

Preview of Award 1331846 Annual Project Report

Cover

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**Human and Natural Forcings of Critical Zone Dynamics and Evolution at the Calhoun
Critical Zone Observatory**

PD/PI Name:

- **Daniel D Richter, Principal Investigator**
- **Mukesh Kumar, Co-Principal Investigator**
- **Brian L McGlynn, Co-Principal Investigator**
- **Sari Palmroth, Co-Principal Investigator**
- **Amilcare Porporato, Co-Principal Investigator**

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Duke University

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Submitting Official (if other than PD\PI):

- **Daniel D Richter**
- **Principal Investigator**

Submission Date:

09/11/2015

Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)

Daniel D Richter

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Accomplishments

* What are the major goals of the project?

Our goal for the Calhoun Critical Zone Observatory (CCZO) is to advance the usefulness and richness of the concept of Earth's critical zone (CZ). "From tree-top to bedrock" or from the aboveground atmosphere to the deepest ground waters, the CZ integrates the climate and vegetation-clad soils, hillslopes, and the full depths of hydrological catchments and river basins. As a research approach, critical zone science at the Calhoun CZO marshals the remarkable advances of the individual Earth sciences and scholarships to understand how the planet and its critical zones are being transformed from natural to human-natural systems. We seek integration of the sciences and scholarships not only at work in the Calhoun CZ but also across all CZOs.

Calhoun CZ research is organized by four hypotheses about CZ structure, function, and evolution that span scales of time and space. Temporal scales range from the instantaneous to the multi-millennia, and are grouped into three phases of CCZO evolution: the evolution of the natural systems, which on the most geomorphically stable surfaces of the Calhoun CZO have residence times of several million years (Bacon et al., 2012); changes affected by the *historic* human-natural system, initiated by Native Americans about 10,000 YBP but accelerated by severe erosion and sedimentation during a century of farming for cotton (1800 to 1930s); and the contemporary human-natural system, marked by impressive reforestation on severely eroded soils, gullied runoff channels, and floodplains inundated with historic sediments.

Because of these time scales of change, the Calhoun CZ presents special opportunities to study both the evolution of ancient, highly weathered CZs and to evaluate CZ responses and resilience in the aftermath of land degradation. Moreover, by the late 20th century, the impressive reforestation of the Southern Piedmont motivated many to describe this degraded region to be undergoing recovery, even characterizing "old-field succession" as a process of ecosystem restoration. Our research team has a more critical perspective: that contemporary reforestation though impressive in many ways is more a *mask* than a recovery given fundamental alterations in CZ hydrologic networks, geomorphology, biology, and biogeochemistry. This critical perspective is scientifically and socially significant because of its implications for CZ resilience and ecosystem services today and in the future.

Four hypotheses provide the platform for achieving our project goals:

H1) Hydrologic and Biogeochemical Recovery from Land Degradation. *In CZs altered by land degradation and associated erosion, hydrologic and biogeochemical processes in surficial*

components of CZs become decoupled from those at depth, with system recoveries dependent on re-establishment of macropores and hydrologic networks, rooting, macroinvertebrate activity, and formation of aggregates.

H2) Erosion-Induced Carbon Dynamics. Delayed oxidation of eroded soil organic carbon (SOC) buried in alluvial sediments represents a substantial fraction of erosion-induced alterations of soil C cycling.

H3) Human-Critical Zone Interactions. Humans alter CZs in ways they do and do not understand, triggering changes that shape livelihoods and land management over time.

H4) Persistence of Alternative States. CZs altered by land degradation, erosion, gullies, and reductions in infiltration, deep rooting, macro-invertebrates, and aggregate formation are impeded by self-reinforcing feedbacks in re-establishing biological productivity and environmental services.

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

Major Activities:

A. ON-GOING (elaborates directly on list of activities discussed in year-one's report)

1. Calhoun CZO Research Areas

We continued to expand our research areas on the Calhoun CZO. While the first six Research Areas installed in Year One contained most of 2nd year activities, we used LiDAR-derived data, historic aerial photos and contemporary remote sensing to locate ten previously unidentified hillslope and catchments that we take to be never plowed across the Sumter National Forest. We have visited all but one of these remarkable areas and are developing them for research.

2. Calhoun CZO-USFS Relations

The Calhoun CZO includes both public and private lands. Public lands are entirely on the Calhoun Experimental Forest and Sumter National Forest. Lead PI Richter has developed close relationships with USFS managers who are responsible for our formal Research Permit. A tour of the Calhoun CZO was organized for senior USFS managers responsible for environmental oversight of our project. The managers, who were impressed with the quality of our students, are earnestly interested in helping our project succeed.

3. Geophysics

PI Richter has continued to work with the Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG), who collected geophysics data during Calhoun Geophysics Week in April 2014. The geophysics data were collected from across landscape transects and down our 70-meter deep groundwater well. The results are exciting especially their visualization of the topography and architecture of the weathering bedrock. A manuscript entitled, Geophysical imaging reveals topographic stress control of bedrock weathering, has been accepted by SCIENCE.

4. Educational and Outreach Tours at the Calhoun CZO

We have developed a tour with education and outreach goals, and have given nearly a dozen day-log tours to a wide variety of groups. Tours evolve as research proceeds. Well over 150 persons visited the Calhoun for day-tours in 2015, and we find persons to be captivated by CZ science, the Calhoun landscape, and its history. We are creating virtual field trips for remote tours.

5. Digitizing historic stripcharts

Historic stripcharts record streamflow and rainfall at four catchments between 1948 and 1962. This summer, we worked with Dr. Chelcy Miniati of Coweeta Hydrologic Lab to train Georgia Tech student, Yawen Shen to manually digitize stripcharts so that we can compare results of manual vs automated digitization obtained with US Geological Survey methods. Yawen is statistically analyzing his Coweeta and USGS results fall 2015.

6. Reinstrumentation of rain and stream gages

Within the four historic experimental watersheds at the Calhoun CZO, three weirs have new stainless steel V-notch blades installed. The fourth still needs to be re-built. Reinstrumentation of the four weirs allow us to quantify how hydrologic responses of these eroded and gullied catchments have changed as they have been reforested over the decades.

7. Soil, plant, and water sampling

Samples continue to be taken in plots, across catenas, on floodplains, and in profiles of incised stream channels, all to evaluate legacies of historic agricultural impact. These samples are chemically and physically analyzed at Duke, the University of Georgia, Penn State, and University of Koblenz-Landau.

8. Vegetation plot network

In 2015, we expanded vegetation plots to 42. The plots are used to estimate ground-based biomass and leaf-area for comparison with LiDAR flight estimates of July 2014. We collect litterfall in 14 of the 42 plots for estimates of leaf-area and for chemical-element cycling studies. Plots contain >900 trees that have been tagged for future estimates of net primary productivity (NPP), fundamental to understanding CZ metabolism and other biologically driven processes.

9. Interdisciplinary modeling

A variety of interdisciplinary models have been developed and tested based on Calhoun CZO data. Results have been submitted for publication and presented in research posters and presentations. The models pertain to all four hypotheses of the Calhoun CZO project.

10. Websites

Data from our project are being added to the website and a end-of-2015 target has been set to have most data sets linked to the CZO website. Though many of us use two Calhoun websites, criticalzone.org and czen.org, we are increasingly relying on criticalzone.org. We anticipate major developments in data management in the coming year.

11. Geospatial data

These data proliferated in year two. We scanned, assembled, geo-rectified, and color-balanced high resolution aerial photographs from 1933, and combined these with LiDAR-derived slope maps. Our environmental anthropologists and historian are combining these incredible GIS layers with USFS-purchase records from the 1930s to describe the 1930s landscape that we study 85 years later.

12. Cross-CZO activities

Many cross-CZO activities involve Calhoun investigators. Several students have dissertation chapters based on multiple CZOs. One cross-site project resulted in a paper accepted for publication (St. Clair et al. 2015, *Science*). At least two research proposals are in the process of being written.

13. Educational and Outreach

We have developed a framework for interactive educational modules that places emerging CZO research within a historic and spatial context. We assessed cloud-based and distributed formats for modules and Virtual Field Experiences and continued testing materials and outreach to educators through pedagogical workshops and presentations. Our outreach to local, regional, and national publics used a variety of media and formats.

B. NEW 2nd-YEAR ACTIVITIES

14. Flux towers

USFS reluctance to permit tall (>35-m) towers without on-site personnel has caused us to redesign our flux experiments and tower measurements. We are coming to agreement with USFS to assemble flux towers in young forest stands and cultivated fields. We will estimate heat, water, CO₂, and CH₄ecosystem-atmosphere fluxes with towers while monitoring belowground heat, water, and gases to >10-m depth. The site will eventually be cored to >70-m for chemical and biological samples and geophysical measurement.

15. Soil gases

Three land uses will be studied for their belowground gas dynamics, complete with monitoring of soil moisture and temperature. Replicates of never-plowed hardwood forests are compared with a) soils cultivated since the early 19th c. and b) similarly long-cultivated soils but reforested with pine 60 to 80 years ago. CO₂, O₂, CH₄, and N₂O, and ²²²Rn are measured at 0.5, 1.5, 3, and 5-m.

16. Kaolin pseudomorphs

Calhoun researchers have long interests in micaceous minerals. Calhoun researchers are testing depth-dependence of kaolinite pseudomorphs after mica in crystal structure and cycling of K via clay interlayers. We are participating in a cross-site K-weathering experiment led by Dr. Namoko of Kyoto University and have installed biotite weathering plugs at the Calhoun CZO. The new studies of K are given context by the invaluable six-decade soil archive from the Calhoun's Long-Term Soil Experiment.

17. Calhoun Drilling Program

We recently received \$10,000 from Duke to initiate a Calhoun CZO drilling program that will explicitly integrate geomorphology, geochemistry, and geophysics. We are writing a research proposal based at the Calhoun CZO but with satellite sites across the Piedmont (e.g., Duke Forest NC; Pond Branch MD; Panola Mountain, GA). We are in contact with the NSF-funded Continental Scientific Drilling Coordination Office (CSDCO).

18. Calhoun CZO Summer Science Days

For two days in June 2015, investigators met at the Calhoun to present posters, discuss priority issues, and make decisions about future work. Over 30 posters were presented in "outdoor classrooms", each presented by authors to the whole group. This meeting aimed to integrate research across the project. The Calhoun CZO's Advisory Committee attended and will submit a report to NSF.

Specific Objectives:

Specific Objectives (These coincide with the four project hypotheses, plus two more for E&O and cross-CZO research):

O1) Hydrologic and Biogeochemical Recovery. To sample, instrument, and model CZ profiles, hillslopes, and ultimately small catchments that have experienced a range of land-use impacts, all to better understand legacies, depth dependence, and recovery rates of hydrologic and biogeochemical processes and specifically their coupling between surficial and deep CZ systems.

O2) Erosion-Induced Carbon Dynamics. To estimate and model the carbon budget of the Calhoun CZO's Holcombe's Branch watershed, 1800 to 2015, including erosional losses and reaccruals on uplands, and burial, storage, and reaccruals on floodplains.

O3) Human-Critical Zone Interactions. To assemble and geographically coordinate a wide variety of historic and contemporary social, land-use, and land-cover data, including regional aerial photography and remote sensing data, deed chains, census data, and individual farm records, all to evaluate and model how land-use practices shape the future of the land, its management, and human livelihoods.

O4) Persistence of Alternative States. To better understand and model how CZs respond to severe disturbance, disturbance that threatens the resilience and recovery of the CZ system.

O5) Education and Outreach. To promote awareness and discussion of critical zone science in the broader communities that ultimately play the citizen's role in shaping land use and public policy, with an emphasis on undergraduate research and education.

O6) Cross-CZO Research. To encourage, develop, and all the while prioritize cross-CZO relationships, sample and data sharing, and new projects. We see our potential cross-CZO contributions to be strongest in modeling, hydrology, biogeochemistry, forest ecology, flux measurements, pedogenesis, systems science, organic carbon cycling, and E&O.

Significant Results:

Six significant results are discussed from the second year of research.

1) Calhoun Geophysics and Geochemistry Data Sets.

Following a week-long work trip to the Calhoun CZO by Dr. Steve Holbrook and WyCEHG staff in April 2014, seismic velocity and electrical resistivity data sets have been assembled and analyzed to describe CZ weathering profiles along five >250-m long horizontal transects, and down-hole through soil, saprolite, and fractured and competent bedrock to 70-m depth. The field data have been used in geophysics models to assess topographic stress control on bedrock weathering. The work led to a manuscript that was formally accepted for publication in *Science* on 24 August 2015.

Solids from the Calhoun's 70-m core geochemically characterized in Bacon et al. (2012), are being further analyzed by thin-section and x-ray diffraction to characterize more closely the fronts of biogeochemical weathering. Across the 70-m core, geophysics and geochemistry data are highly correlated, and both characterize the inception and causal conditions for bedrock fracturing, i.e., the preconditioning of bedrock for biogeochemical weathering. This joint-geophysics and geochemical research was first developed at the CZO Program's Salon on Deep CZ Architecture in June 2015, and the principals (Holbrook, Brantley, Bacon, and Richter) are confident in the data being able to frame a powerful manuscript and directly lead to a successful drilling program proposal at the Calhoun CZO. A poster with results has been presented on several occasions.

2) Network of reference hardwood stands.

Much of our work with land degradation and recovery depends on data about reference conditions, data that are extremely rare. In 2015, we systematically searched the Sumter National Forest for other uncultivated and low-disturbance reference hardwood stands, by scanning and geo-rectifying a historic collection of hundreds of high resolution aerial photographs taken in 1933, and overlaying the 1933 photos with a) a high resolution slope map derived from a 2008 LiDAR flight of the Sumter National Forest, b) contemporary USFS forest stand maps, c) soil maps from the USDA Natural Resources Conservation Service, and d) contemporary remotely sensed satellite data. This allowed us to visit hardwood stands that are potentially arable, that exhibit low surface roughness (due to low historic land use impacts), and that had relatively intact hardwood forest canopies in 1933 and in recent years. We identified about ten small watersheds with various types of hillslopes that we can study in the future.

While these reference hardwood stands are neither pristine or old growth. Though once timbered and grazed, these reference hardwood soils and CZs have not been greatly

disturbed by accelerated runoff or erosion. What is most impressive about these sites is their remarkable smoothness and low roughness indices both in the field and in the LiDAR-derived slope maps.

