# Eel River Critical Zone Observatory

Year 2 Annual Report
June 2015

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# A. Accomplishments

## 1. What are the major goals of the project?

The major goals of the Eel River CZO as outlined in our Management plan are to answer these four questions:

1. Does lithology control rock moisture availability to plants and therefore overall resilience of vegetation to climate change in seasonally dry environments?
2. How are solute and gas effluents from hillslopes influenced by biota in changing moisture regimes?
3. What controls the spatial extent of wetted channels in the channel networks of seasonally dry environments?
4. Will changes in critical zone currencies induced by climate or land use change lead to threshold-type switches in river and coastal ecosystems?

Additionally, we propose to develop a numerical platform – the Atmosphere-Watershed-Ecology-Stream and Ocean Model (AWESOM)- to synthesize findings from smaller scale studies, couple the different critical zone subsystems together, and explore the long-term and large-scale consequences of the dynamics of the critical zone in the context of changes in climate, landuse, and water management policy

## 2. What was accomplished under these goals?

a. Major activities:

Question 1: Does lithology control rock moisture availability to plants and therefore overall resilience of vegetation to climate change in seasonally dry environments?

To explore how lithology controls rock moisture availability to plants and thus the link between vegetation and climate, we intensified our research this year at our principle study site (Rivendell) on argillite and sandstone (dense forest cover) and began an investigation of a nearby second site at the Sagehorn-Russell Ranch (the Shire) on mélange (grassland and mostly sparse forest cover). At Rivendell we performed activities in three general areas: 1) site characteristic and theory testing, 2) rock moisture dynamics during drought, and 3) moisture availability and tree water sources. We continued our monitoring of over 700 sensors across the Rivendell hillslope to quantify local meteorology, soil moisture and temperature, water level in 12 wells, and sap flow.

<u>1) Site characteristic and theory testing</u>

In August of 2014 we collaborated with the Wyoming Center for Environmental Hydrology and Geophysics in an intensive field campaign involving 3 faculty members (2 UWyo, 1 UCB), 5 undergraduates (3 UWyo, 2 UCB), 11 graduate students (2 Wyo, 9 UCB) and 2 technicians (1 UWyo, 1 UCB) aimed at mapping the spatial structure of the critical zone across the landscape. We used a variety of geophysical tools to evaluate a hypothesis for controls on the evolution of the weathering front (Rempe and Dietrich, 2014, PNAS).

We also initiated more detailed mineralogical analysis of the argillite and confirmed the presence of fine pyrite particles in the fresh bedrock.

<u>2) rock moisture dynamics during drought</u>

Neutron probe surveys were continued in 7 wells that documented the storm and seasonal dynamic of rock moisture in the shallow saprolite and the deeper weathered bedrock of the critical zone.

<u>3) moisture availability and tree water sources</u>

We conducted an experiment to test directly the source of water uptake by various tree species. Holes were drilled through the soil and into the weathered bedrock, surrounding selected trees. Deuterium enriched water was dripped into the base of the holes over a 24 hour period. The trees were subsequently sampled to determine if, and at what time, the elevated deuterium signal appears in the trees. Soils and soil water were sampled downslope from the sites of injection throughout the wet season to document transit times and pathways of the flow of this water through the hillslope.

To investigate tree water potential stem psychrometers were deployed multiple times across the north and south facing slopes to measure hourly fluctuations in water potential in 10 different trees. Predawn measurements were found to correlate with nearby soil moisture content.

Question 2: How are solute and gas effluents from hillslopes influenced by biota in changing moisture regimes?

Two extensive field surveys of water chemistry of the tributaries and mainstem of Elder Creek (the 17 $km^2$ watershed into which Rivendell drains) were conducted in May and August 2014.

We have begun analysis of a large DNA sequence information obtained from soil and shallow weathered bedrock underlying the soil from the Rivendell site. A major effort was invested in refining data analysis methods for this unprecedented dataset. In addition, we undertook a field sampling campaign at the Rivendell site using an approach that we developed to collect samples from underneath Douglas fir trees for sequencing. The DNA will be extracted from these samples over summer 2015 and the samples submitted for sequencing at the Joint Genomics Institute (*see additional funding*). In addition, gas monitoring in the cored holes will be undertaken and researchers have begun investigating carbon storage in the vadose zone.

Question 3: What controls the spatial extent of wetted channels in the channel networks of seasonally dry environments?

The extent of wetted channels and many associated attributes including stream flow width, depth, velocity, grain size, and temperature, air temperature and relative humidity, and hillslope soil and air temperature and relative humidity) were mapped in Fox Creek (2.74 $km^2$) and Elder Creek (17 $km^2$) watersheds in May 23-June 7, 2014 and August 17-28, 2014. Water isotope and moss samples were taken at all data points. About 500 point samples were made in each survey period.

A similar survey has just been completed in the site underlain by mélange (the Shire). As anticipated the drainage density of the wetted channels is much smaller.

iButton temperature sensors were deployed at field sites to investigate the effects of flow on stream temperature structure.

Question 4: Will changes in critical zone currencies induced by climate or land use change lead to threshold-type switches in river and coastal ecosystems?

In summer 2014, samples were collected to document patterns in dissolved cyanotoxin concentrations in the water and cyanotoxin concentrations in cyanobacterial mats. From these samples we are beginning to understand the temporal and spatial dynamics of cyanotoxin production in the river.

Several field trips up Elder Creek, using the mapped wetted channels as guides, have enabled us to determine the upper limit of fish habitat in Elder Creek and its tributaries. A similar effort is underway in Fox Creek. Longitudinal sampling in Elder Creek and Fox Creek has been initiated to collect fish tissues (for genetics), density and size and age structure. Antennas to monitor fish movement and migration timing were installed in Elder Creek in Fall of 2014 and will be installed this summer in Fox Creek.

In addition, a collaborative initiative with The Nature Conservancy has begun to address the effects of illegal marijuana cultivation on stream conditions, leading to a policy analysis paper currently being published in Bioscience.

AWESOM: The Atmosphere-Watershed-Ecology-Stream and Ocean Model.

Meso -scale weather models and an ocean model with productivity are developed. Focus this year has been on modeling fracture flow control on the perched groundwater dynamics of the critical zone and on empirical analysis of summer low and diurnal oscillations to infer process controls.

## b. Specific Objectives

**Milestone 1. Does lithology control rock moisture availability to plants and therefore overall resilience of vegetation to climate change in seasonally dry environments?**

**1.1** Map the depth to fresh bedrock under hillslopes using shallow geophysics as a first test of the Rempe and Dietrich (2014) theory

**1.2** Initiate investigation of nitrogen content (through collaborators), of the presence of pyrite in the bedrock (detection at times of strong sulfur in some of the wells), and microporsity of weathered bedrock (collaboration with Shales Hill CZO).

**1.3** Quantify seasonal rock moisture dynamics in the 7 wells are the Rivendell site

**1.4**. Using dual stable isotopes, map potential tree water sources in the critical zone and quantify where different species of trees take their water.

**1.5.** Conduct tracer experiment in which water with elevated deterium is applied just to the weathered bedrock to test for use of rock moisture by trees.

**1.6** Install tree water potential stem psychrometers, test performance and compare results for different trees on north and south slopes at Rivendell.

**1.7** Identify research site and begin instrumentation in a landscape underlain by mélange with characteristic grass and broadleaf tree vegetation.

