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Preview of Award 1331726 - Annual Project Report

Cover |
Accomplishments |
Products |
Participants/Organizations |
Impacts |
Changes/Problems

Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1331726
Project Title:	Using the Susquehanna - Shale Hills CZO to Project from the Geological Past to the Anthropocene Future
PD/PI Name:	Susan L Brantley, Principal Investigator Kenneth J Davis, Co-Principal Investigator David M Eissenstat, Co-Principal Investigator Li Li, Co-Principal Investigator
Recipient Organization:	Pennsylvania State Univ University Park
Project/Grant Period:	10/01/2013 - 11/30/2020
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Submitting Official (if other than PD\PI):	Susan L Brantley Principal Investigator
Submission Date:	09/25/2019
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Susan L Brantley

Accomplishments

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

Overall Project: We are learning to earthcast the CZ. To us, earthcasting means developing quantitative models for earth surface evolution that will enable us to project into the future. We plan to do this by creating models to describe fluxes we see today, by testing the models by hindcasting the geologic record, and then using those models to make forecasts. We focus on a 165 km2 watershed in central PA (Shavers Creek). We have developed an observational model to measure important aspects of the CZ in this large watershed. Over short timescales and large spatial extents, we are developing an atmosphere-land surface model that couples meteorological and ecological processes with hydrological and biogeochemical processes in regolith using information about 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. The models that treat these various processes are built on the Penn State Integrated Hydrologic Model (PIHM). With different modules in PIHM we plan to model changes in water, energy, sediment, and solute (WESS) fluxes at various timescales. 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.

While working on this big picture effort, we have structured our group into 9 teams, as described below.

H1 Team Goal: The H1 team is measuring fracture distributions , using measurements of cosmogenics to assess erosion rates; using boreholes, field observations, and geophysics to predict the structure of porosity and permeability in Shavers Creek watershed and surrounding relevant sites.

H2 Team Goal: This team is 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.

H3 Team Goal: Team H3 is 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.

H4 Team Goal: This team is 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.

H5 Team Goal: Team H5 is 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.

H6 Team Goal: Team H6 is 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.

H7 Team Goal: This team is 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.

H8 Team Goal: The H8 team is developing as complete a dataset as possible that allows multi-scale modelling to project physical processes from Shale Hills to Shavers Creek.

H9 Team Goal: The H9 team is spearheading measurements to understand weathering processes in the target catchments and using models to earthcast weathering and other CZ processes into the future.

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

Major Activities:

H1 : Graduate Student Perri Silverhart has continued to work at the agricultural subcatchment (Cole Farm), with the goal of distinguishing anthropogenic versus periglacial drivers of hillslope erosion and colluvial valley aggradation. At Bear Meadows, a sandstone site near Garner Run, Graduate Student Joanmarie Del Vecchio has been using sediment cores, radiocarbon, and cosmogenic nuclides to investigate the timing of periglacial hillslope erosion and deposition. We submitted one paper on geophysical imaging of the critical zone at Garner Run (DiBiase et al., in review), which is the result of interdisciplinary collaborations with geophysicists at IUP, Dickinson, and Florida Atlantic University that started in summer 2016.

H2 : One manuscript was submitted to and published by the Soil Science Society of America Journal, written by CZO-funded PhD student, Caitlin Hodges. That manuscript compared depth profiles of soil pCO2 and pO2 at in two catchments (Shale Hills and Garner Run) of distinct lithology. In addition, we continued to sample pCO2 and pO2 in three catchments (Shale Hills, Garner Run, and Cole Farm) and we presented results from the Cole Farm dataset at the SSSA International Soil Science.

We completed high-resolution lysimeter sampling at Shale Hills to understand how pore-size controls soil water residence time, redox status, and in turn carbon cycling. Pore waters analyzed for DOC and Fe redox state. We installed and are monitoring fixed-potential electrodes to track iron oxidation/reduction in conjunction with our soil CO2 and O2 and soil moisture data at Shale Hills.

We started extractions to characterize metal-oxide controls on soil carbon stabilization at Shale Hills and Cole Farm. Cole Farm extractions are completed.

One MS student (Dillner) completed his thesis describing how plants and soils are affected when trees are blown down in wind storms.

H3 : One manuscript was submitted and now is in revision in Ecosphere that examines how root distribution varies with lithology. In addition we are developing papers on root length allocation compared to aboveground allocation at Shale Hills and factors influencing soil CO2 efflux and root production and turnover at Shale Hills. We are also examining how roots and mycorrhizal fungi influence wood decomposition at Shale Hills and to a lesser extent, Garner Run using mass balance coupled with microbial analysis of the wood. Finally, we remeasured 2000+ trees in the Garner Run watershed that were originally tagged and surveyed in 2015. We're going to be able to calculate aboveground productivity and track forest dynamics of those transects at different hill slope positions.

One PhD student (Rondy Malik) defended his PhD describing how roots and mycorrhizas influence wood decomposition. Three students (Warren Reed, Ted Primka, and Ismaiel Szink) are in progress.

H4 : Graduate student Qicheng Tang gave posters at AGU and Golden Conference on the influence of lithology on preferential flow. He hopes to publish this paper in the coming year. Over the past year, he set up two additional soil moisture sites, one at Garner Run and one at Shale Hills to more fully understand controls over preferential flow. He also has sampled precipitation, stream and sapwood water for isotopes of oxygen and hydrogen to understand where trees take up water during and after storm events.

H5 : Graduate student Dacheng Xiao has been writing a manuscript on hillslope modeling.

H6 : Dacheng, Li, and other co-authors have been writing a manuscript for Water Resources Research, which has been accepted and is preparing another manuscirpt comparing different types of soil moisture measurements.

Postdoc Hang Wen has also been writing a manuscript on upscaling of hydrological dynamics at the watershed scale.

Masters student Callum Wayman completed several synoptic samplings of Shavers Creek and compared solute loads as a function of lithology and land use.

H7 : Flux data collection continued in the Shale Hills and Cole Farm catchments. Biogeochemical model evaluation continued. Flux data were used to support algorithm development for the ECOSTRESS satellite mission.

H8 : Land surface and hydrologic simulations for all three SSHCZO watersheds have been performed.

Shi has added a deep groundwater module to MM-PIHM to represent the water dynamics and soil chemistry in the deep layer, and is writing an MM-PIHM User's Manual.

Wen has performed 2-grid PIHM simulations at Shale Hills to get insight into upscaling.

H9 : Pam Sullivan, now a professor at Univ of Kansas, finished up using WITCH and FluxPIHM to model Shale Hills soils on the north and south aspects.

Specific Objectives:

H1 : Graduate Student Perri Silverhart processed soil samples for 137Cs and excess 210Pb analysis along two opposing hillslope transects at Cole Farm to quantify decadal patterns of erosion and deposition. We also drilled and collected sediment cores from a 4+ m thick valley fill at Cole Farm, which was sampled for radiocarbon and 137Cs. Graduate Student Del Vecchio visited PI Bierman's lab at the University of Vermont to be trained and process cosmogenic nuclide samples collected from a 19 m hillslope core drilled at Bear Meadows.

H2 : Our main objective was to determine biological and lithological controls on the detph distribution of CO2 and O2 across typical catchments of the Shaver's Creek watershed. We have focussed on soil moisture, particle size, and rock chemistry as key drivers of this variation. A secondary objective is to lin soil gas variabilty with redox reactions, especially those that affect soil organic C cycling.

H3 : Our main objective was to understand how trees influence weathering, water flux, carbon and nutrient cycling and other CZO processes.

H4 : Our main objective was to understand how lithology affects water movement in the soil, particularly contrasting preferential with sequential flow

H5 : Xiao's objective was to understand the formation of regolith and its controlling variables.

H6 : Xiao's objective was to understand how water dynamics differ under similar climate and vegetation condition but contrasting lithological conditions.

Wen's objective was to understand how water dynamics differ at different spatial scales

Masters student Callum Wayman was trying to understand controls on solute chemistry and load in the Shavers Creek watershed and how they were controlled by lithology and land use (forest versus cultivation).

H7 : Our objective is to understand the processes governing the distribution of carbon fluxes and pools in complex terrain, to evaluate the ability of our biogeochemical modeling system to reproduce these fluxes and pools, and to consider what new observations or model processes are needed to simulate the carbon cycle in complex terrain.

H8 : H8 Team's objective was to improve the MM-PIHM modeling system, implement the modeling system at SSHCZO, and understand the impact of soil, land cover, topography, and spatial scales on water dynamics.

H9 : Sullivan's objective was to understand why there are differences between the north and south aspects of the catchment in terms of water chemistry, soil chemistry, and grain size. By looking at differences related to aspect, we hoped to learn how to use WITCH and FluxPIHM to project the impact of changes in climate on water chemistry and soils.