3) Historic and contemporary hydrologic records.

Two efforts are bringing together historic rain and stream flow data from the 1940s to 1962 with contemporary data on four gaged Calhoun CZO watersheds. The historic catchment studies were created to quantify changes in hydrologic responses as degraded lands were reforested over decades time. Good progress has been made with digitizing nearly 70 years of continuous strip charts of rainfall and streamflow. We have worked with the USGS and USFS Coweeta Hydrologic Laboratory in this effort, two organizations with very different approaches digitization. Meanwhile, we are re-instrumenting the four historically monitored streams, with two of the four V-notch weirs being measured for over a year. We attach to this report an annual rainfall-streamflow figure from Weir #4 comparing water years of 1952-53 with 2014-15, the kind of data that we can compare time to peak flow, peak flow relative to rainfall, rates of recessions, and base flows to understand how reforestation has altered catchment responses from seriously degraded catchments. Also being gaged since spring of 2014 is Holcombe's Branch which drains the Calhoun CZO's 650-ha watershed within which are nested the three experimental catchments. The hydrological data will used on their own but also will be extremely useful for our variety of within-CZ ecohydrologic models.

4) Belowground CZ metabolism profiles.

We are extremely interested in how land uses and land-use history alters CZ metabolism and the fluxes of water and gases belowground and between CZ and the atmosphere. Following a rationale outlined in the recent *New Phytologist* paper on critical zone metabolism (Richter and Billings, 2015), we have instrumented in 2015, fifteen sites with gas reservoirs at four depths down to 5-m depth. This system measures CO₂, O₂, CH₄, and N₂O, and 14C-CO₂, and will soon measure water and temperature. At two sites, we will auger and place gas reservoirs as deeply as we can, perhaps to >10- or >15-m. While we have modeled CO₂ at these depths, we have never measured soil CO₂ below 6-m. We hypothesize that this expression of critical zone metabolism is one of the primary drivers of deep biogeochemical weathering and determinant of groundwater chemistry, and the major process that has advanced weathering so intensely and deeply in the Calhoun CZ.

5) Holcombe's Branch floodplain profiles.

We are estimating the Holcombe's Branch carbon budget, both historically and at the present and have collaborated with Dr. Allan James of the University of South Carolina to interpret and initiate sampling of the historic Holcombe's Branch floodplain sediments. PI Cherkinsky has recently estimated 14C ages of the charcoal we have recovered from historic sediments. A larger group of the Calhoun CZO team has been intrigued with these results and it is now clear that not just carbon has been altered by historic erosion and deposition, but that the burial of carbon in the historic alluvial soils has been accompanied by a mixture of large

amounts of B-horizon Fe oxides. Thus the historic floodplain sediments are a novel, highly reactive environment of C-Fe redox cycling.

6) Three modeling results.

We formulated and analyzed a dynamical system describing the interaction of ecohydrological and human dynamics in agroecosystems with particular attention to the Calhoun history of land use, its land degradation and landscape reforestation. We have obtained the mathematical conditions leading to critical shifts in managed ecosystems. In particular, we have examined the Hopf bifurcation that separates a regime with relatively stable dynamics from one with self-sustained cycles of degradation and recovery, all induced by nonlinear interactions of social and ecohydrological processes.

Distributed models are used by several Calhoun researchers. In one study, efficiencies gained by domain partitioning were examined in parallel distributed hydrologic model simulations. Because such simulations are extremely data and computation intensive, understanding efficiencies matters significantly to model development. Results have been submitted for publication in a hydrogeology engineering journal.

Soil erosion-carbon interactions are also being modeled using the Calhoun's Holcombe's Branch catchment by expanding the purview of tRIBS, a distributed model originally developed for simulating hydrologic and geomorphic behaviors of watersheds. The new model simulator called tRIBS-ECO (erosion and carbon oxidation) includes feedbacks, and accounts for oxidation, transportation, and deposition of eroded SOC. Results point to the importance of small scale topographic and temporal complexity in controlling erosion's effect as a carbon sink or source at the watershed scale. The results are submitted for publication and a subject of several poster presentations.

Key outcomes or Other achievements:

"Other achievements" are what we call *research themes of integration*:

CZ systems science: All investigators are contributing to the science of the critical zone, that is, its structure and architecture and its processes both ecohydrological or biogeochemical. Most especially, we are interested in understanding how humans interact with CZ structure and processes.

CZ dynamics and evolution: All investigators are contributing to understanding: the dynamics of Calhoun CZ change over time, from the instantaneous to the seasonal, decadal, and multimillennial; the evolution of Calhoun CZ change that can only be understood from a joint study of geology, geomorphology, pedology, hydrology, geophysics, ecosystems science, biogeochemistry, theoretical systems science, all along with environmental history, agriculture, and sociology.

Erosion and carbon: About a third of the Calhoun CZO team studies how accelerated erosion and deposition has impacted the CZ's carbon budget and in recent months, the CZ's C-Fe redox cycle.

Systems modeling: About a third of the Calhoun CZO team either creates or contributes to models that simulate the dynamics and evolution of the CZ.

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

The Calhoun CZO is composed of researchers entirely committed linking research activities whenever possible with training, both in the field and lab.

Examples of 2015 opportunities for training and professional development include:

- 1) Presentations given by PIs *and students* throughout the year. See Products section for details.
- 2) Three PhD students who earned admission to the competitive two-year Duke WISEnet IGERT Training Program on intelligent and environmental sensor networks. John Mallard (PI McGlynn), Chris Krapu (PI Kumar), and Zach Brecheisen (PI Richter) have incorporated sensor technology into their dissertation research.
- 3) A Research Associate and PhD student trained in the use of soil and enzyme incubation techniques for assessing potential soil microbial activities.
- 3) Undergraduate students at Duke, UGA, Kansas, and Roanoke who participate in a wide range of research activities. Some have presented their work in public forums.
- 4) Our Calhoun CZO annual meeting that was aimed at project integration, and was organized giving all students a chance to present several dozen posters to the project as a whole, nearly all followed by a good amount of time for questions and answers. "Outdoor classrooms" which were field research sites with portable chairs were a big hit.
- 5) A number of visiting scholars were associated with the Calhoun CZO in 2015, including a) Greg Hancock of Univ. of New Castle who ran a number of landscape evolution simulations on Calhoun CZO catchments (McGlynn), b) Valerio Noto of Univ. of Palermo who is estimating volumes and structures of Calhoun gullies with fuzzy logic and remote sensing (Bras), c) Hermann Jungkunst of Univ. of Koblenz-Landau who is studying soil organic carbon structure via differential thermal analysis, d) Zhiquan Huang of Fujian Normal University who was trained in various lab instrumentation and soil incubations, e) Titta Majasalmi of University of Helsinki who used Calhoun CZO LiDAR-derived data and various GIS data to estimate forest biomass calibrated to the ground-estimated biomass in 34 plots across the Calhoun, f) Atsushi Namoko of Kyoto University, who installed biotite weathering plugs as part of a large cross-site field experiment of K-mineral weathering, and last but not least g) Bruno Latour of Sciences Po, Paris, who visits the Calhoun CZO for two days and spends a third at Duke interviewing Calhoun CZ scientists as part of a project to write more on Earth's critical zone science and scientists.
- 6) The use of project-wide listserves and Google calendar, Gmaps, and Gdocs to recruit students to attend field work campaigns and stimulate interaction and communication across campuses.

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

Calhoun CZO research is being and will be published in the main international science journals, including *Science*, *Water Resources Research*, and *New Phytologist* as examples. We also have

presented to many university and national and international scientific conferences (see Products for details). In addition, PIs of the Calhoun CZO have explicitly reached out to individual Earth science, environmental, and ecological disciplines and communities to explain the details and the need for critical zone science.

Hydrologists: PI Porporato has done an incredible job in promulgating the CZ concept in a variety of hydrology forums. He was selected to give the Borlund Lecture in 2015 at AGU's 35th Hydrology Days held this year at CSU where he discussed results of his modeling work that are directly related to the Calhoun CZO. As a CUAHSI Board of Director, PI McGlynn is the informal bridge from CZ science to CUASI program and was influential in planning the recent colloquium, entitled "Water across the Critical Zone".

Ecologists: 1) To promote more concrete collaboration with ecologists on CZOs, PI Richter joined with Tim White of the CZO National Office, and Bill McDowell and Peter Groffman (who are associated with both LTER and CZO), at the All Scientists Meeting of LTER in August 2015. PI Richter gave three talks in three days and the four held a 4-hour working group meeting with 30 to 40 members of the LTER community. The four are writing a paper that outlines the rationale and a vision for transformative collaboration of network science that involves the NSF networks of CZOs, LTERs, and NEON. 2) PIs Billings and Richter were invited to write a concept paper, "One Physical System" for the *New Phytologist* that was published in 2015 and that was delivered at the 100th meeting of the Ecological Society of America in Baltimore. 3) PhD student Zach Brecheisne gave a poster on interfluvial ordering to the Annual Duke Ecology Colloquium that annually gathers students and faculty of several dozen Duke ecology labs.

Earth scientists: Many of us gave talks and posters on the Calhoun CZO at the 2014 AGU meeting in San Francisco and will do so at the 2015 meeting as well.

Clay mineralogists: PI Richter was invited to the once-every-five-years EuroClay 2015 conference to give a Key Note address that opened a day and a half of science talks that included Calhoun CZO scientists Schroeder and Austin.

Stratigraphers: PI Richter gave a talk on Earth's critical zone to stratigraphers who join him on the International Commission on Stratigraphy's Anthropocene Working Group.

Paleosol scientists: PI Richter gave a talk on the critical zone in memory of Prof. Dan Yaalon in Vienna in which the international meeting was attended by about 50 paleosol specialists. He has written and submitted a paper with Dr. Eric Brevik, a science historian of Yaalon's special abilities to excite others in the Earth sciences.

Environmental history: PI Giesen has written an essay entitled "Jack's Cave" about a slave's six-month escape to the Calhoun forest. The essay has been read and discussed by CZO scientists as "a critical zone story" and it has stirred a lot of discussion.

Environmental humanities: PI Richter encouraged the visit of Prof. Bruno Latour to Eel River and Southern Sierra CZOs, and has organized a three-day visit and set of meetings entitled, "The Education of Bruno Latour", in direct reference to Latour's current interest in being "a student" of the critical zone sciences (his words). Richter is initiating with colleagues from across Duke an

Environmental Humanities program in which he sees critical-zone studies to be prominently featured and he has participated in a workshop called "After Nature", composed of a panel of humanities scholars at University of South Carolina. His talk and paper to be published by the Rachel Carson Institute involves the Earth's critical zone and its relations to the Anthropocene.

Geology and environmental science educators (advanced high school and undergraduate): PI O'Neill and her students are disseminating materials through presentations at national scientific and pedagogical meetings, Professional Development Institutes for educators, classroom and laboratory teaching, site visits and tours, public outreach events, and on the CZO website.

Mexican geologists: Richter was invited to give the keynote address on critical zone science at the Mexico City-UNAM celebration of International Year of Soils.

International science: Both Schroeder and Richter have been active in giving talks and participating in discussions to advance CZ science. Schroeder for example gave 10 invited lectures at universities and conferences while on sabbatical in Turkey during 2015.

Graduate and undergraduate student communities: Innumerable presentations, many semiformal, made by to students across many disciplines are being led by the Calhoun CZO graduate and undergraduate students.

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

Plans for work in Year Three are described for the five objectives. At least monthly teleconference calls will be held to advance the five objects. All five objectives will be addressed in oral talks and posters and submitted manuscripts aimed at scientific, educational, and public audiences. Research and educational proposals will be submitted that derive from these activities.

O1) Hydrologic and Biogeochemical Recovery. Continue hydrologic installation and data gathering on streams, soils, and groundwater on Holcombe's Branch (with its three experimental watersheds # 3 and 4), Watershed #1, and on reference hardwood catchments as well. Reinstrument weir on watershed #2. Continue repeated electrical resistivity and EMI measurements in concert with the above instrumentation on hillslopes, whole catchments, and floodplains. Continue forest tree sampling and remote sensing analyses, and soil and saprolite and alluvial floodplain sampling across Holcolme's Branch; in reference hardwood, old-field forest, and continuously cultivated sites; and on flux-tower sites: all to quantify changes in vegetation and soil's hydrologic attributes, biogeochemistry, microbial dynamics, and mineralogy. Continue model development to explore dynamics of land-use degradation on hydrology and biogeochemistry. Complete scanning of historic Calhoun Experimental Forest records and color-photographic slides that document research activities and data gathered from 1947-1962, all archived at Coweeta Hydrologic Laboratory (Major PIs include: Richter, Porporato, McGlynn, Kumar, Palmroth, Markewitz, Thompson, Schroeder, Cherkinsky, Wang, Bras, Nelson, O'Neill, and Billings).

O2) Erosion-Induced Carbon Dynamics. Continue forest-tree sampling and remote sensing analysis, and soil, saprolite, and floodplain sampling combined with gully evaluations across

Holcolme's Branch; and in reference hardwood, old-field forest, and continuously cultivated sites, to quantify erosional losses of soil from uplands and hillslopes and sediment deposition on terraces and floodplains of the Holcombe's Branch watershed. Similar analysis will continue to be conducted in about ten paired reference hardwood and old-field forests across the entire Calhoun CZO.

Continue to develop a variety of modeling approaches to the temporal and spatial dynamics of soil loss and sediment deposition, and the impacts on soil organic carbon. (Major PIs include: Billings, Bras, Richter, Thompson, Porporato, McGlynn, Markewitz, Schroeder, Cherkinsky; with cooperators Allan James, Bill Hansen).

O3) Human-Critical Zone Interactions. Continue to assemble and geographically coordinate a wide variety of historic and contemporary social, land-use, and land-cover data, ranging from regional aerial photography and remote sensing data, to deed chains, census data, and individual farm records, all to evaluate and model how land-use practices transform the land, and alter its management and human livelihoods. These data will continue to be used in the development of a variety of social-ecological models (Major PIs include: Giesen, Nelson, Porporato, Richter; with cooperators Mike Harmon, Terry Ferguson).

O4) Persistence of Alternative States. Continue to develop state transition models that evaluate how CZs respond to severe disturbance, disturbance that threatens both resilience and recovery of the CZ system.

