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Preview of Award 1331828 - Annual Project Report

[Cover](#) |[Accomplishments](#) |[Products](#) |[Participants/Organizations](#) |[Impacts](#) |[Changes/Problems](#)

Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
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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
Recipient Organization:	University of Colorado at Boulder
Project/Grant Period:	10/01/2013 - 09/30/2018
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Submitting Official (if other than PD\PI):	Suzanne P Anderson Principal Investigator
Submission Date:	06/01/2016
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:

We accomplished the following:

1. Maintained year-round monitoring in three watersheds
2. Developed wireless networking of field instrumentation in Gordon Gulch
3. Maintained and augmented an integrated database, which includes 60 datasets, 27 of which are updated monthly, and 1 (Betasso meteorology) streams in real-time.
4. Published 16 journal papers, plus an additional 1 in press, 2 in review, and 1 preprint.
5. Graduated two PhD students (Melissa Foster and Sachin Pandey), five Masters students (Erika Smull, Sydney Wilson, Rachel Feist, Emily Baker, Aaron Bandler), and 2 undergraduate senior honors theses (Emily Gulick, Zach Brown)
6. Hosted Kangwon National University (South Korea) Critical Zone Research Frontier lab. A team of 8 visitors, led by Jin-Yong Lee, traveled to the US solely to spend 2 days with us to learn about the American CZOs, January 2016.
7. Held weekly lunch discussion meeting during the academic year, plus an annual science meeting in September.
8. Offered three different graduate classes: Earth's Critical Zone graduate class (taught by Suzanne Anderson), CZ Hydrologic Modeling graduate seminar (taught by Hari Rajaram), Lidar Remote Sensing of the Critical Zone graduate course (taught by Noah Molotch).
9. Ran extensive K-12, Community College, and teacher professional development outreach programs.
10. Goal 1, *Critical zone evolution*: Work on CZ evolution has focused on adding timing constraints through CRN dates on stream sediments and terrace gravels, modeling fluvial terrace formation, and work critical zone architecture. Team members: RS Anderson, K Singha, GE Tucker; grad students Abby Langston, Melissa Foster. **Three papers** (Langston et al., 2015; St. Clair et al., 2015; Foster et al., 2016) and **one commentary** (Anderson, 2015) published.
11. 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, Jill Marshall; grad students Tess Brewer, Charlie Shobe, Eric Winchell; undergrads Zach Hoepfner, Emily Gulick, REU students Sean Ross, Caihong van der Burgh, Taylor Schoenfeld, and Scott-Wesley Bean. **Five papers published** (Ebel et al., 2015; RS Anderson, 2015; Smets et al., 2016; Winchell et al., 2016; Shobe et al., 2016), and **one preprint** (Carini et al., 2016),

12. 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, Rachel (Feist) Mares, Aaron Bandler, Joe Mills, Theo Barnhart, Sydney Wilson, Joel Singly, Sachin Pandey; undergrad Kristina Cowell, REU students Joey Gamora, Kevin Thirouin, Amanda Espinoza-Martinez, Jesse Barber, Randall Rouse, and Brett Lindgren. **Eight papers published** (Broxton et al., 2015; Berryman et al., 2015; Stielstra et al., 2015; Murphy et al., 2015; Harpold and Molotch, 2015; Harpold et al., 2015; Creed et al., 2015; and Mares et al., 2016), and **three in review** (Barnhart et al.; Bandler et al.; Pandey and Rajaram).

Specific Objectives: Objectives from 2015 Annual Report, and progress in the last year:

1. Maintain field monitoring program.

- 1.1 Weekly sample collection in Betasso and Gordon Gulch maintained
- 1.2 Wireless networking of data-loggers in Gordon Gulch built by Nate Rock.
- 1.3 Installation of solar panels means fewer battery runs and less dropped data.

2. Research teams are working on:

Papers on history of exhumation (Foster, Anderson);

- 2.1 Dissertation completed: Foster (2016).
- 2.2 Paper published: Foster et al. (2016) on basin-averaged erosion rates.
- 2.3 Paper in prep: Foster et al. on punctuated incision revealed by river terraces on Lefthand Creek, for *Geomorphology*. Planned submission June 2016.
- 2.4 Paper in prep: Foster et al. on complex response of Front Range landscape to climate change.

Compiling data and maintaining sapflow, transpiration & rock moisture (Barnard, Barnard, Feist, Singha);

2.5 MS thesis completed: Feist (2015) on electrical resistivity imaging of sapflow.

2.6 REU student Kevin Thirouin working on transpiration and stream proximity

2.7 Post-doc Dave Barnard compiled sap flow data from the montane zone in BcCZO

Snowmelt partitioning into ET and runoff models and data, cross-CZO work (Barnhart and Molotch, D Barnard);

2.8 Collaboration with C. Tague (Southern Sierra CZO) on snowmelt partitioning and runoff models, using RHESSys

2.9 Using Livneh et al. (2015, *Science Data* 2, doi:10.1038/sdata.2015.42) dataset to elucidate the influence of snowmelt rate on streamflow production

Field work on ecogeomorphology (Winchell, R Anderson, D Doak, E Gulick);

2.10 Senior honors thesis completed: Gulick (2016)

2.11 Paper published: Winchell et al. (2016) on gophers and geomorphology

2.12 Student intern Emily Gulick working summer 2016 on documenting ecotone dynamics

Papers on hydrochemistry and hydrology of Gordon Gulch (Mills, S Anderson);

2.13 Collaboration with Lou Derry on Ge/Si and colloids in Gordon Gulch underway

2.14 Manuscripts on colloids in Gordon Gulch and on Gordon Gulch hydrochemistry in prep (summer 2016) by Mills and Anderson

Paper on exhumation using multiple isotope systems (S Anderson, Foster, Chabaux, R Anderson);

2.15 Manuscript in preparation

Microbial processes (Brewer, Fierer);

2.16 Paper preprint available: Carini et al. (2016) on relic DNA

2.17 Paper published: Smets et al. (2016) on 16S rRNA technique

2.18 Ongoing project on seasonal variability in soil microbial communities across different soil types, and how these correlate with shifts in nutrient dynamics

Reactive transport modeling in fractured system (Pandey, Rajaram);

2.19 Dissertation completed: Pandey (2015)

2.20 Paper submitted: Pandey and Rajaram submitted to Water Resources Research, on modeling preferential flow in fractured rock, and influence on weathering rates.