Significant Results:

H1 : The synthesis of geophysical data at Garner Run (DiBiase et al., in review) has yielded a new subsurface model for the sandstone catchment. We have also discovered key contrasts in soil thickness and depth to unweathered bedrock between the Garner Run and Shale Hills subcatchments. Combined with previously published erosion rate data (Del Vecchio et al. 2018; West et al., 2013), our analysis shows how lithology (sandstone vs shale) and erosion rate influence subsurface critical zone architecture and lead to strong contrasts in the residence time of regolith (20 kyr vs. >200 kyr) over short distances (<5 km). These results have important implications for

how watersheds respond to perturbations, including climate change and land use impacts.

H2 : At Shale Hills and Garner Run, we found that hillslope position and lithology affect soil CO2 and O2 and that the ratio of CO2 and O2 (ARQ) fluctuates over the growing season. The ARQ fluctuations indicate seasonal metal redox cycling at all hillslope positions. An important outcome of this pattern is that anaerobic respiration is important to soil CO2 flux during the late growing season. The paper is one of the first and best examples of using measurements of CO2 and O2 in soil gas to determine metabolisms and geochemical reactions during weathering.

We also discovered that, unlike findings from other studies, tip-up pits and mounds do not appear to facilitate regeneration of canopy trees; tree seedling and sapling iv counts were not significantly higher on tip-up sites than the controls. In recent tip-ups, plant nutrients such as nitrogen and phosphorus showed increased availability, but this may not necessarily be a boon for plants since water availability was low compared to the control soils. We observed that pits accumulated thick organic horizons from leaf litter over time, while mounds remained dry and organic matter impoverished. Even after 30 to 50 years, mounds had soil profiles that were distinct from controls; mounds of this age lacked high soil organic matter enrichment in the top 5cm and had remnant O horizon at ~30cm depth. Despite only turning over 0.02% of the soil surface each year, we propose that tip-ups should be incorporated into models of the study forest because they have a disproportionate effect on plant communities, and mounds persist for hundreds of years.

H3 : We found that for the same tree species, much higher root length density occurred in shale-derived soils than sandstone-derived soils despite similar aboveground productivity. We also found that while slope position at Shale Hills can strongly affect tree height, it has negligible effects on total root length per unit ground area. We also observed that soil CO2 efflux is more influenced by root flushes (time periods with high root growth) than moisture or temperature fluctuations at Shale Hills in June and July. To date, the state of the art of carbon cycle science is highly limited by our understanding of root growth and root density and its spatial and temporal distribution. Our project is illuminating patterns related to tree species, lithology, and landscape position, and is starting to explore some of these patterns in terms of modelling carbon fluxes, sinks, and sources.

H4 : We found that both lithology and microtopography can influence preferential flow with reduced preferential flow on toe slopes and ridge-tops compared to midslopes. This has large implications for macropore distribution: macropores are well known to be present but are impossible to predict. For such a phenomenon, the first endeavor must be mapping where they are and our work has strong implications for this.

H5 : We found that subsurface structure, in particular the distribution of permeability, is the major control on regolith formation under similar climate and lithology and structural conditions. This is a first step toward taking away the "black box" aspect of subsurface structure, i.e., to understand what parameters are the most important to be able to model. We are pushing the idea that models of regolith development can yield understanding of the distribution of permeability in the subsurface.

H6 : Masters student Callum Wayman discovered that lithology was a better predictor of most solute fluxes than land use in the Shavers Creek watershed. Working with A. Shaughnessy, we also observed that pyrite may be oxidizing nitrate in the watershed. We are now pushing very hard to use this knowledge to be able to make watershed-wide predictions of nitrate transport and relate it to patterns of denitrification in the agricultural part of the watershed. This is a very important contribution that is also being informed by mass load estimates of the watershed that are based on fine-scale synoptic sampling.

H7 : We found that there are a relatively small number of model parameters that control the carbon pools in the Shale Hills watershed. Simulating spatial structure in carbon pools across the watershed is likely to require altering model structure beyond the simplified plant functional types typically used in ecosystem biogeochemical models. Soil respiration observations were found to improve model representation of the temporal pattern of ecosystem fluxes, but not the spatial structure of soil carbon pools. Our ability to model carbon in Shale Hills is now very advanced and we are moving the approach toward models for the cultivated landscape at Cole Farm.

H8 : We found that 1) soil properties are the first-order control of the flashiness of streamflow generation at the catchment scale compared to topography; 2) A spatially implicit catchment scale model using averaged properties can capture high flow events (flooding) but not low flow events (droughts). This work is moving us forward on the use of Flux-PIHM as a land-air hydrologic model.

H9 : We showed that the differences between the north and south aspects of Shale Hills is related to difference in temperature and water throughflux, and is also related to the differences in particle sizes on the two sides of the catchment. This difference in particle size may in turn be related to the long term effects of differences in weathering on the two sides of the catchment. This is an important result because it shows how ongoing differences in microclimate are manifest in aspect-related differences in water flux and chemistry, but that the cumulative impact of these differences is (probably) manifest in grain size differences on the two sides of the watershed.

Key outcomes or Other achievements:

H1 : In addition to submitting the geophysics synthesis paper at Garner Run (DiBiase et al., in review), two papers that were submitted during the last reporting period have now been published: 1 paper published on periglacial controls on erosion rates (Del Vecchio et al., 2018); and 1 paper published on rock strength controls on erosion rate and topography at Young Womans Creek (DiBiase et al., 2018).

H2 : Our team published one peer reviewed paper and contributed six presentations (two at national meetings).

H3 : Our team published three peer-reviewed papers and contribued four presentations

H4 : Our team presented two presentations at national meetings

H5 : Dacheng Xiao, Yuning Shi, Susan Brantley, Brandon Forsythe, Roman DiBiase, Kenneth Davis, Li Li. 2019. Predominant control of soil properties in storage-discharge relationship and threshold behavior in catchments derived from contrasting lithologies. Water Resources Research (accepted for publication)

Xiao et al., Subsurface controls on regolith formation at the hillslope scale (in prep)

H6 : Wen Hang, *Susan Brantley, Kenneth Davis, + ... Li Li, Upscaling Hydrological Dynamics at the Catchment Scale. (in preparation)*

One thesis was completed: Wayman, C., 2018. Using the effects of seasonality, land cover, and lithology to inform a hydrologic transport model for Shavers Creek Watershed, Department of Geosciences, M.S.Thesis, Pennsylvania State University.

H7 : Graduate student Yuting He defended her Ph.D. dissertation, Understanding the carbon cycle in complex terrain at the Shale Hills Critical Zone Observatory. One manuscript from this dissertaion is in review, and two are in preparation.

Yuting He, Kenneth Davis, Yuning Shi, Dave Eissenstat, Jason Kaye, Margot Kaye (2019): Observing and Simulating Spatial Variations of Forest Carbon Stocks in Complex Terrain. Journal of Geophysical Research: Biogeosciences (in review)

H8 : The upscaling work by Wen and the watershed comparison work by Xiao have led significant insights about different watershed dynamics and about upscaling. We are currently in the process of thinking about upscaling understanding from small headwater watershed (shale hills, garner run) to larger watershed such as Shaver's Creek.

The MM-PIHM system has been implemented at all three SSHCZO watersheds which paves the way to simlating the whole Shaver's Creek watershed.

Shi, Y., D. Xiao, ...: A multi-modular watershed model for the study of critical zone processes (in prep).

A number of versions of MM-PIHM have been released to public. The latest version is v0.13.0-alpha.

H9 Two papers were published that show how earthcasting might be accomplished for weathering: Sullivan, P. L., Y. Goddéris, Y. Shi, X. Gu, J. Schott, E. A. Hasenmueller, J. Kaye, C. Duffy, L. Jin, S. L. Brantley. 2019. Exploring the effect of aspect to inform future earthcasts of climate-driven changes in weathering of shale. *Journal of Geophysical Research - Earth Surface*. doi: 10.1029/2017JF004556;

Sullivan, P. L., S. L. Brantley, Li Li, and Y. Godderis. Poised to Hindcase and Earthcast the Effect of Climate on the Critical Zone: Shale Hills as a Model, chapter in AGU book (ed K. Dontsova). Accepted for publication, Jan 2019

Other achievements:

The entire team contributed to a new peer reviewed manuscript describing best practices for collaboration in Critical Zone Science (Kaye et al. in review).

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

From 2013 to 2018, 32 graduate students worked at SSHCZO (16 female); 9 PhDs and 10 Masters were defended; 13 postdoctoral students were funded; 16 undergraduates were hosted as REUs; and 3 teachers were mentored as RETs. Funding derived from multiple sources for stipends and tuitions. Thirteen PIs were associated with the project (5 female, 2 untenured). Three graduate students and 1 postdoc and 1 member of our management team derived from an under-represented group.

