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Project Title:	Boulder Creek CZO II: Evolution, Form, Function, and Future of the Critical Zone
PD/PI Name:	Suzanne P Anderson, Principal Investigator Robert S Anderson, Co-Principal Investigator Noah P Molotch, Co-Principal Investigator Harihar Rajaram, Co-Principal Investigator Gregory E Tucker, Co-Principal Investigator
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Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Suzanne P Anderson

Accomplishments

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

Boulder Creek CZO (BcCZO) was established in 2007 as a natural laboratory to study how erosion and weathering together shape the architecture of the critical zone. The aim of BcCZO is to develop a deeper understanding of the structure, functioning, and evolution of the critical zone in a mountainous landscape. The Colorado Front Range serves as a natural laboratory, in which variations in rock type, erosion history, climate, and ecosystems have produced recognizable differences in topography and critical zone architecture. We focus on addressing deep chemical and geobiological weathering processes that alter unweathered rock, on monitoring water and weathering fluxes, and on modeling the evolution and behavior of these

landscapes. Boulder Creek exemplifies landscapes in the American West inhabited by large populations and facing changing snow regimes, fires and beetle infestations.

Our goals are to: 1) Document critical zone **evolution** in the Colorado Front Range, where climate has been the chief driver since the end of the Laramide orogeny about 40 Myr ago. This entails determining rates of incision and exhumation of the range and its adjacent basin, as well as describing the structure of the critical zone throughout the range. 2) Understand how individual processes shape the critical zone (**process to form**). Weathering processes and sediment transport processes together shape hillslopes and move weathering fronts into rock. 3) Discover how critical zone architecture influences the storage and flow of water (**form to function**). The critical zone serves as a filter for water quantity and quality delivered to streams. 4) Explore critical zone functional response to **future** perturbations. As temperatures increase (especially summer), and the elevation of the rain-snow transition rises, and as fires or insect infestations change in frequency or intensity, we will require process models to explore the landscape's hydrologic, geomorphic, and biogeochemical response. Anticipated outcomes include models of processes at short timescales, and an integrated model of critical zone evolution, function and response to future climate to 2050. The team brings together expertise in geomorphology, hydrology, geobiology, ecology, and geophysics.

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

Major Activities: Over the last year, we accomplished the following:

1. Maintained year-round monitoring in three watersheds
2. Maintained wireless networking of field instrumentation in Gordon Gulch, and transitioned most field installations to solar power (from battery).
3. Established two new NADP collection sites, one in Boulder and one at Betasso.
4. Maintained and augmented an integrated database, which includes 60 datasets, 27 of which are updated monthly, and 1 (Betasso meteorology) streams in real-time.
5. Published 21 journal papers (two in Nature Microbiology, one in Nature Communications) and our data management plan. An additional 4 papers are in press and 11 in review.
6. Hosted a visit by a delegation of 8 scientists from the Chinese Geologic Survey and the China University of Geosciences, September 8, 2016.
7. Graduated 3 PhD students (Taylor Joseph Mills, Dominik Schneider, Eric William Winchell); 2 undergraduates completed senior theses (Garret Hammack and Dillon Ragar)
8. Held team meetings during the academic year, plus an annual science meeting in September.
9. Offered graduate classes: Surface Processes graduate seminar (taught by Bob Anderson)
10. Ran extensive K-12, Community College, and teacher professional development outreach programs.

1. 11. Will serve as local host for CZO Data Manager workshop, July 31-Aug 2, 2017.
2. 12. Melissa Foster (2016 PhD) led the Kirk Bryan Field Trip, titled "Quaternary landslides, fluvial terraces, and recent geomorphic events along the Colorado Front Range", during the Geological Society of America Annual Meeting in September 2016. There were ~60 participants. **Field guide published** (Foster et al., 2016).
3. 13. PI Anderson convened two CZ sessions at the 2016 AGU Fall Meeting, including an invited speaker-only Union session that was streamed on-line and remains available for viewing in "AGU On Demand".
4. 14. PI Anderson is a guest editor for a special issue of *Hydrological Processes* (with Ying Fan Reinfelder, Rutgers University, and Gerard Govers, KU Leuvan) titled "Passive-Aggressive: Water in the Critical Zone", with planned completion date of February 2018.

15. Goal 1, *Critical zone evolution*: Work on CZ evolution has focused on adding timing constraints through CRN dates on stream sediments and terrace gravels, and on hillslope processes, including sediment movement and evolution of rock slopes with variable rock hardness. Team members: RS Anderson, K Singha, GE Tucker, SP Anderson; grad students Melissa Foster, Abby Langston, Rachel Glade and Brittany

Selander. **Two papers** (Foster et al., in press; Glade et al., 2016) and **one field guide** (Foster et al., 2016) published. One **paper in review** (Langston and Tucker).

16. Goal 2, *Understand how individual processes shape the critical zone* (process to form): Process work has focused on biogeomorphology, microbiology, interactions between slope and channel processes, modeling hillslopes, and work on understanding the conditions—both in state of rock weathering and hydrologic controls—that produce slope instability. Team members: RS Anderson, SP Anderson, DF Doak, BA Ebel, N Fierer, GE Tucker; post-docs Paul Carini, Dave Barnard, Jill Marshall; grad students Tess Brewer, Charlie Shobe, Eric Winchell; undergrads Dillon Ragar, Garret Hammack. **Four papers published** (Brewer et al., 2016; Carini et al., 2016; Pandey and Rajaram, 2016; Rajaram and Arshadi, 2016), **five papers in review** (DM Barnard et al.; Brantley et al.; Brewer et al.; Litaor et al.; Wieting et al.), and **one dissertation** completed (Winchell, 2017).

17. Goal 3, *Discover how critical zone architecture influences the storage and flow of water* (form to function): Work on water includes continued foci on snow and ecohydrology, as well as biogeochemistry, stream chemistry, including dissolved organic matter, wildfire effects on hydrochemistry, and colloidal transport of matter. Team members: SP Anderson, HR Barnard, M Gooseff, ES Hinckley, D McKnight, NP Molotch, SF Murphy, H Rajaram, K Singha; post-doc Dave Barnard; grad students Hallie Adams, Maggie Burns, Joe Mills, Theo Barnhart, Sachin Pandey; undergrad Kristina Cowell, REU students Joey Gamora, Kevin Thirouin, Amanda Espinoza-Martinez, Jesse Barber, Randall Rouse, and Brett Lindgren. **Nine papers published** (Aguirre et al., 2017; DM Barnard et al., 2017; Barnhart et al. 2016; Burns et al. 2016; Hinckley et al., 2017; Miller et al. 2016; Mills et al. 2017; Rue et al., in press; Swetnam et al., 2017), and **two in review** (HR Barnard et al.; Zhang et al.). **Two dissertations** completed (Mills, 2016; Schneider, 2016).

Specific Objectives: Objectives listed in 2016 Annual Report:

1) Maintain monitoring in existing catchments, coordinate with Niwot Ridge LTER.

1.1 Weekly water sample collection and snow depth measurements maintained.

1.2 Instrumentation & networking of data-loggers maintained.

1.3 Added two new National Atmospheric Deposition Program (NADP) collection sites in Spring 2017, in cooperation with Scott Wetherbee, USGS. BcCZO is handling weekly sample collection.

1.4 Re-instrumented the historic B-1 site (part of a 1950 climate station array built by John Marr), in collaborative effort with Niwot LTER. BcCZO supplied a tipping bucket rain gage, while Niwot LTER provided relative humidity and air temperature sensors.

1.5 Supplied personnel for annual Green Lakes Valley snow survey.

2) Support cross-CZO postdoc on Hydrologic partitioning.

2.1 Adam Wlostowski began the cross-CZO post doc position in May 2017. He joined BcCZO meetings and has been on our internal email list in Spring 2017.

2.2 Wlostowski met with S Anderson, N Molotch, R Anderson, field manager Nate Rock, and data manager Jeri Fey and others to compile Boulder data and discuss perceptual/conceptual models of Boulder sites.

2.3 PI Anderson emailed all CZO PIs in May 2017 to introduce Wlostowski, and encourage engagement.

3) Plan and possibly host cross-CZO landscape modeling workshop, collaborating with the Community Surface Dynamics Modeling System (CSDMS) and Lejo Flores (Reynolds CZO).

3.1 Lejo Flores (Reynolds CZO), Greg Tucker, and Hari Rajaram are participating in X-CZO modeling web-ex meetings, organized by Praveen Kumar (IML-CZO).

3.2 Discussions are underway for an "idea generator" workshop, perhaps in Fall 2017, on modeling, bringing together people from a) CZOs, b) CSDMS, and c) X-CZO post-doc Wlostowski. Boulder has pledged participant support funds.

4) X-CZO Biogeochemistry and microbial ecology

4.1 Fierer lab is doing microbial sequencing on soil samples collected from two soil profiles in every CZO, part of cross-CZO project led by Emma Aronson (SSierra CZO).

5) Support the Research Experience for Community College Students in Critical Zone Science (RECCS) REU program

5.1 We supply 1 month salary for Jennifer Taylor, RECCS program coordinator

5.2 PI Anderson works with RECCS PIs Lesley Smith and Anne Gold on planning, mentor recruitment, student selection, and advisory board meetings.

5.3 In 2017, 2 of 11 RECCS students will be mentored by CZO team members.

5.4 BcCZO team members assist with trainings for RECCS students in Summer 2017: PI Anderson leads local geology field trip on June 8, Bob Anderson gives seminar on BcCZO science on June 21, Mickey Rush provides field and lab notebook training on June 9, PI Anderson will meet with RECCS students for lunchtime discussions.

5.5 Former RECCS student Patrick Marsden (from 2014) has worked with Noah Fierer's lab continuously, and is now a co-author on Carini et al. (2016).

6) Support K-12 education outreach programs of Science Discovery.

6.1 Teacher Mountain Research professional development class: 12 K-12 teachers for four-day in residence class, July 2016. Class runs again in July 2017.

6.2 Bob Anderson led field trip on Niwot Ridge for Teacher Mountain Research PD class.

6.3 CZO-based STEM workshops delivered to 356 kids and 19 teachers in 2 workshops and 11 classroom presentations.

7) Lead Kirk Bryan field trip at the 2016 GSA Annual Meeting

7.1 Melissa Foster (PhD 2016), Bob Anderson, Pete Birkeland, and Rachel Glade organized the 2016 Kirk Bryan field trip, attended by ~60 participants.

7.2 Field guide published by GSA (Foster et al., 2016)

8) Science Goal 1, *Critical zone evolution*:

- Produce papers on complex response of post-Laramide landscape of the Front Range to climate change and on critical zone architecture

Outcomes:

8.1 Papers published or submitted:

Foster et al (2016) The 2016 Kirk Bryan field trip: Quaternary landslides, fluvial terraces, and recent geomorphic events along the Colorado Front Range.

Glade et al (2017): *Geology*.

Foster (in press): *Geomorphology*.

Langston and Tucker (submitted): *Earth Surface Dynamics*.

- Conduct preliminary research on rock weathering on steep slopes.