Hydrology & geochemistry following disturbance (Murphy, Ebel);

2.21 Paper published: Murphy et al. (2015) on water quality influenced by wildfire

2.22 Paper published: Ebel et al. (2015) on extreme rainfall

Dissolved organic matter (McKnight, Rue);

2.23 Analyses of DOM in Boulder Creek samples collected in 2013 storm completed.

2.24 Paper published: Creed et al. (2015) on DOM in rivers

Hyporheic exchange (Singha, Gooseff, Wilson);

2.25 MS thesis completed Wilson (2015)

2.26 REU student Joey Gamora working on hyporheic exchange in Gordon Gulch

Fracture characterization (Magill, Singha)

2.27 MS thesis completed: Bandler (2016)

2.28 Paper submitted: Bandler et al. to Hydrological Processes.

3. Run cross-CZO working Salon on Deep Critical Zone, June 14-18, 2015

3.1 Workshop held with 17 participants

3.2 AGU presentation: Anderson et al. (2015) Seeking GUTH, the Grand Unified Theory of Hillslopes: Linking weathering, erosion and landscapes.

3.3 Manuscript in preparation

4. Participate in REU Site for community college students (RECCS), training 5 community college students in STEM research in critical zone science

4.1 CZO team members mentored 5 students in summer 2015

4.2 Three RECCS students presented or were co-authors at AGU 2015

4.3 Three of the 2015 RECCS cohort are supported in 2016 by Supplemental funding to continue their research projects (Gamora, Thirouin, van der Burgh)

4.4 Eight CZO team members mentoring 7 students in summer 2016

5. Support K12 outreach programs of Science Discovery (STEM workshops for middle school students, teacher professional development, high school student research experience)

5.1 Eric Carpenter developed a new module “Exploring Erosion in the Critical Zone”, which introduces Lidar DEMs and how to make a DEM of difference to measure change.

5.2 A total of 1383 K-12 students reached in the last year, with 3311 total contact hours.

5.3 A total of 203 teachers participated, including 12 in a 3-day PD class.

Significant Results: Goal 1, *Critical zone evolution*:

Specific objectives: Papers on history of exhumation; Paper on exhumation using multiple isotope systems; Fracture characterization

Results: With the completion of Melissa Foster’s dissertation in January, 2016, we are now in a position to assemble a quantitative description of evolution of the Front Range landscape. The most recently published part of this analysis (Foster and Anderson, 2016) shows that basin averaged erosion rates determined from stream sediment ^{10}Be concentrations were not changed by the major storm of September 2013. The work constituted a field-test of the common assumption of steady erosion rates, and demonstrated that one significant erosion event does not change interpretations of this type of data. The reassuring finding of this work lends confidence in our interpretation of cosmogenic nuclide based analysis across the landscape, which will be forthcoming in two manuscripts, one tackling the history of fluvial incision of one channel, Left Hand Creek, on the Plains, and a second manuscript on the response times of different parts of the landscape (glacial headwaters, and the hillslopes and channels in granitic and shale

bedrock). We have argued in the past that erodibility and response time are key components of landscape evolution (Tucker and van der Beek, 2013), so this work will quantify these parts of the landscape. The timing constraints from cosmogenic nuclides have already been used to constrain a model of channel incision/floodplain widening devised by Abby Langston and published in Langston et al. (2015, *JGR*).

We contributed to the Science paper published by St Clair et al. (2015): BcCZO's Gordon Gulch was one of the field sites that formed the basis of this paper, team member Kamini Singha is a coauthor on the paper, and team member Bob Anderson wrote the Perspectives piece that accompanied the paper in Science. The finding of a surface parallel weathering front in Gordon Gulch by seismic refraction profiling contrasted with the deep weathering front under a ridge and shallow weathering front under a valley floor (the weathered-fresh rock interface essentially a mirror image of the surface topography) discovered at Calhoun CZO. The key idea in the St Clair et al. paper is that these differing patterns could be explained by topographic stress, a finding that suggests that regional tectonic stresses play a key role in setting the architecture of the critical zone. If correct, this finding again points to the importance of geologic history in the fundamental architecture of the critical zone.

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

Specific objectives: Fieldwork on ecogeomorphology, Microbial processes

Results: Our process studies have focused on biologic processes in the last year. Winchell et al. (2016) mapped pocket gopher activity for two years in meadows within the subalpine forest of the Front Range. The spatio-temporal data revealed that the 0.15 m thick "biomantle" (the part of the regolith churned by gophers) is turned over on century timescales, and suggests a diffusivity of 0.008 m²/yr. The gophers prefer meadow edges in winter, and move into the central parts of meadows in summer. The connection between gopher activity and migration of the forest-meadow ecotone remains to be discerned. A parallel project mapping these ecotones using ~70 years of aerial photography is ongoing (Gulick, 2015).

Understanding the role of microbes in critical zone processes will come into clearer view with some new techniques. Smets et al. (2016) developed a DNA sequencing-based approach to permit quantitative assessments of microbial abundances. This method is critical for more effectively linking DNA sequence-based information to rates of soil processes. Another approach identifies amounts of relic DNA found in soil (i.e. DNA not coming from living cells) and how this relic DNA can obscure estimates of microbial diversity and the taxonomic composition of soil microbial communities (Carini et al., 2016). Using this tool, the team is investigating 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.

A modeling paper (Anderson, 2015) animates the pathways of sediment in mobile regolith moving by slope-dependent transport processes. The model work was inspired in part by work elsewhere that presents net erosion as a mass loss independent of sediment transport on the slope, i.e. sediment is "vacuumed" or "ablated" off the top, rather than mass loss reflecting divergence of sediment flux

on the hillslope. The model has direct applications to interpretations of cosmogenic nuclide concentrations in sediment on hillslopes, and provides the context for understanding chemical evolution of soil on a slope.

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

Specific objectives: Snowmelt partitioning into ET and runoff models, Compiling data and maintaining sapflow, transpiration & rock moisture, Hydrology & geochemistry following disturbance, Hyporheic exchange, Dissolved organic matter, Papers on hydrochemistry and hydrology of Gordon Gulch, Reactive transport modeling in fractured system

Results: Many team members work on aspects of water flow and storage in the critical zone, so here we focus only on a few key results.

The most significant result this year is the publication of a paper on water quality following wildfire (Murphy et al., 2015). The paper is based on three years of high resolution monitoring of stream flow and water quality following the 2010 Fourmile Canyon wildfire. Brief, high intensity convective storms produced excursions of suspended sediment, dissolved organic carbon, nitrate and manganese concentrations that were 10-156 times greater below burned areas compared to above burned areas several times per year over the three years of record. Assessing and modeling post-wildfire stream response requires high frequency sampling and high density rain gauge networks (since convective storms tend to be localized). The findings are relevant to water supply in many areas where forested watersheds, high intensity rainstorms, and wildfire hazards coincide.

Across the western United States, Theo Barnhart has found that snowmelt rate controls streamflow production. Additionally, snowmelt rate has been found to be the dominant streamflow generating metric at point scales. Process modeling using RHESSys has also revealed a subsurface streamflow generation pathway linking snowmelt rate to streamflow generation.

