organization Type: Academic Institution
Organization Location: Corvallis, Oregon

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Princeton University

Organization Type: Academic Institution
Organization Location: Princeton, NJ

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Saint Louis University

Organization Type: Academic Institution
Organization Location: Saint Louis, MO

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

State College Area School District

Organization Type: School or School Systems
Organization Location: State College, PA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Technical Univ. of Munich

Organization Type: Academic Institution
Organization Location: Munich, Germany

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Temple University

Organization Type: Academic Institution
Organization Location: Philadelphia, PA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

UMass-Amherst

Organization Type: Academic Institution
Organization Location: Amherst, MA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

USDA Forest Service

Organization Type: State or Local Government
Organization Location: Corvallis, OR.

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:
USDA-NRCS-NSSC

Organization Type: State or Local Government
Organization Location: Newtown Square, PA

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:
Univ of Kansas

Organization Type: Academic Institution
Organization Location: Lawrence, Kansas

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:
University of Guelph, Canada

Organization Type: Academic Institution
Organization Location: Guelph, ON, Canada

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:
University of Texas @ El Paso

Organization Type: Academic Institution
Organization Location: El Paso, TX

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

University of Toulouse, France

Organization Type: Academic Institution
Organization Location: Toulouse, France

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

What other collaborators or contacts have been involved?

H1. Roman Dibiase, Sridhar Anadakrishnan.

H2. Elizabeth Hasenmueller, Lixin Jin, Xin Gu, Erica Smithwick, Gary Stinchcomb.

H3. Margot Kaye.

H4. Beth Boyer.

H5. Chris Duffy.

H6. Nothing to report.

H7. Armen Kemanian.

H8. Nothing to report.

H9. Victor Balashov, Marina Lebedeva.

USGS seed grant: Tiffany Yesavage.

Impacts

What is the impact on the development of the principal discipline(s) of the project?

H1. The sampling completed at Hickory Run will provide the first quantitative age and rate data for blockfields, a common relict, climatically-related regolith landform.

H2. Testing a simple and robust pore chemistry monitoring approach, emphasizing comparisons among catenas, could lead to a widely applied strategy to compare pore chemistry across the CZ.

H3. Coordinating with H2 and H9, the team analyzed vegetation in the sandstone site and compared it to the shale site, and examined root length density at the shale site for understanding water uptake and other biotic interactions in regolith.

H4. The main impact is the innovative time-lapsed GPR technique developed for revealing subsurface lateral flow in hillslopes, which was featured as a cover story in WRR (Dec. 2014 issue).

H5. RT-Flux-PIHM is likely the first numerical model capable of modeling hydrological, land surface interactions, and multi-component reactive transport all together. This provides a powerful tool not only for SSHCZO, but also for other CZOs.

H6. This team has collected stream chemistry and discharge data, and has integrated physical and chemical measurements to locate and characterize groundwater – streamwater interactions.

H7. The watershed-resolving coupled carbon-water-nitrogen studies will lead to questions about common assumptions that homogeneous ecosystem and subsurface quantities are sufficient for simulating ecosystem-atmosphere carbon and water cycling.

H8. Team H8 will provide insight into hydrologic model upscaling and parameter transferability, and provide guidance of watershed observational system design.

H9. The principal impact of the work by team H9 is to articulate a method for measuring and modelling the CZ: in essence, with limited resources, how can the CZ be understood and modelled into the future?

What is the impact on other disciplines?

H1. The age and rate control provided on major regolith features will allow others, such as soil scientists, botanists, and ecologists, to better understand the influence of regolith age/erosion rate on critical zone processes.

H2. Ecological experimental designs could be impacted if the team's catena monitoring approach proves successful in illuminating key drivers of ecosystem dynamics from a few carefully located sampling points.

H3. Work for H3 helped bring aspects of Critical Zone science to the ecological community.

H4. Inference via GPR techniques, of moisture storage and its change over time in fractured shale bedrock can help geoscientists and ecologists understand the importance of fractures in weathering and tree root growth.

