Boulder Creek Critical Zone Observatory (BcCZO-II)
Annual report, year 2 (2015)

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

First (Middle)	Last	Project role	Disciplinary background,
Suzanne	Anderson	Principal Investigator	Geomorphology, weathering, hydrology
Greg	Tucker	Co-PI	Geomorphology, modeling
Harihar	Rajaram	Co-PI	Hydrology, reactive transport modeling
Robert	Anderson	Co-PI	Geomorphology, geochronology
Noah	Molotch	Co-PI	Snow hydrology
Holly	Barnard	Co-Investigator	Ecohydrology, forest evapotranspiration
Alex	Blum	Co-Investigator	Geochemistry and mineralogy
Daniel	Doak	Co-Investigator	Ecology, biological roles in transport processes
Noah	Fierer	Co-Investigator	Microbial ecology
Diane	McKnight	Co-Investigator	Biogeochemistry and organic matter
Sheila	Murphy	Co-Investigator	Hydrology, geochemistry, disturbance
Anne	Sheehan	Co-Investigator	Applied geophysics
Kamini	Singha	Co-Investigator	Hydrogeology and geophysics
Alexis	Templeton	Co-Investigator	Geobiology and incipient weathering
Dave	Barnard	Postdoctoral Fellow	Ecohydrology and snow
Meghann	Chavez	Other Professional	Accounting technician for PI Anderson
Chad	Stoffel	Technician	IT support
Nathan	Rock	Technician	Field manager, sensor network and sampling
Clayton	Jensen	Technician	Lab manager, sampling and analysis
Wendy	Roth	Technician	Sediment lab coordinator
Jeri	Tebbetts Fey	Technician	Data manager
Eric	Parrish	Technician	GIS-graphics specialist
Eric	Carpenter	Other Professional	Education designer- K-12 outreach and teacher professional development
Hester	Nadel	Other Professional	Admin support for education outreach
Alex	Rose	Other Professional	Manager outreach Field science and Citizen science
Jennifer	Taylor	Other Professional	REU coordination (RECCS program)
Melissa	Foster	Graduate Student (RA)	Soil geomorphology, mentor high school students
Taylor (Joe)	Mills	Graduate Student (RA, mostly USGS support)	Aqueous geochemistry, hydrology
Eric	Winchell	Graduate Student (RA)	Bio-geomorphic interactions
Sachin	Pandey	Graduate Student (RA)	Reactive transport modeling
Theodore	Barnhart	Graduate Student (RA, TA, RA on WSC grant)	Snow hydrology
Tess	Brewer	Graduate Student (RA)	Microbial ecology
Rachel	Glade	Graduate Student (summer RA)	Rocky hillslopes

Garrett	Rue	Graduate Student (RA summer)	Dissolved organic matter
Rachel	Feist	Graduate Student (unfunded; Mines)	Tree transpiration and rock moisture movement
Sydney	Wilson	Graduate Student (unfunded; Mines)	Hyporheic exchange and groundwater infiltration
Richard	Magill	Graduate Student (unfunded; Mines)	Fracture characterization in Gordon Gulch
Aaron	Bandler	Graduate Student (unfunded; Mines)	GPR and seismic anisotropy
Satya	Akquia	Undergraduate Student	Geog work study field assistant
Kristina	Cowell	Undergraduate Student	Geog work study field assistant
Brett	Heithusen	Undergraduate Student	Geog work study field assistant

Changes to personnel:

a) Adrian Harpold completed his NSF post-doctoral Fellowship, and is now an Assistant Professor at Univ. Nevada, Reno

b) BcCZO Post-doctoral Fellow Dave Barnard joined us in January 2015, mentored by Holly Barnard and Noah Molotch.

c) Christina Zetterholm (accounting technician) was replaced by Meghann Chavez in October 2014

d) Colin Millar (Lab manager) departed in November 2014; his position was filled temporarily by Theresa O'Halloran (January-May 2015), and permanently by Clayton Jensen in May 2015.

e) Val Sloan left to work at UCAR; we are spending that salary on Jennifer Taylor, who supports the Research Experience for Community College Students (RECCS) REU, a partnership with CIRES. Barbara Monday did this work in 2014.

f) Graduate students Rachel Gabor and Abigail Langston graduated; neither was supported in Yr 2

g) New graduate students: Theodore Barnhart, Tess Brewer; partial support for Rachel Glade, Garrett Rue.

h) Technician Kristen Medina and undergraduate workers Kelley Rich, Kelly Gjestvant, Fiona Maguire, Michael Johnson, William (Ryan) Currier, James Smith, and Devon Theune no longer work for BcCZO; we are currently recruiting for some replacements

i) REU participants Jorge Marquez, David Schellhase and Amanda Brenner completed the program in 2014; the REU students for 2015 arrive in June.

j) Scott Anderson completed work on landslides with us, took on a position at USGS Tacoma working on landslides

k) The following co-investigators have diminished roles: Alex Blum retired, Anne Sheehan is working primarily on other projects

l) Kamini Singha has a cadre of unfunded MS students working in BcCZO (Rachel Feist, Sydney Wilson, Richard Magill, Aaron Bandler)

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

Note: underlined and italicized section headings are taken from our proposal text.

Interface and Zone 1: Land Surface and Mobile Regolith R.S. Anderson, D. Doak, H. Barnard, N. Molotch, S. Murphy, A. Blum, G. Tucker, S.P. Anderson, D. McKnight, N. Fierer

Lumps and blocks: Patchiness in the landscape. R.S Anderson paper on lumpy nature of glaciated valley floors was published (Anderson, RS, *Geology*, 2015) on the lumpy, which reflects a combination of underlying fracture spacing and competing mechanisms of glacial erosion. With newly arrived (2014 fall) PhD student Rachel Glade, he is developing numerical models and field data sets that target the lumpy bedrock-dotted landscapes of the BcCZO. They will first approach the layered rocks at the edge of the high Plains, including both hogbacks and the flatirons that are the icons of the Boulder landscape, as a training ground to address how to include discrete blocks into our thinking and our numerical algorithms. This spawned a separate NSF/GLD proposal that has been identified as a project to be funded.

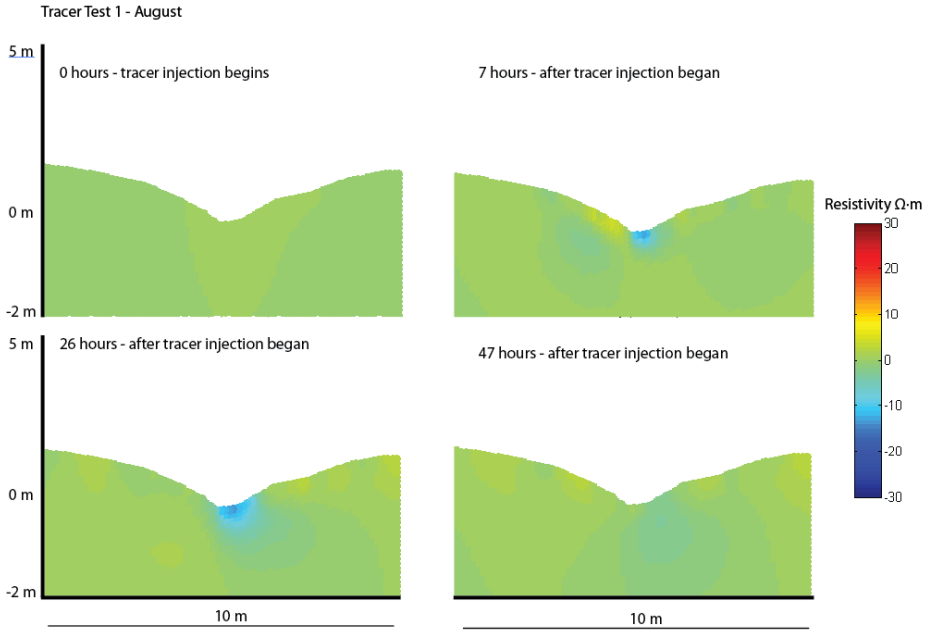
Transport of mobile regolith: The roles of biology. Both trees and gophers have been studied in the context of mobile regolith transport. PhD student Eric Winchell (who passed his PhD comprehensive exam 2015) is working with Bob Anderson and Dan Doak to document the spatial and temporal patterns of gopher activity in the meadows that dot the montane landscape characteristic of the BcCZO. Winchell has demonstrated that the intensity of the digging can explain the presence of "stonelines" reflecting century scale overturn of the top 20 cm of soil. That the spatial pattern of digging evolves over the summer from the edges of the meadows toward their centers inspired the hypothesis that the subsurface thermal and soil-moisture fields tightly control the location of gopher activity. The team is also developing data sets of tree age that can be combined with gopher herbivory to test a hypothesis that gophers play a key role in sharpening and maintaining the edges of meadows. Winchell mentored an REU student in summer 2014 (Jorgie Marquez), and will mentor another student in summer 2015 (Andrea Weber). In an associated effort, undergraduate researcher Emily Gulick is working with Dan Doak on a spatial analysis of boundaries between meadows and forests in the same setting as Winchell's study.