**Milestone 2: How are solute and gas effluents from hillslopes influenced by biota in changing moisture regimes?**

**2.1** Examined the mobilization, transport and delivery of chemical species from subsurface waters to Elder Creek and then further downstream using automated sampling and point samples taken throughout the Elder Creek watershed

**2.2** Determined temporal dynamics and biotic origin of high $CO_2$ and other atmospherically reactive gases within the critical zone. New profile data collected and new sampler device built

**2.3** Collection of soils samples with the goal of describing the microbial community over time and with depth into the Critical Zone.

**Milestone 3: What controls the spatial extent of wetted channels in the channel networks of seasonally dry environments?**

**3.1** Map the extent of wetted channels (and associated hydrologic and meteorological attributes) at the beginning and end of the summer low flow in Fox and Elder Creek

**3.2** Map the extent of wetted channels (and associated hydrologic and meteorological attributes) in the landscape underlain by mélange.

**3.3** Initiated the development and test models of stream network contraction during summer low flow.

**Milestone 4: Will changes in critical zone currencies induced by climate or land use change lead to threshold-type switches in river and coastal ecosystems?**

**4.1** Compared algae and cyanobacteria production at three main-stem South Fork Eel reaches that experience different radiation and flow regimes.

**4.2** Monitored salmonid performance in two tributaries of the South Fork Eel.

**Milestone 5: Synthesis Modeling (the Atmosphere-Watershed-Ecology- Stream-Ocean Model)**

**5.1** Develop and test models for hillslope scale groundwater recharge and discharge incorporating the effects of preferential fracture flow.

**5.2** Analyze summer recession limbs for signature of hydrologic processes and conduct inverse modeling studies of diurnal oscillations in summer base flow

## c. Significant results:

**1.1** A strong correspondence between seismic velocity and the bottom boundary of the critical zone, Zb (elevation of fresh bedrock) was found at Rivendell. Using the velocity- Zb relationship we then mapped structure of base critical zone under 4 other hillslopes and found that depth to Zb increased systematically towards the divide- consistent with the proposed theory. This suggests we may be able to predict the spatial pattern of the critical zone thickness across landscapes where assumptions in the model are met.

**1.2** Based on neutron probe measurements, we found rock moisture content in individual wells reached 60% of the total precipitation in the drought year. Rock moisture stays elevated farther into the dry season than soil moisture. Weathered bedrock moisture increases as soil and saprolite moisture decreases during in the spring. Summer elevated rock moisture either is depleted by vegetation or drains to and recharges the groundwater- which sustains summer low flow in streams. These observations highlight the significance of this previously unmeasured moisture dynamic in the deep critical zone.

**1.4** Stable isotope measurements of moisture in the soil, saprolite, and weathered bedrock through which the meteoric water transits are consistently isotopically light (negative δ□□□□□ δ□□□) relative to both the average rainfall and the more mobile water contributing to runoff. This persistently light composition of soil and rock moisture suggest that subsurface fractionation and/or filtration processes, or inheritance of paleo-meteoric rock moisture associated with rock uplift may lead to enduring large isotopic differences between high and low mobility water. These differences suggest that the use of water isotopes as tracer of sources, pathways and residence times must consider the possibility of subsurface isotopic evolution and the influence of exchange with more tightly held water.

Systematic stabile isotope analysis of the dominant trees (all evergreen) at Rivendell demonstrated that broadleaf trees rely primarily on soil moisture but may, on south facing slopes, use increasing amounts of rock moisture in the summer. In contrast the needle trees (Douglas fir, *Pseudotsuga menziesii*) mostly lies in a dual-isotope space dissimilar to any of the mapped water sources in the critical zone. Based on deuterium isotopes alone it appears Douglas fir use rock moisture. The similarity of the dual isotope signature of Douglas fir at sites more than10 km away and on a different rock type (mélange) with likely different subsurface isotope regimes suggest that Douglas fir may not faithfully record the stable isotope signature in its source water. This has implications both for the use of Douglas fir isotopes to track water sources and for how their root uptake is mediated.

**1.5** Experimental addition of an elevated deuterium tracer confirm that Douglas fir use rock moisture (and that the nearby broadleaf trees did not).

**1.6** Stem psychrometers, which measure plant water potential, were deployed multiple times across the north and south slopes near Rivendell to measure hourly fluctuations in tree water potential in 10 different trees. These measurements were verified with predawn and midday pressure chamber measurements, and reveal differences between Douglas Fir and broadleaf trees.

**1.7** A mélange study site, the Shire was established on a privately-held 20 $km^2$ active ranch (Sagehorn-Russell Ranch) in the headwaters of the Middle Fork of the Eel River, 20 km southeast of the Rivendell site. It is underlain by chemically and mineralogically similar bedrock as that underlying Rivendell, but is intensively deformed mélange. This bedrock makes up about 40% of the Eel River watershed. South facing slopes are primarily grasslands, north slopes are mixtures of grass and mostly broadleaf forest. Large blocks of sandstone in the mélange support discrete stands of Douglas fir. Consistent with the mechanically weak bedrock, the hillslopes are considerably gentler than at the Rivendell area. Initial stable isotope surveys suggest a very different water history.

**2.1** The mainstem chemistry was invariant, but tributaries showed wide variation in major elements. Streams draining south facing slopes had higher Na, K, Mg and Ca but lower Si than streams draining north slopes. Elder Creek has a well-studied concentration-discharge relationship and the detailed well sampling done at Rivendell at three wells and this recently completed spatial survey will contribute to a process-based interpretation of this relationship.

**2.2** Gas profiling in wells has revealed major shifts in $CO_2$ and $O_2$ at depths of 5 m in response to a rain event. Time series data also show strong diurnal variation in $CO_2$ and $O_2$ at 6.5 m below the surface in the weathered bedrock zone. Several hypotheses for controls on the diurnal dynamics are being explored. These data have further motivated an investigation of the microbial communities.

**2.3** To date, we have achieved an overview of microbial composition as a function of sampling depth and begun the process of genome recovery. Preliminary soil samples have been collected for whole genome resolved metagenomics. We are also investigating carbon storage in the vadose zone. Preliminary results indicate that there is both more labile carbon and recalcitrant carbon in the Douglas fir tree rhizosphere, area directly influence by roots, when compared to vadose zone material not associated with roots. This work will work toward finding mechanistic links between tree physiology, subsurface microbial communities, and nutrient cycling on a seasonal and daily level.

**3.1** Drainage density (length of wetted channel divided by total drainage area) was identical for Fox and Elder in the May/June survey (1.95 versus 1.92 km/km2, respectively) and August (1.45 versus 1.43 km/km2). Stream discharge greatly declined but the extent of wetted channels, pinned to distinct spring origins varied much less. The drainage density decline, however, was much higher on the south facing drainages, pointing, possibly to the greater evapotranspiration loss.

**4.1** We found that streamside pulsed-amplitude modulated fluorometry can be used for quick performance measures (photosynthesis-irradiance curves) of algal assemblages in river microhabitats. This paves the way for expanded common garden and transplant experiments to examine performances of edible, structural, and potentially toxic algal and cyanobacterial taxa under different temperature, solar radiation, flow, and nutrient regimes to better delimit the fundamental niches of key algae and cyanobacteria. This in turn will help us predict links between sub-basin critical zone storage, transformation, and release will interact with seasonal climate to determine whether algae at the base of Eel food web will support predators like salmon, or proliferate as harmful blooms.