H5. The RT-FLUX-PIHM model is cross-disciplinary in its capability of integrating processes important for different disciplines (hydrology and geochemistry).

H6. Nothing to report.

H7. Development of the PIHM suite of models is bringing together land surface and atmospheric models.

H8. Nothing to report.

H9. For people not working on CZOs, it is not clear what CZ science is. This team is trying to grapple with the question of what it means to measure and model the CZ and what can be learned by doing that instead of working as separate disciplinary teams.

What is the impact on the development of human resources?

The CZO has funded 9 graduate students, 9 undergraduate students, 2 postdoctoral students, 1 research scientist, and 8 faculty members over the last year. One Research Experience for Teachers participant was also funded to work with the CZO. Of the graduate and postgraduate students, 55% are women and 9% derive from minority. These students derive from 5 departments and 3 colleges on the Penn State campus. Many other Penn State people and visitors participate in CZO work. For example, the SSHCZO is currently hosting postdoctoral scholars Wenjing Liu (Chinese Academy of Sciences) and Grit Steinhofel (Germany), and hosted faculty member Fabio Reis (Brazil), and will host a 2015 REU/RET cohort which includes: Kelsey Bicknell (U. New Mexico, kbicknell@unm.edu), Sarah Granke (Pomona C., sbg12013@mymail.pomona.edu), Megan Shaw (SMU, meshaw@smu.edu), Margaret Ruppel (Wittenberg, ruppelm@wittenberg.edu), Meagan Redmon (Hanover C., redmonm16@hanover.edu), Anna Schuyter (PSU, axs5408@psu.edu), Sharon Dykhoff (sdykhoff@msn.com), and Siobhan Donnelly (CLC, sheabowhan@aol.com). The RET (Research Experience for Teachers) participant is working with Brantley. A. Krapiel, a faculty member at Princeton University, worked at the CZO and published a paper with us this year. Ashlee Dere, a faculty member at the University of Nebraska at Omaha, continues to collaborate

on the Shale Transect with 4 undergraduates from UNO. Beth Herndon (faculty member at Kent State) and Carleton Bern (scientist at USGS) both received seed grants from the CZO and are working on projects with CZO personnel. L. Derry and J. Sparks, faculty at Cornell, continue to collaborate in the Shale Hills catchment. The newest team collaborator is Kristen Brubaker, faculty at Hobert and William Smith Colleges, who will begin her 2015 seed grant project this field season.

What is the impact on physical resources that form infrastructure?

H1. Nothing to report.

H2. Soil gas and water samplers were installed in one shale and one sandstone catchment at multiple depths in pits at ridgetop, midslope, and valley floor positions. These permanent installations will allow continuous monitoring of pore fluid chemistry.

H3. In one shale and one sandstone catchment, soil moisture sensors were installed at multiple depths in pits at ridgetop, midslope, and valley floor positions. These will allow continuous monitoring of soil moisture.

H4. New EMI profiler has been tested in the Garner Run and Shale Hills catchments and will be used extensively in the coming year.

H5. Nothing to report.

H6. This team has deployed a flume at Garner Run, installed stilling wells at several sites for monitoring stream stage, and deployed thermal probes for measuring streambed seepage in Shale Hills.

H7. The team assisted with repair of the eddy covariance measurement equipment at Shale Hills.

H8. A COSMOS sensor will be installed at Garner Run.

H9. Nothing to report.

What is the impact on institutional resources that form infrastructure?

H1. Nothing to report.

H2. Nothing to report.

H3. The CZO research was leveraged to acquire a DOE grant (Eissenstat, Kaye, Shi, Davis, Lin, & Duffy) aimed at assessing the influence of topography on belowground carbon fluxes, and modeling these processes in the Shale Hills CZO with a coupled Earth system and hydrological model. The Shale Hills observatory was also used to assess species variation in mycorrhizal root foraging by a Ph.D. student working in the Eissenstat lab and funded by NSF BIO Directorate, IOS program.

H4. The collaboration with Jon Nyquist and Laura Toran at Temple Univ. will last beyond the project.

H5. Nothing to report.

