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Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1331408
Project Title:	Transformative Behavior of Energy, Water and Carbon in the Critical Zone II: Interactions between Long- and Short-term Processes that Control Delivery of Critical Zone Services
PD/PI Name:	Jon D Chorover, Principal Investigator David D Breshears, Co-Principal Investigator Jennifer C McIntosh, Co-Principal Investigator Jon D Pelletier, Co-Principal Investigator Craig Rasmussen, Co-Principal Investigator
Recipient Organization:	University of Arizona
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Submission Date:	N/A
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	N/A

Accomplishments

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

The Catalina-Jemez (C-J) CZO project aims to improve our understanding of the mechanisms underlying quantitative relations between climatic forcing and critical zone evolution in water-limited systems by

focusing on linkages between long time-scale climate/lithology interactions and short time-scale ecological/geological feedbacks, and how both affect CZ services.

This goal motivates the proposal's central thematic questions:

1) How do the long-term drivers of CZ structure and function (EEMT and tectonics) alter parent material to control current CZ structure and response to perturbation?

2) How is long-term CZ evolution affected by ecosystem process controls, including especially localized plant and microbial activities?

3) What is the impact of CZ structure on buffering climate- and disturbance-driven variability in water, soil and vegetation resources and how does this translate into changes in CZ services?

We postulate that the climatic forcing of subsurface CZ evolution is effectively predicted on the basis of effective energy and mass transfer (EEMT), which combines into a single climatic term the energy transferred to the CZ as effective precipitation (precipitation in excess of evapotranspiration) and reduced carbon (i.e., net primary production).

The CZO site focus is on the water-limited (semi-arid to sub-humid) southwestern US. A broader impact of our research is, therefore, to improve societal understanding of processes that govern water resource delivery and quality in this region. Mountain block and mountain front recharge processes serve as the principal source of all freshwater resources to human inhabitants in this part of the world, and hence our project focuses strongly on factors affecting the water cycle, including the partitioning of water delivered (as a result of orogenic forcing) to higher elevation catchments, and the influence of hydraulic throughput on CZ geochemical and geomorphic evolution. We are investigating how event-based partitioning feeds back to affect the development of hydrologic flow paths, landscape structure and (bio)geochemical heterogeneities.

Our approach involves a combination of field-based observational measurements, controlled experimentation, and conceptual/numerical modeling at each of two principal research sites in the water-limited southwestern US - Santa Catalina Mountains (SCM, AZ) and Jemez River Basin (JRB, NM). In year 2 of the CZO grant, we have initiated and completed several activities and made substantive progress in each of these areas.

Our transdisciplinary research approach interrogates CZ process dynamics and structure along four integrated lines of inquiry: (i) Ecohydrology and Hydrologic Partitioning; (ii) Subsurface Biogeochemistry; (iii) Surface Water Dynamics; and (iv) Landscape Evolution.

By building bridges across these four lines of inquiry, we address linkages between short time-scale (e.g., hydrologic) events and long time-scale (e.g., geomorphic) evolution of the CZ.

In addition to the goals we have for testing hypotheses given in the proposal, the Catalina-Jemez CZO is active in pursuit of CZO network goals. Transformative, network-level science findings should result from comparably quantified structural properties and process rates at multiple sites. By doing so, we can, as a network, assess CZ parameter trends and test response hypotheses across the wider climate, lithology space afforded by the network. For these reasons, Chorover has led cross-CZO (X-CZO) development of "common measurements" conceptual frameworks for the CZO network, along with several collaborators.

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

Major Activities: Major activities in year 2 of the current CZO grant in each of the four areas are

described below, and the PIs and senior personnel that led efforts in each of these areas are referred to here by last name.

1. Ecohydrology and Hydrologic Partitioning (EHP):

- Maintained a continuous record of carbon, water and energy exchange in two towers (situated in Ponderosa Pine and Mixed Conifer Forest, respectively) in the JRB and one tower (situated at the interface of Ponderosa Pine and Mixed Conifer Forest) in the SCM (Litvak, Barron-Gafford et al.).
- Collected and initiated analysis of stable water isotope samples from precipitation, shallow soil, deep soil, and plant xylem from the Bigelow zero order basin (ZOB) site to resolve sources of plant water use (Papuga et al.).
- Examined impacts of wildfire on net water input to the CZ during snowmelt with a particular focus on sublimation and evaporation from the snow and soil surfaces.
- Initiated several reviews and assessments of climate-driven vegetation change affecting CZ services were developed (Breashears et al.).
- Model assessments using regional-scale ecosystem models and global dynamic vegetation models both predicted broad-scale loss of conifers under warming within the model projected regions of each (McDowell et al. Nature Climate Change - in revision). The potential for a species range shift of an endangered cactus (Pima Pineapple Cactus, *Coryphantha scheeri var. robustispina*), including across the Santa Catalinas portion of the Jemez Catalinas CZO was assessed using an ecohydrological framework (Kidder; Thesis; 2014).
- Incorporated to TIMS topographic shading and radiative scattering effects into catchment-scale hydrologic models (Niu et al.).
- Co-convened an AGU Fall Meeting oral and poster session entitled "Ecohydrology in the Critical Zone"
- Initiated a multi-year X-CZO study of evapotranspiration in mixed conifer forests in collaboration with Kathleen Lohse (Reynolds Creek CZO) and Roger Bales (Southern Sierra CZO) (Papuga et al.).

2. Subsurface Biogeochemistry (SSB):

- Instrumented pedons were installed in four locations of the Bigelow ZOB (SCM) to enable time series measurements of soil gas (CO2 and O2) concentrations, soil moisture, water potential, temperature, pore water chemistry, and redox potential, similar to ongoing in JRB (Chorover, Barron-Gafford, Schaap et al.)
- Depth resolved soil samples were collected to characterize the catchment scale spatial variability associated with biogeochemical and microbial composition for year 2 postburn in the mixed conifer ZOB (JRB) (Gallery, Chorover, Rasmussen et al.).
- Pore water chemistry data were collected to continue the time series results for instrumented pedons in the SCM and JRB (Chorover et al.).
- Examined how CZ topographic structure mediates soil carbon response to climate through modulation of of energy vs. moisture controls over soil respiration (Brooks et al.)
- Post-burn (JRB) assessment of microbial enzyme activities and their geo-spatial distribution at the ZOB scale (Gallery et al.)
- Developed an improved method for calculating a high resolution version of EEMT that accounts for local scale variation in topography and water, energy and carbon balances (Rasmussen et al.)
- Completed quantitative analysis of clay mineral composition in granite ZOB subsurface horizons(SCM) to enable assessment of landscape position

controls on secondary mineral neogenesis (Rasmussen et al.)
- Incorporating to TIMS: (i) root dynamics in response to soil moisture, (ii) hydrologic controls on microbial enzyme activities and associated soil organic matter (SOM) decomposition, and (iii) reactive transport controls on pedogenic weathering (Niu et al.)
- C-J CZO representation in multiple X-CZO activities related to SSB including (i) CZ biogeochemistry, (ii) organic matter, and (iii) redox processes working groups.

3. Surface Water Dynamics (SWD):

- A continued record for time series of surface water hydrological and biogeochemical data were collected for streams in both the SCM (Marshall Gulch Weir, Granite ZOB, Schist ZOB, Oracle Ridge, B2 Desert Sites) and JRB (mixed conifer ZOB, La Jara stream, History Grove stream, Upper Jaramillo stream) (McIntosh, Chorover et al.).
- Physical hydrologic data included discharge, temperature.
- Aqueous geochemical data included major and trace elements (ICPMS), anions (IC), DOC, DIC and TN (TC/TN analyzer), pH and EC (by electrode), and stable water isotopes (stable isotope analyzer) (Chorover, McIntosh, Troch et al).
- Combined CZO observations with downstream long-term records of stream flow and MODIS vegetation productivity to document how the JRB sites have responded to a long-term warming and drying trend (McIntosh, Brooks, Troch et al.)
- Assessment of wildfire impacts on catchment-scale C effluxes and spectroscopic properties pertaining to organic matter chemistry (Meixner, Chorover et al.)
- Combining data streams to interpret C/Q phenomena through improved CZO-derived hydrologic, biogeochemical and geomorphic understanding (Trostle et al.).
- Leading X-CZO working on concentration-discharge (C/Q) relations, breakout sessions at SS CZO all hands are being followd by July 2015 workshop at UNH (organized by Chorover, McDowell and Derry). Proposal to Powell Center with Derry as PI to build on X-CZO momentum.

4. Landscape Evolution (LSE):

- Our CZO team collaborated with Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG) to complete a one-week detailed geophysical survey in the Bigelow ZOB and surrounding terrain (SCM). Surveys were designed to understand deeper CZ structure in an instrumented catchment, and to extend to depth information collected in near surface (soil) surveys and instrumentation. Data are used, e.g., to model infiltration from soils to the deeper subsurface by combining soil and geophysical surveys (Ferre, Pelletier, et al.)
- Tested whether EEMT and/or landscape characteristics control water transit times (WTT) and mineral weathering in headwater catchments with relatively uniform geology (JRB).
- Measured millenial-scale erosion rates at 10 watersheds across the full elevation/climate gradient of the SCM. This dataset allows us to test the hypothesis that erosion rates are controlled by soil production rates in weathering-limited environments.
- Developed set of digital soil mapping techniques to produce 3-D predictions of soil physical and chemical properties in the SCM (Rasmussen et al.)
- Analyzed post-wildfire vegetation recovery and erosion in a high severity burn

area of the JRB following the Thompson Ridge Wildfire of 2013 using terrestrial LiDAR and numerical modeling (Pelletier, Papuga et al.).
- Developed new algorithms to (i) quantify mid and understory forest structure and (ii)degree and types of forest disturbance from airborne LiDAR data (Pelletier et al.).
- Participating in cross-CZO working group on the deep CZ (Suzanne Anderson, BC CZO, Pelletier, et al.)

5. Critical Zone Services (CZS):

- Field, Breshears et al. are leading the expansion of the conceptual framework of ecosystem services to assimilate the services of the critical zone, which provides, through long-term geological processes essential 'life' support (Field et al., 2015). The perspective has received coverage in the media (e.g., CSA News FEB 2015: 10; doi:10.2134/csa2015-60-2-2).
- Participating in a cross-CZO working group on CZ and ecosystem services, led by Bill McDowell (PI, Luquillo CZO).

6. Education and Public Outreach (EPO):

- Integration of a writer and illustrator into team for Flandrau exhibit on CZ science, planning toward construction (Bill Plant)
- Production of Mount Lemmon (SCM) iPhone app that integrates CZ science into the broader geological context of the Santa Catalina Mountains (Shipherd Reed)
- Critical Zone series as part of the Tucson public Science Cafe.
- Continued website development and CZO data posting (Durcik).

Specific Objectives: For the full list of Catalina-Jemez CZO objectives, please refer to original proposal.

Selected objectives of highlighted focus in this past year include:

Quantify, through direct observation, how CZ processes, such as hydrologic, hydrochemical, ecological, geomorphic and biogeochemical responses, vary across lithologies (granite, schist, rhyolite) and elevational (hence climatic) gradients in the southwestern US.

Compare the sensitivity of these processes to variation in climate and disturbance.

Continue to improve on our project conceptual model of CZ climatic forcing by inclusion of topographic convergence and aspect induced effects on EEMT.

Develop a numerical, terrestrial integrated modeling system (TIMS) applicable to our CZO sites that couples land-atmosphere exchange, saturated/unsaturated and surface water flows, sediment flux, and reactive geochemical transport.

Create an iPhone app for introduction of public to critical zone science in the larger geological and biological context of the Santa Catalina Mountains (SCM).

Conduct X-CZO site research on multiple thematic fronts through collaboration with PIs, senior personnel, students and staff working at other CZOs nationwide. Utililze the larger parameter space of the CZO network to collaboratively test cross-site hypotheses related to network-wide "common questions" by employing "common measurements".

Significant Results: Selected results are presented here under each of the C-J CZO cross-cutting science themes (EHP, SSB, SWD, LSE, and CZS). Jemez River Basin site (NM) results are indicated as JRB, whereas Santa Catalina Mountain site (AZ) results are indicated as SCM. (Figures/Tables in PDF)

1. **Ecohydrology and Hydrologic Partitioning:**

- The stand replacing Thompson Ridge wildfire of June 2013 in JRB resulted in a significant reduction in net ecosystem carbon uptake in the year following the burn. The JRB mixed conifer forest CZ, which has been a significant C sink over all prior years of our project, became a net C source to the atmosphere for the first year since CZO establishment (**Fig. 1**, *Litvak et al.*).
- Terrestrial LiDAR data indicate that postfire regrowth of understory vegetation occurs preferentially at higher slope (**Fig. 2**) and on east or west aspects of forested terrain, but to a lesser extent on north facing aspects (**Fig. 3**) (*Papuga, Pelletier et al.*).
- Stable water isotopes reveal plant water use in a snow-dependent subalpine mixed conifer system. Plant xylem water is isotopically similar to summer (monsoon) precipitation (**Fig. 4**, *Papuga et al*.).
- Examination of relations between precipitation and soil moisture data in the SCM indicates that: (i) deep soil moisture responds only to large storms or storm series (**Fig. 5**); (ii) there was a decrease in overall precipitation over the past two decades largely driven by decreases in winter precipitation (**Fig. 6**); higher summer precipitation is largely the result of large summer storms (**Fig. 7**); surface soil moisture is quickly lost (exponentially) after large storms while deep soil moisture persists (**Fig. 8**) (*Papuga et al.*).
- A conceptual framework relating how evapotranspiration is partitioned into soil evaporation and plant transpiration as the % cover by woody plants changes (Villegas et al., 2014) reported a resultant relationship from an experiment and then showed that the specific nature of the relationship had implcations for regional scale model predictions (Villegas et al., in press).
- Developed a modeling scheme within TIMS that is capable of accounting for topographic effects on direct and diffuse radiation transfer processes with TIMS and tested it over Gordon Gulch catchment (BC CZO), where snow measurements on both south- and nort-facing slopes are available (**Figs. 9-10**).
- Analysis of long-term (1984-2012) climate variation trends - including increasing temperature and decreasing winter precipitation - coupled with basin scale water balance modeling, revealed the impacts of climate change on water partitioning in the JRB CZ: (i) all water partitioning components, including precipitation, discharge and vaporization, showed decreasing trends over the 28 year period (**Fig. 11**), Basin scale precipitation and baseflow were the strongest control on NPP variability indicating that forest productivity is water limited. An increasing trend in Horton index suggests that water limitation and vegetation water use are increasing in the basin (Zapata-Rios et al., in review).

2. **Subsurface Biogeochemistry:**

- Published review that highlights recent advances regarding decomposition in drylands with a focus on the importance of UV photodegradation and soil-litter mixing as key processes that drive decomposition (Barnes et al., 2015).
- Rare earth elements signatures in soil, pore waters and surface waters provide signature patterns of ligand-promoted (bio)weathering and dust input (Vazquez-Ortega et al., 2015a).
- Reactive transport of dissolved organic matter reflects adsorptive fractionation and completitive displacement reactions during transport through hydroxylated mineral media (Vazquez-Ortega et al., 2015b).
- Incorporated into TIMS a newly developed microbial model (Zhang et al., 2014) and applied it to a small catchment to study the impacts of rainfall distribution in complex terrain through lateral flows on plant and microbial enzyme activities and associated carbon exchanges with the atmosphere. Model results reveal

sensitivity to soil moisture of decomposition of soil organic C and show microbial enzyme activity "hot spots" near stream channels (**Fig. 12,** *Niu et al*.).

- Stielstra et al. (2015) and Berryman et al. (2015) demonstrate how topographic structure mediates soil carbon response to climate by regulating importance of energy vs. moisture in soil respiration.
- An integrated geospatial model of measured microbial enzyme activity shows variation across across the mixed conifer ZOB (JRB) with landscape position, microclimate and soil chemistry. Consistent with model results discussed above, the greatest microbial enzyme activity was concentrated in the channel drainages and convergent zones of the catchment (**Fig. 13**, *Fairbanks, Gallery et al*.)
- Significant location-specific variation in unsaturated zone moisture fluxes are observed that require more advanced inversion methods (*Schaap et al*.).

3. **Surface Water Dynamics:**

- Spring waters on Redondo massif (JRB) were dominated by Ca2+, Na+, Si, and HCO3- and have water stable isotope signatures that indicate they are predominantly derived from infiltration of snowmelt (Zapata et al., 2015).
- Larger concentrations of Na+ and sum of base cations were observed in springs with longer path lengths, larger contributing areas, and north-facing slopes (**Fig. 14**, Zapata et al., in press). In addition, longer water transit times (based on tritium and water stable isotopes) were observed in springs draining north-facing terrains subjected to higher EEMT (**Fig. 15**, Zapata et al., in press). Strongest prediction of mineral weathering fluxes were derived from maximum and range EEMT values (**Fig. 16**).
- Concentration-discharge relations for Marshall Gulch (SCM) across a wide range of major and trace elements reveal negative (dilution), zero (chemostatic), and positive (enrichment) concentration trends with discharge, indicating distinct hydrochemical process controls (**Fig. 17,** *Chorover et al*.)
- Analytical cascade filtration, employed to separate nanoparticulate and truly dissolved constituents, along with assymetric field flow fractionation studies, indicates the presence of organically-complexed and colloidal constituents that exhibit positive C/Q relations (**Fig. 18,** *Trostle et al., in prep.*).

4. **Landscape Evolution:**

- Millenial-scale erosion rates measured at 10 watersheds across SCM show strong correlations with mean annual precipitation and northness (proxy for solar insolution that controls water availability at sites of comparable elevation).
- Digital soil mapping and interpolation of data from SCM provides 3D predictions of soil physical, chemical and mineralogical properties in SCM catchments (*Rasmussen et al*.)
- Systematic relations were observed between water partitioning, vegetation structure/greening, and terrain aspect in high elevation catchments of the JRB: Significant differences in cover/biomass were observed, with north-facing catchments having smaller cover/biomass (**Fig. 19**), less vaporization, wetting and vegetation water consumption making more water available for surface runoff and baseflow (**Fig. 20**), along with shorter insolation and hence growing season for vegetation greening (**Fig. 21)**. Impacts of aspect-induced variation in microclimate on long-term landscape evolution (regolith weathering, soil depth, etc.) are depicted in **Fig. 22** *(Zapata-Rios et al., in review)*.
- WyCEHG geophysics survey of Bigelow ZOB indicated lithologic control over aspect variation in regolith depth.

5. **Critical Zone Services:**

- Proposed a conceptual framework for integrating critical zone services with the well-known concept of ecosystem services that highlights the importance of CZ processes, occurring over geological time scales, for the provision of ecosystem services (**Fig. 23**, Field et al., 2015).
- Articulated CZ perspective on ecosystem services across the full range of "provisioning", "habitat" or "supporting", "regulating" and "cultural" services (**Table 1**, Field et al., 2015).

Key outcomes or Other achievements:

- **EHP:** Water balance data from both SCM and JRB CZO sites indicate diminishing winter precipitation in montane environments of Arizona and New Mexico, which has important implications for groundwater and reservoir recharge (McIntosh, Papuga, Troch, Zapata et al.).
- **SSB:** Modeling and observation both support wide heterogeneity in microbial enzyme activity and organic matter degradation as a function of catchment landscape position, with "hot spots" of disproportionately high activity along lateral hydrologic flow paths (Gallery, Niu, Chorover, Rasmussen et al.)
- **LSE:** Reconciliation of long-term erosion rates (derived from catchment Be-10 or topographic analysis) with short-term sediment transport rates can only be achieved by inclusion of the much larger sediment transport events that occur immediately following wildfire (Pelletier et al.).
- **SWD:** Element speciation strongly impacts concentration-discharge relations of catchment streams, with organic complexes and nanoparticulates contributing significantly to positive C/Q power law slopes (Chorover, Niu, Trostle, et al.).
- **CZS:** The conceptual framework of "ecosystem services" as described in the Millenial Ecosystem Assessment (2005) was expanded to account for long-term evolution of the critical zone, and the geological processes that drive it, in order to account for its essential ecosystem supporting function (Breshears, Field et al.).
- **EPO:** An iPhone app was created that introduces the visiting public to earth science of the Santa Catalina Mountains (SCM) and the role of CZ in that larger context (Reed, Plant et al.).