Within and among CZO sites, Dave Barnard has identified a positive relationship between growing season length and forest growth and productivity. This is a curious finding that is in contrast and/or compliments the current understanding of these systems being primarily limited by soil moisture availability.

Sachin Pandey's dissertation in Fall of 2015 focused on reactive transport modeling in fractured rock. The modeling was inspired by the rock flow systems in crystalline rock in settings like Gordon Gulch and Betasso watersheds within BcCZO. As detailed in Pandey and Rajaram (in review), weathering in a discrete fracture network differs from that in a random permeability field, due to preferential flow through connected fractures. The departures can explain departures from chemostatic behavior of outflow.

Key outcomes or
Other achievements:

1. Wildfires can significantly impact water quality for years after the fire, influencing downstream public water supplies and aquatic ecosystems. Following the Fourmile Canyon wildfire in 2010, high intensity convective storms rather than snowmelt runoff produced the largest impacts on water quality. Forests act like "sponges" says Sheila Murphy, lead author of a paper published in 2015 documenting water quality impacts of the Fourmile Canyon wildfire (Murphy et al., 2015). About half the public water supply in the southwestern US comes from forested lands, which are vulnerable to wildfire.

The Fourmile Canyon wildfire study does not demonstrate the full potential threat, as only 23% of the watershed burned in 2010. A larger or more severe fire could have more deleterious effects.

2. "Miraculous Microbes" was the topic for three hour-long webinars for the general public delivered by team member Noah Fierer in winter of 2016. Some 60-100 participants attended each webinar, and they are still available for viewing at <http://cires.colorado.edu/outreach/projects/mysterious-microbes>. Webinar topics are: *Microbes and the miracle of compost tea*, *The emerging and exciting science of microbial research*, and *The secret life of microbes in and around our homes*. The webinar series was followed by a 2-day Mysterious Soil Microbes workshop in May 2016, open to anyone interested in soil. Educators could sign up for 1.0 hour of continuing education credit for the workshop, plus an additional 0.5 hours of credit for participating in the webinar series.
3. We all know that gophers leave dirt piles on the ground surface, but how much can these little rodents do? Researcher Eric Winchell measured and mapped gopher mounds in two subalpine meadows over two summers and can now answer that question. Each year gophers moved 1mm of sediment, averaged over the meadows Winchell studied. At this rate, gophers stir the entire 15 cm depth they burrow every 150 years. While this may seem slow to a gardener, it is relatively fast for a natural soil. The gophers preferred meadow edges in winter, probably because of greater snow depth and warmer soil temperatures there. Over the summer their burrowing activity shifts toward meadow centers. No gopher activity was noted in forests surrounding the meadows, which raises questions about sediment transport efficiency and soil development in these adjacent areas. The research is published in an article in *Geomorphology* in April 2016.

*** 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 participated in Hari Rajaram's Critical Zone Processes graduate seminar, and was a regular attendee to CZO lunch meetings.

Graduate student classes:

GEOG 5241: *Special Topics: Earth's Critical Zone* graduate class (taught by Suzanne Anderson); enrollment 8 students, Fall 2015

CVEN 5833: *Critical Zone Processes* graduate seminar (taught by Hari Rajaram); enrollment 5 students, Spring 2016

GEOG 5100: *Special Topics: Intro to Lidar Data Processing* graduate course (taught by Noah Molotch), enrollment 15 students, Summer 2014.

Undergraduates:

Participation in RECCS program (Research Experience for Community College Students in Critical Zone Science, NSF 1461281). In summer 2016, eight BcCZO-II faculty and students are mentoring 7 of the 10 student researchers.

REU supplement funding is being used to support three student researchers from the summer 2015 RECCS program to continue their research.

Two undergraduate senior honors theses completed at University of Colorado.

Suzanne Anderson led a field trip in the Boulder Creek CZO for an undergraduate geoscience field class from University of Nebraska, Omaha, reaching 20 students and 4 faculty members, May 17, 2016.

Sheila Murphy was interviewed by a student at the University Denver for an undergraduate project about the history, current issues, and conservation efforts related to Boulder Creek.

K-12 Teacher Professional Development classes:

Earth Systems Science Teacher Mountain Research Professional Development Workshop/Graduate Level Field Course (3-Day/24 Hour), July 26-28, 2016. Anticipated enrollment: 12 teachers.

Exploring Physical Science Teacher Professional Development Workshop and Exploring Erosion in the Critical Zone Workshop Module (2 Hour), March 20, 2016. Enrollment: 10 teachers.

K-12 Learners

1383 K-12 students participated in BcCZO-Science Discovery science outreach (<http://sciencediscovery.colorado.edu/program/school-teacher-programs/>) in the period June 2015-May 2016, in programs as follows:

- Exploring Physical Science STEM workshop and Exploring Erosion in the Critical Zone workshop (1.5 hours): 893 students, 172 teachers in 12 workshops
- Earth Systems Science classroom presentations (Foundations for Flow, Exploring Erosion in the CZ, or Ice, Snow and H2O) (1 hour) : 307 students, 15 teachers in 12 presentations
- Earth Systems Science STEM workshop (4.5 hours) : 79 students, 3 teachers in 2 workshops
- CZO classroom integration project and Materials loan program: 86 students, 1 teacher in 1 project
- Fire and Ice, Earth Systems Science Summer camp program, 5-day/15 hours): 6 students in 1 program
- High School Mountain Research Experience (5-day residential field program): 12 students in 1 program

Breakdown of 1383 K-12 students:

- 727 (53%) in rural areas
- 159 (11%) African-American or Latino
- 712 (51%) female.

BcCZO team members directly engaged in Science Discovery: Bob Anderson, Suzanne Anderson, Eric Winchell, Noah Molotch, Theo Barnhart, in addition to Alex Rose and Eric Carpenter, who work for Science Discovery.

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

Presentations at Conferences

We gave 32 presentations at professional science meetings around the world, including:

- AGU Fall Meeting, San Francisco, CA (14 presentations)
- GSA Annual Meeting (1 presentation)
- Goldschmidt Conference (2 presentations)
- EGU General Assembly (2 presentations)
- International Union of Geodesy and Geophysics General Assembly, Prague, Czech Republic (2 presentations)
- Western Snow Conference, Seattle, WA (2 presentations)
- National Association of Black Geoscientists Technical Conference, Houston, TX (1 presentation)
- National Groundwater Association Summit, Denver, CO (1 presentation)

These presentations are detailed under “Products” as “Other Conference Presentations/Papers”.

