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CZO: Critical Zone Observatory--Snowline Processes in the Southern Sierra Nevada

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Accomplishments

(8000 characters) *** What are the major goals of the project?**

Initially, the Southern Sierra Critical Zone Observatory (CZO) set out to investigate multi-disciplinary impacts on the critical zone across the rain-snow transition of the Sierra Nevada. Gradients in elevation and aspect provided a natural laboratory that fostered the establishment of the CZO. The location of this CZO continues to provide crucial information as changes in temperature and precipitation shift the timing and quantity of snow accumulation and runoff. In turn, changes to water supply have major environmental and economic implications for the region. To be most effective, this knowledge must be translated and available for those managing regional policy and resources. As a data-rich community resource, the Southern Sierra CZO has worked to make the data accessible to stakeholders, resource managers, legislators and the broader public through its digital library and website, field trips, published results and numerous presentations.

When first established, there were five immediate research questions that defined and focused the core measurement and research programs:

1. How do coupled hydrologic and biogeochemical fluxes vary across the rain-snow transition and how do the different parts of the system respond to seasonal transitions?

2. What is the role of extreme hydrologic events in hydrologic and biogeochemical balances?
3. To what extent does vegetation modulate or actively control the primary subsurface fluxes of water and nutrients, versus act as passive agents?
4. Over what time and space scales, and during what seasons, are macropores and other short-circuit pathways dominant in the critical zone?
5. How does the presence of a seasonal snowpack affect the subsurface, critical zone, soils, geomorphology, biogeochemistry and hydrology in Sierra watersheds and hillslopes, and how will the relevant processes and reservoirs respond as the climate warms and snowpacks recede?

To answer these questions, sites were intensively instrumented at the Providence catchment in the Sierra National Forest (co-located with the Kings River Experimental Watersheds) and at Wolverton in Sequoia National Park. Specific installations during the first phase included the 50-m eddy covariance flux tower in a Providence Creek subcatchment. Near the tower is the most intensively instrumented tree in the Sierra Nevada (to our knowledge) with more than 200 sensors tracking snow depth, sap flux, soil moisture, soil matric potential, soil temperature, incoming solar radiation, air temperature and relative humidity. Further, sensors were installed to investigate the patterns of snow accumulation and ablation at the scale of a tree canopy, a hillslope, and a catchment.

As these sites were instrumented and the data collected, we refined the original questions by asking:

- Does vegetation actively control hydrology/biogeochemical fluxes across land/atmosphere boundaries?
- What physiological mechanisms regulate interactions between vegetation and hydrology/biogeochemical fluxes?
- How do soil moisture and topographic variability interact to influence soil formation and weathering?

Several researchers have shown that the elevational gradient of the Sierra Nevada ecosystem results in systematic patterns of soil development. However, much of the work focused on the top meter of soil without attention to the deeper vadose zone or links with the vegetation and atmosphere. Hence we used the opportunity to better understand the critical zone by exploring the full elevational gradient of the rain-snow transition, from oak/pine savanna to sub-alpine forests. The major focus was and continues to be on the weathering, regolith formation, nutrient cycling, and vegetation/ecosystem distribution and function under the different water cycles of the rain-snow transition.

Finally, our ongoing goal is to extend the education and professional development for all persons involved. A special emphasis is placed on graduate students and post-doctoral researchers. Education and professional development encompasses the installation and maintenance of new instrumentation in the field, as well as the development of new methods. Graduate students have been significant contributors to the formation and execution of hands-on workshops, as well as novel methods of information dissemination – such as online webinars.

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

(8000 characters) **Major Activities:**

These research questions were addressed through a coordinated set of activities involving investigators from seven institutions and the USDA Forest Service, plus many more collaborators who used Critical Zone Observatory (CZO) data and infrastructure to address the questions listed above, and complementary questions. Results from the CZO research over the past 5 years are described in more

than 36 peer-reviewed publications, plus an additional 6 that are submitted and under review, and more than a dozen in preparation. Eleven primary activities were carried out.

1. Characterizing the deep vadose zone, including measurements to estimate deep soil-water storage and fluxes, and to improve understanding of weathering and pedogenesis.
2. Developing multi-scale observation networks using innovative sensor technologies, to support process studies and model predictions. For example, the water-balance instrument cluster, with over 380 individual sensors and other characterizations, is giving an unprecedented window on the catchment-scale water cycle.
3. Measuring biomass, productivity, and water balances along an elevation transect from low-elevation oak savanna, through mixed conifer forest, and up to subalpine forest. Snowpack, soil moisture, evapotranspiration (ET), runoff, and catchment water yield all vary systematically across the elevation (temperature) gradients of the rain-snow transition in the Southern Sierra Nevada.
4. Coupling above-ground with below-ground critical-zone processes, with further integration of data streams and relevant modeling for hypothesis testing.
5. Coordinating measurements tracking groundwater and surface water fluxes, in conjunction with collaborators. Field and modeling results emphasize groundwater and near-surface runoff as main contributors to stream baseflow, and meadow groundwater is highly connected to the surrounding forest.
6. Developing nutrient budgets and cycling rates across the rain-snow transition, including changes with biomass removal (tree thinning).
7. Analyzing the geochemical signature of rocks, soils and dust; and measuring landscape-erosion rates from cosmogenic nuclides in sediment within the CZO and surrounding environment.
8. Conducting spatial analysis of geology, geochemistry, vegetation characteristics, water fluxes and productivity for scaling results across the heterogeneous landscape of the Southern Sierra Nevada.
9. Serving quality-controlled data to CZO users and to the broader critical zone community through a digital library and other community platforms. This includes ongoing, spatially distributed measurements of water, energy and carbon fluxes and reservoirs, geochemical data, and spatial data on vegetation, nutrient stores, and landscape features.
10. Leveraging education opportunities and creating broader impacts through K-12 partnerships, undergraduate experiences, published results, posted data, stakeholder meetings, and media projects.
11. Encouraging cross-site science activities, including planning for common data products, sharing results, encouraging cross-site research, and building common infrastructure.

The Southern Sierra CZO initially focused on the mixed-conifer forest at the rain-snow transition, spanning an elevation range of 1500-2100 m (see Figure 1). A brief timeline follows, detailing the growth of the Southern Sierra CZO.

- During the 2007-2008 field seasons, the first flux tower and the water balance instrument clusters were installed in the Providence Creek catchment of the Sierra National Forest. Baseline hydrologic modeling through RHESSys (Regional Hydro-Ecologic Simulation System) was begun promptly with previous stream discharge and meteorological data from the Forest Service KREW project.

- In 2009, hydrologic modeling and data collection were expanded, and the first results were published. Additional work that year focused on water, carbon and nutrient fluxes, from groundwater through the vegetation-atmosphere interactions, and physical erosion. Also, a wireless sensor network was developed for mountain water balance measurement. Further efforts targeted challenges in equipment failure and power loss - especially during winter storms.
- In 2009-10 CZO infrastructure was expanded to include 3 new flux towers at elevations that collectively span 2500 m of relief (Figure 1). This expanded transect was the focus of research by the CZO team during the last years of the initial granting period. Airborne LiDAR was flown during peak snow accumulation and during summer for each of the main sites as well as Wolverton basin. Other noteworthy activities in 2010 included geophysical investigations of tree root structure, installations of more wells and piezometers for surface-groundwater flows. Heavy snows and strong winds damaged the guy wires and platforms at the Short Hair site.
- In 2011, additional snow surveys were conducted to validate sensor data, and more measurements were made in the tower footprint to supplement tower data. Between tower sites, ecological observations were made at 400' intervals. A second critical zone tree was instrumented to provide data in shallower and rockier soil. A catchment scale soil depth model was created. The CZO helped support KREW efforts during staffing and budgetary shortfalls. Cosmic-ray soil moisture observation systems (COSMOS) were installed at the two mid-elevation sites with further soil moisture surveys for calibration. Hydrologic modeling at the tree, stand, and catchment levels continued, with an emphasis on scaling. Biogeochemical work focused on hotspots as well as sediment leaving the catchments. A team from Wyoming conducted extensive geophysical surveys – including seismic transects and ground-penetrating radar. There was high participation in the 2011 CZO All-Hands meeting.
- In 2012, an additional six trees were instrumented, to bring the total number of critical zone trees to eight. Combined with microclimate sensors, data from the trees were used to refine the existing hydrologic model. LiDAR-derived digital elevation models improved modeling and mapping efforts. Further ground surveys were conducted to validate LiDAR data. In addition to resins, manipulations of the litter layer were used to investigate preferential flow. Geophysical surveys indicate deeply (>30 m) weathered bedrock in some areas. Geochemical results are contributing to a new hypothesis for geomorphology in the Sierra Nevada.
- For the 2012-2013 year, results from our instrumented transect have contributed to the more-mature conceptual model that was developed by the CZO team during the past year. The first critical zone tree has been running for more than 50 months. Strategically, core measurements will be completed at each of the four transect sites. Much of that work began this year, including geophysical surveys, drilling and sampling at the lower three sites.

Over the entire time period, the Southern Sierra CZO team carried out data management, education, and outreach. One of the first objectives was the digital library, where data, photographs, and presentations are organized. Data processing and organization were advanced by a dedicated data manager in conjunction with researchers and the field hydrologist. Educational partnerships begun in the first year of the CZO continue; since then the educational network has been expanded and strengthened, with a focus on local educational organizations like NatureBridge and CART, on regional conservation and science days, and on collaborating with local news outfits for video, radio, and print news items. Finally, the new national websites provide a central networking site - the Southern Sierra CZO fully moved to this new website in the past year. The Southern Sierra team views the site as a strong tool in building the national CZO network. However there are limitations to what the individual

observatories can update and maintain on the site. Ongoing support of a website developer is soundly needed at the national level.

(8000 characters) **Specific Objectives:**

A CZO spanning the rain-dominated oak savannah to the snow-dominated conifer forests of the southern Sierra Nevada is providing opportunities to develop much-needed process-based understanding of critical-zone function, evolution, and response to both rapid seasonal changes and human-induced perturbations. This understanding has applications in many areas relevant to society, including forest management, water resources management and adaptation to climate change.

The twin threats of a changing climate and land-use practices raise fundamental questions about the sustainability of critical-zone services in the southern Sierra Nevada. The Southern Sierra CZO was developed to make progress on these questions, using an integrated, multi-disciplinary approach.