The CZO also hosted geophysics field workshops run by Rutgers University from 2016 to 2019 and funded by an NSF GEOPATHS grant to Rutgers Univ. The most recent GEOPATHS near surface geophysics field experience was held from May 18 to May 31 of 2019 and had 20 participants (15 students and 5 peer-mentors). Students were recruited primarily from TU, RN and 2-year colleges associated with RN (Passaic County Community College and Essex Community College). Students from the following institutions also participated: Community College of Philadelphia, Montclair State University, Indiana University of Pennsylvania, and Dickinson College. The mentors were from RN, TU, Dickinson College, and the University of Georgia. Of the 20 participants 12 self-identified that they belonged to an under-represented minority (URM) group; in total, over the two years that the program has run, of 37 unique participants, 21 have self-identified as belonging to a URM group. Of the student participants, 7 self-identified as from a URM group (2 Black/African American, 5 Hispanic/Latino); of the mentor participants 5 of 5 self-identified as from a URM group (2 Black/African American, 3 Hispanic/Latino).

The CZO is also now the locus for a USDA National Needs Fellowship grant that will fund three PhD students (offers extended to three women, one from an under-represented group) to use Critical Zone approaches to improve forest management planning. These students will be mentored by CZO faculty Kaye and Duncan, as well as M. Kaye, to use the CZO for research, and disseminate their work to forest management stakeholders in the Northeast.

J. Williams, CZO project coordinator, spearheaded TeenShale Network, an effort that puts adolescents from State College middle school and high school into the field. Since Fall 2013, 59 students have been involved in the program, along with 6 teachers, 5 Penn State students, 7 Penn State faculty, and both the CZO project and watershed coordinators. At least 5 of the students are pursuing geology or energy engineering post-highschool. Fifty-nine middle or high school students participated in TeenShale Network from 2013-2018, with 20 of those participating for multiple years.

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

More than 100 papers are in review, in press, or published from the CZO from 2013 to today. Almost all published or conference-presented papers are co-authored with students. Almost 200 papers were presented and 12 scientific special sessions were organized at national meetings, and 3 workshop papers were published from NSF-funded PI-led workshops (Brantley et al., 2017; Brantley et al., 2017; Li et al., 2017). Throughout the funding period, postdocs and students have been mentored by multiple PIs and have made presentations at meetings. Fourteen undergraduate senior theses have investigated the SSHCZO.

The SSHCZO team has worked closely with the staff of the Shavers Creek Environmental Center to implement i) CZO instrumentation near the Center for families to observe; ii) an exhibit describing the history of the site of the Center over geological time to human timescales; iii) a family trail highlighting different findings of CZ science.

An article was written about the work of Perri Silverhart and Roman DiBiase on legacy sediments in the Cole Farm subcatchment of the SSHCZO: this article was published in the newsletter of the Chesapeake Research Consortium.

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

The majority of what we have proposed for this supplement year will focus on synthesis and modelling of datasets to achieve understanding that exemplifies the CZ goal of integration across disciplines. This is time-consuming and difficult (very!). We will have postdocs work on three areas: i) pulling together the many geophysical datasets that have been collected by nonCZO scientists A. Nyblade (Penn State), J. Hayes (Dickinson College), L. Slater, C. Keating (Rutgers U.), and G. Mount (Indiana Univ. of Pennsylvania); ii) synthesis of observations with terrestrial ecosystem models, and evaluation of the processes and data that are most critical for constructing high-fidelity re-analyses and predictions of the terrestrial carbon cycle in the forested, complex landscapes of the Appalachian Mountains; iii) upscaling the spatially distributed Flux-PIHM model for the complex terrain in the CZO to a simplified water-land surface model with two grid blocks connected by a river channel. The postdocs will synthesize datasets and develop models (conceptual and numerical) to understand the geophysical, carbon, and water data. Each of these projects will be highly interdisciplinary and will therefore require a high-level postdoctoral thinker and the participation of many personnel inside and outside of the CZO.

Watershed technical staff also will maintain our field and data efforts in monitoring the subcatchments and Shavers Creek mainstem .

To complete the hydrologic upscaling work we started, we have recruited another grad student (M. Forgeng) who is working to complete the nutrient budget for Shavers Creek. He is also spearheading a day of synoptic sampling that will incorporate almost 50 volunteers from the community. This "Snapshot Day" is being co sponsored by Penn State Shavers Creek Environmental Center, SSHCZO, and Trout Unlimited.

At the end of the next year, we will have finalized and modelled a set of CZ measurements for a HUC10 watershed in the Appalachian Mountains, including all three subcatchments and the mainstem of Shaver's Creek. A paper about our first upscaling from Shale Hills to Shaver's Creek will be completed, and our models will link the cycles of water, nitrogen, and carbon (Fig. 3). This investment represents a huge step forward in our understanding of the CZ. Throughout our project, we have been disseminating our knowledge and working to teach our new insights and approaches. Dissemination of CZ science around the world is one testament to our work as summarized in our recent paper describing the CZO network more broadly (Brantley et al., 2017) and the paper we published after running a workshop on Trees in the Critical Zone (Brantley et al., 2017). We will continue to coordinate data management among CZOs and to work with NSF and the CZO network to disseminate CZ science worldwide.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
AdditionalReporting Requirements.pdf	Additional Reporting Requirements	Susan Brantley	09/25/2019

Products

Books

Book Chapters

Billings SL, Sullivan PL (2019). Working across scales to project soil biogeochemical responses to climate. *Multi-scale Biogeochemical Processes in Soil Ecosystems: Critical Reactions and Resilience to Climate Changes* Y. Yang, M. Keiluweit, N. Senesi, B. Xing. . Status = AWAITING_PUBLICATION; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

Sullivan PL, Li L, Goddéris Y, Brantley SL. (2020). Poised to Hindcast and Earthcast the Effect of Climate on the Critical Zone: Shale Hills as a Model. *Biogeochemical Cycles: Ecological Drivers and Environmental Impact.* 252. K. Dontsova, Z. Balogh-Brunstad, G. L. Roux. Wiley. ISBN 9781119413301. . Status = AWAITING_PUBLICATION; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

Inventions

Journals or Juried Conference Papers

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Brantley Susan, White Timothy, West Nicole, Williams Jennifer, Forsythe Brandon, Shapich Dan, Kaye Jason, Lin Hangsheng (Henry), Shi Yuning, Kaye Margot, Herndon Elizabeth, Davis Kenneth, He Yuting, Eissenstat David, Weitzman Julie, DiBiase Roman, Li Li, Reed Warren, Brubaker Kristen, Gu Xin (2018). Susquehanna Shale Hills Critical Zone Observatory: Shale Hills in the Context of Shaver's Creek Watershed. *Vadose Zone Journal - Special Section - Hydrologic Observatories*. 17 (1), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.2136/vzj2018.04.0092

Chen W, Eissenstat DM, Koide RT (2018). Root diameter predicts the extramatrical hyphal exploration distance of the ectomycorrhizal fungal community.. *Ecosphere*. 9 DOI: 10.1002/ecs2.22. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/ecs2.2202

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Del Vecchio, J., DiBiase, R.A., Denn, A.R., Bierman, P.R., Caffee, M.W., and Zimmerman, S.R. (2018). A record of coupled hillslope and channel response to Pleistocene erosion and deposition in a sandstone headwater valley, central Pennsylvania. *GSA Bulletin*. 130 1903. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1130/B31912.1

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Fan, Y., Clark, M., Lawrence, D.M., Swenson, S.,Band, L.E., Brantley, S.L., Brooks, P.D., Dietrich, W.E., Flores, A., Grant, G., Kirchner, J.W., Mackay, D.S., McDonnell, J., Milly, P.C.D., Sullivan, P.L., Tague, C., Ajami, H., Chaney, N., Hartmann, A., Hazenberg, P., McNamara, J., Pelletier, J., Perket, J., Rouholahnejad-Freund, E. Wagener, T., Zeng, X., Beighlye, E., Buzan, J., Huang, M., Livneh, B., Mohanty, B.P., Nijssen, B., Safeeq, M., Shen, C., van Verseveld, W., Volk, J., Yamazaki, D. (2019). Structures and Functions of Hillslope Hydrology with Relevance to Earth Systems Modeling: Syntheses and Testable Hypotheses. *Water Resources Research*. 55 (2), 1737. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1029/2018WR023903

Gu, X., Rempe, D.M., Dietrich, W.E., West, A.J., Lin, T.-C., Jin, L., Brantley, S.L. (2019). Chemical reactions, porosity, and microfracturing in shale during weathering: The effect of erosion rate. *Geochimica Cosmochimica Acta*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