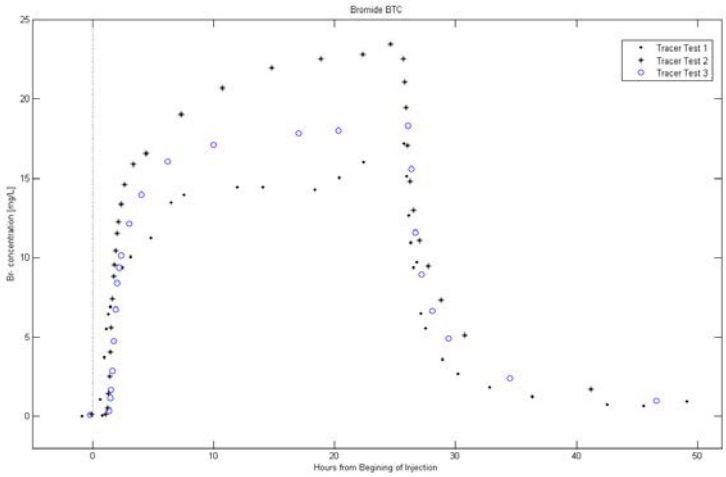
PhD student Eric Winchell in meadow site in late Fall 2014. Flags denote gopher mounds, colors each identify new mounds in any particular visit to the site.

Surface Hydrology: Infiltration, runoff, and water balance. We now have five complete water years of monitoring of snow, soil moisture, water table dynamics, and runoff in Gordon Gulch watershed through above-average, below average, and "normal" precipitation years. S.P. Anderson is analyzing these rich datasets to develop conceptual models of precipitation-runoff

in this watershed. She has a manuscript in preparation for submission in summer 2015 (Anderson, SP et al, *Water Resources Research*, in prep).

Colorado school of Mines graduate student Sydney Wilson is working with Kamini Singha and Mike Gooseff (faculty arriving at CU in July 2015), on hyporheic exchange and groundwater infiltration in Gordon Gulch. Hyporheic exchange and groundwater infiltration into the stream was estimated during the three tracer tests performed from August to November 2014. Preliminary results suggest little difference in transient zone storage during these months. Breakthrough curves from tests and geophysical images across the stream during the tracer test are below.

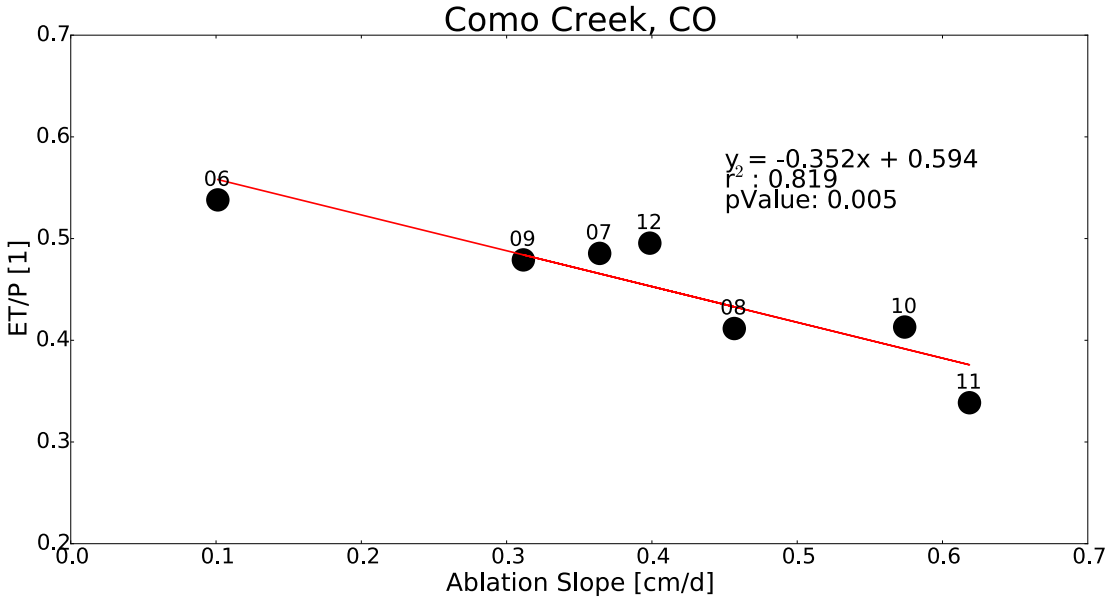




Snow in the BcCZO. Noah Molotch and graduate student Theo Barnhart are exploring the response of evapotranspiration and streamflow to shifts in snowmelt timing and rate. They have

compiled observations of evapotranspiration from eddy covariance and snowpack measured at a co-located snow pillow and ultrasonic snow depth sensors from a forested site on Niwot Ridge, CO. These analyses explore the sensitivity of hydrologic partitioning of snowmelt between runoff and evapotranspiration using interannual variability. Analysis of adjacent soil moisture data allows hypothetical mechanisms of snowmelt driven runoff generation to be tested. A comparative data set at Providence Creek in the Southern Sierra CZO is available, enabling a cross-CZO comparison. Complementary to the observational data analysis, the Regional Hydro-Ecologic Simulation System (RHESSys) is being used to test a wide range of snowmelt scenarios. Calibrated simulations of Como Creek on Niwot Ridge are underway, which prepare them for model testing.

Preliminary results show that growing season partitioning of snowmelt between evapotranspiration and runoff is strongly controlled by the ablation slope (i.e. the intensity of snowmelt). This suggests that rapid snowmelt is better able to overwhelm atmospheric demand and bring the soil to field capacity, causing recharge and generating streamflow.



The intensity of snowmelt (ablation slope) controls how snowmelt is partitioned between evapotranspiration (ET) and runoff. Data are normalized by annual precipitation (P).

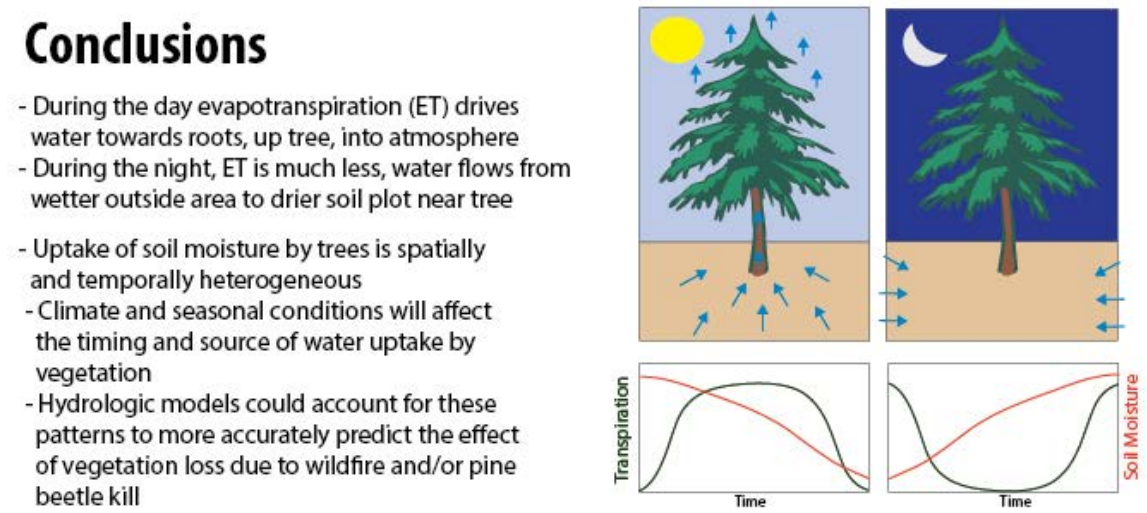
Using a space for time substitution and the Variable Infiltration Capacity (VIC) Model they see the same pattern across the mountainous, runoff producing regions of the western United States. Relative to the Budyko Framework, model grid cells with more rapid snowmelt over-produce runoff relative to the Budyko curve.