Outcomes:

8.2 RECCS student Sean Ross surveyed rock strength at 21 locations in Boulder Canyon and within steep debris flow chutes. Ross and Anderson (2016): *GSA Abstracts with programs*.

8.3 Grad student Brittany Selander started working on Boulder Canyon rock slopes for her PhD.

9) Science Goal 2, *Understand how individual processes shape the critical zone* (process to form):

- investigate the seasonal variability in soil microbial communities across different soil types and how these seasonal changes in soil microbial communities correlate with shifts in nutrient dynamics

Outcomes:

9.1 Post-doc Paul Carini led ~monthly sampling of surface soils in plots in Gordon Gulch for one year. Sample splits were used for microbial analyses (Carini), DOM characterization (Rue), nutrient status (Hinckley).

9.2 Paper published:

Carini et al. (2016): *Nature Microbiology*.

- describe dominant soil microbial taxa and their physiological and ecological attributes.

Outcomes:

9.3 Paper describing a single verrucomicrobia group: Brewer et al. 2016. *Nature Microbiology*.

- exploratory field measurements of forces at the root-rock interface at both the Eel River and Boulder Creek CZOs (Marshall, Anderson)

Outcomes:

9.4 NSF Post-doc Jill Marshall installed anemometers, force sensors and accelerometers on trees in Eel River CZO and BcCZO. This is a novel technique, using force-sensors to measure tree-induced forces.

9.5 Marshall engaged undergrad Dillon Ragar on instrument programming; met with Tucker, Anderson, Anderson, Toby Minear.

- examine controls on vertical structure of bioturbation by gophers using Cs and 210Pb, model behavior observed (Winchell, RS Anderson)

Outcome:

9.6 Eric Winchell completed dissertation; one chapter focused on Cs and 210Pb.

- measure and model rocky landscapes (hogbacks, Flatirons, blocks in channels)

Outcomes:

9.7 Paper on hogback slope evolution: Glade et al (2017): *Geology*.

9.8 Francis Rengers (USGS) and S Anderson did T-Lidar survey of 2015 earthflow on Dakota Ridge.

10) Science Goal 3, *Discover how critical zone architecture influences the storage and flow of water* (form to function):

- model and build observational data on snowmelt influence on streamflow from point to regional scale

Outcomes:

10.1 Paper on hydrologic partitioning: Barnhart et al (2016):, *Geophysical Research Letters*.

- submit papers on variations and sources of colloidal silica in stream water, and concentration-discharge variations in major species

Outcomes:

10.2 Joe Mills completed dissertation

10.3 Papers published: Mills et al (2017):. *J Environ. Qual*.; Aguirre et al. (2017): *Water Resour. Res*.

- submit papers on growing season length, climate, forest productivity, and carbon exchange

Outcomes:

10.4 Papers published: Barnard, DM et al (2017): *Environ Res Lett*. ; Barnard, DM (submitted) *Global Change Biology*

Significant Results:

Science Goal 1, *Critical zone evolution*:

Langston and Tucker (in review) tackle the problem of lateral bedrock incision by rivers, important in understanding the evolution of the shale landscape of the Plains. In Foster et al., (2017) we demonstrate that the Table Mountain(TM) terrace along Lefthand Creek was occupied for a million years before abandonment at ~ 100 ka. The extraordinary length of occupation negates a simple model of lateral planation in glacials, and fluvial incision in the next interglacial. The TM surface was occupied for many glacial cycles. We still believe that sediment and water production in the source basins drive evolution, hence is a critical zone issue. It is forcing us to develop models of CZ operation, including both weathering production of soil and its transport, and the hydrology of the hislope system, over multiple glacial cycles.

Glade et al. (2017) addressed the evolution of iconic hogback scarp slopes. No theory exists for the evolution of landscapes in layered rocks, or for that matter in landscapes in which discrete blocks of rock play a significant role. Glade's model simultaneously reproduces the concave rather than convex upper slope, and the distribution of the blocks that litter the ramp. Working in Boulder Canyon, Shobe et al. (2017) demonstrated that large blocks that roll into rivers can significantly stall the bedrock erosion. This represents a major feedback between fluvial and hillslope systems. Understanding the hillslope source areas for the large blocks (>1 m diameter) motivates the PhD research of Brittany Selander.

Software development: BRaKE is a 1-D bedrock channel profile evolution model written by Charles Shobe at the University of Colorado Boulder. It calculates bedrock erosion in addition to treating the delivery, transport, degradation, and erosion-inhibiting effects of large, hillslope-derived blocks of rock. It uses a shear-stress bedrock erosion formulation with additional complexity related to flow resistance, block transport and erosion, and delivery of blocks from the hillslopes. BRaKE is now available through the Community Surface Dynamics Modeling System (CSDMS) Model Repository. Website: http://csdms.colorado.edu/wiki/Model:BRaKE

An email from Dan Richter (Calhoun CZO) on the "clay factory" in his weathered profile has sparked development of a model to describe how weathered profiles evolve, using hydrologic and geochemical processes. Bob Anderson has built a model that follows water along flowpaths from soil surface to channel, and evolves its chemistry as feldspar weathers to clay. A preliminary version will be presented in a poster at the CZO meeting in Arlington, in June 2017

Goal 2, *Understand how individual processes shape the critical zone* (process to form):

Brewer and Fierer (in review) sampled tombstones across the globe and found that rock type, not tombstone location, is the primary control on microbial community assembly on these exposed rock surfaces. Microbes colonizing distinct rock types appear to have unique physiological adaptations for survival and nutrient acquisition on rock surfaces, adaptations that are directly relevant to understanding the microbial controls on weathering rates.

Brewer et al. (2016) has found that a group of bacteria within the phylum Verrucomicrobia is often dominant in deeper soil depths and members of this group have unique metabolic strategies for survival in resource limiting conditions (including

genome streamlining). We are extending this to a cross- CZO study to determine if similar metabolic strategies are used by bacterial taxa across a wide range of distinct soil profiles.

Field sample collection for an investigation of seasonal variability in soil microbial communities across different soil types and correlation with shifts in nutrient dynamics is now complete. The team, led by post-doc Paul Carini, sampled surface soils in plots on north-facing and south-facing sites in Gordon Gulch at monthly intervals for 1 year.

To understand physical weathering by roots, NSF Post-doc Jill Marshall installed 10 force sensors at Betasso and 10 force sensors (3 trees) at Gordon Gulch, and a similar array in Eel River CZO, a novel and extensive dataset. The style and magnitude of root-driven forces may depend on individual species, size distribution, forest structure and regional wind patterns. Diurnal root pressure fluctuations due to sap flow may be enough to weaken enfolding rock due to persistent stress.

Winchell et al (in review) developed a model of sediment transport driven by fossorial rodents. The cellular automata approach adopted allowed for differential excavation of rocks and fine-grained soil material, and included tunnel collapse.

Goal 3, *Discover how critical zone architecture influences the storage and flow of water* (form to function):

Hydrologic modeling experiments (Barnhart et al., 2016) reveal how changes in snowmelt will influence runoff at the Boulder Creek CZO and the Southern Sierra CZO. Runoff decreases due to slow snowmelt may be partially to fully offset by runoff increases due to earlier snowmelt depending on site specific characteristics.

DM Barnard et al. (2017) used a novel method for analyzing sapflow data to show that montane forest growing season length (GSL) varies significantly with elevation and slope aspect. There is substantial uncertainty regarding the impact of GSL on ecosystem carbon exchange. DM Barnard et al. (in review) found significant differences in GSL when determined by different methods. As a result, GSL-NEP scaling coefficients varied among methods and, in some cases, produce opposite results. This highlights the need for standardized ecosystem phenological representation.

Gordon Gulch hydrochemistry: Both silica colloids (Mills et al., 2017) and Ge/Si ratios (Aguirre et al., 2017) in streamwater demonstrate that baseflow is generated from groundwater, conditioned chemically by weathering, while high discharges include water from a shallow and/or near-stream source. Si colloids comprised 30-35% of the Si mass flux, an often overlooked component of the weathering budget.

Pandey and Rajaram (2016) present a quantitative evaluation of the influence of preferential flow on weathering rates using reactive transport modeling. The simulations reveal spatial variability in the weathering rate, multidimensional distribution of reactions zones, and the formation of rough weathering interfaces and corestones due to preferential flow. The simulations also reveal relatively constant horizontally averaged weathering rates over a significant depth range, challenging the very notion of a weathering front.

Michael Rush has implemented a coupled thermo-hydrologic model for hillslope snowmelt and hydrology using a customized snow model and PFLOTRAN. The model reproduce aspect-controlled differences in snowmelt patterns.

Key outcomes or Other achievements:

What organisms live in soil, and what do they do? These questions animate the field of microbial ecology and soil science. Boulder Creek CZO began examining soil microbial ecology in 2008, with a survey of the microbial diversity and leachable organic matter (DOM) characteristics in soil profiles (Eilers et al., 2012; Gabor et al., 2014) in Gordon

Gulch. This work showed that microbial communities showed diversity within the depths of a soil pit that were as great as the diversity one finds by comparing extremes of biomes on the surface (tropical rain forest to desert sands). The DOM suggested that microbes were active even at great depths in the soil, and perhaps harnessing mineral weathering reactions. Our most recent advance on soil organisms reveals that much of the DNA extracted from soils, such as those in our earlier work, contain both DNA from living organisms and extracellular DNA (Carini et al., 2016). This latter bit, the extracellular DNA, is essentially a ghost that obscures the true composition of the active microbial community in the soil. Temporal variations in microbial community composition may be hidden by the persistence of relic DNA "ghosts". Having demonstrated that relict DNA does persist in soils, we have undertaken a seasonal study of soil microbial ecology in which care was taken to separate the living from the dead DNA. Results from that experiment are expected later in 2017.

The importance of measurement technique on results also became clear when we switched from measuring silica in stream water colorimetrically to using ICP-OES. Our silica concentrations increased dramatically after the switch. Graduate student Joe Mills undertook the painstaking work to show that both techniques yield "correct" data, but that they measure different things. The molybdate blue colorimetric analysis is sensitive to dissolved elemental Si, while the inductively coupled plasma-optical emission spectrometer (ICP-OES) measured total Si, a combination of dissolved Si and colloidal (very fine particulate) Si. The finding is not a new development in analytical chemistry. The significance here is that in many streams, colloidal material is insignificant and hence not looked for. The two analytical techniques are treated as interchangeable, when clearly they are not. In Gordon Gulch, colloidal silica accounts for some 30-35% of the total silica flux (Mills et al., 2017). This finding is more than just a footnote: it actually offers insight into the hydrology of Gordon Gulch, and perhaps into soil formation processes. Colloidal silica concentrations peak during the spring discharge peak, and plummet during late summer baseflow conditions. Mills et al. (2017) and Aguirre et al. (2017) showed that the colloids are absent in groundwater collected from wells deep in the saprolite, but are easily released by leaching a surface soil sample. We are beginning to explore the role of colloids in developing the soil profile through translocation in near-surface horizons.