He, Y., Kenneth Davis, Yuning Shi, Dave Eissenstat, Jason Kaye, Margot Kaye (2019). Observing and Simulating Spatial Variations of Forest Carbon Stocks in Complex Terrain. *Journal of Geophysical Research: Biogeosciences*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Hodges, C. Kim, H. Brantley, S.L. Kaye, J. (2019). Soil CO2 and O2 concentrations illuminate the relative importance of weathering and respiration to seasonal soil gas fluctuations. *Soil Science Society of America Journal*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/sssaj2019.02.0049

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Li Li, DiBiase Roman A., Del Vecchio Joanmarie, Marcon Virginia, Hoagland Beth, Xiao Dacheng, Wayman Callum, Tang Qicheng, He Yuting, Silverhart Perri, Szink Ismaiel, Forsythe Brandon, Williams Jennifer Z., Shapich Dan, Mount Gregory J., Kaye Jason, Guo Li, Lin Henry, Eissenstat David, Dere Ashlee, Brubaker Kristen, Kaye Margot, Davis Kenneth J., Brantley Susan L. (2018). Investigating the Effect of Lithology and Agriculture at the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO): The Garner Run and Cole Farm Subcatchments. *Vadose Zone Journal - Special Section - Hydrologic Observatories*. 17 (1), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/vzj2018.03.0063

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Licenses

Other Conference Presentations / Papers

Eissenstat, D.M., Alexandra Orr, Ismaiel Szink, Kusum Naithani, Jason Kaye and Thomas Adams (2018). *Biomass Partitioning to Absorptive Roots in the Context of Multiple Resource Limitation*. American Geophysical Union. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

Eissenstat*, D.M., Alexandra S. Orr, Ismaiel Szink, Kusum J. Naithani, Jason P Kaye, Thomas S Adams (2018). *Biomass Partitioning to Absorptive Roots in the Context of Multiple Resource Limitation, #B41K-2856*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Keating, K., G. Mount, J. Nyquist, J. L. Hayes, A. Gates, S. L. Brantley, E. Iverson, K. O'Connell, J. Zan Williams (2019). *Broadening the Participation of Underrepresented Minorities in the Geosciences Using a Practical Field Camp Experience in Geophysics (Invited)*. PittCon. Philadelphia, PA.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Donaldson*, Y.Y., Joaquin Cambeiro, Gina Pope, Paul O'Neill, Gregory Mount, Kristina Keating, Susan Brantley, Jonathan Nyquist (2018). *Characterizing the subsurface of the Critical Zone in the Garner Run Catchment at the Susquehanna Shale Hills Critical Zone Observatory using Electrical Resistivity, #NS41B-0819*. 2018 AGU Fall Meeting, Washington, D.C., 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Accardo*, N.J., Andy Nyblade, Xin Gu, Gregory Mount, Susan Brantley (2018). *Chemical vs physical influences on weathering at the Susquehanna Shale Hills Critical Zone: Preliminary Results from a 3D seismic imaging experiment (Invited), #NS43A-05*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Marcon*, V.Z., Hang Wen, Li Li, Susan Brantley (2018). *Co-precipitation of calcite and sulfur at depth signifies biotic activity at the onset of weathering in crystalline rocks from temperate climates, #B23H-2625*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Perdrial*,J.N., Malayika M Cincotta, Jesse Armfield, Thomas Adler, James B Shanley, Kristen Underwood, Donna M Rizzo, Hang Wen, Li Li, Adrian Harpold, Gary Sterle (2018). *Combining long-term observations with experiments to test hypotheses on stream water dissolved organic carbon dynamics at the Sleepers River Research Watershed, #H12D-07*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Tang, Q., Jonathan Duncan, Dacheng Xiao, Li Li, Li Guo, Henry Lin, David Eissenstat (2018). *Comparing preferential flow between two catchments with contrasting lithologies*. American Geophysical Union. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

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Lutz*, K., Natalie J Accardo, Andrew Nyblade, Susan Brantley (2018). *Constraints on Ridge-to-Valley Critical Zone Structure from the Susquehanna Shale Hills Critical Zone Observatory, #NS41B-0816*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Renzaglia*, J., Natalie J Accardo, Andrew Nyblade, Susan Brantley (2018). *Constraints on Valley Structure from Two Seismic Refraction Lines in the Susquehanna Shale Hills Critical Zone Observatory, #NS41B-0817*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Xiao*, D., Yuning Shi, Qicheng Tang, Henry Lin, David M Eissenstat, Susan Brantley, Li Li (2018). *Critical measurements of hydrologic response in a first-order, forested catchment at the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO), #EP11C-2065*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Brantley*, S.L., David M Eissenstat, Roman A DiBiase, Kenneth J Davis, Jason P Kaye, Margot Kaye (2018). *Defining the Importance of Upland Landscapes Using Critical Zone and Other Similar Observatories, #H13J-1860*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Shi*, Y., Armen Kemanian, Charles White, Felipe Montes (2018). *Development of a Next Generation Spatially Distributed Agroecosystem Model, #B33G-2761*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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Wen*, H., Li Li, Julia N Perdrial, Benjamin Abbott, Thomas Adler, Susana Bernal, Remi Dupas, Sarah Godsey, Rebecca L Hale, Adrian Harpold, Donna M Rizzo, Gary Sterle, Kristen Underwood (2018). *Hydrologic Control of Catchment-Scale Dissolved Organic Carbon (DOC) Dynamics, #H13J-1880*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Wlostowski*, Adam, Ciaran J Harman, Noah P Molotch (2018). *Hydrologic Storage and Partitioning Across the CZO Network, #H23N-2149*. 2018 AGU Fall Meeting, Washington, D.C., 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Cambeiro, J. Angelo Tarzona*, Yonesha Y Donaldson, Gina Pope, Paul O'Neill, Jorden L Hayes, Gregory Mount, Kristina Keating, Susan Brantley, Jonathan Nyquist (2018). *Imaging the critical zone structure using seismic refraction in Garner Run at the Susquehanna Shale Hills Critical Zone Observatory, #NS41B-1159*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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Wayman*, Callum, Tess A Russo, Jonathan M Duncan, Li Li, Brandon Forsythe, Beth Hoagland, Susan Brantley (2018). *Land use and lithology controls on export of nitrate and other solutes from headwaters to HUC10 watersheds, #H13J-1861*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Tang, Q., Duncan, J. M., & Eissenstat, D. M. (2019). *Lithologic and slope positions controls on preferential flows in Shale Hills Critical Zone Observatory, Pennsylvania, (USA).*. Golden Research Conference. Andover, NH. Status = OTHER; Acknowledgement of Federal Support = Yes

Reed WP, Kaye MW (2019). *Lithologic influences on forest productivity and carbon storage in the central Appalachian Ridge and Valley*. Ecological Society of America. Louisville, KY. Status = OTHER; Acknowledgement of Federal Support = Yes

Gu*, X., Gary Mavko, Natalie J Accardo, Andrew Nyblade, Susan L Brantley (2018). *Mapping geochemistry onto geophysics to understand the architecture of shale weathering in the shallow subsurface, #NS43A-06*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Comas, X.; Conveners - Gregory Mount, Jorden L Hayes, Roman A DiBiase; Chairs - Xavier Comas, Gregory Mount (2018). *NS41B: Near-Surface Geophysics in the Critical Zone Posters*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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Mount*, G. Jorden Hayes, Perri Silverhart, Callum Richard Wayman, Joanmarie Del Vecchio, Roman A DiBiase, Susan L Brantley (2018). *Near-surface Geophysical Characterization of Cole Farms in the Susquehanna Shale Hills Critical Zone Observatory, Pennsylvania, USA., #NS41B-0820*. 2018 AGU Fall Meeting, Washington, D.C., 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

He, Y., K. J. Davis, Y. Shi, D. M. Eissenstat, J. Kaye, M. Kaye (2018). *Observing and simulating spatial variations of carbon fluxes and stocks in complex terrain*. CZO_LTER_NEON_ISMC cross network workshop. Boulder, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Del Vecchio, J., DiBiase, R.A., Corbett, L., Bierman, P.R., Caffee, M.W., and Ivory, S. (2019). *Pleistocene climate-modulated erosion: Interpretations from cosmogenic nuclide concentrations of an 18 m hillslope core in central Appalachia*. Geological Society of America Fall Meeting. Phoenix, Arizona. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Del Vecchio*, J.M. (2018). *Reading rocks and ground that once were cold but now are not, #ED21B-02*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