The Sierra Nevada provides water to over 10% of the U.S. population and about 40% of the runoff for California as a whole. Climate warming is shifting the elevation of the rain-snow transition, the seasonal timing of snowmelt runoff, soil-water dynamics, plant water use and growing-season temperatures, thus dramatically altering the water cycle, weathering processes and ecosystem function. Snowmelt and streamflow timing are already occurring earlier each spring in response to warming (as much as +2 ºC in recent decades). This will likely increase the risks of springtime floods and late-summer moisture stress. Increased frequency of multi-year droughts and higher-intensity rainfall events have been predicted and may compound the hazards associated with seasonal shifts. A range of forest disturbances, including drought-related dieback, fire, disease, and background mortality, are expected to intensify with increasing drought frequency and severity. Short- to medium-term effects of climate change (floods and drought) will interact with long-term processes, including species shifts, with as yet poorly understood consequences for ecosystem function and material fluxes.

Forest-management practices are changing throughout the Western United States, with unclear consequences for critical-zone processes, including biogeochemical cycling and material fluxes. High densities of forest fuels in western mountains elevate the risk of catastrophic wildfire, and reflect fundamental changes in the structure and composition of mixed-conifer forests. Competition for resources has reduced forest resiliency, allowing pests to spread faster and with more virulence, and possibly increasing vulnerability to drought. In the absence of periodic fire, standing dead and surface fuels accumulate and thus alter weathering and biogeochemical cycling. This also drastically alters fire behavior, especially when coupled with increased understory growth of shade-tolerant, “ladder-fuel” species. The implications for soil properties, water retention, nutrient movement, and erosion are largely unknown but likely significant. The Southern Sierra CZO addresses these questions in an integrated framework.

The 2009-2010 expansion of the Southern Sierra CZO from one main site to four sites anchored by flux towers signaled the beginning of a new phase. Focus on the full span of the 2500-m elevational gradient has helped researchers at the CZO to better understand the full suite of processes impacting the hydrologic behavior of these catchments, which in turn improves modeling results and flexibility. We are refining the predication capabilities of our ecosystem and hydrologic models to apply to catchments across the region. Going forward, both one-time characterizations (for geology, vegetation, soil biogeochemistry and saprolite depth) and ongoing measurements (for meteorology, soil moisture, sap flux, snow cover and melt timing) will be expanded at each of the four sites. This will provide much-needed information for calibrating modeling efforts and further integrating our research questions.

(8000 characters) **Significant Results:**

Summary. Among the many results at the Southern Sierra Critical Zone Observatory (CZO), four key findings show the disciplinary linkages and integration of critical-zone science. First is closing the water budget at multiple scales. At the headwater catchment scale our estimates of evapotranspiration (ET) using a water-balance approach are in good agreement with flux- tower measurements. Similarly, our estimate of the water balance across the entire Upper Kings River basin also matches observations. This level of confidence both builds on and provides a foundation for in-depth process research. Second, we have observed a year-round growing season at mid elevation. We had expected the mid-montane forest to shut down both in winter due to cold and in late summer due to drought stress. Instead the forest largely avoids these limitations through deep rooting and cold tolerance, explaining high productivity and biomass in the mid-montane belt. Third we have found high rates of ET at mid-elevation sites. The lower-elevation site exhibited less ET due to greater water stress; the higher-elevation site exhibited less ET due to greater cold stress. This confirms the inverse drought and energy limitation conceptual model, with implications for effects of warming on ET. Fourth, we have found that deep rooting and soil development are important for sustaining high rates of net primary productivity. At our main instrumented headwater catchment, we found that over one-third of the ET came from depths below 1 m. The main state factors that control ET and net primary productivity include local topography (slope/regolith thickness), climate (temperature/water), and biota/parent material (e.g. nutrients).

Conceptual model. The Southern Sierra CZO involves measurements and research across multiple spatiotemporal scales (Figure 1). It includes four primary sites spanning a 2500-m elevation range, exploiting gradients in climate, regolith properties, soils, vegetation and material cycles. The subalpine forest (2700-3000 m) has thin patchy soil that may limit soil-moisture storage. The mixed-conifer forest (2000 m) is a heavily instrumented research area, with 3 gauged headwater catchments nested in a fourth, 4.6 km^2 gauged catchment (see inset map, Figure 1). The pine/oak-forest (1100 m) has the most intense weathering; soil profiles display subsurface horizons with evidence of clay and iron illuviation and a deep regolith. The oak-savannah (400 m) has little woody vegetation but high below-ground biomass (in grass roots), posing sharp contrasts in soil-water utilization and nutrient cycling relative to the upper sites. Greenness (a measure of vegetation density) peaks at mid-elevations (image in lower right of figure). The conceptual framework for the Southern Sierra CZO can be divided into three parts: i) regulators of critical-zone evolution; ii) the influence of regolith-biota interactions on hydrology and biogeochemistry; and iii) implications of critical-zone structure and function for ecosystem goods, services, and sustainability (Figure 2). Cooperation with land-management agencies, water and hydropower organizations, and other interested stakeholders underscores the duel nature of the Southern Sierra CZO: the motivation is to both understand basic critical-zone science and contribute useful information to society.

Designing the Southern Sierra CZO*.* One of the initial challenges was to define the observatory's architecture and measurement principles. The architecture that we adopted is a series of nested instrument networks at a range of scales, moving from vertical profiles within plots, to plots along hillslopes, to hillslopes within individual catchments, to catchments and ecosystem types along large elevation and climate gradients, and ultimately to the entire upper Kings River basin (Figure 1, Figure 3). The development of wireless sensor networks allowed the Southern Sierra CZO to make denser meteorological and hydrologic observations in time and space and over larger areas than had previously been possible. Our design for optimal sensor placement emerged from algorithms based on information-theoretic criteria, with significantly better results than expert judgment. This structured network design and strategic sampling facilitated both scaling and robust operation in remote settings. This design is being replicated at other locations.

***Subsurface science: The structure and formation of regolith*.** Geophysical surveys show evidence of weathering 10-30 m below the surface at the Southern Sierra CZO's 2000-m site (Figure 4). Together

with erosion rates from cosmogenic nuclides, this indicates regolith residence times of 10^5-10^6 years. This implies that we will ultimately need to consider the influence of Pleistocene climate variability to fully understand the current depth and development of regolith. Cosmogenic nuclides and terrain analysis of the stepped topography of the CZO domain show that steps are soil-mantled as often as are the treads, and that erosion rates of treads are lower than erosion on steps. This contradicts a classical hypothesis for formation of the stepped topography and calls for a new model of landscape evolution in the region.

Subsurface science: Interactions between the regolith, plants, and the water cycle. The deeper regolith (below mapped soils) is critical for supplying water for ET and baseflow in streams for 5 or more months each year. Mid-montane forests largely avoid summer water stress despite a 5-month dry season. Over one-third of annual ET at the 2000-m site comes from depths below one meter. Geophysical surveys and subsurface samples confirm that the water-holding capacity of weathered regolith at these depths is sufficient to account for the deeply sourced ET. Regolith development, and plant access to water stored at depth, are critical for sustaining high rates of ecosystem production and ET within the mixed-conifer zone. The mechanism by which plants access deep water is still under debate. There is some evidence that roots extend deeply through cracks in the regolith, and access water either directly or through mycorrhizal associations. However, a terrestrial-LiDAR-based 3-D map of root architecture for an excavated mature white fir indicates that the majority of roots are in the top 60 cm. This leads to the alternative hypothesis that trees gain access to deep soil water through upward capillary flow. Mid-elevation sites (1100 and 2000 m) exhibited year-round growing seasons. The highest-elevation site (2700 m) was dormant in winter and the lowest-elevation site (400 m) was dormant in summer. ET and productivity peaked at mid elevation and were reduced at low elevation due to summer moisture stress and at high elevation due to cold stress (Figure 5). This confirms the inverse drought and energy limitation model, with implications for the impact of climate change on ET and plant production.

Subsurface science: Interactions between the regolith, biota, and biogeochemistry. Nutrient hotspots in soil, and a high degree of heterogeneity, were found for all nutrients and at all spatial scales studied. Hot-spot locations did not persist at any place from one year to the next, and were not correlated with preferential water flow, nor consistently with microbial biomass. We hypothesized that high concentrations of nutrients in O-horizon solutions (stemming in part from a lack of plant root uptake), coupled with preferential flow of nutrients into the mineral soil was the primary mechanism creating hotspots. However, this hypothesis was not supported by manipulations of hydrologic flowpaths using barriers. Snowmelt frequently had higher nutrient concentrations than runoff below the O horizon. These results suggest the potential importance of atmospheric inputs of nutrients, and the potential contribution of differences in snowpack depth or nutrient concentrations in creating hotspots.

(8000 characters) **Key outcomes or Other achievements:**

From the outset the Southern Sierra CZO was planned as a resource for the critical-zone research community, and our team has actively engaged others in using this resource. Three levels of users are represented at the Southern Sierra CZO: the core CZO team, research collaborators, and cooperators. Our core team represents 7 universities plus the USFS. Over 20 research groups are collaborators; these groups are not formally part of the Southern Sierra CZO grant but work with the core team using largely other resources and are an important part of the CZO. In addition, several additional cooperators use Southern Sierra CZO data, collect samples at the Southern Sierra CZO or make use of other CZO resources in their own work. There is both a wide range of disciplinary focus and time scales represented in these investigations, from the response of the seasonal water cycle to perturbations, to the formation of soils to the weathering of the Sierra Nevada. There is also a high degree of integration between investigators. The main institutions with faculty/students/post-docs doing research focused at

the CZO include: UC Merced, UC. Davis, UC Berkeley, UC Santa Barbara, UC Irvine, UCLA, U. Nevada Reno, U. Colorado, U. Wyoming.

The Southern Sierra CZO has a high profile with resource-management stakeholders in California and the broader region. Our research addresses fundamental knowledge gaps around management of water supplies, forests, hydropower and integrated ecosystem services. The enhanced predictive capabilities that we are developing provide much-needed tools to understand the effects of management actions, disturbance and climate warming on ecosystem services. Adapting to climate change basically involves managing ecosystem services, with water-related ecosystem services being an early if not primary focus. Having a CZO with major capability to inform and influence adaptation around water supply in California is very timely, given the state's global leadership role in implementing climate solutions.