BcCZO Post-doctoral Fellow Dave Barnard is working with Toby Minear (USGS) to image (LiDAR) and characterize forest canopy temperature and radiation transfer to better inform snow pack energy balance computations under canopy cover.

Forest Evapotranspiration (ET). Holly Barnard student Hallie Adams published her MA thesis work (Adams et al., Ecosphere, 2014) on tree growth rates. BcCZO Post-doctoral Fellow Dave Barnard is working on questions concerning the influence of site elevation, aspect, and snow cover persistence on tree sapflow (i.e. transpiration) at three sites in the Boulder Creek CZO and an additional sub-alpine site near the Niwot Ridge LTER. These questions will lead to better knowledge of the role of vegetation transpiration on the hydrologic cycle and water cycle investigations. He is compiling sapflow, snow depth and meteorological data from Betasso, Gordon Gulch and Niwot Ridge, and will continue to monitor and upkeep sapflow collection sites throughout the remainder of 2015. Data analysis is underway and a manuscript

is expected by early September.

Colorado School of Mines (Mines) grad student Rachel Feist, working with Kamini Singha and Holly Barnard, is investigating the role of tree transpiration in soil and rock moisture movement- see Figure below.



The role of disturbance. Sheila Murphy continues monitoring runoff and water quality in the burned areas within the Boulder Creek Watershed to evaluate recovery from wildfire and flooding. She has instrumented three sites with continuous monitoring of turbidity, specific conductance, and discharge, and will again collect storm samples to correlate with the continuous monitoring. This work will enable us to assess the climate and hydrological conditions under which solutes and sediment are transferred to the stream.

Substantial hydrologic and geochemical responses downstream of a burned area were primarily driven by convective storms with a 30-minute rainfall intensity >10 mm h^{-1}. These storms, which typically occur several times each year in July-September, are often small in area, short-lived, and highly variable in intensity and geographic distribution. We measured total suspended sediment, dissolved organic carbon, nitrate, and manganese concentrations that were 10 to 156 times higher downstream of a burned area compared to upstream during relatively common rainstorms, and water quality was sufficiently impaired to pose water treatment concerns. Short-term water-quality impairment was driven primarily by increased surface runoff during higher intensity convective storms that caused erosion in the burned area (including from historical mining waste), and transport to streams. Annual sediment yields downstream of the burned area were controlled by storm events and subsequent remobilization, whereas dissolved organic carbon yields were closely linked to annual runoff and thus were more dependent on interannual variation in spring runoff. Nitrate yields were highest in the third year post-wildfire. We have demonstrated that water quality can be altered for several years after wildfire.

Unanticipated opportunities from the September 2013 storm. We pushed hard to use LiDAR data to analyze landsliding in the storm. Researcher Scott Anderson, hired under the auspices of a RAPID grant, used FEMA LiDAR data collected in November 2013 and the BcCZO LiDAR data from August 2010 to compute a DEM of difference. The results, published in Anderson et al. (2015, Geology), showed 15 mm of lowering on average in basins with failures in crystalline rock. This is equivalent to ~400 years of denudation based on basin-averaged ^{10}Be rates. Scott Anderson took a job with the USGS (Tacoma) working on

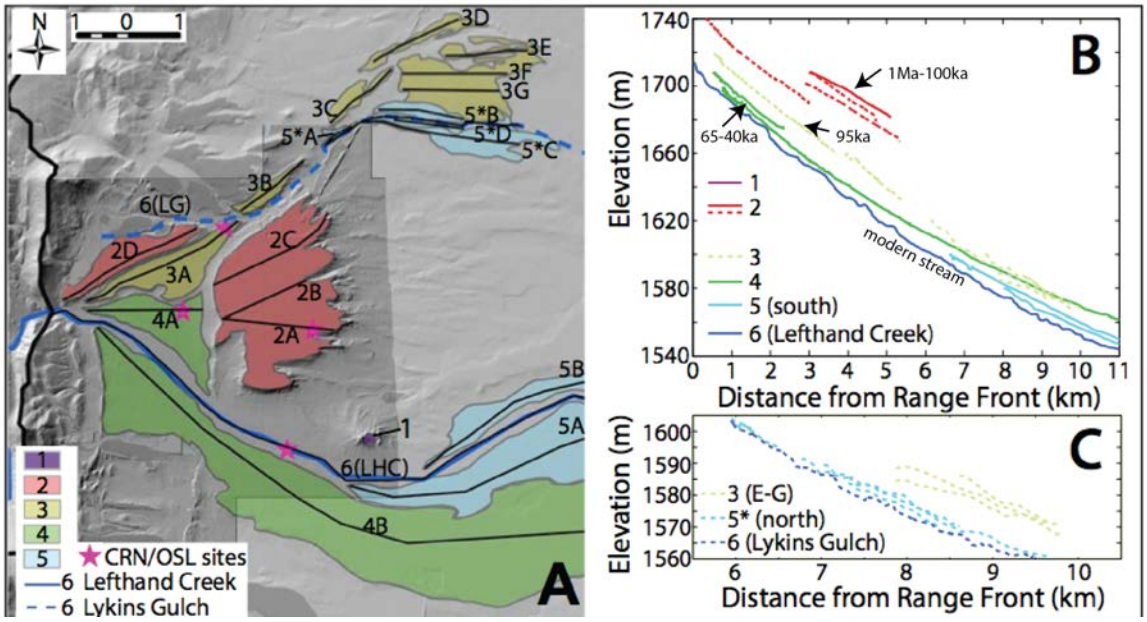
landslides in September 2014, and so has not continued working on the BcCZO datasets. REU student Dave Schellhase analyzed the velocity of debris flows from field evidence in several debris flow chutes. His data have been incorporated into a laboratory exercise used by SP Anderson in her Geomorphology class.

Water samples collected at locations we could access during and immediately following the storm (many roads were closed), are still being processed. Graduate student Garrett Rue will complete dissolved organic matter analysis of filters and frozen samples in summer 2015. The groundwater well at Betasso created from our "drill-the-ridge" coring project in January 2013 yielded important data on the groundwater response to this event, which we continue to follow. CU undergraduate student Satya Akquia is completed a senior thesis on breakdown of shale clasts such as were found on floodplains of rivers on the Plains following the storm.

Interface 2: Base of mobile regolith and weathered rock/saprolite R.S. Anderson, G. Tucker, S.P. Anderson

Lowering rates. Graduate student Melissa Foster, working with R.S. Anderson and S.P. Anderson has completed analysis of ^{10}Be samples to determine denudation rates at our Betasso field site. This cosmogenic radionuclide (CRN) data will complement U-series analyses that collaborator François Chabaux (Univ. Strasbourg, France) has done. A manuscript is now in preparation on the combined ^{10}Be and U-series analyses. This work was presented at the EGU General Assembly in 2015 (Anderson SP et al., Pelt et al). Meanwhile, Foster et al. (2015, GSA Bulletin) on denudation in Gordon Gulch was published.

Melissa Foster and Bob Anderson have completed the analysis of the incision history of Lefthand Creek and associated strath terraces (Foster et al., in prep for *EPSL*). This importantly constrains longterm erosional history on the edge of the High Plains, which in turn governs the boundary condition for the master streams draining the crystalline core of the Front Range. These record a punctuated erosional history in which bedrock-cut (strath) terraces broaden through time by lateral erosion of shale rock valley walls, and are occupied by the streams and associated alluvial deposits for tens to hundreds of thousands of years before being abandoned by vertical incision into the shale. This work reconciles age estimates based upon the degree of development of soils on these surfaces, with the cosmogenic radionuclide-based ages (including ^{10}Be, ^{26}Al).