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

Post-docs

BcCZO Post-doctoral Fellow Dave Barnard has held regular mentoring meetings with Noah Molotch and Holly Barnard, and meets with PI Suzanne Anderson at least annually. He mentored two REU students with the RECCS program, and supervised a poster presentation at AGU by one of these students.

NSF Post-doctoral Fellow Jill Marshall met with Greg Tucker, Bob Anderson, and (less often) Suzanne Anderson during her visits to Boulder. All gave her advice on all aspects of her job search, all the way through to negotiation advice when she was offered a tenure-track faculty position (U Arkansas, Geology Dept.). She gave a talk in the INSTAAR seminar series.

Graduate students:

GEOL 5700-010: *Geological Topics: Earth Surface processes* graduate class (taught by Bob Anderson); Spring 2017 enrollment 2 students, regularly attended by two post-docs, two faculty members, and up to 6 additional students.

CU Hydrologic Sciences Symposium in a graduate-student organized meeting held each Spring. CZO grad student Mickey Rush served as a member of the steering committee for 2017. Mickey invited and hosted visiting scholars, presented his

work at the symposium, and organized a community outreach event in which graduate students demonstrated their science in engaging ways to students from Casey Middle School.

Undergraduates: RECCS program

Participation in RECCS program (Research Experience for Community College Students in Critical Zone Science, NSF 1461281). In summer 2017, three BcCZO-II faculty and students are mentoring 2 of the 11 student researchers.

In summer 2016, BcCZO-II faculty and students mentored 7 of the 10 students:

1) Post-doc Dave Barnard mentored **Brett Lindgren**. Final poster: *Does site physiography and canopy type influence incident solar radiation at the forest floor?*

2) Grad student Theodore Barnhart mentored **Randall Rouse** Final poster: *Slope orientation and Topographic Wetness Index Effects on Leaf Area and Height in a Coniferous Forest*, and **Jesse Barber,** Final poster: *Slope orientation and Topographic Wetness Index Effects on Leaf Area and Height in a Coniferous Forest*,

Final poster: *Terrestrial Based Leaf Area Index Compared to Leaf Area Index Derived from Remote Sensing in the Boulder Creek Critical Zone Observatory*

3) Grad student Tess Brewer and Prof Noah Fierer mentored **Scott-Wesley Bean**. Final poster: *Diversity of Spore-forming bacteria in soil from the Boulder Creek Critical Zone Observatory*

4) Grad student Charlie Shobe and Co-PI Greg Tucker mentored **Taylor Schoenfeld**. Final poster: *Processes affecting spatial variability in sediment size at Chalk Creek, Colorado*

5) PI Suzanne Anderson and grad student Trevor Klein mentored **Sean Ross**. Final poster: *Rock weathering observed in outcrops and bedrock exposed by debris flows: A preliminary investigation of granodiorite weathering in a landscape context*

6) Co-PI Michael Gooseff mentored **Amanda Espinoza-Martinez**. Final poster: *Stream water temperature in the Gordon Gulch creek for the summer of 2015*

REU supplement funding supported three RECCS student researchers from the summer 2015 cohort to continue their research; one (Thirouin, mentored by Dave Barnard) presented his findings at AGU in Fall 2016. One (Gamora, mentored by Mike Gooseff) is now an upper division undergraduate at CU.

Undergraduates: other activities

Murphy, S.F. guest lectured in University of Colorado undergraduate course “Water Resources and Management in the Western U.S.,” on Fires, floods, and water quality. Feb. 3, 2017.

Two undergraduate senior honors theses completed at University of Colorado:

Hammack, G. (2017): *Runoff generation in Betasso catchment: Investigation of Hortonian overland flow*. Geological Sciences senior thesis, advisor SP Anderson.

Ragar, D. (2017): *Short-Term Wildfire Impacts in a Rocky Mountain Catchment: Searching for Evidence of Riverine Black Carbon Transport after the Cold Springs Wildfire*. Environmental Studies senior honors thesis, advisor D McKnight.

All of our undergraduate field techs (Dillon Ragar, Kristina Cowell, Nagam Gill, Jamie Glass) are being offered partial support for the cost of a Wilderness First Aid training course offered at the Mountain Research Station.

K-12 Teacher Professional Development class (Science Discovery):

Earth Systems Science Teacher Mountain Research Professional Development Workshop/Graduate Level Field Course (3-Day/24 Hour), July 26-28, 2017. Anticipated enrollment: 12 teachers.

K-12 Learners (Science Discovery)

356 middle school students participated in BcCZO-Science Discovery science outreach programs in the period May 2016-May 2017, broken down as follows:

- Exploring Erosion in the Critical Zone workshop (1.5 hours):
  18 students, 2 teachers in 1 workshop

- Earth Systems Science classroom presentations (Foundations for Flow; Fire and Water) (1 hour) :
256 students, 10 teachers in 10 presentations

- Earth Systems Science STEM and Physical Science workshop (5 hours) :
  82 students, 7 teachers in 2 workshops

Breakdown of 356 K-12 students:

167 (47%) in rural areas

169 (47%) African-American or Latino

161 (45%) female.

Website for these programs:

http://sciencediscovery.colorado.edu/resources/teacher-resources/czo-workshop/

12 high school students participated in the Science Discovery High School Mountain Research Experience. This is a 5-day residential field program, based at the Mountain Research Station located at an elevation of 9500 ft in the Colorado Front Range.

BcCZO team members directly engaged in Science Discovery: Bob Anderson, Suzanne Anderson, Michael (Mickey) Rush, Eric Winchell, in addition to Alex Rose and Eric Carpenter, who work for Science Discovery.

Some details on Mickey Rush's work with Science Discovery:

On Tuesday, August 3, 2016, Mickey led a full-day activity for high school students participating in the Mountain Research Experience. He presented his work with the CZO to high school students, and explained the role of hill slope aspect in controlling solar radiation, vegetation, snow accumulation, and the formation of seasonally-frozen ground. He led the students on a field trip to Gordon Gulch, where they identified the vegetation and canopy cover present on the north- and south-facing slopes. Returning to the Mountain Research Station, Mickey led the students through a solar radiation modeling exercise in which they used their observations from Gordon Gulch to guide the albedo and canopy interception parameters used in the model.

INSTAAR Middle School Open House, April 21, 2017

Annually, INSTAAR opens its doors to ~200 middle school students from Southern Hills Middle School (Boulder). Over the course of the morning, groups of 10-15 students rotate through ten different lab/field stations for a brief (15 minute) activity or lesson.

Boulder Creek CZO team members ran these stations:

Nate Rock, Clay Jenson and our undergraduate field team engaged students in stream gaging and water quality (pH) measurement at two outdoor stations.

Mickey Rush offered a hydrology experience (stream table)

Wendy Roth (Sed Lab manager) demonstrated sediment sample processing

Alex Rose (from Science Discovery) offered a "My Water" station

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

How have the results been disseminated to communities of interest?

Kirk Bryan Field Trip at GSA Meeting

Melissa Foster organized the Kirk Bryan field trip for the GSA Annual meeting in September 2016. Some *60 researchers* from around the US and world attended the field trip. Pete Birkeland led participants through the Quaternary mapping, soils geomorphology, and relative dating that laid the foundation for recent research conducted by CU students. Bob Anderson highlighted new dating techniques and models used to constrain Quaternary landscape evolution. Melissa Foster presented her research on cosmogenic radionuclides to date Quaternary strath terraces and Rachel Glade discussed her modeling of the evolution of hogbacks like Dakota Ridge.

Other Field Trips

1) Sheila Murphy and Deb A. Martin (USGS), led field trip for new students in CU Masters of the Environment Program on "Wildfire and watershed management in the Colorado Front Range". August 16, 2016.

2) Suzanne Anderson, Nate Rock and Bob Anderson, hosted visit for visiting delegation of 8 from Chinese Geologic Survey and China University of Geosciences. Activities included a tour of labs, discussion of instrumentation, and a field tour of Gordon Gulch. September 8, 2017

3) Suzanne Anderson to lead a field trip of Front Range geology for Research Experience for Community College Students (RECCS) in Critical Zone Science students, June 8, 2017. 11 students.

4) Robert Anderson to lead field trip to Niwot Ridge, Boulder Creek CZO for Earth Systems Science Teacher Mountain Research Professional Development class, July 24, 2017. 12 teachers.

Presentations at Conferences

We gave 46 presentations at professional science meetings:

- 24 presentations at AGU Fall Meeting, San Francisco, CA
- 6 presentations at GSA Annual Meeting, Denver, CO
- 2 presentations at Internat'l Society of Microbial Ecology (ISME) meeting, Montreal, Quebec
- 2 presentations at Community Sediment Dynamics Modeling System (CSDMS) Annual Meeting, Boulder, CO
- 12 presentations at 9 other meetings and workshops, including American Chemical Society, Ecological Society of America, and others.

AGU sessions

Two AGU sessions at the 2016 Fall Meeting merit some notice here.

1) Union Session

Session Title: *The Critical Zone: Revealing the Structure, Function, and Evolution of Earth's Living Skin*

Speakers:

W E Dietrich, UC Berkeley, *The Critical Zone: A necessary framework for understanding surface Earth processes*

W.S Holbrook, U Wyoming, *Critical Zone architecture and processes: A geophysical perspective*

J C McIntosh, U Arizona, *Changing energy inputs at Earth's surface translates to differences in water availability, weathering rates, and biotic activity at depth*

Ying Fan, Rutgers University, *Plant rooting depth, soil hydrology, and implications to terrestrial environmental change*

Amilcare Porporato, Duke U, *Propagation of hydroclimatic variability through the critical zone*

David John Beerling, U Sheffield, *Harnessing the agricultural critical zone for climate change mitigation through enhanced rock weathering with croplands*

The session was streamed online, and continues to be available for viewing via AGU On-Demand: http://fallmeeting.agu.org/2016/virtual-options/

2) EPSP Session

Suzanne Anderson teamed with Sue Brantley (Shale Hills-Susquehanna CZO) and Bill Dietrich (Eel River CZO) to propose a session titled "The Architecture and Workings of Earth's Critical Zone". The session attracted 46 presenters; was one of the larger Earth and Planetary Surface Processes sessions at the Fall AGU meeting.

CZO-LTER Data Fair

INSTAAR's Center for Water, Earth Science, and Technology (CWEST) sponsored a one-day meeting of Niwot LTER and Boulder Creek CZO on October 14, 2016.