**4.2** In collaboration with Mike Miller at University of California, Davis, analysis of preliminary genetic data has confirmed the presence of both migratory (steelhead) and resident (rainbow) trout in both Elder Creek and Fox Creek and longitudinal zonation. This provides an opportunity to explore how the timing of winter high flows influences distribution of migratory fish within tributary breeding streams, and the vulnerability of these life history strategies to environmental change.

**5.1** We have developed a new parameterization of hydraulic conductivity that includes a stochastic representation of preferential flow through weathered bedrock. The parameterization has been applied to the other wells at the Angelo Coast Range Reserve and can capture the high-frequency fluctuations of the water table seen in the data. Also the amount of rock moisture in the model is comparable to that measured using a neutron probe.

## d. Key outcomes or other achievements:

The role of "rock moisture" in the critical zone has emerged as a central discovery in the Eel River Critical Zone. We propose that the term "rock moisture" refers to moisture, like that found in soil, that is accessible to plants and can vertically drain (as unsaturated flow) and recharge groundwater. In seasonally dry environment, discharge of groundwater from hillslopes sustains summer base flow in streams. Hence, rock moisture has a dual ecological function: supporting vegetation or sustaining low flow in streams. Significant dynamic storage of rock moisture is a consequence of development of the critical zone, where weathering of bedrock creates fractures and porosity. In essence, the weathering makes otherwise poorly-conductive bedrock into a dynamic hydrologic reservoir and draws the hydrologic response deep inside hillslopes.

We have shown at our intensive monitoring site in the ER CZO (Rivendell) that a well-defined bottom of the critical zone (the elevation of the fresh bedrock (Zb)) systematically rises from the channel to the divide. The hillslope surface steepens more quickly and consequently the thickness of the critical zone beneath the surface thickens towards the divide. The Zb profile and weathering zone thickness can be predicted from a simple analytical theory (Rempe and Dietrich, PNAS, 2014). This past summer shallow seismic refraction surveys showed similar upslope thickening weathering profiles at three other hillslopes nearby. The Zb surface marks a transition to bedrock of low permeability where a seasonally perched groundwater table develops. In essence, then, all runoff at Rivendell passes through an upslope thickening vadose zone, then recharges a perched groundwater table which drains laterally to the channel controlling stream runoff. This vadose zone is the region of significant rock moisture dynamics.

Repeat neutron probe measurements down 7 wells at the Rivendell site demonstrate dynamic rock moisture in response to rain storms and seasonal drainage to depths of up to 25m. Early in the wet season in our mediterranean climate, over 80% of the total rainfall may become stored as rock moisture in just the first 4 m into the weathered bedrock. For example an individual rainstorm 220 mm increased rock moisture by 186 mm. After rock moisture increase of about 200 to 400 mm, further rainstorms cause significant rise in the groundwater table and rock moisture does not increase significantly. As the dry season progresses in late spring and into the summer and fall, rock moisture stays elevated farther into the dry season than soil moisture. Rock moisture actually increases as soil and saprolite (here the first two meters of weathered bedrock) moisture decrease. The thickening weathered bedrock zone towards the divide causes delays in arrival and storage of rock moisture to greater depth.

In the drought of 2014 we received 1000 m of rain (about ½ of normal), nonetheless, on average 300 mm of that seasonal rainfall was in storage as rock moisture at the beginning of the dry season. By the end of summer this moisture storage was gone: the water was either transpired back to the atmosphere by trees and drained to groundwater, providing critical water during summer low flow to salmon supporting streams. (The rock moisture observations are from the dissertation research by Daniella Rempe)

Rock moisture plays several roles in the critical zone. Extensive monitoring of stable isotopes in soil and rock moisture and of tree xylem now shows that the evergreen broad leaf trees (primarily oaks and madrone) primarily use soil moisture all year long, but on the hot south facing slopes trees may take rock moisture. In contrast, deuterium isotope data and direct experiments with tracers indicate that the Douglas firs (needle tree) rely on rock moisture. No trees use groundwater. This finding is important to understanding how lithology may control (through rock moisture availability) dominant tree type. Rock moisture can be significant in a drought and thus support trees (Douglas fir) even as stream flow greatly decreases. Rock moisture may become an important resource for vegetation competition for water in a warming climate. (Oshun et al., submitted; dissertation work of Jasper Oshun)

Douglas fir significantly reduces rock moisture use in the summer when madrone soil moisture use peaks. We find in a regional climate model that a shift from a madrone dominated California Coast Range to a Douglas Fir could therefore locally increase air temperatures by 2 degree C. This illustrates the importance of species-specific transpiration and the possible role of rock moisture as a source of water and influence on dominant tree type. (Link et al., 2014, Water Resources Research and Dissertation by Link, 2015).

Rock moisture in weathered fractured bedrock is not treated in climate models, so our group has developed a model (with intended generality for climate models) that predicts how fractures influence precipitation delivery to the groundwater table and dynamics of rock moisture.

Rock moisture dynamics also influence subsurface gas release, as we have documented large shifts in $O_2$ and $CO_2$ in response to rainfall events. Water potential is known to strongly influence microbial composition and activity, and rock water potential will vary with moisture levels. We are now exploring the use of tree pyschrometers to reveal the potential in the vicinity of their roots in the rock moisture zone. Rock moisture dynamics is likely a critical driver of the poorly understood microbial community in the weathered bedrock.

Early winter rains enter into the weathered bedrock where they contribute to rock moisture gain. Successive storms of differing stable isotope signatures enter and mix with previous rock moisture. This mixing damps the isotopic signature of individual storms. Once sufficient water has arrived, water passes to the groundwater (likely along fractures) but the isotopic signature is nearly constant, such that the stable isotope signature of the recharged groundwater is nearly invariant. This suggests that in seasonally dry environments in landscapes, transient rock moisture storage may essentially erase stable isotopes signals.

We also have found that this arriving water is distinctly lower in many major elements compared to that in the groundwater during the low flows of the summer. This lower element concentration is likely controlled by relatively rapid carbonic acid driven cation exchange processes in the rock moisture. These observations then link rock moisture dynamics to solute chemistry and ultimately to the concentration-discharge relationship in streams. (Kim et al., 2014 and Kim (2014) dissertation)

Collectively these observations tell us the rock moisture is a key component of the critical zone, influencing many of its processes. It is essential to understanding how vegetation, water resources, and regional climate with co-evolve. We need to be able to predict seasonal storage of rock moisture across landscapes to answer questions about how watersheds- the water they convey and the ecosystems they support- will respond to extensive periods of drought. Such a model will require that we can predict the spatial pattern of the thickness of the critical zone and how seasonal moisture storage occurs. Rock moisture dynamics influence the microbial community, which in turn influences gas return to the atmosphere. Furthermore, rock moisture dynamics influence seasonal variation in stream chemistry.

We are now expanding our fieldwork to a radically different bedrock (though geochemically very similar) to see how lithology (in this case mélange) influences rock moisture dynamics and all its consequences for critical zone processes.