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

- Integration of junior faculty into theme leadership roles operative within a collaborative transdisciplinary framework.
- Support for undergraduate, graduate and postdoctoral student training and mentoring.
- Undergraduate and graduate students participated in various local symposia at UA where CZO research was highlighted institutionally (EarthWeek 2015; Research Insights in Semiarid Ecosystems 2014; Phenology Research and Obsrvations of Semiarid Ecosystems 2014; School of Earth and Environmental Sciences Symposia.
- Series of lectures for GEOG 220 (*Our Diverse Biosphere*) developed entitled "We are the critical zone", in which lectures focus on the need for integrated science and the contributions from our breadth of earth and ecological science disciplines (Barron-Gafford).
- Post-doc Jason Field presented CZ concepts to high school students in the Project Yes! Program (http://www.tucsonurbanleague.org/what-we-do/project-yes). Field also received mentoring on career opprounities and strategic ways to improve his CV
- REU Alma Provencio and one undergraduate volunteer (Becky Hall) were mentored on equipment installation (datalogger and microclimate sensors) and data analysis for microclimate assessment at the Mt. Bigelow flux tower.
- New class on snowpack partitioning in western CZO's was developed at University of Utah
- A new reading group, composed of students, postdocs, and faculty in eco-hydro-biogeochemical interactions in the

critical zone was initiated at University of Utah (Brooks).
- The Hydrology and Water Resources Field Course collects samples in Sabino Creek (SCM) and uses data from SCM catchments to understand coupled hydrologic, geomorphic and geochemical processes as part of their training.
- Data from the JRB are used in a course on computational methods in geochemistry.
- CZO results have been incorporated into the Valles Caldera National Preserve's education program, which supports many class field trips to the Preserve by public school students (elementary, middle school, and high school).
- Information from CZO results on water balances from snowpack sublimation interactions with forest stand structure (tree densities and canopy cover) are presented to students measuring trees in restored and untreated forests. (See **Fig. 24** for locations of student class field sites.) Students are taught the value of restoring forests to improve hydrologic function of forested watersheds for ecosystem services.
- Developing curriculum activities for the CZ Discovery program, some of which are being piloted during the UA Fusion Camp this summer at Flandrau Science Center and Planetarium.
- Launching the CZ Discovery program in late fall of 2015. Camp counselors and students are being trained to deliver the CZ Discovery activities.
- The "Critical Zone Science Café Series" will run through Fall 2015 as part of ongoing "Downtown Science Café" series.
- The "Mt. Lemmon Science Tour" app, an audio tour for the drive/bike up the road from Tucson to the top of the Santa Catalina Mountains (SCM) will engage locals and regional visitors who travel up the road to Mt. Lemmon every year. The Tour, a free download, will introduce users to the fascinating science of Arizona's "Sky Islands Region" including the Critical Zone concept and many of the integrated CZ science concepts. The "Mt. Lemmon Science Tour" app started beta tests in June and will be ready for public distribution in Fall 2015.

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

- Peer reviewed journal publications, book chapters, and conference presentations.
- Uploading of all CZO data to the CZO website for community use and collaboration.

- Data/Datasets
  - More than 53 million data values are currently stored in the database.
  - To present, 41 datasets have been published on the Catalina-Jemez website. Published datasets contains 289 data files in the CZO data display format and GIS standard formats such as ArcGIS shapefile and GeoTIFF. All published datasets are periodically updated after data are processed and quality controlled.
  - Eight (8) new datasets were added from 6/1/2014 to 5/30/2015 which includes post-fire LiDAR, surface and soil water chemistry, and geo-spatial datasets.
  - 766 unique users downloaded 6876 data files from the Catalina-Jemez datasets published on the website.
  - To present, more than 16.6 million data values have been harvested to the CZO Central data and metadata depository hosted by the San Diego Supercomputer Center (SDSC). 7 million values were harvested to the CZO Central from 6/1/2014 to 5/30/2015. These data are available for download via the CUAHSI Water Data Center services (http://hiscentral.cuahsi.org/pub_services.aspx). These are direct links for 2 Catalina-Jemez services: http://hiscentral.cuahsi.org/pub_network.aspx?n=158 and http://hiscentral.cuahsi.org/pub_network.aspx?n=177.
- The CZO website (http://criticalzone.org/catalina-jemez/) had 5210 visits by 3956 visitors from 6/1/2014 to 5/30/2015. The number of new visitors was 2670 which is 72.8 % of all visitors.
- Several colleagues (e.g., Jan Hendrixx, Tom Schmugge) – using ET data from across the New Mexico Environmental Gradient to validate several ET models (METRIC, ALEXI, MOD16, SSEB).
- Submission of flux data to Ameriflux on an annual basis and these are posted and disseminated to those who are interested.

- As documented in the "products" section, the C-J CZO team has consistently produced high quality, peer-reviewed articles that are published in top quality journals; presented at professional conferences and workshops; and generated novel K-16 curricular materials.

- Substantial development of curriculum for Critical Zone/Sky Islands Discovery school field trip program. This process engaged students interested in outreach. We will pilot test some of the learning activities for CZ Discovery during UA Fusion Camp science summer camp at Flandrau Science Center & Planetarium.

- Revised and refined conceptual design for Critical Zone Science exhibit, identified contractors for exhibit writing, artwork, and construction.

- Developed and produced the “Mt. Lemmon Science Tour” app, an audio tour for the drive/bike up the road from Tucson to the top of the Santa Catalina Mountains. Thousands of locals and regional visitors travel up the road to Mt. Lemmon every year, and the Tour, a free download, will introduce them to the fascinating science of Arizona’s “Sky Islands Region” including the Critical Zone concept and many of the integrated CZ science concepts. The “Mt. Lemmon Science Tour” app will start beta tests in June and be ready for public distribution in Fall 2015.

- Organized “Critical Zone Science Café Series” for Fall 2015 as part of ongoing “Downtown Science Café” series.

- Photos and video of field instrumentation and research at UA CZO’s Marshall Gulch and Mt. Bigelow research sites.

- CZO Ph.D. student, Rebecca Lybrand produced a popular Youtube Video on soil science research: https://youtu.be/3JarDy53PLQ
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- In addition to the publications listed, the expanded framework on CZ services (Field et al. 2015) was posted By CSA to twitter and facebook sites (https://twitter.com/SSSA_soils; https://twitter.com/ASA_CSSA_SSSA; and https://www.facebook.com/SSSA.soils) and written up for CSA News (Feb 2015: 10; doi:10.2134/csa2015-60-2-2; https://www.soils.org/publications/csa/pdfs/60/2/10). This article was written the most read paper in Vadose Zone Journal for February 2015 and has remained in the top 5 most read papers for March and April 2015, with a total of >250 downloads to date.
- High school students with the **YES! Project** from Southern Arizona heard about the CZ from postdoc J.P. Field. The program, including part of Field’s CZ presentation were covered in *AZ Illustrated video special: **“The New Keepers*** (https://originals.azpm.org/arizonaillustrated.childrens/)**,** and *The Nature Conservancy Field Notes: “**Teen Stewards Beat the Heat to Bring Back the Grass”*** (Fall 2014, p11-12; http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/arizona/arizona-field-notes-fall-2014.pdf)
- Results from Broxton et al. Harpold et al. and Zapata-Rios et al are being incorporated into forest management activities within the watersheds of the Salt River Project (SRP). The SRP is responsible for supplying water to the Phoenix metropolitan area, one of the most rapidly growing urban areas in the US.
- Three community white papers have been developed to engage the broader research community in CZ science and approaches. One paper is focused more on the ecological community (Field et al.), a second paper is focused on the unique LEO for coupled pedologic, hydrologic, and hydrochemical research, while the third paper is focused more on the hydrologic community (Brooks et al.)
- PhD student Fairbanks has been involved in developing CZ-related outreach activities with Shipherd Reed through the CZO discovery program. Activities are hands-on activities designed for kids ages K-12 that will be used for summer camps at Flandrau Science Center and the Discovery program at Biosphere 2.
- Developed code to compute Effective Energy and Mass Transfer (EEMT) using High-Performance Computing resources for any U.S. location and for any time interval 1970-present using just a Digital Elevation Model (DEM) (climate data is automatically extracted from DAYMET). Code currently being implemented for use within Open Topography.
- During 2014-2015, Bob Parmenter of VCNP has presented published hydrologic results from CZO in various venues, including large science meetings with the New Mexico Interstate Stream Commission, the U.S. Army Corps of Engineers, and the U.S. Forest Service. CZO data/results have been incorporated into many of Parmenter’s public presentations to both government agencies and NGO meetings.
- CZO data from flumes and other instrumentation is being used in a major $2.7 million study by scientists from Los

Alamos National Laboratory. LANL scientists are using supercomputers to model climate change impacts on small-scale watershed hydrology for the coming 50 and 100 years. Grant information: Richard Middleton (PI) plus 12 co-PIs, *Critical Watersheds: Climate Change, Tipping Points, and Energy-Water Security Impacts.* 2014-2017, $2,700,000. Department of Energy.

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

Consistent with the C-J Project Management Plan submitted along with the full proposal, research, training and public outreach in the C-J CZO will continue to focus on integrated studies of (i) ecohydrology, (ii) subsurface biogeochemistry, (iii) surface water dynamics, (iv) landscape evolution, and (v) critical zone services.

Whole CZO group meetings will continue as in the past, with collaborative synthesis projects and weekly presentations and discussions in the Marshall Building on the UA campus by CZO personnel.

Specific foci for the next reporting period include:

1. Install a control site flux tower in the JRB in unburned mixed conifer (MC) forest for direct comparison to the Thompson Ridge wildfire burned MC flux tower site;
2. Continue acquisition of CZO data streams pertaining to energy, water, carbon and lithogenic element fluxes as measured using CZO instrumentation installed in the SCM and JRB;
3. Collaborate with WyCEHG on multi-method geophysics survey of mixed conifer ZOB site in JRB, ;
4. Drill, core and instrument boreholes in JRB to assess deep CZ physical, chemical and biological character;
5. Develop quantitative characterization of weathering profile in drill core samples (element chemistry, mineralogy, organic matter, microbial composition);
6. Analyze data pertaining to fire effects on catchment water quality, including variation in DOM composition and spectral quality;
7. Analyze data on subsurface water, solute and gas fluxes (as measured by instrumented pedons in SCM and JRB sites) for development of predictive response to energy, water and carbon fluxes across the upper CZ boundary (as measured by flux tower instrumentation in SCM and JRB sites);
8. Model deep subsurface CZ water flux by integration of instrumented pedon data with deep CZ geophysical and borehole datasets;
9. Conduct integrated modeling of subsurface moisture dynamics and fluxes in mixed conifer forest sites using novel pedotransfer function assisted inversion technique using observation data;
10. Determine pre-fire and postfire differences in subsurface moisture dynamics;
11. Develop TIMS to include colloid mobilization and transport, as well as (bio)geochemical reaction;
12. Measure wildfire propagation through the CZ (solute flux, biochar burial, carbon redistribution at the catchment scale);
13. Meet weekly to biweekly as a full CZO team to maintain cross-project dialogue to enable synthesis projects that merge EHP, SSB, SWD, LSE, CZS and EPO thematic foci;
14. Collaborate across the CZO network on multiple X-CZO activities including data management, common questions, common measurements, C/Q relations, biogeochemistry, CZ organic matter, deep CZ, and critical zone services;
15. Maintain pro-active participation in the CZO data management project (lead PI Anthony Aufdenkampe) with C-J CZO represented by Tom Meixner and Matej Durcik;
16. Lead X-CZO workshop on concentration-discharge relations and their interpretation in light of CZO data and modeling streams;
17. Invite and volunteer presentations in professional meetings and public venues on CZO science by undergraduate and graduate students, postdoctoral scientists, and senior personnel;
18. Complete and submit several collaborative CZO manuscripts;
19. Design, develop and build the Critical Zone exhibit for the Flandrau Science Center and Planetarium. The exhibit is scheduled to open Spring 2016;
20. Finish development, then training, for the CZ Discovery program, promote it to regional schools, schedule school field trips, and deliver programming starting in late fall 2015;
21. Debut the “Mt. Lemmon Science Tour” app (MLST), including CZ introduction and science, in fall 2015, to engage the general public;

22. Run monthly “Critical Zone Science Café Series” from September to December 2015 as part of ongoing “Downtown Science Café” series;
23. Begin work on the “Critical Zone Tour” podcast that will build on the science concepts in the MLST app and provide a more complex look at CZ science for users with a higher level of education and interest;
24. Begin production of videos about CZO research and scientists for the “CZO Journey” series.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
CZO_annual_report_2015_FIGS.pdf	Figure file to accompany "Accomplishments" section of annual report.	Jon Chorover	07/06/2015

Products

Books

Book Chapters

Barnes P.W., Throop H.L., Archer S.R., Breshears D.D., McCuley, R.L. and Tobler M.A. (2015). Sunlight and soil-litter mixing: Drivers of litter decomposition in drylands.. *Progress in Botany 76* U. Lüttge and W. Beyschlag eds.. Springer International Publishing. Switzerland. . Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

Breshears D.D., Field J.P., Law D.J., Villegas J.C., Allen C.D., and Cobb N.S. (2014). Rapid broad-scale ecosystem changes and their consequences for biodiversity.. *Climate Change and Biodiversity 2nd.* TE. Lovejoy and L. Hannah, eds.. Yale University. . Status = UNDER_REVIEW; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

Ecohydrology and the Critical Zone: Processes and Patterns across Scales. (2015). Ecohydrology and the Critical Zone: Processes and Patterns across Scales.. *Principles and Dynamics of the Critical Zone* Giardino and Houser (Eds.). Elsevier.. . Status = AWAITING_PUBLICATION; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

Perdrial, J., A. Thompson, and J. Chorover (2015). Chapter 6. Soil Geochemistry in the Critical Zone: Influence on Atmosphere, Surface- and Groundwater Composition. *Principles and Dynamics of the Critical Zone* 19. Giardino and Houser. Elsevier. New York, NY. 171. Status = AWAITING_PUBLICATION; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; OTHER:

Conference Papers and Presentations

Hoskinson, J. and C. Rasmussen. (2015). *An analysis of clay-formation processes in Marshall Gulch, Mount Lemmon, Arizona.*. Arizona Statewide Space Grant Symposium. Tempe, AZ. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Barron-Gafford, G.A, R.L. Minor, M. Heard, J. Yang, C. Wright, D.L. Potts (2014). *Aspect as a source of heterogeneity in carbon & water fluxes in space and time.*. National Critical Zone Observatory All-Hands Meeting. Yosemite, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Barron-Gafford, G.A. (2015). *Capturing heterogeneity in carbon & water fluxes in space and time across a semiarid montane forest*.. American Association of Geographer’s Annual Meeting. Chicago, IL.. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Chorover J. (2015). *Carbon and contaminants in the critical zone.*. Keynote Presentation, National Meeting of the American Chemical Society 2015.. Denver, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Lybrand, R., K. Heckman, and C. Rasmussen (2013). *Climate and topographic controls on soil organic carbon cycling in southern Arizona, USA.*. Goldschmidt International Geochemistry Conference, 2013. Florence, Italy. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Zapata-Rios, X., J. McIntosh., P. Troch., P.D. Brooks, J. Chorover (2014). *Co-evolution of climate, soil and vegetation and their interplay with hydrological partitioning at the catchment scale.*. 2014 Fall meeting, AGU. San Francisco, CA.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Chan, A., P. Brooks, S. Burns, M. Litvak, P. Blanken, D. Bowling (2014). *Ecohydrological and Biophysical Controls on Carbon Cycling in Two Seasonally Snow-covered Forests*.. 2014 AGU Fall Meeting. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Murphy, M., D. Fairbanks, J. Chorover, V. Rich, and R.E. Gallery (2014). *Impact of Wildfire on Microbial Biomass in the Critical Zone Observatory*.. SWES-x. Tucson, AZ. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Murphy, M., D. Fairbanks, J. Chorover, R.E. Gallery, V. Rich (2014). *Impact of Wildfire on Microbial Biomass in the Critical Zone Observatory*.. American Geophysical Union. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Fairbanks, D., M. Murphy, G. Frost, J. Chorover, V. Rich, and R.E. Gallery (2014). *Impact of fire, landscape position and soil depth on extracellular enzyme activities at the Jemez River Basin Critical Zone Observatory*.. American Geophysical Union. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Fairbanks, D., M. Murphy, G. Frost, J. Chorover, V. Rich, and R.E. Gallery. (2014). *Impact of fire, landscape position and soil depth on extracellular enzyme activities at the Jemez River Basin Critical Zone Observatory*.. Critical Zone Observatory All-Hands Meeting. Yosemite N.P., CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Krofcheck, D., C. Lippitt, M. Litvak. (2014). *Impacts of drought on regional carbon uptake dynamics in the Southwestern US, using the New Mexico Elevation Gradient of flux towers and the Temperature-Greenness model.*. 2014 AGU Fall Meeting. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

White, A., J. McIntosh, T. Meixner, P. Brooks, and J. Chorover, (2014). *Impacts of wildfire on throughfall and stemflow precipitation chemistry*.. AGU Fall Meeting. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Rasmussen, C. (2014). *Interactive control of minerals, wildfire, and erosion on soil carbon stabilization in conifer ecosystems of the western US.*. American Geophysical Union Fall Meeting, 2014. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Krofcheck, D., L. Morillas, M. Litvak. (2014). *Investigating the biophysical controls on mass and energy cycling in Southwestern US ecosystems using the New Mexico Elevation Gradient of flux towers*.. AGU Fall Meeting. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Fairbanks, D., M. Murphy, G. Frost, J. Chorover, V. Rich, and R. Gallery (2015). *Measuring and modeling soil microbial enzyme activities in the Jemez River Basin CZO.*. SWESx. Tucson, AZ. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Troch P.A., G.A. Barron-Gafford, K. Dontsova, Y. Fang, G.-Y. Niu, L.A. Pangle, M. Tuller, J.L.M. Van Haren. (2014). *Monitoring and modeling water, energy and carbon fluxes at the hillslope scale in the Landscape Evolution Observatory*.. American Geophysical Union's Annual Fall Meeting. American Geophysical Union's Annual Fall Meeting. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Litvak, M.E., D. Krofcheck, L. Morillas, A. Fox (2014). *Observing and Quantifying Ecological Disturbance Impacts on Semi-arid Biomes in the Southwestern US.*. 2014 AGU Fall Meeting. San Francisco, CA.. Status = ACCEPTED;