California is grappling with many challenges at the intersection of water, forests and climate. Water security is the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks. Water security in semi-arid regions is founded on adequate water storage. In California, as in many regions, that storage is provided by dams, in the mountain snowpack, in soil/regolith, and in groundwater. In this case we are distinguishing the soil/regolith in the mountains from groundwater in the Central Valley. In the Sierra Nevada, storage behind dams is about equal to average storage in mountain snowpack and soil/regolith. Our research informs how climate warming, disturbance and management actions (e.g., vegetation management) affect Sierra Nevada water storage, which in turn influences operation of the large foothill dams. In some cases, management actions can in part offset the effects of climate warming, and can lower the risk of severe disturbance, e.g. wildfire. Both the knowledge and technology developed by the Southern Sierra CZO are informing decision making around water storage and ecosystem services.

The debate around water security in California involves advocates for both “hard” (e.g. new storage and conveyance infrastructure) and “soft” (e.g. institutional arrangements, demand management) solutions to water-supply challenges. Our messages focus on the need for better information to support both approaches, and on the role of research and development in providing this better information.

In addition to stakeholders and decision makers, the Southern Sierra CZO has an active program of education and outreach to K-16 and the general public. Some of the most successful education and outreach activities over the past year include building relationships with schools and local organizations. Colleagues and staff began working with NatureBridge Yosemite (formerly Yosemite Institute) in 2009 to provide instructor trainings on hydrologic concepts and snowpack science. NatureBridge has provided award-winning, residential outdoor education programs in Yosemite National Park (YNP) for school groups since 1971. Approximately 13,000 California students cycle through this program every year. Additional instructor trainings are planned over the coming years, and we plan to collaborate with their local Yosemite-area school program, Project Pluton, focused this year on *Yosemite Rocks!*.

Other K-12 partnerships include presenting each year at Southern California Edison's Science Days and the American Association of University Girls Science Camp. CZO staff also presented at the Auberry Conservation Days. At these events CZO colleagues facilitate hands-on activities for students that focus on how Sierra Nevada hydrology impacts California's water resources. Combined, these presentations reached more than 600 grade school students in 2012-2013. Likewise, in previous years, outreach efforts have reached a combined total of several hundred students, with the audience growing every year. Our K-12 partnership with the Center for Advanced Research and Technology (CART) in Clovis, CA, continued, with CZO staff mentoring teams of CART students to conduct a comprehensive snow survey research project.

Since 2007, CZO colleagues have been providing opportunities for undergraduate students. Students from UC Merced and partnering universities have worked as field and lab technicians. The Southern

Sierra CZO summer undergraduate research intern program has given students the chance to apply their knowledge of scientific concepts. In addition to research interns, the Southern Sierra CZO has developed field-methods courses for undergraduates at UC Merced and UC Davis. A major component of these courses is visiting the CZO to learn about research and to collect data for use in class. Each year, several dozen undergraduate students gain firsthand experience with the survey protocols and technology used at the CZO.

In cooperation with the USFS Sierra National Forest, the Dinkey Collaborative Forest Landscape Restoration Project is an ongoing effort to collaborate on Forest Service projects as part of the Forest Landscape Restoration Act. Dinkey Creek is located next to the mixed conifer site; one of our CZO staff is a member of the group who represents CZO interests in land management projects. In addition, Southern Sierra CZO research results were contributed to the Sierra National Forest Assessment Plan process, which concludes in December 2013.

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

Several graduate students, undergraduates and recent Ph.D. graduates are involved with the CZO, and are preparing themselves for independent measurement and data analysis work in field hydrology, biogeochemistry, geophysics, and modeling. The wireless sensor network remains an uncommon approach to gathering remote field data. The network installed at the Southern Sierra CZO consists of 57 wireless nodes, constituting one of the largest wireless networks for this purpose. Through the work on the wireless sensor network, training and experience continues for both investigators and graduate students.

Other training opportunities have been organized through open workshops. In December of 2012, UC Merced Professor Quinghua Guo and several students organized the CZO LiDAR Acquisition Initiative workshop at UC Berkeley. The workshop, which was timed to coincide with the 2012 AGU Fall Meeting in San Francisco, catered to researchers from across the CZO network. Several presentations covered applications of LiDAR data in the CZO network, available LiDAR products, and emphasized collaboration possibilities for cross-site projects. In the area of geophysics, Riebe actively worked as PI on a grant to organize and NSF-sponsored workshop on Drilling, Sampling, and Imaging the Depths of the Critical Zone. The workshop was held October 24–26, 2013, in Denver, CO. It featured an international group of speakers from a variety of disciplines. Southern Sierra CZO investigator C. Tague is a professor for, and has been a major contributor to the preparation of the Watershed Science Master Class, to be hosted by CUAHSI and the University of Arizona this coming January 2014. The short course will provide training in watershed science and modeling for graduate students and post-doctoral researchers from across the country.

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

Our communication and sharing of scientific products with stakeholders includes frequent talks around the state, hosting visits to our laboratories and CZO site, news articles in local publications, op-ed pieces in newspapers, radio interviews, television reports and web publications. A major focus has been on working with water leaders in the state to define and develop prototypes for a new water-information system for California that builds on advances in wireless-sensor networks developed at the CZO, plus parallel advances in cyberinfrastructure and in measurements by satellite and aircraft. Since the Southern Sierra CZO began, we have worked with producers on television and radio features and online educational videos , had multiple editorial pieces in San Joaquin Valley newspapers, briefed a U.S. Senator and other federal legislative staff. CZO investigators have presented results to annual meetings of the Merced Farm Bureau and the Modesto Business Council, and a workshop of the board for the Association of California Water Agencies. Water and climate, particularly adaptation of California's water systems to climate warming, are of special interest to these stakeholders. Other talks by CZO

investigators reached audiences at the University of California Sacramento campus, the Mountain Counties Water Resources Agency, the California Department of Food and Agriculture, and other local and regional entities.

The Southern Sierra CZO has made an effort to work with a variety of news and media outlets. Past features on the Southern Sierra CZO have appeared on PBS, National Public Radio, University of California Research, Portuguese-language public television and in numerous local newspapers. In 2013, NBC Learn visited UC Merced and the CZO for educational films on snowpack and water security. We have taken multiple film crews to our CZO research sites, generally in winter using snowshoes. In fall 2012, as part of an effort by the UC president's office to highlight benefits of UC research to the state, professionally produced video clips on our CZO research aired on television statewide; longer clips were posted on web pages. This latter represents the high regard that our multi-campus CZO team and our CZO science have within UC, and the important broader impacts that our results are having in the region.

Facilitating field trips to the CZO such as our July 2011 outing allowed stakeholders and the public to see the cutting-edge research being conducted at the site. Five congressional staff and 2 state senate staff members attended, along with representatives of several local organizations. Additionally, in August 2011, California Senator Barbara Boxer toured our lab at UC Merced and learned about CZO research. The CZO hosted another field trip in August 2013 for more than 20 participants, including stakeholders, resource managers, and policy makers.

The general public is also the audience for many of our communications, including press reports. We have given public talks in local communities, as well as presentations to civic organizations. The Southern Sierra CZO has been employing internet tools as part of its outreach program. In 2013, the Southern Sierra CZO established a presence on Twitter and Facebook, and CZO researchers are active contributors to the new blog started by Sierra Nevada Research Institute at UC Merced. These social media platforms are available to the public but also provide a way to disseminate information about events and activities to CZO and non-CZO researchers and students.

The CZO education team is working with researchers to create new interactive activities for undergraduate and K-12 students using CZO data. These activities are designed to meet new common core standards for analytical thinking and problem solving. Through partnerships with NatureBridge Yosemite and the Center for Advanced Research and Technology (CART) our researchers share results with educators and students alike. Students in the CART program work with CZO staff to design and conduct a comprehensive snow survey project. CZO researchers and education staff also present to hundreds of grade school students every year, facilitating hands-on activities for students that focus on how Sierra Nevada hydrology impacts California's water resources. Those K-12 partnerships include the Southern California Edison's Science Days and the American Association of University Girls Science Camp.

Dissemination to the research community to share research findings included alerting potentially interested colleagues publications and presentations through our web pages and email, attending scientific meetings and workshops, and participating in CZO-network activities. More than 35 articles have been published to-date by Southern Sierra CZO researchers in peer-reviewed journals. Improvements to our digital library and engagement with CZO-network data-sharing activities were also carried out. Two online webinars were given by CZO-investigators on watershed-level science and on nutrient deserts in the Sierra Nevada. A LiDAR workshop in December shared Southern Sierra CZO and cross-CZO LiDAR procedures and results, and taught attendees how to process raw LiDAR data into useful products. Co-PI Riebe helped organize critical-zone sessions at the Cordilleran Section meeting of the Geological Society of America as well as the American Geophysical Union's (AGU) Fall Meeting in

December 2012. At that AGU Fall Meeting, CZO PIs, graduate students and research staff presented over 20 talks and posters.The national CZO program was an exhibitor throughout the duration of the conference, providing information on all CZO sites. Colleagues also present at other national meetings, provide seminars for universities, and give talks to stakeholders and the general public.

Modeling also has been an important role in disseminating research results. Modifications to the Regional Hydro-Ecologic Simulation System (RHESSys) serve as mechanisms for encoding advances made by our field-based analyses. RHESSys is made freely available to the community and regular user training is provided. We also couple RHESSys with larger-scale modeling activities. Lessons on using RHESSys will be incorporated into the Watershed Science Master Class, to be held January 2014 and taught in part by Southern Sierra CZO investigator C. Tague.

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

Our findings over the last 5 years shed light on many of the feedbacks and interactions within the regolith-vegetation-atmosphere system (the CZ), and how climate, weather, nutrient deposition, and land management influence Sierran hydrology, biogeochemistry, and sustainability, resulting in a well-developed conceptual model for CZ and the CZO. Our work highlights the need to study CZ feedbacks in a cross-disciplinary approach that bridges the physical and biological sciences and that relies on diverse methods in a coordinated approach. During the one-year no-cost extension to the current grant, more than six new collaborators visited the CZO sites for field campaigns. Since 2007, Southern Sierra CZO researchers published 36 papers, with another six papers in review or awaiting publication, and more than a dozen papers in preparation. In the coming years, the Southern Sierra Critical Zone Observatory will continue to publish results on the objectives outlined above.

At the annual meeting in August 2013, the Southern Sierra CZO research team had several intensive planning discussions for the coming five years. The strategy for the next grant will be to consolidate the current knowledge of forest and water management for improved modeling and prediction purposes. Building on the diversity of ongoing projects at the Southern Sierra CZO, a suite of core measurements will be expanded from the main Providence site across the elevational transect. Each location will be the site of one-time assessments (soil, rock, and water characterizations) as well as ongoing time series (including meteorology, water and carbon fluxes). In addition, the tower at the highest elevation site, Short Hair Creek, will be reconstructed. The sum of these efforts will inform modeling efforts for more accurate and flexible results. Southern Sierra CZO investigators will continue to share those results with regional stakeholders and policymakers to improve resource management.