O5) Education and Outreach. Continue to develop a series of web-based, interactive education modules; disseminate prototype education module within the Calhoun CZO community and selected others for feedback; finalize iBook (or comparable interactive media platform) and circulate for review; document and evaluate pedagogical materials in professional presentations and manuscripts to be submitted for peer-review pedagogical journals.

Supporting Files

	Filename	Description
(Download)	Porporato_A LabWork 2015 CCZO.pdf	An example lab progress report for Calhoun CZO Year Two - this is comprehensive
(Download)	Weir4_PastPresent.pdf	Historic rainfall & streamflow stripcharts (1940s-1962) archived at catchments, each of which are being re-instrumented to quantify hydrological responses of seriously degraded
(Download)	StClair_J2015 SCIENCE.pdf	Exciting & transformative geophysics manuscript of Calhoun and E
(Download)	dSupplementary Information for Calhoun CZO Year 2.pdf	Supplementary Information for Calhoun CZO. 18 items

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Products

Books

- Intergovernmental Technical Panel on Soils led by Montanarella, L. and eight editors with nearly 200 contributing authors including D. deB. Richter. (2015). *Status of the World's Soil Resources Report* Food and Agriculture Organization of the United Na. Rome, Italy. Status = ACCEPTED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes

Book Chapters

- Nziguheba G., R. Vargas, A. Bationo, H. Black, D.E. Buschiazzo, D. de Brogniez, H. Joosten, J. Melillo, D.deB. Richter, M. Termansen (2015). Soil carbon: a critical natural resource – Wide-scale goals, urgent actions. *Soil carbon: Science, Management, and Policy for Multiple Benefits* 71. SCOPE. Wallingford, UK. 10. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; DOI:
- Perdrial J., Thompson A., Chorover J. (2015). Soil Geochemistry in the Critical Zone: Influence on Atmosphere, Surface- and Groundwater Composition. *Developments in Earth Surface Processes* 19. John R. Giardino and Chris Houser. 173. Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1016/B978-0-444-63369-9.00006-9.
- White T., Brantley S., Banwart S., Chorover J., Dietrich W., Derry L., Lohse K., Anderson S., Aufdendkampe A., Bales R., Kumar P., Richter D., McDowell B. (2015). The Role of Critical Zone Observatories in Critical Zone Science. *Developments in Earth Surface Processes* 19. John Giardino, Chris Houser. 15. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/B978-0-444-63369-9.00002-1.

Conference Papers and Presentations

- Richter, Daniel deB. (2014). *"One Physical System": Why soil is critical to Earth's critical zone*. North Carolina State University. Raleigh, NC. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D.deB. and S.A. Billings (2015). *"One Physical System": Sir Tansley's Ecosystem and Earth Science's Critical Zone*. Ecological Society of America. Baltimore. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D. deB., and Billings, S. A. (2015). *"One Physical System": Tansley's Ecosystem Concept as Earth's Critical Zone*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D deB and Billings SA. (2014). *"One Physical System": Tansley's Ecosystem as Earth's Critical Zone*. Berkeley Univ California. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D. deB., Billings, S. A. (2015). *"One physical system": Tansley's ecosystem as Earth's critical zone*. Ecological Society of America Annual Meeting. Baltimore, MD. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Cherkinsky, A. (2015). *14C and 137Cs distribution in the Ultisol profile*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No

- Cherkinsky, A., and Markewitz, D. (2015). *14C distribution in soils with different history of land use in Calhoun CZO*. Goldschmidt 2015 Conference. Prague, CZ. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Brecheisen, Z., and Cook, W. (2015). *1933 CCZO aerial photography mosaic*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Dialynas, Y. G., Bastola, S., Bras, R. L., Billings, S. A., Richter, D. deB., and Markewitz, D. (2015). *A Coupled Spatially Explicit Modelling Approach to Assess the Influence of Soil Erosion and Deposition on the Redistribution of Soil Organic Carbon at the Watershed Scale*. Southeastern Biogeochemistry Conference. Georgia Tech, Atlanta, GA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D.deB. (2015). *A Crisis of Environmental Narrative in the Anthropocene*. After Nature. Columbia, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D. (2015). *A Proposal for a Calhoun Drilling Program: Where geophysics meets (bio)geochemistry*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Mau Y; Porporato A (2014). *A dynamical study on sodium accumulation and soil reclamation in secondary salinization*. AGU Fall Meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Billings, S.A., Min, K., Lehmeier, C., Ballantyne, F. (2014). *A first step towards unravelling SOC responses to large-scale perturbations: microbial C use efficiency responses to temperature vary with resource C:N*. Soil Organic Matter 6 bi-annual meeting. Kiawah Island, South Carolina. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Billings, S.A., Richter, D. deB. (2014). *Accelerated erosion and soil atmospheric CO2 exchange: the Calhoun Critical Zone as a model for historically farmed soils*. National Science Foundation's Critical Zone Observatories' All-Hands meeting. Tenaya Lodge, California. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D.deB. (2014). *Anthropocene Imperatives for Long-Term Soil Experiments*. Annual Meetings of Soil Science Society of America. Long Beach, CA. Status = PUBLISHED; Acknowledgement of Federal Support = No
- Dialynas, Y. G.; Bastola, S.; Billings, S. A.; Bras, R. L. (2014). *Assessing the impact of landscape evolution on carbon dynamics: a coupled physically-based modelling approach*. American Geophysical Union annual meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Austin, J., Bacon, A., Billings, S.A., Cherkinsky, A., Richter, D. deB., Schroeder, P. (2014). *CZ-tope at the Calhoun CZO*. National Science Foundation's Critical Zone Observatories' All-Hands meeting. Tenaya Lodge, California. Status = OTHER; Acknowledgement of Federal Support = Yes
- Mallard, J., B. McGlynn, D. Richter, D. Markewitz, Z. Brecheisen (2014). *Calhoun CZO: understanding critical zone evolution after a legacy of degradation*. Consortium of Universities for the Advancement of Hydrologic Sciences (CUAHSI) Biennial Colloquium. Sheperdstown, WV. Status = OTHER; Acknowledgement of Federal Support = Yes
- Mallard, J., B. McGlynn, D. Richter, D. Markewitz, Z. Brecheisen (2014). *Calhoun CZO: understanding critical zone evolution after a legacy of degradation*. Consortium of Universities for the

- Advancement of Hydrologic Sciences (CUAHSI) Biennial Colloquium. Shepherdstown, WV. Status = OTHER; Acknowledgement of Federal Support = Yes
- Cherkinsky, A., and Markewitz, D. (2015). *Carbon turnover rates in soils with the different history of land use*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
 - Coughlan, M., and Nelson, D. (2015). *Comparison of piedmont and mountain fire regimes during forest transition periods*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
 - Richter, D.deB. and S.A. Billings (2015). *Congruence of Sir Tansley's Ecosystem with Earth Science's Critical Zone*. EuroClay 2015. Edinburgh. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
 - Richter, D.deB. and S.A. Billings (2015). *Congruent Core Concepts of the Ecological and Earth Sciences*. LTER All Scientist Meetings. Estes Park. Status = OTHER; Acknowledgement of Federal Support = Yes
 - Pelak, N. F.; Manzoni, S.; Wang, J.; Bras, R. L.; Porporato, A. M. (2013). *Coupled dynamics of soil formation and erosion in natural and agricultural ecosystems*. American Geophysical Union Fall Meeting. San Francisco. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
 - Bastola, S. (2015). *Coupling of Carbon-Nitrogen cycle on a physically based distributed hydrological model, tRIBS*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
 - Schroeder, P. A. (2015). *Creating deep soil core monoliths: Beyond the Solum*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
 - Schroeder, P. A., Ö. I. Ece, and N. C. Balci (2015). *Critical Zone Observatories: Overview and current research activities in Turkey and the United States*. 68th Turkish Geological Congress. Ankara, Turkey. Status = OTHER; Acknowledgement of Federal Support = No
 - Thompson, A. (2015). *Critical zone research at the University of Georgia*. Departmental Seminar, University of Padua. Padua, Italy. Status = OTHER; Acknowledgement of Federal Support = Yes
 - Mallard, J., McGlynn, B. (2015). *Current Calhoun Hydrologic Sensor Network, Selected Data, and next steps!*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
 - Dypvik, L.R.H., R. Sørli, N. Oberhardt, P. Tan, K. Stangvik, S. A. A.-E-M. Naqvi, P. A. Schroeder, A. Begonha, and R. Ferrell (2015). *Deeply buried Mesozoic weathering profiles from the Norwegian North Sea*. EuroClay2015. Edinburgh, Scotland. Status = OTHER; Acknowledgement of Federal Support = No
 - Dypvik, L.R.H., R. Sørli, N. Oberhardt, P. Tan, K. Stangvik, S. A. A.-E-M. Naqvi, P. A. Schroeder, A. Begonha, and R. Ferrell (2015). *Deeply buried Mesozoic weathering profiles from the Norwegian North Sea*. Geological Society of America Annual meeting. Baltimore, MD. Status = OTHER; Acknowledgement of Federal Support = No
 - Thompson A, Barcellos D, Wilmoth J, & Richter D (2015). *Depth Variation of Soil Iron Crystallinity at the Calhoun Critical Zone Observatory*. Goldschmidt Conference. Prague, CZ. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Thompson, A., Barcellos, D., Wilmoth, J., and Richter, D. (2015). *Depth variation of soil iron crystallinity at the Calhoun CZO*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Pelak, N. (2015). *Description of topographically-derived spatial soil moisture patterns and finding optimal sampling points*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- O'Neill, KP (2014). *Disturbance and management impacts on the Critical Zone. Coast Dynamics: Stewardship through Problem and Place-based Learning..* Invited webinar for teacher development series. Portsmouth, VA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D.deB. and A.R. Bacon (2014). *Does Be10 Underestimate Residence Time of Critical Zones in Acid Environments?*. AGU Fall Meetings. San Francisco. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Schroeder, P. A. and J. C. Austin (2015). *Dynamics of mineral recrystallization at the Earth's surface: Evidence from Utisols, kaolins, and paleosols with implications for the ages of rocks*. Euroclay2015. Edinburgh, Scotland. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D. deB., Billings, S.A. (2014). *Earth's Critical Zone as Expanded Ecosystems*. National Science Foundation's Critical Zone Observatories' All-Hands meeting. Tenaya Lodge, California. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D.deB. and James Giesen (2014). *Earth's Critical Zone as Interdisciplinary Research Ground*. University of South Carolina History Center. Columbia, SC. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D.deB. (2014). *Earth's Critical Zones in the Anthropocene*. International Commission on Stratigraphy's Working Group on the Anthropocene Meeting. Berlin, Germany. Status = OTHER; Acknowledgement of Federal Support = No
- Vico G; Manzoni S; Thompson S; Molini A; Porporato A (2015). *Ecophysiological and phenological strategies in seasonally-dry ecosystems: an ecohydrological approach*. EGU General Assembly Conference. Vienna, Austria. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D., Billings, S. (2014). *Ecosystem and geoscientists to hybridize their sciences*. American Geophysical Union annual meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- O'Neill, K., and Ramey, A. (2015). *Education and Outreach at the Calhoun CZO: Updates and Request for Input*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- O'Neill KP; Ramey AJ (2015). *Engaging students through virtual field trips: Calhoun CZO*. Virginia Association of Science Teachers. Chantilly, VA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes
- Majasalmi, T., Palmroth, S., Cook, W., Brecheisen, Z., Richter, D. (2015). *Estimation of LAI, fPAR and AGB based on data from Landsat 8 and LiDAR at the Calhoun CZO*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Mallard, John M. (2014). *Field to forecast: Leveraging wireless environmental sensor networks to facilitate real-time hydrologic prediction*. CUAHSI 2014 Biennial Colloquium. . Status = OTHER; Acknowledgement of Federal Support = Yes

- Zimmer MA and BL McGlynn (2015). *Flowpath and stream network activation threshold influences on Piedmont runoff generation and biogeochemistry*. Gordon Research Conference on Catchment Science. Andover, NH. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, Daniel deB. (2014). *From "The Changing Model of Soil" to "The Changing Model of Ecosystems"*. Virginia Tech. Blacksburg, VA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D.deB. (2014). *Global Soil Change: Perspectives from Long-Term Experiments and Critical Zone Science*. Keynote address for UNAM's International Soil's Day Colloquium. Mexico City. Status = OTHER; Acknowledgement of Federal Support = Yes
- Billings, S., Ballantyne, F., Lehmeier, C., Min, K. (2014). *Guiding empirical and theoretical explorations of organic matter decay using disparate fields*. American Geophysical Union annual meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Markewitz, D. and D. Richter (2014). *Historic rainfall-runoff relationships in the Calhoun and Future Critical Zone Research*. Southern Sierra Critical Zone Observatory All Hands Meeting. Fish Camp, CA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Richter, D.deB. and S.A. Billings (2014). *How are Earth's Critical Zones Congruent with Terrestrial Ecosystems?*. AGU Fall Meetings. San Francisco. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Min, K. J., Lehmeier, C. A., Billings, S. A. (2015). *How deep and persistent are the influences of aboveground disturbance on soil microbial activities at the Calhoun CZO?*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Noto, L. V., Dialynas, Y., Bastola, S., and Bras, R. L. (2015). *Integration of fuzzy logic and image analysis for the detection of gullies in the Calhoun forest using airborne LiDAR data*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Parolari A; Katul GG; Porporato AM (2014). *Irrigation and fertilization controls on critical zone carbon and nitrogen cycles in harvested ecosystems*. AGU Fall Meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Lehmeier, C. A., Min, K. J., Billings, S. A. (2015). *Is $\delta^{13}C$ of respired CO₂ dependent on growth rate? Exploring carbon isotope discrimination in soil microbes*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Giesen, J. C. (2015). *Jack's Cave: A Critical Zone Story*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Buchanan, C and KP O'Neill (2014). *Land use and the Critical Zone in the southern Piedmont: A GIS analysis*. Roanoke College Showcase of Research and Creativity. Roanoke, VA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Cherkinsky, Alex (2014). *Lecture on ^{14}C analyses of soil fractions*. Soil Science seminar at UGA. Athens, GA. Status = OTHER; Acknowledgement of Federal Support = Yes
- O'Neill, KP (2014). *Linking human activity and CZ processes in undergraduate educational modules at the Calhoun CZO*. National Critical Zone All Hands Meeting, Southern Sierra CZO. Fish Camp, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