Other talks by team members:

1. ***Barnhart, T.B., N.P. Molotch**, B. Livneh, A.A. Harpold, J.F. Knowles, and D. Schneider, 2015, Rapid Snowmelt Leads to Greater Streamflow Across the Western United States, presented at the Universidad de Chile, Santiago, Chile, 29 Sept 2015.
2. **Murphy, S.F.**, 2015, Understanding water quality impacts—Boulder Creek case study: Guest speaker for University of Colorado massive open online course “Water in the Western U.S.” Boulder, Colo., April. Available online at <https://www.youtube.com/watch?v=0jsyq760-Kc>
3. **Molotch, N.P.**, Remote sensing and modeling of the mountain snowpack: tools for understanding the mountain water cycle under a changing climate, Portland State University, Portland, Oregon, 2 June.
4. **Molotch, N.P.**, Remote sensing and modeling of the mountain snowpack: tools for understanding the mountain water cycle under a changing climate, Oregon State University, Corvallis Oregon, 3 June.
5. **Anderson, S.P.**, NSF EarthCube Building Block: Earth System Bridge, Environmental Chemistry Names/Ontology Workshop, Boulder, CO, “Geochemistry Names: Geochemical data in the CZOs”, May 12, 2016
6. **Anderson, S.P.**, Montana State University, Department of Earth Sciences colloquium, “The long and the short of it: Frost cracking, debris flows, and critical zone architecture”, 14 April 2016.
7. **Anderson, S.P.**, University of Iceland, Faculty of Earth Sciences, Reykjavík, “Weathering in glaciated landscapes”, 4 March 2016.
8. **Anderson, S.P.**, University of Wisconsin-Madison, Department of Geosciences, Weeks Lecture Series, “The long and the short of it: Frost cracking, debris flows, and critical zone architecture”, 20 Nov. 2015.

Field trips

Suzanne Anderson led Kangwon National University researchers on field trip to Boulder Creek CZO, January 29, 2016. 4 faculty, 4 graduate students from South Korea.

Suzanne Anderson led Boulder Creek CZO field trip for University of Nebraska, Omaha students, May 17, 2016. 20 students, 4 faculty members.

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 2, 2016. 10 students.

Suzanne Anderson to lead a field trip, tentatively on June 9, 2016, of Boulder Creek CZO for visiting delegation from Chinese Geologic Survey and academic/research institutes. Plans are not confirmed as to date, size of tour group, who will be present, etc. The trip is part of an effort to learn how CZO sites operate.

Robert Anderson to lead field trip to Niwot Ridge, Boulder Creek CZO for Earth Systems Science Teacher Mountain Research Professional Development class, July 28, 2016. 12 teachers.

Stakeholder outreach

Sheila Murphy provided information on the management of Boulder Creek watershed in response to a request from the Congressional Research Service, May 27, 2015.

Noah Fierer and his lab gave a CIRES webinar series and workshop entitled "Mysterious microbes" (series of 3 online webinars, Jan-Mar, 2016 with 60-100 attendees per webinar, plus a 2-day workshop May 9-10, 2016, held for members of general public). See <http://cires.colorado.edu/outreach/projects/mysterious-microbes>

Noah Molotch co-organized a CIRES Western Water Assessment workshop titled “Snowpack monitoring for streamflow forecasting and drought planning”, aimed at communicating new snow research to water managers in Colorado, Utah, and Wyoming. Dates and links:

- Aug 11, 2015 in West Jordan, UT (>50 participants)
- <http://wwa.colorado.edu/events/workshops/UTsnow2015.html>
- Aug 27, 2015 in Lander, WY (50 participants)

- <http://wwa.colorado.edu/events/workshops/WYsnow2015.html>
- Sept 9, 2015 in Broomfield, CO (75 participants)
- <http://wwa.colorado.edu/events/workshops/COsnow2015.html>

Media: print and radio

Sheila Murphy was interviewed and quoted in a thinkprogress.org article, “The West Is Literally On Fire, And The Impacts Could Be Widespread,” by Natasha Geiling, July 1, 2015, available online at

<http://thinkprogress.org/climate/2015/07/01/3675710/western-wildfires-impacts/>

Sheila Murphy's work was featured in:

- USGS press release, “Storms after Wildfire Lead to Impaired Water Quality,” September 28, 2015. Available online at http://www.usgs.gov/newsroom/article.asp?ID=4342#.Vh6Lv_IVhBc
- “Fires, floods, and the future of water supplies in the southwestern U.S.” in the USGS Climate Research and Development Program newsletter “Climate Matters,” vol. 4, winter 2016. Available online at https://www2.usgs.gov/climate_landuse/clu_rd/pdfs/newsletterV4Winter2016.pdf

Suzanne Anderson interviewed on KUNC, Greeley public radio station, 9/10/15: <http://www.kunc.org/post/2013-s-historic-storm-caused-1000-years-erosion-boulder-canyon>

Suzanne Anderson's work on landslides in the 2013 Colorado storm was featured in Fall 2015 issue of *Research and Creative Work 2014-2015*, a magazine published by the University of Colorado Office of the Vice Chancellor for Research: <http://www.colorado.edu/vcr/sites/default/files/attached-files/2015%20Research%20Magazine.pdf>

Website

Content was created and/or updated and on many of the webpages at www.criticalzone.org/boulder. In particular, material found on menus for Research, Models, and Education/Outreach was updated in Fall 2015. (Review of these pages in May 2016 shows that continued updating is required!)

Social media presence

Fall AGU 2015 meeting presentation by Suzanne Anderson (Anderson S.P. et al., 2015) inspired a cartoon by blogger Miles Traer: <http://blogs.agu.org/geospace/2015/12/17/hillslopes-and-hobbes/>, was tweeted, and was included in the CU Geography Department spring newsletter to alumni and donors. See page 13: http://geography.colorado.edu/images/about_uploads/2016_Spring_Newsletter.pdf

PI *Suzanne Anderson* has been tweeting on CZ-related topics, including publications and accomplishments by our team. [Suzanne Anderson @Suzanne44827923](https://twitter.com/Suzanne44827923)

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.