Other professional talks by team members:

1. **Anderson, Suzanne,** "The critical zone: Geo-bio-hydro interactions that shape the Earth's surface", University of Potsdam, Germany, Earth Surface Processes speaker series, Jan. 9, 2017.
2. **Anderson, Robert**, "Hillslopes of Colorado's Front Range: From frost to trees to gophers to boulders", University of Potsdam, Germany, Earth Surface Processes speaker series, Jan. 9, 2017.
3. **Anderson, Robert**, "**Quaternary evolution of Colorado's Front Range: Through the lens of cosmogenic radionuclides**", University of California, Santa Barbara, Department of Earth Sciences Crowell Lecturer, Nov 1, 2016.
4. **Anderson, Suzanne**, "In the wake of a knick zone: From block fall to debris flows", University of California, Santa Barbara, Department of Earth Sciences Crowell Lecturer, Nov 2, 2016.
5. **Anderson, Robert**, "Of rocks and ice: The glacier-rock glacier continuum Of rocks and ice: The glacier-rock glacier continuum", University of California, Santa Barbara, Department of Earth Sciences Crowell Lecturer, Nov 3, 2016.
6. **Murphy, S.F**., Fires, floods, and water quality: Guest speaker for UCAR Center for Science Education, June 15, 2016.
7. **Murphy, S.F**., Fires, floods, and water quality: Science speaker for USGS Wildfire Science Community of Practice meeting, July 5, 2016.
8. **Murphy, S**.F. and Martin, D.A., "Research needs related to wildfire, atmospheric deposition and water quality". Invited talk for the Air Quality Research Subcommittee of the National Science and Technology Council's Committee on Environment, Natural Resources, and Sustainability, July 18, 2016.

9. **Fierer, N**., 2017. Exploring soil microbial diversity. Center for Genome Research and Biocomputing. Oregon State University (invited seminar).
10. **Fierer, N**. 2017. Searching for simplicity amidst the complexity of the soil microbiome. Biogeochemistry and Environmental Science and Sustainability Seminar Series. Cornell University (invited seminar).

11. **Fierer, N**. 2017. Searching for simplicity amidst the complexity of the soil microbiome. U.S. Department of Energy, Pacific Northwest National Laboratory, Richland, WA (invited seminar)

12. **Fierer, N.** 2016. Known knowns and known unknowns: exploring the diversity of microorganisms in soil. Instituto de Ecologia, UNAM, Mexico City, Mexico (invited lecture, 'Frontiers in Ecology & Evolution' series)

13. **Fierer, N.** 2016. Microbes and the terrestrial carbon cycle. Board on Earth Sciences and Resources, National Academy of Science, Washington DC (panelist and invited speaker)

Sheila Murphy and her USGS colleague Deb Martin were invited to speak last summer to the Air Quality Research Subcommittee of the National Science and Technology Council's Committee on Environment, Natural Resources, and Sustainability. Their presentation on "Research needs related to wildfire, atmospheric deposition and water quality" was heard by regulators and officials from the National Oceanic and Atmospheric Administration, Federal Highway Administration, National Science Foundation, Environmental Protection Agency, National Aeronautics and Space Administration, National Institute of Science and Technology, National Park Service, and Department of Energy.

Stakeholder contacts

Sheila Murphy

NADP program

City of Boulder Sourcewater Protection program

City of Boulder Stormwater Program

Boulder County Public Health

Noah Molotch

-Wyoming State Engineer

- Denver Water

- Northern Colorado Water

- City of Boulder

Media: print and radio

The RECCS REU program was featured in Fall 2016 issue of *Research and Creative Work 2015-2016*, a magazine published by the University of Colorado Office of the Vice Chancellor for Research:

http://www.colorado.edu/research-report/2015-16/fieldwork-dreams

Grad student *Theo Barnhart* received considerable media attention surrounding his paper in GRL (Barnhart et al., 2016)

Website

Our webpages at www.criticalzone.org/boulder now have content on a variety of styles of models (http://criticalzone.org/boulder/models/conceptual-models-boulder/). A recent focus is developing more streamlined field logs to accompany our numerous data sets in the database, and developing a set of data quality flags within the dataset itself.

Social media presence

Boulder Creek CZO has a twitter account: Boulder Creek CZO @bc_czo

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

1) Maintain monitoring in existing catchments, coordinate with Niwot Ridge LTER on field monitoring in the alpine settings. Maintain sampling at the two new NADP sites (Betasso and Boulder) we established this year.

2) Support cross-CZO postdoc Adam Wlostowski on Hydrologic partitioning.

3) Plan and possibly host cross-CZO landscape modeling workshop, collaborating with the Community Surface Dynamics Modeling System (CSDMS) and Lejo Flores (Reynolds CZO).

4) Complete microbial DNA analysis of soil samples from all CZOs for the cross-CZO microbial ecology project (headed by Emma Aronson). Fierer is working with microbial ecologists, soil scientists, and biogeochemists from every CZO site to plan, coordinate, and implement a cross-CZO microbial ecology that spans all current CZO sites. The research focuses on exploring the structure and function of microbial communities in deeper soil horizons.

5) Support the Research Experience for Community College Students in Critical Zone Science (RECCS) program, by supporting administrative staff needed to run an REU, providing mentors and research support, participating in the skills training in the program.

6) Support K-12 education outreach programs of Science Discovery.

7) Facilitate production of *Hydrologic Processes* special issue on the critical zone. The working title for the issue is: *Passive-Aggressive: Water in the Critical Zone*. The project was initiated by Ying Fan Reinfelder (Rutgers Univ), with the support of Editor-in-Chief Doerthe Tetzlaff . Ying Fan's co-guest editors are Suzanne Anderson and Gerard Govers (KU Leuven, Belgium). A list of 27 authors from around the world have agreed to contribute; publication deadline is February 2018.

8) Goal 1, *Critical zone evolution*:

- Produce paper on hillslope evolution, incorporating water flow paths and geochemical alteration of rock (Bob Anderson, Hari Rajaram, Dan Richter (Calhoun CZO) and SP Anderson).
- Conduct preliminary research on rock weathering on steep slopes (SP Anderson, Brittany Selander).

9) Goal 2, *Understand how individual processes shape the critical zone* (process to form):

- Complete investigation of seasonal variability in soil microbial communities across different soil types and how these correlate with shifts in nutrient dynamics (Carini, Hinckley, Rue)
- Preliminary work on snow mold and N-dynamics (Hinckley, Chiara Forrester)

- continue field measurements of forces at the root-rock interface at both the Eel River and Boulder Creek CZOs (Marshall)
- document shifts in ecotones from airphotos over the last 70 years in the subalpine forest zone (Doak, Anderson, Gulick)
- examine controls on vertical structure of bioturbation by gophers using Cs and 210Pb, model behavior observed (Winchell, RS Anderson)
- measure and model rocky landscapes (hogbacks, Flatirons, blocks in channels) (Tucker, RS Anderson, SP Anderson, Glade, Shobe, Selander, with Francis Rengers, USGS)

10) Goal 3, *Discover how critical zone architecture influences the storage and flow of water* (form to function):

- model and build observational data on snowmelt timing, rate and amount influence on streamflow production from point to regional scale (Barnhart, D Barnard, Molotch, SP Anderson)
- submit paper on Gordon Gulch hydrology (SP Anderson)
- submit paper on extreme precipitation event in Betasso (SP Anderson)
- write paper on groundwater dynamics elucidated from analysis of Betasso deep well (RS Anderson, H Rajaram, SP Anderson, Cowell)

Supporting Files

Filename	Description	Uploaded By	Uploaded On
Additional reporting 2017.pdf	Additional reporting requirements	Suzanne Anderson	06/08/2017
Fieldwork of Dreams | University of Colorado Boulder.pdf	Research&Creative Works article on RECCS	Suzanne Anderson	06/08/2017

Products

Books

Book Chapters

Foster, M.A., Anderson, R.S., Rindfleisch, P.R., Birkeland, P.W., Redwine, J.R., Pitlick, J., and *Glade, R.C (2016). The 2016 Kirk Bryan field trip: Quaternary landslides, fluvial terraces, and recent geomorphic events along the Colorado Front Range. *Unfolding the Geology of the West: Geological Society of America Field Guide* 44. Keller, S.M., and Morgan, M.L. Geological Society of America. Boulder, CO. 267. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1130/2016.0044(12).

Inventions

Journals or Juried Conference Papers

Aguirre, A, Derry, LA, *Mills, TJ, and Anderson, SP (2017). Colloidal transport in the Gordon Gulch catchment of the Boulder Creek CZO and its effect on C-Q relationships for silicon. *Water Resources Research*. 53 (3), 2368. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016WR019730

Barnard, DM, Barnard, HR, and Molotch, NP (2017). Topoclimate effects on growing season length and montane conifer growth in complex terrain. *Environmental Research Letters*. 12 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1088/1748-9326/aa6da8

Barnard, DM, JF Knowles, HR Barnard, ML Goulden, J Hu, ME Litvak, NP Molotch (2017). Reevaluating growing season length controls on net ecosystem production. *Global Change Biology*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Barnard, HR, BA Skeets, HR Adams, CJ Crosby, WB Ouimet (2017). Using stable isotopes of trees to examine moisture dynamics in bedrock outcrops of a Semi-Arid Catchment. *Hydrological Processes*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Barnhart, T.B., N.P. Molotch, B. Livneh, A.A. Harpold, J.F. Knowles, D. Schneider (2016). Snowmelt Rate Dictates Streamflow. *Geophysical Research Letters*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Brantley, S.L., Eissenstat, D.M., **Marshall, J.A., Godsey, S.E., Balogh-Brunstad, Z., Karwan, D.L., Papuga, S.A., Roering, J., Dawson, T.E., Evaristo, J., Chadwick, O., McDonnell, J.J., and Weathers, K.C. (2017). Reviews and syntheses: On the roles trees play in building and plumbing the critical zone. *Biogeosciences Discussions*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Brantley, SL, McDowell, W, Dietrich, WE, Kumar, P, Anderson, SP, Chorover, J, Lohse, KA, Bales, R, Richter, DdeD, Grant, G, Gaillardet, J, and Derry, LA (2017). Designing a network of Critical Zone Observatories to explore the living skin of the terrestrial Earth. *Earth Surface Dynamics*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Brewer, T.E., K.M. Handley, P. Carini, J.A. Gilbert, N. Fierer. (2016). Genome reduction in an abundant and ubiquitous soil bacterium, 'Candidatus Udaeobacter copiosus'. *Nature Microbiology*. 2 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/nmicrobiol.2016.198

Brewer, T.E., N. Fierer (2017). Tales from the tomb: the microbial ecology of exposed rock surfaces. *mBio*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Bueno de Mesquita, C., L.S. Tillmann, C.D. Bernard, K.C. Rosemond, N.P. Molotch, K.N. Suding (2017). Topographic heterogeneity mediates vegetation response to climate change in the Rocky Mountains, USA. *Landscape Ecology*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Burns, M.A., Barnard, H.R., Gabor, R.S., McKnight, D.M., and Brooks, P.D. (2016). Dissolved organic matter transport reflects hillslope to stream connectivity during snowmelt in a montane catchment. *Water Resources Research*. 52 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2015WR017878

Carini, P., Marsden, P.J., Leff, J.W., Morgan, E.E., Strickland, M., and Fierer, N. (2016). Relic DNA is abundant in soil and obscures estimates of soil microbial diversity. *Nature Microbiology*. 2 16242. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1038/nmicrobiol.2016.242

Cowie, R.M., J.F. Knowles, K.R. Dailey, M.W. Williams, J.T. Mills, N.P. Molotch (2017). Sources of streamflow along a headwater catchment elevational gradient. *Journal of Hydrology*. 549 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.jhydrol.2017.03.044

Driscoll, J.M., T. Meixner, P.A.T. Ferre, M.W. Williams, J.O. Sickman, N.P. Molotch (2017). An elliptical model of catchment-scale response to snowmelt and the role of dynamic and long-term storage in dampening discharge variability. *Water Resources Research*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Foster, L., L. Bearup, N.P. Molotch, P. Brooks, R. Maxwell (2016). Energy budget changes impact arid mountain hydrology more than snow-rain transitions. *Environmental Research Letters*. 11 (40), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1088/1748-9326/11/4/044015

Foster, M.A., Anderson, R.S., Gray, H.J., and Mahan, S.A. (2017). Dating of river terraces along Lefthand Creek, western High Plains, Colorado, reveals punctuated incision. *Geomorphology*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.geomorph.2017.04.044

Fyfe, J.C., C. Derksen, L. Mudryk, N.C. Swart, N.P. Molotch, G.M. Flato, X. Zhang, H. Wan, V.K. Arora, J. Scinocca, Y. Jiao (2017). Large near-term projected snowpack loss over the western United States. *Nature Communications*. 8 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/ncomms14996

Glade, RC, Anderson, RS, and Tucker, GE (2017). Block-controlled hillslope form and persistence of topography in rocky landscapes. *Geology*. 45 (4), 311. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1130/G38665.1

Hallar, A.G., N.P. Molotch, J. Hand, L.R. Lestak, I.B. McCubbin, B. Livneh, R. Petersen, J. Michalsky, D. Lowenthal (2017). Impacts of increasing aridity and wildfires on aerosol loading in the intermountain western U.S.