White*, T.S., Ashlee Laura Denton Dere, Sarah Sharkey (2018). *Sediment flux rates by tree throw in the Shale Hills Critical Zone Observatory and associated satellite sites in the Appalachian Mountains, #EP11D-2079*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Li Li; Conveners - Bhavna Arora, Harry Vereecken; Chairs - Li Li, Bhavna Arora, Harry Vereecken (2018). *Session - EP11C: Modeling the Critical Zone: Integrating Processes and Data Across Disciplines and Scales I Posters*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Li Li; Conveners - Bhavna Arora, Harry Vereecken; Chairs - Li Li, Harry Vereecken (2018). *Session - EP14A: Modeling the Critical Zone: Integrating Processes and Data Across Disciplines and Scales II*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Duncan, J.; Conveners - Suzanne P Anderson, Susan L Brantley, Stephen D Sebestyen; Chairs - Jonathan M Duncan, Stephen D Sebestyen (2018). *Session - H12D: Advancing Catchment Science: Process Understanding and Societal Benefits from Long-Term Observation and Experimentation II*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Duncan, J., Converers - James B Shanley, Stephen D Sebestyen; Chairs - James B Shanley, Jonathan M Duncan, Stephen D Sebestyen (2018). *Session - H13J: Advancing Catchment Science: Process Understanding and Societal Benefits from Long-Term Observation and Experimentation III Posters*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Conveners: J. M. Duncan, S. P. Anderson, S. L. Brantley, and S. D. Sebestyen (2018). *Session H12D: Advancing Catchment Science: Process Understanding and Societal Benefits from Long-Term Observation and Experimentation II*. American Geophysical Union. Washington, DC, 10-14 December. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Guo*, L., Henry Lin (2018). *Soil Moisture Sensor Network Advances the Monitoring and Understanding of Catchment Hydrology: Case Studies from the Shale Hills CZO, #H53J-1721*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hodges, C, H. Kim, S.L. Brantley, J. Kaye (2019). *Soil gas concentrations at the Susquehanna Shale Hills CZO indicate different physical and chemical drivers of gas production and consumption in shale and sandstone watersheds*. International Soils Meeting. San Diego, CA, USDA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

DiBiase*,R.A., Alison Denn, Paul R Bierman, Eric Kirby, Nicole West, Alan Hidy (2018). *Stratigraphic control of landscape response to base-level fall, Young Womans Creek, Pennsylvania, USA, #EP21D-2271*. 2018 AGU Fall Meeting, 10-14

Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hasenmueller*, E.A., Xin Gu, Julie N Weitzman, Thomas S Adams, Gary E. Stinchcomb, David M Eissenstat, Patrick J Drohan, Susan Brantley, Jason P Kaye (2018). *The Weathering of Rock to Regolith: Activity of Deep Roots in Bedrock Fractures (Invited), #EP11D-2082*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Primka IV, E. J., T. Adams, L. Orr, J. Kaye, and D. M. Eissenstat. (2018). *Topographic effects on fine root production and soil respiration in the Susquehanna-Shale Hills Critical Zone Observatory*. Environmental System Science (ESS) PI Meeting. Potomac, MD. Status = OTHER; Acknowledgement of Federal Support = Yes

Soper*, F. Samuel Chamberlain, Louis A Derry, Jed P Sparks (2018). *Tree-driven redistribution of mineral nutrients in a temperate forested shale catchment, #B21I-2439*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Zhi*, W., Li Li, Jason P Kaye, Wenming Dong, Wendy Brown, Carl I Steefel, Kenneth Hurst Williams (2018). *Understanding Contrasting Concentration-discharge (CQ) Behaviors in a Seasonally Snow-covered Watershed, #EP11C-2077*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Li Li, Wei Zhi*, Christopher Duffy, Gopal Bhatt (2018). *Understanding Hydrobiogeochemical Controls of Nutrient Export Using Process-based Watershed Modeling, #H12E-03*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

He, Y., Kenneth Davis, Yuning Shi, Dave Eissenstat, Jason Kaye, Margot Kaye (2019). *Understanding the carbon cycle in complex terrain at Susquehanna Shale Hills Critical Zone Observatory*. Invited seminar at at Pacific Northwest National Laboratory (PNNL). PNNL, Silver Spring, MD. Status = OTHER; Acknowledgement of Federal Support = Yes

Wen*, H., Li Li, Susan Brantley (2018). *Upscaling Hydrological Dynamics at the Watershed Scale, #H43C-2405*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Keating*, K., Gregory Mount, Jonathan Nyquist, Jorden L Hayes, Alexander E Gates, Susan Brantley, Kristin O'Connell, Ellen A R Iverson (2018). *Using a Near Surface Geophysics and Critical Zone Science Field Experience to Broaden the Participation of Underrepresented Minorities in the Geosciences, #ED41C-1124*. 2018 AGU Fall Meeting, 10-14 Dec. Washington, D.C.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hodges, C., J.M. Regan, B. Forsythe, S.L. Brantley, J. Kaye (2019). *Using apparent respiratory quotient and fixed potential electrodes to quantify iron redox in upland soils of the Susquehanna Shale Hills Critical Zone Observatory*. American Geophysical Union Meeting. San Francisco, CA, USA. Status = SUBMITTED; Acknowledgement of Federal Support = Yes

Other Products

Other Publications

Patents

Technologies or Techniques

Multi-Modular Penn State Integrated Hydrologic Model v0.13.0-alpha

https://github.com/PSUmodeling/MM-PIHM

Thesis/Dissertations

Del Vecchio, J.. *A record of coupled hillslope and channel response to Pleistocene periglacial erosion in a sandstone headwater valley, central Pennsylvania*. (2018). The Pennsylvania State University. Acknowledgement of Federal Support = Yes

Gu, Xin. *Characterizing Structure and Geochemistry of Shale Pores by Neutron Scattering*. (2017). The Pennsylvania State University. Acknowledgement of Federal Support = Yes

Denn, A.. *DETECTING LANDSCAPE RESPONSE TO PERTURBATIONS BY CLIMATE AND BASE LEVEL IN CENTRAL PENNSYLVANIA USING IN-SITU 10Be AND 26Al*. (2017). The University of Vermont. Acknowledgement of Federal Support

= Yes

Dillner, Benjamin. *IF A TREE FALLS: PLANT REGENERATION AND SOIL TRENDS IN A PENNSYLVANIA TREE TIP-UP CHRONOSEQUENCE*. (2019). Penn State. Acknowledgement of Federal Support = Yes

Hill, L.Z.. *Lithological controls on soil properties of temperate forest ecosystems in central Pennsylvania*. (2017). The Pennsylvania State University. Acknowledgement of Federal Support = Yes

David Yoxtheimer. *UTILIZATION OF THE SQUARE ARRAY EARTH RESISTIVITY METHOD FOR CHARACTERIZING ANISOTROPY IN FRACTURED SEDIMENTARY ROCK*. (2019). Pennsylvania State University. Acknowledgement of Federal Support = Yes

He, Y.. *Understanding the carbon cycle in complex terrain at Susquehanna Shale Hills Critical Zone Observatory*. (2019). The Pennsylvania State University. Acknowledgement of Federal Support = Yes

Wayman, C.. *Using the effects of seasonality, land cover, and lithology to inform a hydrologic transport model for Shavers Creek Watershed*. (2018). Pennsylvania State University. Acknowledgement of Federal Support = Yes

Websites

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Brantley, Susan	PD/PI	2
Davis, Kenneth	Co PD/PI	1
Eissenstat, David	Co PD/PI	1
Li, Li	Co PD/PI	1
Bern, Carleton	Co-Investigator	0
Bierman, Paul	Co-Investigator	1
Brubaker, Kristen	Co-Investigator	0
Comas, Xavier	Co-Investigator	0
Dere, Ashlee	Co-Investigator	0
DiBiase, Roman	Co-Investigator	2
Hasenmueller, Elizabeth	Co-Investigator	0
Hayes, Jorden	Co-Investigator	0
Karwan, Diana	Co-Investigator	0
Kaye, Margot	Co-Investigator	0

Name	Most Senior Project Role	Nearest Person Month Worked
Kaye, Jason	Co-Investigator	1
Keating, Kristina	Co-Investigator	2
Kirby, Eric	Co-Investigator	0
Lin, Henry	Co-Investigator	1
Liu, Wenjing	Co-Investigator	0
Long, Robert	Co-Investigator	0
Mount, Greg	Co-Investigator	1
Nyquist, Jon	Co-Investigator	0
Perdrial, Julia	Co-Investigator	1
Pett Ridge, Julie	Co-Investigator	0
Richter, Dan	Co-Investigator	0
Shi, Yuning	Co-Investigator	2
Singha, Kamini	Co-Investigator	0
Slater, Lee	Co-Investigator	0
Stottlemyer, Aaron	Co-Investigator	0
Sullivan, Pamela	Co-Investigator	0
West, Nicole	Co-Investigator	0
Caffee, Marc Caffee (PRIME lab, Purdue Univ	Faculty	0
Duncan, Jonathan	Faculty	1
Ivory, Sarah	Faculty	1
Nyblade, Andrew	Faculty	1
Clarke, Brian	Postdoctoral (scholar, fellow or other postdoctoral position)	0
Gu, Xin	Postdoctoral (scholar, fellow or other postdoctoral position)	0