Additional technologies will be employed to explore the regolith and bedrock geomorphology at the CZO sites. Geoprobe drilling in August and September 2013 provided for deep regolith samples as well as the installation on new wells and Neutron probe access tubes at the San Joaquin Experimental Range site. Similar efforts at Soaproot are schedule for mid-November. For groundwater-surface water interactions, additional wells will be coordinated with drilling operations; data collection will continue for stable isotopes, a meteorological station and a eddy flux station installed in the meadows, and salt dilutions for water flow estimates. Recent improvements in hardware and programs will be integrated into the wireless sensor network for increased capacity and resiliency. Information on subsurface geomorphology will be collected at the three lower elevation sites during autumn 2013. Additional soil and sediment samples will be analyzed for stable isotopes and carbon dating to assess sediment sources and the impact of planned management burns to be conducted in the coming fall and spring. Hydrologic modeling efforts including RHESSys and PIHM will further explore sensitivity to time and space resolution. An additional focus is scaling the model across the region so as to increase applications for state water managers and utility companies. Results and crossover from each study will be analyzed going forward.

Supporting Files (add additional files with the previous Figures?)

Filename	Description	Uploaded By	Uploaded On
Results_figs.pdf	The pdf file Results_figs.pdf presents figures 1-5 with explanatory captions (includes conceptual models and overarching findings)	Roger Bales	09/03/2013

Impacts

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

The Southern Sierra Critical Zone Observatory provides a multi-disciplinary platform for research. Major scientific findings have impacted disciplines from plant physiology to geomorphology and land management. In fact, previous findings from the project contributed to the broader structure of the recent CZO proposal for funding. For instance, evidence that mid-elevation forests (1100-2100 m) have high winter productivity contradicted the long-standing understanding that the forests shut down for the winter. Because the winter productivity results in higher water needs, shifting climate will then likely lead to lower water yields overall for the state. Cosmogenic nuclides and terrain analysis of the stepped topography of the CZO area show that the steps are soil-mantled as often as the treads, and that erosion rates of treads are lower than erosion rates on steps. This is directly counter to the classical hypothesis for formation of stepped topography. Hence the Southern Sierra CZO will be expanding the suite of core measurements at each site in the elevational transect from 400-2700 m. Doing so will clarify the impact of bedrock and forest on regolith development and water resources.

Another impact is the development of research methods, particularly in the area of integrated field measurements using wireless sensor networks. The innovations in data collection and network design have vastly increased the frequency, distribution and accuracy of information on snowpack. Better information on snowpack distribution and water content means that water managers have more options for effective water management. Infrastructure first installed and tested at the CZO has been used in a larger snow monitoring project in the American River Basin.

A list of the main CZO collaborators for the first phase follows:

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What is the impact on other disciplines?

The cross-disciplinary understanding of critical-zone processes developed at the Southern Sierra Critical Zone Observatory (CZO) provides a foundation for further research by CZO cooperators and others in the research community. Results from studies at the Southern Sierra CZO provide a foundation for new research projects, including a test for field-based stable isotope measurements and a project estimating the potential impact of climate on vegetation communities through remote sensing and spatial modeling.

Infrastructure of the wireless sensor network, which was installed and tested first at the Southern Sierra CZO, has wide applications for other disciplines. Lessons from the network can be applied to streamlining agricultural operations, monitoring recreation areas, and improving renewable power operations. In a regional context, the CZO is sharing information on the network structure with local utility companies, who manage land for water, hydropower and timber resources.

In addition, research at the Southern Sierra CZO provides a bilateral benefit to other research projects. These programs include the U.S. Forest Service Kings River Experimental Watersheds and the NSF National Ecological Observatory Network (NEON). At the 2013 annual meeting, CZO researchers and Pacific Southwest Research Station (Forest Service) representatives discussed upcoming needs for personnel, equipment and maintenance, and how to successfully provide for those needs in a way that is efficient and mutually beneficial. With the NEON project, several of the Domain 17 sites will be co-located with CZO work. Biological data gathered by NEON will complement CZO results in geology, hydrology, and ecosystem fluxes. Southern Sierra CZO staff work closely with the interdisciplinary Dinkey Restoration Landscape Project. That project provides a strong and stable connection to local residents and stakeholders.

What is the impact on the development of human resources?

The foundation of the Southern Sierra Critical Zone Observatory is to provide a cross-disciplinary research environment. This guiding principle is what we use to train undergraduates, graduate students, postdoctoral researchers and staff to become the next generation of researchers. Working in a team environment allows participants to combine skills to achieve wide-ranging goals. Going forward from the 2012-2013 reporting period, the Southern Sierra CZO continues to mentor graduate students and a postdoc, plus engage junior faculty. CZO staff members will also continue to develop through formal and informal training and mentoring. Training opportunities included workshops on Project Learning Tree and facilitation and collaboration, which will improve education programs and increase the efficacy and efficiency of CZO planning meetings.

Staff member E.M. Stacy gained additional education training and experience, as did previously untried undergraduate student employees assisting with Outreach during the summer. Work with the Southern California Edison Science Days, Auberry Conservation Days, Merced Riverfair, and American Association of University Women Science Camp exposed grade school students and the public to recent findings from the CZO. Activities largely focused on the health and activity of the forest, impacts of the water cycle on wildlife, and surface-groundwater interactions. An interactive display at the UC Merced library was in place for 2 months, allowing university students and staff to learn about the wireless sensor network and snow depth sensors. Additional educational material is under development for a university course on critical zone science. This course will educate students on the structure and function of the critical zone with activities that used CZO data in the classroom.

Training for graduate students and post-doctoral scholars has included a broad suite of field work as well as external classes and workshops. In the field, students, scholars, and investigators have broadened their knowledge base through the use of instruments including ground penetrating radar, a Geoprobe drill, field validation for LiDAR flights, testing and improving the hardware and software needed for the novel wireless sensor networks, and the ongoing construction and maintenance demanded by an extensive research site. Workshops have included in-person classes as well as online webinars presented by CZO investigators and collaborators. Students comprise a large portion of first authors from the Southern Sierra CZO presenting at conferences each year.

What is the impact on physical resources that form infrastructure?

The Southern Sierra Critical Zone Observatory (CZO) provides a platform to encourage and enable research in a landscape that is of vital importance to society yet poorly understood and subject to unprecedented changes as the climate warms. The Sierra Nevada is representative of seasonally snow-covered mountain regions, and the data and information developed as a result of the Southern Sierra CZO enhances the science of individuals and research groups well beyond the immediate CZO team. The Southern Sierra CZO is an important and well-used community research platform. This use is consistent with the founding vision of the CZO network and its goal of fostering broader impacts on research. Research partnerships continue to grow, extending that impact to more critical-zone disciplines, questions and scientists.

What is the impact on institutional resources that form infrastructure?

As a major component of the field research infrastructure that is accessible from campus, the Southern Sierra Critical Zone Observatory (CZO) is central to the research infrastructure of UC Merced's Sierra Nevada Research Institute (SNRI). The SNRI was established by UC specifically to use the Sierra Nevada and surrounding valleys as a natural laboratory for research, and to address knowledge gaps around management of resources in that region, and comparative regions worldwide. Many of the 30 faculty and their research groups affiliated with SNRI make use of these field resources in their research and educational programs. The Southern Sierra CZO is the best instrumented and equipped set of headwater catchments in the Sierra Nevada region, and the only elevational transect of research infrastructure dedicated to critical-zone science. Thus it is a resource for researchers well beyond SNRI and UC Merced.

What is the impact on information resources that form infrastructure?

Most of the Southern Sierra Critical Zone Observatory (CZO) data are available to the broader research community, and other data to CZO cooperators who agree to data-sharing protocols. These are significant and unique data sets that elucidate the many science questions described above. The data sets will have many secondary uses, as is already evident from the many downloads at our digital library.

As part of the national working group, staff are building a new portal on the standardized website. The new pages on the national website (criticalzone.org and criticalzone.org/sierra) will offer an easily navigable portal and additional information to data already posted on the independent Sierra Nevada San Joaquin Hydrologic Observatory digital library. Steps were taken in 2012-2013 to ensure more reliable and stable off-site backup. Southern Sierra CZO researchers and staff contributed to the new data level definitions and restructuring of the data vocabulary in the CUAHSI system.

Education efforts use Southern Sierra CZO data in classroom exercises for undergraduate and secondary students. More in-depth activities with integrated assessment procedures are being formulated as part of the InTeGrate Critical Zone course. Social media platforms act as a portal for the public, students and potential collaborators to reach the CZO website, where they can access in-depth information about the project.

What is the impact on technology transfer?

The Southern Sierra Critical Zone Observatory (CZO) measurement, research and outreach programs provide valuable lessons that are applicable to other multi-disciplinary earth-science observatories. Our wireless-sensor network is being scaled up to the entire American River basin (also in the Sierra Nevada) to provide a well-instrumented hydrologic observatory at the scale of interest for operational hydrology. The Southern Sierra CZO is an important testbed for new technology. Integration of this technology with our outreach helps generate strong interest in our science as well. We continue to use the CZO network, our own publications and other forums to share these lessons.

What is the impact on society beyond science and technology?

The knowledge developed at the Southern Sierra Critical Zone Observatory advances not only earth system science, but also directly informs societal decisions around management of ecosystem services. The Sierra Nevada provides ecosystem services, ranging from water to biodiversity, to a large segment of California's and the nation's population. Our growing partnerships with federal, state and local resource-management agencies show the interest that decision makers have in using research results to improve their predictive capabilities. We work with water-supply, forest and hydropower managers and the stakeholders directly affected by their decisions.

Changes

Changes in approach and reason for change

The Southern Sierra CZO initially focused on single site at the rain-snow transition (receiving approximately a 50-50 mix). Based on initial results, the CZO was expanded in 2009-2010 to four sites comprising a 2500-m elevation gradient. The additional investment broadened understanding of plant water-use, regolith development, and hydrologic flows across the transect. Ongoing research at these sites will broaden and deepen our understanding of critical zone science across the rain-snow transition.

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

Nothing to report.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.

Products

Journals

Blankinship, J.C., Meadows, M.W., Lucas, R.G., and Hart, S.C. (2013). Snowmelt timing alters shallow but not deep soil moisture in the Sierra Nevada. *Water Resources Research*. .

Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Blankinship, J.C., E.P. McCorkle, M.W. Meadows, S.C. Hart (). Earlier snowmelt constrains warming-induced soil greenhouse gas emissions in the rain-snow transition zone. *In prep for submittal to Science*. .

Status = OTHER; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes

Holbrook, W.S., C.S. Riebe, J.L. Hayes, D. Harry, K. Reeder, A. Malazian, A. Dosseto, P.C. Hartsough, J.W. Hopmans (). Geophysical constraints on deep weathering and water storage potential in the Southern Sierra Critical Zone Observatory. *Earth Surface Processes and Landforms*. .

Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Johnson, D.W., C. Woodward, M.W. Meadows. 2013 (). A Three-dimensional View of Nutrient Hotspots in a Sierra Nevada Forest Soil. *TBD*. .

Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Lui, F., Hunsaker, C.T., Bales, R.B. (2013). Controls of streamflow generation in small catchments across the snow-rain transition in the southern Sierra Nevada, California. *Hydrological Processes*. 27 1959.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/hyp.9304

Musselman, K.N., N.P. Molotch, S.A. Margulis, P.B. Kirchner, R.C. Bales (). Influence of canopy structure and direct beam solar irradiance on snowmelt rates in a mixed conifer forest. *Agricultural and Forest Meteorology*. .

Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Son, K., C. Tague (). Strategic sampling microclimate, soil moisture and sapflux for improving ecohydrological predictions of the Sierra Mountain watersheds. *Hydrological Processes, in prep.*. .

Status = OTHER; Acknowledgment of Federal Support = Yes

Tague, C., and H. Peng. (2013). The sensitivity of forest water use to the timing of precipitation and snowmelt recharge in the California Sierra: Implications for a warming climate. *J. Geophys. Res. Biogeosci.*. 118 .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/jgrg.20073

Welch, S.C., B. Kerkez, R.C. Bales, S.D. Glaser, K. Rittger, R.R. Rice. (2013). Sensor placement strategies for SWE estimation in the American River Basin. *Water Resources Research*. 49 (2), .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/wrcr.20100

Blankinship, J.C., Hart, S.C., (2012). Consequences of manipulated snow on soil gaseous emission and N retention in the growing season: a meta-analysis. *Ecosphere*. 3 .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1890/ES11-00225.1

Goulden, M.L., Anderson, R.G., Bales, R.C., Kelly, A.E., Meadows, M., and Winston, G.C. (2012). Evapotranspiration along an elevation gradient in the Sierra Nevada. *Journal of Geophysical Research - Biogeosciences*. 117 (G3), .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1029/2012JG002027

Hartsough, P.C., and Meadows, M.W. (2012). Critical Zone Observatory: Snowline Processes in the Southern Sierra Nevada. *Mountain Research Initiative Newsletter*. 7 .

Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = No

Hopmans, J.W., R.C. Bales, A.T. O'Geen, C.T. Hunsaker, D. Beaudette, P.C. Hartsough, A. Malazian, P. Kirchner, and M. Meadows (2012). Response to Comment on Soil moisture response to snowmelt and rainfall in a Sierra Nevada mixed-conifer forest. *Vadose Zone Journal*. 11 .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No ; DOI: 10.2136/vzj2012.0004r

Kerkez, B., S.D. Glaser, R.C. Bales, M.W. Meadows. (2012). Design and Performance of a Wireless Sensor Network for Catchment-scale Snow and Soil Moisture Measurements. *Water Resources Research*. 48 .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1029/2011WR011214

Riebe, C.S., Granger D. E., (2012). Quantifying effects of deep and near-surface chemical erosion on cosmogenic nuclides in soils, saprolite and sediment. *Earth Surface Processes and Landforms*. 38 (5), .

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/esp.3339

Johnson, D.W., M.W. Meadows, and C. Woodward (). A three-dimensional view of nutrient hotspots in a forest soil. *Soil Sci. Soc. Amer. J. (submitted August 2013).*. .

Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Woodward, C., D.W. Johnson, M.W. Meadows, W.W. Miller, M.M. Hynes, and C.M. Robertson. (2013). Nutrient hot spots in a Sierra Nevada forest soil: Characteristics and relations to microbial communities.. *Biogeochemistry (rejected, see Soil Science entry under same title)*. .

Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Woodward, C., D.W. Johnson, M.W. Meadows, W.W. Miller, M.M. Hynes, and C.M. Robertson (2013). Nutrient hot spots in a Sierra Nevada forest soil: Temporal characteristics and relations to microbial communities. *Soil Science (submitted August 2013, rewritten with addtions from Biogeochemistry submission)*. .

Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

K.Son, Tague. C and , Hunsaker, C.T, (). Effect of spatial resolution of DEM on ecohydrologic predictions and its sensitivity to climate variability in Sierra mountain catchments. *Water Resources Research, in prep.*. .

Status = OTHER; Acknowledgment of Federal Support = Yes

K. Son and Tague, C. (). Importance of soil parameter uncertainty in assessing climate change projections in small two Sierra watersheds,. *Water Resources Research, in prep*. .

Status = OTHER; Acknowledgment of Federal Support = Yes

K.Son and Tague, C (). Effect of climate warming on ecohydrologic fluxes of two Sierra mountain watersheds. *Eco-hydrology, in prep.*. .

Status = OTHER; Acknowledgment of Federal Support = Yes

Books

Book Chapters

- Granger, D. E., Riebe, C. S. (). Cosmogenic Nuclides in Weathering and Erosion. *Surface and Ground Water, Weathering, and Soils: Treatise on Geochemistry, Volume 5 (Treatise on Geochemisty) 3.* 5. Drever, J.I.. .

Status = ACCEPTED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = No ; ISBN: 978-0080447193.

Thesis/Dissertations

- Woodward, C.. *Nutrient Hot Spots in a Sierra Nevada Soil: Physical Assessments and Contributing Factors*. (2012). University of Nevada, Reno.

Acknowledgment of Federal Support = Yes

- Stacy, E.. *Composition and stabilization mechanisms of organic matter in soils and sediments eroded from granitic, low-order catchments in the Sierra Nevada, California*. (2012). University of California, Merced.

Acknowledgment of Federal Support = Yes

Conference Papers and Presentations

- Hartsough, P.C., A.I. Malazian, M. Meadows, A.T. O'Geen, J. W. Hopmans. (2013). *Characterization of Water Use Patterns in the Deep Vadose Zone through Geoprobe Drilling into Weathered Bedrock*. GSA 109th Cordilleran Section Meeting. Fresno, CA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Son, K., and Tague, C.N. (2013). *Improvement of model predictions and reduction of uncertainty in Sierra Critical Zone Observatory watersheds using strategic sampled ecohydrologic data*. CUAHSI Conference on Hydroinformatics and Modeling. Utah State University, Logan, UT.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Meadows, M. (2013). *Using large-scale, shallow soil water measurements to estimate deeper soil water storage in a mixed-conifer forest of the Southern Sierra Nevada*. GSA 109th Cordilleran Section Meeting. Fresno, CA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Stacy, E.M., A.A. Berhe, D.W. Johnson, C.T. Hunsaker, S.C. Hart. (2013). *Decomposability of organic matter eroded from eight low-order catchments*. GSA 109th Cordilleran Section Meeting. Fresno, CA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Hartsough, P.C., E. Roudneva, A. I. Malazian, M. W. Meadows, R. C. Bales, and J. W. Hopmans (2012). *Paired tree and soil instrumentation: what can we learn from two instrumented sites across various gradients in a forested catchment. Abstract H31G-1211*. Fall meeting, American Geophysical Union, December 2012. San Francisco, CA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Holbrook, S.W., C.S. Riebe, J. L. Hayes, K. Reeder; D. L. Harry, A. I. Malazian, A. Dosseto, P.C. Hartsough, and J. W. Hopmans. (2012). *Geophysics in the Critical Zone: Constraints on Deep Weathering and Water Storage Potential in the Southern Sierra CZO*. Fall meeting, American Geophysical Union, December 2012. San Francisco, CA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Hopmans, J.W. (2012). *Soil Water and Tree Water Status Dynamics in a Mixed-Conifer Forest of the Southern Sierra Critical Zone Observatory (CZO)*. Invited Lecture, Texas A&M University. College Station, TX.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Hopmans, J.W., J. Rings, T. Kamai, M. M. Kandelous, P.C. Hartsough, J.A. Vrugt (2012). *Modeling of Soil and Tree Water Status Dynamics in a Mixed-Conifer Forest of the Southern Sierra Critical Zone Observatory. Abstract H52E-01*. Fall meeting, American Geophysical Union, December 2012. San Francisco, CA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Kerkez, B., Zhang, Z., Glaser, S.D., and Bales, R. (2012). *Connecting the Snowpack to the Internet of Things: an IPv6 Architecture for Providing Real-Time Measurements of Hydrologic Systems. Invited presentation, Abstract C32B-07*. Fall meeting, American Geophysical Union, December 2012. San Francisco, CA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Malazian, A.I., P.C. Hartsough, and J. W. Hopmans (2012). *Soil Moisture Dynamics in Deep Southern Sierra Nevada Soils*. Fall meeting, American Geophysical Union, December 2012. San Francisco, CA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Meadows, M.W., P.C. Hartsough, R.C. Bales, J.W. Hopmans, and A.I. Malazian (2012). *Integrating soil water measurements from plot to catchment scale in a snow-dominated, mixed-conifer forest of the southern Sierra Nevada. Abstract H31G-1198*. Fall meeting, American Geophysical Union, December 2012. San Francisco, CA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Son, K., and Tague, C. (2012). *Strategic sampling of microclimate, soil moisture and sapflux for improving ecohydrological model estimates in the California Sierra. Abstract H31G-1208*. Fall meeting, American Geophysical Union, December 2012. San Francisco, CA.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Stacy, E.M., S.M. Meding, S.C. Hart, C. Hunsaker, D. Johnson, A.A. Berhe (2012). *Lateral redistribution of dissolved vs. complexed organic matter with soil. Abstract B34C-07*. Fall meeting, American Geophysical Union, December 2012. San Francisco.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Welch, S, Kerkez, B, Bales, R., and Glaser, S.D (2012). *Sampling Design and Optimal Sensor Placement Strategies for Basin-Scale SWE Estimation. Abstract C33C-0683*. Fall meeting, American Geophysical Union, December 2012. San Francisco.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Other Publications

- Bales, R. (2013). *Water information, water security and climate change in the Sierra Nevada.*. Presentation to UC Sacramento research science group.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Meadows, M. and Stacy, E. M. (2013). *Snowpack monitoring research & techniques. Center for Advanced Research and Technology (CART): talks and student mentoring.*. Mentoring and educational project for high school students at the Center for Advanced Research and Technology. Student presented final project..