## 3. What opportunities for training and professional development has the project provided for funded personnel?

A key attribute of the ER CZO is that post-docs, graduate students and undergraduate typically work with several of our PIs whose expertise range across atmospheric science, tree physiology, geomorphology, microbial ecology, geobiology, hydrology, stream ecology and geochemistry. Geologists and atmospheric scientists work on where trees get their water, microbial ecologists study hydrologic processes and geochemistry, and stream ecologists explore the geomorphic processes that control fish distribution and foodwebs. Students freely interact across four departments, four deans and three colleges. This training will create "critical zone scientists".

During monthly meetings attended by all ER CZO participants, both undergraduate and graduate students present their research and debate findings. These presentations fine tune their speaking skills and sharpen their research efforts. We discuss research findings, future plans and ways to connect the pieces of the critical zone. We support graduate students to attend meetings (including the many CZO workshops planned this summer and fall) and work closely with them to prepare them for presentations and to advise them on manuscript preparation. (See Products section for abstract). In turn, the most of the CZO graduate students have worked with multiple undergraduates, both in the field and in the laboratory.

The graduate students are forming a group identity and have begun sharing technology and field skills. One student recently organized a field training session for other graduate students in gauging steep shallow streams so that all the students working in the field can contribute to developing rating curves for our various stream-side water level recorders. The PIs also spend considerable time in the field with graduate students, training them in field methods and developing measurement procedures, and in the laboratory to teach analytical and modeling methods.

The ER CZO is also used for courses. For example, in the Earth and Planetary Science course, Introduction to Aquatic and Marine Geochemistry, taught by Co-I Jim Bishop, undergraduates are taught to collect water and gas samples and use the data they obtain to explore critical zone processes. In June 2015, a graduate student will co-host with Co-I Mary Power the biennial, 2015 Algal Foray at the Angelo Coast Range Reserve (where Rivendell is located) along the Eel River. Some 26 students, nearly all citizen scientist, will participate.

## 4. How have the results been disseminated to communities of interest?

Our CZOMP lists our strategy for engagement with other CZOs – which focused on common questions and measurements and cross-site research.  We proposed that several strategies to engage the larger community including publishing papers, presenting findings at meetings, sharing data, and welcoming participation by groups not affiliated with the CZO network.

In the Products section we list our publications and conference papers, which show the diversity of meetings attended, included American Geophysical Union, American Fisheries Society, Ecological Society of America, CUASHI Biannual Symposium, Math and Climate Network, Lectures in Microbiology,  and Geochemistry the Earth's Surface.

Engagement by the research community is growing.  We have developed collaborations with University of California, Davis (Houlton) on nitrogen in bedrock, Penn State (Brantley) on microporsity in the weathering zone, Wyoming (Holbrook) on structure of the critical zone, Northwestern/UC Riverside (Packman/ Aronson) on microbiology, Wuhan University (Dedi Liu) on hydrologic modeling, Wright State (Vadeboncoeur) on toxic algae blooms, and UC Berkeley Visiting Scholar Kupferberg on amphibian conservation.  We anticipate starting collaboration with Stanford (Maher) on reactive transport modeling soon.

A NSF supported post-doc, Jill Marshall starts soon and will across three CZOs: Southern Sierra, Boulder and the ER CZO.

## 5. Goals during next reporting period

As specified in the CZO reporting guidelines our goals are presented as a graphical timeline.

| | 2015 | | | | | | 2016 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | June | July | Aug | Sept | Nov | Dec | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept |
| **Question 1** | | | | | | | | | | | | | | | |
| **Continue** automated monitoring system at Rivendell | | | | | | | | | | | | | | | |
| **Continue** monitoring of rock moisture dynamics by performing repeat neutron probe surveys in deep wells at the Rivendell field | | | | | | | | | | | | | | | |
| **Collect** samples for stable isotope measurements for identifying the role of ectomychorizae on tree water use in rock | | | | | | | | | | | | | | | |
| **Continue** do to collect and analyze sap flow and tree psychrometer data on North and South Rivendell | | | | | | | | | | | | | | | |
| **Install** Vadose Zone Monitoring System at Rivendell field site | | | | | | | | | | | | | | | |
| **Comparative** analysis of LiDAR data for Angelo and Russell Ranch | | | | | | | | | | | | | | | |
| **Develop** monitoring network on melange study site (the Shire) | | | | | | | | | | | | | | | |
| **Create** a geospatial database of geological, biogeochemistry and hyrdaulic conductivity for Angelo and melange site (the Shire) | | | | | | | | | | | | | | | |
| **Question 2** | | | | | | | | | | | | | | | |
| **Document** the phylogenetic and functional profile of vadose zone microbial communities | | | | | | | | | | | | | | | |
| **Document** the phylogenetic and functional profile of the Douglas fir rhizosphere | | | | | | | | | | | | | | | |
| **Investigate** seasonal changes in microbial populations and influence on atmospherically reactive trace gasses | | | | | | | | | | | | | | | |
| **Analyze** chemistry of rainwater and of groundwater samples and streamflow collected by ISCO samplers at Rivendell | | | | | | | | | | | | | | | |
| **Monitor** CO2 and O2 profiles in wells Rivendell | | | | | | | | | | | | | | | |
| **Question 3** | | | | | | | | | | | | | | | |
| **Conduct** two wetted channel surveys (May and August 2015) in two watersheds on melange landscape (the Shire) | | | | | | | | | | | | | | | |
| **Establish** a rating curves multiple channels in Eel River CZO | | | | | | | | | | | | | | | |
| **Continue** streamflow recession analyses | | | | | | | | | | | | | | | |
| **Question 4** | | | | | | | | | | | | | | | |
| **Conduct** experiments to investigate the effects of nutrients, light, and temperature on the growth of cyanobacterial mats | | | | | | | | | | | | | | | |
| **Collect** cyanobacterial samples for genetic analysis to understand the dispersal patterns of cyanobacterial mats | | | | | | | | | | | | | | | |
| **Continue** to track fish using stationary antennae | | | | | | | | | | | | | | | |
| **Conduct** fish surveys and classify abundance by pool | | | | | | | | | | | | | | | |
| **Compile** synoptic food web surveys linked to environmental regimes of temperature, light, and flow regimes | | | | | | | | | | | | | | | |
| **Explore** spatial and temporal variation in temperature with flow in confluences and pools | | | | | | | | | | | | | | | |
| **AWESOM Model** | | | | | | | | | | | | | | | |
| **Continue** hillslope hydrologic model refinement, including root-rock interactions and lateral flow | | | | | | | | | | | | | | | |
| **Advance** theory for diurnal stream flow oscillations | | | | | | | | | | | | | | | |

## B. Products

1. Publications

PUBLISHED

Bode, C. A., Limm, M. P., Power, M. E., & Finlay, J. C. (2014). Subcanopy solar radiation model: predicting solar radiation across a heavily vegetated landscape using LiDAR and GIS solar radiation models. *Remote Sensing of Environment*, *154*, 387–397.

Dralle, D. N., Boisramé, G., & Thompson, S. E. (2014). Spatially variable water table recharge and the hillslope hydrologic response: Analytical solutions to the linearized hillslope Boussinesq equation. *Water Resources Research*, *50*(11), 8515–8530.