Name	Most Senior Project Role	Nearest Person Month Worked
Adams, Tom	Technician	0
Corbett, Lee	Staff Scientist (doctoral level)	1
Guo, Li	Staff Scientist (doctoral level)	1
Hidy, Alan	Staff Scientist (doctoral level)	0
Zimmerman, Susan	Staff Scientist (doctoral level)	0
Bao, Chen	Graduate Student (research assistant)	0
Chen, Weile	Graduate Student (research assistant)	0
Del Vecchio, Joanmarie	Graduate Student (research assistant)	5
Denn, Alison	Graduate Student (research assistant)	1
Dillner, Benjamin	Graduate Student (research assistant)	8
Douglas, Baldwin	Graduate Student (research assistant)	0
He, Yuting	Graduate Student (research assistant)	12
Heidari, Peyman	Graduate Student (research assistant)	0
Hill, Lillian	Graduate Student (research assistant)	0
Hoagland, Beth	Graduate Student (research assistant)	8
Hodges, Caitlin	Graduate Student (research assistant)	12
Malik, Rondy	Graduate Student (research assistant)	12
Orr, Alexandra	Graduate Student (research assistant)	0
Osterman, Gordon	Graduate Student (research assistant)	1
Primka, Edward	Graduate Student (research assistant)	6
Reed, Warren	Graduate Student (research assistant)	6
Silverhart, Perri	Graduate Student (research assistant)	6
Szink, Ismaiel	Graduate Student (research assistant)	12
Tang, Qicheng	Graduate Student (research assistant)	12

Name	Most Senior Project Role	Nearest Person Month Worked
Wade, Anna	Graduate Student (research assistant)	0
Wayman, Callun	Graduate Student (research assistant)	10
Weitzman, Julie	Graduate Student (research assistant)	0
Xiao, Dacheng	Graduate Student (research assistant)	12
Yoxtheimer, David	Graduate Student (research assistant)	3
Zarif, Fardous	Graduate Student (research assistant)	0
Forsythe, Brandon	Non-Student Research Assistant	12
Harper, Jeremy	Non-Student Research Assistant	3
Shaphic, Dan	Non-Student Research Assistant	2
Williams, Jennifer	Non-Student Research Assistant	12
Carpenter, Nathan	Undergraduate Student	0
Forgeng, Michael	Undergraduate Student	12
Potter, Joshua	Consultant	0

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: 2

Contribution to the Project: PI

Funding Support: 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: col

Funding Support: 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: Supported students and investigations associated with Hypotheses 3 and 4

Funding Support: In addition to NSF, funding from DOE and Penn State University is acknowledged

International Collaboration: No
International Travel: No

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

Contribution to the Project: col

Funding Support: NSF

International Collaboration: No
International Travel: No

Carleton Bern
Email: cbern@usgs.gov
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Advancing the understanding of colloidal transport

Funding Support: USGS

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

Kristen Brubaker
Email: brubaker@hws.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Contributes to H3

Funding Support: Hobart & William Smith Colleges

International Collaboration: No
International Travel: No

Xavier Comas
Email: xcomas@fau.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Hydrogeophysics Specialist

Funding Support: NSF

International Collaboration: No
International Travel: No

Ashlee Dere
Email: ald271@psu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: shale weathering along transect sites

Funding Support: University of Nebraska, Omaha

International Collaboration: No
International Travel: No

Roman DiBiase
Email: rad22@psu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Coordinator of geomorphological soils analysis

Funding Support: Penn State and NSF

International Collaboration: No
International Travel: No

Elizabeth Hasenmueller
Email: hasenmuellerea@slu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Hydrochemist - works on Hypothesis 2

Funding Support: St. Louis University

International Collaboration: No
International Travel: No

Jorden Hayes
Email: hayesjo@dickinson.edu

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

Contribution to the Project: New member of advisory board, hydrogeophysics specialist

Funding Support: Dickinson College

International Collaboration: No
International Travel: No

Diana Karwan
Email: dlkarwan@umn.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Cross-CZO Investigator

Funding Support: NSF

International Collaboration: No
International Travel: No

Margot Kaye
Email: mwk12@psu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Contributes to H3

Funding Support: Penn State

International Collaboration: No
International Travel: No

Jason Kaye
Email: jpk12@psu.edu
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 CZO

International Collaboration: No
International Travel: No

Kristina Keating
Email: kmkeat@andromeda.rutgers.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Contributing collaborator, hydrogeophysics field workshop

Funding Support: Rutgers, NSF

International Collaboration: No
International Travel: No

Eric Kirby
Email: eric.kirby@geo.oregonstate.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Geomorphologist - works on Hypothesis 1

Funding Support: Oregon State University

International Collaboration: No
International Travel: No

Henry Lin
Email: hul3@psu.edu
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: Yes, China - 0 years, 1 months, 0 days

Wenjing Liu
Email: wul26@psu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: collaborative investigator

Funding Support: Chinese Academy of Sciences

International Collaboration: No
International Travel: Yes, China - 1 years, 1 months, 20 days

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Robert Long
Email: rlong@fs.fed.us
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: collaborating investigator

Funding Support: US Forest Service

International Collaboration: No
International Travel: No

Greg Mount
Email: Gregory.Mount@iup.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Hydrogeophysical specialist, collaborator

Funding Support: IUP, NSF

International Collaboration: No
International Travel: No

Jon Nyquist
Email: nyq@temple.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: collaborating investigator

Funding Support: Temple, NSF

International Collaboration: No
International Travel: No

Julia Perdrial
Email: Julia.Perdrial@uvm.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: contributing collaborator

Funding Support: University of Vermont, NSF

International Collaboration: No
International Travel: No

Julie Pett Ridge
Email: julie.pett-ridge@oregonstate.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Contributing collaborator

Funding Support: Oregon State

International Collaboration: No
International Travel: No

Dan Richter
Email: drichter@duke.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: contributing collaborator

Funding Support: Duke

International Collaboration: No
International Travel: No

Yuning Shi
Email: yshi@psu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

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

Funding Support: CZO

International Collaboration: No
International Travel: No

Kamini Singha
Email: ksingha@mines.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Hydrogeologist - works on Hypothesis 1

Funding Support: Colorado School of Mines

International Collaboration: No
International Travel: No

Lee Slater
Email: lslater@andromeda.rutgers.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Collaborative investigator

Funding Support: Rutgers University

International Collaboration: No
International Travel: No

Aaron Stottlemyer
Email: ads175@psu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: collaborative investigations

Funding Support: Penn State

International Collaboration: No
International Travel: No

Pamela Sullivan
Email: pls21@psu.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

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

Funding Support: The University of Kansas

International Collaboration: No
International Travel: No

Nicole West
Email: west2n@cmich.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: geomorphologist - works on Hypothesis 1

Funding Support: Central Michigan University

International Collaboration: No
International Travel: No

Marc Caffee (PRIME lab, Purdue Univ Caffee
Email: mcaffee@purdue.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 0

Contribution to the Project: measurement of new cosmogenic nuclides for H1

Funding Support: PRIME lab, Purdue University

International Collaboration: No
International Travel: No

Jonathan Duncan
Email: jxd523@psu.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: contributed to H6

Funding Support: Penn State

International Collaboration: No
International Travel: No

Sarah Ivory
Email: sji15@psu.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Pollen analysis of sediment cores

Funding Support: Penn State

International Collaboration: No
International Travel: No

Andrew Nyblade
Email: aan2@psu.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Advised PhD student David Yoxtheimer who completed a resistivity study of Shale Hills

Funding Support: unfunded

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

Xin Gu
Email: xug102@psu.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 0

Contribution to the Project: collaborative research, postdoc

Funding Support: Penn State

International Collaboration: No
International Travel: No

Tom Adams
Email: tsa3@psu.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 0

Contribution to the Project: Contributes to H3

Funding Support: Penn State and DOE

International Collaboration: No
International Travel: No

Lee Corbett
Email: Ashley.Corbett@uvm.edu
Most Senior Project Role: Staff Scientist (doctoral level)
Nearest Person Month Worked: 1

Contribution to the Project: Trained graduate student Joanmarie Del Vecchio in cosmogenic nuclide analysis techniques

Funding Support: NSF/University of Vermont

International Collaboration: No
International Travel: No

Li Guo
Email: lug163@psu.edu
Most Senior Project Role: Staff Scientist (doctoral level)
Nearest Person Month Worked: 1

Contribution to the Project: Contributes to H4

Funding Support: NSF

International Collaboration: No
International Travel: No

Alan Hidy
Email: hidy3@llnl.gov
Most Senior Project Role: Staff Scientist (doctoral level)
Nearest Person Month Worked: 0