H6. The collaboration with Beth Parker and John Cherry at Univ of Guelph will last beyond the project.

H7. Nothing to report.

H8. Nothing to report.

H9. The collaboration between Yves Godderis and the modelling team will last beyond the project.

What is the impact on information resources that form infrastructure?

H1. Nothing to report.

H2. A "Precepts for Collaboration" guide to best practices for collaborative science at the SSHCZO was completed as a living document for the team and collaborators.

H3. Nothing to report.

H4. Nothing to report.

H5. A user manual is being developed for RT-FLUX-PIHM.

H6. Nothing to report.

H7. Nothing to report.

H8. A user manual is being produced to provide guidance for running PIHM models.

H9. Nothing to report.

The CZO cyberspecialist Dan Arthur developed new database access web pages that are designed to be self-explanatory. He also set up, populated, and maintained a locally-hosted MS SQL Server database for storage and archiving of local CZO data. It is presumed this database will be maintained beyond the project.

Program coordinator J. Williams and S.L. Brantley have worked for a long time directly with Kerstin Lehnert of IEDA (Lamont Doherty) on the cyberinfrastructure for geochemical data. One of Brantley's students, M. Carter, now works for Lehnert at Lamont. Periodically, the team of Brantley, Carter, Lehnert, and others in IEDA have held phone conferences to discuss

advancement of the geochemical database. The team published a paper on the geochemical database and ontology.

What is the impact on technology transfer?

Nothing to report.

What is the impact on society beyond science and technology?

H1. In accordance with the sampling permit, findings will be shared with the Pennsylvania Bureau of State Parks and thus with the general public.

H2. Jason Kaye gave a tour of the Shale Hills catchment to students in a Penn State forest soils class regarding forest C balance.

H3. David Eissenstat talked to REU students on vegetation in the Shale Hills CZO. David Eissenstat recruited a Hispanic Student to work on his Ph.D. in Ecology for the CZO project. Ismaiel Szink, who comes from a home where his mother only speaks Spanish, received his B.S. from Brigham Young University, has a Jr/Sr GPA of 3.52 and GRE scores of Verbal 93%, Quantitative 90% and Analytical Writing 38%. Eissenstat's graduate student Katie Gaines participated in the NSF CarbonEARTH project, wherein she taught elementary school students about earth science matters.

H4. Team H4 leader H. Lin gave a talk to Holidaysburg Area High School students on the importance of macropores with a demonstration of GPR and infiltrometer use.

H5. Nothing to report.

H6. Nothing to report.

H7. Nothing to report.

H8. Nothing to report.

H9. Team H9 leader S. Brantley gave 2 talks to State College High School students: one on data sonification (with Matt Kenney) in the "Fred Talks" series for Penn State scientists, and one to the Teen Shale Network students, explaining CZ science.

The CZO provides significant contributions to TeenShale Network, an outreach program started by another NSF project led by Brantley and which ends in 2015 (TSN will be maintained by the CZO). The TSN this year engaged 6 eighth graders, 14 freshman, and 11sophomores during the 2014-2015 academic year in water quality investigations at two locations: a state park and downstream of the park where anthropogenic influences are present. Students presented their findings during poster sessions at the Shale Network Workshop (May 7, Atherton Hotel, State College, PA) and the 2015 SSHCZO All-Hands Meeting (May 12, Penn State, PA) where they interacted with university personnel, watershed groups, government agency workers, and gas

industry workers. The students also engaged in science writing, producing a student byline article which describes the project and take home message for the public which will be released in the Centre Daily Times on June 7, 2015 (http://www.centredaily.com/2015/06/08/4782850_focus-on-research-hands-on-project.html?rh=1).

Susan Brantley hosted Justin Richardson at the 2014 SSHCZO All Hands and participated on his thesis committee at Dartmouth College. Justin is the only African American graduate student in Dartmouth College and is getting a degree in Earth Sciences with a specialization in soil science. Brantley also recommended him to the CZ Junior Scientists workshop in NH and as a possible hire for the National Office.