Terrace sites on Lefthand Creek, north of Boulder at the edge of the High Plains. Colors denote terraces of different elevations, the upper three having been dated using CRNs and OSL. Ages and durations of occupation are noted on

the long profiles of the terraces in the upper right plot. (from Foster et al., in prep.)

Rock fracture and Entrainment. We do not have any graduate students working on these topics at present. Kamini Singha has begun a collaboration with external investigators Taylor Perron (MIT) through an Army grant, and with Steve Martel (U Hawaii) and Steve Holbrook (U Wyoming) in which the role of sheet fracturing and topographic stress was explored in Gordon Gulch in summer 2014. A manuscript is in preparation.

Hydrology and chemical weathering of saprolite. Graduate student Joe Mills, working with S.P. Anderson, is writing a manuscript on several years of water chemistry from Gordon Gulch watershed (stream, groundwater, springs, precipitation, snow, and a small number of lysimeter samples) to examine the interplay of weathering and water flow paths in the watershed. Graduate student Sachin Pandey, working with Hari Rajaram, set up the reactive transport model PFLOTRAN for chemical weathering in fractured rock. Modeling results demonstrate the time-dependence of weathering rates induced by transport limitations in fractured rock. As primary minerals become depleted near the fracture-matrix interface, diffusion limitations result in slower bulk weathering rates. A manuscript is in preparation.

Interface 3: Deep Weathering Front A. Templeton, N. Fierer, K. Singha, D. McKnight, H. Rajaram, A. Sheehan, S.P. Anderson

A key set of questions about the deep critical zone revolves around the roles of microbes in the chemical evolution of rock far below the surface. Noah Fierer and grad student Tess Brewer are working on microbes in soils. Tess is trying to understand the dominant Verrucomicrobia found in the Gordon Gulch subsurface horizons. She now has the genome from this bacterium and is using the genome to investigate its physiological capabilities. She is also trying to grow this bacterium in the lab with the ultimate goal of figuring out why it is so abundant in the BcCZO soils and its roles in soil biogeochemistry.

In another project, Tess Brewer is investigating the diversity and function of microbial communities associated with rock surfaces across the globe. To do this, she collected samples from the surfaces of >250 tombstones across North America, South America, and Europe. She has found strong effects of sampling location, rock type, and tombstone age on the types of microbes found on the tombstone surfaces. She is currently investigating in more detail how rock type influences the functional capabilities of these communities with the goal of understanding microbial metabolic strategies associated with mineral weathering.

CS Mines graduate student Richard Magill is working with Kamini Singha, Taylor Perron and Steve Martel on fracture characterization in Gordon Gulch. Seven boreholes (6-12 m deep) have been logged with optical televiewer and gamma.

Steve Holbrook (WyCEHG) found much less spatial variation in depth to fresh rock in Gordon Gulch relative to the relief than they saw in the Calhoun CZO and elsewhere. This supports an analysis of weathering slaved to topographic stress derived by Steve Martel, Taylor Perron, and Seulgi Moon. A manuscript is in preparation.

Science Implementation: Integrative activities

We set out modeling objectives in our proposal that will integrate across the interfaces discussed above, and across disciplinary boundaries (e.g., geomorphology, hydrology, geobiology, ecohydrology). We laid out plans for integrative modeling in three areas: water, landscape evolution, and future-casting. At this point, our integrative modeling efforts have been directed primarily at landscape evolution. Two manuscripts are in advanced stages that integrate in differing ways. Abigail Langston developed a model of the genesis of terrace

flights along the foothills of the Front Range. A landscape evolution model was used to map out the consequences of three alternative mechanistic hypotheses for the origins of flights of gravel-capped strath terraces along the fringes of the Colorado Front Range. Her manuscript (Langston, A.L., G.E. Tucker, R.S. Anderson, Interpreting climate-modulated processes of terrace development along Colorado Front Range using a landscape evolution model) was submitted to JGR-Earth Surface in February 2015, and a revision was submitted in May 2015. Melissa Foster has been building histories of exhumation through several chronometers applied to features on the Plains. She has one manuscript that will be submitted by June 1, 2015 (Foster, M., Duhnforth, M., Gray, H., Anderson, R.S., Incision of Lefthand Creek, Colorado as constrained by ^{10}Be , ^{26}Al and OSL profiles, for *ESPL*), and is working on a second manuscript that will integrate our understanding of exhumation from the Plains to the Continental Divide for *Geology* by July 2015.

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

K-12 outreach

With CU's Science Discovery, we offer an Earth Systems Science STEM workshop for students and teachers (in 1-hour, half-day or full day formats), a 5-day summer camp for middle school students, a 5-day summer research experience for high school students, and a 3-day teacher professional development course. Total numbers for the period June 2014-June 2015 are as follows:

1st-12th Grade Learners: 679
College-Aged Learners: 7
K-12 Teachers and Professionals: 47
Total Contact Time: 2226.5 hours

Formats:
2 Science Explorers and STEM Workshops
20 Classroom Presentations
3 Teacher Professional Development Opportunities/Workshops
2 Science Discovery Summer Camp Programs

BcCZO faculty and researchers who contributed to Science Discovery programs: Bob Anderson, Eric Winchell, Hallie Adams, Sheila Murphy, Melissa Foster, Suzanne Anderson

Post-doc training

BcCZO Post-doctoral Fellow Dave Barnard arrived in Boulder in January 2015 for a two-year fellowship. He is co-mentored by Holly Barnard and Noah Molotch, and has met with each of them on a regular basis for science and career advising. In addition, PI Suzanne Anderson has met with Dave both formally and informally during his tenure.

REU program

A pilot REU program run in summer 2014 on supplement funds to BcCZO and support from the CIRES Director's Fund launched a program called *RECCS: Research Experience for Community College Students*. CIRES staff Lesley Smith and Anne Gold used that pilot program to craft a successful REU Site proposal (NSF1461281, REU site: Research Experience for Community College Students (RECCS) in Critical Zone Science). BcCZO is supporting the REU site through salary for administrative staff (Jennifer Taylor), and supplying mentors for about half of the 10 participants. BcCZO faculty and grad students mentoring REU students in

summer 2015 are: Bob Anderson, Holly Barnard, Dave Barnard, Noah Fierer, Mike Gooseff, Diane McKnight, Greg Tucker, and Eric Winchell. PI Suzanne Anderson is leading a field trip for participants on June 11, 2015, and will hold weekly brown bag lunches with the students when her travel schedule permits.

SP Anderson presented a poster on the pilot REU program at the AGU Fall Meeting:

Anderson, SP, Smith, L, Gold, AU, Batchelor, R, and Monday, B (2014): Attracting students into science: Insights From a Summer Research Internship Program for Community College Students in Colorado. *Eos Trans. AGU* 95 (52), Fall Meeting Suppl., Abstract ED31A-3426.

Student Training

PI Bob Anderson offered graduate seminar on "Weathering & geomorphology in the Critical Zone" in spring 2015 (1 cr; ~12 attended each week, 5 for credit)

BcCZO funding has been used to train 6 graduate students in Geological Sciences, Geography, Molecular, Cellular and Developmental Biology, and Environmental Studies. Colorado School of Mines has an additional 4 graduate students (unfunded) engaged in BcCZO research.

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

1) Graduate student Theodore Barnhart (mentored by Noah Molotch) is spending summer, 2015, at UC Santa Barbara to work with Christina Tague of the Southern Sierra CZO as part of a cross-CZO effort comparing snow, evapotranspiration, and streamflow data and model results at Providence Creek (SSCZO) and Como Creek (BcCZO). Anticipated products:

A cross-CZO publication examining how the sensitivity of hydrologic partitioning of snowmelt changes across sites.

A manuscript on RHESSys model calibration, and model experiments on snowmelt rate and timing.

2) Jill Marshall was awarded an NSF-Postdoctoral Fellowship, to begin in summer 2015, on "Cracking the critical zone: tree roots in fractures and hypothesized limits to bio-physical weathering –towards a mechanistic soil production law". Jill will spend several weeks in Boulder in July 2015 as part of this project, which also connects with efforts at Eel River CZO and Southern Sierra CZO.