Kim, H., Bishop, J. K. B., Dietrich, W. E., & Fung, I. Y. (2014). Process dominance shift in solute chemistry as revealed by long-term high-frequency water chemistry observations of groundwater flowing through weathered argillite underlying a steep forested hillslope. *Geochimica et Cosmochimica Acta*, *140*, 1–19. http://doi.org/10.1016/j.gca.2014.05.011

Müller, M. F., Dralle, D. N., & Thompson, S. E. (2014). Analytical model for flow duration curves in seasonally dry climates. *Water Resources Research*, *50*(7), 5510–5531. http://doi.org/10.1002/2014WR015301

Poinar, G., Walder, L., & Uno, H. (2015). *Anomalomermis ephemerophagis* n. g., n. sp. (Nematoda: Mermithidae) parasitic in the mayfly *Ephemerella maculata* Traver (Ephermeroptera: Ephermerellidae) in California, USA. *Systematic Parasitology*, *90*(3), 231–236. http://doi.org/10.1007/s11230-015-9551-6

Power, M. E., Bouma-Gregson, K., Higgins, P., & Carlson, S. M. (2015). The Thirsty Eel: Summer and Winter Flow Thresholds that Tilt the Eel River of Northwestern California from Salmon-Supporting to Cyanobacterially Degraded States. *Copeia*, *2015*(1), 200–211.

Schubel, J. R., Conrad, C. C., Debinski, D., Kareiva, P. M., Matsumoto, G. I., McKnight, D. M., Parmesan, C., Plowes, R., Power, A.G., Power, M.E., Stromberg. M.R. 2014. Enhancing the Value and Sustainability of Field Stations and Marine Laboratories in the 21st Century. National Research Council of the National Academies of Science, 1–84.

Vico, G., Thompson, S. E., Manzoni, S., Molini, A., Albertson, J. D., Almeida-Cortez, J. S., … Porporato, A. (2014). Climatic, ecophysiological, and phenological controls on plant ecohydrological strategies in seasonally dry ecosystems. *Ecohydrology*. http://doi.org/10.1002/eco.1533

IN PRESS

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Passalacqua, P., Belmont, P., Staleyc, D. , Simleyc, J., Arrowsmith, J.R., Bode, C., Crosby, C., DeLong, S., Glenn, N., Kelly, S., Lague, D., Sangireddya, H., Schaffrath, K., Tarboton, D., Wasklewicz, T., Wheaton, J (*in press*). Analyzing high resolution topography for advancing the understanding of mass and energy transfer through landscapes: A review. *Earth Science Reviews*.

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SUBMITTED

Riebe, C., Hahm, W., & Brantley, S. (*Submitted*). Going deep to quantify limits on weathering in the Critical Zone. *Earth Surface Processes and Landforms*.

Oshun, J., Dietrich, W. E., Dawson, T. E., & Fung, I. (*Submitted*). Dynamic, structured heterogeneity of water isotopes inside hillslopes. *Water Resources Research*.

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## 2. Technologies or Techniques

Nothing to report.

## 3. Inventions, Patent Applications, and Licenses

Nothing to report.

## 4. Websites

Nothing to report

## 5. Other Products

Nothing to report

# C. Participants

## 1. Individual Participants

See attached list for full details

| First name | Last name | Email address | Role |
|---|---|---|---|
| William | Dietrich | bill@eps.berkeley.edu | PI |
| Mary | Power | mepower@berkeley.edu | Co-I |
| Stephanie | Carlson | smcarlson@berkeley.edu | Co-I |
| Sally | Thompson | sally.thompson@berkeley.edu | Co-I |
| Jim | Bishop | jkbishop@berkeley.edu | Co-I |
| Jill | Banfield | jbanfield@berkeley.edu | Faculty |
| Todd | Dawson | tdawson@berkeley.edu | Faculty |
| Mary | Firestone | mkfstone@berkeley.edu | Faculty |
| Inez | Fung | ifung@berkeley.edu | Faculty |
| Hiromi | Uno | hiromiuno1@berkeley.edu | Graduate Student |
| Philip | Georgakakos | pgeorgakakos@berkeley.edu | Graduate Student |
| Keith | Bouma-Gregson | kbg@berkeley.edu | Graduate Student |
| W. Jesse | Hahm | wjhahm@berkeley.edu | Graduate Student |
| Ilana | Stein | istein@berekeley.edu | Graduate Student |
| Claire | Willing | cwilling@berkeley.edu | Graduate Student |
| George | Greer | georgegreer@berkeley.edu | Graduate Student |
| David | Dralle | daviddralle@gmail.com | Graduate Student |
| Suzanne | Kelson | skelson@berkeley.edu | Graduate Student |
| Hyojin | Kim | hyojin820@berkeley.edu | Graduate Student |
| Percy | Link | plink@berkeley.edu | Graduate Student |
| Sky | Lovill | skylovill@berkeley.edu | Graduate Student |
| Jasper | Oshun | matazzter@gmail.com | Graduate Student |
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| Evan | Starr | evan.starr@berkeley.edu | Graduate Student |
| Ben | Thurnhoffer | bthurn@berkeley.edu | Graduate Student |
| Jennifer | Hunter | jshunter@berkeley.edu | Other Professional |
| Virginia | Ogle | ginger@berkeley.edu | Other Professional |
| Susan | Spaulding | suespaulding@gmail.com | Other Professional |
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| Itai | Sharon | itaish@berkeley.edu | Postdoctoral |
| Michail | Vrettas | m.vrettas@berkeley.edu | Postdoctoral |
| Athena | Nghiem | anghiem@berkeley.edu | REU Participant |
| Sara | Beroff | sara.beroff@berkeley.edu | REU Participant |
| Cody | Schaaf | codyschaaf@berkeley.edu | REU Participant |
| Shelley | Pneh | shelleypneh@berkeley.edu | REU Participant |

| | | | |
|---|---|---|---|
| Collin | Bode | collin@berkeley.edu | Technician |
| Chris | Wong | cwong88@berkeley.edu | Technician |
| Todd | Wood | tjwood@lbl.gov | Technician |
| Tom | Ogasawara | tom.ogasawara@gmail.com | Technician |
| Yizhuang | Liu | liuyizhuang@berkeley.edu | Undergraduate Student |
| Meghna | Rajendran | meghnar@berkeley.edu | Undergraduate Student |
| Arianna | Tabibzdeh-Nuri | arianna.nuri@berkeley.edu | Undergraduate Student |
| Jeanine | Porzio | jporzio@berkeley.edu | Undergraduate Student |
| Natalie | Soto | nds01@berkeley.edu | Undergraduate Student |
| Katie | Kobayashi | kt.kobay@gmail.com | Undergraduate Student |
| Betty | Huang | bettyhuang@berkeley.edu | Undergraduate Student |
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| Alondra | Prado | alondrabprado@berkeley.edu | Undergraduate Student |
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| Shawn | Lee | shawnlee@berkeley.edu | Undergraduate Student |
| Matt | Grisanu | Matt.grisanu@gmail.com | Undergraduate Student |
| Brenda | Luna | bluna@berkeley.edu | Undergraduate Student |

### 2. Partner Organizations

See attached list

### 3. Other Collaborators

None

## D. Impacts

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

The critical zone is a "thing" and, as such, a kind of critical zone science discipline can and should emerge. By practice the network of US critical zones is showing the necessity and fruitful consequence of scientists working across traditionally distinct disciplines: geology, atmospheric science, ecology, tree physiology, microbiology and so on. At Berkeley this is expressed not only in the diversity of fields the 9 PIs represent, but in the fact that students freely work across disciplines, departments and colleges to gain deep insight into integrated critical zone processes. Strong expertise in existing disciplines is still essential, but now such expertise can spread and gain new perspectives in a critical zone context. A new discipline appears to be emerging.