Environmental Research Letters. 12 (1), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1088/1748-9326/aa510a

Hinckley, ES, Ebel, BA, Barnes, RT, Murphy, SF, and Anderson, SP (2017). Critical zone properties control the fate of nitrogen during experimental rainfall in montane forests of the Colorado Front Range. *Biogeochemistry*. 132 (1), 311. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1007/s10533-017-0299-8

Knowles, JK, Lestak, L, and Molotch, NP (). Forest disturbance interacts with snow-related drought to reduce remotely sensed productivity in the southern Rocky Mountains, USA. *Water Resources Research*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Langston, A, and Tucker, G (). Developing and evaluating a theory for the lateral erosion of bedrock channels for use in landscape evolution models. *Earth Surface Dynamics*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Litaor, M.I., Suding, K., Anderson, S.P., Litus, G., and Caine, T.N. (2017). Trend analysis of alpine catena response to nitrogen deposition. *Environmental Monitoring and Assessment*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

McKnight, DM (2017). Debates--- Hypothesis testing in hydrology: A view from the field: The value of hydrologic hypotheses in designing field studies and interpreting the results to advance hydrology. *Water Resources Research*. 53 1779. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016WR020050

Miller, M.P., Boyer, E.W., McKnight, D.M., Brown, M.G., Gabor, R.S., Hunsaker, C.T., Iavorivska, L., Inamdar, S., Johnson, D.W., Kaplan, L.A., Lin, H., McDowell, W.H., and Perdrial, J.N. (2016). Variation of organic matter quantity and quality in streams at Critical Zone Observatory watersheds. *Water Resources Research*. 52 (10), 8202. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016WR018970

Mills, TJ, Anderson, SP, Bern, C, Aguirre, A, and Derry, LA (2017). Colloid mobilization and seasonal variability in a semi-arid, headwater stream. *J Environ. Qual.*. 46 (1), 88. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2134/jeq2016.07.0268

Pandey, S., and Rajaram, H. (2016). Modeling the influence of preferential flow on mineral weathering rates in the critical zone. *Water Resources Research*. 52 9344. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016WR019026

Rajaram, H., and Arshadi, M. (2016). A similarity solution for reaction front propagation in a fracture-matrix system. *Phil. Trans. R. Soc. A*. 374 20150424. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1098/rsta.2015.0424

Richter, D., Billings, S., Groffman, P., Kelly, E., Lohse, K., McDowell, W., Riebe, C., Silver, W., White, T., Anderson, S., Brantley, S., Brecheisesn, Z., Chadwick, O., Hartnett, H., Hobbie, S., Kazanski, C., Markewitz, D., O'Neill, K., Schoeder, P., Thompson, A. (2017). What would Darwin and Lyell say about integrating biology and geology across environmental science networks. *BioScience*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Rue, GP, Rock, ND, Gabor, RS, Pitlick, J, Tfaily, M, and McKnight, DM (2017). Concentration-discharge relationships during an extreme event: Contrasting behavior of solutes and changes to chemical quality of dissolved organic material in the Boulder Creek Watershed during the September 2013 flood. *Water Resources Research*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016WR019708

Swetnam, TL, Brooks, PD, Barnard, HR, Harpold, AA, and Gallo, EL (2017). Topographically driven differences in energy and water constrain climatic control on forest carbon sequestration. *Ecosphere*. 8 (4), e01797. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Wieting, C.*, Ebel, B., and Singha, K (2017). Quantifying the effects of burn severity on changes in soil properties by simulated burning of soils from the Boulder Creek Critical Zone Observatory. *Journal of Hydrology-Regional Studies*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Winchell, T.S., D.M. Barnard, R.K. Monson, S.P. Burns, and N.P. Molotch (2016). Early snowmelt reduces atmospheric carbon uptake in mid-latitude subalpine forests. *Geophysical Research Letters*. 43 8160. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016GL069769

Wymore, A. S., N. R. West, K. Maher, P. L. Sullivan, A. Harpold, D. Karwan, J. A. Marshall, J. Perdrial, D. M. Rempe and L. Ma (2017). Growing New Generations of International Critical Zone Scientists. *Earth Surface Processes and Landforms*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Zhang, Q, Knowles, J, Cowie, RM, Rock, N, and Williams, MW (2017). The influence of surface-subsurface connectivity on mesoscale streamflow generation in complex terrain. *Hydrological Processes*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses

Other Conference Presentations / Papers

Klein, TI, Anderson, SP, Murphy, SF, Ross, M., Hammack, G, and Anderson, RS (2017). *-intensity rain storm connects hillslopes to channels in a steep semi-arid catchment*. AGU Chapman Conference on Extreme Climate Events on Aquatic Biogeochemical Cycles and Fluxes. San Juan, Puerto Rico. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Ward, A.S., Schmadel, N., Wondzell, S.M., Gooseff, M.N., Singha, K. (2016). *An inductive model of hyporheic flowpath geometry and dynamics during baseflow recession (Invited)*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Arshadi, M., Rajaram, H. (2016). *Analytical Solution for Transport with Bimolecular Reactions in Fracture-Matrix Systems with Application to In-Situ Chemical Oxidation*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hinckley, E.S. (2016). *Aspect affects the fate of N deposition during major hydrologic events in the BcCZO*. Cross-CZO workshop on Slope-Aspect. Tucson, AZ. Status = OTHER; Acknowledgement of Federal Support = Yes

Jennings, K.S., Molotch, N.P. (2016). *Assessing the Climate Sensitivity of Cold Content and Snowmelt in Seasonal Alpine and Subalpine Snowpacks*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnhart, T.B.,Molotch, N.P., Tague, C. (2016). *Bidirectional Response of Runoff to Changes in Snowmelt Rate, Timing, and Amount*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Glade, R.C., Anderson, R.S. and Tucker, G.E. (2016). *Blocks control hillslope evolution in landscapes developed in layered rock*. Geological Society of America Annual Meeting. Denver, Colorado. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Glade, R.C., Anderson, R.S. and Tucker, G.E. (2016). *Blocks control hillslope evolution in layered landscapes*. Community Surface Dynamics Modeling System- Sediment Experimentalists Network Meeting (CSDMS-SEN). . Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Li, D., Wigmore, O.,Vaderjagt, B.J., Durand, M.T., Molotch, N.P., Bales, R.C. (2016). *Catchment-scale snow depth monitoring with balloon photogrammetry*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Murphy, S.F., Martin, D.A., McCleskey, R.B., Writer, J.H. (2016). *Climatic Events and Historical Disturbances Control Acute and Chronic Water-Quality Impairment After Wildfire*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Rue, G., McKnight, D, Rock, N, Gabor, R, and Tfaily, M (2017). *Concentration-discharge relationships during the recession of an extreme flood in the Boulder Creek Watershed: Patterns of lithologic solute concentrations contrast with decreases in concentration and changes in chemical quality of dissolved organic material*. American Chemical Society National Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Harmon, R.E., Szutu, D.J., Barnard, H.R., Randall, J., Singha, K. (2016). *Connecting Evapotranspiration and Groundwater Fluxes in the Critical Zone*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Marshall, J. (2017). *Considering the role of trees as Critical Zone architects*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, Virginia. Status = OTHER; Acknowledgement of Federal Support = Yes

Langston, A.L., Tucker, G.E. (2016). *Developing and Evaluating a Theory for Lateral Erosion by Bedrock Channels in a Landscape Evolution Model*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnhart, T.B., N.P. Molotch, and C.L. Tague (2017). *Disentangling the Importance of Snowmelt Rate, Timing, and Amount on Runoff Production*. Western Snow Conference. Boise, ID. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnhart, T.B., N.P. Molotch, and C.L. Tague (2017). *Disentangling the Importance of Snowmelt Rate, Timing, and Amount on Runoff Production*. CU Hydrologic Sciences Symposium. Boulder, CO. Status = OTHER; Acknowledgement of Federal Support = Yes

Hinckley, E.S. (2016). *Does rapid ecological change have consequences for the deep critical zone?*. AGU Townhall Meeting: Critical Zone Observatories: Platforms for Collaborative Science". San Francisco, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