3) Suzanne Anderson is leading the *Deep Critical Zone Salon* with Sue Brantley (Penn State, Shale Hills and Luquillo CZOs), Daniella Rempe (Eel River CZO), and Nikki West (Shale Hills CZO). This cross-CZO workshop, which grew out of the Critical Zone Architecture theme breakout group meeting at the Yosemite CZO All Hands meeting in October 2014, will bring 17 researchers together representing 13 sites (8 CZO and 5 non-CZO sites). The group will meet June 14-18, 2015 at Snow Mountain Ranch, Colorado to compare data, share hypotheses for deep critical zone evolution, and begin writing paper(s?) that outline commonalities, differences, and ways forward through either modeling, filling data gaps, or analyzing existing data. This workshop is hosted by BcCZO, and funded by workshop funds within this project.

4) Noah Fierer is working microbial ecologists at other CZO sites to put together plans for cross-site research. A proposal has been submitted (led by Emma Aronson and Aaron

Packman) to support planning and improve the portal for sharing microbial data across CZOs.

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

Nothing to report.

vi. **tabulation of defined performance metrics for the period** and comparison with proposed goals;

Goal 1

Interface and Zone 1: R.S. Anderson, D. Doak, H. Barnard, N. Molotch, S. Murphy, A. Blum, G. Tucker, S.P. Anderson, D. McKnight, N. Fierer

Metrics:

Maintain surface monitoring (meteorology, soil moisture and temperature, runoff, water chemistry, sapflow, snow depth)

- ✓ Done.

Produce papers on surface water hydrology, ecohydrology, biologic influences on sediment transport, landscape evolution

- ✓ See publications list

Train at least 2 graduate students in surface water hydrology, ecohydrology, surficial processes

- ✓ Abigail Langston, PhD completed Dec 2014 (surficial processes)
- ✓ Joe Mills, PhD student, passed comprehensive exams Jan 2015 (surface water hydrology and aqueous geochemistry)
- ✓ Theo Barnhart, PhD student (surface water hydrology and snow)
- ✓ Rachel Feist, MS student, Colorado School of Mines (ecohydrology)
- ✓ Sydney Wilson, MS student, Colorado School of Mines (hyporheic exchange)

Goal 2

Interface 2: R.S. Anderson, G. Tucker, S.P. Anderson

Metrics:

Measure mobile regolith production rates in Betasso, measure fracture patterns in rock underlying this interface

- ✓ Cosmogenic, OSL, U-series data from Betasso, Left Hand Creek complete.

Produce papers on regolith production across BcCZO, role of fracturing in mobile regolith production

- ✓ See publications list.

Train at least 1 graduate student in the area of mobile regolith production

- ✓ Melissa Foster, PhD expected Winter 2015 (surficial processes & soils)
- ✓ Eric Winchell, PhD student, passed comprehensive exams Jan 2015 (bio-geomorphology)

Goal 3

Interface 3: A. Templeton, N. Fierer, K. Singha, D. McKnight, H. Rajaram, A. Sheehan

Metrics:

Maintain groundwater monitoring, plan new drilling program, initiate study of geobiology of deep weathering front

- ✓ Groundwater monitoring done
- ✓ Kamini Singha drilled in Gordon Gulch, summer 2014

- ✓ Geobiology studies are currently on soils and surface rock; insights from these will inform deep biology

Produce papers on geohydrology of fractured rock, and geobiology in rock hosted systems

- ✓ See publications list

Train at least 1 graduate student in deep CZ processes

- ✓ Tess Brewer, PhD student (microbiology)
- ✓ Richard Magill, MS student, Colorado School of Mines (fracture characterization)
- ✓ Aaron Bandler, PhD student, Colorado School of Mines (GPR and seismic anisotropy)

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

Journal articles, book chapters

(*Graduate student, **Postdoctoral researcher, ***Undergraduate student)

Published (n=17)

Trujillo, E., and **N. P. Molotch** (2014), Snowpack regimes of the Western United States, *Water Resour. Res*., 50, 5611–5623, doi:10.1002/2013WR014753.

Molotch, N.P., Durand, M.T., Guan, B., Margulis, S.A., and Davis, R.E. (2014): Snow cover depletion curves and snow water equivalent reconstruction: six decades of hydrologic remote sensing applications. *In* Lakshmi, Venkataraman, ed., AGU Monograph on Remote Sensing of the Terrestrial Water Cycle, American Geophysical Union, p. 159-174, ISBN 978-1-118-87203-1.

Anderson, R.S. (2014): Evolution of lumpy glacial valleys, Geology 42(8): 679-682, doi:10.1130/G35537.1.

Hinckley, E.-L., Barnes, R.T., **Anderson, S.P**., Williams, M.W., and Bernasconi, S. (2014): Ecosystem N retention and transport differ by hillslope aspect at the rain-snow transition of the Colorado Front Range, Journal of Geophysical Research Biogeosciences 119(7): 1281-1296, doi:10.1002/2013JG002588.

Kirchner, P.B., Bales, R.C., **Molotch, N.P.,** Flanagan, J., and Guo, Q. (2014): LiDAR measurement of seasonal snow accumulation along an elevation gradient in the southern Sierra Nevada, California, *Hydrology and Earth System Sciences* 18: 4261-4275, doi:10.5194/hess-18-4261-2014.

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Submitted (n=7)

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*, submitted June 5, 2014.

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*Langston, A.L., **G.E. Tucker, R.S. Anderson**, Interpreting climate-modulated processes of terrace development along Colorado Front Range using a landscape evolution model (*JGR-ES*, submitted December 2014; in revision May 2015)

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Feist, R., **Barnard, H.R**., Mao, D., Revil, A. and **Singha, K**. Determining the influence of transpiration on soil moisture movement using electrical resistivity imaging. In preparation for *Journal of Hydrology* in June 2015.

Theses (n=2)

Langston, Abigail L. (2014). *The torrential and the mundane: Climate controls on hillslope weathering, channel bed material, and landscape evolution in the Colorado Front Range*. PhD dissertation, University of Colorado, Boulder

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

Other products

Data visualization: Video of a fly-through of high resolution terrestrial LiDAR of burned hillside from Francis Rengers dissertation (http://criticalzone.org/boulder/news/story/point-cloud-derived-from-a-terrestrial-lidar-at-fourmile-canyon-field-site/)

Audio product: Radio interview of PI Suzanne Anderson and Robert Anderson with Ryan Warner on Colorado Public Radio for "Colorado Matters", on research published in Geology on landslides in the 2013 storm. Interview archived at http://www.cpr.org/news/story/study-2013-front-range-floods-caused-thousand-years-worth-erosion. Broadcast April 29, 2015.

Presentations (n=28)

The 28 conference presentations by members of BcCZO-II are listed in the Research.gov report

viii. **an assessment of progress towards meeting the goals for engaging** the broader community that are established in the CZOMP;

Goals for engagement and our progress on these goals:

1) We will advertise annually on listservs (geomorphlist, czen, gilbert club) that BcCZO welcomes outside researchers.

Progress: There were complaints from other CZO PIs about the announcements inviting researchers to use BcCZO and the CZO network on list-servs (geomorphlist, czen.org, and gilbert club) in June 2014, so we have discontinued this activity.

2) BcCZO researchers will visit other institutions along the Front Range corridor to promote using BcCZO for research.
Progress:

Sheila Murphy was a co-leader of a field trip to view flood impacts for the Colorado Scientific Society, September 27, 2014.

Suzanne Anderson and Robert Anderson presented at the Rocky Mountain Hydrologic Research Center, 69th Annual meeting, Wild Basin lodge, Allenspark, CO, Oct 14, 2014. "Exhumation by debris flows in the 2013 Front Range storm: A role in landscape response to base-level lowering", and "Groundwater in the 2013 storm".

Alexis Templeton presented at the Colorado School of Mines Civil & Environmental Engineering seminar series, April 16, 2015, "Subsurface Hydrogeochemistry & Life Activity in Serpentinizing Rocks"

3) We will invite our Advisory Board members to present at our annual science meetings. The Advisory Board members will be drawn from local institutions, and can serve as ambassadors.
Progress:

Advisory Board members will be invited to our Annual Meeting on August 29, 2015.