## 2. What is the impact on other disciplines?

Berkeley PIs are giving talks at the annual meetings in their disciplines and in invited lectures at universities where they are illustrating how the critical zone matters now to their disciplines. This will help attract others into the intriguing science of the critical zone.

## 3. What is the impact on the development of human resources?

During the past year we have partially or wholly supported 16 graduate students and 17 undergraduate students. Working through the ER CZO has provided these students with invaluable experience in the practical aspects of designing and conducting research projects as well as access to the broad experiences and perspectives of our PIs and senior personnel.

Several graduate students have attained professional positions related to their work at the ER CZO. Hyojin Kim began a post-doctoral appointment at Penn State University and is now working at the Shale Hills Critical Zone Observatory. Jasper Oshun will become an assistant professor in Geomorphology at Humboldt State University (Arcata, CA) in August, 2015. Percy Link is working in a consulting firm. Daniella Rempe has accepted an assistant professor position at the University of Texas, Austin, which she will begin in Fall 2016. An undergraduate, Sara Beroff, recently began a position as a post-baccalaureate researcher studying geochemistry at the Los Alamos National Laboratory.

## 4. What is the impact on physical resources that form infrastructure?

Sagehorn-Russell Ranch (location of the Shire intensive monitoring site)

Since late 2014 director William Dietrich and Co-I Mary Power have been negotiating with several landowners near Angelo to gain access to property with mélange rock type to allow for comparative investigations by ER CZO researchers. Dietrich and Power have made an agreement with land owner Marilyn Russell, with a 5,000 acre parcel of mélange, with a line of site to ER CZO network tower on nearby Cahto Peak (Mendocino County, CA). In May, 2015 a weather station was installed at the site for recording meteorological data (air temperature, relative humidity, wind speed and direction, precipitation, total solar radiation and photosynthetically active radiation, and leaf moisture). The weather station will also serve as the point of wireless uplink for all future instrumentation to be placed at the site. There are plans to install water level and temperature recorders in early summer 2015. These instruments will be configured to be uploaded to the wireless CZO network and near real-time data will be available in fall 2015.

Vadose Zone Monitoring System

In February 2015 we were awarded supplemental funding from NSF (supplemental funding action 1450522) to purchase and install a Vadose zone Monitoring System (VMS; Sensoil, Ltd) at our Rivendell site. The VMS is composed of sleeves (fabricated from thin polyurethane liners) that host multiple monitoring units that are designed to enable continuous measurements of moisture and allow water and gas sampling at regular intervals from land surface to the water table. This equipment is currently being built and will be permanently installed at our field site in August 2015 and will allow us to sample a 1m interval to 10 m below the surface close to the water table in winter.

## 5. What is the impact on institutional resources that form infrastructure?

During the 2014-2015 funding period further refinement was made to the ER CZO sensor database to increase ease of use and to update system components. These changes included developing an automated incident report system; data for multiple data streams is now automatically flagged when a researcher submits notification of data collection or instrument modification that may result in abnormal data outputs. New derived data streams were created for three weather stations, incorporating unit conversions and reporting pages for past years were modified to reflect new data streams. ER CZO database administrator Virginia Ogle worked with staff at the Berkeley Natural History Museums (BNHM) to implement and troubleshoot changes in database connections, IP address resolution, networking, backups, and upgrades to hardware associated with moving BNHM data to the server used by ER CZO. These modifications will serve to increase the usability and accessibility of ER CZO data to all current and future users.

The primary field site for the ER CZO is the Heath and Marjorie Angelo Coast Range Reserve (Angelo). Angelo is one of 39 protected natural areas managed by the University of California Natural Reserve System (UCNRS). These areas are maintained by University for the purposes of research, education and public service. Various monitoring apparatuses exist and many of these sites and the UCNRS as recently committed to making near real-time biological, hydrological and meteorological data available to the broader research community. The UCNRS is providing salary support to ER CZO personnel Chris Wong (field technician) and Virginia Ogle (database administrator) to establish and maintain a network of weather stations and to create a database structure to enable access to various data streams generated at the UC reserves. This effort is being modelled after the ER CZO's sensor database, which Virginia Ogle created and will continue to be supported by UCNRS beyond the lifetime of the ER CZO award.

## 6. What is the impact on information resources that form infrastructure?

Nothing to report.

## 7. What is the impact on technology transfer?

Nothing to report.

## 8. What is the impact on society beyond science and technology?

ER CZO researchers, anchored by Co-I Mary Power, have participated in many outreach efforts. In addition to various speaking engagements and meetings (some listed below) we have been involved in several long-term collaborative partnerships, some of which are ongoing. ER CZO has strong interactions with the very active citizen's river watch group, the Eel River Recovery Project (ERRP). We coordinate and share temperature and algal monitoring efforts. CZO researchers regularly attend and speak at ERRP watershed meetings.

We have also worked closely with the California Department of Forestry and Fire Protection (Cal Fire). Prior to the 2014 fire season, Mary Power and Angelo reserve manager Peter Steel initiated an Angelo fire management plan with Laytonville Battalion Chief Tony Howard. In late July-August 2014, the Lodge Fire burned 12,536 acres north of, then into, the Angelo reserve. Peter Steel, Mary Power, and William Dietrich remained on site, in communication with Cal Fire crews. The Cal Fire crews said that NCALM generated LiDAR maps of Angelo and nearby wilderness areas, freely available through Open Topography, would save property, forests, and lives.

The California Academy of Sciences reached out to ER CZO researchers Todd Dawson, William Dietrich and Mary Power seeking advice for a team of scientific film makers. "Habitat Earth," directed by Tom Kennedy, is a 3D film that portrays human, ecological and hydrologic networks: food webs and hydrologic fluxes linking cities, oceans, forests, soils, trees, and the near boundary atmosphere. Much of this 3D planetarium show was filmed at the Angelo Reserve, where Mary Power and Peter Steel hosted the film makers. It has been continuously showing at the California Academy Morrison Planetarium through spring 2015.

NSF sponsored post-doctoral fellow, Jill Marshall and Mary Power have been organizing exchanges between ER CZO scientists and Round Valley High School, which serves largely native students and is located in Covelo, CA. We are also in touch and hoping to collaborate with Chuck Striplen of the San Francisco Estuarine Institute, who is working with the Round Valley tribes on historical ecological studies of the upper mainstem Eel within their ancestral lands.

Four CZO researchers (Sally Thompson, Stephanie Carlson, Mary Power, and David Dralle) collaborated with Nature Conservancy, the California Dept. Fish and Wildlife, and NGO researchers to investigate ecological impacts of marijuana cultivation in Eel watershed and other sites in Northern California. A paper from this work is in press in BioScience.

Graduate student Daniella Rempe regularly participates in a 'science in the classroom' program through the Math, Science and Engineering Resource Support (MASERS), Bay Area Scientists in Schools (BASIS), and Community Resources for Science (CRS) programs. She works with several other earth scientists to introduce the concept of the critical zone and the basics of her research (ER CZO Task 1). She also helps with a hands-on mountain building activity that exposes middle-school students in low income areas to the fundamentals of tectonics, climate, and hydrology.