- Richter, D.deB. (2014). *Long-Term Soil Experiments: Keys to Managing Earth's Rapidly Changing Ecosystems*. AGU Fall Meetings. San Francisco. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- O'Neill, K. P. (2015). *Making connections: Linking human and natural systems through education and outreach at the Calhoun Critical Zone Observatory*. Ecological Society of America Annual Meeting. Baltimore, MD. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Hodges, C., Markewitz, D., and Thompson, A. (2015). *Mapping the Potential for Iron Reduction Using Electromagnetic Induction*. Southeastern Biogeochemistry Symposium. Atlanta, GA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Ramos, A and KP O'Neill (2014). *Modeling soil erosion potential (RUSLE) in a southern piedmont landscape using GIS*. Roanoke College Showcase of Research and Creativity. Roanoke, VA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Nelson, D., and Coughlan, M. (2015). *Multitemporal Human Forcings in the Calhoun CZO*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Law, D. L., and Hansen, W. F. (2015). *Native Plants and Fertilization Help to Improve Sites and Stabilize Gullies on the Sumter National Forest*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Parolari AJ; Pelak N; Katul GG; Richter D; Porporato A (2014). *Non-linear dynamics in plant-soil interactions and implications for critical zone processes*. Critical Zone Observatory All Hands Meeting. Fish Camp, CA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Krapu, C. (2015). *Nonlinear Clustering of Spatially Distributed Hydrometric Data*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Cherkinsky, A. (2015). *Old soil carbon in Calhoun Ultisols*. Max Plank Institute workshop. Hamburg, Germany. Status = OTHER; Acknowledgement of Federal Support = Yes
- Brecheisen, Z.R., J.M. Mallard, N.F. Pelak (2014). *Optimizing Hydrologic and Biogeochemical Sensor Networks in the Calhoun Critical Zone Observatory*. 2nd Annual Workshop on Wireless Intelligent Sensor Networks. . Status = OTHER; Acknowledgement of Federal Support = Yes
- Brecheisen, Zachary S., and Daniel deB. Richter (2014). *Ordering Interfluves: A Simple Proposal for Understanding Critical Zone Evolution*. Geochemistry of the Earth's surface GES-10. Paris, France. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Brecheisen, Zachary S., Xing Chen, and Daniel deB. Richter (2014). *Ordering interfluves: a simple proposal for understanding critical zone evolution and function*. CZO Network 2014 All Hands Meeting. Fish Camp, CA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Cook, C. W. (2015). *Overview of Sampling Sites at the Calhoun CZO*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Thompson A., and Wilmoth, J. (2015). *Oxygen flux modulates net rates of Fe reduction and Fe solid phase composition in redox dynamic soils*. American Chemical Society National Meeting. Denver, CO. Status = OTHER; Acknowledgement of Federal Support = Yes
- Cherkinsky, Alex (2014). *Posters on 14C analyses of soil fractions*. 2014 CZO All Hands meeting at the Southern Sierra CZO. Fish Camp, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

- Austin, J.C., and P.A. Schroeder (2015). *Preliminary interpretations of differences in the clay mineralogy of the Calhoun CZO between 'pristine' and eroded soils at the Long-Term Pine Plots*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Cherkinsky, Alex (2014). *Presentation about 14C age of soil fractions*. Alaska Anthropological Association. Fairbanks, AK. Status = OTHER; Acknowledgement of Federal Support = Yes
- Cherkinsky, Alex (2014). *Presentation on AMS analyses of different soil fractions from paleosols buried by tephra, Alaska*. AMS-13 conference. Aix-en-Provence, France. Status = OTHER; Acknowledgement of Federal Support = Yes
- Shahnaz, S., Shen, Y., Wang, J. (2015). *Processing High Resolution Hydrologic Data from Historic Records at the Calhoun CZO*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Foroughi, M. (2015). *Proposal: Assessing soil phosphorus status over time and under different land uses*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Huang, S.-Y., Y. Deng, and J. Wang (2014). *Re-evaluation of the Earth's Surface Energy Balance using a New Method of Heat Fluxes*. AGU Fall Meeting. San Francisco. Status = OTHER; Acknowledgement of Federal Support = Yes
- Bartlett MS; Parolari AJ; McDonnell JJ; Daly E; Porporato A (2015). *Runoff production in stochastic soil moisture models: saturation-excess threshold and soil moisture-dependent progressive partitioning*. Gordon Research Conference for Catchment Science: Interactions of Hydrology, Biology & Geochemistry. Andover, NH. Status = OTHER; Acknowledgement of Federal Support = Yes
- Foroughi, M., D. Markewitz, and C. A. Hodges (2015). *Sample Modeling for Soil Phosphorus at the Calhoun CZO via GIS Applications*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Hansen, W. F., and Law, D. L. (2015). *Sediment from a Small Ephemeral Gully in South Carolina*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- O'Neill, K. P. (2015). *Seeing is believing: Exploring land use/land cover change in the southern Piedmont using virtual field trips*. Association for Environmental Studies and Sciences. San Diego, CA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Feng X; Souza R; Vico G; Antonino A; Montenegro S; Porporato A (2015). *Semi-arid ecosystem response under seasonal hydroclimatic forcings*. EGU General Assembly Conference. Vienna, Austria. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Billings, S., Wood, T., Buckeridge, K., Min, K., Lehmeier, C., Flournoy, R., Huang, Z., Ziegler, S., Richter, D., Pett-Ridge, J., Brodie, E., Bouskill, N. (2015). *Small-scale experiments in diverse ecosystem highlight intricate linkages between microbial behavior and ecosystem-scale processes*. Ecological Society of America Annual Meeting. Baltimore, MD. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Wang, J., Parolari, A., and Huang, S.-Y. (2015). *Soil Moisture and Vegetation Controls on Surface Energy Balance using MEP Model of ET*. American Geophysical Union annual meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Parolari AJ; Katul GG; Porporato A (2014). *Soil N as a buffer of critical zone carbon and nitrogen cycles in harvested ecosystems*. AGU Fall Meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Giesen, James C., Daniel d.B. Richter (2014). *Soil as Time Machine: The Calhoun Critical Zone Observatory*. History Center/SEOE, University of South Carolina. . Status = OTHER; Acknowledgement of Federal Support = Yes
- Austin, Jason C. and Schroeder, Paul A. (2014). *Soil depth dependence of stable and radiogenic carbon and stable oxygen isotopes in gibbsite (Al(OH₃)) occluded CO₂ as an indicator of recovery after anthropogenic disturbance*. Southern Sierra Critical Zone Observatory All Hands Meeting. Fish Camp, CA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Wang, J., A. Parolari, and S.-Y. Huang (2014). *Soil moisture and vegetation controls on surface energy balance using the maximum entropy production model of evapotranspiration*. AGU Fall Meeting. San Francisco. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Parolari, A. J., Pelak, N. F., Porporato, A. (2015). *State transitions in coupled social-ecological agro-ecosystem models*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- O'Neill, KP (2014). *Sustaining Earth's life support system: Soils and the Critical Zone*. Roanoke College Coffee Shop talks (public outreach). Roanoke, VA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Billings, S., Lehmeier, C., Min, K., Ballantyne, F. (2014). *Temperature and substrate C:N drive microbial carbon use efficiency and 13C discrimination*. Soil Science Society of America annual meeting. Long Beach, California. Status = OTHER; Acknowledgement of Federal Support = Yes
- Markewitz, D. (2015). *Temporal electrical resistivity imaging for assessing subsurface water flow at multiple watershed scales*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Chen, X. (2015). *Testing of streamflow prediction using storage-discharge relation*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Mallard, J. M.; McGlynn, B. L.; Richter, D. (2014). *The Calhoun Critical Zone Observatory: understanding the evolution of the critical zone after centuries of anthropogenic degradation*. American Geophysical Union annual meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D deB and Billings Sharon A. (2014). *The Changing Models of Soil, Ecosystems, and Earth's Critical Zones*. Stanford University. Palo Alto, CA. Status = OTHER; Acknowledgement of Federal Support = Yes
- O'Neill, K. P., and Richter, D. D. (2015). *The Earth's Critical Zone as an integrating theme for undergraduate environmental science courses: A case study at the Calhoun Critical Zone Observatory*. Association for Environmental Studies and Sciences. San Diego, CA. Status = OTHER; Acknowledgement of Federal Support = Yes
- Zimmer, M.A. and B.L. McGlynn (2014). *The Roles of Groundwater Flowpaths and Stream Network Expansion in Landscape Connectivity and Resulting Runoff and Solute Dynamics in an Ephemeral Piedmont Catchment*. American Geophysical Union, Fall Meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Callaham, M. A. (2015). *The new Calhoun CZO at the Calhoun Experimental Forest: An exemplary collaboration between managers and scientists*. Joint meeting of USDA FS Southern Region leadership teams. Asheville, NC. Status = OTHER; Acknowledgement of Federal Support = Yes
- Zimmer M.A., B.L. McGlynn (2014). *The role of groundwater and stream network dynamics in baseflow and stormflow generation*. Consortium of Universities for the Advancement of Hydrologic Sciences (CUAHSI) Biennial Colloquium. Shepherdstown, WV. Status = OTHER; Acknowledgement of Federal Support = Yes
- Pelak, Norman F. (2014). *Theoretical considerations for stochastic soil moisture dynamics and the optimal design of soil moisture sensor networks*. CUAHSI 2014 Biennial Colloquium. . Status = OTHER; Acknowledgement of Federal Support = Yes
- Bartlett MS; Parolari AJ; McDonnell JJ; Porporato A (2015). *Theory of event based rainfall-runoff models: Spatially variable runoff generate by threshold or progressive partitioning over stochastic source areas*. Gordon Research Conference for Catchment Science: Interactions of Hydrology, Biology & Geochemistry. Andover, NH. Status = OTHER; Acknowledgement of Federal Support = Yes
- Thompson A., Ginn, B., Meile, C., Wilmoth, J, Barcellos, D. (2015). *Timescales of soil redox oscillations and the role of iron in the critical zone*. American Chemical Society National Meeting. Denver, CO. Status = OTHER; Acknowledgement of Federal Support = Yes
- Dialynas, Y. G., Bastola, S., Bras, R. L., Billings, S. A., Richter, D. deB., and Markewitz, D. (2015). *Topographic variability in the influence of soil erosion on the carbon cycle*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = Yes
- Coughlan, M., D.R. Nelson, T. Gragson (2015). *Transitioning from livelihood fire to fire suppression in the US Southeast: Causes and consequences of fire regime transition in two forested landscapes*. Fire Ecology and Management Congress. San Antonio, TX. Status = OTHER; Acknowledgement of Federal Support = Yes
- Cook, C. W. (2015). *Trees of the Enoree District*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Kumar, M., Chen, X., and McGlynn, B. (2014). *Understanding the Variations in Flood Responses to Tropical-Storms and Hurricanes*. American Geophysical Union annual meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Hodges, C., Markewitz, D., and Thompson, A. (2015). *Using Electromagnetic Induction to Determine Spatial and Temporal Patterns of Iron Reduction at the Calhoun CZO*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = Yes
- Chen, X. (2015). *Variations in streamflow response to large hurricane-season storms in a southeastern US watershed*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Brecheisen, Z. (2015). *Watersheds and Landsheds: Bringing Hortonian Stream Ordering to Upland Systems*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No
- Callaham, M. (2015). *What about earthworms? Human influence on earthworm communities at the Calhoun Experimental Forest*. Calhoun CZO Summer Science Meeting. Union, SC. Status = OTHER; Acknowledgement of Federal Support = No

- Richter, D. deB., Billings, S.A., Plante, A., and members of the cross-CZO Soil Organic Matter Working Group (2014). *What controls organic carbon in and flux from the critical zone?*. National Science Foundation's Critical Zone Observatories' All-Hands meeting. Tenaya Lodge, California. Status = OTHER; Acknowledgement of Federal Support = Yes
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Inventions

Journals

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Licenses

Other Products

- *Educational aids or Curricula.*
T. Parolari and M. Bartlett. Soil and hydrology experiment module developed for elementary school students as part of the Scientific Research and Education Network (<http://www.thesciren.org/>). The

lesson plan will describe a rainfall-runoff experiment (grades 3-5) and tie the experiment to contemporary research topics like land use change and climate change. Lesson plan to be submitted Sept. 2 and advertised at a teacher/researcher networking event on Sept. 10, 2015.

- *Online Forum.*

The CCZO google group was created to foster communication among the researchers involved with the Calhoun Critical Zone Observatory, replacing the older group at czen.org.

<https://groups.google.com/forum/#!forum/cczo>

Other Publications

- James, A., D. Richter, A. Cherkinsky (2015). *Working Paper: Analysis of Radiocarbon on Holcombe's Branch*. Two editions of this report have been circulated amongst the CZO investigators as it describes the initial characterization of the historic floodplain sediments in the CZO's major watershed, that of Holcombe's Branch. Eleven sites along the branch have been had profiles excavated from the floodplain's surface down to water level. In many sites this is 2- or more meters in depth. Dr. Allan James of Univ. South Carolina, an internationally regarded expert in historic sediments is collaborating closely on this research. Early in year two James and Richter visited the site and described a number of profiles, concluding that historic sediment was as much as a meter in thickness and sampled a number of layers, including five charcoal samples that Dr. Alex Cherkinsky has dated using 14C. The results have been very promising with four charcoal samples estimated to be from the 1800s and one from 1000 YBP. In the fall of 2015, we are scheduled to intensely sample all 11 sites for solids and charcoal 14C analyses.. Status = OTHER; Acknowledgement of Federal Support = No

Patents

Technologies or Techniques

- Research Associate Christoph Lehmeier (University of Kansas) is developing a technique to test how microbial growth rate influences C flow through microbes and into the atmospheric CO₂ pool. The 'beta' version of this system is developed and in the coming year he will further expand on its details.

Thesis/Dissertations

- Bacon, AR.. *Pedogenesis and Anthropedogenesis on the Southern Piedmont*. (2014). Duke University. Acknowledgement of Federal Support = No

Websites

- *Calhoun Critical Zone Observatory*
<http://criticalzone.org/calhoun/>

The main website for disseminating information about the Calhoun CZO for both the research community and the public. Includes sections on News, Events, Research, Infrastructure, Data, Models, Publications, People, and Education/Outreach.