Status = PUBLISHED; Acknowledgement of Federal Support = No

- Bales, R.C. (2013). *Water implications of various forest management strategies.*. Conference presentation to stakeholders, resource managers and policy makers..

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Stacy, E. M., M. Meadows, J. Laird, and W. Mayse (2013). *How wildlife is affected by the water cycle in Sierra Nevada.*. Southern California Edison Science Days, with assistance from Shaver Lake Volunteers. May 9, 16, and 31, 2013. Contact: Stephen Byrd, SCE. (Approximately 600 students, grades K-8 from 3 schools)..

Status = PUBLISHED; Acknowledgement of Federal Support = No

- Conklin, M. H., Q. Guo and R. C. Bales (2013). *Articulating research needs for a new program on improved management of California's headwaters.*. Presenters were on a panel at the annual meeting of the Association of California Water Agencies.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Conklin, M. H. (2013). *Sierra in a Box*. Display of soil moisture and snow depth sensors presented at a fair for Congressional staffers, Washington D.C., May 7..

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Stacy, E.M. (2013). *At the Southern Sierra Critical Zone Observatory: Tracking soil erosion & its impacts in Sierra Nevada forests.*. Presentation to science teachers from NatureBridge-Yosemite program, April 16.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Hartsough, P. (2013). *Seeing the Forest through the roots: A bottom up approach to forest hydrology.*. Presentation to science teachers from NatureBridge-Yosemite program, February 26.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Stacy, E. M. and Meadows, M. (2013). *Groundwater and surface water resources, with a focus on how pollution moves through groundwater.*. Auberry Forest Conservation Days, organized by the Sierra Association of Foresters. Contact: Thomas Catchpole. April 16, 2013. (Approximately 150 students, grade 5, from 3 schools)..

Status = PUBLISHED; Acknowledgement of Federal Support = No

- Riebe, C., C. Lukens, and W.J. Hahm (2013). *Nutrient Deserts of the Sierra Nevada and Their Effects on Life, Soils, and Topography*. Live webinar April 5, with archived recording available at https://sas.elluminate.com/mrtbl?suid=M.1442DCA2C6BB3AD379385DE3BDE242&sid=2008263 .

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Bales, R. (2013). *Fresno Forum: Climate Preparedness in the Valley*. Panel Discussion, April 15.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Bales, R. (2013). *Sierra Nevada & California's Water.*. Presentation to local interest group Merced Association of Realtors, April 4.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Bales, R. C. (2013). *How better information can transform water management in California*. Presentation at Center for Information Technology Research in the Interest of Society, March 20.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Hunsaker, C. (2013). *Watershed-scale experimental design and pre-treatment N-flux results: Kings River Experimental Watersheds, Sierra Nevada, CA*. Webinar, U.S. Forest Service, Research & Development, March 19.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Conklin, M.H. (2013). *Sierra Nevada Meadows: the Wet and Dry*. Presentation at Sierra Nevada Research Institute, 2013 Symposium. March 4..

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Bales, R. C. (2013). *Managing Forests to Maximize Water Yields.*. Presentation at Climate Change Adaptation Consortium. California Department of Food & Agriculture, January 22-23.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Riebe, C. (2013). *Looking Deep, Beyond the Average, and Into the Future of Surface Processes Research*. Presentation at EarthCube Domain End-User Workshop: Engaging the Critical Zone community to bridge long tail science with big data at the University of Delaware. January 22.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Conklin, M. H. and Stacy, E. M. (2013). *Environmental engineering and water resources in the Southern Sierras*. Presentation and activity for American Association of University Women Girl's Science Camp - Engineering Day. UC Merced. January 16. (Approximately 12 students and their mothers participated in the 2013 Science Camp.).

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Riebe, C. (2012). *Water Crises*. Presentation to ~20 students at the annual Good Mule Conference in Laramie, Wyoming. November 10.

Status = PUBLISHED; Acknowledgement of Federal Support = No

Technologies or Techniques

- Additional improvements were made to the RHESSys eco-hydrologic model for the Providence site, including refinements to the strategic sampling protocol, as well as evaluating the effects of DEM resolution and soil parameter uncertainty. Model adjustments will aid the models in becoming more adaptable for catchments across the region. Publications are forthcoming.

Patents

Nothing to report.

Inventions

Nothing to report.

Licenses

Nothing to report.

Websites

Title:

Southern Sierra Critical Zone Observatory

URL:

http://www.criticalzone.org/sierra

Description:

This website is the new home of the Southern Sierra CZO. In the 2012-2013 year, CZO staff worked with the national website committee to transition the website to a centralized, standardized format. This site hosts easily accessible background information, an events calendar and news stream, infrastructure and field site information, people profiles, and data. In the coming months, we will focus on adding further links to data, interactive maps, more photo galleries and news stories, and centralizing information for CZO presentations at upcoming conferences.

Title:

CZO Twitter

URL:

http://twitter.com/CZO

Description:

So far as we know, the Southern Sierra CZO is the only location in the network to post to Twitter. The platform allows us to reach a broader audience than we otherwise would have, and our followers have been growing consistently since we started in February. After 8 months, we have 43 followers, the majority of whom are outside the Critical Zone network. Southern Sierra CZO posts events, photos, and links to other pertinent stories and blog posts on the Twitter page.

Title:

CZO Facebook

URL:

https://www.facebook.com/SouthernSierraCZO

Description:

The Southern Sierra CZO may also be the only location to host a Facebook page. This page is slowly growing, and reaches a local cross-discipline audience (broader than environmental science).

Title:

Blog of the Sierra Nevada Research Institute

URL:

http://SNRIblog.ucmerced.edu

Description:

This blog was recently started as a centralized location to feature researchers, research projectrs, and events hosted by the Sierra Nevada Research Institute (SNRI) at UC Merced. It is designed to strengthen and enhance the connection between academia and the local community, including school children, to increase dissemination of results and issues in environmental research - especially for water security and ecosystem stability in the west. The Southern Sierra CZO is hosted within SNRI, and is a major contributor. Erin Stacy, the CZO education and outreach coordinator is hosting the blog and coordinating posts from contributors. The blog is young, but plans include engaging local students at all levels to contribute to the blog. The blog will also act as the main page for Science Cafe Merced. Though focused in California at UC Merced, other CZO researchers will be contributors as well.

Other Products

Product Type:

Audio or Video Products

Description:

NBC Learn visited the Southern Sierra CZO as part of a filming expedition for an educational project. Two researchers associated with the CZO were interviewed for the videos. CZO co-PI Martha Conklin and collaborator Tom Harmon discussed research projects and findings on the science of snowpack distribution, water supply, and water quality. The videos can be viewed at: http://www.nbclearn.com/water/cuecard/65303 and http://www.nbclearn.com/water/cuecard/65227. These videos were included in the DLM In the Lab: CZO Library Exhibit July 16-September 20, 2013.

Other:

Product Type:

Other

Description:

From July 16 to September 20, 2013, the UC Merced Kolligian Library displayed an exhibit entitled DLM In the Lab: CZO Library Exhibit. The exhibit featured videos, photos, equipment, and interactive exhibits detailing snowpack depth sensors and groundwater infiltration rates. CZO staff member Erin Stacy worked with the Access Services Librarian Robin Milford at UC Merced and Downtown Life Magazine writer K Chico, author of the "In the Lab" series to coordinate the exhibit.

Other:

Exhibit

Product Type:

Audio or Video Products

Description:

Onward California, a University of California Office of the President effort, filmed at the Southern Sierra CZO. Roger Bales traveled with them. A longer video entitled Calfiornia's Water Tower (~2.25 minutes), as well as three shorter spots (~30 second, featuring water, management and climate) were produced. The main video has nearly 1000 views.

Videos are available here:

www.youtube.com/watch?v=HEv7q2vB3d8

www.youtube.com/watch?v=_aMK_OFnKj8

www.youtube.com/watch?v= tHOUMPko7YQ&t=0

www.youtube.com/watch?v=jps9gK-4_qg

Other:

Product Type:

Other

Description:

Article released in the San Francisco Chronicle publicized the wireless sensor networks and their many applications as well as our research locations.

"Sensors so smart they feel, think." August 12, 2013. San Francisco Chronicle. Feature on UC Berkeley Professor Steven Glaser and the wireless sensor technology.

Other:

Media feature

Product Type:

Other

Description:

Article published by Live Science featured Dr. Steven Glaser and the work on wireless sensor networks.

Researcher Designs Sensors to Gather Earth Details. Live Science Feature on UC Berkeley professor Steven Glaser. March 29, 2013. Available online: http://www.livescience.com/28291-earth-sensors-steven-glaser-nsf-sl.html

Other:

Media feature

Product Type:

Other

Description:

Article published in several regional newspapers publicized the opening of the library exhibit at UC Merced which featured the Southern Sierra CZO.

UC Merced Connect: Exhibits take look at research. July 30, 2013. Available online: http://www.sacbee.com/2013/07/30/5610483/uc-merced-connect-exhibits-take.html. Also appeared in the Modesto Bee, Fresno Bee, and Merced Sun-Star.

Other:

Media feature

Product Type:

Other

Description:

UC Merced news feature highlighted open symposium for Sierra Nevada Research Institute with presentations on the CZO. Publication reaches UC Merced students, alumni, and visitors to the website.

Research Week Highlights Cutting-Edge Work. Feature on UC Merced presentations, including Sierra Nevada Research Institute 2013 Symposium and Reserve Tour. UC Merced University News. February 20, 2013. Available online: www.ucmerced.edu/news/research-week-highlights-cutting-edge-work

Other:

Media feature

Product Type:

Other

Description:

Regional newspaper editorial featured Roger Bales and the CZO work in an opinion piece on water jobs.

Water jobs of the future. Editorial in The Modesto Bee. February 16, 2013. www.modbee.com/2013/02/16/2581756/water-jobs-of-the-future.html. Also published in Merced Sun-Star, February 19, 2013. Available online: www.mercedsunstar.com/2013/02/19/2827639/our-view-report-eyes-water-jobs.html

Other:

Media feature

Product Type:

Audio or Video Products

Description:

Video recording of live presentation available freely for reference and learning. Covers the major ideas behind improving the water knowledge structure in the Sierra Nevada for water and environmental security.

Bales. R. Data Innovation Day: Visualizing the Environment. Center for Information Technology Research in the Interest of Society. Internet video, first posted January 24, 2013 and accessible online. Available online: www.youtube.com/watch?v=WYq2bU1u0hw.