In addition to the efforts detailed above, ER CZO personnel have spoken or attended meetings with various community organizations and have used these opportunities to discuss the research objectives and outcomes of the ER CZO.

**October 4, 2014:** William Dietrich joined Tony Howard (Cal Fire) and several other spokespersons from Cal Fire and the Bureau of Land Managment to give talks at a Public Meeting in Laytonville, CA organized by ERRP, focused on post fire discussion and resources available for controlling erosion and improving forest health. Dietrich also posted LiDAR maps and explained how to access them to agency personnel.

**October 9, 2014:** Mary Power attended a dinner and meeting of Karuk-Berkeley Consortium, with tribal leader Ron Reed, who was speaking at the Berkeley Law School.

**October 29, 2014:** Mary Power and Keith Bouma-Gregson met with Karuk staff biologist Susan Corum, to discuss algal toxin sampling in the Klamath River. Susan will attend the 2015 Eel River Algal Foray to learn algal identification.

**December 2, 2014:** Mary Power attended Redwood Forest Foundation Inc. (RFFI) lunch and workshop on the future of community based forestry (Leggett, CA).

**February 27, 2015**: Mary Power appeared on the radio program "Coastal Conversations," hosted by Jerry Schubel, Director of the Long Beach Aquarium to discuss ER CZO efforts in the Eel River watershed.

**March 21, 2015:** Earth Water and Fire Day (Garberville CA): Talks by CZO grad student Keith Bouma-Gregson on Eel River Algae (of concern due to toxic blooms exacerbated by drought and water withdrawals), and by ER CZO affiliate researcher Sarah Kupferberg on Monitoring Eel River Amphibians and Reptiles (some threatened by low flows).

**April 16, 2015:** Mary Power was Humboldt State University's (Arcata, CA) Michael Scott Distinguished Lecture Speaker. She presented a technical seminar on River-watershed-coastal ocean linkages mediated by algal-based food webs and a public presentation on Drought, floods, and alternate states in algal-based river food webs: The Thirsty Eel.

**April 16, 2015:** Inez Fung spoke on "Plants, Water and Climate" at the Mills College (Oakland, CA) Women in Science Lecture Series.

**April 18, 2015:** CalDay (Berkeley, CA). ER-CZO personnel Chris Wong, Mary Power, Stephanie Carlson, Philip Georgakakos entertained several hundred public visitors who came by the ERCZO/Angelo table at CalDay, when Berkeley welcomes parents, alums, and the general public to view research and teaching. The ER CZO/Angelo display featured a 3D visualization of Angelo Reserve in LiDAR that people could fly around to look at the trees vs bare-earth LiDAR images of the reserve, posters explaining the research ongoing at particular sites, and a looping movie showing the scenes from the Cal Academy 'Habitat Earth' Morrison Planetarium show featuring the Angelo Reserve and CZO inspired research depictions.

**May 6, 2015**: Researchers from the University of California Cooperative Extension conducted a fire tour at the Angelo Reserve (Branscomb, CA), attended by ER CZO Co-I Mary Power. Participants included agency, tribal, NGO, and citizen scientists concerned with fire management and post-fire restoration.

**June 1, 2015:** Mary Power was featured on KMUD (Redwood Community Radio; Humbolt County, CA) Monday Morning Magazine and spoke about the ER CZO.

## E. Changes/Problems

1. Changes in approach and reasons for change
   N/A
2. Actual or anticipated problems or delays and actions or plans to resolve them
   N/A
3. Changes that have significant impact on expenditures
   N/A
4. Changes in use or care of human subjects
   N/A
5. Changes in use or care of vertebrate animals
   N/A
6. Changes in use or care of biohazards
   N/A

# F. Special Reporting Requirements

## Metrics

| Five milestones and their metric of progress (in color) | Anticipated (2015) | Status |
|---|---|---|
| Milestone 1. Does lithology control rock moisture availability to plants and therefore overall resilience of vegetation to climate change in seasonally dry environments? | | |
| 1.1 Compare relative water potential gradients and plant water use on north vs. south facing slopes on mudstones at the Rivendell site. | Compare data on continuous psychrometer and sap flow measurements | First set of comparison data collected Rivendell, set up at the Shire |
| 1.2 Compare observations on mudstones with similar data collected on mélange (the Shire). | Further sampling of vegetation, soil and weathered bedrock for stable isotopes on both mudstone and mélange. | Begun in May 2015 |
| 1.3 Model moisture storage and transport, evapotranspiration, and other energy balance components for hillslopes under different aspects, lithology, and vegetation. | Continue development of several models | elements of model developed |
| Milestone 2: How are solute and gas effluents from hillslopes influenced by biota in changing moisture regimes? | | |
| 2.1 Examine the mobilization, transport and delivery of chemical species from subsurface waters to Elder Creek and then further downstream. | Continue automated sampling to track seasonal and storm dynamics and effects of drought | Ongoing |
| 2.2 Determine temporal dynamics and biotic origin of high $CO_2$ and other atmospherically reactive gases within the critical zone. | Expand this effort to include other gasses and explore controls on diurnal signal | $O_2$ added, diurnal variations in both $O_2$ and $CO_2$ detected. |
| 2.3 Characterize the microbial community over time and with depth into the Critical Zone. | Obtain samples through cores and possibly a trench of samples to characterize the community | Ongoing, early stages of sample analysis |
| Milestone 3: What controls the spatial extent of wetted channels in the channel networks of seasonally dry environments? | | |
| 3.1 Map the extent of wetted channels during summer low flow for varying lithology, topography and precipitation. | Move to two watersheds outside the Angelo Reserve and repeat the mapping survey | One survey of two watersheds in mélange site completed |
| 3.2 Establish a network of runoff and stream temperature monitoring and use that to motivate and test models of water transport and in-stream energy balance. | Improve network recording and calibration | Network being built |
| 3.3 Characterize drawdown, flow and temperature oscillations in Russian River using the existing flow gauge network. | Begin the analysis | Developing analytical framework |
| 3.4 Develop and test models of stream network contraction during summer low flow. | Continue model development | Initiated collaboration to develop appropriate model |
| Milestone 4: Will changes in critical zone currencies induced by climate or land use change lead to threshold-type switches in river and coastal ecosystems? | | |
| 4.1 Compare algae and cyanobacteria production at three main-stem South Fork Eel reaches that experience different radiation and flow regimes. | Continue seasonal mapping and monitoring for evidence of controls | done |
| 4.2 Monitor salmonid performance in two tributaries of the South Fork Eel. | Explore controls on steelhead versus rainbow trout performance | done |
| 4.3 Develop coupled biological-physical models for the study reaches. | Initiate this modeling effort | Physical model started |
| Milestone 5: Synthesis Modeling (the Atmospheric, Watershed, Ecology, Stream, and Ocean Model) | | |

| | | | |
|---|---|---|---|
| | 5.1 Assemble pre-existing model components. | Expand this effort to include progress in 5.2 and 5.3 | Progress in 5.2, need field data for 5.3 |
| | 5.2 Develop and test models for hillslope scale groundwater recharge and discharge incorporating the effects of preferential fracture flow. | Advance the stochastic model with further testing | Manuscripts under preparation |
| | 5.3 Develop and test model for species- and lithology-specific water uptake from the critical zone. | Continue model develop obtain more data on mélange | Anticipate obtaining data from the mélange starting this Fall |
| | 5.4 Develop and test models of the diurnal oscillations in flow and stream temperature for entire stream network. | Perform testing with models using our network of data | Analysis is underway |
| | 5.5 Project from AWESOM the effects of climate and land use change on future critical zone currencies. | This will become a major goal in the next year | Still expect progress on this next year |