- 2) Support cross-CZO postdoc on Hydrologic partitioning across the CZO Network, mentored by team member Noah Molotch and Ciaran Harman, Johns Hopkins University.
- 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) Team member 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) Lead Kirk Bryan field trip at the 2016 GSA Annual Meeting: Quaternary landslides, fluvial terraces, and recent geomorphic events along the Colorado Front Range. (Foster and RS Anderson)
- 8) Goal 1, *Critical zone evolution*:
 - Produce papers on complex response of post-Laramide landscape of the Front Range to climate change (RS Anderson, Foster, Tucker, SP Anderson), and on critical zone architecture from Deep CZ Salon (SP Anderson lead).
 - Conduct preliminary research on rock weathering on steep slopes (SP Anderson, with RECCS student Ross).
- 9) 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 (Fierer, Carini, Rue)
 - describe dominant soil microbial taxa and their physiological and ecological attributes. To date, this work has primarily focused on undescribed bacteria within the Verrucomicrobia phylum that appear to dominate many of the soils at the Boulder Creek CZO (Fierer)
 - exploratory field measurements of forces at the root-rock interface at both the Eel River and Boulder Creek CZOs (Marshall, Anderson)
 - 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, grad students Glade and Shobe, with RECCS student Taylor Schoenfeld, SP Anderson with RECCS student Ross and collaboration with Francis Rengers, USGS)
 - Measure forest canopy and its effects on radiation transfer (D Barnard with RECCS student Lindgren; T Barnhart with RECCS students Jesse Barber and Randall Rouse)
- 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 papers on seasonal variations and possible sources of colloidal silica in stream water, and concentration-discharge variations in major species (Mills, SP Anderson)
 - examine surface water-groundwater connections in Gordon Gulch (Gooseff with RECCS student Amanda Espinoza-Martinez and RECCS alum Joey Gomora)
 - submit papers on growing season length, climate, forest productivity, and carbon exchange, drawing on data from stem sap flow sensors throughout the montane zone in the BcCZO and eddy flux data from the Boulder Creek, Catalina-Jemez, and Southern Sierra CZOs (D Barnard, H Barnard, N Molotch)
 - 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.pdf	Contains responses to additional reporting requirements.	Suzanne Anderson	06/01/2016
RECCS summary for Annual report.pdf	Summary of participants in RECCS REU program	Suzanne Anderson	06/01/2016

Products

Books

Book Chapters

White, T., Brantley, S., Banwart, S., Chorover, J., Dietrich, W., Derry, L., Lohse, K., Anderson, S., Aufdenkampe, A., Bales, R., Kumar, P., Richter, D., and McDowell, B. (2015). The role of critical zone observatories in critical zone science. *Developments in Earth Surface Processes* 19. Elsevier. 15. Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1016/B978-0-444-63369-9.00002-1.

Inventions

Journals or Juried Conference Papers

*Bandler, A., *Magill, R. C., Hendricks, S., and Singha, K. (). Geophysical constraints on critical zone architecture and subsurface hydrology of opposing montane hillslopes. *Hydrological Processes*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

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

Anderson, R.S. (2015). Particle trajectories on hillslopes: Implications for particle age and ¹⁰Be structure. *Journal of Geophysical Research*. 120 1626. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.1002/2015JF003479

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

Berryman, E.M., Barnard, H.R., *Adams, H.R., *Burns, M.A., Gallo, E., and Brooks, P.D. (2015). Complex terrain alters temperature and moisture limitations of forest soil respiration across a semiarid to subalpine gradient. *Journal of Geophysical Research- Biogeosciences*. 120 707. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1002/2014JG002802

Broxton, P. D., Harpold, A, Biederman, J. A., Troch, P. A., Molotch, N.P., Brooks, P. (2015). Quantifying the effects of vegetation structure on snow accumulation and ablation in mixed-conifer forests. *Ecohydrology*. 8 (6), 1073. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: DOI: 10.1002/eco.1565

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. *bioRxiv preprint*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No ; DOI: http://dx.doi.org/10.1101/043372

Creed, I. F., McKnight, D. M., Pellerin, B. A., Green, M. B., Bergamaschi, B. A., Aiken, G. R., Burns, D. A., Findlay, S. E. G., Shanley, J. B., Striegl, R. G. (2015). The river as a chemostat: Fresh perspectives on dissolved organic matter

- flowing down the river continuum. *Canadian Journal of Fisheries and Aquatic Sciences*. 72 (8), 1272. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi.org/10.1139/cjfas-2014-0400
- Ebel, BA, Rengers, FK, and Tucker, GE (2015). Aspect-dependent soil saturation and insight into debris-flow initiation during extreme rainfall in the Colorado Front Range. *Geology*. 43 (8), 659. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1130/G36741.1
- Foster, M.A. and Anderson, R.S. (2016). Assessing the effect of a major storm on ¹⁰Be concentrations and inferred basin-averaged denudation rates. *Quaternary Geochronology*. 34 58. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.1016/j.quageo.2016.03.006
- Harpold, A. A., and N. P. Molotch (2015). Sensitivity of soil water availability to changing snowmelt timing in the western U.S.. *Geophysical Research Letters*. 42 8011. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1002/2015GL065855
- Harpold, A.A., J.A. Marshall, S.W. Lyon, T.B. Barnhart, B. Fisher, M. Donovan, K.M. Brubaker, C.J. Crosby, N.F. Glenn, C.L. Glennie, P.B. Kirchner, N. Lam, K.D. Mankoff, J.L. McCreight, N.P. Molotch, K.N. Musselman, J. Pelletier, T. Russo, H. Sangireddy, Y. Sjöberg, T. Swetnam, N. West (2015). Laser vision: Lidar as a transformative tool to advance critical zone science. *Hydrology and Earth System Science*. 19 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.5194/hess-19-2881-2015
- Harpold, A.A., N.P. Molotch, K.N. Musselman, R.C. Bales, P.B. Kirchner, M. Litvak, and P.D. Brooks (2014). Soil Moisture Response to Snowmelt Timing in Mixed-Conifer Subalpine Forests. *Hydrological Processes*. 29 (12), 2782. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1002/hyp.10400
- Hinckley, E-L, Anderson, SP, Baron, JS, Blanken, PD, Bonan, G., Bowman, WD, Elmendorf, S, Fierer, N, Fox, A, Goodman, K, Jones, K, Lombardozzi, D, Lunch, C, Neff, J, SanClements, M, Suding, K, and Wieder, W (2016). Optimizing available network resources to address questions in environmental biogeochemistry. *BioScience*. XX 1. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1093/biosci/biw005
- Langston, A, Tucker, GE, Anderson, RS, and Anderson, SP (2015). Evidence for climatic and hillslope-aspect controls on vadose zone moisture and saprolite weathering. *Earth Surface Processes and Landforms*. 40 1254. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.1002/esp.3718
- Langston, A.L., G.E. Tucker, R.S. Anderson (2015). Interpreting climate-modulated processes of terrace development along Colorado Front Range using a landscape evolution model. *Journal of Geophysical Research*. 120 2121. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.1002/2014JF003403
- Mares, R., Barnard, H.R., Mao, D., Revil, A., and Singha, K. (2016). Examining diel patterns of soil and xylem moisture using electrical resistivity imaging. *Journal of Hydrology*. 536 327. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.1016/j.jhydrol.2016.03.003
- Murphy SF, Writer JH, McCleskey RB, and Martin DA (2015). The role of precipitation type, intensity, and spatial distribution in source water quality after wildfire. *Environmental Research Letters*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1088/1748-9326/10/8/084007
- Pandey, S., and Rajaram, H. (2016). Modeling the influence of preferential flow on mineral weathering rates in the critical zone. *Water Resources Research*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Rajaram, H., and Arshadi, M. (). A similarity solution for reaction front propagation in a fracture-matrix system. *Phil. Trans. A* . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Shobe, C., G.E Tucker, and R.S. Anderson (2016). Hillslope-derived blocks retard river incision. *Geophysical Research Letters*. 43 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.1002/2016GL069262