Fierer, N (2016). *Ecological strategies for bacterial growth in the 'extreme' environment of soil (invited speaker)*. Biennial meeting of the International Society for Microbial Ecology. Montreal, Canada. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Shobe, C.M., and Tucker, G.E. (2016). *Experimental study of the influence of large blocks on fluvial response to baselevel fall*. Geological Society of America Annual Meeting. Denver, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Brewer T, Handley K, Carini P, Gilbert J, Fierer N. (2016). *Genome reduction in an abundant and ubiquitous soil bacterial lineage.*. International Society for Microbial Ecology (ISME). Montreal, Canada. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Winchell, E., R.S. Anderson, Lombardi, E., D.F. Doak, J. Kaste (2016). *Gophers as geomorphic agents in the Colorado Front Range*. Geological Society of America Annual Meeting. Denver, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Glade, R., Anderson, R.S. (2016). *Hillslope evolution in landscapes dominated by layered rocks*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Shobe, C.M., Tucker, G.E., and Rossi M.R. (2017). *Hillslope-derived blocks, erosion thresholds, and topographic scaling in mountain rivers*. CSDMS Annual Meeting. Boulder, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Molotch, N.P., Harpold, A.A., Barnhart, T.B., Trujillo, E. (2016). *Hydrologic Response to Changes in the Timing and Rate of Snowmelt: Implications for Water Resource Management in the Western U.S. (Invited)*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Livneh, B, Badger, A, Molotch, N.P., Bueno de Mesquita, C., Suding, K (2016). *Hydrologic Response to Climatic and Vegetation Change in an Extreme Alpine Environment*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Thirouin, KR, Barnard, DM, and Barnard, HR ((2016). *Influence of microclimate on semi-arid montane conifer forest sapflux velocity in complex terrain.*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Moon, S., Perron, J.T., Martel, S.J., Holbrook, S.J., St. Clair, J.T., Singha, K. (2016). *Interplay between tectonics and topography: Topographic stress controls on bedrock fractures and surface processes (Invited)*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Kallenbach, C., Fierer, N., Frey, S.D., Grandy, S. (2016). *Mineralogy impacts microbial community establishment with subsequent effects on initial microbial physiology and soil organic matter formation and chemistry*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Anderson, R.S., Anderson, L.S. (2016). *Modeling the Rock Glacier Cycle*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Schoenfeld, TE, Shobe, CM, and Tucker, GE (2016). *Processes affecting spatial variability in sediment size at Chalk Creek, Colorado*. Geological Society of America Annual Meeting. Denver, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Rajaram, H. and Pandey, S. (2016). *Quantifying the Influence of Preferential Flow on the Scale and Time Dependence of Weathering Rates*. European Geosciences Union General Assembly. Vienna, Austria. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Marshall, J.A., Anderson, R.S., Dawson, T.E., Dietrich, W.E., Sklar, L.S. (2016). *Quantifying the role of trees as Critical Zone architects employing crowbars, wedges and other tools of soil production*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Smith, L, Gold, A, Anderson, SP, Taylor, J, and Batchelor, R (2016). *Research Experience for Community College Students in Colorado: Insights on Improving the Pipeline of 2YC Students into the Geosciences.*. Geological Society of America Annual Meeting. Denver, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Ross, SL, and Anderson, SP (2016). *Rock weathering observed in outcrops and in bedrock exposed by debris flows: A preliminary investigation of granodiorite weathering in a landscape context*. Geological Society of America Annual Meeting. Denver, Colorado. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Anderson, SP, and Mills, TJ (2016). *Seasonal variations in stream chemistry in a semi-arid montane headwater stream reveal changing hydrologic flowpaths*. American Geophysical Union Fall Meeting. San Francisco, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Eldam, R., Navarre-Stichler, A., Singha, K., Moore, J. (2016). *Slope-Aspect Control on Geochemical Weathering within the Boulder Creek Critical Zone Observatory*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Tucker, GE (2016). *Some aspect-related process contrasts in the Boulder Creek Critical Zone Observatory*. Cross-CZO Workshop on Slope-Aspect. Tucson, AZ. Status = OTHER; Acknowledgement of Federal Support = Yes

Barnhart, T.B., C.L. Tague, B. Livneh, A.A. Harpold, J.F. Knowles, D. Schneider, and N.P. Molotch (2017). *The Cross-Scale Influence of Snowmelt Rate and Timing on Runoff Production Across the Western United States*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, Virginia. Status = OTHER; Acknowledgement of Federal Support = Yes

Hinckley, E.S. (2016). *The critical zone: A novel framework for questions in ecosystem biogeochemistry*. CZO Network Review Showcase. Arlington, VA (NSF headquarters). Status = OTHER; Acknowledgement of Federal Support = Yes

Hess, L., Hinckley, E.-L. S.,Robertson, G.P.,Matson, P.A. (2016). *The effects of more extreme rainfall patterns on nitrogen leaching from a field crop system in the upper Midwest, USA*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnard, DM, Knowles, JF, Molotch, NP, Litvak, ME (2016). *The seasonal role of moisture and energy limitations to net ecosystem exchange along an elevational and latitudinal gradient in the Rocky Mountains, USA*. Ecological Society of America Annual Meeting. Fort Lauderdale, FL. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Winchell, E.W., Anderson, R.S., Kaste, J.M. (2016). *The vertical signature of gophers on the critical zone in the Colorado Front Range subalpine zone*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Ebel, B (2016). *Unsaturated flow processes in structurally-variable pathways in wildfire-affected soils and ash (Invited)*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support

= Yes

Schneider, D., Molotch, N.P. (2016). *Using Remotely Sensed Fractional Snow Covered Area to Predict Snow Depth*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Langston, A.L., and Tucker, G.E. (2017). *Using a landscape evolution model to evaluate the role of pulses of uplift on bedrock valley width and channel mobility*. CSDMS Annual Meeting. Boulder, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Foster, M.A. and R. S. Anderson (2016). *Using surficial deposits to constrain Quaternary fault movement in Colorado: insights from relative dating and cosmogenic radionuclides*. Geological Society of America Annual Meeting. Denver, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Tucker, G.E., Adams, J.M., Doty, S.G., Gasparini, N.M., Hill, M.C., Hobley, D.E.J., Hutton, E, Istanbulluoglu, E., Nudurupati, S.S. (2016). *Using the Landlab toolkit to evaluate and compare alternative geomorphic and hydrologic model formulations (Invited)*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Shobe, C.M., Tucker, G.E. (2016). *When hillslope-derived blocks alter river evolution: A sensitivity analysis*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Other Products

Other Publications

Fey, J. and Anderson, S.P. (2016). *Boulder Creek Critical Zone Observatory Data Management Plan*. Research Ideas and Outcomes 2: e9419, doi:10.3897/rio.2.e9419.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Patents

Technologies or Techniques

BRaKE is a 1-D bedrock channel profile evolution model written by Charles Shobe at the University of Colorado Boulder. It calculates bedrock erosion in addition to treating the delivery, transport, degradation, and erosion-inhibiting effects of large, hillslope-derived blocks of rock. It uses a shear-stress bedrock erosion formulation with additional complexity related to flow resistance, block transport and erosion, and delivery of blocks from the hillslopes. BRaKE is now available through the Community Surface Dynamics Modeling System (CSDMS) Model Repository. Website: http://csdms.colorado.edu/wiki/Model:BRaKE

Thesis/Dissertations

Pandey, Sachin. *Advances in reactive transport modeling of geochemical systems: Applications to acid rock drainage and the evolution of the critical zone*. (2015). PhD thesis, Civil Eng, Univ of Colorado, Boulder. Acknowledgement of Federal Support = Yes

Feist, R.. *Determining the influence of transpiration on soil moisture pathways using electrical resistivity imaging*. (2015). MS thesis, Colorado School of Mines. Acknowledgement of Federal Support = Yes

Schneider, Dominik. *Estimating the Distribution of Snow with Remotely Sensed Fractional Snow Covered Area*. (2016). University of Colorado, Dept. of Geography, PhD dissertation. Acknowledgement of Federal Support = Yes

Foster, Melissa. *From the mountains to the plains: constraining the evolution of Front Range surfaces through Quaternary dating*. (2016). PhD thesis, Geological Sci, Univ of Colorado, Boulder. Acknowledgement of Federal Support = Yes

Bandler, A.. *Geophysical constraints on critical zone architecture and subsurface hydrology of opposing montane hillslopes*. (2016). MS thesis, Colorado School of Mines. Acknowledgement of Federal Support = Yes

Wilson, S.S.. *Groundwater-surface water exchange within montane and alpine regions of the Front Range and Rocky Mountains, Colorado*. (2015). MS thesis, Colorado School of Mines. Acknowledgement of Federal Support = Yes

Smull, Erika. *Physical and biological removal of nitrate along a Colorado montane headwater stream: Understanding the role of bidirectional hydrologic exchange at the reach to catchment scale*. (2015). M.S. Civil Engineering, Colorado State University. Acknowledgement of Federal Support = Yes

Wieting, C. *Quantifying Soil Hydraulic Property Changes with Fire Severity by Laboratory Burning*. (2016). MS thesis, Colorado School of Mines. Acknowledgement of Federal Support = Yes

Baker, Emily. *Quantifying forest mortality with the remote sensing of snow*. (2015). MA thesis, Dept of Geography, University of Colorado, Boulde. Acknowledgement of Federal Support = Yes

Winchell, Eric W.. *Understanding the geomorphic imprint of the Northern Pocket Gopher on the subalpine zone of the Colorado Front Range*. (2017). PhD thesis, Geological Sci, University of Colorado, Boulder. Acknowledgement of Federal Support = Yes

Mills, T. Joseph. *Water chemistry under a changing hydrologic regime: Investigations into the interplay between hydrology and water-quality in arid and semi-arid watersheds in Colorado, USA*. (2016). PhD thesis, Geography, University of Colorado, Boulder. Acknowledgement of Federal Support = Yes

Websites

Participants/Organizations

Research Experience for Undergraduates (REU) funding

Form of REU funding support:	REU supplement
How many REU applications were received during this reporting period?	41
How many REU applicants were selected and agreed to participate during this reporting period?	11
REU Comments:	Reporting on the RECCS REU program (EAR 1461281)

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Anderson, Suzanne	PD/PI	3
Anderson, Robert	Co PD/PI	1
Molotch, Noah	Co PD/PI	1
Rajaram, Harihar	Co PD/PI	1
Tucker, Gregory	Co PD/PI	1
Barnard, Holly	Co-Investigator	1
Doak, Daniel	Co-Investigator	1
Ebel, Brian	Co-Investigator	1

Name	Most Senior Project Role	Nearest Person Month Worked
Fierer, Noah	Co-Investigator	1
McKnight, Diane	Co-Investigator	0
Murphy, Sheila	Co-Investigator	1
Sheehan, Anne	Co-Investigator	0
Singha, Kamini	Co-Investigator	1
Templeton, Alexis	Co-Investigator	0
Carpenter, Eric	Other Professional	2
Chavez, Meghann	Other Professional	1
Langston, Abigail	Other Professional	0
Nadel, Hester	Other Professional	1
Rose, Alex	Other Professional	1
Taylor, Jennifer	Other Professional	1
Jensen, Clayton	Technician	12
Parrish, Eric	Technician	8
Rock, Nathan	Technician	12
Roth, Wendy	Technician	1
Stoffel, Chad	Technician	1
Tebbetts Fey, Jeri	Technician	12
Bandler, Aaron	Graduate Student (research assistant)	0
Barnhart, Theodore	Graduate Student (research assistant)	12
Brewer, Tess	Graduate Student (research assistant)	12
Bukoski, Isaac	Graduate Student (research assistant)	1
Eddy, Alex	Graduate Student (research assistant)	0
Feist, Rachel	Graduate Student (research assistant)	0