4) We will host field trips. These will include both informal small-group visits and larger field trips associated with national and international conferences.
Progress:

Sheila Murphy presented at the Colorado Scientific Society Field Trip, Sept. 27, 2014, on Boulder floods of September 11-15, 2013 and impact on the landscape, with co-leaders Madole, R., Birkeland, P., Godt, J., and Sutherland, D

Suzanne Anderson will lead a field trip on Front Range geology for the Research Experience for Community College Students (RECCS) program, June 11, 2015.

ix. **summarized results of evaluation forms submitted** by participants of supported activities;

Teacher Professional Development evaluations (2014 program)
Overall Program Evaluation Data
(cumulative/final evaluation, 5-1 Likert Scale, Where 5 is strongly agree/1 is strongly disagree)

The program provided valuable information:
11-5's or All participants agreed with the statement
The program presented tools I can use in the classroom:
9-5's and 2-4's or All participants agreed with the statement
The program was presented in a professional manner:
11-5's or All participants agreed with the statement
The program allowed for professional collaboration:
9-5's and 2-4's or All participants agreed with the statement

Please rate the likelihood you will incorporate these activities into your classroom using the scale below:
All teacher respond 'Likely' or 'Very Likely' to the question (2 and 9 respectively)

Participant/Teacher Quotes:

"This workshop left me inspired and renewed my love for teaching science"

"This workshop provided me with countless valuable resources and activities to confidently lead meaningful inquiry-based science lessons with my student in nature"

"This was an amazing three days of information, tools and activities…what an experience to be in the mountains learning more ways to creatively connect students, through science, to the outdoors and Earth system"

"This experience provided inspiration and the tools /skills to revamp my [Earth Science] curriculum…I am excited to implement many new lab/field inquiries in the coming year"

"I truly enjoyed the workshop. I learned so much about Earth Systems Science and came away with a plethora of ideas on how to incorporate it into my classroom"

"I plan to start collecting field science data when school starts…it seems like a great way to get kids engaged and they can help in the design of our experiments"

"I loved learning about the cutting-edge science at the MRS and how I can bring it back to my high school students"

"The plot studies and transect surveys will be an easy tool to pass on to our teachers and incorporate into our curriculum"

"I liked learning about the scientific tools and research at the Mountain Research Stations and on Niwot Ridge. Being on the top of the watershed really put it all together for me"

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

Funded projects working in BcCZO:

1) Carbon-water cycling in the critical zone: understanding ecosystem process variability across complex terrain. U.S. Dept. of Energy Terrestrial Ecosystem Science. $647,020. 9/15/11 - 9/14/14. PI – HR Barnard, co-PI – PD Brooks

2) Taylor Perron and Kamini Singha (co-PIs) "small" Army Research Office grant, that will fund the drilling work in Gordon Gulch in June 2015.

3) Steve Holbrook (WyCEHG), with Steve Martel (U Hawaii), Taylor Perron (MIT), and Kamini Singha will spend 2 weeks doing shallow geophysics in Gordon Gulch in June 2014. Not sure of all the funding involved (in particular, how Martel is funded).

4) Project Title: Growth Dynamics in the Climate Control of Tree-Ring Variability for Paleoclimatology
Principle Investigators: Dr. Malcolm Hughes, Laboratory of Tree-Ring Research, University of Arizona, Tucson (mhughes@ltrr.arizona.edu); Dr. Peter M. Brown, Rocky Mountain Tree-Ring Research, Ft Collins CO (pmb@rmtrr.org); Dr. Kiyomi Morino, Laboratory of Tree-Ring Research, University of Arizona, Tucson (kmorino@ltrr.arizona.edu)

Sampling is planned in Betasso, and the team will use sap flow and meteorological data from BcCZO. Did not hear from this team in 2014-15; do not know status of their project.

5) Lou Derry, NSF, "*A Cross Site Study of Silica Dynamics in the Critical Zone*". Lou and a graduate student visited in June 2014 to collect water and rock samples from Gordon Gulch and Betasso; additional samples sent to them in Fall 2014.

6) Greg Tucker, NSF-GLD EAR-0952247; Graduate student Francis Rengers mapped erosion after the Fourmile fire. Among other things, he used CZO lidar as the basis for calculating overland flow shear stress. A visualization of Renger's data is now posted on BcCZO website: http://criticalzone.org/boulder/news/story/point-cloud-derived-from-a-terrestrial-lidar-at-fourmile-canyon-field-site/

7) Noah Molotch, NSF WSC grant; Graduate student Theo Barnhart will be supported 50% by BcCZO and 50% by Molotch's NSF/USDA WSC grant, and will work across both projects.

8) RAPID grant to S.P. Anderson, R.S. Anderson and G. Tucker, "Effects of an extreme rain event in the Boulder Creek CZO. $22,142. The project uses BcCZO LiDAR data as a basis to study erosion in the storms of September 2013, as well as providing support for extra water analyses from storm samples.

9) RAPID grant "RAPID: Characterizing sediment mobilization and landscape response to the combined effects of wildfire and extreme flooding along Fourmile Canyon, Front Range Colorado," to Will Ouimet, University of Connecticut, on post-storm erosion and sedimentation in Fourmile Canyon. Sheila Murphy is a collaborator on this project.

10) USDA/NSF - $1.4M PI-Molotch: Snowpack and Ecosystem Dynamics: The Sustainability of Inter-basin Water Transfers under a Changing Climate (2012 – 2016).

11) NSF - $256,625 PI-Molotch: Climatic controls on snow-vegetation interactions across an elevational gradient (2012 – 2015).

12) NSF grant "Quantifying Near-Surface Patterns of Bedrock Fractures and Assessing Controls on Fracture Formation" with Brian Clarke and Doug Burbank. This team plans geophysical characterization of subsurface architecture across opposing slope aspects on Niwot Ridge. Last heard from Brian Clarke in June 2014.

13) In 2014, USGS and CZO co-funded a National Association of Geology Teachers (NAGT) intern, James Smith from Louisiana State University, to work on a project entitled "Response of Colorado Front Range Watershed to fire and flood disturbances." The student was mentored by Sheila Murphy and Deborah Martin, USGS. For more information please see http://education.usgs.gov/nagt/NAGTFlyer2014.pdf

xi. **unanticipated collaborations, research projects, and other endeavors** enabled or stimulated by the CZO or CZO-NO;

All of the projects listed in the previous item (#1-13 under point x.) can be construed as stimulated by the CZO.

xii. **other impacts of the CZO activities**, including local community engagement, and policy;

1) *Suzanne Anderson*: Presentation followed by Q&A in the One Year Later: Boulder County Flood Seminar Series. "Flood landscape: The physical geography of the Front Range and the 2013 storm", Sept 15, 2014, Lyons Middle/Senior High School.

2) *Suzanne Anderson, Sheila Murphy, RECCS REU participant Patrick Barbar*: On 3 different days worked with students in Gold Hill School, a "one-room" K-5 school with about 25 students in Gold Hill, CO. Suzanne gave a presentation on hydrology and floods, Sheila led a field trip on watershed response to wildfire, and Patrick (who lives next door to the school) worked with students on erosion. All events in October 2014.

3) *Suzanne Anderson and Robert Anderson*: publication of Anderson et al., (2015) Exhumation by debris flows in the 2013 Colorado Front Range storm, *Geology* 43 (5): 391-394, doi:10.1130/G36507.1, led to the following media coverage:
   a. Radio interview on Colorado Public Radio's *Colorado Matters* show, broadcast April 29, 2015. http://www.cpr.org/news/story/study-2013-front-range-floods-caused-thousand-years-worth-erosion
   b. *Wired* magazine: http://www.wired.com/2015/03/lasers-map-earth-moved-colorados-epic-floods/
   c. *Ars Technica*: http://arstechnica.com/science/2015/04/epic-2013-colorado-rainstorm-accomplished-centuries-worth-of-erosion/
   d. *Live Science*: http://www.livescience.com/50367-colorado-floods-scoured-hills.html
   e. *Physics.org*: http://phys.org/news/2015-03-lidar-sept-colorado-front-range.html
   f. *Yahoo! News*: http://news.yahoo.com/huge-colorado-floods-helped-sculpt-mountains-120131227.html

4) *Diane McKnight*: students in her lab led the Boulder Creek activities for the INSTAAR Open House on April 16, 2015, a day-long event for ~150 middle school students.