Contribution to the Project: Laboratory Analyst

Funding Support: Lawrence Livermore National Laboratory

International Collaboration: No
International Travel: No

Susan Zimmerman
Email: zimmerman17@llnl.gov
Most Senior Project Role: Staff Scientist (doctoral level)
Nearest Person Month Worked: 0

Contribution to the Project: Laboratory Analyst

Funding Support: Lawrence Livermore National Laboratory

International Collaboration: No
International Travel: No

Chen Bao
Email: cub200@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: works on Hypothesis 5

Funding Support: unknown

International Collaboration: No
International Travel: No

Weile Chen
Email: wuc139@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: collaborative research

Funding Support: DOE

International Collaboration: No
International Travel: No

Joanmarie Del Vecchio
Email: jzd5570@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 5

Contribution to the Project: PhD student in geomorphology working on H1

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: 1

Contribution to the Project: contributing to H1

Funding Support: CZO

International Collaboration: No
International Travel: No

Benjamin Dillner
Email: bmd42@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 8

Contribution to the Project: contributes to H2

Funding Support: CZO

International Collaboration: No
International Travel: No

Baldwin Douglas
Email: dcb5006@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: collaborative investigations

Funding Support: Penn State

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

Peyman Heidari
Email: heidarip@mst.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: collaborator on reactive transport modeling

Funding Support: Missouri University of Science and Technology

International Collaboration: No
International Travel: No

Lillian Hill
Email: lzh157@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: contributing to H2

Funding Support: CZO

International Collaboration: No
International Travel: No

Beth Hoagland
Email: neh137@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 8

Contribution to the Project: contributing to H6

Funding Support: CZO

International Collaboration: No
International Travel: No

Caitlin Hodges
Email: cah423@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: contributes to H2

Funding Support: CZO

International Collaboration: No
International Travel: No

Rondy Malik
Email: rjm472@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: contributes to H3

Funding Support: CZO and Penn State

International Collaboration: No
International Travel: No

Alexandra Orr
Email: aso124@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: collaborative investigations

Funding Support: Penn State

International Collaboration: No
International Travel: No

Gordon Osterman
Email: gko4@rutgers.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: groundwater geophysics

Funding Support: Rutgers

International Collaboration: No
International Travel: No

Edward Primka
Email: ejp25@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: contributes to H3

Funding Support: CZO, Penn State, and DOE

International Collaboration: No
International Travel: No

Warren Reed
Email: wpr5005@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Contributes to H3

Funding Support: Penn State, NSF CZO

International Collaboration: No
International Travel: No

Perri Silverhart
Email: phs8@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: MS Student working on H1

Funding Support: CZO

International Collaboration: No
International Travel: No

Ismaiel Szink
Email: ips5062@PSU.EDU
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Contributes to H3

Funding Support: NSF Graduate Fellowship

International Collaboration: No
International Travel: No

Qicheng Tang
Email: qut9@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: contributes to H4

Funding Support: CZO

International Collaboration: No
International Travel: No

Anna Wade
Email: anna.wade@duke.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: collaborating student working with postdoc to learn hydrology sampling techniques in the CZO.

Funding Support: Duke University

International Collaboration: No
International Travel: No

Callun Wayman
Email: crw5269@psu.edu

Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 10

Contribution to the Project: contributed to H6

Funding Support: CZO

International Collaboration: No
International Travel: No

Julie Weitzman
Email: jnw142@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: works on Hypothesis 2

Funding Support: unknown

International Collaboration: No
International Travel: No

Dacheng Xiao
Email: dzx102@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: contributing to H5 and H8

Funding Support: CZO

International Collaboration: No
International Travel: No

David Yoxtheimer
Email: day122@psu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Completed one chapter of his dissertation on resistivity measurements in Shale Hills

Funding Support: none

International Collaboration: No
International Travel: No

Fardous Zarif
Email: fardous zarif
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: collaborator on geophysical methods, specifically electrical resistivity surveys

Funding Support: Rutgers University

International Collaboration: No
International Travel: No

Brandon Forsythe
Email: brf11@psu.edu
Most Senior Project Role: Non-Student Research Assistant
Nearest Person Month Worked: 12

Contribution to the Project: watershed coordinator

Funding Support: CZO

International Collaboration: No
International Travel: No

Jeremy Harper
Email: jph217@psu.edu
Most Senior Project Role: Non-Student Research Assistant
Nearest Person Month Worked: 3

Contribution to the Project: field assistant

Funding Support: CZO

International Collaboration: No
International Travel: No

Dan Shaphic
Email: dms139@psu.edu
Most Senior Project Role: Non-Student Research Assistant
Nearest Person Month Worked: 2

Contribution to the Project: data management

Funding Support: CZO

International Collaboration: No
International Travel: No

Jennifer Williams
Email: jzw126@psu.edu
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

Nathan Carpenter
Email: ncarpenter@mtech.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 0

Contribution to the Project: undergraduate thesis on Cole Farm

Funding Support: unknown

International Collaboration: No
International Travel: No

Michael Forgeng
Email: mjf5807@psu.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 12

Contribution to the Project: undergraduate field assistant

Funding Support: CZO, unknown

International Collaboration: No
International Travel: No

Joshua Potter
Email: jep189@psu.edu
Most Senior Project Role: Consultant
Nearest Person Month Worked: 0

Contribution to the Project: collaborative outreach

Funding Support: Penn State

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
Kent State University	Academic Institution	Kent, Ohio
Missouri University of Science and Technology	Academic Institution	Rolla, MO
Ninxia University	Academic Institution	Ningxia, China
Oregon State University	Academic Institution	Corvallis, Oregon
Princeton University	Academic Institution	Princeton, NJ
Purdue University	Academic Institution	West Lafayette, IN
Rutgers University	Academic Institution	New Brunswick, New Jersey

Name	Type of Partner Organization	Location
Saint Louis University	Academic Institution	Saint Louis, MO
State College Area School District	School or School Systems	State College, PA
Technical Univ. of Munich	Academic Institution	Munich, Germany
CTEMPS	Academic Institution	University of Nevada, Reno
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 Nebraska Omaha	Academic Institution	Omaha, NE
University of Texas @ El Paso	Academic Institution	El Paso, TX
University of Toulouse, France	Academic Institution	Toulouse, France
Chinese Academy of Sciences	Academic Institution	Beijing, China
Colgate University	Academic Institution	Hamilton, NY
Dickinson College	Academic Institution	Carlisle, Pennsylvania
Florida Atlantic University	Academic Institution	Boca Raton, FL
Hollidaysburg Area High School	School or School Systems	Hollidaysburg, PA
Horbart & William Smith Colleges	Academic Institution	Geneva, New York
Indiana University of Pennsylvania	Academic Institution	Indiana, Pennsylvania

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:

Dickinson College

Organization Type: Academic Institution
Organization Location: Carlisle, Pennsylvania

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Florida Atlantic University

Organization Type: Academic Institution
Organization Location: Boca Raton, FL

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:

Horbart & William Smith Colleges

Organization Type: Academic Institution
Organization Location: Geneva, New York

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Indiana University of Pennsylvania

Organization Type: Academic Institution
Organization Location: Indiana, Pennsylvania

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Kent State University

Organization Type: Academic Institution
Organization Location: Kent, Ohio

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Missouri University of Science and Technology

Organization Type: Academic Institution
Organization Location: Rolla, MO

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:

Purdue University

Organization Type: Academic Institution
Organization Location: West Lafayette, IN

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Rutgers University

Organization Type: Academic Institution
Organization Location: New Brunswick, New Jersey

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 Nebraska Omaha

Organization Type: Academic Institution
Organization Location: Omaha, NE

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?
Nothing to report

Impacts

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

Our efforts in the SSHCZO, partly funded by DOE funding to several PIs, have been extrapolated to other sites: we submitted a paper interpreting weathering reaction fronts at Eel River CZO and Taiwan (Gu et al., 2019, submitted) and interpreting geophysical data in terms of weathering reactions at Calhoun CZO (Holbrook et al., 2019).

We have also shown for the first time how the complexity of landscape topography can affect carbon fluxes. This is an important contribution because this complexity will eventually have to be incorporated into earth surface models / climate models.

We are also showing for the first time that a COSMOS can be used to measure soil moisture in different environments (forested and cultivated landscapes). Measurement of soil moisture over landscapes is a significant hurdle for hydrologic predictions, for climate predictions, and for predictions of simple observables such as mud on roads.

We are showing that nitrate denitrifies through reactions in bedrock with pyrite, and we are now mapping out where that reaction occurs, and where pyrite occurs in the subsurface.

Very little is know about root density and how it is distributed across the landscape, and yet, root density influences carbon sequestration in the subsurface, water uptake and evapotranspiration, and carbon balance. We have observed for the first time that root length density depends on rock type in a given climate. On the other hand, we also discovered that root length density does not vary with landscape position (in contrast to tree height).