The CZO has served as a field trip destination for two CarbonEarth fellows with their 6th grade students from Philipsburg-Osceola Middle School, a field site for class projects in Environmental Geophysics (Geosc 483, Spring 2015) and Techniques in Environmental Geochemistry (Geosc 413W, Fall 2014) at Penn State, and Hydrogeochemistry (Geol 42069, Fall 2014) at Kent State University. The field site was also the site of two senior theses in Geosciences led by Sridhar Anadakrishnan.

The CZO is working with Matt Kenney, a student in Fine Arts and Multimedia at Penn State who is interested in data sonification. Kenney has produced two sonifications of the CZO data which we referred to in the proposal as “Four Seasons.” This is an experimental sonification of scientific data stemming from research in the Shale Hills Critical Zone Observatory. The project uses data and creates a sonification of the fingerprints of storms as they pass through the CZO. Variables tracked include groundwater, stream water, and precipitation data. Data are transformed into sound, creating a novel and informative representation of the data, removed from the constraints of the line graph, providing a unique look at weather events. The sonification, poster " Isotopic data sonification: Shale Hills Critical Zone Observatory," and extended abstract were presented at the International Conference on Auditory Display (ICAD) 2014 at New York University. The two versions of the sonifications were also presented at the 2014 and 2015 All Hands meetings. We are considering what to do with these pieces.

Changes/Problems

Changes in approach and reason for change

The initial proposal suggested the CZO would investigate 3 subcatchments within Shavers creek watershed in addition to Shale Hills subcatchment. The CZO team has chosen one of these (Garner Run) and almost has it fully instrumented. The team hopes to have the second subcatchment chosen this year, and instrumentation begun. The CZO as a whole has realized that 4 subcatchments will be impossible to achieve. For that reason, the team will limit itself to investigations of one shale-underlain forested catchment (Shale Hills), one quartzite-underlain forested catchment (Garner Run), and one shale-underlain agricultural catchment (still to be chosen). Instead of investigating one more subcatchment as originally proposed, the team will work to integrate results from Leading Ridge subcatchment (a longstanding project led by faculty in the College of Agricultural Sciences) into the CZO. The team is actively now

searching for the agricultural subcatchment and hopes to have it chosen by the end of the summer. The team has experienced some issues with respect to permitting and usage in the Garner Run catchment and has had some difficulties finding landowners who want to participate in the agricultural subcatchment.

H1. Both Kamini Singha (hydrogeophysicst) and Eric Kirby (geomorphologist) left Penn State and are less involved with the project (although both are still actively pursuing the research activities and the publications). Both Tess Russo (hydrologist) and Roman DiBiase (geomorphologist) joined Penn State and have become actively involved with the project. DiBiase is taking an active research role in the CZO H1 team in terms of using geomorphology to understand the distribution of soils in Garner Run watershed. The CZO is providing support for a student for DiBiase but no salary support.

H2. The rocky nature of soils in the sandstone catchment made installation of soil pore water chemistry monitoring equipment challenging. A jackhammer was used to reach the bottom of the soil profile, and sensors were carefully emplaced within corridors of soil between large rocks. One resulting change was to use the open pits to their fullest extent and install many sensors in them. This is different from the original plan, which was to install manual samplers throughout the watershed. It was not possible to dig enough pits to distribute the manual samplers as planned.

H3. Again because of the rocky nature of soils in the sandstone catchment, soil coring to estimate root length density will not be feasible and we will have to rely on soil pits. A graduate student was not recruited as soon as expected delaying progress on the hypothesis. This will mean the team will have to dig new pits for some of its desired data.

H4. Investigating regolith thickness distribution and macropore contribution in the rocky Garner Run hillslope is challenging; the team plans to adopt a more integrated approach to use additional measurements beyond what was initially proposed. In addition, the H4 team was going to be in charge of mapping soil distribution through use of EMI and GPR. However, GPR and EMI will not achieve that goal in its entirety. Instead, Roman Dibiase, the new geomorphologist is going to work with both the H1 and H4 teams to provide information about the distribution of soils.

H5. Nothing to report.