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Participants/Organizations

What individuals have worked on the project?

Richter, Daniel	PD/PI
Kumar, Mukesh	Co PD/PI
McGlynn, Brian	Co PD/PI
Palmroth, Sari	Co PD/PI
Porporato, Amilcare	Co PD/PI
Billings, Sharon	Co-Investigator
Bras, Rafael	Co-Investigator
Callaham, Mac	Co-Investigator
Cherkinsky, Alexander	Co-Investigator
Giesen, James	Co-Investigator
Markewitz, Daniel	Co-Investigator
Nelson, Donald	Co-Investigator
O'Neill, Katherine	Co-Investigator
Schroeder, Paul	Co-Investigator
Thompson, Aaron	Co-Investigator
Wang, Jingfeng	Co-Investigator

Hancock, Gregory	Faculty
Austin, Jason	Postdoctoral (scholar, fellow or other postdoctoral position)
Bacon, Allan	Postdoctoral (scholar, fellow or other postdoctoral position)
Bastola, Satish	Postdoctoral (scholar, fellow or other postdoctoral position)
Coughlan, Michael	Postdoctoral (scholar, fellow or other postdoctoral position)
Lehmeier, Christoph	Postdoctoral (scholar, fellow or other postdoctoral position)
Majasalmi, Titta	Postdoctoral (scholar, fellow or other postdoctoral position)
Parolari, Anthony	Postdoctoral (scholar, fellow or other postdoctoral position)
Cook, Charles	Technician
Crouch, William	Technician
Heine, Paul	Technician
Sutter, Lori	Staff Scientist (doctoral level)
Barcellos, Diego	Graduate Student (research assistant)
Biesel, Shelly	Graduate Student (research assistant)
Block, Ashley	Graduate Student (research assistant)
Brecheisen, Zachary	Graduate Student (research assistant)
Calabrese, Salvatore	Graduate Student (research assistant)
Chen, Xing	Graduate Student (research assistant)
Dialynas, Yannis	Graduate Student (research assistant)
Foroughi, Maryam	Graduate Student (research assistant)
Hodges, Caitlin	Graduate Student (research assistant)
Huang, Shih-Yu	Graduate Student (research assistant)

Husayn, El Sharif	Graduate Student (research assistant)
Krapu, Christopher	Graduate Student (research assistant)
Liu, Yanlan	Graduate Student (research assistant)
Livingston, Fraser	Graduate Student (research assistant)
Lonneman, Michael	Graduate Student (research assistant)
Mallard, John	Graduate Student (research assistant)
Min, Kyungjin	Graduate Student (research assistant)
Noor, Nadia	Graduate Student (research assistant)
Pelak, Norman	Graduate Student (research assistant)
Shahnaz, Sabina	Graduate Student (research assistant)
Shen, Yawen	Graduate Student (research assistant)
Tang, Yao	Graduate Student (research assistant)
Wade, Anna	Graduate Student (research assistant)
Barger, Keelan	Undergraduate Student
Elledge, Samantha	Undergraduate Student
Good, Holly	Undergraduate Student
Guimares-Dias, Ruan	Undergraduate Student
Heroneme, Carl	Undergraduate Student
McAvoy, Ashley	Undergraduate Student
Perry, Amelia	Undergraduate Student
Ramey, Alexandra	Undergraduate Student
Varner, Brandon	Undergraduate Student

[Flournoy, Rebecca](#)

Research Experience for Undergraduates (REU) Participant

Full details of individuals who have worked on the project:

Daniel deB Richter

Email: drichter@duke.edu

Most Senior Project Role: PD/PI

Nearest Person Month Worked: 9

Contribution to the Project: Lead-PI

Funding Support: 1-month summer salary

International Collaboration: Yes, Australia, China, Germany, Japan, Mexico, United Kingdom

International Travel: Yes, United Kingdom - 0 years, 0 months, 6 days; China - 0 years, 0 months, 10 days; Austria - 0 ye

Mukesh Kumar

Email: mukesh.kumar@duke.edu

Most Senior Project Role: Co PD/PI

Nearest Person Month Worked: 2

Contribution to the Project: Guide and oversee research with graduate students. The research included data analyses, mod

Funding Support: None

International Collaboration: No

International Travel: No

Brian L McGlynn

Email: brian.mcglynn@duke.edu

Most Senior Project Role: Co PD/PI

Nearest Person Month Worked: 1

Contribution to the Project: McGlynn has provided guidance and collaboration on watershed hydrology research including precipitation gauges, and soil water content monitoring stations. In addition, we have instrumented a set of ephemeral and pe inference to the larger piedmont region. This Duke Forest site includes an expansive network of nested wells and piezometer ephemeral streamflow generation and channel network expansion.

Funding Support: Duke University salary and lab startup funds

International Collaboration: No

International Travel: No

Sari Palmroth

Email: sari.palmroth@duke.edu

Most Senior Project Role: Co PD/PI

Nearest Person Month Worked: 0

Contribution to the Project: Planning, advising

Funding Support: Physically-based remote sensing applications for forest ecosystems, Rautiainen M., PI

International Collaboration: Yes, Finland

International Travel: No

Amilcare Porporato

Email: amilcare.porporato@duke.edu

Most Senior Project Role: Co PD/PI

Nearest Person Month Worked: 2

Contribution to the Project: Organization and supervision of all aspects of modeling of ecohydrology, biogeochemistry and a PhD student working in the CCZO research project

Funding Support: This grant only

International Collaboration: No

International Travel: No

Sharon A Billings

Email: sharon.billings@ku.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 3

Contribution to the Project: Billings helped contribute ideas about the categories of land use history investigated for the project at UGA, Georgia Tech, and Duke. She designed soil incubations, began 2-D erosion/deposition model development, assisted in research associate, graduate student, and undergraduate students at U. Kansas, conducted multiple consultations with graduate experimental design for laboratory experiments. Billings also is a contributor to three cross-CZO Working Groups (CZ-TOP Organizing Committee for the Cross-CZO Organic Matter Workshop at Purdue to be held in October 2015, and will assist in erosion class at the workshop. Billings is responsible for all aspects of the project sub-contracted to the University of Kansas

Funding Support: Partial month this award

International Collaboration: Yes, Switzerland

International Travel: No

Rafael Bras

Email: rlbras@gatech.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 1

Contribution to the Project: Dr. Bras serves as the co-PI of GT team supervising all team members and coordinating collaboration experience, Dr. Bras worked on the eco-hydrological recovery theme through design of field experiment, model development

Funding Support: This award only.

International Collaboration: No

International Travel: No

Mac Aaron Callahan

Email: mcallahan@fs.fed.us

Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1
Contribution to the Project: Research on soil ecology and macroinvertebrates.
Funding Support: USDA Forest Service, Center for Forest Disturbance Science
International Collaboration: No
International Travel: No

Alexander Cherkinsky
Email: acherkin@uga.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1
Contribution to the Project: The sample collection and analyses for ^{14}C and d^{13}C composition of soil organic matter to es Goldschmidt conference August 16-21, 2015 " ^{14}C Distribution in soils with different history of land use in Calhoun CZO"
Funding Support: This award only.
International Collaboration: No
International Travel: No

James C Giesen
Email: jcg245@msstate.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2
Contribution to the Project: Continuing research on land use history.
Funding Support: This award only.
International Collaboration: No
International Travel: No

Daniel Markewitz
Email: dmarke@uga.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2
Contribution to the Project: Field work, professional mentoring.
Funding Support: This award only.
International Collaboration: No
International Travel: No

Donald R Nelson
Email: dnelson@uga.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2
Contribution to the Project: Responsible for activities in the human-CZO theme and contributes to interdisciplinary model
Funding Support: This award only.

International Collaboration: No

International Travel: No

Katherine P O'Neill

Email: oneill@roanoke.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 3

Contribution to the Project: Education and outreach.

Funding Support: Roanoke College Environmental Studies program, Roanoke College Dean's Office

International Collaboration: No

International Travel: No

Paul A Schroeder

Email: schroe@uga.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 2

Contribution to the Project: Field work, professional mentoring, planning of international symposium. Schroeder has received the recipient of a TUBITAK visiting scholar award. He is in daily contact with the UGA Calhoun CZO team and is using this planning a workshop between Turkish scientists and US CZO scientists. The intent is establishment of the first Turkish CZC

Funding Support: UGA Provost International Travel Fund, TÜBITAK, University of Oslo, Karadeniz Technical University

International Collaboration: Yes, Norway, Turkey

International Travel: Yes, Turkey - 0 years, 11 months, 0 days; Greece - 0 years, 0 months, 4 days; Norway - 0 years, 0 m

Aaron Thompson

Email: aaront@uga.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 1

Contribution to the Project: Field work, laboratory analysis and training, professional training.

Funding Support: This award only.

International Collaboration: No

International Travel: Yes, Czech Republic - 0 years, 0 months, 5 days

Jingfeng Wang

Email: jingfeng.wang@ce.gatech.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 1

Contribution to the Project: Dr. Wang serves as the lead co-PI of GT team responsible for daily operation of research and the test of the Eco-hydrological Recovery Hypothesis (H1) through design of field experiment, model development/simulation

Funding Support: This award only.

International Collaboration: No

International Travel: No

Gregory Hancock**Email:** greg.hancock@newcastle.edu.au**Most Senior Project Role:** Faculty**Nearest Person Month Worked:** 0**Contribution to the Project:** Working on landscape evolution modeling at Calhoun.**Funding Support:** Visiting scholar; funding is from the University of Newcastle (Australia)**International Collaboration:** Yes, Australia**International Travel:** No**Jason C Austin****Email:** austinj1@uga.edu**Most Senior Project Role:** Postdoctoral (scholar, fellow or other postdoctoral position)**Nearest Person Month Worked:** 12**Contribution to the Project:** Field work, X-ray diffraction, stable isotope sample collection and analysis, undergrad student**Funding Support:** This award only.**International Collaboration:** No**International Travel:** Yes, United Kingdom - 0 years, 0 months, 5 days**Allan R Bacon****Email:** allan.bacon@duke.edu**Most Senior Project Role:** Postdoctoral (scholar, fellow or other postdoctoral position)**Nearest Person Month Worked:** 0**Contribution to the Project:** Attended workshop; assisted with manuscript preparation related to dissertation research on p**Funding Support:** None**International Collaboration:** No**International Travel:** No**Satish Bastola****Email:** satish.bastola@ce.gatech.edu**Most Senior Project Role:** Postdoctoral (scholar, fellow or other postdoctoral position)**Nearest Person Month Worked:** 3**Contribution to the Project:** Model development and simulation of the effects of soil erosion and deposition on the carbon**Funding Support:** This award only.**International Collaboration:** No**International Travel:** No**Michael Coughlan****Email:** coughlan@uga.edu**Most Senior Project Role:** Postdoctoral (scholar, fellow or other postdoctoral position)**Nearest Person Month Worked:** 4**Contribution to the Project:** Fieldwork and database development

Funding Support: Nelson overhead account

International Collaboration: No

International Travel: No

Christoph Lehmeier

Email: christoph.lehemeir@gmail.com

Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)

Nearest Person Month Worked: 5

Contribution to the Project: Lehmeier has assisted in field installations of gas wells and soil coring, conducted laboratory i analyzed exo-enzyme activities, designed microbial growth experiments, developed a poster presentation for the Calhoun C2 He also has assisted in the training of the graduate student, three undergraduates, and one REU student.

Funding Support: This award

International Collaboration: No

International Travel: No

Titta Majasalmi

Email: titta.majasalmi@helsinki.fi

Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)

Nearest Person Month Worked: 1

Contribution to the Project: Analysis of LiDAR data, field work.

Funding Support: Department of Forest Sciences, University of Helsinki: Physically-based remote sensing applications for

International Collaboration: Yes, Finland

International Travel: No

Anthony Parolari

Email: anthony.parolari@duke.edu

Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)

Nearest Person Month Worked: 2

Contribution to the Project: Development of all aspects of modeling of ecohydrology, biogeochemistry and social dynam project.

Funding Support: NSF EAR hydrology grant

International Collaboration: No

International Travel: No

Charles W Cook

Email: cwcook@duke.edu

Most Senior Project Role: Technician

Nearest Person Month Worked: 12

Contribution to the Project: Field lab manager in charge of field construction, operations, sample collection, and data man

Funding Support: This project only.

International Collaboration: No

International Travel: No

William Brandon Crouch

Email: bcrouch@uga.edu

Most Senior Project Role: Technician

Nearest Person Month Worked: 1

Contribution to the Project: Assistance with forest plot measurements and leaf litter collection.

Funding Support: This award only

International Collaboration: No

International Travel: No

Paul Heine

Email: pheine@duke.edu

Most Senior Project Role: Technician

Nearest Person Month Worked: 12

Contribution to the Project: Field, laboratory, data, and website contributions.

Funding Support: This award only.

International Collaboration: No

International Travel: No

Lori A Sutter

Email: lsutter@uga.edu

Most Senior Project Role: Staff Scientist (doctoral level)

Nearest Person Month Worked: 1

Contribution to the Project: Dr. Sutter will be responsible for laboratory analysis of water and soil and will assist with field

Funding Support: Dr. Sutter is partly supported by the Warnell School at UGA.

International Collaboration: No

International Travel: No

Diego Barcellos

Email: diego.barcellos@yahoo.com.br

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 3

Contribution to the Project: Field work, laboratory analysis, research focusing on carbon assemblies.

Funding Support: This award only.

International Collaboration: No

International Travel: No

Shelly Biesel

Email: shelly.biesel@gmail.com

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 1

Contribution to the Project: Fieldwork and database development.

Funding Support: UGA Graduate Research Opportunity scholarship

International Collaboration: No

International Travel: No

Ashley Block

Email: ashley.block25@uga.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 1

Contribution to the Project: Fieldwork and database development.

Funding Support: UGA Graduate Research Assistant scholarship

International Collaboration: No

International Travel: No

Zachary S Brecheisen

Email: zachary.brecheisen@duke.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 9

Contribution to the Project: Geospatial analysis, soil and tree coring, plot mapping, and helping construct wireless sensor

Funding Support: This award and IGERT: Training Program in Wireless Intelligent Sensor Networks (WISeNet) at Duke U

International Collaboration: No

International Travel: No

Salvatore Calabrese

Email: salvatore.calabrese@duke.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 1

Contribution to the Project: Development of water age modeling.