Other:

Product Type:

Other

Description:

Article published by UC Merced University news:

California is Home to Extreme Weather, Too. Feature on SNRI research on California weather. UC Merced University News. November 1, 2012. Available online: http://www.ucmerced.edu/news/california-home-extreme-weather-too

Other:

Media feature

Product Type:

Other

Name	Most Senior Project Role	Nearest Person
Steven Glaser	Faculty	2
Asmeret Asefaw Berhe	Faculty	2
Stephen Hart	Faculty	2
Peter Hartsough	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Branko Kerkez	Graduate Student (research assistant)	1
Peter Kirchner	Graduate Student (research assistant)	2
Jorden Hayes	Graduate Student (research assistant)	1
Armen Malazian	Graduate Student (research assistant)	12
Ryan Lucas	Graduate Student (research assistant)	11
Ram Ray	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Anne Kelly	Graduate Student (research assistant)	12
Erin Stacy	Other Professional	12
Emma McCorkle	Graduate Student (research assistant)	10
Jesse Hahm	Graduate Student (research assistant)	12
Heather Rogers	Graduate Student (research assistant)	4
Ekaterina Roudneva	Undergraduate Student	2
Laura Jalpa	Undergraduate Student	2
Nicholas Marlowe	Undergraduate Student	1
Alex Newman	Undergraduate Student	4
Emily Mecke	Undergraduate Student	3
Matt Meadows	Other Professional	12
Xiande Meng	Other Professional	12
Kyongho Son	Graduate Student (research assistant)	12
Jan W Hopmans	Co PD/PI	2
Michael L Goulden	Co PD/PI	2
Martha H Conklin	Co PD/PI	2
Roger C Bales	PD/PI	2
Clifford Riebe	Faculty	2
Christina Tague	Co PD/PI	2
Claire Lukens	Graduate Student (research assistant)	2

Description:

Article published by UC Merced University news:

Snowy, Sandy Research Explores Climate Change. Feature on UC Merced Professor Stephen Hart and postdoctoral researcher Joey Blankinship. UC Merced University News. September 5, 2012. Available online: http://www.ucmerced.edu/news/snowy-sandy-research-explores-climate-change

Other:

Media feature

Participants

Research Experience for Undergraduates (REU) funding

What individuals have worked on the project?

What other organizations have been involved as partners?

Name	Location
US Forest Service, Pacific Southwest Research Station	Fresno, CA

Have other collaborators or contacts been involved? Y

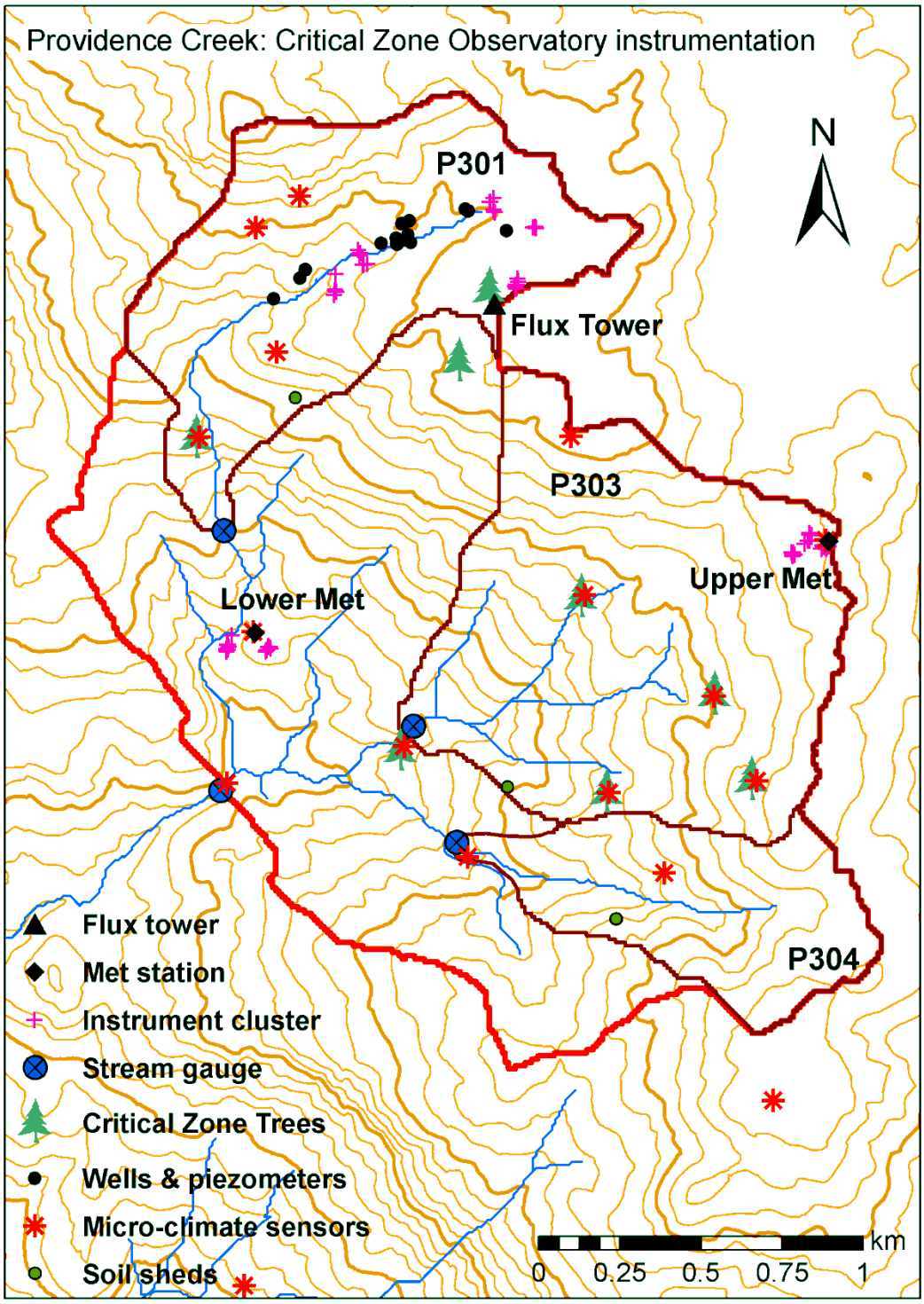

Figure 1. Instrument cluster design at the Critical Zone Observatory site that overlaps with the Kings River Experimental Watershed. Instrument node locations are strategically placed to capture variability in aspect, elevation, and vegetation properties.

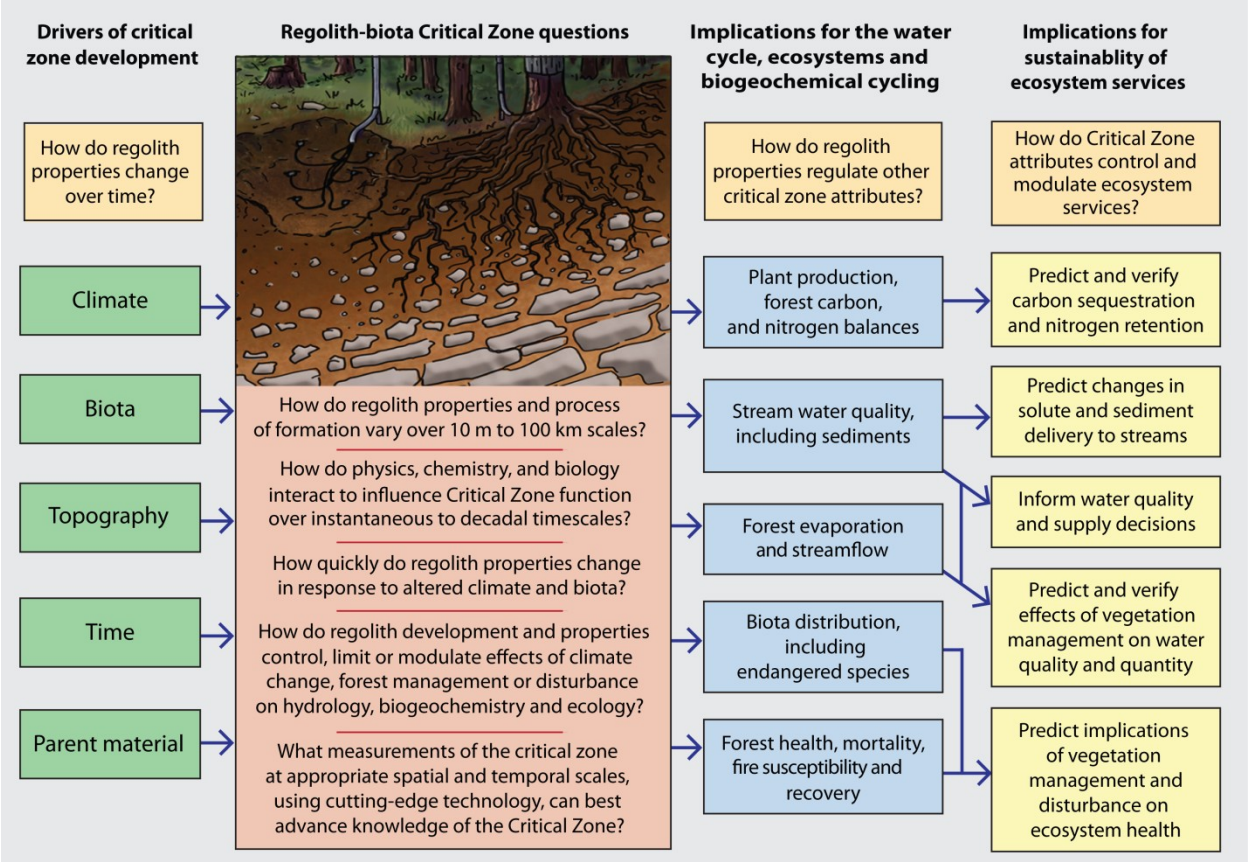

Figure 2. Schematic of relationships among drivers of critical-zone development, science questions that guide Southern Sierra Critical Zone Observatory research, implications for critical-zone attributes and implications for critical-zone services and sustainability.