H6. Mike Gooseff, the original leader of team H6, left the original CZO team after moving from Penn State. Tess Russo, a new Penn State hydrogeologist, now leads team H6. Chris Duffy, also originally involved in H6, has indicated he wants minimal involvement with the CZO other than with respect to PIHM modelling. The H6 team, now under the leadership of Russo, is progressing with only a few issues. For example, the team changed methods for measuring discharge at Garner Run due to the low average stream stage, braided channels, and rocky channel; a flume was installed in spring 2015. In addition, measurement of stream discharge from Shale Hills has been hampered because of the need to install a new weir. It has taken the

CZO the better part of a year to figure out how best to do this: during this period, no discharge data are available for Shale Hills subcatchment itself. The team will be emplacing a fiberglass weir this summer. The H6 team is also working with the H2 team to choose a new subcatchment on calcareous shale that contains working farms. Several discussions with farmers have been pursued: a subcatchment has not yet been identified but it is hoped that a subcatchment will be chosen by the end of the summer. Finally, the CZO has realized that drilling on this subcatchment will be very expensive and difficult. To overcome difficulties, the team is working with Beth Parker and John Cherry at Univ of Guelph. To fund the drilling, the team seeks to reallocate the Field Campaign money to drilling and the team has floated a supplemental request for funds to NSF.

H7. The team is attempting to implement TowerHOG, the installation for Garner run that will enable eddy correlation measurements. To do this requires access or installation of a tower. The goal has been to use a commercial tower in the area but the team has had significant difficulties interfacing with the tower owners. Contact has recently been made and progress appears to be imminent.

H8. Chris Duffy has indicated he would like to have minimal involvement with the CZO other than with respect to PIHM modelling. Instead, Yuning Shi, who has been involved in the CZO since its inception and now works part time on the project, is leading the H8 team in collaboration with Li Li. In addition, despite repeated attempts, the CZO has found it hard to interact easily or efficiently with Joe Graney (Univ of Binghamton), who is working at Snake Creek. Given these two factors, the CZO team will most likely not model the Snake Creek watershed. C. Duffy has completed a model for the YWC watershed so that part of the project is complete.

H9. Pam Sullivan, the postdoctoral student working on this project, started a position at Univ. of Kansas during the last year. She will be first author of the WITCH paper, but progress on this paper has been slowed because she started her faculty position at KS.

Teen Shale Network: The original intent of the proposal was to incorporate many Penn State personnel into the Teen Shale Network team. However, because of issues at Penn State, the state has instituted strict rules about background checks for university personnel working with minors. In essence, 2 or 3 background checks are needed for anyone at Penn State to work with the high school students. This has restricted the number of CZO workers who interact with Teen Shale Network. There is now a subgroup from the CZO that has achieved all the background checks and that work actively with the students and teachers. In addition, the students can participate in the All Hands meeting and interact with the entire CZO at that venue.

Program coordinator J. Williams and S.L. Brantley have worked for a long time directly with Kerstin Lehnert of IEDA (Lamont Doherty) on the cyberinfrastructure for geochemical data (together, they even published a paper on this topic). One of Brantley's students, M. Carter, now

works for Lehnert at Lamont. Periodically, the team of Brantley, Carter, Lehnert, and others in IEDA have held phone conferences to discuss advancement of the geochemical database. This advance has been significantly slowed as the CZO National Data team has implemented ODM2. Brantley and Williams have not known what to do to help progress given the new implementation of ODM2. The SSHCZO has now decided to post geochemical data on the SSHCZO website as Excel spreadsheets while simultaneously working with the national CZO team to advance the cyberinfrastructure for geochemical data.

Actual or Anticipated problems or delays and actions or plans to resolve them

H1. See above.

H2. See item above. In addition, delays in collecting sensor data occurred due to the high battery power consumption of new CO_2 and O_2 sensors. Planned installations of propane generators should solve this problem.

H3. Due to the rocky nature of soils in the sandstone catchment, soil coring to estimate root length density will not be feasible and the team will have to rely on soil pits. A graduate student was not recruited as soon as expected, delaying progress on the hypothesis. This will mean the team will have to dig new pits for some of its data.