Acknowledgement of Federal Support = Yes

Kopp, E.S., M.A. Pohlmann, C.A. Jones, J. Chorover and M.G. Schaap (2015). *Pre- and Post- Fire Infiltration Rates in a Montane Mixed Conifer Ecosystem: Does fire reduce mineral soil hydraulic conductivity?*. SWESx section of UA's Earthweek. Tucson, AZ. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Elshall A.S., M. Ye, G.A. Barron-Gafford. (2014). *Quantification of Model Uncertainty in Modeling Mechanisms of Soil Microbial Respiration Pulses to Simulate Birch Effect.*. American Geophysical Union's Annual Fall Meeting. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Kuklewicz, K.B., and C. Rasmussen. (2014). *Quantifying Soil Organic Carbon Redistribution after Forest Fire using Thermal Analyses, Valles Caldera, New Mexico.*. American Geophysical Union Fall Meeting, 2014. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Rasmussen C. (2014). *Quantifying topographic, vegetation, and disturbance effects on the transfer of energy and mass to the critical zone.*. Geological Society of America meeting, 2014. Vancouver, British Columbia, Canada. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Gallery, R.E., N. Trahan, E. Dynes, D. Fairbanks, and D.J.P. Moore. (2014). *Short-term responses of soil microbe communities to fire: functional shifts in high elevation mixed conifer forests.*. Critical Zone Observatory All-Hands Meeting. Yosemite N.P., CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Chorover J. (2014). *Soil biogeochemical processes in the critical zone.*. Keynote presentation at the 20th World Congress of Soil Science.. Jeju, South Korea. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Chorover J. (2015). *Soil carbon (de)stabilization under changing climate.*. Invited presentation at the Soil Science Society of America National Meetings, 2014.. Long Beach, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Chorover J. (2014). *Soil carbon (de)stabilization under changing climate: Scaling from micropores to catchments.*. Invited presentation at the Annual Meeting of the American Chemical Society 2014.. Dallas, TX. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Barron-Gafford, G.A., J. Duncan, E. Marín-Spiotta (2015). *Spatial and temporal heterogeneity in ecosystem response to environmental change.*. American Association of Geographer's Annual Meeting. Chicago, IL.. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Scott, R.L., J.A. Biederman, G.A. Barron-Gafford (2014). *The coupling of ecosystem productivity and water availability in dryland regions.*. American Geophysical Union's Annual Fall Meeting. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Zapata-Rios, X., J. McIntosh., T. Meixner., P.D. Brooks, J. Chorover. (2014). *The role of aspect on water residence time and weathering of silicates in a high elevation semi-arid region.*. Global Fair and Workshop on Long-Term Observing of Mountain Social-Ecological Systems. University of Nevada. The Mountain Research Initiative (MRI). Reno, NV.. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Zapata-Rios X., J. McIntosh., T. Meixner., L. Rademacher., P.D. Brooks., P.A. Troch., J. Chorover. (2014). *The role of terrain aspect on the input of effective energy and mass (EEMT), water residence times and weathering of silicates in a semi-arid region.*. Geochemistry of the Earth's surface (GES-10). Paris, France. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Shepard, C., M. Schaap, J. Chorover, and C. Rasmussen (2014). *Three-dimensional prediction of soil physical, chemical, and hydrological properties in a forested catchment of the Santa Catalina CZO.*. CZO All Hands Meeting. Yosemite National Park, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Shepard, C., M. Holleran, R. Lybrand, M. Schaap, J. Chorover, and Rasmussen C (2014). *Three-dimensional*

prediction of soil physical, chemical, and hydrological properties in a forested catchment of the Santa Catalina CZO.. American Geophyiscal Union Fall Meeting. San Francisco, CA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Shepard, C., M. Schaap, and C. Rasmussen. (2015). *Three-dimensional predictiong of soil physical, chemical and hydrological properties in a forested catchment of Santa Catalina CZO.*. SWESx Earth Week. Tucson, AZ. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Inventions

Journals

Barron-Gafford G.A., Cable J.M., Bentley L.P., Scott R.L., Huxman T.E., Jenerette G.D., Ogle K. (2014). Quantifying the timescales over which exogenous and endogenous conditions affect soil respiration.. *New Phytologist*. 202 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1111/nph.12675

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

Biederman J. A., Meixner T., Harpold A.A., Reed D.E., Gutmann E.D., Guan J.A. and Brooks,P.D. (). Carbon availability regulates nitrogen loss and transformation along hydrologic flowpaths following insect-driven forest disturbance.. *Biogeochemistry*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Biederman J.A., Somor A.J., Troch P.A., Harpold A.A., Meddens A., Breshears D.D., Scott R., and Brooks P.D. (). Streamflow response to beetle-caused tree mortality in subalpine catchments.. *Ecohydrology*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Biederman, J. A., Harpold A.A., Gochis D.J., Ewers B.E., Reed D.E., Papuga S.A., and Brooks P.D. (2014). Increased evaporation following widespread forest mortality limits streamflow response.. *Water Resources Research*. 50:7 5395-5409. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2013WR014994

Biederman, J., Harpold, A., Gochis D., Ewers B., Reed D., Papuga S.A., and Brooks. P. (2014). Compensatory vapor flux reduces water for streamflow following severe bark beetle-induced forest mortality. *Water Resources Research*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Breshears D.D., Whicker J.J., Sáez A.E., and Field J.P. (2014). Introduction to a special issue of Aeolian Research airborne mineral dust contaminants: Impacts on human health and the environment.. *Aeolian Research*. 14 1-2. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Brooks P.D., Chorover J., Reinfelder, Y.F. Godsey S.E., Maxwell R.M, McNamara J.P., Tague N.C. (). Hydrological Partitioning in the Critical Zone: Recent Advances and Opportunities for Developing Transferable Understanding of Water Cycle Dynamics.. *Water Resources Research*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Broxton P., Harpold A., Biederman J., Troch P., Molotch N., Brooks P.D. (2014). Quantifying the Effects of Vegetation Structure on Snow Accumulation and Ablation in Mixed-Conifer Forests. *Ecohydrology*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Broxton, P., Harpold A., Biederman J., Troch P., Molotch N., Brooks P.D. (2014). Quantifying the Effects of Vegetation Structure on Snow Accumulation and Ablation in Mixed-Conifer Forests.. *Ecohydrology*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/eco. 1565

Burghelea C., Zaharescu D. G., Dontsova K., Maier R. M., Huxman T., Chorover J. (2015). Mineral nutrient

mobilization by plant from rock: Influence of rock type and arbuscular mycorrhiza.. *Biogeochemistry*. 124 187. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; OTHER:

Collins S.L., Belnap J., Grimm N.B., Rudgers J.A., Dahm C.N., D'Odorico P., Litvak M., Natvig D.O., Peters D.C., Pockman W.T., Sinsabaugh R.L., and Wolf B.O. (2014). A multi-scale, hierarchical model of pulse dynamics in arid land ecosystems.. *Annual Review of Ecology, Evolution and Systematics*. 45 397-419. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Dontsova K., Zaharescu D., Henderson, W., Verghese S., Perdrial N., Hunt E., and Chorover J. (2014). Impact of organic carbon on weathering and chemical denudation of granular basalt.. *Geochim. Cosmochim. Acta.*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Fairbanks D. F., Shepard C., Murphy M. Rasmussen C., Chorover J., Rich V., Gallery R. (). Topographic controls on soil microbial enzyme activity following fire disturbance in the Jemez River Basin Critical Zone Observatory.. *Soil Biology and Biochemistry*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Fang Y.H., Niu G.Y., et al. (2014). The effects of soil depth and terrain slope/aspect on snowmelt and runoff production.. *JGR*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Fang, Y. H., Broxton P.D., Niu B.-Y., Troch P.A., and Chorover J. (2015). Topographic shading and radiative scattering effects on catchment-scale snow cover and runoff processes.. *Vadose Zone Journal*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Field J.P, Breshears D.D., Law D.L., Villegas J.C., López-Hoffman L., Brooks P.D., Chorover J., Barron-Gafford G.A., Gallery R.E., Litvak M.E., Lybrand R.A., McIntosh J.C., Meixner T., Niu G.Y., Papuga S.A., Pelletier J.D., Rasmussen C.R., and Troch P.A. (2014). Critical Zone Services: Expanding context, constraints, and currency beyond ecosystem services.. *Vadose Zone Journal*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Field J.P., Breshears D.D., Law D.J., López-Hoffman L., Brooks P.D., Chorover J., Pelletier J.D., Villegas J.C. (). Broadening ecosystem services with geosciences perspectives.. *EOS*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Field J.P., Breshears D.D., Law D.J., Villegas J.C., López-Hoffman L., Brooks P.D., Chorover J., Barron-Gafford G.A., Gallery R.E., Litvak M.E., Lybrand R., McIntosh J., Meixner T., Niu G-Y., Papuga S.A., Pelletier J.D., Rasmussen C.R., and Troch P.A. (2015). Critical zone services: Expanding context, constraints, and currency beyond ecosystem services.. *Vadose Zone Journal*. 14(1) . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/vzj2014.10.0142

Field J.P., Breshears D.D., Law D.J., Villegas J.C., López-Hoffman L., Brooks P.D., Chorover J., Barron-Gafford G.A., Gallery R.E., Litvak M.E., Lybrand R., McIntosh J., Meixner T., Niu G., Papuga S.A., Pelletier J.D., Rasmussen C.R., and Troch P.A. (2015). Critical zone services: Expanding ecosystem services with context, constraints and currency. *Vadose Zone Journal*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Field J.P., Breshears D.D., Law D.J., Villegas J.C., López-Hoffman L., Brooks P.D., JChorover J., Barron-Gafford G.A., Gallery R.E., Litvak M.E., Lybrand R., McIntosh J., Meixner T., Niu G.Y., Papuga S.A., Pelletier J.D., Rasmussen C.R., and Troch P.A. (2015). Critical Zone Services: Expanding context, constraints, and currency beyond ecosystem services.. *Vadose Zone Journal*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/ vzj2014.10.0142.

Field, J.P. Breshears D.D., Law D.J., López-Hoffman L., Brooks P.D., Chorover J., Barron-Gafford G.A., Gallery R.E., Litvak M.E., Lybrand R., McIntosh J., Meixner T., Niu G.Y., Papuga S.A., Pelletier J.D., Rasmussen C.R., and Troch P.A. (2014). A perspective on areas of emphasis for critical zone services.. *Vadose Zone Journal*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/vzj2014.10.0142

Field, J.P., Breshears D.D., Law D.J., López-Hoffman L., Brooks P.D., Chorover J., Pelletier J.D. (). Broadening Ecosystem Services with Geoscience Perspectives. *EOS, Transactions of the American Geophysical Union*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Hamerlynck E.P., Scott R.L, Cavanaugh M.L., and Barron-Gafford G.A. (2014). Water use efficiency of annual-dominated and bunchgrass-dominated savanna intercanopy space.. *Ecohydrology*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; ISBN: 7:1208-1215

Harpold A.A., Biederman J. A., Condon K., Merino M., Korgaondar Y., Nan T., Sloat L., Ross M., and Brooks P.D. (2014). Changes in Snow Accumulation and Ablation Following the Las Conchas Forest Fire, New Mexico, USA. *Ecohydrology*. 7 440-452. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/eco.1363

Harpold A.A., Molotch N.P., Musselman K.N., Bales R.C., Kirchner P.B., Litvak M., and Brooks P.D. (2014). Soil Moisture Response to Snowmelt Timing in Mixed-Conifer Subalpine Forests.. *Hydrological Processes*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/hyp. 10400

Harpold A.A., Molotch N.P., Musselman K.N., Bales R.C., Kirchner P.B., Litvak M., and Brooks P.D. (2014). Soil moisture response to snowmelt timing in mixed-conifer subalpine forests.. *Hydrological Processes*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/hyp.10400

Harpold, A.A., Brooks P.D., Perdrial J., McIntosh J., Meixner T., Lohse K.A., Zapata-Rios X., Rios-Vasquez A., and Chorover J. (). Quantifying Variation in Solute Sources and Nutrient Cycling in Montane Headwater Catchments. *Hydrological Processes*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Harpold, A.A., Guo Q., Molotch N., Brooks P.D., Bales R., Fernandez-Diaz J.C., Musselman K.N., Swetnam T.L., Kirchner P., Meadows M., Flanagan J., and Lucas R. (2014). LiDAR-Derived Snowpack Datasets From Mixed Conifer Forests Across the Western U.S.. *Water Resources Research*. 03/2014 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2013WR013935

Harpold, A.A., Marshall, J.A., Lyon, S.W., Barnhart, T.B., Fisher, B., Donovan, M., Brubaker, K.M., Crosby, C.J., Glenn, N.F., Glennie, C.L., Kirchner, P.B., Lam, N., Mankoff, K.D., McCreight, J.L., Molotch, N.P., Musselman, K.N., Pelletier, J.D., Russo, T., Sangireddy, H., Sjöberg, Y., Swetnam, T., and West, N. (2015). Laser vision: lidar as a transformative tool to advance critical zone science.. *Hydrol. Earth Syst. Sci. Discuss.*. 12 1017-1058. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/hessd-12-1017-2015

Heckman K., Throckmorton H., Clingensmith C., Vila F.J.G., Horwath W.R., Knicker H., Rasmussen C. (2014). Factors affecting the molecular structure and mean residence time of occluded organics in a lithosequence of soils under ponderosa pine.. *Soil Biology & Biochemistry*. 77 1-11. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Holleran M., Levi M., Rasmussen C. (2015). Quantifying soil and critical zone variability in a forested catchment through digital soil mapping.. *SOIL*. 1 1-49. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Huckle D., Ma L., McIntosh J., Rasmussen C., Chorover, J. (2015). U-series isotope signatures of soils and headwater streams in a semi-arid complex volcanic terrain.. *Chemical Geology*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Lybrand R.A., Rasmussen C. (2014). A Cross-scale Study of Feldspar Transformation in the Santa Catalina Mountain Critical Zone Observatory.. *Procedia Earth and Planetary Science*. 10 63-68. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Lybrand R.A., Rasmussen C. (2014). Linking soil element-mass-transfer to microscale mineral weathering across a semiarid environmental gradient.. *Chemical Geology*. 381 26-39.. Status = PUBLISHED; Acknowledgment of Federal

Support = Yes ; Peer Reviewed = Yes

Lybrand R.A., Rasmussen C. (2015). Quantifying climate and landscape position controls on soil development in semiarid ecosystems.. *Soil Science Society of America Journal*. 79 104-116. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

McDowell N.G., Coops N.C., Bieck P., Chambers J., Gangodagmage C., Hicke J.A., Huange C., Kennedy R., Krofcheck D., Litvak M., Meddens A., Muss J., Negron-Juarez R., Peng C., Schwantes A., Swenson J.J., Vernon L., Williams A.P., Xu C., Zhao M., Running S., and Allen C. (2014). Global satellite monitoring of climate-induced vegetation disturbances.. *Trends in Plant Science*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

McDowell N.G., Williams A.P, Xu C., Pockman W.T., Dickman L.T., Sevanto S., Pangle R., Limousin J., Plaut J., Maccay D.S., Ogee J., Domec J.C., Allen C.D., Fisher R.A., Jiang X., Muss J.D., Breshears D.D., Rauscher S.A. and Koven C. (). Multi-scale predictions of massive conifer mortality due to chronic temperature rise.. *Nature Climate Change*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

McGuire, L.A., Pelletier, J.D., and Roering, J.J. (2014). Development of topographic asymmetry: Insights from dated cinder cones in the western United States.. *Journal of Geophysical Research*. 119 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2014JF003081

Nelson K., Kurc S.A., John G., Minor R.L., and Barron-Gafford G.A. (2014). Influence of snow cover duration on soil evaporation and respiration efflux in mixed- conifer ecosystems.. *Ecohydrology*. 7 869-880. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Ogle K., Barber J.J., Barron-Gafford G.A., Bentley L.P., Young J.M., Huxman T.E., Loik M.E., and Tissue T.E. (2015). Quantifying ecological memory in plant and ecosystem processes.. *Ecology Letters*. 18 221-235. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Orem, C.A., and Pelletier, J.D. (2015). Quantifying the time scale of elevated geomorphic response following wildfires using multi-temporal LiDAR data: An example from the Las Conchas fire, Jemez Mountains, New Mexico.. *Geomorphology*. 232 224-238. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.geomorph.2015.01.006

Pangle L.A., DeLong S.B., Abramson N., Adams J., Barron-Gafford G., Breshears D.D., Brooks P.D., Chorover J., Dietrich W., Dontsova K., Durcik M., Espeleta J., Ferre T., Ferriere R., Henderson W., Hunt E., Huxman T.E., Millar D., Murphy B., Niu G.Y., Pavao-Zuckerman M., Pelletier J.D., Rasmussen C., Ruiz J., Saleska S., Schaap M., Sibayan M., Troch P.A., Tuller M., van Haren J., Zeng X. (2015). The Landscape Evolution Observatory: large-scale controllable infrastructures to study coupled Earth-surface processes.. *Geomorphology*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: , http://dx.DOI.org/10.1016/j.geomorph.2015.01.020

Pelletier, J.D., and Orem, C.A. (2014). How do sediment yields from post-wildfire debris-laden flows depend on terrain slope, soil burn severity class, and drainage basin area? Insights from airborne-lidar change detection.. *Earth Surface Processes and Landforms*. 39 1822-1832. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/esp.3570

Perdrial J., McIntosh J., Harpold A., Brooks P., Zapata-Rios X., Ray J., Meixner T., Kanduc T., Litvak M., Troch P., Chorover J. (2014). Stream water carbon controls in seasonally snow-covered mountain catchments: impact of interannual variability of water fluxes, catchment aspect and seasonal processes.. *Biogeochemistry*. 118 273-290. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10533-013-9929-y

Potts D.L., Barron-Gafford G.A., and Jenerette G.D. (2014). Metabolic acceleration quantifies biological systems' ability to up-regulate metabolism in response to episodic resource availability.. *Journal of Arid Environments*. 104 9-16. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Rasmussen C., Pelletier J.D., Troch P.A., Swetnam T.L., Chorover J. (2015). Quantifying Topographic and Vegetation Effects on the Transfer of Energy and Mass to the Critical Zone.. *Vadose Zone Journal*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/vzj2014.07.0102

Rocca-Serra P. Walls R., Parnell J., Gallery,R.E., Zheng J., Sansone S.A., and Gonzalez-Beltran A. (2015). Modeling a Microbial Community and Biodiversity Assay with OBI and PCO OBO Foundry Ontologies: The Interoperability Gains of a Modular Approach.. *Database*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1093/database/bau132

Scott R.L., Huxman T.E., Barron-Gafford G.A., Jenerette G.D., Young J.M., and Hamerlynck E.P. (2014). When vegetation change alters ecosystem water availability.. *Global Change Biology*. 20 2198-2210. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1111/gcb.12511

Stielstra, C.M., Lohse K.A., Chorover J., McIntosh J.C., Litvak M., Baron-Gafford G., Barnard H., 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*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10533-015-0078-3

Swetnam T.L., Falk D.A., Enquist B.J., Lynch A.M., Guertin D.P., and Yool S. (2014). Assessing the generality of Metabolic Scaling Theory in differing forest disturbance regimes. *The American Naturalist*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Swetnam, T.L., and Falk, D.A. (2014). Allometric scaling rules to limit commission error in aerial LiDAR forest inventories.. *Forest Ecology and Management*. 323 158-167. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.foreco.2014.03.016

Swetnam, T.L., Falk, D.A., Lynch, A.M., and Yool, S.R. (2014). Estimating individual tree mid- and understory rank-size distributions from airborne laser scanning in semi-arid forests.. *Forest Ecology and Management*. 330 271-282. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.foreco.2014.07.011

Swetnam, T.L., Lynch, A.M., Falk, D.A., Yool, S.R., and Guertin, D.P. (2015). Discriminating disturbance from natural variation with LiDAR in semi-arid forests in southwestern USA.. *Ecosphere*. 6(5) . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1890/ES14-00384.1

Villegas J.C., Dominguez F., Barron-Gafford G., Adams H.D., Guardiola-Claramonte M., Sommer E.D., Wiede A., Espeleta J.E., Zou C.B., Breshears D.D., and Huxman T.E. (2015). Sensitivity of regional evapotranspiration partitioning to variation in woody plant cover: insights from experimental dryland tree mosaics.. *Global Ecology and Biogeography*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Villegas J.C., Espeleta J.E., Morrison C.T., Breshears D.D., and Huxman T.E. (2014). Factoring in canopy cover heterogeneity on evapotranspiration partitioning: Beyond big-leaf surface homogeneity assumptions.. *Journal of Soil and Water Conservation*. 69(3) 78A-83A. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Vázquez-Ortega, A., Perdrial J., Harpold A., Zapata-Ríos X., Rasmussen C., McIntosh J., Schaap M., Pelletier J.D., Brooks P.D., and Amistadi M.K. (2014). Rare earth elements as reactive tracers of biogeochemical weathering in forested rhyolitic terrain.. *Chemical Geology*. 391 19-32. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Whicker J.J., Breshears D.D., and Field, J.P. (2014). Progress on relationships between horizontal and vertical dust flux: Mathematical, empirical and risk-based perspectives.. *Aeolian Research*. 14 105-111. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Zapata-Rios X., Troch P.A., Brooks P.D., McIntosh J., Guo Q. (). Influence of terrain aspect on water partitioning,

vegetation structure and vegetation greening in high elevation catchments in northern New Mexico.. *Ecohydrology*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Zhang X., Niu G.-&., Elshall A.S., Ye M., Barron-Gafford G.A., and Pavao-Zuckerman M. (2014). Assessing five evolving microbial enzyme models against field measurements from a semiarid savannah—What are the mechanisms of soil respiration pulses?. *Geophys. Res. Lett*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2014GL061399