Funding Support: CEE Department graduate fellowship of the Pratt School of Engineering.

International Collaboration: No

International Travel: No

Xing Chen

Email: xing.chen@duke.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 8

Contribution to the Project: Working on: (a) Role of full and weak coupling on model accuracy; (b) Using storage-dischar

Funding Support: NSOE TA-ship; Mukesh Kumar's Startup Fund

International Collaboration: No

International Travel: No

Yannis G Dialynas**Email:** ydialynas@gatech.edu**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 6**Contribution to the Project:** Model development and simulation of the effects of soil erosion and deposition on the carbon**Funding Support:** Luquillo CZO (half)**International Collaboration:** No**International Travel:** No**Maryam Foroughi****Email:** mforoughi@uga.edu**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 11**Contribution to the Project:** Field and laboratory research, water chemistry.**Funding Support:** This award only.**International Collaboration:** No**International Travel:** No**Caitlin Hodges****Email:** chodges@uga.edu**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 12**Contribution to the Project:** Field work, laboratory analysis, research focusing on iron redox.**Funding Support:** This award only.**International Collaboration:** No**International Travel:** No**Shih-Yu Huang****Email:** shuang83@gatech.edu**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 12**Contribution to the Project:** Modeling soil temperature and soil moisture dynamics and surface water and energy budget u**Funding Support:** This award only**International Collaboration:** No**International Travel:** No**El Sharif Husayn****Email:** helsharif@gatech.edu**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 0**Contribution to the Project:** Modeling crop yields in response to hydrometeorological forcing (H4).

Funding Support: This award only.

International Collaboration: No

International Travel: No

Christopher Krapu

Email: clk27@duke.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 12

Contribution to the Project: Identification of optimal sensor network locations for prediction quick flow at the watershed c

Funding Support: IGERT: Training Program in Wireless Intelligent Sensor Networks (WISeNet) at Duke University, NSF

International Collaboration: No

International Travel: No

Yanlan Liu

Email: yanlan.liu@duke.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 12

Contribution to the Project: Understanding the controls on wetland groundwater dynamics in the piedmont region of south

Funding Support: This project only.

International Collaboration: No

International Travel: No

Fraser Livingston

Email: fraserlivingston@gmail.com

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 1

Contribution to the Project: Assisted James Giesen (Mississippi State) on finding relevant research materials. He also trav

Funding Support: This award only.

International Collaboration: No

International Travel: No

Michael Lonneman

Email: mlonneman@gmail.com

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 1

Contribution to the Project: Fieldwork and database development

Funding Support: NSF GRFP

International Collaboration: No

International Travel: No

John Mallard

Email: john.mallard@duke.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 10

Contribution to the Project: Ongoing installation of sensor network; field hydrologic measurements; data acquisition and 1

Funding Support: This award and IGERT: Training Program in Wireless Intelligent Sensor Networks (WISeNet) at Duke U

International Collaboration: No

International Travel: No

Kyungjin Min

Email: kjmin21@gmail.com

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 3

Contribution to the Project: Min has conducted laboratory incubations and performed incubation sampling for extracts and varying substrate stoichiometry modifies microbial C flows, developed a poster presentation for the Calhoun CZO workshop assisted in the training of three undergraduates and one REU student.

Funding Support: This award only.

International Collaboration: No

International Travel: No

Nadia Noor

Email: nadianoor63@gmail.com

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 2

Contribution to the Project: Field work, laboratory analysis, research focusing on carbon assemblies.

Funding Support: NSF Suschem project.

International Collaboration: No

International Travel: No

Norman F Pelak

Email: norman.pelak@duke.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 2

Contribution to the Project: Development of all aspects of modeling of ecohydrology, biogeochemistry and social dynam

Funding Support: NDSEG graduate fellowship.

International Collaboration: No

International Travel: No

Sabina Shahnaz

Email: sshahnaz3@gatech.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 1

Contribution to the Project: Retrieving and processing historical hydrometeorological data (stream-flow and rainfall)(H1).

Funding Support: This award only.

International Collaboration: No

International Travel: No

Yawen Shen

Email: yawen8617@gatech.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 6

Contribution to the Project: Retrieving and processing historical hydrometeorological data and modeling gas fluxes (stream-flow and rainfall)(H1).

Funding Support: This award only.

International Collaboration: No

International Travel: No

Yao Tang

Email: tangyao1208@gatech.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 0

Contribution to the Project: Modeling gas fluxes (stream-flow and rainfall) (H1).

Funding Support: None

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: 1

Contribution to the Project: Planning and execution of Calhoun CZO Summer Science Days. Worked in laboratory on sampling and analysis of water samples.

Funding Support: This project

International Collaboration: No

International Travel: No

Keelan Barger

Email: k337b844@ku.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 2

Contribution to the Project: Barger develops protocols for and runs inorganic nutrient analyses of Calhoun CZO samples in the laboratory.

Funding Support: This award only.

International Collaboration: No

International Travel: No

Samantha Elledge**Email:** samanthaelledge@gmail.com**Most Senior Project Role:** Undergraduate Student**Nearest Person Month Worked:** 1**Contribution to the Project:** Elledge contributes to general lab upkeep, performs multiple administrative tasks, and assists**Funding Support:** This award only.**International Collaboration:** No**International Travel:** No**Holly Good****Email:** holly.good@ku.edu**Most Senior Project Role:** Undergraduate Student**Nearest Person Month Worked:** 1**Contribution to the Project:** Good conducted soil incubations testing ideas about substrate stoichiometry influencing C flo**Funding Support:** None**International Collaboration:** No**International Travel:** No**Ruan Mateus Guimares-Dias****Email:** ruanguimaraes06@gmail.com**Most Senior Project Role:** Undergraduate Student**Nearest Person Month Worked:** 3**Contribution to the Project:** Field and laboratory assistance.**Funding Support:** This award only.**International Collaboration:** No**International Travel:** No**Carl Heroneme****Email:** carl.heroneme@gmail.com**Most Senior Project Role:** Undergraduate Student**Nearest Person Month Worked:** 4**Contribution to the Project:** Heroneme serves as a general lab assistant, and has been instrumental in the development of l. microbial biomass C and N, and assists in all aspects of incubations.**Funding Support:** This award only.**International Collaboration:** No**International Travel:** No**Ashley McAvoy****Email:** adkendrick@mail.roanoke.edu**Most Senior Project Role:** Undergraduate Student**Nearest Person Month Worked:** 1

Contribution to the Project: Analysis of leaf litter from vegetation plots
Funding Support: Roanoke College Office of Student Research, Work Study Research Assistantship Program
International Collaboration: No
International Travel: No

Amelia A Perry

Email: amperry@uga.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1
Contribution to the Project: X-ray diffraction sample prep, Stable isotope sample collection.
Funding Support: This award only.
International Collaboration: No
International Travel: No

Alexandra Ramey

Email: ajramey@mail.roanoke.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2
Contribution to the Project: Development of prototype electronic educational module.
Funding Support: Roanoke College Office of Student Research
International Collaboration: No
International Travel: No

Brandon Varner

Email: bvarner@uga.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1
Contribution to the Project: Field and laboratory assistance.
Funding Support: This award only.
International Collaboration: No
International Travel: No

Rebecca Flournoy

Email: rflourno@tulane.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 1
Contribution to the Project: Flournoy conducted the soil incubations performed in summer 2015 and sampled gases and sc
Funding Support: NSF's REU program at KU
International Collaboration: No
International Travel: No
Year of schooling completed: Junior

Home Institution: Tulane University

Government fiscal year(s) was this REU participant supported: 2015

What other organizations have been involved as partners?

Coweeta Hydrologic Lab	Other Organization
Rose Hill Plantation State Historic Site	State or Local Gov
South Carolina State Parks	State or Local Gov
Sumter National Forest, Enoree District	Other Organization
USFS Southern Research Station	Other Organization
WyCEHG: Wyoming Cent Environmental Hydrology & Geophysics	Academic Instituti

Full details of organizations that have been involved as partners:

Coweeta Hydrologic Lab

Organization Type: Other Organizations (foreign or domestic)

Organization Location: Otto, NC

Partner's Contribution to the Project:

In-Kind Support

Facilities

Collaborative Research

More Detail on Partner and Contribution: Training given to PhD student for a summer's work (2015) digitizing historic s to the work.

Rose Hill Plantation State Historic Site

Organization Type: State or Local Government

Organization Location: Union, SC

Partner's Contribution to the Project:

In-Kind Support

Facilities

More Detail on Partner and Contribution: The South Carolina State Park Service issued the CCZO a research permit on t work with the old hardwood forest to the north of the Gist home and in exploring the seriously gullied old fields of the Gist p

South Carolina State Parks

Organization Type: State or Local Government

Organization Location: Columbia, SC

Partner's Contribution to the Project:

Collaborative Research

More Detail on Partner and Contribution: Our project's LiDAR-derived data and our interpretation of geomorphological with the State Park system itself, all to enrich the understanding of the remarkable history of South Carolina.

Sumter National Forest, Enoree District

Organization Type: Other Organizations (foreign or domestic)

Organization Location: Union and Whitmire, SC

Partner's Contribution to the Project:

In-Kind Support

Facilities

More Detail on Partner and Contribution: The USDA Forest Service is responsible for managing research activities on the activities that were contained in 30-page Research Plan. In 2015 we gave a half-day tour to two prominent USFS managers.

USFS Southern Research Station

Organization Type: Other Organizations (foreign or domestic)

Organization Location: Athens, GA

Partner's Contribution to the Project:

In-Kind Support

More Detail on Partner and Contribution: Dr. Mac Callaham participates in our observatory as a soil biologist

WyCEHG: Wyoming Cent Environmental Hydrology & Geophysics

Organization Type: Academic Institution

Organization Location: University of Wyoming

Partner's Contribution to the Project:

In-Kind Support

More Detail on Partner and Contribution: Collaboration on geophysical measurements and modeling. Writing of a 2015

What other collaborators or contacts have been involved?

NCSU Soil Science REU (Josh Heitman)

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Impacts

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

The principle fields of scholarship at the Calhoun CZO are geology and geomorphology, geochemistry and biogeochemistry, hydrology and ecohydrology, ecology and ecosystem science, environmental history and anthropology, and Earth systems science and modeling. This combination of disciplines represented in the work of the 15 PIs, their students, and collaborators, ensures that the Calhoun CZO's research planning, techniques, findings, and interpretations impact all the principle fields of the project.

For example, the full value of high resolution LiDAR-DEM data (from the Calhoun CZO flight in July 2014), the geophysics data sets obtained from WyCEHG instrumentation (April 2014), and the observations of deep CZ metabolism (data streams that began in 2015) will be realized as these data impact the full range of Earth science, ecological disciplines, and environmental history and anthropology.

Our project's education activities strive to use as many of our scientific developments to develop new approaches for teaching Earth and environmental sciences. Formally, the Calhoun Education and Outreach activities are aimed at undergraduate education but have a wider greater audience, including advanced high school students and the general public.

What follows is a sample of how our projects' individual laboratories are impacting principal disciplines. The following are quotes from the labs' annual reviews, with only slight rewordings.

Our modeling advances understanding of geophysical systems in several ways. The development of coupled ecohydrological/biogeochemical models helps clarify space and time scales of propagation of hydroclimatic fluctuations through hydrologic and biogeochemical systems. Our modeling contributes to understanding feedbacks among biologic, chemical, and physical processes in critical-zone ecosystems.

We are working to develop ground-based tools (EMI, resistivity, and NIRS), which via digital soil-landscape mapping, will parameterize ecohydrologic and biogeochemical models with far greater spatial intensity and accuracy.

The theory of water age has extended modeling frameworks to address water-age distributions in a time-varying environment.

The coupling of soil chemical models with stochastic ecohydrological models provides a new framework for predicting effects of hydrologic fluctuations on soil formation, mineral weathering, and drainage water chemistry.

We are expanding our understanding of social, political, and cultural aspects of human forcings of the critical zone, specifically the CZ of the Calhoun.

Educational materials contribute to the development of pedagogical approaches in the Earth, environmental, and ecological sciences. The pedagogy of the CZ is new but has the potential to

contribute to new teaching methods, especially with regard to the interdisciplinary Earth sciences and coupled human-natural systems.

What is the impact on other disciplines?

Because critical zone science is explicitly defined as broadly interdisciplinary, sometimes framed to include not only the natural but social sciences but even environmental humanities, this question seems not applicable.

However, in favor of keeping this question for CZO annual reports are the two following statements from our environmental historian (a historian of 19th century cotton) and one of our environmental engineers: "Environmental history is a relatively new field of history and for all of its growth and impact, it has not yet successfully convinced environmental scientists that a human-historical perspective on their sciences is not only beneficial but necessary."

And from the environmental engineer, "the theory of age and residence time on Earth's surface systems is of great interest not only to hydrology and geophysics but to chemical engineering, population dynamics, and statistical and fluid mechanics."

Clearly, one of the most exciting and potentially fruitful aspects of critical zone science is its capability to span the disciplines, marshalling them to interact in new and important ways.

What is the impact on the development of human resources?

The Calhoun CZO has 15 PIs based at six universities and colleges as well as the USDA Forest Service. These institutions and PIs involve a diverse set of students, and most involve students at all educational levels from undergraduates to postdoctorates.

The Calhoun CZO held its second all-hands meeting in 2015 (its first "Calhoun Summer Science Days"), complete with >30 posters, a special colloquium given via posters that were presented by PIs and students that were based on Calhoun data! We were constructively demanding on our scientists and scholars, on students and PIs alike, for every poster presentation was explicitly followed by questions and discussions, all positively but critically motivated.

Educational and outreach materials created by our Calhoun project are targeted mainly for students at 4-year and 2-year collegiate institutions. Representation of the Earth sciences within these institutions is often low relative to research universities. Providing educational materials and opportunities in the Earth sciences to these collegiate communities will enhance development of human resources in Earth science fields.

What is the impact on physical resources that form infrastructure?