5) *Sheila Murphy:* Mentored an intern to work on "Response of Colorado Front Range watershed to fire and flood disturbances", co-funded by BcCZO and USGS through the National Association of Geology Teachers (NAGT).

xiii. **data management**

We continue to build our Oracle database. Time-series data from our field dataloggers is added to the database on a monthly basis for 26 datasets. Snow, time lapse cameras, and surface chemistry are updated on an annual basis. The following additions have been made this year:

a) Soil respiration data (2012-2013).
b) Gordon Gulch tree growth and physiology (from Hallie Adams).
c) Manual discharge measurements, Betasso, Lower Gordon Gulch, Upper Gordon Gulch.
d) Betasso well water level, 2013-2015.
e) Betasso groundwater chemistry, 2013.
f) Betasso time lapse camera, 2014.

Data manager Jeri Tebbets Fey has worked with Eric Parrish to improve metadata. Fey has improved accessibility of datasets, and is actively seeking datasets from researchers.

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

Not requested for this year.

xv. **a plan for remedial action** where project milestones in the CZOMP have been significantly impacted;

Nothing to report.

xvi. **problems likely to delay accomplishment** of annual, strategic goals;

Nothing to report.

xvii. **description of programmatic goals and objectives** with specific activities/timetable to be accomplished in the upcoming year; and

Interface and Zone 1: R.S. Anderson, D. Doak, H. Barnard, N. Molotch, S. Murphy, A. Blum, G. Tucker, S.P. Anderson, D. McKnight, N. Fierer
Metrics: Datasets, papers, and theses
Maintain surface monitoring (meteorology, soil moisture and temperature, runoff, water chemistry, sapflow, snow depth)
Produce papers on surface water hydrology, ecohydrology, biologic influences on sediment transport, landscape evolution,
Train at least 2 graduate students in surface water hydrology, ecohydrology, surficial processes

Interface 2: R.S. Anderson, G. Tucker, S.P. Anderson
Metrics: Datasets, papers, and theses
Measure mobile regolith production rates in Betasso, measure fracture patterns in rock underlying this interface
Produce papers on regolith production across BcCZO, role of fracturing in mobile regolith production
Train at least 1 graduate student in the area of mobile regolith production

Interface 3: A. Templeton, N. Fierer, K. Singha, D. McKnight, H. Rajaram, A. Sheehan
Metrics: Datasets, papers, and theses
Maintain groundwater monitoring, plan new drilling program, initiate study of geobiology of deep weathering front
Produce papers on geohydrology of fractured rock, and geobiology in rock hosted systems
Train at least 1 graduate student in deep CZ processes

xviii.	**Projected budget** with detailed justification that breaks down costs according to activity and includes individual budget subawards using the NSF Budget Form 1030 along with appropriate budget justifications (budget detail is to be provided offline in a spreadsheet).

Projected budget: Year 3

CU Proposal No. 0213.05.0211B		**Title:** Boulder Creek CZO II: Evolution, Form, Function and Future of the Critical Zone	
(Revised 05/24/15)			
	The Regents of the		
	University of Colorado		
	Campus Box 572		
	Boulder, Co. 80309-0019		
PI:	Suzanne Anderson	10/1/13-9/30/18	
		Duration: 5 years	
			Year 3
A. Salaries and Wages			
	PI: Suzanne Anderson, 1.42 mo		14749
	Co.PI: Robert Anderson,	3.6% time summer	1591
	Co. PI: Noah Molotch	5% time summer	1591
	Co.PI: Hari Rajaram	3.7% time summer	1591
	Co.PI: Greg Tucker,	5.5% time summer	1591
	Sr. Personnel: Holly Barnard	5.8% time summer	1591
	Sr. Personnel: Daniel Doak	2.9% time summer	1591
	Sr. Personnel: Brian Ebel (RA)	3% time /year	
	Sr. Personnel: Noah Fierer	5.5% time summer	1591
	Sr. Personnel: Diane McKnight	3.2% time summer	1591
	Sr Personnel: Anne Sheehan	4.1% time summer	1591
	Sr. Personnel: Alexis Templeton	5.1% time summer	1591

	Research Associate: E&O for REU, Jennifer Taylor		7426
	Research Associate: Post-doc Dave Barnard	100% time	50000
	Research Associate: Post-doc TBN	100% time, start Spring 2016	25000
	PRA:Field manager (Nate Rock)	100% time	42412
	PRA: Lab manager (Clayton Jensen)	100% time	38957
	PRA: Data Manager (Jeri Tebbetts Fey)	100% time	49757
	PRA: Graphics/GIS staff (Eric Parrish)	50% time	21965
	Science Discovery Coordinator: (Hester Nadel)	10% time	5298
	Science Discovery Education Designer: (Eric Carpenter)	20% time	10609
	Science Discovery: Field and Citizen Science: (Alexandra Rose)	5% time	3636
	GRA: 9 mos. AY, 50% time,4 students	**Lowest Base Rate**	71577
	GRA: 3 mos. Summer, 50% time, 4 students	**Lowest Base Rate**	23627
	Undergraduate Students academic year	1080 hours (3 students x 10 hrs/wk x $11.33/hour)	12603
	Undergraduate Students summer	1440 hours (3 students x 40 hrs/wk x $11.33/hr)	16804
	Science Discovery Undergraduate Student Hourly	120 hrs x $10/hr	1273
	Lab Coord.: Wendy Roth	2 months at 50% time	4963
	System Administrator: Chad Stoffel		8216
	Project Accounting Asst.: Meghann Chavez		16434
	Total Salaries and Wages		441216
B. Fringe benefits			
	PI: 27.5%		4056
	Co.PI: 27.5%		438
	Co.PI: 27.5%		438
	Co.PI: 27.5%		438
	Co.PI: 27.5%		438
	Sr. Personnel: 27.5%		438
	Sr. Personnel: 27.5%		438
	Sr. Personnel: 30.9%		0
	Sr. Personnel: 27.5%		438
	Sr. Personnel: 27.5%		438
	Sr. Personnel: 27.5%		438

	Sr. Personnel: 27.5%		438
	Research Assoc.: 30.9%		2295
	Research Assoc.: 30.9%		15450
	Research Assoc.: 30.9%		7725
	PRA: Field manager: 30.9%		13105
	PRA: Lab manager: 30.9%		12038
	PRA:Data manager: 30.9%		15375
	PRA: Graphics/GIS staff: 30.9%		6787
	SD Coordinator: 30.9%		1637
	SD Educ. Design.: 30.9%		3278
	SD Manager: 30.9%		1124
	GRA: 7.9%		5655
	GRA: 7.9%		1867
	Undergrad: 1.0%		126
	Undergrad: 1.0%		168
	Undergrad: 1.0%		13
	Lab Coord: 30.9%		1534
	Sys. Adm.: 30.9%		2539
	Prjt. Acctg. Asst.: 30.9%		5078
	Total Fringe benefits		104223
C. Equipment			
	Total Equipment Costs		0
D. Travel			
	Domestic:		
	PI meetings, travel for 2 people, 2 trips		
		RT airfare, $530.5 per trip, 2 trips	2122
		Meals & lodging, 3 days/trip, $148.5/day	891
	Cross-CZO: Modeling (7.1K total for this activity over grant)		
		Travel allowance for 2 modelers to visit CZOs	2000
	Students to professional meetings (AGU, ESA, etc)		0

		$712 x 5 students for airfare, registration &/or lodging	3561
	Science Discovery: Mileage to Schools		530
	Total Travel Costs		9104
E. Participant Support Costs			
	Cross-CZO: Joint Research Field Campaign: Graduate Student Trg ($15K total for activity)		
		RT Airfare: $6000 x 12 people	7200
		MRS Lodging, meals, 12 students x $100/day x 5 days	6000
		Vans for Transportation - 2 vans x $400/wk x 1 wk	800
	Science Discovery: 3-Day PD workshop for teachers at MRS		
		Stipends (12 participants, $100/day, 3 days)	3600
		Vans	424
		Accomodations - 2 nights (@$433) + 1 add'l day (@$200)	1098
		Meals - 3 days, $25.75/day, 12 teachers	955
		Materials and Supplies for workshop (12x100)	1200
	Science Discovery: 5-Day High School student field course		
		Vans	637