Macropore flow is ubiquitous in the subsurface but there are no models to predict its prevalence. We have discovered that preferential flow is more important at mid slope positions than at valley floor and ridgetop positions: this significantly simplifies how models can be formulated.

We discovered that aspect has an important and direct effect on water and weathering on opposite sides of a watershed, but that the cumulative effect of such differences in weathering (as observed in grain size differences) also impacts water chemistry and can explain chemical differences as a function of aspect.

What is the impact on other disciplines?

This CZO work has led us to publish i) a generalized hypothesis for how to predict subsurface water fluxes for catchments based on geochemical weathering fronts in the subsurface (Brantley et al., 2017), ii) a model relating controls on concentration-discharge relationships (Li et al., 2017), and iii) papers relating geological history and geochemical weathering to rates of stream incision or erosion (Sullivan et al., 2016; Del Vecchio et al., 2018).

At the state level, state agencies are seeking out CZO expertise. For example, the PA Department of Environmental Protection reached out to the CZO to help define classifications of headwater watersheds in the state in terms of resiliency to human impact. The outcome is that CZO personnel are now working on using geological, hydrological, and ecological criteria to determine resiliency of watersheds. Likewise, 15 environmental scientists from the PA Dept of Conservation and Natural Resources spent a day in the CZO learning about the specifics of our approach (Spring 2016).

At the national level, the US Army Corp of Engineers has been using our Shale Hills watershed to study the use of cosmic ray neutron soil moisture data (COSMOS) to study and develop models to estimate soil moisture over broad regions in complex terrain: the Army needs to know how to predict when roads are mud-clogged. Similarly, we are working with the USDA Forest Service to explore belowground constraints that help explain why oak re-establishment is more problematic on shale than on sandstone. Finally, most terrestrial carbon models are point models that do not account for the effects of complex topography on environmental factors such as soil moisture, or root and microbial processes. We leveraged the extensive observations and hydrological and biogeochemical modeling work at the Shale Hills CZO to study this problem and used our data to improve ecosystem carbon cycle models and establish an extensive spatial network to monitor root processes and soil CO2 efflux. That effort received $2m from the Department of Energy, and was enabled by the CZO study site.

Also at the national level, J. Kaye's research on the CZO has informed his invited presentations to the Science and Technical Advisory Committee (STAC) to the Chesapeake Bay Program. Specifically, he was invited to present a paper, "Best Management Practices and Landscape properties and their effects on nitrogen speciation in loads delivered to streams," in a workshop for STAC. Implications of the work by SSHCZO are large for understanding nutrient and sediment fluxes to the Chesapeake Bay. An article was therefore written about the work of Perri Silverhart and Roman DiBiase on legacy sediments in the Cole Farm subcatchment of the SSHCZO: this article was published in the newsletter of the Chesapeake Research Consortium.

We are also in the process of publishing a paper that describes precepts of collaboration for large interdisciplinary teams. This topic is not discussed much (how to cooperate across disciplines) but it is a huge and difficult problem...that we have been addressing at our CZO and that we are writing about so as to help other such activities.

What is the impact on the development of human resources?

From 2013 to 2018, 32 graduate students worked at SSHCZO (16 female, Table 1); 9 PhDs and 10 Masters were defended; 13 postdoctoral students were funded; 16 undergraduates were hosted as REUs; and 3 teachers were mentored as RETs. Funding derived from multiple sources for stipends and tuitions. Thirteen PIs were associated with the project (5 female, 2 untenured). Three graduate students and 1 postdoc and 1 member of our management team derived from an under-represented group. Fifty-nine middle or high school students participated in TeenShale Network from 2013-2018, with 20 of those participating for multiple years.

Several classes at Penn State or from local universities (e.g., Kent State Univ., Franklin & Marshall, Indiana Univ of Pennsylvania, Dickinson College, Temple Univ., Rutgers Univ.) use the CZO for research and teaching: PSU Geoscience 203 – Physical Processes in Geology,

PSU Geoscience 413W – Techniques in Environmental Geochemistry, PSU Geoscience 483 – Environmental Geophysics, PSU Forestry 471 – Watershed Management Laboratory,

PSU Forestry 475 – Principles of Forest Soils Management, PSU ERM 435 – Limnology,

Kent State GEOL 4/5/72065 – Watershed Hydrology, Kent State GEOL 42069 – Hydrogeochemistry,

PSU RPTM 425 – Principles of Interpretive Materials, PSU RPTM 430 – Environmental Education Methods and Materials, Dickinson College ERCS 335 – Global Geophysics and Tectonics, IUP GEOSC 481 – Environmental Geophysics, Franklin & Marshall BIO 323 – Ecological Concepts and Applications.

List of the 14 senior theses completed using the SSHCZO (*indicates they are known to be pursuing a graduate degree)

- *Carpenter, N. (2018) The effect of cultivation on soil chemistry in the SSHCZO.
- Delisser, T. (2018) Analysis of the subsurface structure of the swales in the Shale Hills watershed using electrical resistivity tomography.
- *Forgeng, M. (2018) Surface and shallow subsurface nutrient transport within an agriculturally active central Pennsylvanian landscape.
- Miles, R. (2018) Using S-wave models to image the subsurface at Shale Hills observatory.
- *Nyblade, M. (2018) Interdisciplinary modeling for sustainability: a reflection on hydrologic-agricultual-economic modeling of Punjab, India. (directed by T. Russo, SSHCZO hydrologist)
- Adira, A. (2015) Assessing the subsurface geology of Garner Run through the relationship between seismic velocity and layer density.

- *Cain, M. (2015) Elucidating the effects of reservoir filling on watershed hydrodynamics and shallow groundwater chemistry in a previously impounded lake.
- Macdonald, S (2015) Thick soil formation on orthoquartzite since the Wisconsinan in Huntingdon County.
- Wang, E. (2015) Seismic refraction for subsurface analysis of Garner Run.
- Davis, R. (2014) Reading atmospheric and biotic influences in soils: the relationship between soil gas and weathering properties in soils on granite and diabase.
- Snyder, D. (2014) Impact of oil and gas industry wastewater on water and sediment chemistry in one stream in west-central Pennsylvania.
- *Bingham, N. (2013) C, N, and Mn in shale soil profiles along a climate gradient
- *Gorski, I. (2013) The use of water sensors to examine water chemistry related to Marcellus Shale natural gas development
- *Neely, A. (2013) Characterizing the recent Cenozoic erosional history of the Appalachian Mountains through spatial variation in stream profile metrics across the Allegheny Front.

What is the impact on physical resources that form infrastructure?

The CZO is itself "infrastructure" that enables science for Penn Staters and non Penn Staters. For example, we have ben monitoring tree carbon over more than a decade and we now have a very valuable dataset that is attracting researchers from DOE and elsewhere. We also have weirs, boreholes, eddy flux towers, and soil lysimeter and soil moisture stations that are attracting interest.

In terms of impact on the university, the CZO is now working with the University physical plant to complete a C sequestration inventory for the Penn State Sustainable Forest. Also, the CZO is working with two Penn State museums (the Shaver's Creek Environmental Center and the Pasto Ag Museum), both of which host about 10,000 visitors annually, to implement CZ-motivated exhibits and trails.

What is the impact on institutional resources that form infrastructure?

The SSHCZO has worked with the Shavers Creek Environmental Center to implement instruments at the Center that teach about CZ science. In addition, the CZO and SCEC have implemented a trail for families that teaches about CZ science and an exhibit in the museum about the geological and human history of Shavers Creek.

What is the impact on information resources that form infrastructure?

SSHCZO maintains a website with a large dataset that is available to the public.

What is the impact on technology transfer?

SSHCZO has hosted a new project on chronoamperometry and ambient noise seismometry (funded by NSF SiTS). The new techniques are working well and are being compared to data collected at the CZO. These techniques are providing data about microbial reactions and water influx to shallow soils and weathered rock, respectively.

What is the impact on society beyond science and technology?

Teen Shale Network is training high school students in science process.

The opportunities we are providing at Shavers Creek Environmental Center provide families with entertainment.

We belive that some of our work on nutrient cycling in Cole Farm may inform better models of nutrient loading into the Chesapeake Bay.

Changes/Problems

Changes in approach and reason for change

Over the years, the hypothesis teams have changed personnel and research thrusts. For example, Henry Lin did not retain graduate students and so his student(s) began to work with other faculty. The funding for that project followed the student and the actual topic of study therefore changed. Likewise, another student left after a Masters degree instead of staying for a PhD (C. Wayman). This curtailed his project.

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

We have collected a lot of geophysical data and we do not have enough participants to work all the data up. We are struggling to keep up. We have hired a new postdoc to help us work up and publish geophysical data.

Changes that have a significant impact on expenditures

We are spending out all the money. Some wells have become plugged or have collapsed. We have had to drill and log a new well.

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.