The Calhoun CZO leverages nearly 75 years of research (1947 to present) of land, vegetation, and water in a landscape seriously degraded by 150 years of agricultural land use (1800 to 1950). The USDA Forest Service initiated the Calhoun research program in 1947, but in 1962 dismantled the

scientific infrastructure of the Calhoun Experimental Forest, despite 15 years of productive research led by US Forest Service soil, ecology, and hydrology scientists.

PIs Richter and Markewitz have worked continuously at the Calhoun since 1989 and in that time have marshalled nearly continuous and significant financial support from the National Science Foundation (Biological and Geosciences Directorates), several USDA research programs, and the Andrew Mellon, Wallace, and Trent Foundations. With the support of many colleagues, they are re- and up-instrumenting a number of hydrologic and biogeochemical investigations across the Calhoun CZO. Not only are we re-instrumenting four experimental catchments, but an inverted flux tower is being constructed in 2015, with above and deep belowground data streams aimed to quantify the legacies of land-use effects on critical zone hydrology, geomorphology, biology, and biogeochemistry.

What is the impact on institutional resources that form infrastructure?

The Calhoun CZO unites and mutually strengthens a diversity of institutions, including at least two professional societies' Working Groups. The institutions include an undergraduate college (Roanoke), land grant universities (Mississippi State and University of Georgia), an EPSCoR university (Kansas), large public research universities (Kansas, UGA, Georgia Tech, and Mississippi State), and a private research university (Duke).

Within each institution, PIs and students are based in a variety of departments (e.g., History, Geology, Engineering, Environmental Sciences, Anthropology, Biology, and Earth Sciences). We manage this diversity of departments in an attempt to contribute to the project at large. For example, in the fall of 2013, PI Aaron Thompson organized a set of web-based CZ science seminars among the PIs and their students. We intend to return to this practice in coming years.

At Roanoke College, a 4-year liberal arts college, the interdisciplinary Environmental Studies curriculum has been redesigned with the Critical Zone as one of the organizing themes. All three of the introductory courses in the Environmental Studies curriculum (Environmental Science, Environment and Society, and Environment and Culture) will address different perspectives of the Earth's critical zone. Moreover, in addition to a new upper-level course is being offered entitled, "Critical Zone Science and Management". These programmatic changes will be documented and disseminated in journal articles and presentations to provide a model for other institutions.

What is the impact on information resources that form infrastructure?

In addition to email and the telephone, two websites are used for project management and communication, CZEN.ORG and CRITICALZONE.ORG. While the CZEN.ORG site has been a repository for proposals, data sets, figures, miscellaneous documents, and communications among Calhoun PIs, we are gradually moving towards a Google based system of Google Maps, Calendar, Docs, and Sheets to share writing, maps, sampling locations, and general communications. Calhoun staff (Will Cook, Paul Heine) continue to build the Calhoun website on CRITICALZONE.ORG. Data

continue to be uploaded and we have scheduled several meetings with the CZO Data Managers later in the fall of 2015.

What is the impact on technology transfer?

Technology transfer is research and education based.

The visit of WyCEHG during Calhoun Geophysics Week was not negatively competitive with our own geophysics investigations, rather it was greatly stimulating. Our team with geophysics interests and equipment (Markewitz, Schroeder), now have additional colleagues at WyCEHG who have gotten to know our CZ conditions but WyCEHG staff have been helpful in sharing their technical knowledge and experience. During the 2014 geophysics visit by WyCEHG, we invited soil surveyors from the National Resource Conservation Service to our site. NRCS personell were extremely interested in the instrumentation deployed and the data.

Educational materials have been disseminated to undergraduate educators and students and field tested with new critical-zone courses and curriculum offered at Roanoke College as part of the college's Environmental Program. The project has developed outreach materials to help K12 educators link critical zone concepts to national and state standards in order to facilitate transfer critical zone science to the K12 and undergraduate classroom.

What is the impact on society beyond science and technology?

Amilcare Pororato, the CCZO's Co-Lead PI, perhaps answers this question best.

"Simple models of social-CZ dynamics have the potential to capture the imagination and interest of the scientific and general public, providing simple and tantalizing explanations for long-term land-management practices. At the Calhoun CZO, we link social-land practices to a remarkable history of soil and land degradation of historical importance. Such cross-disciplinary approaches are important to educating citizens about a more respectful use of water and soil resources and to encourage younger generations to appreciate the usefulness of quantitative tools that address environmental problems."

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Changes/Problems

Changes in approach and reason for change

Developing the Calhoun CZO on the USDA Forest Service's Sumter National Forest has required a considerable effort on the part of the Lead PI and selected PIs and students to interact with managers and NEPA coordinators and to comply with environmental assessment requirements. While in the fall of 2014 we received a Research Permit for most of our proposed research, based on a decision of "nominal environmental impact", in 2015 we have continued to

work with the USFS on approaches to permit amendment as the CZO continues to grow and develop.

One example of the latter point is that we have redesigned the flux tower components in our research plan to better comply with USDA Forest Service concerns and are confident that we can get this approved in the last months of 2015. We have turned this to our research advantage and in the last half of 2015 are purchasing equipment at Georgia Tech and Duke Universities to assemble and construct inverted flux towers that are to be deployed in small statured vegetation (<10-m aboveground, >10-m belowground).

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

Described above.

Changes that have a significant impact on expenditures

We anticipate the nearly all of the Equipment budget lines in the budgets of Kansas, UGA, and Georgia Tech to be spent by the end of Year Two. We anticipate being within budget over the first three years.

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.

Supplement i. Lists of CZO participants, including postdoctoral fellows, and undergraduate and graduate students, and summary of any changes to prior approved personnel. Information will include demographic data and disciplinary background.

Participant category	Number	Gender		Disciplinary background
		male	female	
Total participants	60	37	23	
Main personnel	21	17	4	Accelerator mass spectrometry (1), Anthropology (1), Biogeochemistry (3), Biology (1), Pedology (2), Ecophysiology (1), Environmental education (1), Environmental fluid mechanics (1), Environmental history (1), Forest ecosystem ecology (3), Geology (1), Geomorphology (1), Geomorphology modeling (1), Hydrologic modeling (1), Hydrology (1), Soil ecology (1), Systems science modeling (1)
Postdoctoral	7	6	1	Anthropology (1), Biogeochemistry (1), Geoinformatics (1), Geology (1), Geomorphology modeling (1), Plant and microbial ecophysiology (1), Systems science modeling (1)
Graduate students	22	12	10	Anthropology (3), Biogeochemistry (5), Ecosystem Ecology (1), Environmental fluid mechanics (5), Environmental history (1), Geomorphology modeling (1) Hydrologic modeling (3), Hydrology (1), Pedology (1) Systems science modeling (2)
Undergraduate students	10	3	7	Biology (1), Chemistry (3), Environmental Education (2), Environmental Science (1), Forest ecosystem ecology (2), Geology (1)
External participants	11	10	1	Anthropology (1), Archaeology (1), Ecosystem Ecology (1), Geoarchaeology (1), Geocology (1), Geomorphology (1), Geophysics (2), Hydrology (2), Soil physics (1)

See further details with lists of names and organizations in Research.gov Annual Report, Participants/Organization.

Supplement ii. Summary of status and results of research projects supported by the CZO and undertaken by participants, including web links to abstracts, theses, publications, and reports and products.

Research Products, Two years	Number
Total	167
Journals	39

Conference papers and presentations	116
Doctoral dissertations	1
Book chapters	4
Books	1
Web portals for data storage and dissemination	1
Websites for outreach and education	1
Educational aids or Curricula	1
Other Products	1
Other Publications	1
Technologies or Techniques	1

See further details and list of authors, titles, etc. in Research.gov Annual Report, Products.

Supplement iii. Summary of status and results of education and outreach activities supported by the CZO, including student training and post-doc mentoring, meetings and lectures, abstracts and other publications.

The Calhoun CZO project strives to link research activities with training and education, both in the field and laboratory.

Six examples of the opportunities for training and professional development at the CCZO include:

- 1) The many presentations given by PIs and students throughout the year (see Products)
- 2) The three Calhoun CZO PhD students who earned admission and a high-level of financial support from the two-year Duke WISEnet IGERT Training Program in intelligent sensor networks
- 3) One PhD student participated in a 10-week research exchange at University of Freiburg (Germany) with Prof. Dr. Markus Weiler. Training in high-resolution, spatially-distributed hydrologic sensing at the CAOS (Catchments as Organized Systems) site in Luxemburg.
- 4) One PhD student worked at Coweeta Hydrological Laboratory with the professional hydrologists being trained to use Coweeta's manual method of digitizing rainfall and streamflow strip charts. The student has already worked with a more computer-based program used by the US Geological Survey. He also worked one day per week with the Coweeta weir-maintenance crew.
- 5) A small team of students from several of our universities worked together in the data archive room at Coweeta Hydrological Lab in western NC to scan and catalogue historical data, photographs, and files from the historic Calhoun Experimental Forest (1947-62). A preparatory day was organized at UGA prior to the drive to Coweeta.
- 6) Undergraduate students at Roanoke, Duke, UGA, and Kansas are mentored and trained to participate in a wide range of research activities. Some will present results in public forums. Undergraduate training and development is particularly a focus of projects at Roanoke College,

where skills developed include GIS, plant identification, soil analysis, erosion modeling, and historical archiving.

Supplement iv. Summary of status and results of cross-CZO activities supported by the CZO, including working-group activities, data efforts, field and laboratory measurements, meetings and workshops, student training and post-doc mentoring, outreach, abstracts and other publications.

Of the Cross CZO working groups, CCZO individuals are involved with several with a number of us taking leadership roles in working group meetings and other activities.

Cross CZO Activities	CCZO participation (interest)
CZ modeling	(Porporato, Kumar)
Concentration-discharge relations	(McGlynn, Markewitz)
2015 Salon on CZ Architecture**	Bacon, Richter
Organic matter**	Billings, Thompson
Redox reactions	Thompson, Richter
CZtope	(Austin, Cherkinsky, Richter)
CZ Education & Outreach	(O'Neill)
Geophysics*	Richter, Markewitz, Schroeder, Kumar, McGlynn

*Peer-review manuscript in press

**Peer-review manuscript in process

Supplement v. Summary of status and results of activities supported by the CZO and initiated by the CZO-NO; including brief descriptions of activities hosted by the CZO.

National CZO and CZO-NO initiated activities	Description of activities hosted by CCZO
PI Richter is 2015 Chair of the CZO Lead PI committee and as such is in close communication with the NO. He also serves on the CZO Program's National Executive Committee.	Hosted over 10 groups of university students, professional societies, and visiting groups of all kinds for day-long and half-day educational, research, or outreach tours of the Calhoun CZO (see Research.gov Major Activities A.4 for details)
NSF PI Meeting at IML (April 2015)	
Outreach to NSF's LTER community (PI Richter gave 3 talks in 3 days and led a working group discussion on increasing geoscientists at LTERs and biologists at CZOs (Aug 2015)	Hosted NCSU's Soil Science REU program
Outreach to China CZO workshop (Oct	Hosted specialist tours for experts who are archeologists, geomorphologists, soil erosion experts, etc.

2015). We are promoting a sister site concept for China-USA CZOs, specifically between the Red Soil Experiment Station LTER/CZO and CCZO

Several (not all) Science Across Virtual Institutes (SAVI) workshops & other activities

Supplement vi. Tabulation of defined performance metrics for the period and comparison with proposed goals.

We use the UC performance measurement system in our CCZO. Our performance objectives and goals are to make progress toward fulfilling our four research objectives and one education and outreach objective. Our criteria and measures are keyed to second-year performance.

Performance objective	Criteria for accomplishment	Measures of accomplishment
Hydrologic & biogeochemical recovery	Re- & up-instrument experimental catchments; train students Continue expanding research sites and sampling soil & geochemical observations; select & train students	Four of five catchments instrumented; trained students Seven main CCZO research areas selected; >500 soil samples taken, at 15 sites to 5-m depth; selected & trained students. Combined digitized and measured rain and streamflow data from 1952-53 and 2014-15.
Erosion-induced carbon dynamics	Run distributed soil-erosion models; sample soil in uplands & floodplains of experimental catchments; select & train students	Soil-erosion-carbon models developed & presented at AGU; soils sampled & described, including legacy sediments on floodplains; organized four field trips (one with nearly 20 persons) to legacy sediment sites with alluvial sedimentology experts; selected & trained students
Human-critical zone interactions	Gather relevant environmental history & anthropology data; select & train students	Scanned, georectified, & made available aerial photos from 1933 of CCZO area; assembled historic data and deed chains from CCZO main research areas; selected & trained students

Persistence of alternate states	Develop first-order models; select & train students	Presented model results at AGU; selected & trained students
Education & outreach	Develop educational modules, outreach to local to national publics	Beta-testing several formats for modules; developed template for soil model; developed semester-long undergrad class in CZ science & management

Supplement vii. Lists of all publications and products from activities within the past year, including categories for published, accepted, and submitted.

	Sum	Published	Accepted	Submitted	Other*
Products	126	52	5	12	57
Journals	35	22	1	12	0
Conference papers & presentations	83	28	1	0	54
Doctoral dissertations	0	0	0	0	0
Book chapters	3	2	1	0	0
Books	1	0	1	0	0
Web portals for data storage and dissemination	0	0	0	0	0
Websites for outreach & education	0	0	0	0	0
Educational aids or Curricula	1	0	1	0	0
Other Products	1	0	0	0	1
Other Publications	1	0	0	0	1
Technologies or Techniques	1	0	0	0	1

*Oral/poster presentations and other products without published abstracts.

See further details in Products section of Research.gov Annual Report.

Supplement viii. An assessment of progress towards meeting the goals for engaging the broader community that are established in the CZOMP.

Engaging the broader community is a high priority to the CCZO. Some communities are included in the following table. Additional community outreach is found in the Annual Report under Accomplishments.