Zhang X., Niu G.-Y., Elshall A.S., Ye M., Barron-Gafford G.A., and Pavao-Zuckerman M. (2014). Assessing five evolving microbial enzyme models against field measurements from a semiarid savannah-What are the mechanisms of soil respiration pulses?. *Geophysical Research Letters*. 41 6428-6434. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses

Other Products

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Kidder, A.L.. *"Ecohydrological conditions contributing to the distribution and phenology of the pima pineapple cactus (Coryphantha scheeri var. robustispina)"*.. (2014). School of Natural Resources and the Environment, University. Acknowledgement of Federal Support = Yes

Orem, C.A.. *"The Frequency and Magnitude of Flood Discharges and Post-wildfire Erosion in the Southwestern U.S."*. (2014). Geosciences, University of Arizona. Acknowledgement of Federal Support = Yes

Lybrand, R.. *"The effects of climate and landscape position on mineral weathering and soil carbon storage in the Santa Catalina Critical Zone Observatory of southern Arizona"*.. (2014). Soil, Water and Environmental Science, University of Arizona. Acknowledgement of Federal Support = Yes

Zapata-Rios, X.. *"The influence of climate and landscape on hydrological processes, vegetation dynamics, biogeochemistry and the transfer of effective energy and mass to the critical zone"*.. (2015). Hydrology and Water Resources, University of Arizona. Acknowledgement of Federal Support = Yes

Websites

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Chorover, Jon	PD/PI	1
Breshears, David	Co PD/PI	1
McIntosh, Jennifer	Co PD/PI	1
Pelletier, Jon	Co PD/PI	1

Rasmussen, Craig	Co PD/PI	1
Barron-Gafford, Greg	Co-Investigator	1
Ferré, Ty P.A.	Co-Investigator	1
Meixner, Thomas	Co-Investigator	1
Niu, Guo-Yue	Co-Investigator	1
Papuga, Shirley	Co-Investigator	1
Schaap, Marcel	Co-Investigator	1
Brooks, Paul	Faculty	2
Litvak, Marcy	Faculty	1
Plant, Bill	Faculty	1
Potts, Daniel	Faculty	2
Reed, Shipherd	Faculty	1
Biederman, Joel	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Field, Jason	Postdoctoral (scholar, fellow or other postdoctoral position)	3
Harpold, Adrian	Postdoctoral (scholar, fellow or other postdoctoral position)	2
Maurer, Gregory	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Mitra, Bhaskar	Postdoctoral (scholar, fellow or other postdoctoral position)	2
Nesbitt, Lindsey	Postdoctoral (scholar, fellow or other postdoctoral position)	2
Swetnam, Tyson	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Trostle, Kyle	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Villegas, Juan	Postdoctoral (scholar, fellow or other postdoctoral	1

Villegas, Juan	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Abramson, Nathan	Other Professional	12
Dhakal, Prakash	Other Professional	1
Fields, Jen	Other Professional	1
Kobilka, Sara	Other Professional	1
Losleben, Mark	Other Professional	6
Parmenter, Robert	Other Professional	1
Ruiz, Ruben	Other Professional	1
Minor, Rebecca	Technician	2
Furst, Jonathan	Staff Scientist (doctoral level)	1
Balocchi, Francisco	Graduate Student (research assistant)	6
Coe, Michelle	Graduate Student (research assistant)	6
Dwivedi, Ravindra	Graduate Student (research assistant)	6
Fairbanks, Dawson	Graduate Student (research assistant)	1
Fang, Yuanhao	Graduate Student (research assistant)	2
Kidder, Amy	Graduate Student (research assistant)	3
Kopp, Emily	Graduate Student (research assistant)	6
Logie, Cianna	Graduate Student (research assistant)	6
Lybrand, Rebecca	Graduate Student (research assistant)	3
McClure, Brianna	Graduate Student (research assistant)	6
Murphy, Margretta	Graduate Student (research assistant)	5
Olyphant, Jared	Graduate Student (research assistant)	3
Orem, Caitlin	Graduate Student (research assistant)	3
Paras, Ben	Graduate Student (research assistant)	6

Pohlmann, Michael	Graduate Student (research assistant)	3
Runjian, Wu	Graduate Student (research assistant)	6
Sanchez, Rodrigo	Graduate Student (research assistant)	3
Shepard, Christopher	Graduate Student (research assistant)	3
White, Alissa	Graduate Student (research assistant)	6
Yuanhao, Fang	Graduate Student (research assistant)	6
Zapata-Rios, Xavier	Graduate Student (research assistant)	6
Law, Darin	Non-Student Research Assistant	2
Bergeron, Hannah	Undergraduate Student	2
Blum, Aidan	Undergraduate Student	1
Bojorquez Ochoa, Mirsa	Undergraduate Student	2
Braun, Zev	Undergraduate Student	2
Garlant, James	Undergraduate Student	1
Guan, Janelle	Undergraduate Student	2
Hall, Becky	Undergraduate Student	2
Heard, Maggie	Undergraduate Student	3
Heydorn, Katherine	Undergraduate Student	2
Hoskinson, Joshua	Undergraduate Student	6
Matos, Katarena	Undergraduate Student	2
Pedron, Shawn	Undergraduate Student	2
Reynoso, Erick	Undergraduate Student	2
Smith, Rebecca	Undergraduate Student	1
Sutter, Leland	Undergraduate Student	3
Tritz, Claire	Undergraduate Student	2

[illegible]	[illegible]	2
Van Dop, Molly	Undergraduate Student	1
Wehr, Rachel	Undergraduate Student	1
Yang, Julia	Undergraduate Student	2

Full details of individuals who have worked on the project:

Jon D Chorover
Email: Chorover@cals.arizona.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Principal Investigator

Funding Support: NSF

International Collaboration: Yes, Japan
International Travel: Yes, Korea, Republic Of - 0 years, 0 months, 7 days

David D Breshears
Email: daveb@email.arizona.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Critical Zone Services - Theme Lead

Funding Support: NSF

International Collaboration: No
International Travel: No

Jennifer C McIntosh
Email: mcintosh@hwr.arizona.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Theme Lead: Geobiological Feedbacks

Funding Support: NSF

International Collaboration: No
International Travel: No

Jon D Pelletier
Email: jdpellet@email.arizona.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Leader of landscape evolution team

Funding Support: NSF

International Collaboration: No
International Travel: No

Craig Rasmussen
Email: crasmuss@cals.arizona.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Leader of soil team

Funding Support: NSF

International Collaboration: Yes, Japan
International Travel: No

Greg Barron-Gafford
Email: gregbg@email.arizona.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Assistant Professor and Ecosystem Ecologist

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Ty P.A. Ferré
Email: tyferre@gmail.com
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Professor and Hydrogeophysicist

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Thomas Meixner
Email: tmeixner@email.arizona.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Professor and Catchment Hydrologist/Biogeochemist

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Guo-Yue Niu
Email: niug@email.arizona.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Assistant Professor and Land-Atmosphere Exchange Modeler

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Shirley Papuga
Email: papuga@email.arizona.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Associate Professor and Ecohydrologist

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Marcel Schaap
Email: mschaap@cals.arizona.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Associate Professor and Soil Physicist

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Paul Brooks
Email: paul.brooks@utah.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 2

Contribution to the Project: Performed observations, analysis, and modeling on snow cover, water balance, carbon and nutrient cycling and CA evolutuion.

Funding Support: DOE and this award

International Collaboration: Yes, Sweden
International Travel: No

Marcy Litvak
Email: mlitvak@unm.edu

Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Has performed work in the area of keeping the flux towers running and data processed.

Funding Support: Ameriflux Core support (160 hours), DOE TES (80 hours), NSF LTER (80 hours)

International Collaboration: No
International Travel: No

Bill Plant
Email: wplant@email.arizona.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Education and outreach

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Daniel Potts
Email: pottsdl@buffalostate.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 2

Contribution to the Project: Daniel has performed work in the area of plant ecophysiology - developing an understanding of the physiological constraints of the tree community around the Mt. Bigelow eddy covariance towar site.

Funding Support: Daniel is faculty of Buffalo State College

International Collaboration: No
International Travel: No

Shipherd Reed
Email: shipherd@email.arizona.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Appointed Personnel

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Joel Biederman
Email: joel.biederman.ua@gmail.com
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)

Nearest Person Month Worked: 1

Contribution to the Project: Graduate student/postdoc associate

Funding Support: Other

International Collaboration: No
International Travel: No

Jason Field
Email: jpfield@email.arizona.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 3

Contribution to the Project: postdoc

Funding Support: NSF

International Collaboration: No
International Travel: No

Adrian Harpold
Email: adrian.harpold@gmail.com
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 2

Contribution to the Project: postdoc associate

Funding Support: NSF

International Collaboration: No
International Travel: No

Gregory Maurer
Email: gregmaurer@gmail.com
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 1

Contribution to the Project: Has performed work in the area of keeping the flux towers running and data processed.

Funding Support: Ameriflux Core support

International Collaboration: No
International Travel: No

Bhaskar Mitra
Email: bhaskar.mitra6@gmail.com
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 2

Contribution to the Project: postdoc

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Lindsey Nesbitt
Email: lindseychr@gmail.com
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 2

Contribution to the Project: Coupled water and biogeochemical modeling

Funding Support: DOE and other NSF

International Collaboration: No
International Travel: No

Tyson Lee Swetnam
Email: tswetnam@email.arizona.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 6

Contribution to the Project: postdoc

Funding Support: NSF

International Collaboration: No
International Travel: No

Kyle Trostle
Email: ktrostle@email.arizona.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 12

Contribution to the Project: CZO postdoc leading concentration-discharge analyses and aqueous geochemistry.

Funding Support: NSF

International Collaboration: No
International Travel: No

Juan Camilo Villegas
Email: villegas@email.arizona.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 1

Contribution to the Project: postdoc

Funding Support: NSF

International Collaboration: No
International Travel: No

Nathan Abramson
Email: nabramso@email.arizona.edu
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 12

Contribution to the Project: Research Specialist

Funding Support: NSF

International Collaboration: No
International Travel: No

Prakash Dhakal
Email: dhakal@email.arizona.edu
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 1

Contribution to the Project: Laboratory Director

Funding Support: Other funding

International Collaboration: No
International Travel: No

Jen Fields
Email: fieldsj@email.arizona.edu
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 1

Contribution to the Project: Giving advice as Staff, Director of Education for CZ Discovery development meetings, we provided CZ activities for some of the UA Fusion summer camps that she manages. Has performed work by providing advice and expertise on K-12 educational activities for the CZ Discovery program.

Funding Support: Staff at Flandrau Science Center, no CZO funding, volunteered her time.

International Collaboration: No
International Travel: No

Sara Kobilka
Email: kobilka@email.arizona.edu
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 1

Contribution to the Project: Provided coordination with schedule and camp counselors to pilot some of the CZ Discovery activities. She is staff, summer camp coordinator.

Funding Support: Staff at UA Fusion Camp (Flandrau summer camp), no CZO funding. Volunteers time.

International Collaboration: No
International Travel: No

Mark Losleben
Email: losleben@email.arizona.edu
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 6

Contribution to the Project: Research Technician

Funding Support: NSF

International Collaboration: No
International Travel: No

Robert Parmenter
Email: bparmenter@vallescaldera.gov
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 1

Contribution to the Project: Project Site coordination, presentation of results from CZO group to agencies and general public.

Funding Support: As a Federal Employee (Director, Scientific Services Division VCNP) salary is covered by the U.S. Government.

International Collaboration: No
International Travel: No

Ruben Ruiz
Email: rubelruiz@gmail.com
Most Senior Project Role: Other Professional
Nearest Person Month Worked: 1

Contribution to the Project: classified part-time staff - videography

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Rebecca Minor
Email: rlminor@email.arizona.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 2

Contribution to the Project: Research Technician

Funding Support: NSF

International Collaboration: No
International Travel: No

Jonathan Furst
Email: jfurst@unm.edu

Most Senior Project Role: Staff Scientist (doctoral level)
Nearest Person Month Worked: 1

Contribution to the Project: Has performed work in the area of keeping the flux towers running and data processed.

Funding Support: Ameriflux Core support

International Collaboration: No
International Travel: No

Francisco Balocchi
Email: fbalocchi@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Is working on understanding the hydrologic processes operating during snowmelt that induce either infrilatration or runoff.

Funding Support: Funded by the nation of Chile.

International Collaboration: Yes, Chile
International Travel: No

Michelle Coe
Email: macoe@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Michelle Coe has performed work towards our Broader Impacts in terms of leading in-class activities with elementary students.

Funding Support: NASA Space Grant Fellowship

International Collaboration: No
International Travel: No

Ravindra Dwivedi
Email: ravindradwivedi@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Has worked on understanding the origins and mechanisms for residence time distribution functions in fractured rock systems

Funding Support: This award and teaching assistantship

International Collaboration: No
International Travel: No

Dawson Fairbanks
Email: dawsonfairbanks@email.arizona.edu

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

Contribution to the Project: Has contributed outreach experience and topic expertise to the development of the CZ Discovery activities, will give time to activity delivery. Also has performed work in the area of soil microbial ecology including a number of field campaigns to CZO sites to characterize and collect soils samples, laboratory assays of microbial exoenzyme activity, microbial biomass Carbon and Nitrogen quantification, DNA extractions and quality control, data analysis, and manuscript preparation.

Funding Support: She is a grad student on CZO. Sloan Indigenous Graduate Partnership Fellowship.

International Collaboration: No
International Travel: No

Yuanhao Fang
Email: yhfang@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 2

Contribution to the Project: Has perfromed modeling of the topgraphic shading effects on snow and runoff

Funding Support: Chinese National Science Foundation (CNSF) visiting scholar

International Collaboration: Yes, China
International Travel: No

Amy Kidder
Email: akidder@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Ecohydrological assessment of changes in distribution of endangered Pima Pineapple Cactus, including potential migration across Catalinas of Jemez-Catalina gradient.

Funding Support: Raytheon

International Collaboration: No
International Travel: No

Emily Kopp
Email: ekopp@optics.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: SWES graduate student

Funding Support: NSF

International Collaboration: No
International Travel: No

Cianna Logie

Email: clogie@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: M.S. student

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Rebecca Lybrand
Email: rlybrand@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Ph.D. student

Funding Support: NSF

International Collaboration: No
International Travel: No

Brianna McClure
Email: briannamcclure@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Has worked on impact of fire on DOM indices and whether fire effects DOM quality and quantity.

Funding Support: This award and from teaching assistantship

International Collaboration: No
International Travel: No

Margretta Murphy
Email: mamurphy@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 5

Contribution to the Project: Has performed work in the area of soil microbial ecology including a number of field campaigns to CZO sites to characterize and collect soil samples, laboratory assays of microbial biomass Carbon and Nitrogen quantifications, DNA extractions and quality control, and troubleshooting protocols for quantitative PCR.

Funding Support: N/A

International Collaboration: No
International Travel: No

Jared A. Olyphant

Email: jolyphant@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Ph.D. student

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Caitlin A. Orem
Email: orem@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Ph.D. student

Funding Support: NSF

International Collaboration: No
International Travel: No

Ben Paras
Email: bkp@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Subsurface imaging with geophysics

Funding Support: NSF

International Collaboration: No
International Travel: No

Michael Pohlmann
Email: mapohlmann@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: M.S. student

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Wu Runjian
Email: wurunjian@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: graduate student

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Rodrigo Andres Sanchez
Email: andressanchez@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: MS student

Funding Support: Other

International Collaboration: No
International Travel: No

Christopher Shepard
Email: cbs9h@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Has performed work in the area of soil modeling

Funding Support: University Fellows program through UA graduate college

International Collaboration: No
International Travel: No

Alissa White
Email: alissawhite@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: M.S. student

Funding Support: NSF

International Collaboration: No
International Travel: No

Fang Yuanhao
Email: yuanhao.fang@outlook.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Ph.D. student

Funding Support: NSF and other

International Collaboration: No
International Travel: No

Xavier Zapata-Rios
Email: xavierzapata@email.arizona.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Ph.D. student

Funding Support: NSF

International Collaboration: No
International Travel: No

Darin Law
Email: dlaw@email.arizona.edu
Most Senior Project Role: Non-Student Research Assistant
Nearest Person Month Worked: 2

Contribution to the Project: Co-author on critical zone services papers (Vadose Zone Journal and Eos); led installation of microclimate array at Mt. Bigelow

Funding Support: Arizona Agricultural Experiment Station

International Collaboration: No
International Travel: No

Hannah Bergeron
Email: hlberg12@gmail.com
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: undergraduate research technician

Funding Support: NSF

International Collaboration: No
International Travel: No

Aidan Blum
Email: aidanblum@email.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Processing water samples for the CZO project. Also raqn samples for water stable isotopes on the isotope analyzer.

Funding Support: TRIF and HWR

International Collaboration: No
International Travel: No

Mirsa Bojorquez Ochoa
Email: m.holly.boom@gmail.com
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Undergraduate

Funding Support: NSF

International Collaboration: No
International Travel: No

Zev Braun
Email: braunzev@grinnell.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: undergrad student

Funding Support: NSF

International Collaboration: No
International Travel: No

James Garlant
Email: garlant@email.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Undergraduate contributing to Ecohydrology Theme - looking at sources of plant water use in our SCM Mixed Conifer Site at Mt. Bigelow.

Funding Support: This research is suppported in salary by NSF Career Award

International Collaboration: No
International Travel: No

Janelle Guan
Email: jguan@email.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: undergraduate student

Funding Support: NSF

International Collaboration: No
International Travel: No

Becky Hall
Email: beckyh@email.arizona.edu

Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: post B.S. volunteer

Funding Support: other

International Collaboration: No
International Travel: No

Maggie Heard
Email: maggieheard@gmail.com
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: Undergraduate Student and Accelerated MS on CZO

Funding Support: NSF

International Collaboration: No
International Travel: No

Katherine Heydorn
Email: kheydorn@email.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: undergrad student

Funding Support: NSF

International Collaboration: No
International Travel: No

Joshua Hoskinson
Email: jhoskinson@emai.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 6

Contribution to the Project: Has performed work in the area of soil minerology

Funding Support: NASA Space Grant

International Collaboration: No
International Travel: No

Katarena Matos
Email: katarenamatos@email.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: undergraduate student

Funding Support: NSF

International Collaboration: No
International Travel: No

Shawn Pedron
Email: sped398@email.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: undergraduate student

Funding Support: NSF

International Collaboration: No
International Travel: No

Erick Reynoso
Email: edreynoso@miners.utep.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: undergraduate student

Funding Support: NSF

International Collaboration: No
International Travel: No

Rebecca Smith
Email: rkramersmith@gmail.com
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Laboratory and data analyses

Funding Support: DOE and other NSF

International Collaboration: No
International Travel: No

Leland Sutter
Email: lelandsutter@email.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: undergraduate student who has performed work in the area of soil CO2 and water fluxes in the SCM CZO sites, particularly the Mt. Bigelow eddy covariance tower site. Leland also compiles datasets for analysis.

Funding Support: NSF

International Collaboration: No
International Travel: No

Claire Tritz
Email: ckat@email.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Worked on processing water samples for the CZO project.

Funding Support: TRIF

International Collaboration: No
International Travel: No

Molly Van Dop
Email: mvandop@email.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: undergraduate student

Funding Support: NSF

International Collaboration: No
International Travel: No

Rachel Wehr
Email: rachelwehr@email.arizona.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Undergraduate contributing to Ecohydrology Theme - looking at precipitation and soil moisture trends in SCM at Marshall Gulch.

Funding Support: This research is supported in salary by NSF Career award.