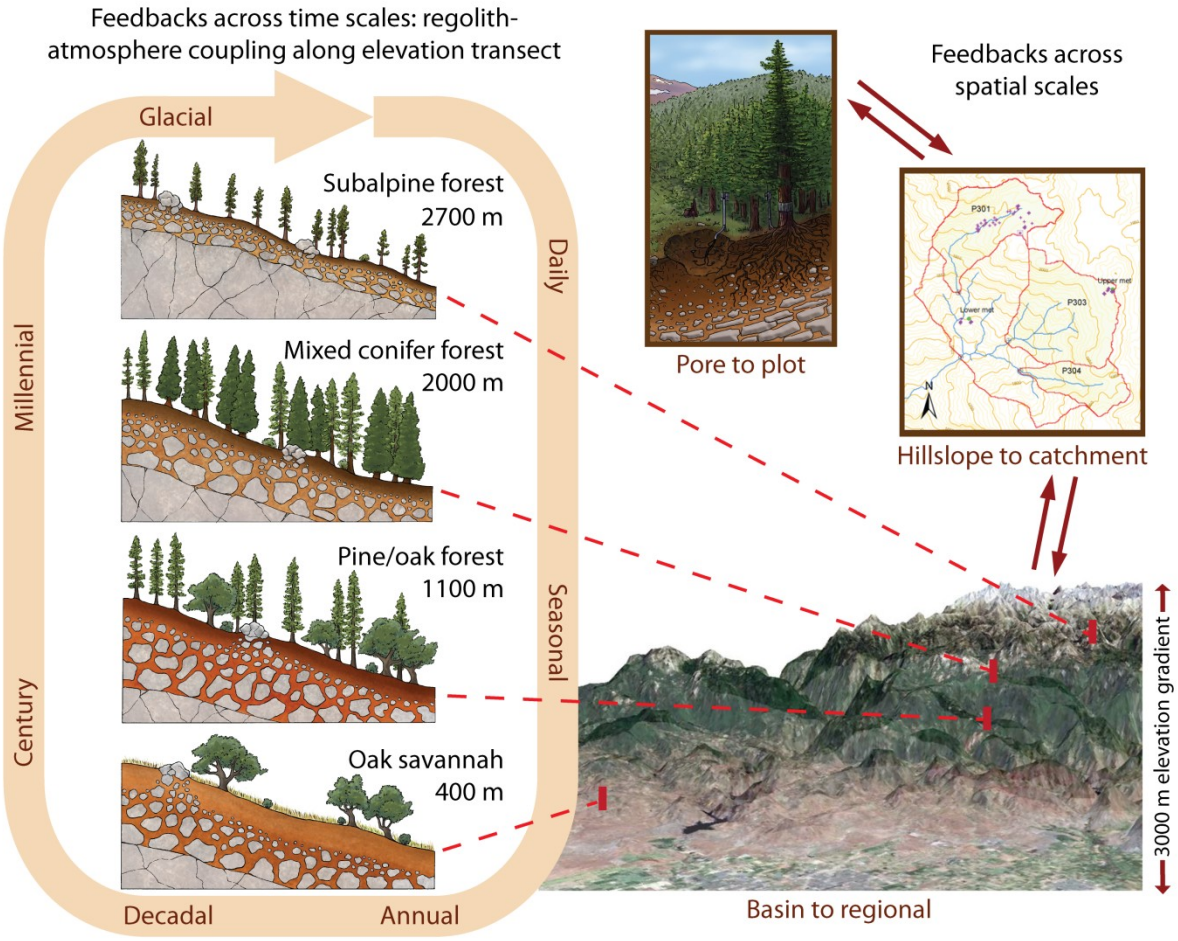

Figure 3. The Southern Sierra Critical Zone Observatory involves measurements and research across multiple scales of space and time. We have established four focus sites spanning a 2500-m elevation range, exploiting gradients in climate soil properties, vegetation, and material cycles. The subalpine forest (2700-3000 m) has thin patchy soil that may limit soil-moisture storage. The mixed-conifer forest (2000 m) is our most heavily instrumented research area, with three gauged headwater catchments nested in a fourth, 4.6 km2 gauged catchment (see inset map). Instrumentation around 2000 m includes a flux tower, two meteorological stations, soil lysimeters, groundwater wells, over 1000 continuous sensors for snow depth, soil moisture, streamflow, water quality, and sap flow. The local vegetation, soils, streams and other attributes have been well characterized. The pine/oak-forest (1100 m) has the most intense weathering; soil profiles display subsurface horizons with evidence of clay and iron accumulation and a deep regolith. The oak-savannah (400 m) has little woody vegetation but high belowground biomass (in grass roots), posing sharp contrasts in soil-water utilization and nutrient cycling relative to the upper sites. Image in lower right of figure indicates greenness (a measure of vegetation density).

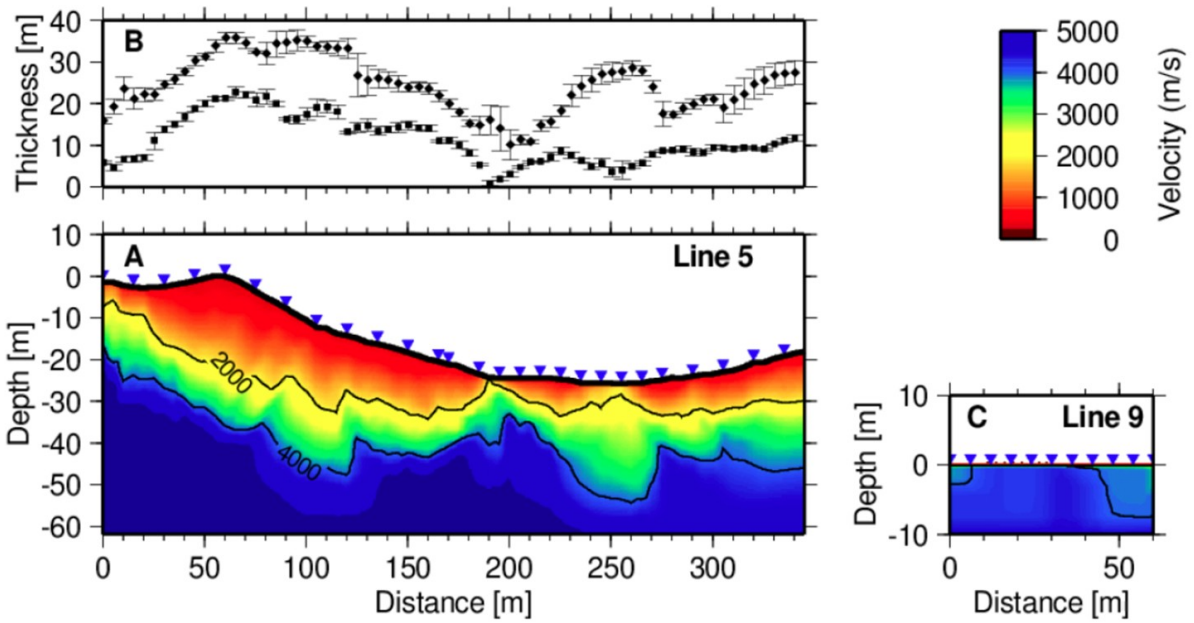

Figure 4. Regolith thickness from a seismic survey at the Southern Sierra CZO. Upper panel shows thickness to the 2000 and 5000 m/s velocity profiles (Holbrook et al. 2013).

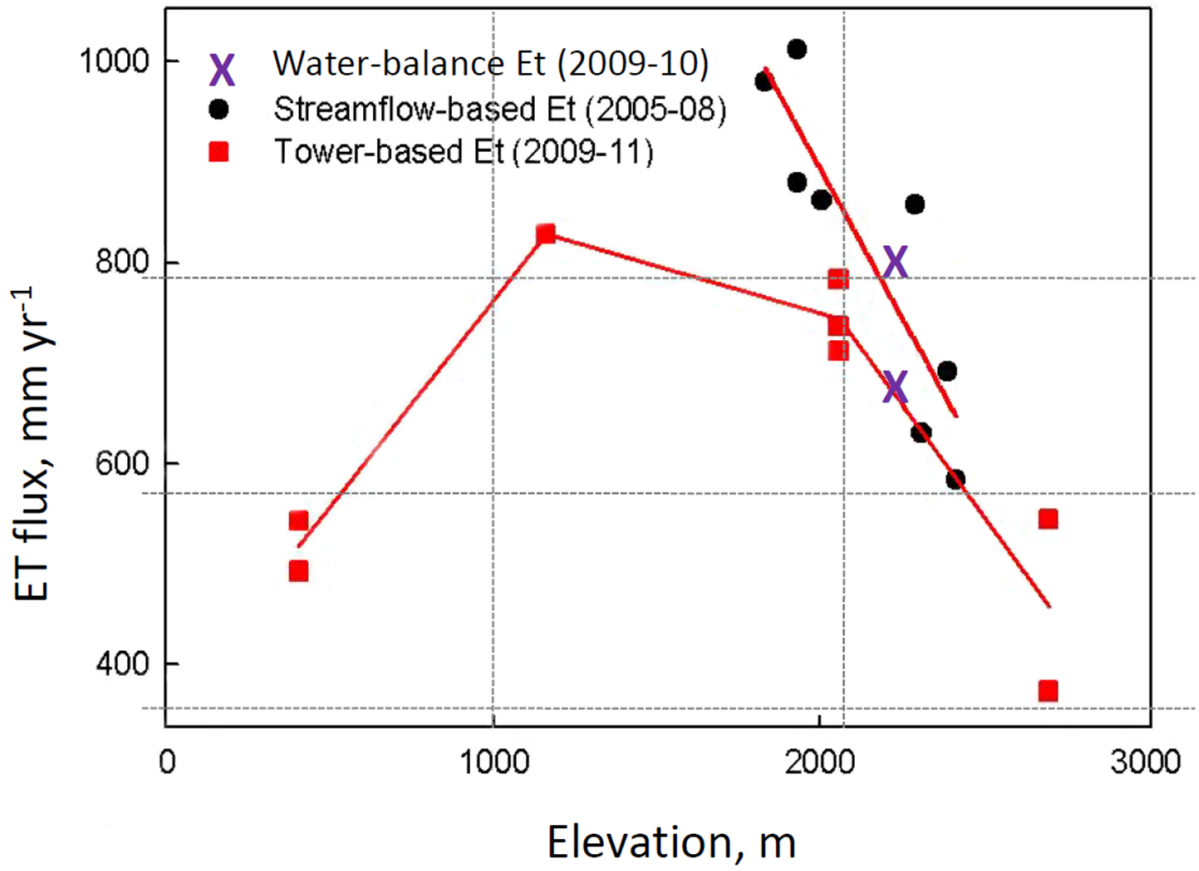

Figure 5. Annual evapotranspiration across the CZO elevation gradient (Goulden et al. 2012).