Community	Activity
National & university scientists (includes outreach to ecologists, Earth scientists, LTER, mineralogy communities)	Presentations to scientific societies and university groups throughout the year

International scientists & science policy professionals	As 2015 Chair of CZO Lead PIs, Richter was invited to give keynotes to the international EuroClay2015 meeting in Edinburgh and the Guiyang in China in Oct 2015, where we will attempt to encourage China's NSF to launch their CZO program. PI Schroeder gave a number of lectures on the critical zone science to various universities and audiences in Turkey during his sabbatical.
USDA Forest Service managers	Circulation of a 30-page research plan among forest service managers
Undergraduate & advanced high school educators	Developed and field-tested first web-based CZ educational materials
International scientists & science policy	Outreach as 2015 Chair of Lead PIs to >500 scientists at LTER All Scientists Meeting, with trips to China in Oct 2015 and to EuroClays2015 in July
Anthropocene Work Group of the International Commission on Stratigraphy	PI Richter was asked to join work group as a representative from the soil and critical zone sciences
Environmental humanities	a) Multi-day visit including 2 days at the Calhoun with Prof. Bruno Latour interviewing CZ scientists and one day at Duke discussing CZ science in the Anthropocene. b) Richter's Duke humanities colleagues are using the concept of Earth's critical zone as they initiate a new Environmental Humanities program at Duke. c) University of South Carolina's Environmental History program hosted a multi-day meeting, <i>After Nature</i> , at which PI Richter spoke on Earth's critical zone.
South Carolina State Parks	On the Rose Hill State Park which is within the Calhoun CZO, we are planning a day-long field tour with local and high-level state park officials to develop the environmental interpretation of Rose Hill to include land use history and Earth's critical zone
Union County Historical Society	PI Richter joined as member and has used the Society's collections and interacted with several of the Society's officers

Supplement ix. Summarized results of evaluation forms submitted by participants of supported activities.

Lead-PI failed to circulate evaluation forms following key meetings.

Supplement x. Information on any additional funding that impacts and/or overlaps the activities of the CZO, making clear the distinction between on-going research activities that are funded by other NSF awards, other agencies and/or organizations and the work done under the CZO award.

We developed and submitted several research proposals during the year. One to the Duke-based NSF-IGERT in wireless sensing technologies funds three of our Duke PhD students. This program that has heavy course-work training, group-based projects, and full-financial support for two years. Another that was successful (at \$10,000) is funded by Duke research administration to increase opportunities and defray costs in writing large-grant proposals, which we are writing to NSF for a Calhoun CZO Drilling Program, combining geophysics, geochemistry, geomorphology, and geobiology.

Supplement xi. Unanticipated collaborations, research projects, and other endeavors enabled or stimulated by the CZO or CZO-NO.

We continue to expand the number of individuals who are interacting with us at the CCZO, individuals with whom we have had no previous relationship prior to funding in December 2013. These interactions have greatly enriched the internal and external operation of the Observatory. All of these unexpected colleagues are expected to continue to interact with our project in years ahead.

Unexpected collaborators	Description
Paul Sutter	Sutter is an environmental historian of the agricultural history of the American South, now a Professor at the University of Colorado. We invited Sutter as a featured guest at our first all-hands field meeting of the CCZO in June 2014, and we have engaged him in several ways since then. Sutter is the author of a forthcoming book, <i>Let Us Now Praise Famous Gullies</i> , which is about land use history of the South, and which deals explicitly with the Calhoun Experimental Forest and the Sumter National Forest. We nominated Sutter to be a honorary speaker at Duke University in November 2015.
Alan James	James is a professor of alluvial geomorphology at the University of South Carolina, and is fascinated by our CZO. James has visited the CCZO four times in the last 18 months, once for a project introduction, the second as an all-day work trip, third to help lead a exploration with about 20 students and

scientists of the legacy sediments along Holcombe's Branch, and in late August an initial sampling trip of 11 profiles which we expect will be a publishable paper. James recently won the AAG's Gilbert Award for his 2015 paper on legacy sediments.

Mike Harmon Harmon is a long-time archeologist on the Sumter National Forest and has not only taken a special interest in our CZO, but has visited us in the field on at least four occasions, communicated regularly by email, and volunteered a spectacular set of 100s of high resolution, black and white aerial photos taken in 1933 prior to the purchasing of the farms that became the Sumter National Forest. We scanned and georectified the photos; these are proving invaluable to reconstructing the land use history of the CCZO. Harmon is helping us expand the historical window of the CCZO back to Mississippian and Woodland periods, prior to settlement by Europeans and Africans.

Terry Ferguson Ferguson is a professor at nearby Wofford College and was recruited to the 2015 CZO Advisory committee. He is expert in native American cultures on the Piedmont and sees the Calhoun CZO as an excellent destination for his college's students. We are planning the first Wofford tour.

Josh Heitman Heitman is a professor of soil physics at North Carolina State University and lead PI of the REU at NCSU in soil science of which the Calhoun CZO is a part. He has organized an overnight trip to the Calhoun CZO for the REUs and has helped us consider soil moisture instrumentation. He also serves on our 2015 Advisory committee.

Bruno Latour Latour is a highly influential philosopher of science and technology and recently has taken a keen interest in Earth's critical zones. He gave a talk at the 2014 Geochemistry meetings in Paris, and is author of a paper that we believe to be a special achievement. We have developed a close relationship with Latour and have helped him schedule visits to the Eel River and Southern Sierra CZOs in the summer of 2015. Latour is scheduled to visit the CCZO in September 2015, on a multi-day field tour in which he will observe and question scientists and get an overview of the project. We expect that his entry into CZ science is a major development. He will spend one day on the Duke campus interviewing labs who study the critical zone. We will also organize several public discussions, all under the title of "The Critical Zone Education of Bruno Latour."

Hermann Jungkunst Jungkunst is a professor of physical geography at the University of Koblenz-Landau. He has experience with greenhouse gas chemistry and fluxes from the soil and is advising us on lab and field methods. He also has expertise in thermal analysis of soil organic carbon combustion. He is an active participant in Future Earth, a Working Group charged with understanding and promoting positive interactions of human management and the Earth system.

Supplement xii. Other impacts of the CZO activities, including local community engagement, and policy.

See Education & Outreach section of this report and the itemized summary in Supplement iii.

Continuing from 2014, during which PI Richter worked with writer Michael Tennesen to propose and write a 4-page science news piece on land degradation for *Science* magazine (complete with photos of the Calhoun CZO), we have explicitly reached out to various communities that have yet to hear about critical zone science. PI Richter, for example, gave critical zone science talks to many organizations as detailed in several places in this report.

Our education and outreach program led by co-investigator O'Neill at Roanoke College has continued to engage K-12 educators and especially undergraduate audiences linking CZ concepts and science in Earth science and environmental education.

Supplement xiii. Data management.

The CCZO data manager, Will Cook, has attended a data management meeting in Stroud PA for data managers in 2014 and participated in the CZO data management cyber-seminars. Cook has had contact with data managers of other CZOs and aims specifically to have more communication with data managers of more mature CZOs to gain better grasp of priorities for early-project data management. While data management of the CZO program appears to have temporarily slowed, Cook has prioritized work in the field and lab as we have pushing hard to move the CCZO through its early phase of field instrumentation and construction. We are scheduled with the CZO Data Management Team for a series of one-on-one consultation meetings later in the fall of 2015.

We have based the CCZO communications system on Google calendar, docs, sheets, and maps, facilitating communication among investigators and students based at six universities. These are also useful for data sharing with other CZOs, collaborators, and the public.

Cook has uploaded several historic Calhoun CZO data sets to the Calhoun CriticalZone.org website. Our goal is that by the end of the second year we will have much more historic data entered and also contemporary data streams from all sub-components of our project.

Our goal is a web server that can efficiently host a variety of data types: from geo-referenced historical aerial photography (back to 1933), to LiDAR derived data sets (from the July 2014 flight), to live streams of hydrological and soil water and gas data. We are approaching Verizon and ATT to upgrade local cell towers to support live data streams from the CCZO to the internet. Currently much of the CCZO is without viable cell service.

Cook and PI Richter are drafting a short guide to data management as a supplement to the current data management plan, specifically for all the CCZO investigators, listing priorities,

procedures, and formats for data storage. Cook will schedule personal meetings with each CCZO investigators to discuss specific data-management needs for each research subproject.

Supplement xiv. Comparison of expenditures versus budget by program area/activity (with explanation of cost overruns), and indication of leveraging from other sources.

The CCZO has no budgetary overruns in year two across its five programic activities of Recovery, Erosion-Carbon, Human-CZ, Alternative States, and Education and Outreach.

As discussed in the first annual report, the CCZO budget was frontloaded with most equipment expenditures budgeted to year one. This proved not possible due to the USDA Forest Service requirements for an environmental-impacts evaluation. Our 30-page research plan written specifically for the Forest Service produced a decision of categorical exclusion for most of our proposed research and a procedure for amendments.

By the end of year two, equipment purchases will be largely if not entirely complete at Kansas and UGA, and will be continuing at Duke and Georgia Tech into the final quarter. Overall, thanks to USFS managerial discretion, the formal environmental-evaluation process has not adversely impacted the progress of the Calhoun CZO. In fact, the environmental evaluation has created a much closer interaction of research and management on the Calhoun and the Sumter National Forests and we plan field days focused on management and restoration of degraded-gullied lands between researchers and managers in the future. Several CZO researchers are closely familiar with National Forest management plans and restoration projects, and we have recently co-authored a peer-reviewed book chapter about the Calhoun forest and CZO with several USFS managers (Richter et al. 2014).

Supplement xv. A plan for remedial action where project milestones in the CZOMP have been significantly impacted.

Our planned research has been reorganized in terms of timing in response to the USDA Forest Service environmental impacts permitting, and our weir redesign.

The USDA Forest Service permitting process continues to be deliberate, slow, and demanding in its approval of our research plans. While we planned to move into a “CZO construction phase” in year one, we were delayed by USDA Forest Service review procedures to begin this activity in years two and three. While we received a “nominal impacts” decision from the USFS covering most of our proposed research in the fall of 2014, 2015 is when we are actively instrumenting sites and installing monitoring wells, gas reservoirs, and a variety of environmental sensors.

The extra level of evaluation required for our flux tower has caused us to redesign flux monitoring in a most exciting fashion. At what we call the Tower Site, the USFS has approved belowground sensor and sampler placement; we have been installing these throughout 2015. We will thereby gather one to two years of belowground moisture, gas, solution, and solid samples prior to USFS approval for a clear cut and well drilling, when we will clearcut half of the

monitored plots and immediately construct a relatively short flux tower that monitors energy, carbon, and water fluxes. We will also be free to hire well drillers to sample saprolite and unweathered granite very deeply (>50-m).

Additionally, we have shifted priorities on weir re-instrumentation. Work on weir maintenance and refurbishment and the associated removal of historically accumulated sediments in year one revealed that the original estimates for weir repair and reconstruction were somewhat low. While Weirs 1, 3, and 4 have had sediment excavated, cement repaired, new V-notch blades installed, and automatic level sensors installed, the fourth historic weir (Weir 2) has proven more technically challenging to repair. We have received verbal approval from the USFS to use heavy machinery as part of the upgrade and reinstrumentation of Weir 2.

Supplement xvi. Problems likely to delay accomplishment of annual, strategic goals.

No problems will likely delay accomplishment of annual strategic goals.

Supplement xvii. Description of programmatic goals and objectives with specific activities/timetable to be accomplished in the upcoming year.

Hypotheses	Objectives Year Three
Ecohydrologic & biogeochemistry recovery	<ul style="list-style-type: none"> • Complete statistical analysis of digitized historic stripchart data of precipitation & streamflow for all four experimental watersheds • Continue data gathering of rainfall, soil water and gases, groundwater, and extend and upgrade networks of samplers at experimental watersheds and inverted tower sites • Continue hydrologic installation and data gathering on streams, soils, and groundwater on Holcombe's Branch (with its three experimental watersheds), Watershed #1, and on reference hardwood catchments as well • Reinstrument weir on watershed #2 • Continue repeated electrical resistivity and EMI measurements in concert with the above instrumentation on hillslopes, whole catchments, and floodplains • Continue forest tree sampling and remote sensing analyses • Continue soil, saprolite, and alluvial floodplain sampling across Holcolombe's Branch; in reference hardwood, pine forest, and continuously cultivated sites; and on flux-tower sites: all to quantify changes in vegetation and soil's hydrologic attributes, biogeochemistry, microbial dynamics, and mineralogy • Continue model development to explore dynamics of land-use degradation on hydrology and biogeochemistry • Complete scanning of historic Calhoun Experimental Forest records and color-photographic slides that document research activities and data gathered from 1947-1962, all archived at Coweeta Hydrologic

Erosion-induced carbon dynamics	<p>Laboratory</p> <ul style="list-style-type: none"> • Continue forest-tree sampling and remote sensing analysis to hindcast the regrowth of the forest during 20th century • Continue soil, saprolite, and floodplain sampling combined with gully evaluations across Holcolombe's Branch; and in reference hardwood, old-field forest, and continuously cultivated sites, all to quantify erosional losses of soil from uplands and hillslopes and sediment deposition on terraces and floodplains of the Holcombe's Branch watershed • Geomorphology, soils, and hillslopes will continue to be conducted in about ten paired reference hardwood and old-field forests across the Calhoun CZO • Continue to develop a variety of modeling approaches to the temporal and spatial dynamics of soil loss and sediment deposition, and specifically the impacts on soil organic carbon • Develop new ideas and hypotheses concerning legacy sediments of floodplains being novel C-Fe redox cycling hotspots • Continue to assemble and geographically coordinate a wide variety of historic and contemporary social, land-use, and land-cover data, ranging from regional aerial photography and remote sensing data, to deed chains, census data, and individual farm records, all to evaluate and model how land-use practices transform the land, and alter its management and human livelihoods
Human-critical zone interaction	<ul style="list-style-type: none"> • Continue to assemble and geographically coordinate a wide variety of historic and contemporary social, land-use, and land-cover data, which includes regional aerial photography and remote sensing data, to deed chains, census data, and individual farm records, all to evaluate and model how land-use practices transform the land, and alter its management and human livelihoods • Continue to use these social-land use data developing a variety of social-ecological models
Persistence of alternative states	<ul style="list-style-type: none"> • Continue to develop state transition models that evaluate how CZs respond to severe disturbance, disturbance that threatens both resilience and recovery of the CZ system
Education & Outreach	<ul style="list-style-type: none"> • Continue to develop a series of web-based, interactive education modules • Disseminate prototype education module within the Calhoun CZO community and selected others for feedback • Finalize iBook (or comparable interactive media platform) and circulate for review • Document and evaluate pedagogical materials in professional presentations and manuscripts to be submitted for peer-review pedagogical journals