International Collaboration: No
International Travel: No

Julia Yang
Email: juj.yang@gmail.com
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: undergraduate student

Funding Support: NSF

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
Arizona State University	Academic Institution	Tempe, AZ
Cornell University	Academic Institution	Ithaca, NY
Valles Caldera National Preserve	Other Organizations (foreign or domestic)	Jemez Springs, NM
Los Alamos National Laboratory	Other Organizations (foreign or domestic)	Los Alamos, NM
Los Alamos National Laboratory	Industrial or Commercial Firms	New Mexico
State University of New York	Academic Institution	Buffalo, NY
Tucson Unified School District	School or School Systems	Tucson, AZ
USDA-Agricultural Research Services Southwest Watershed	State or Local Government	Southwest
USGS	State or Local Government	New Mexico
University of Utah	Academic Institution	Utah

Full details of organizations that have been involved as partners:

Arizona State University

Organization Type: Academic Institution
Organization Location: Tempe, AZ

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

More Detail on Partner and Contribution: ASU personnel including Arjun Heimsath and coworkers are conducting collaborative research in the SCM CZO.

Cornell University

Organization Type: Academic Institution
Organization Location: Ithaca, NY

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: Through PI Louis Derry, Cornell University is conducting geochemical

research at the SCM-JRB CZO.

Los Alamos National Laboratory

Organization Type: Other Organizations (foreign or domestic)
Organization Location: Los Alamos, NM

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

More Detail on Partner and Contribution: Los Alamos National Laboratory loans field based equipment to the JRB-SCM CZO that is associated with our eddy covariance and ecohydrologic studies.

Los Alamos National Laboratory

Organization Type: Industrial or Commercial Firms
Organization Location: New Mexico

Partner's Contribution to the Project:
Facilities

More Detail on Partner and Contribution:

State University of New York

Organization Type: Academic Institution
Organization Location: Buffalo, NY

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution:

Tucson Unified School District

Organization Type: School or School Systems
Organization Location: Tucson, AZ

Partner's Contribution to the Project:
Facilities

More Detail on Partner and Contribution:

USDA-Agricultural Research Services Southwest Watershed

Organization Type: State or Local Government
Organization Location: Southwest

Partner's Contribution to the Project:

Facilities

More Detail on Partner and Contribution:

USGS

Organization Type: State or Local Government
Organization Location: New Mexico

Partner's Contribution to the Project:
Facilities

More Detail on Partner and Contribution:

University of New Mexico

Organization Type: Academic Institution
Organization Location: Albuquerque, NM

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

More Detail on Partner and Contribution: Professor Marcy Litvak is a subcontracted PI focusing on eddy covariance research at the JRB site.

University of Utah

Organization Type: Academic Institution
Organization Location: Utah

Partner's Contribution to the Project:
Facilities

More Detail on Partner and Contribution:

Valles Caldera National Preserve

Organization Type: Other Organizations (foreign or domestic)
Organization Location: Jemez Springs, NM

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

More Detail on Partner and Contribution: Dr. Robert Parmenter of VCNP (US Forest Service) is a subcontractor on the project and assists through provision of hydrologic technician support and collaborative research.

What other collaborators or contacts have been involved?

School of Geography and Development's Community School Garden Programs

Salt River Project

Impacts

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

Critical Zone Science: This is a young field of research that combines the sub-disciplines contained within NSF EAR (geomorphology, geochemistry, and hydrology), in addition to ecology, to resolve how physical, chemical and biological processes are coupled in the earth's near surface.

The C-J CZO has impacted this new field in several ways including:

- (i) by proposing and testing a conceptual framework for coupled climatic and ecological drivers of CZ evolution that combines quantitatively meteoric and biological forcings into a single term (EEMT);
- (ii) by constructing a CZO at the warmer-drier end of the CZO network climate continuum; (iii) by organizing CZ science symposia at national and international meetings;
- (iv) by extending CZ science to the public through a variety of media (public presentations, exhibits, iPhone applications, etc.) as discussed elsewhere in this report;
- (v) by coordinating with other CZOs and the CZO National Office to develop a high-impact set of common questions and common measurements that are pursued by cross-CZO working groups network-wide; and
- (vi) by designing, executing, publishing and publicizing high-quality, integrated CZ science.

Some examples of our scientific impacts, discussed in "Results" and pertaining to the thematic foci of our CZO include:

- **Ecohydrology:** Developed long term records of catchment water balances that show statistically significant negative trends in the past three decades for precipitation, vaporization and discharge for Southwestern study sites.
- **Biogeochemistry:** Developing aqueous geochemical methods for quantifying nano-particulate and organically-complexed contributions to soil porewater, groundwater, and streamwater effluents.
- **Microbial Ecology:** Identifying landscape positions that operate as biogeochemical hotspots because of convergent hydrologic flows in water-limited hillslopes.
- **Geomorphology:** Developed code to compute Effective Energy and Mass Transfer (EEMT) using High-Performance Computing resources for any U.S. location and for any time interval 1970-present using just a Digital Elevation Model (DEM) (climate data is automatically extracted from DAYMET). Code currently being implemented for use within OpenTopography.

What is the impact on other disciplines?

CZ science as an example of transdisciplinary earth surface process research: Science of the critical zone is generating a great deal of interest across earth and ecosystem science disciplines, as indicated by the proliferation of symposia, articles, and professional meetings dedicated to integrating hydrology, geomorphology, geochemistry and ecology from vegetation canopy to groundwater.

The C-J CZO and the CZO network as a whole is most strongly impacting its constituent and allied disciplines by bringing them together to focus attention on grand challenge questions that require an interdisciplinary approach, such as:

- How is the hydrologic cycle controlled by ecosystem function?

- How are the compositions and activities of microbial communities affected by landscape position?

- How does climate change alter the rate of regolith development?

- How does lithology affect the capacity of ecosystems to provide services to society?

CZ Services: The advances we have developed in providing an expanded framework for CZ services (Field et al. 2015, Field et al. in review) and associated coverage (CSA News Feb 2015: 10; doi:10.2134/csa2015-60-2-2; https://www.soils.org/publications/csa/pdfs/60/2/10) enables direct applications within CZ disciplines and applicability across the CZ network and beyond.

What is the impact on the development of human resources?

In the past year, the C-J CZO project has impacted the training of over 20 undergraduate, graduate and postdoctoral students. These students become part of a C-J CZO team that comprises and seeks to integrate a diversity of disciplines represented by staff, faculty and students from a range of earth science fields (hydrology, geomorphology, (bio)geochemistry, soil science, ecology).

In the context of CZO research, students are taught to seek out disciplinary interfaces and utilize tools traditionally associated with other disciplines to address their research questions. Students in the C-JH CZO are trained in components of field-based sensing and sampling, analytical chemistry and molecular biology, and numerical modeling, as needed to test CZO hypotheses.

Graduates of our program have taken jobs in academia (three of our CZO postdocs are now assistant professors at state and private Research I universities), with federal or state agencies (USGS, NFS, AZDEQ) and in the private sector (environmental consulting firms). B.S., M.S., Ph.D. and postdoctoral graduates of our CZO represent a new generation of scientists in the workforce that are trained to work in teams and across disciplines to solve problems in earth surface science that require the integration of hydrologic, geochemical, geomorphic and ecological expertise.

What is the impact on physical resources that form infrastructure?

- CZO field based infrastructure is attracting an increasing number of non-CZO funded scientists to conduct research in both SCM and JRB field sites. These scientists derive from both US and non-US institutions.
- CZO data are used in management decisions on forest thinning and restoration on the VCNP and in Coronado National Forest, based on hydrologic functioning of watersheds. In addition, the presence of the CZO instrumentation and information (data, LiDAR, etc.) make the VCNP an attractive site for additional scientific investigations. In 2014, the Preserve hosted 52 research projects with outside funding of >$5.2 million.
- The CZO project generates a large number of time series samples of soil, sediment, water and biomass for laboratory based analyses, which requires optimization of throughput and QA/QC procedures. This has driven an improvement in functionality of CZO-affiliated laboratories.

What is the impact on institutional resources that form infrastructure?

Because C-J CZO investigators are located at the three flagship universities in the southwestern U.S. (University of Arizona, University of New Mexico, and University of Utah), CZ science has been integrated into the policies, practices and organizations of these institutions in a variety of ways. For example, integrated surface earth science was the focus of a recent NRT proposal submitted to NSF by the University of Arizona (UA). The primary objective of this proposal, submitted with matching support from UA, is to train students in efficient and effective approaches to interrogation of the rapidly growing data streams associated with observatory science worldwide.

Critical Zone science is now recognized by these Southwestern universities as an essential component of research, teaching and Extension that will enhance the sustainability and quality of life in our water-limited region.

What is the impact on information resources that form infrastructure?

The C-J CZO project is making publically available all data generated with NSF funding. Several university investigators, public agency scientists, graduate students from other institutions, and K-12 schools are utilizing the publically available data for research, teaching and management purposes.

The data management project (PI Anthony Aufdenkampe) involves collaborators from all CZOs across the network, and it is focused on making CZO data available to the community of CZ science related researchers, in real-time (or as near to it as possible). Time series and geospatial data streams are currently being generated for the surface earth sciences at unprecedented rates. These data streams enable testing of hypotheses by the broad community of public, scientists, students, etc., that may have never even seen the sites from which the data are derived.

What is the impact on technology transfer?

Results from the C-J CZO are being utilized by technology transfer to educational programs and the public land management organizations associated with the sites under investigations. For example:

- CZO results have been incorporated into the Valles Caldera National Preserve's education program, which supports many class field trips to the Preserve by public school students (elementary, middle school, and high school). Information from CZO results on water balances from snowpack sublimation interactions with forest stand structure (tree densities and canopy cover) are presented to students measuring trees in restored and untreated forests. Students are taught the value of restoring forests to improve hydrologic function of forested watersheds for ecosystem services.
- During 2014-2015, Bob Parmenter of VCNP has presented published hydrologic results from CZO in various technology transfer venues, including large science meetings with the New Mexico Interstate Stream Commission, the U.S. Army Corps of Engineers, and the U.S. Forest Service. CZO data/results have been incorporated into many of Parmenter's public presentations to both government agencies and NGO meetings.
- CZO data from flumes and other instrumentation is being used in a major $2.7 million study by scientists from Los Alamos National Laboratory. LANL scientists are using supercomputers to model climate change impacts on small-scale watershed hydrology for the coming 50 and 100 years. Grant information: Richard Middleton (PI) plus 12 co-PIs, *Critical Watersheds: Climate Change, Tipping Points, and Energy-Water Security Impacts.* 2014-2017, $2,700,000. Department of Energy.

What is the impact on society beyond science and technology?

CZ Services: The advances we have developed in providing an expanded framework for CZ services (Field et al. 2015, Field et al. in review) and associated coverage (CSA News Feb 2015: 10; DOI: 10.2134/csa2015-60-2-2; https://www.soils.org/publications/csa/pdfs/60/2/10) enables direct applications of CZ research from across the CZ network not only within the scientific community but to society at large.

Rio Grande Water Fund: CZO results on watershed hydrology have been incorporated into the mission goals and objectives for the Rio Grande Water Fund, a fund being developed by The Nature Conservancy in the middle Rio Grande basin of New Mexico. This fund, supported by private businesses and corporations, government agencies and NGOs, will provide support for watershed restoration projects, designed to improve watershed discharge and water quality (through high-severity forest fire prevention). CZO data are being used to illustrate the hydrologic changes that result from different stand structures.

The CZ Discovery Program: Will introduce elementary school kids, many of them from underserved (Title 1) schools, to the concept of the Critical Zone, how cycles and systems interact in the CZ to support terrestrial life, and how the CZ provides clean air and water for people and agriculture.

The "Mt. Lemmon Science Tour": Will introduce a wide cross-section of the general public to the concept of the Critical Zone, to many of the science cycles, layers, and time scales that are part of CZ processes, and to CZ services.

Changes/Problems

Changes in approach and reason for change

- **Change in Exhibit Format.** Due to unanticipated high costs of construciton, the team looked at ways to meet the same educational goals for the Critical Zone Science exhibit outlined in the proposal while using a lower cost approach. The new exhibit will be a "Journey through the Critical Zone" that will take visitors through a maze-like environment, exploring CZ layers from the top to the bottom (from the trees down to the bedrock). Immersive displays will highlight the connections between natural cycles at different levels and scales. Large size illustrations of organisms, hands-on artifacts, interpretive graphics, and interactive games will provide an engaging and stimulating exhibit experience.

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

- The 2013 Thompson Ridge wildfire was a clear unanticipated change that resulted in a 5 month gap in fluxes from the mixed conifer site, and 3 month gap from the ponderosa pine tower site. We leveraged considerable funds from Ameriflux funding to Litvak to get the tower up and running again. We also have received some support to initially instrument a third tower in the VC to continue to monitor an unburned subalpine mixed conifer site. We had numerous delays in finding a site we could use for the unburned site. Our initial attempts focused on Mohawk Ridge, to get the most closely matched site to the stand that burned. The burn was so patchy in the region, the only large patches of mostly green, treed, sites, had sizeable burned areas, questionable fetch, or were attacked by spruce budworm in 2014. Our proposed site on the western edge of the Valles Caldera is currently being considered by the National Park Service personnel. We expect to install in August 2015.

Changes that have a significant impact on expenditures

Significant expenditures were required to replace cables, instruments, batteries that burned in the Thompson Ridge wildfire (burned through our most intensively instrumented site in the JRB).

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.

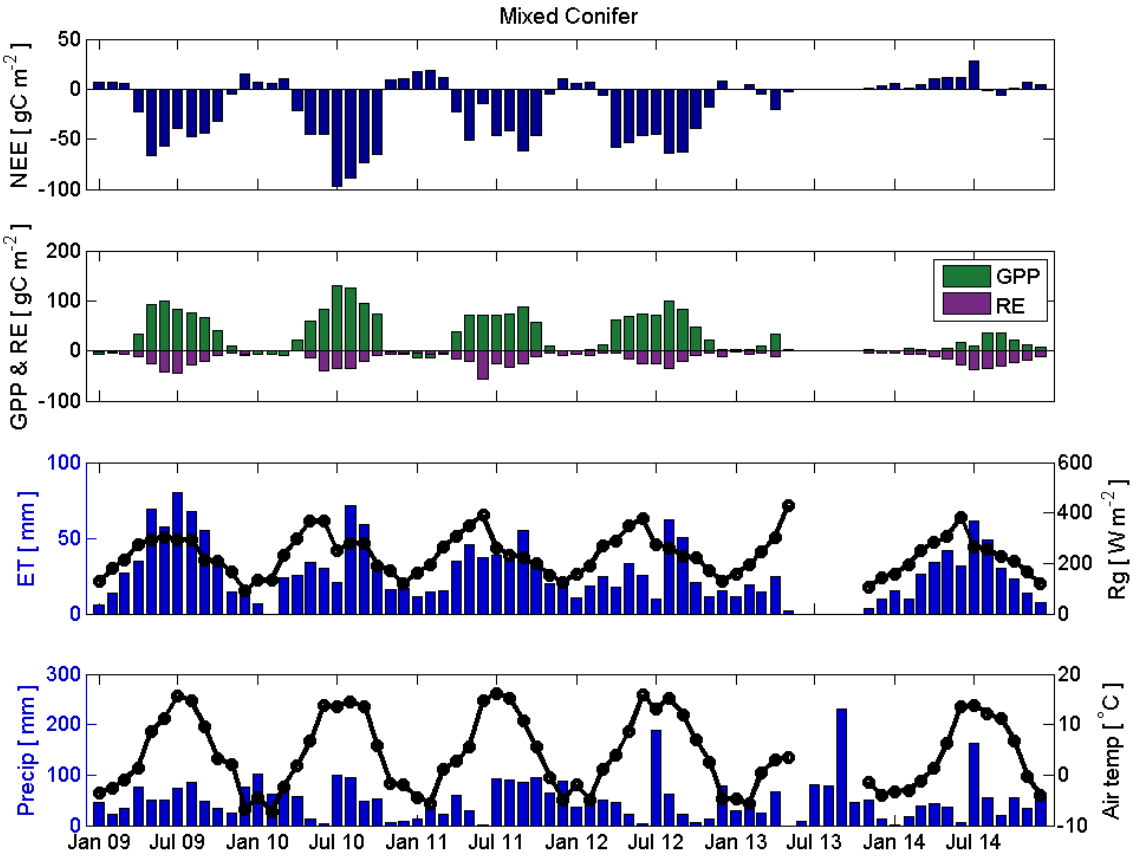


Figure 1. Eddy covariance flux tower data from the mixed conifer site in JRB shows a large reduction in ecosystem C uptake following the stand replacing wildfire in July 2013 (*Litvak et al.*).

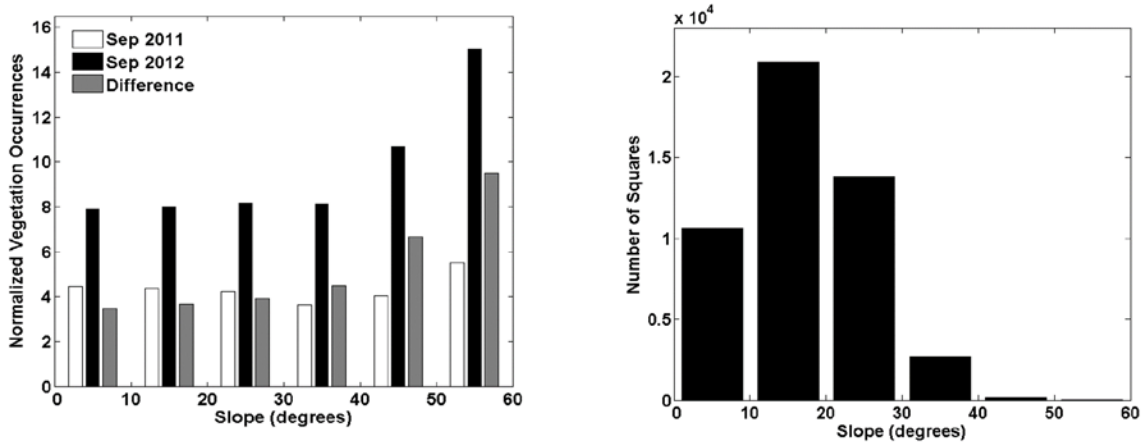
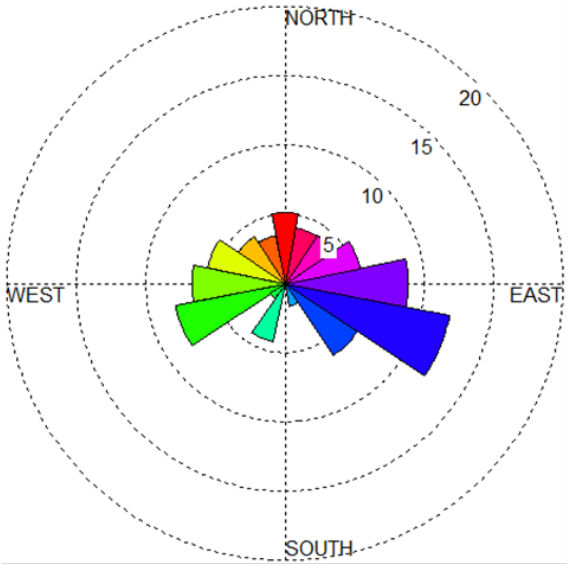
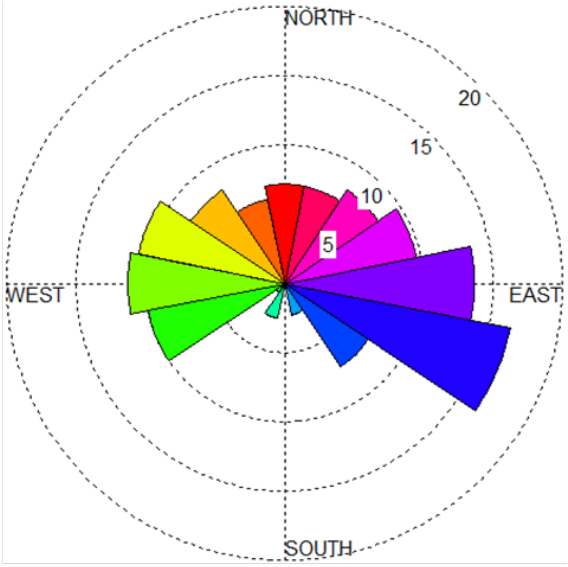