		Accomodations - 4 nights (@$433) + 1 add'l day (@$200)	1989
		Meals - 5 days, $25.75/day,	1591
	Total Participant Costs		25494
F. Other Direct Costs			
Materials and supplies			
	Batteries, Cables, Datalogger Maintenance, Tools, Calibration		4456
	Dionex Lab Supplies		3183
	Filters, Bottles		7426
	Deionized Water		1167
	Misc Lab supplies		4350
	Science Discovery Programs		2000
Publication costs			2000
Computer Services			
	Unix Ops		7957
Subawards			
	USGS (Blum and Murphy)		26710
Other costs			
	Cross-CZO: Supplies for Joint Field Research campaign		1000
	BcCZO Annual Meeting (room, refreshments)		500
	Computer Upgrades(server)		0
	Lab Computers		0
	Software		0
	Backup Drives		0
	Data Loggers		0
	Field Instrument Budget (New and Replacements)		1000
	Poster printing		500
	Vehicle Maintenance		1910
	Vehicle Fuel		1591
	Vehicle Admin/Risks		1061
	Chemical Analysis of Waters (LEGS)	$8/sample, 1500 samples/year	12000
	stable Isotope Analysis	$5/sample, 800	4000

		samples/year	
	Cosmogenic Radionuclide Sample Prep and Analysis	$375/sample, 10 samples/year	3750
	Cross-CZO Drill the Ridge Core Drilling		0
	Microbial Community Sequencing		6000
	Communication		209
	Duplication		296
	Express mail/postage		100
	Tutition, resident	**Lowest base rate**	45092
	Total Other Direct Costs		138258
G. Total Direct Costs			
			718295
H. Total Indirect Costs			
	On Campus: 52.5%		326025
I. Total Costs			$1,044,320

Justification- Year 3

Salaries and wages: PI Anderson will receive 1.42 mo summer salary, a reduction from the 1.5 mo in year 1, owing to a significant raise in her pay rate. All co-PIs and senior personnel will each receive $1591 summer salary, which ranges from 3-6% (0.09-0.18 mo) of summer salary. This is token salary support; we feel it is more important to share students and post-docs, access to support staff, lab and field resources, and cross-CZO opportunities.

We shall support 4 *grad students* with 50% time GRA (Grad Research Assist) appointments in the academic year and summer. We are supporting students at a low pay rate; INSTAAR has moved to level grad student pay rates (which vary across schools and departments), which should mean higher rates. But we did not build our budget a year ago with this in mind, so will have to stay at the lower rate for the present. We have support from the Graduate School for 1 additional student.

Four years of *Post-Doc Research Assoc*. support is planned, envisioned as supporting 2 individuals for 2 years each. The request is spread across all years as: 10 mo in yr 1, 12 mo in yr 2-4, and 2 mo in yr 5. Our first post-doc arrived in Jan 2015, so we have carryover, and can begin searching for a 2nd post-doc this year. We have included this 2nd post-doc in the budget for this year, which is why our total costs exceed $1.0M.

Education and outreach: In total, we include 4.2 mo/yr support for 4 individuals working on E&O as follows. For undergrad outreach, we budget $7426 to admin. support to oversee the RECCS community-college focused REU program. For K-12 outreach, we support Science Discovery personnel, including 10% time (1.2 mo) for Teacher Program coordinator, 20% time

(2.4 mo) for Education Designer, and 5% time (0.6 mo) for a Citizen Science/Field coordinator. These personnel work with our grad students and faculty to develop and deliver outreach activities described in the proposal.

Full-time PRA (Pro. Research Assist.) staff include *field manager, lab manager*, and *data manager*; 50% (6 mo) for our *graphics/GIS specialist*.

INSTAAR's *system administrator* and *project accounting* assistant are budgeted according to established practices.

Equipment: No equipment funding is planned in year 3.

Travel: Expenses are requested for PI and one other person to travel to Fall AGU meeting and to one other National CZO PI meeting each year. Total request is $3013 this year (incremented by 3%/yr) for airfare and per diem for 2 travelers.

Cross-CZO modeling: Per agreement with other CZO PIs, we include funds for modelers in our group to travel. We have $1188 budgeted for this activity; we anticipate that this money will support some travel for post-doctoral researcher Dave Barnard.

Cross-CZO CZ Joint Field Campaign Student Training: Per agreement with other CZO PIs, we budgeted $15k for a research workshop in yr 3 to bring 12 students from outside BcCZO for a 5-day intensive training workshop.

Student meeting travel: We budget a total of $3561 to defray costs of attending professional meetings for students and post-doc. This amount is augmented in year 3 by funds that had been earmarked for Alexis Templeton's travel to lightsource (not happening, as no student).

Participant Support Costs: Two activities fall in this budget category.
Science Discovery Professional Development teacher workshop: We will offer a 3-day PD class for 12 teachers, providing stipends ($100/d, 3 d, 12 teachers), subsistence meals and lodging ($1993), materials and supplies ($100/teacher), a van for field trips ($424).
Science Discovery High School student summer class: We offer a 5-day summer science field class for 12 high school students at the Mountain Research Station. We provide subsistence meals and lodging ($3476) and vans for transporting to field sites ($637).

Other Direct Costs: These include *Materials and Supplies* that are primarily for our field monitoring and sampling program. We have $2000 budgeted for materials and supplies for Science Discovery programs that do not constitute participant support costs. This covers materials for the Middle School workshops on critical zone science that travel around the state for instance. We budgeted $2000 for *Publication costs*. We include $7957 for CU's Office of Information Technology *Managed Services and Consulting* program, an internal service center that contracts its expertise to meet the computational needs of CU PIs. BcCZO contracts its server software and hardware support needs, licenses, and memory backup cycling for our database to Managed Services and Consulting. *Other costs* include a small budget for refreshments for local BcCZO meetings ($500). We have a small budget ($1000) for replacement and expansion of field instrumentation. We anticipate costs for vehicle maintenance ($1910), for fuel ($1591), and for insurance/admin ($1061). The latter cost is set by CU's Transportation Services. We collect ~1500 water samples each year, and so budget $12000 for chemical analyses of water, and an additional $4000 for stable isotope analyses. We plan on processing 10 cosmogenic samples this year, at a total cost of $3750. We budget $6000 for microbial community sequencing. We have a tiny budget for poster printing ($500), and a similar amount for any communication costs (duplication, postage, teleconferencing) ($602). Finally, tuition for our graduate students is $45092.

USGS Subcontract: Our USGS team members are responsible for continued follow-up work on the Fourmile fire (Murphy) and for geochemical analysis of soil and rock (Blum). Their $26710 subcontract includes 520 hours of student field assistance ($13/hr, including fringe benefits), field vehicle costs ($500), field supplies ($2000), meeting travel ($1000), and analytical costs (XRF, XRD, trace metals) ($6000). The USGS indirect cost rate is 57.36%.

INSTAAR BUDGET JUSTIFICATION

The Institute of Arctic and Alpine Research (INSTAAR) is a unique unit of the University of Colorado, solely dedicated to research and completely separate, though complementary, to the traditional academic department. INSTAAR is an interdisciplinary institute, designed to house large and complex research programs. Each individual investigator has access to a depth and broad range of scientific expertise that complements his/her research.

Support is requested for *System Administration*. The System Adminstrator's tasks include maintenance and upgrades for computer networking, printers, communication, network access, software installation, maintenance of INSTAAR'S servers and poster printing.

Support is also requested for *Project Accounting* technical assistance that is necessary for executing, administering and accounting for the proposed project. This position provides administrative support in the areas of grant administration, finance, budget, and accounting (including payroll, travel, purchasing, accounts receivable/payable, inventory, etc.)

Communication, duplication, and postage include such items as toll calls, postage, fax charges, telephone equipment and photocopies that specifically support this project. CU maintains telecommunications services that include the capability of tracking expenses to specific projects. INSTAAR maintains photocopy services that include capability of tracking expenses to specific projects.