Smets, W., J.W. Leff, M.A. Bradford, R.L. McCulley, S. Lebeer, N. Fierer (2016). A method for simultaneous measurement of soil bacterial abundances and community composition via 16S rRNA gene sequencing. *Soil Biology & Biochemistry*. 96 145. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.1016/j.soilbio.2016.02.003

St. Clair, J., Moon, S., Holbrook, W.S., Perron, J.T., Riebe, C.S., Martel, S.J., Carr, B., Harman, C., Singha, K., and Richter, D. deB. (2015). Geophysical imaging reveals topographic stress control of bedrock weathering. *Science*. 350 534. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.1126/science.aad2210

Stielstra, C.M., Lohse, K.A., Chorover, J., McIntosh, J.C., Barron-Gafford, G.A., Perdrial, J.N., Litvak, M., Barnard, H.R., and Brooks, P.D. (2015). Climatic and landscape influences on soil moisture are primary determinants of soil carbon fluxes in seasonally snow-covered forest ecosystems. *Biogeochemistry*. 123 447. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.1007/s10533-015-0078-3

Winchell, E.W., Anderson, R.S., Lombardi, E.M., and Doak, D.F. (2016). Gophers as geomorphic agents in the Colorado Front Range. *Geomorphology*. 264 41. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi: 10.1016/j.geomorph.2016.04.003

Licenses

Other Conference Presentations / Papers

Foster, M.A., Anderson, R.S., Gray, H.J., Mahan, S.A (2015). *Absolute dating of strath terraces along the western High Plains reveals complicated history of occupation and incision*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Bandler, A.* , Magill, R. C.* , Hendricks, S., Singha, K. (2016). *Aspect controls on bedrock fracturing and seismic velocity within the Boulder Creek Critical Zone Observatory*. National Groundwater Association Groundwater Summit. Denver, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Bandler, A.* , Magill, R. C.* , Hendricks, S., Singha, K. (2015). *Aspect controls on bedrock fracturing and seismic velocity within the Boulder Creek Critical Zone Observatory*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Bandler, A.* , Magill, R. C.* , Hendricks, S., Singha, K. (2016). *Aspect controls on weathering and permeability in the montane Critical Zone*. Symposium on the Application of Geophysics to Engineering and Environmental Problems. Denver, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hendricks, S.+ , Bandler, A.* , Singha, K. (2015). *Assessing aspect control on adjacent weathering hillslopes using seismic anisotropy velocity models within the Boulder Creek Critical Zone Observatory, Colorado*. Geological Society of America Annual Meeting. Baltimore, MD. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Gomora, J.A., Gooseff, M.N., and Smull, E.M. (2015). *Assessing stream-groundwater exchange in a headwater montane catchment in Colorado*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Smith, LK, Gold, AU, Anderson, SP, Taylor, J, Fierer, N, and Batchelor, R (2016). *Attracting Students Into Science: Insights From a Summer Research Internship Program for Community College Students in Colorado*. CIRES Rendezvous. Boulder, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Gold, A., L. Smith, S. Anderson, J. Taylor, R. Batchelor (2015). *Attracting Students Into Science: Insights From A Summer Research Internship Program For Community College Students In Colorado*. STEM Community College

Summit. Boulder, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

*Shobe, C., G. Tucker and R.S. Anderson (2015). *Big blocks and river incision: A numerical modeling perspective*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Molotch, N.P., D. Schneider (2015). *Combining ground-based observations, distributed models, and remotely sensed data for real-time SWE estimates*. International Union of Geodesy and Geophysics General Assembly. Prague, Czech Republic. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Marshall, Jill A. (2016). *Cracking the Critical Zone- How trees grow their own pot and influence landscape evolution*. European Geophysical Union General Assembly. Vienna, Austria. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Molotch, N.P., D. Schneider, (2015). *Establishing Transferable Sub-Pixel Relationships between Snow Depth, Snow Covered Area and Terrain Roughness*. International Union of Geodesy and Geophysics General Assembly. Prague, Czech Republic. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Winchell, Eric W., Robert S. Anderson, Elizabeth M. Lombardi, Daniel F. Doak (2015). *Exploring the landscape evolution of the subalpine meadow-forest system driven by the geomorphic work performed by the Northern Pocket Gopher*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Murphy, S., Martin, D., McCleskey, R., and Writer, J. (2015). *Factors Affecting Source-Water Quality after Disturbance of Forests by Wildfire*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Eldam, R.*, Navarre-Sitchler, A., Singha, K., Hinckley, E. (2015). *Geochemical depth characterization of the Boulder Creek CZO*. Goldschmidt Conference. Prague, Czech Republic. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Glade, R., and R.S. Anderson (2015). *Honoring the reality of blocky hillslopes: Case study of a vertical dike at Shiprock, New Mexico*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnard, D.M., H.R. Barnard, and N.P. Molotch (2015). *Montane forest transpiration activity and seasonality varies along an elevation gradient*. American Geophysical Union Fall meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Smull, E, and MN Gooseff (2015). *Nitrate removal along a Colorado montane headwater stream: The role of bidirectional hydrologic exchange at reach to catchment scales*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Anderson, R.S. (2015). *Particle trajectories on hillslopes: Implications for particle age and ^{10}Be structure*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Rajaram, H. and S. Pandey (2016). *Quantifying the influence of heterogeneity and preferential flow on the scale and time dependence of weathering rates*. EGU General Assembly. Vienna, Austria. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnhart, T.B., N.P. Molotch, B. Livneh, A.A. Harpold, J.F. Knowles, and D. Schneider (2015). *Rapid Snowmelt Leads to Greater Streamflow Across the Western United States*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnhart, T.B., N.P. Molotch, B. Livneh, A.A. Harpold, J.F. Knowles, and D. Schneider, (2016). *Rapid Snowmelt Leads to Greater Streamflow Across the Western United States, presented at the*. Western Snow Conference. Seattle, WA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Anderson, SP, Dietrich, WE, Rempe, D, West, N, Brantley, SL, Bacon, AR, Buss, HL, Fisher, BA, Flinchum, B,