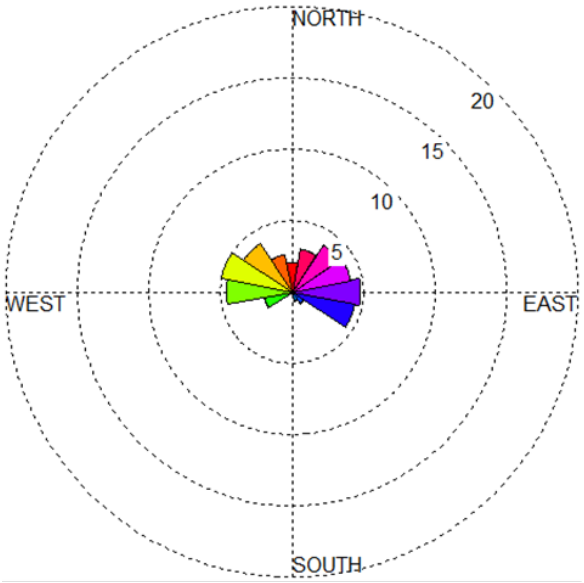
Figure 2. Results from terrestrial LiDAR scans for understory vegetation occurrence and regrowth following the Los Conchas wildfire in JRB (July 2011) (*Papuga, Pelletier, et al.*)



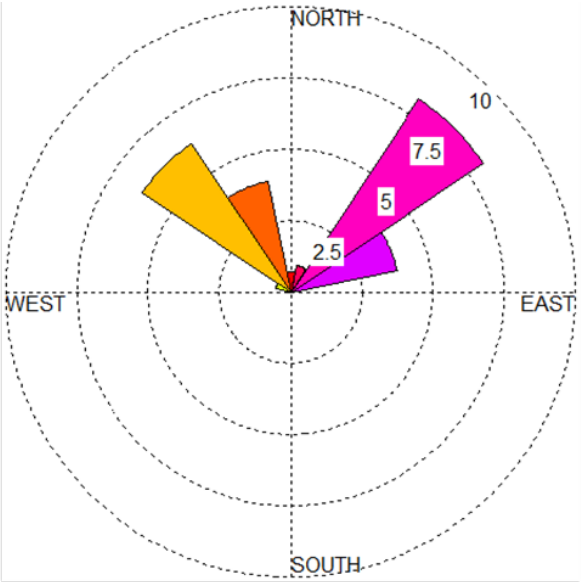
Vegetation Density vs. Terrain Aspect (Sept 2011)



Vegetation Density vs. Terrain Aspect (Sept 2012)



Vegetation Density vs. Terrain Aspect (2012 minus 2011)



Number of 1m squares for each aspect (in thousands)

Figure 3. Results from terrestrial LiDAR scans for understory vegetation occurrence and regrowth following the Los Conchas wildfire in JRB (July 2011) (*Papuga, Pelletier, et al.*)

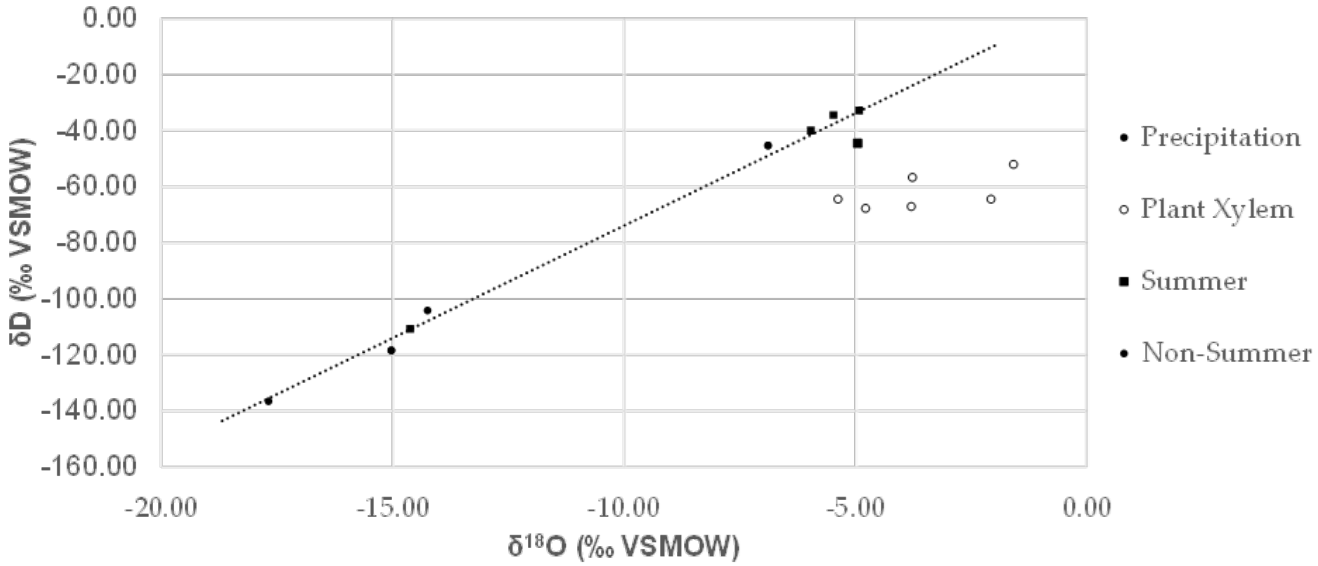


Figure 4. Stable water isotopes associated with summer and winter precipitation and plant xylem in mixed conifer forest of the SCM (*Papuga et al.*).

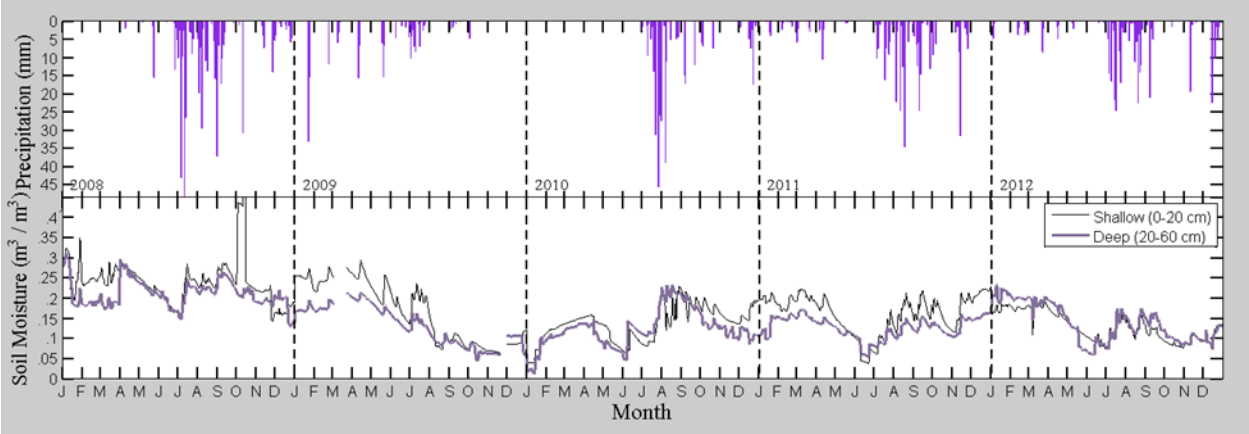


Figure 5. Relations between precipitation and shallow versus deep soil moisture (*Papuga et al.).*

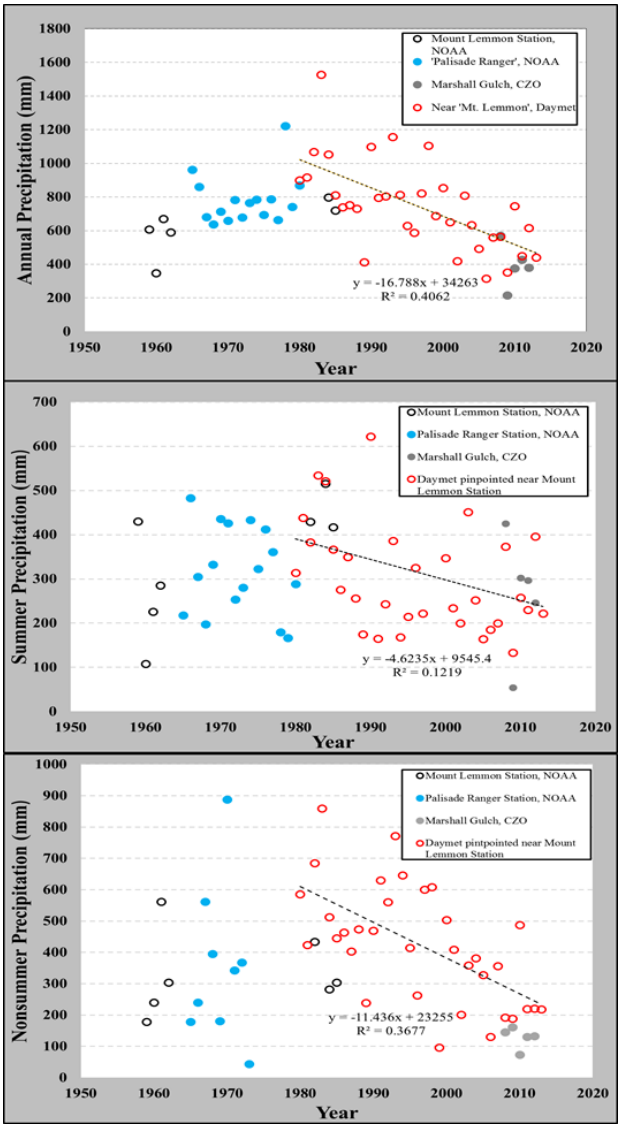


Figure 6. Decrease in overall precipitation in the SCM in the past two decades was largely driven by decreases in winter precipitation (*Papuga et al.*)

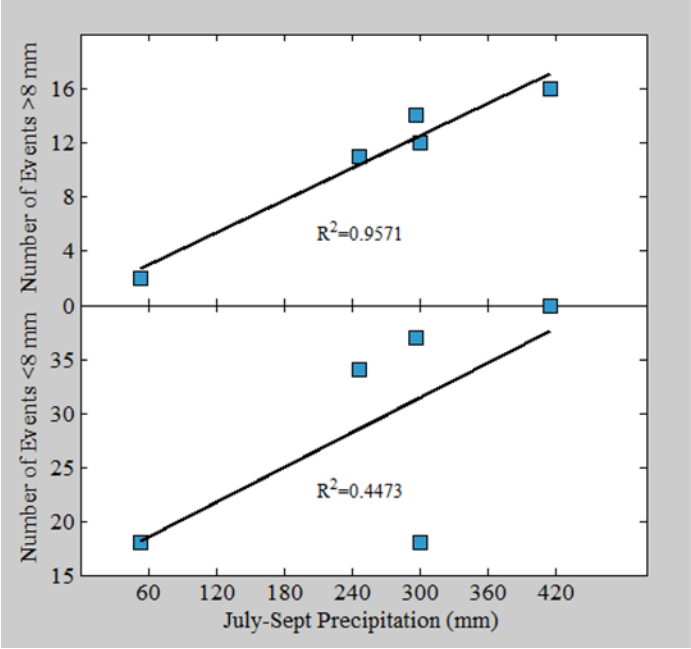


Figure 7. Correlation between total summer precipitation (July-September) and size of precipitation events (*Papuga et al.*).

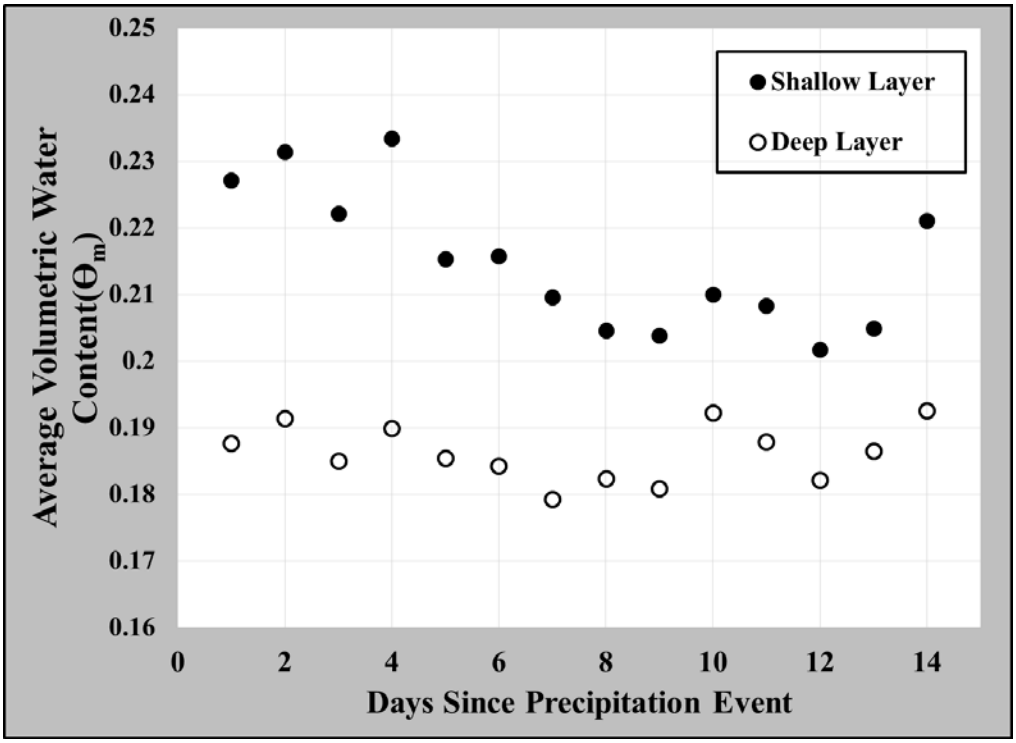


Figure 8. Long term persistence of soil moisture in deep soils following large storm events (*Papuga et al.*).

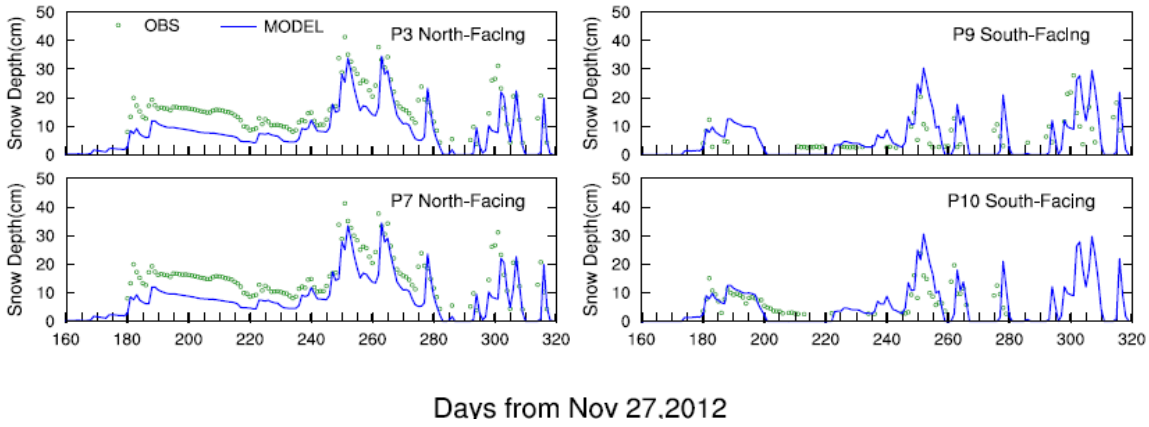


Figure 9. Comparison of modeled with observed snow depth (in centimeters) over north-facing (left two panels) and south-facing slopes (right two panels), in Gordon Gulch (*Niu et al.*).

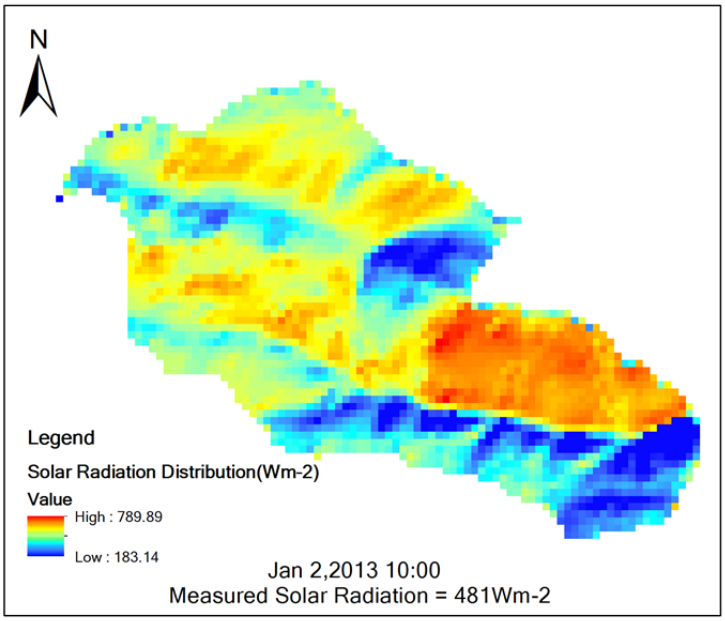


Figure 10. Spatial distribution of solar radiation at 10:00 am of Jan. 2, 2013 over the Golden Gulch, Boulder Creek CZO. North-facing slopes receive much less direct radiation despite increases in adsorption of scattered radiation from the south-facing slopes (*Niu et al.)*.

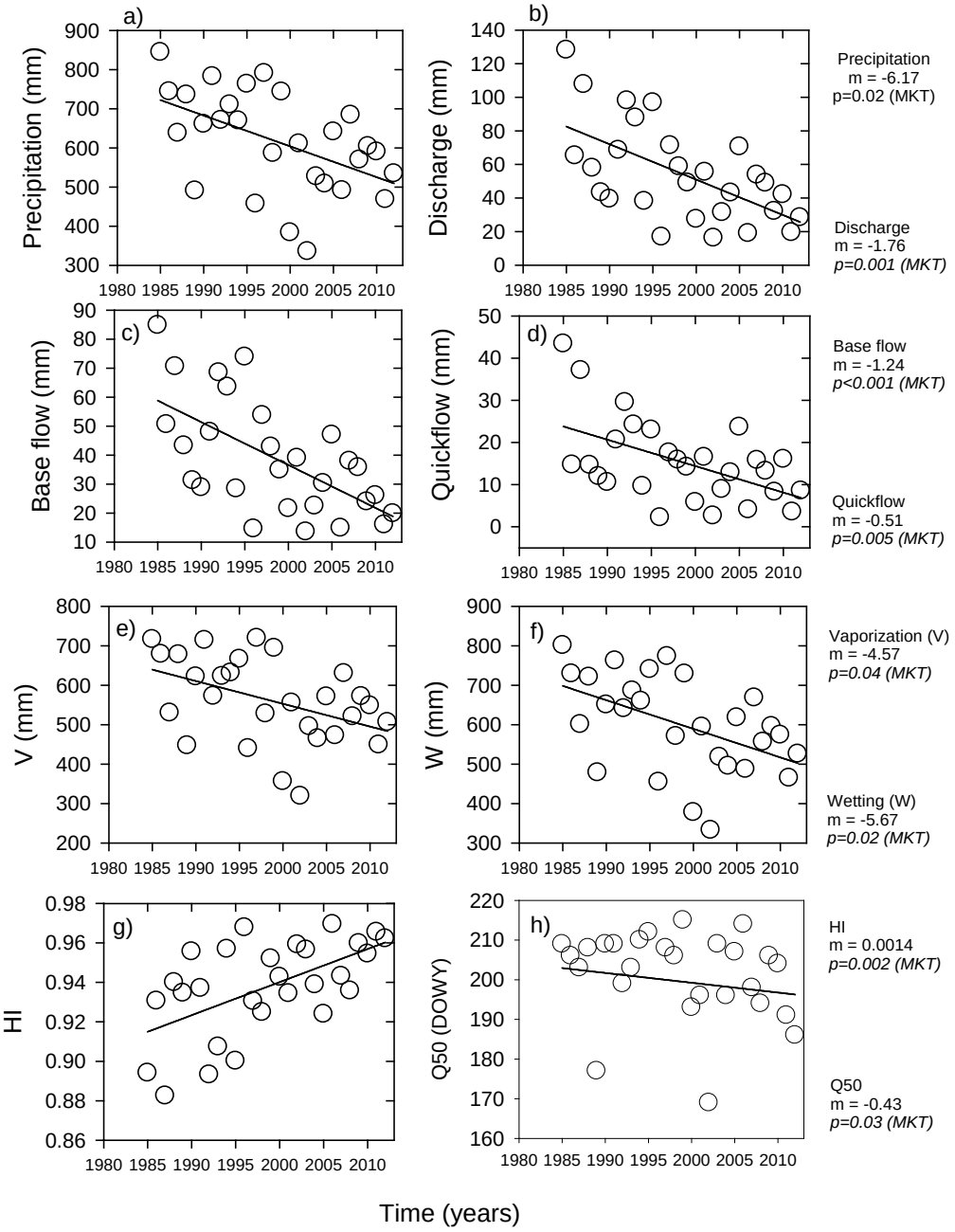


Figure 11. Precipitation and water partitioning at the upper Jemez River catchment scale. There was a significant decreasing trend quantified by the Mann-Kendall test (MKT) in the Jemez River Basin precipitation and all the components of the water partitioning. For instance, precipitation at the catchment scale decreased during the last three decades at a rate of 6.17 mm per year and discharge at 1.76 mm per year. From 1984-2012, Horton index (HI) increased as the basin dried up, indicating that vegetation used more of its available water with increasing water limitation in the basin. Q_{50} indicated that discharge is occurring 4.3 days earlier per decade.