H4. This team didn't successfully recruit a qualified graduate student to work on this hypothesis. One has now been recruited to start in Fall 2015.

H5. Nothing to report.

H6. Finding an active agricultural field area on shale in which the land owner is willing to allow access has so far been unsuccessful. The team is working with the On-Farm Research Coordinator from the College of Agriculture and the Director of Forestlands to identify local land-owners who may be interested, and they are in the process of finding a site.

H7. Permission to install flux tower instrumentation at Garner Run has been difficult to obtain. Efforts to contact tower owners continue.

H8. Nothing to report.

H9. Pam Sullivan, the postdoctoral student working on H9, started a position at Univ. of Kansas during the last year – before anticipated. She will be first author of the WITCH paper, but progress on this paper has been slowed because she started her faculty position at KS.

Field Challenges: One major technical difficulty that remains unsolved is the internet outage in Shale Hills. Two repairs by Get Wireless have temporarily resolved the connection at $300.00 per visit. Get Wireless equipment has continued to fail preventing automated data transfer back to our database on campus. Data are manually downloaded from the data-logger and imported to the database at this time. The infrared gas analyzer (IRGA) had stopped working due to a bad chopper motor and was repaired under warranty. The IRGA has been reinstalled on the Flux

Tower. The Flux Tower data-logger flashcard was also found to be corrupt and is currently being analyzed by Campbell Scientific. A spare flashcard is currently being used as a backup. The current weir in Shale Hills is in disrepair, leaks, and cannot be used in its current condition to obtain discharge rates. A new H-flume will be purchased with an estimate of $4,500.00. Two propane generators have been purchased for use in Garner Run that will provide power to Leading Ridge Mid-slope and Tussey Mountain Mid-slope locations. These locations require additional power due to the sap-flux sensors drawing more power for the heat resistors. These generators cost $7,898.40. General maintenance and upkeep costs are estimated at $300.00.

Changes that have a significant impact on expenditures

The CZO identified a need for a field vehicle which was not budgeted on the original grant. The team is currently searching for this vehicle. It appears that the team will be able to use overhead return money to buy the vehicle but that remains to be determined and may depend on the cost of the vehicle.

H1. Brian Clarke, a postdoc who worked on the project for 1.5 years, did not produce any publications; this team has had to hire a new postdoc, N. West, to complete the project. West anticipates submitting one or two papers for publication this summer.

H2. The number of soil CO_2 and O_2 sensors was reduced relative to planned levels due to budget constraints.

H3. Nothing to report.

H4. Nothing to report.

H5. Nothing to report.

H6. Money allocated for drilling boreholes was underestimated; the team has not been able to complete boreholes in the sandstone watershed. The team has worked hard to involve Beth Parker and John Cherry in the drilling program and needs the funds to do this. The CZO would like to reallocate funds from the proposed Field Campaign to enable the drilling work with Parker and Cherry (this would only partially defray the costs of the drilling campaign). The CZO has also asked for supplemental support to bring Cherry and Parker into the project (no salary is requested) and to defray some of the costs of the drilling. The weir at Shale Hills is now defunct (it was made of wood and it simply decayed). Replacement of the weir will cost about $3k. The CZO had access to two sc::ann units upon initiation of the CZO; however, one of these was a loaner. The CZO had anticipated that the company would give the CZO this unit. Unfortunately, the company asked for remuneration ($10k) which had not been budgeted. The CZO paid this amount.

H6. The Li-Cor CO_2/H_2O sensor from the Shale Hills flux tower was returned to the manufacturer for repairs (at a cost).

H7. Nothing to report.

H9. Nothing to report.

The CZO cyberspecialist Dan Arthur has identified a need for 2 computers to be installed in the field during summer 2015, one for Shale Hills and one for the Garner Run field site, to receive and store high-frequency flux tower data, due to increasing unreliability of internet access to the former and unavailability of internet access to the latter. Sufficient disk storage, including portable drives for transfer of data between field sites and campus resources, is also required. These additional computing/data hardware expenses are estimated to be approximately $3-4k at most.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.