Name	Most Senior Project Role	Nearest Person Month Worked
Forrester, Chiara	Graduate Student (research assistant)	3
Foster, Melissa	Graduate Student (research assistant)	0
Glade, Rachel	Graduate Student (research assistant)	1
Hoffman, Claire	Graduate Student (research assistant)	1
Klein, Trevor	Graduate Student (research assistant)	3
Mills, Taylor	Graduate Student (research assistant)	1
Pandey, Sachin	Graduate Student (research assistant)	0
Rue, Garrett	Graduate Student (research assistant)	1
Rush, Michael	Graduate Student (research assistant)	12
Selander, Brittany	Graduate Student (research assistant)	3
Wilson, Sydney	Graduate Student (research assistant)	0
Winchell, Eric	Graduate Student (research assistant)	9
Glass, Jamie	Non-Student Research Assistant	7
Gulick, Emily	Non-Student Research Assistant	0
Cowell, Kristina	Undergraduate Student	6
Flechsenhaar, Jon	Undergraduate Student	0
Gill, Nagam	Undergraduate Student	4
Gupta, Amrita	Undergraduate Student	4
Heithusen, Brett	Undergraduate Student	0
Ragar, Dillon	Undergraduate Student	5
Straight, Joshua	Undergraduate Student	2
Barber, Jesse	Research Experience for Undergraduates (REU) Participant	0
Bean, Scott-Wesley	Research Experience for Undergraduates (REU) Participant	0

Name	Most Senior Project Role	Nearest Person Month Worked
Espinoza-Martinez, Amanda	Research Experience for Undergraduates (REU) Participant	0
Fish, Thomas	Research Experience for Undergraduates (REU) Participant	0
Gamora, Joey	Research Experience for Undergraduates (REU) Participant	1
Lindgren, Brett	Research Experience for Undergraduates (REU) Participant	0
Ross, Sean	Research Experience for Undergraduates (REU) Participant	1
Schoenfeld, Taylor	Research Experience for Undergraduates (REU) Participant	1
Thirouin, Kevin	Research Experience for Undergraduates (REU) Participant	1
VanderBurgh, Caihong	Research Experience for Undergraduates (REU) Participant	1

Full details of individuals who have worked on the project:

Suzanne P Anderson
Email: suzanne.anderson@colorado.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 3

Contribution to the Project: Management of the project. Hiring, supervising staff. Co-managed REU program (RECCS) with Lesley Smith and Anne Gold. Represented CZO at international level, including convening two AGU sessions (one Union session, available online "on demand"). Supervised three graduate students, several undergraduates.

Funding Support: NSF (this project) provides 1.5 months.

International Collaboration: Yes, France
International Travel: No

Robert S Anderson
Email: andersrs@colorado.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Executive committee member, CZSim team. Supervised 2 CZO grad students; co-supervised NSF post-doc Jill Marshall. Geochronology, geomorphology measurements and modeling.

Funding Support: NSF (this project) $1500

International Collaboration: No
International Travel: No

Noah P Molotch
Email: noah.molotch@colorado.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Supervised 1 CZO grad student. Co-supervised post-doc Dave Barnard. Co-supervising cross-CZO post-doc Adam Wlostowski with Ciaran Harman (Johns Hopkins). Snow hydrology, snow measurements, modeling.

Funding Support: NSF (this project) $1500

International Collaboration: No
International Travel: No

Harihar Rajaram
Email: hari@colorado.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Executive Committee member. Supervised CZO graduate student. Taught CZ graduate class on hydrologic modeling. Groundwater and reactive transport modeling.

Funding Support: NSF (this project) $1500

International Collaboration: No
International Travel: No

Gregory E Tucker
Email: gtucker@cires.colorado.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Executive Committee member. CZSim team. Supervised grad student; co-supervising NSF post-doc Jill Marshall. Landscape evolution modeling.

Funding Support: NSF (this project) $1500

International Collaboration: No
International Travel: No

Holly Barnard
Email: holly.barnard@colorado.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Research on ecohydrology, forest evapotranspiration. Co-Mentored CZO post-doc Dave Barnard (with Noah Molotch). Co-supervising CZO grad student (with Sheila Murphy)

Funding Support: NSF (this project) DOE

International Collaboration: No
International Travel: No

Daniel Doak

Email: daniel.doak@colorado.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Research on ecology, biological roles in transport processes; co-supervised CZO grad student.

Funding Support: NSF (this project) $1500

International Collaboration: No
International Travel: No

Brian Ebel
Email: bebel@usgs.gov
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Research on hydrology and response to extreme events.

Funding Support: USGS

International Collaboration: No
International Travel: No

Noah Fierer
Email: noah.fierer@colorado.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Research on microbial ecology. Supervising CZO graduate student, 2 CZO undergraduate researchers, and post-doc Paul Carini. Working with microbial ecologists, soil scientists, and biogeochemists from every CZO site to plan, coordinate, and implement a cross-CZO microbial ecology that spans all current CZO sites.

Funding Support: NSF (this project) $1500

International Collaboration: No
International Travel: No

Diane McKnight
Email: diane.mcknight@colorado.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Research on biogeochemistry and organic matter. Supervising one graduate student.

Funding Support: none

International Collaboration: No
International Travel: No

Sheila Murphy
Email: sfmurphy@usgs.gov
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Research on hydrology, geochemistry and disturbance. Five years of storm sampling have yielded an unprecedented post-fire water quality dataset and has allowed us to evaluate the effects of different types of storms on post-fire water quality. Supervised undergraduate researcher. Outreach with stakeholders, including the Congressional Research Service. co-supervising CZO grad student with Holly Barnard.

Funding Support: USGS NSF (this project)

International Collaboration: No
International Travel: No

Anne Sheehan
Email: anne.sheehan@colorado.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Research on applied geophysics

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Kamini Singha
Email: ksingha@mines.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Research on hydrogeology and geophysical measurements of the critical zone. Supervised 3 graduate students.

Funding Support: NSF

International Collaboration: No
International Travel: No

Alexis Templeton
Email: alexis.templeton@colorado.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

Contribution to the Project: Research on geobiology and incipient weathering

Funding Support: NSF

International Collaboration: No
International Travel: No

Eric Carpenter
Email: eric.carpenter@colorado.edu
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 2

Contribution to the Project: Education designer- K-12 outreach and teacher professional development

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Meghann Chavez
Email: meghann.chavez@colorado.edu
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 1

Contribution to the Project: Accounting technician for PI Suzanne Anderson

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Abigail Langston
Email: abigail.langston@colorado.edu
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 0

Contribution to the Project: Left Colorado in 2015.

Funding Support: none

International Collaboration: No
International Travel: No

Hester Nadel
Email: hester.nadel@colorado.edu
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 1

Contribution to the Project: Admin support for education outreach (Science Discovery)

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Alex Rose
Email: alexandra.rose@colorado.edu
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 1

Contribution to the Project: Manager for outreach Field science and Citizen science (5% time). Runs High School research experience in summer.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Jennifer Taylor
Email: jennifer.l.taylor@colorado.edu

Most Senior Project Role: Other Professional
Nearest Person Month Worked: 1

Contribution to the Project: Administrative support for REU site (NSF Award 1461281, REU Site: Research Experience for Community College Students (RECCS) in Critical Zone Science)

Funding Support: NSF (this project, and RECCS REU)

International Collaboration: No
International Travel: No

Clayton Jensen
Email: clayton.jensen@colorado.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Lab manager, sampling, data generation, and analysis

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Eric Parrish
Email: eric.parrish@colorado.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 8

Contribution to the Project: GIS-graphics specialist; web support; working on children's book

Funding Support: NSF (this project; CZO Integrated data management) and INSTAAR

International Collaboration: No
International Travel: No

Nathan Rock
Email: nathan.rock@colorado.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Field manager, sensor network and sampling, primary data generation

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Wendy Roth
Email: wendy.freeman@colorado.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 1

Contribution to the Project: Sediment lab coordinator; assisting with logistics of CZO NO Data Managers meeting July 2017.

Funding Support: NSF

International Collaboration: No
International Travel: No

Chad Stoffel
Email: chad.stoffel@colorado.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 1

Contribution to the Project: IT support

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Jeri Tebbetts Fey
Email: jeri.tebbetts@colorado.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Data manager; participates in cross-CZO data managers working group.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Aaron Bandler
Email: abandler@mymail.mines.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: Research on GPR and seismic anisotropy; completed MS thesis with K. Singha in 2016

Funding Support: Unfunded Colorado School of Mines student

International Collaboration: No
International Travel: No

Theodore Barnhart
Email: theodore.barnhart@colorado.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Research on hydrologic partitioning and snowmelt; cross-CZO work with Christina (Naomi) Tague, using RHESSys.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Tess Brewer
Email: Tess.Brewer@Colorado.EDU

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

Contribution to the Project: PhD research on microbial ecology and microbial function

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Isaac Bukoski
Email: ibukoski1@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Research on ecohydrology; starting July 2017

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Alex Eddy
Email: alex.eddy@colorado.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: Research on natural hazards. Worked on EarthLab project "Team Erosion" Left CU in 2016

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Rachel Feist
Email: rachel.feist@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: Research on tree transpiration and rock moisture movement, working with K. Singha, H. Barnard. Completed MS in 2015.

Funding Support: Colorado School of Mines

International Collaboration: No
International Travel: No

Chiara Forrester
Email: Chiara.Forrester@colorado.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Research on snow mold and N dynamics; partial support

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Melissa Foster
Email: melissa.a.foster@colorado.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: Research on Quaternary geology. Completed PhD with Bob Anderson in 2016. Lead 2016 Kirk Bryan Field Trip during GSA meeting to field sites in BcCZO.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Rachel Glade
Email: rcglade@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Hillslope geomorphology research

Funding Support: NSF

International Collaboration: No
International Travel: No

Claire Hoffman
Email: c.hoffman42@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Research on hydrology and weathering; starting July 2017

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Trevor Klein
Email: trevorik276@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Graduate student, worked on particulate C and hydrology. Left CU at end of 2016.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Taylor Joseph Mills
Email: taylor.mills@colorado.edu

Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Research on aqueous geochemistry, hydrology. Completed PhD with Suzanne Anderson in Fall 2016.

Funding Support: NSF (this project), US Geological Survey

International Collaboration: No
International Travel: No

Sachin Pandey
Email: sachin.pandey@colorado.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: Reactive transport modeling- set up Pflotran model for Gordon Gulch-type conditions. Completed PhD with Hari Rajaram in 2015.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Garrett Rue
Email: Garrett.Rue@Colorado.EDU
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Research on dissolved organic matter, especially in flood waters

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Michael Rush
Email: michael.rush-1@colorado.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Research on coupled thermo-hydrologic models incorporating snowmelt and PFLOTRAN. Involved in outreach with RECCS and Science Discovery.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Brittany Selander
Email: brittany.selander@Colorado.EDU
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Research on rock-dominated hillslopes; summer 2017 support

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Sydney Wilson
Email: sywilson@mymail.mines.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 0

Contribution to the Project: Research on Hyporheic exchange and groundwater infiltration, working with K. Singha, M. Gooseff. Completed MS in 2015.