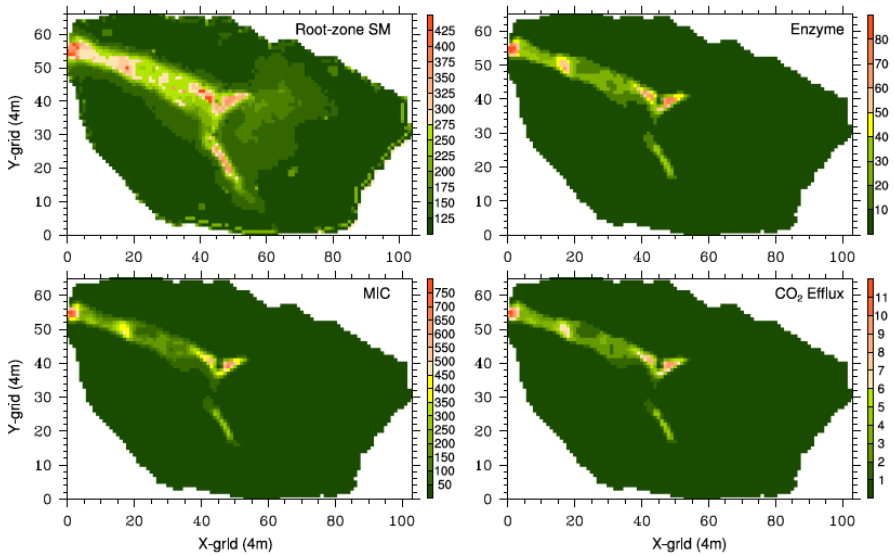


Figure 12. Modeling root-zone soil moisture in top 1-m (in mm), enzyme (g/m^2), microbial biomass (g/m^2), and CO_2 efflux from the soil surface (g/m^2/s) over the Kendall catchment, Walnut Gulch, Arizona.

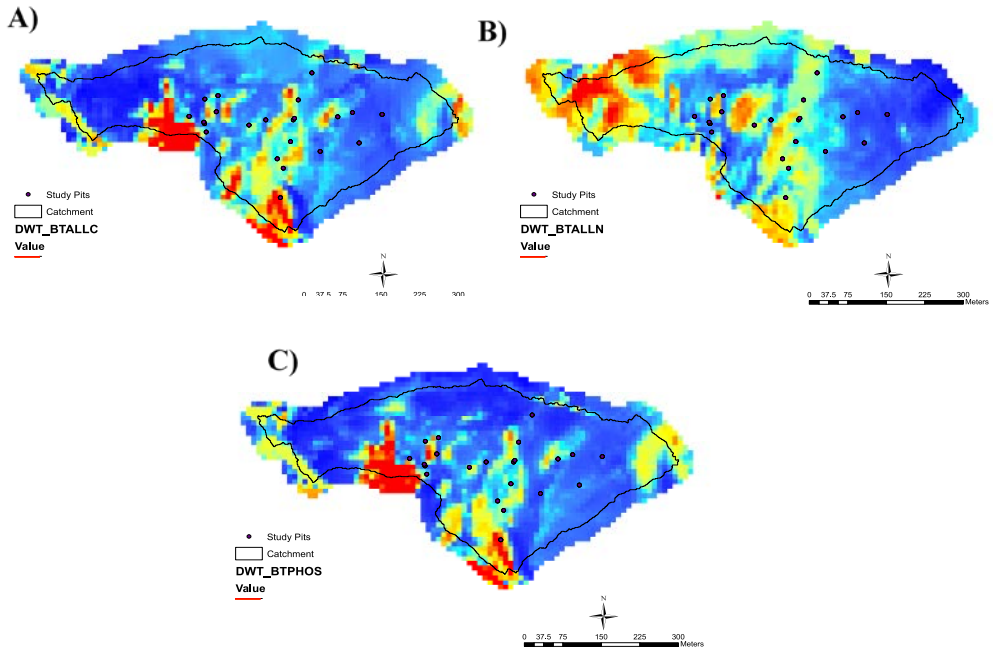


Figure 13. Predicted potential enzyme activity of **A)** four carbon degrading enzymes (β-glucosidase (BG), β-D-cellobiohydrolase (CB), xylosidase (XYL), and α-glucosidase (AG)), **B)** two nitrogen degrading enzymes (N-acetyl-β-glucosaminidase (NAG) and leucine aminopeptidase (LAP)) and **C)** one phosphorus hydrolyzing enzyme (acid phosphatase). Regression model uses 22 point-scale enzyme measurements and topographic variables from LiDAR 10 m resolution digital elevation map. Values are weighted averages across six depth intervals from 0-40 cm. Modeled activity is based on Saga Wetness Index, slope, curvature, aspect and distance from local summit to predict enzyme activity across the transect.

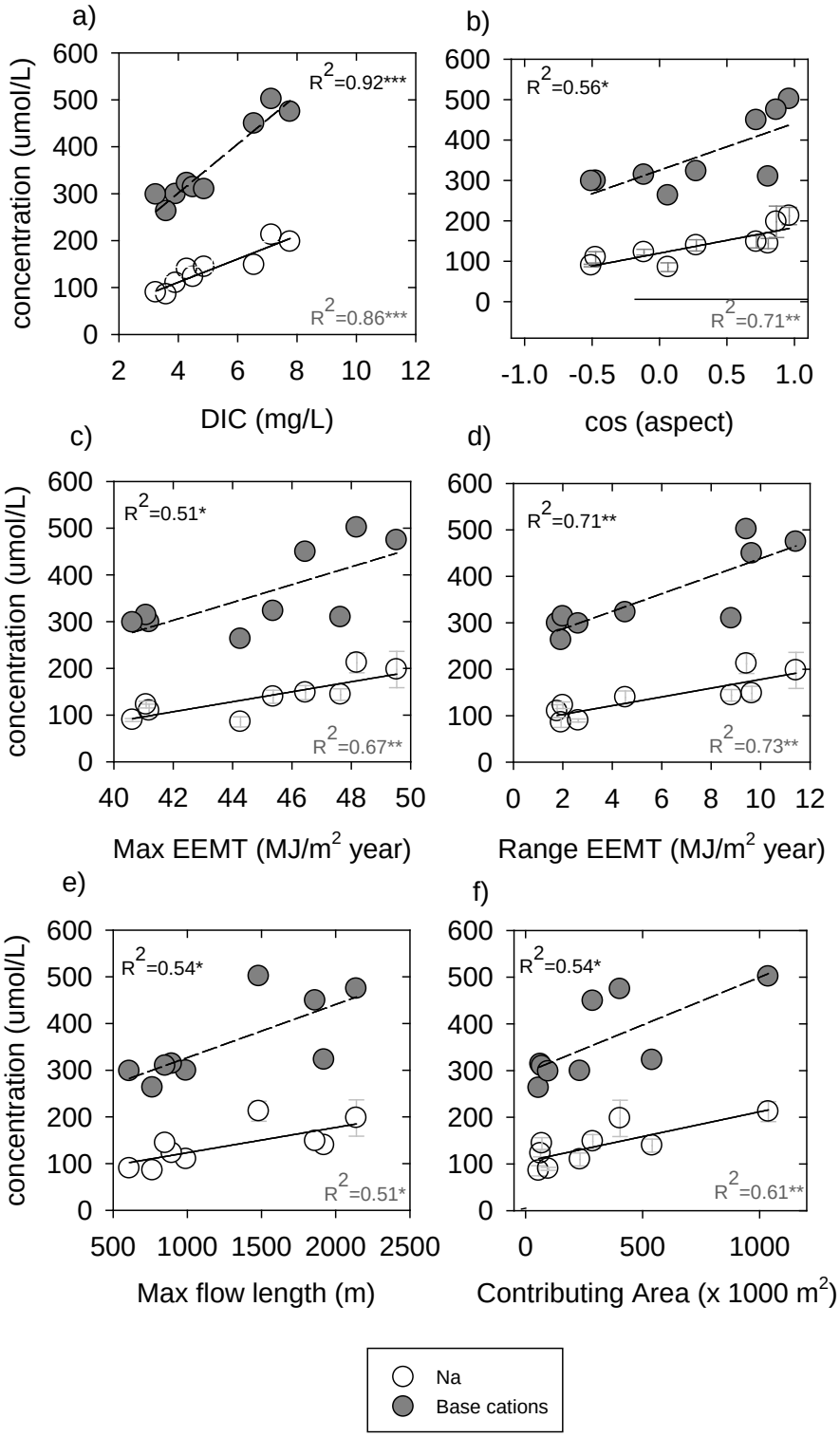


Figure 14. Concentrations of base cations, Na+ and DIC in spring water versus EEMT and landscape characteristics. Statistical significance (*p≤0.05; **p≤0.01; *** p ≤ 0.001)

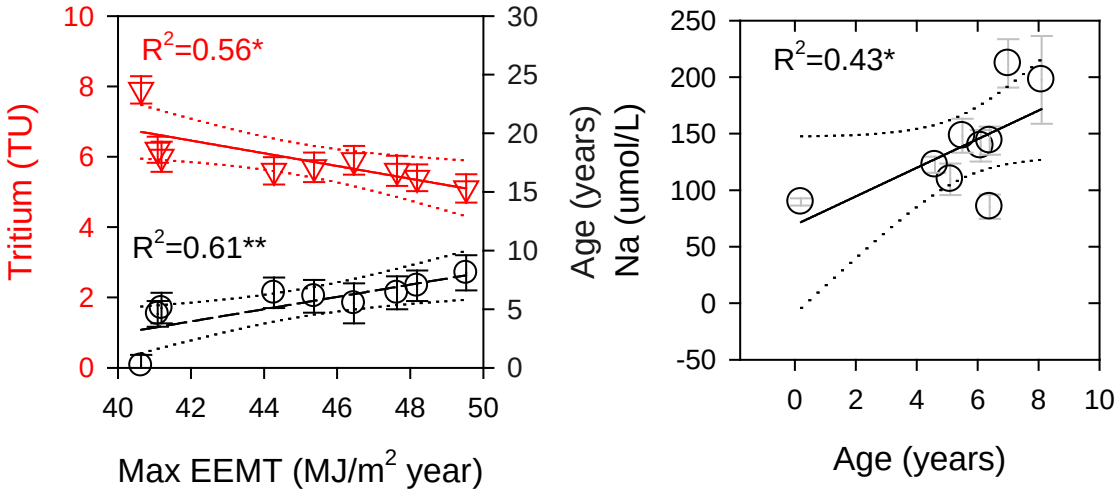


Figure 15. Max EEMT versus tritium concentration and apparent age (left). Apparent age versus Na^+ concentrations (right). Statistical significance (*p≤0.05; **p≤0.01) (Zapata-Rios et al., 2015).

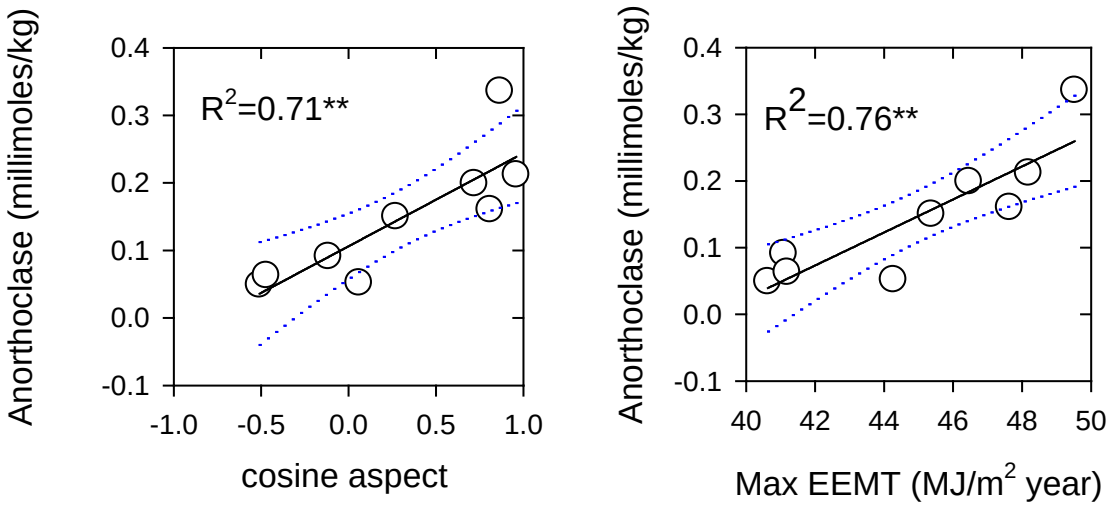


Figure 16. Dissolution of Anothoclase estimated using NETPATH (Plummer et al., 1994) versus aspect and max EEMT. Statistical significance (**p≤0.01) (Zapata-Rios et al., 2015).

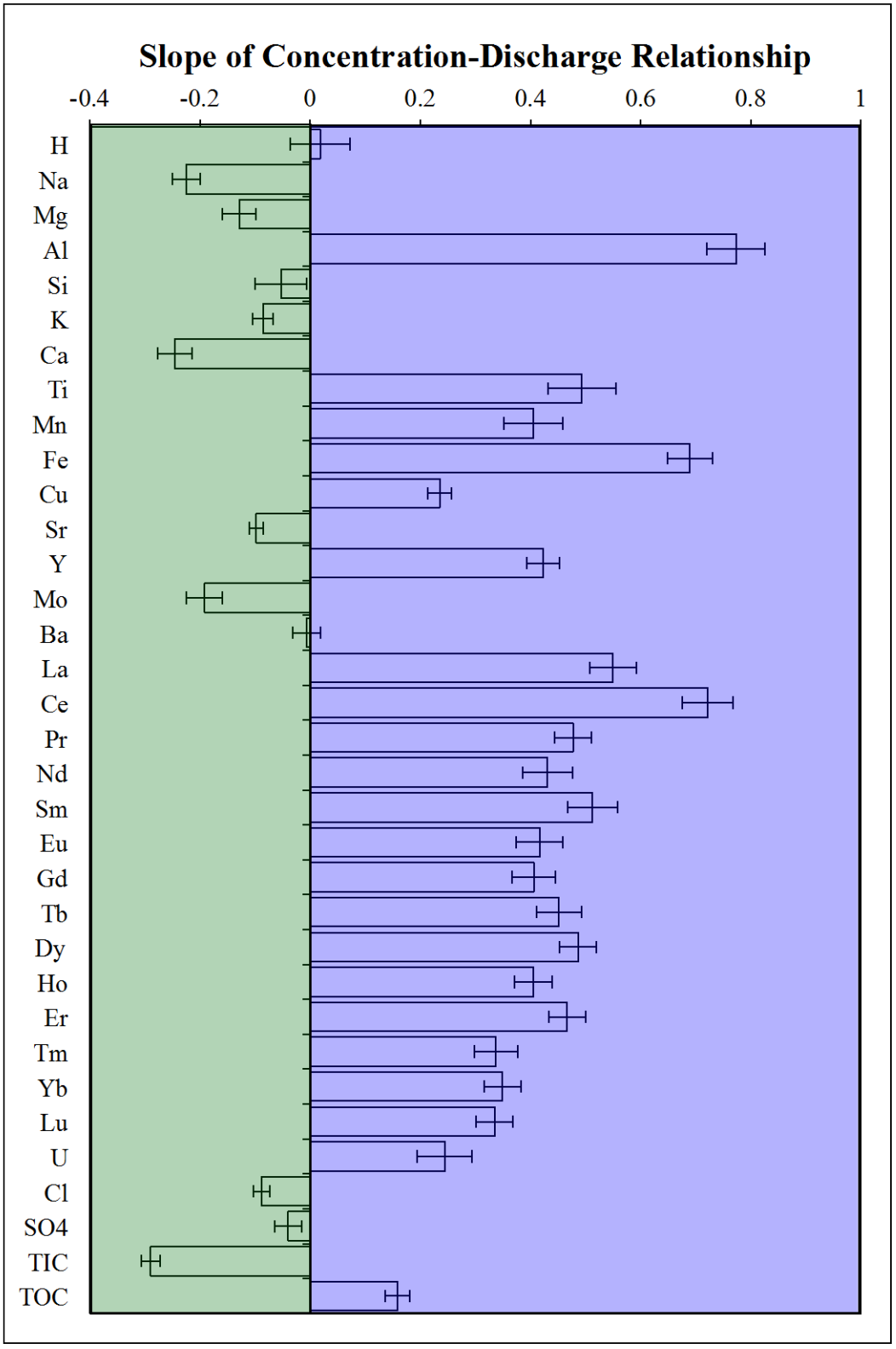


Figure 17. Power law slopes of concentration-discharge curves for Marshall Gulch by element (Trostle et al., in prep.).

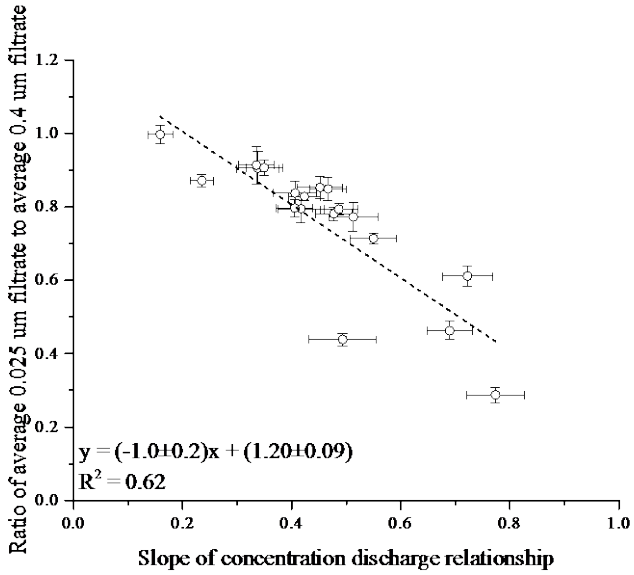


Figure 18. Average 0.025 µm filtrate/0.4 µm filtrate over the course of the Marshall Gulch monsoon event vs. slopes of concentration-discharge relationships at Marshall Gulch for species with positive concentration-discharge relationships. Uncertainties shown are the standard error of the slope for concentration-discharge relationships and standard error of the mean for colloidal influence. Dashed line shows the results of a weighted linear regression through the data (Trostle et al., in prep.).