Holbrook, S, Klos, PZ, Leopold, M, Moon, S, Nielson, T, Pelletier, J, and Terry, N (2015). *Seeking GUTH, the Grand Unified Theory of Hillslopes: Linking weathering, erosion and landscapes.*. AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnhart, T.B., Molotch, N.P., Livneh, B., Harpold, A.A., Knowles, J.F., Anderson, S.P., Bales, R.C., and Hunsaker, C.T. (2015). *Sensitivity of Hydrologic Partitioning to Snowpack Dynamics.* Western Snow Conference. Grass Valley, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnhart, T.B., B. Livneh, D.J. Gochis, and N.P. Molotch (2016). *Streamflow Sensitivity to Changes in Snowpack Across Trans-Basin Diversions.* University of Colorado Hydrologic Sciences Symposium. Boulder, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnhart, T.B., B. Livneh, D.J. Gochis, and N.P. Molotch (2016). *Streamflow Sensitivity to Changes in Snowpack Across Trans-Basin Diversions.* Water Sustainability and Climate Principle Investigator Meeting. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Sato, M.M., Shobe, C.M., and Tucker, G.E. (2015). *The influence of hillslope steepness on sediment supply size distribution along rivers draining the Colorado Front Range.* AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barnard, D.M., H.R. Barnard, and N.P. Molotch (2016). *Transpiration phenology along an elevational gradient in montane coniferous forests.* University of Colorado Hydrology Symposium. Boulder, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Sainvil, A., Voytek, E. *, Singha, K., Barnard, H. (2015). *Using the self potential method to analyze the spatial and temporal variation of shallow groundwater flow through meadows within the Boulder Creek Critical Zone Observatory in Boulder, Colorado.* Geological Society of America Annual Meeting. Baltimore, MD. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Sainvil, A.+, Voytek, E. *, Singha, K., Barnard, H. (2015). *Using the self potential method to analyze the spatial and temporal variation of shallow groundwater flow through meadows within the Boulder Creek Critical Zone Observatory in Boulder, Colorado.* National Association of Black Geoscientists Technical Conference. Houston, TX. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Fierer, N. (2015). *Verrucomicrobia and their role in soil methanol consumption.* AGU Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Marshall, J.A. (2015). *Which came first - trees, fractures or soils?.* SAVI Exploring Four Critical Puzzles about Trees, Water, and Soil: A Vision for Research. Penn State University. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Other Products

Audio or Video Products.

Virtual field trip to the Boulder Creek Critical Zone Observatory to accompany McKnight's Physical Geography, A Landscape Appreciation, 12th Edition, by Darrel Hess, published by Pearson. The video is by Michael Collier.

Students access virtual field trip videos through a QR link.

Link to the video is here: <https://mediaplayer.pearsoncmg.com/assets/secs-geog-mft-the-critical-zone>

Other Publications

Anderson, R.S. (2015). *Pinched topography initiates the critical zone.* Insights/Perspectives article published in Science to accompany St. Clair et al. (2015). doi: 10.1126/science.aad2266. Status = PUBLISHED; Acknowledgement of Federal Support = No

Patents

Technologies or Techniques

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

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*. (2015). 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

Burns, Margaret. *Hillslope Dissolved Organic Matter Transport and Transformation in a Semi-Arid Headwater Catchment*. (2014). MA thesis, Dept. of Geography, Univ. of Colorado, Boulder. Acknowledgement of Federal Support = Yes

Adams, Hallie R.. *Linking topography, hydrology, climate and ecology in semi-arid forests: Within catchment annual tree growth and water use efficiency*. (2014). MA thesis, Dept. of Geography, University of Colorado, Boulder. 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

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

Langston, Abigail L.. *The torrential and the mundane: Climate controls on hillslope weathering, channel bed material, and landscape evolution in the Colorado Front Range*. (2014). PhD thesis, Geological Sci, Univ 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? 37

How many REU applicants were selected and agreed to participate during this reporting period? 10

REU Comments: Reporting on the Research Experience for Community College

Students (RECCS) in Critical Zone Science project (NSF1461281), to which BcCZO provides staff support (~1 mo salary) and mentoring.

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
Fierer, Noah	Co-Investigator	1
McKnight, Diane	Co-Investigator	1
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)	6
Brewer, Tess	Graduate Student (research assistant)	12
Eddy, Alex	Graduate Student (research assistant)	9
Feist, Rachel	Graduate Student (research assistant)	6
Foster, Melissa	Graduate Student (research assistant)	7
Glade, Rachel	Graduate Student (research assistant)	1
Klein, Trevor	Graduate Student (research assistant)	2
Mills, Taylor	Graduate Student (research assistant)	6
Pandey, Sachin	Graduate Student (research assistant)	1
Rue, Garrett	Graduate Student (research assistant)	9
Wilson, Sydney	Graduate Student (research assistant)	1
Winchell, Eric	Graduate Student (research assistant)	12
Gulick, Emily	Non-Student Research Assistant	3

Cowell, Kristina	Undergraduate Student	5
Flechsenaar, Jon	Undergraduate Student	3
Gill, Nagam	Undergraduate Student	3
Glass, Jamie	Undergraduate Student	5
Heithusen, Brett	Undergraduate Student	4
Ragan, Dillon	Undergraduate Student	5
Barber, Jesse	Research Experience for Undergraduates (REU) Participant	2
Bean, Scott-Wesley	Research Experience for Undergraduates (REU) Participant	2
Espinoza-Martinez, Amanda	Research Experience for Undergraduates (REU) Participant	2
Fish, Thomas	Research Experience for Undergraduates (REU) Participant	2
Gamora, Joey	Research Experience for Undergraduates (REU) Participant	4
Lindgren, Brett	Research Experience for Undergraduates (REU) Participant	2
Ross, Sean	Research Experience for Undergraduates (REU) Participant	2
Schoenfeld, Taylor	Research Experience for Undergraduates (REU) Participant	2
Thirouin, Kevin	Research Experience for Undergraduates (REU) Participant	4
VanderBurgh, Caihong	Research Experience for Undergraduates (REU) Participant	4

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 (from CIRES). Taught graduate class "Earth's Critical Zone", Fall 2015. Represented CZO at international level, including travel to Sino-CZO workshop in Guiyang, China and helping to run CZO Town Hall meeting at Goldschmidt in Prague. Supervised three graduate students, four undergraduate researchers.

Funding Support: NSF (this project) pays 1.2 months.

International Collaboration: Yes, France

International Travel: Yes, China - 0 years, 0 months, 8 days; Czech Republic - 0 years, 0 months, 8 days

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-supervising 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, CZO post-doc. Attended CZO Strategic Planning meeting. Leading cross-CZO Post-doc initiative with Ciaran Harman (Johns Hopkins Univ). 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 graduate student working on reactive transport modeling. Taught CZ graduate class on hydrologic modeling, spring 2016. Groundwater and reactive transport.

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 CZO 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. Attended cross-CZO workshop on trees (Penn State). Co-Mentoring CZO post-doc Dave Barnard (with Noah Molotch).**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-supervising CZO grad student. Supervised CZO undergraduate honors thesis.**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: 1

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.