Funding Support: Unfunded Colorado School of Mines student

International Collaboration: No
International Travel: No

Eric Winchell
Email: eric.winchell@colorado.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 9

Contribution to the Project: Research on bio-geomorphic interactions, mentoring REU students, involved in outreach. Completed PhD with Bob Anderson in 2017.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Jamie Glass
Email: ocepheus@gmail.com
Most Senior Project Role: Non-Student Research Assistant
Nearest Person Month Worked: 7

Contribution to the Project: Undergraduate work study field assistant. Graduated in Fall 2016, continued on as a field assistant.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Emily Gulick
Email: emily.gulick@colorado.edu
Most Senior Project Role: Non-Student Research Assistant
Nearest Person Month Worked: 0

Contribution to the Project: Completed senior honors thesis analyzing forest-meadow ecotones using aerial photography. Worked summer 2016 to extend her project over greater area in upper montane and sub-alpine forests of Boulder Creek.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Kristina Cowell
Email: Kristina.Cowell@Colorado.EDU
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 6

Contribution to the Project: Undergraduate work study field assistant; working on Senior thesis project

Funding Support: NSF (this project), CU Geography Department von Dreden Stacey fellowship

International Collaboration: No
International Travel: No

Jon Flechsenhaar
Email: Jon.Flechsenhaar@Colorado.EDU
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 0

Contribution to the Project: Undergraduate field assistant; now working for Niwot LTER

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Nagam Gill
Email: nagam.gill@colorado.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 4

Contribution to the Project: Undergraduate work study field assistant.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Amrita Gupta
Email: Amrita.Gupta@Colorado.EDU
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 4

Contribution to the Project: Undergraduate work study field assistant.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Brett Heithusen
Email: brett.Heitshusen@colorado.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 0

Contribution to the Project: Undergraduate work study field assistant. Graduated in 2016, left Colorado in spring 2016.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Dillon Ragar
Email: Dillon.Ragar@Colorado.EDU
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 5

Contribution to the Project: Undergraduate work study field assistant. Completed senior honors thesis in spring 2017 on black carbon in stream water following the Cold Creek fire in 2016. Graduated spring 2017.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Joshua Straight
Email: Joshua.Straight@Colorado.EDU
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Undergraduate work study field assistant.

Funding Support: NSF (this project)

International Collaboration: No
International Travel: No

Jesse Barber
Email: jbanddawn@att.net
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 0

Contribution to the Project: Research in summer 2016 with Theo Barnhart on assessing trends in forest type and density In the Boulder Creek watershed.

Funding Support: NSF1461281

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: Red Rocks Community College, Lakewood, CO
Government fiscal year(s) was this REU participant supported:

Scott-Wesley Bean
Email: scottwesleybean@gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 0

Contribution to the Project: Research with Noah Fierer and Tess Brewer on the microbial ecology of the atmosphere.

Funding Support: NSF1461281

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: Arapahoe Community College, Littleton, CO
Government fiscal year(s) was this REU participant supported:

Amanda Espinoza-Martinez
Email: amanda_espinozam@hotmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 0

Contribution to the Project: Research with Mike Gooseff on base flow hydrology in Gordon Gulch.

Funding Support: NSF1461281

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: Community College of Denver
Government fiscal year(s) was this REU participant supported:

Thomas Fish
Email: thomaswfish@yahoo.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 0

Contribution to the Project: Research with Theo Barnhart on assessing trends in forest type and density In the Boulder Creek watershed

Funding Support: NSF1461281

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: Community College of Aurora, Aurora, CO
Government fiscal year(s) was this REU participant supported:

Joey Gamora
Email: joeygomora@gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 1

Contribution to the Project: 2015 REU participant working on watershed hydrology with Mike Gooseff

Funding Support: Supplement to this grant (NSF)

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: Front Range Community College-Larimer
Government fiscal year(s) was this REU participant supported:

Brett Lindgren
Email: BrettLindgren87@gmail.com

Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 0

Contribution to the Project: Research with Dave Barnard on using laser scanning to quantify the interception of solar radiation by forest canopies

Funding Support: NSF1461281

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: Colorado Northwest Community College: Craig, CO
Government fiscal year(s) was this REU participant supported:

Sean Ross
Email: seanlross@gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 1

Contribution to the Project: Research w/Suzanne Anderson on rock weathering.

Funding Support: NSF1461281

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: Red Rocks Community College, Lakewood, CO
Government fiscal year(s) was this REU participant supported:

Taylor Schoenfeld
Email: teschoenfeld@student.cccs.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 1

Contribution to the Project: Research with Greg Tucker and Charlie Shobe on how large blocks of rock are distributed in river channels.

Funding Support: NSF1461281

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: Front Range Community College, Fort Collins, CO
Government fiscal year(s) was this REU participant supported:

Kevin Thirouin
Email: kevin.thirouin@gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 1

Contribution to the Project: 2015 REU researcher working with Dave Barnard and Holly Barnard, now supported by Supplement to this grant.

Funding Support: Supplement to this grant (NSF)

International Collaboration: No
International Travel: No

Year of schooling completed: Sophomore
Home Institution: Red Rocks Community College
Government fiscal year(s) was this REU participant supported:

Caihong VanderBurgh
Email: qiucaihong67@gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 1

Contribution to the Project: 2015 REU research with Noah Fierer, now supported by Supplement to this grant.

Funding Support: Supplement to this grant (NSF)

International Collaboration: No
International Travel: No
Year of schooling completed: Sophomore
Home Institution: Front Range Community College-Westminster
Government fiscal year(s) was this REU participant supported:

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
CIRES	Academic Institution	University of Colorado
Colorado School of Mines	Academic Institution	Golden, CO
Niwot Ridge LTER	Other Organizations (foreign or domestic)	Boulder, CO
United States Geological Survey	Other Organizations (foreign or domestic)	Boulder, CO

Full details of organizations that have been involved as partners:

CIRES

Organization Type: Academic Institution
Organization Location: University of Colorado

Partner's Contribution to the Project:
Personnel Exchanges

More Detail on Partner and Contribution: BcCZO-II is partnering with CIRES to run RECCS (Research Experience for Community College Students) in summers 2015-2017. Both groups are contributing to the considerable administrative and intellectual work required to support 10 community college students.

Colorado School of Mines

Organization Type: Academic Institution
Organization Location: Golden, CO

Partner's Contribution to the Project:
Collaborative Research
Personnel Exchanges

More Detail on Partner and Contribution: Professor Kamini Singha is a member of the team, and is spearheading work on geophysics and hydrogeology. She has several grad students (supported elsewhere) working in BcCZO.

Niwot Ridge LTER

Organization Type: Other Organizations (foreign or domestic)
Organization Location: Boulder, CO

Partner's Contribution to the Project:
Facilities
Personnel Exchanges

More Detail on Partner and Contribution: Boulder Creek CZO shares one field site- Green Lakes Valley- with the Niwot LTER. LTER personnel assist CZO personnel, and we are sharing some lab work. The CZO will augment instrumentation in the Niwot LTER- notably the met station in Green Lakes Valley

United States Geological Survey

Organization Type: Other Organizations (foreign or domestic)
Organization Location: Boulder, CO

Partner's Contribution to the Project:
Facilities
Collaborative Research

More Detail on Partner and Contribution: USGS scientists Sheila Murphy and Alex Blum are members of the team, and bring expertise in fires, hydrology, and geochemistry. Murphy has spearheaded monitoring in Fourmile Canyon in the wake of the 2010 Fourmile Canyon wildfire. Blum is a resource to many on mineralogy and geochemistry, and we use his lab. With Blum's retirement, and Brian Ebel's hire at USGS, we will transition to Ebel replacing Blum.

What other collaborators or contacts have been involved?
Nothing to report

Impacts

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

Work on microbes has potential to open up our understanding of microbial processes within the critical zone. A DNA sequencing technique we developed, coupled with quantification of relic DNA in soils, are allowing us to build field observations of living microbial communities over seasonal changes and nutrient dynamics. This work has been published in Nature Microbiology (Carini et al., 2016; Brewer et al., 2016).

Our genetic sequencing of a single group of bacteria within phylum Verrucomicrobia from1000s of soil samples is revealing the metabolic strategies of this ubiquitous group of soil microbes. A separate study of microbial communities colonizing bare rock surfaces (tombstones) around the world is directly relevant to understanding the microbial controls on weathering rates.

Our early attention to slope aspect and its manifestation in the subsurface, dating back to a 2009 AGU abstract (Anderson et al., 2009, Weathering, water, and slope aspect. *Eos Trans. AGU* 90 (52), Fall Meeting Suppl., Abstract EP53D-0639), has been followed by exploration of this concept in many ways, from chemical weathering, hydrologic, nutrient and physical weathering process variations. Slope aspect at one level is a natural experiment on climate effects, but at another it allows separation of sensible heat and radiation driven components of critical zone systems.

Snow, vegetation, and water supplies are intimately related to each other. Our work on snowmelt timing, vegetation impacts on snow accumulation, and snow impacts on vegetation greening contribute to the general understanding of these important interactions. Our papers on snow, runoff, and vegetation are among our most highly cited, and most likely to receive media coverage.

We continue to develop models of processes that shape the critical zone through the action of gravity, water, and thermal energy that lead the field. To date, we have modeled CZ evolution through frost cracking, hillslope denudation with explicit particle trajectories, bedrock channel incision—both with blocks as obstacles and with lateral bedrock incision, layered rock slope evolution (hogbacks), evolution of uplifted mountain blocks and their adjacent basins (range scale over orogenic time-scales), hydrochemical evolution of fractured rock, and glacier advance and decay. We are currently working on hydro-geochemical-geomorphic evolution of hillslopes, a model that will add to CZ evolution models used by the CZ community (topographic stress, “top-down” weathering, frost cracking, “bottom-up” water table control). This work influences understanding of hazards, interpretation of cosmogenic nuclide data used in quantifying ages and process rates, formation and transport of soil and sediment, and will lead to understanding iconic landscapes such as the Flatirons of the Front Range. One measure of the impact of this work is the Lifetime Achievement Award for Modeling, bestowed on Bob Anderson at the Community Sediment Dynamics Modeling System (CSDMS) Annual Meeting in 2017, and the Ralph Bagnold Medal in geomorphology awarded to Greg Tucker at the European Geosciences Union General Assembly in 2012. Greg Tucker will be the next Director of CSDMS, another indication of his stature in the surface processes modeling community.

What is the impact on other disciplines?

Critical zone science is, at its best, interdisciplinary. Our impact lies in the fact that geology-trained scientists are increasingly aware of and conducting research that involves biology (trees, microbes), and that biology-trained scientists are increasingly aware of the geologic context and impact of their research questions, and that hydrology-focused scientists address both deep time and biological connections in their work.

What is the impact on the development of human resources?

We have graduated 7 PhD and 9 Masters level scientists during this project, who are all trained in interdisciplinary critical zone science.

We have mentored >10 undergraduate researchers each year, most at the community college level, introducing them to both the world of scientific research and to the interdisciplinary approach of critical zone science.

What is the impact on physical resources that form infrastructure?

We have established two new National Atmospheric Deposition Program (NADP) sampling sites. One is in an urban area (city of Boulder), and the other is at a lower altitude than most NADP sites in Colorado. We are committed to maintaining these stations for at least two years.

What is the impact on institutional resources that form infrastructure?
Nothing to report.

What is the impact on information resources that form infrastructure?
Nothing to report.

What is the impact on technology transfer?
Nothing to report.

What is the impact on society beyond science and technology?
Nothing to report.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them
Nothing to report.

Changes that have a significant impact on expenditures
Nothing to report.

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.