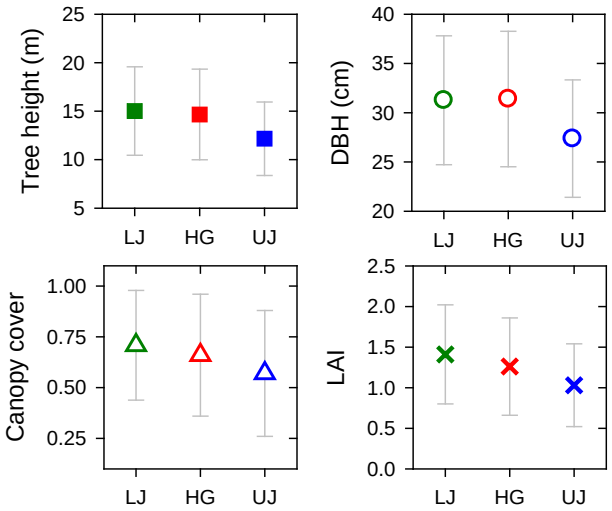


Figure 19. Lidar derived indicators of vegetation structure in the three study catchments. Whiskers represent one standard deviation. Mean tree height, mean diameter at the breast height (DBH), fractional canopy cover and leaf area index (LAI) are larger in the LJ and HG, the eastern catchments. UJ, the northern catchment, has smaller biomass than the two eastern catchments. Statistical differences between the northern and eastern catchments were tested with the Mann-Whitney U test *p* values <0.05.

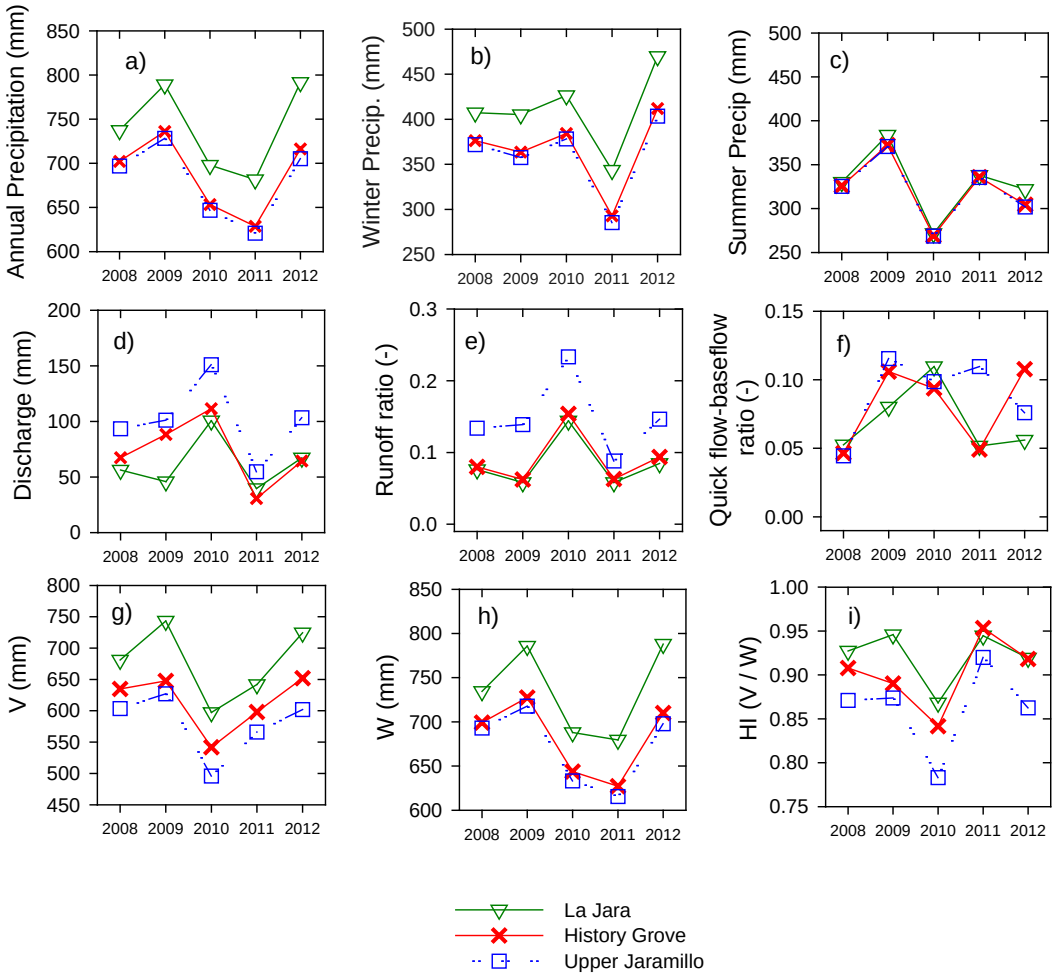


Figure 20. Water partitioning affects long-term evolution three experimental catchments in the JRB. The three study catchments showcase similar variability in (a) annual, (b) winter and (c) summer precipitation. However, LJ the highest elevation catchment receives the largest amount of precipitation, approximately 50 mm more than HG and UJ. Mean discharge (d), runoff ratio (e) and quick to baseflow ratio (f) are consistently large and less variable in UJ, the north facing catchment. Vaporization (V), wetting (W) and Horton index (HI), shown in plots (g) through (h), are smaller in UJ. HI is an indicator of climate and landscape controls of available water to vegetation. HI is smaller in UJ and larger in LJ and HG, the east facing catchments. A higher HI in the eastern catchments indicates vegetation uses more of its available water than in UJ. These plots indicate the catchments process precipitation differently. Both, W and V variability are controlled principally by climate but W is further influenced by landscape characteristics while V is secondarily controlled by vegetation. A lower V is expected in a catchment that receives a smaller solar loading and in contrast higher V values are expected in the two catchments facing east. W depends on catchment landscape characteristics and indicates water availability to vegetation. W is consistently smaller in the north facing catchment.

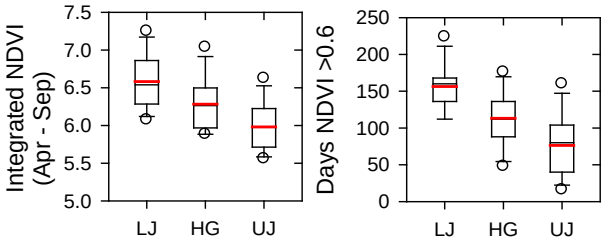


Figure 21. NDVI response metrics between the three study catchments from 2000 through 2012. The north facing catchment (UJ) has the smallest vegetation greening indicated by the integrated NDVI response and the shortest growing season length. Statistical differences in NDVI response between eastern and northern catchments was tested with both the Mann-Whitney U test and pair t test *p* values <0.05.

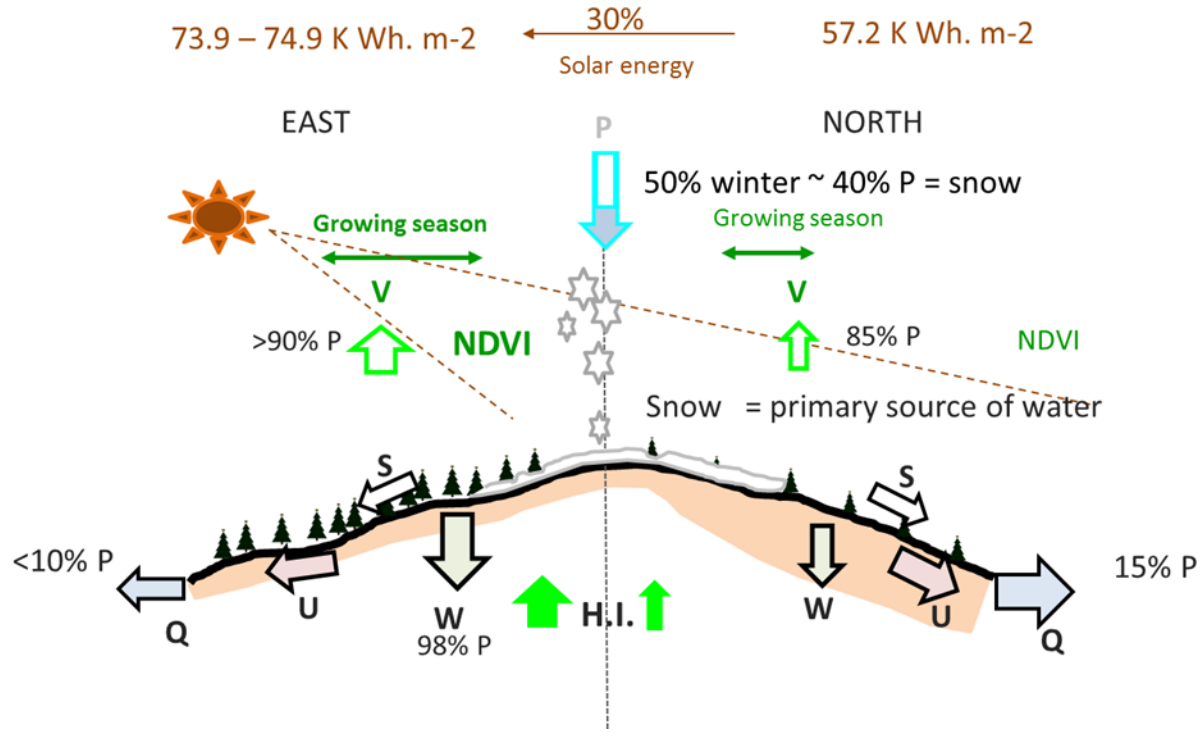


Figure 22. Conceptual model of vegetation structure, water partitioning and vegetation greening between contrasting slopes (northern and eastern) around Redondo Peak. The eastern slopes receive more solar loading and have larger biomass. Snow represents 40% of annual precipitation and controls water partitioning around Redondo Peak. Eastern slopes have larger vaporization, and vegetation takes advantages of a larger portion of its water availability. Also they have larger NDVI response and longer growing season. In contrast, in the northern slopes there is more water availability as baseflow and discharge, and the annual rates of vaporization and Horton index are smaller.

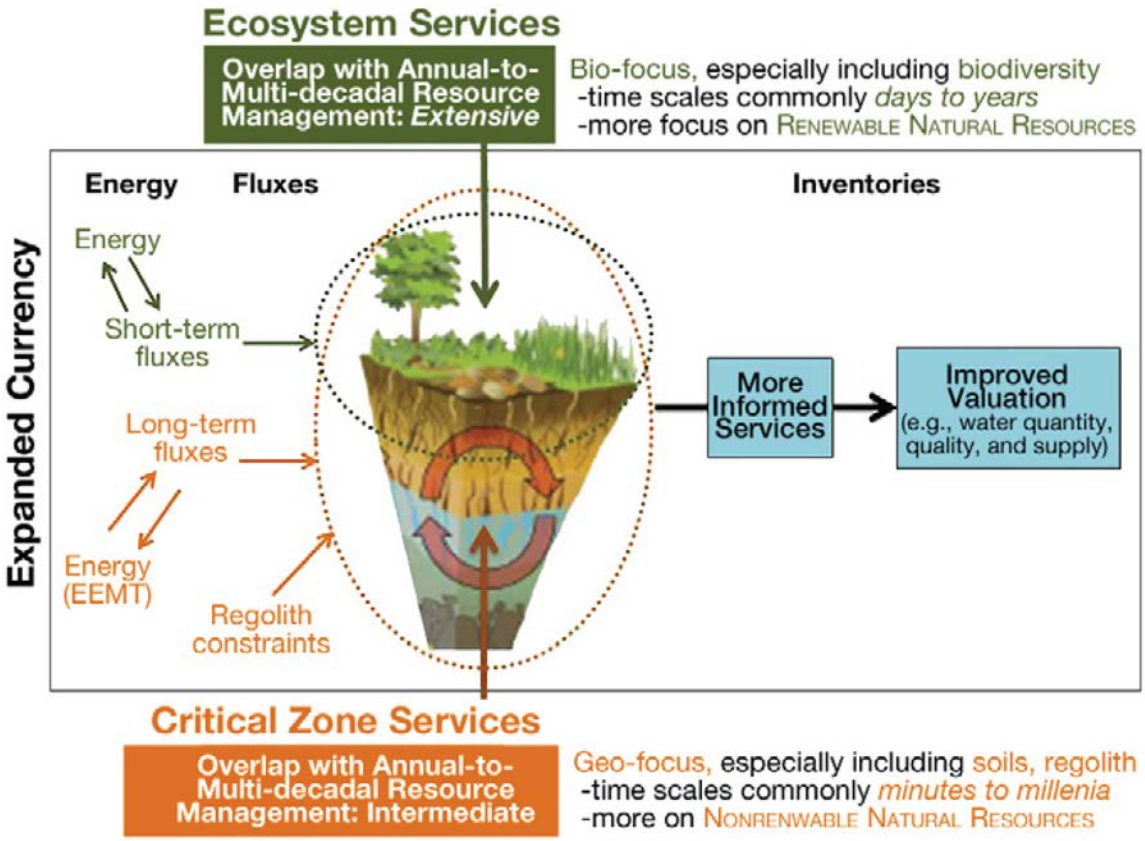


Figure 23. Critical zone services provide context, constraints, and currency that enable more effective management and valuation of ecosystem services (adapted from Millenium Ecosystem Assessment, 2005).

Table 1. Expanding context, constraints, and currency for ecosystem services by considering a critical zone perspective (modified from Costanza et al., 1997; Haygarth and Ritz, 2009).

	Context	Constraints	Currency
Provisioning Services			
Water storage	Expand focus on shorter-term water retention to include longer-term water retention and supply	Surface water storage is constrained by longer-term water retention (e.g., surface recharge to groundwater)	Water supply
Food supply	Expand current perspective on crop and livestock production to include provisioning source material	Crop and livestock production are constrained by soil productivity (e.g., topsoil, mineral, aggregates)	Food security
Habitat or Supporting Services			
Primary Production	Expand biological focus on plant productivity to include geophysical processes from soil to groundwater	Long-term primary production is constrained by rate-limiting processes in soil (e.g., soil genesis, fertility and erodibility)	Production of agricultural crops, bioenergy crops, timber, forage, and livestock
Soil Formation	Expand ecosystem-centered view to include longer geo-cognizant time scales	Rate of soil formation is constrained by longer-term geophysical processes (e.g., weathering of parent material)	Water storage and purification, nutrient storage, carbon sequestration
Nutrient Cycling	Expand current framework to include longer-term storage and processing of nutrients	Nutrient cycling is constrained by biogeochemical processes in soil (e.g., mineralization and immobilization)	Supports primary production, helps prevents eutrophication
Regulating Services			
Water quality regulation	Expand shorter-term focus to include longer time scales and deeper depths	Hydrological supply rates (e.g., groundwater supply)	Filtration and buffering
Water supply regulation	Expand focus on vegetation management to include more emphasis on soils and geology	Water supply management (e.g., irrigation, flood control)	Regulation of hydrological flows
Gas regulation	Expand shorter-term focus on plant and microbe responses to include longer time scale constraints	Greenhouse gas regulation (e.g., mineral weathering rates)	Regulation of atmospheric chemical composition
Climate regulation	Explicitly incorporate geochemical controls on biologically mediated climate processes	Vegetation responses (e.g., respiration and photosynthesis) are constrained by geochemical processes (e.g., weathering and soil formation)	Regulation of global temperature, precipitation, and environmental processes
Cultural Services			
Recreation	Expand ecotourism focus on biodiversity to include more geotourism focus on geological features	Geologic aesthetic value (e.g., Grand Canyon)	Providing a platform for recreational activity
Cognitive	Expand current perspectives related to biodiversity to include geological features	Educational and scientific value (e.g., Yellowstone)	Opportunities for noncommercial activities (e.g., aesthetics, education, and spiritual value)

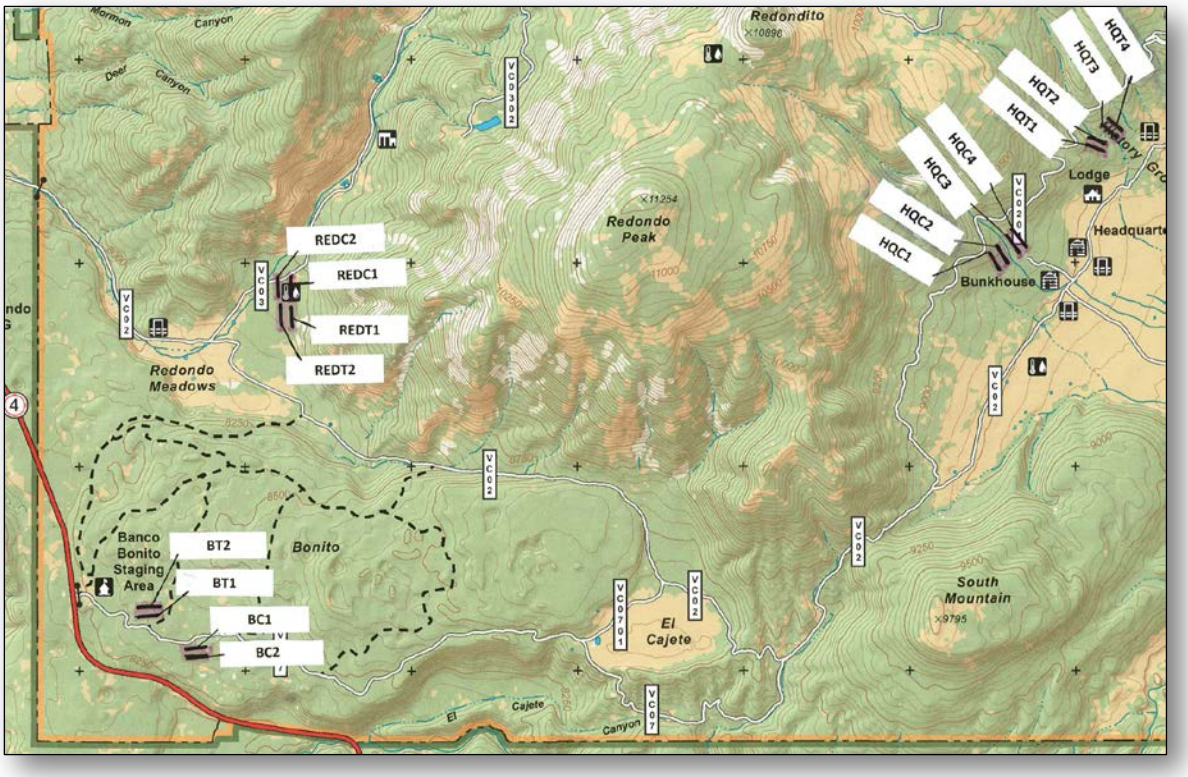


Figure 24. Map of VCNP student study sites, with Treatment sites (T) being thinned and/or burned forest stands and Control sites (C) being untreated forests.

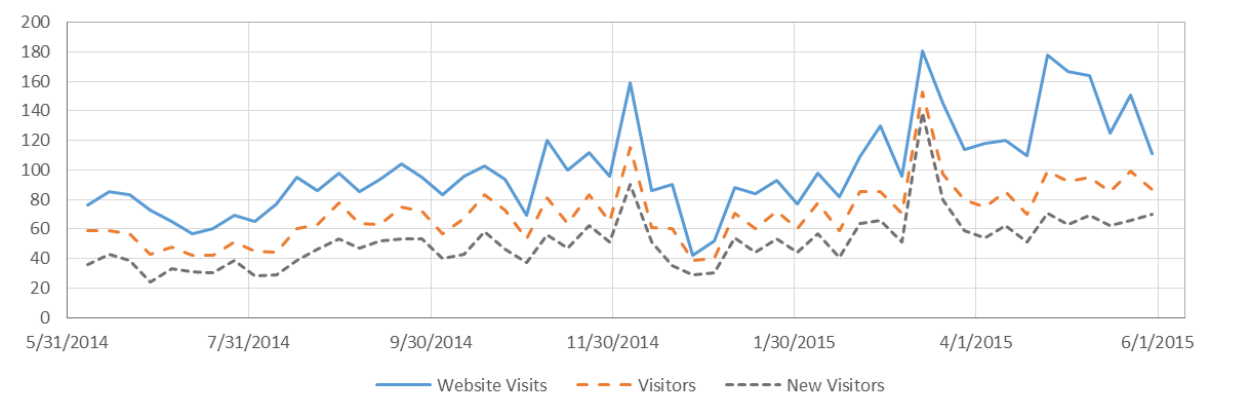


Figure 25. The number of weekly Catalina-Jemez CZO website visits, and new and all visitors.