Funding Support: 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, worked with WyCHEG on work leading to St. Clair et al. paper in Science.

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: Getting out dissertation papers.

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 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; 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

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; assisted with logistics of CZO NO Strategic Planning meeting.

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: 6

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

Funding Support: Unfunded Colorado School of Mines student

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

Alex Eddy

Email: alex.eddy@colorado.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 9

Contribution to the Project: Research on natural hazards. Worked on EarthLab project (http://www.colorado.edu/geography/jkbalch/jkbp/profile/Earth_Lab.html) "Team Erosion"

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: 6

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

Melissa Foster

Email: melissa.a.foster@colorado.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 7

Contribution to the Project: Research on Quaternary geology. Completed PhD with Bob Anderson in 2016. Leading 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

Trevor Klein

Email: trevorik276@gmail.com

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 2

Contribution to the Project: New graduate student, working on weathering and hydrology.

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: 6

Contribution to the Project: Research on aqueous geochemistry, hydrology

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: 1

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

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: 9

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

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: 1

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: 12

Contribution to the Project: Research on bio-geomorphic interactions, mentoring REU students, involved in outreach

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: 3

Contribution to the Project: Completed senior honors thesis analyzing forest-meadow ecotones using aerial photography. Working for summer 2015 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:** 5**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:** 3**Contribution to the Project:** Undergraduate field assistant**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:** 3**Contribution to the Project:** Undergraduate work study field assistant.**Funding Support:** NSF (this project)**International Collaboration:** No**International Travel:** No

Jamie Glass**Email:** ocepheus@gmail.com**Most Senior Project Role:** Undergraduate Student**Nearest Person Month Worked:** 5**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:** 4**Contribution to the Project:** Undergraduate work study field assistant**Funding Support:** NSF (this project)**International Collaboration:** No**International Travel:** No**Dillon Ragan****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**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:** 2**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:** Red Rocks Community College, Lakewood, CO**Government fiscal year(s) was this REU participant supported:** 2016**Scott-Wesley Bean****Email:** scottwesleybean@gmail.com**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant**Nearest Person Month Worked:** 2**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: 2016

Amanda Espinoza-Martinez
Email: amanda_espinozam@hotmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 2

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: 2016

Thomas Fish
Email: thomaswfish@yahoo.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 2

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: 2016

Joey Gamora
Email: joeygomora@gmail.com
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 4

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: 2015

Brett Lindgren**Email:** BrettLindgren87@gmail.com**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant**Nearest Person Month Worked:** 2**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:** 2016

Sean Ross**Email:** seanlross@gmail.com**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant**Nearest Person Month Worked:** 2**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:** 2016

Taylor Schoenfeld**Email:** teschoenfeld@student.cccs.edu**Most Senior Project Role:** Research Experience for Undergraduates (REU) Participant**Nearest Person Month Worked:** 2**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:** 2016

Kevin Thirouin

Email: kevin.thirouin@gmail.com

Most Senior Project Role: Research Experience for Undergraduates (REU) Participant

Nearest Person Month Worked: 4

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: 2015

Caihong VanderBurgh

Email: qiucaihong67@gmail.com

Most Senior Project Role: Research Experience for Undergraduates (REU) Participant

Nearest Person Month Worked: 4

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: 2015

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?

Lou Derry, Cornell University

Jane Willenbring, Penn

EarthLab, University of Colorado initiative

Impacts

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

1. Work on **microbes** has potential to open up our understanding of microbial processes within the critical zone. A DNA sequencing technique we developed allows quantitative assessment of microbial abundances, and is critical for more effectively linking DNA sequence-based information to rates of soil processes. Coupled with quantification of relic DNA in soils, we are now developing field observations of living microbial communities over seasonal changes and nutrient dynamics.
2. 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.
3. **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. Team member Noah Molotch coordinated and participated in three workshops on these topics for water resource managers in 2015, reaching 50-75 participants in each state (Utah, Wyoming, and Colorado).
4. Model development on soil particle trajectories and on the impacts of block production on hillslope evolution and river incision are components of understanding **how rocky landscapes function as geomorphic systems**. This work influences understanding of hazards (rockfall and landsliding), of interpretation of cosmogenic nuclide data used in quantifying ages and process rates, and will lead to understanding iconic landscapes such as the Flatirons of the Front Range.

What is the impact on other disciplines?

Nothing to report.

What is the impact on the development of human resources?

1. We train graduate students and post-docs in interdisciplinary science. In the past year we offered three different graduate courses in aspects of critical zone science, graduated 2 PhDs (both now employed, M. Foster with US Bureau of Reclamation, S. Pandey with Los Alamos National Lab), and 4 Master's students.
2. We make a strong impact through the Research Experience for Community College Students in Critical Zone Science (RECCS). A student in the 2014 cohort (Patrick Marsden) has continued to work with his mentor, Noah Fierer, and is co-author on a paper (Carini et al., 2016). Three students in the 2015 cohort (Thirouin, Gomora, and van der Burgh) are supported by a supplement to continue their research in 2016. These alums help us to mentor the new student researchers, providing key near-peer support.
3. SP Anderson and the Boulder Creek CZO are featured in a video supplemental "virtual field trip" to Hess' Physical Geography: A Landscape Appreciation textbook, published by Pearson. This will reach a number of students of physical geography, and introduce the "big idea" of the critical zone to them. The videographer, Michael Collier, is now pursuing an effort to create a series of videos and educational program on the critical zone and all of the CZOs, which will spread this influence beyond the reach on one textbook.

What is the impact on physical resources that form infrastructure?

Boulder Creek CZO has added to its field instrumentation a wireless networking system.

What is the impact on institutional resources that form infrastructure?

Three Boulder Creek CZO team members (G. Tucker, R.S. Anderson, and S.P. Anderson) form "Team Erosion", one of eight core groups in the University of Colorado's new **Earth Lab** initiative (see

<http://www.colorado.edu/news/releases/2015/09/14/cu-boulder-announces-our-space-our-future>, and <http://www.colorado.edu/p1ff7b88f3a9/>). Earth Lab will harness big data observations of Earth from space and integrate them to answer outstanding questions about the pace and pattern of environmental change. Through Earth Lab, Team Erosion has hired a post-doc and a student intern to begin working with them. For starters, the team is using BcCZO lidar data and building on our work on landslides to learn more about site characteristics at debris flow initiation points.

What is the impact on information resources that form infrastructure?

Suzanne Anderson participated in NSF EarthCube Building Block: Earth System Bridge, Environmental Chemistry Names/Ontology Workshop, Boulder, CO, May 12, 2016. She represented the CZOs in a presentation on "Geochemistry Names: Geochemical data in the CZOs".

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.