## CZO Network Activities

1. Participation in CZO network meetings. ER CZO PIs and graduate students are participating in and or helping to organize the five schedule workshops:

    a) June 14-18: Deep Critical Zone Structure: assemble data sets on of the deep critical zone and discuss process and theory ( Boulder CZO host). Graduate student Daniella Rempe is co-organizer of this meeting. PI Dietrich will attend and contribute discussion of two field sites with extensive data.

    b) July 20 -22: Concentration- discharge (Jemez/Catlina host). Recent PhD Hyojin Kim (now at Shale Hills, whose PhD explored the mechanisms controlling the concentration-discharge relationships in Elder Creek will represent the ER CZO.

    c) September 9-11: Trees in the Critical zone (Shale Hills host) Co-I Dawson will attend

    d) September: Biogeochemistry (Emma Aronson, UC Riverside) CoI Firestone will attend

    e) November 16-18: Microbial Ecology (Argonne host) Firestone will attend

We participated in the Southern Sierra all hands meeting in September 2014 and attending the IML PI meeting in May 2015. We anticipate contributing to a cross-CZO modeling workshop and Research Coordination Network.

2. Cross-site collaborations:

    a) Shale Hills- (Brantley) neutron scattering to measure porosity changes due to weathering of shale bearing turbidites. First set of samples have been sent for analysis from Rivendell

    b) Jill Marshall will start in July as a post-doc working across Boulder, Southern Sierra and Eel River CZOs. She intends to parameterize and calibrate a soil production function for forested landscapes based on observations of the mechanics of root-driven bedrock damage and detachment, using observations at each of the CZOs.

    c) Hyojin Kim completed her PhD with research at the ER CZO and is now doing comparison work at the Shales Hill CZO.

    d) Jesse Hahm completed his M.S. field project at the Southern Sierra CZO (published a paper in PNAS on his findings and led a field discussion is site during the 2014 all hands meeting) and now is a PhD student at Berkeley focused on understanding the critical zone architecture and processes on the mélange.

3. Common Questions

PI Dietrich developed the common questions document and collaborated with Chorover (Catalina/Jemez) and White (National Office) to integrate common questions and measurements.

4. International CZO

At the request of NSF, PI Dietrich presented an overview of the Critical Zone Observatories at the Frontiers in International Critical Zone Science international workshop held in Beijing May 21-23, 2014. This is the start of building an international network of CZOs. After the meeting he lectured about the critical zone in Lanzhou University. He also contributed to a workshop held in San Francisco in December focused on fostering further international collaborations.

## CZO Program Budgets

| **SUMMARY PROPOSAL BUDGET** | | | | | **FOR NSF USE ONLY** | |
|---|---|---|---|---|---|---|
| ORGANIZATION<br>**University of California, Berkeley** | | | | | PROPOSAL NO. | DURATION (MONTHS)<br>Proposed / Granted |
| PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR<br>**William E. Dietrich** | | | | | AWARD NO. | |
| A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates<br>List each separately with name and title. (A.7. Show number in brackets) | NSF-Funded Person-months | | | Funds Requested By Proposer | Funds Granted by NSF (If Different) | |
| | CAL | AC | SUMR | | | |
| 1. **William E. Dietrich – PI** | 0.0 | 0.0 | 0.50 | $**9,866** | $ | |
| 2. **James K. Bishop** | 0.0 | 0.0 | 0.25 | **3,794** | | |
| 3. **Stephanie M. Carlson** | 0.0 | 0.0 | 0.25 | **2,133** | | |
| 4. **Mary E. Power** | 0.0 | 0.0 | 0.25 | **2,813** | | |
| 5. **Sally Thompson** | 0.0 | 0.0 | 0.25 | **2,765** | | |
| 6. ( **0**) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE) | 0.0 | 0.0 | 0.0 | **0** | | |
| 7. ( **5**) TOTAL SENIOR PERSONNEL (1-6) | 0.0 | 0.0 | 1.50 | **21,371** | | |
| B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS) | | | | | | |
| 1. ( **2**) POSTDOCTORAL ASSOCIATES | 14.5 | 0.0 | 0.0 | **66,541** | | |
| 2. ( **2**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.) | 24.0 | 0.0 | 0.0 | **70,532** | | |
| 3. ( **5**) GRADUATE STUDENTS | | | | **158,704** | | |
| 4. ( **5**) UNDERGRADUATE STUDENTS | | | | **19,200** | | |
| 5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY) | | | | **0** | | |
| 6. ( ) OTHER | | | | **0** | | |
| TOTAL SALARIES AND WAGES (A + B) | | | | **336,348** | | |
| C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) | | | | **146,178** | | |
| TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C) | | | | **482,526** | | |
| D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) | | | | | | |
| TOTAL EQUIPMENT | | | | **0** | | |
| E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS) | | | | **36,139** | | |
| 2. FOREIGN | | | | **0** | | |
| F. PARTICIPANT SUPPORT<br>1. STIPENDS $ 0<br>2. TRAVEL 0<br>3. SUBSISTENCE 0<br>4. OTHER 0 | | | | | | |
| TOTAL NUMBER OF PARTICIPANTS ( 0) TOTAL PARTICIPANT COSTS | | | | **0** | | |
| G. OTHER DIRECT COSTS | | | | | | |
| 1. MATERIALS AND SUPPLIES | | | | **37,399** | | |
| 2. PUBLICATION/DOCUMENTATION/DISSEMINATION | | | | **0** | | |
| 3. CONSULTANT SERVICES | | | | **0** | | |
| 4. COMPUTER SERVICES | | | | **0** | | |
| 5. SUBAWARDS | | | | **74,361** | | |
| 6. OTHER | | | | **38,732** | | |
| TOTAL OTHER DIRECT COSTS | | | | **150,492** | | |
| H. TOTAL DIRECT COSTS (A THROUGH G) | | | | **669,157** | | |
| I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) | | | | | | |

| | | | |
|---|---|---|---|
| **MTDC (Rate 57.000, Base: 492706)** | | | |
| TOTAL INDIRECT COSTS (F&A) | | **280,842** | |
| J. TOTAL DIRECT AND INDIRECT COSTS (H + I) | | **949,999** | |
| K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.) | | **0** | |
| L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K) | | $**949,999** | $ |

| | | | | |
|---|---|---|---|---|
| M. COST SHARING: PROPOSED LEVEL $ **0** | AGREED LEVEL IF DIFFERENT: $ | | | |
| PI/PD TYPED NAME AND SIGNATURE*<br>**William E. Dietrich** | DATE | **FOR NSF USE ONLY**<br>INDIRECT COST RATE VERIFICATION | | |
| ORG. REP. TYPED NAME & SIGNATURE* | DATE | Date Checked | Date of Rate Sheet | Initials-ORG |

**NSF Form 1030 (10/99)** ***Supersedes All Previous Editions*** *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

We anticipate spending according to our proposed Year 3 budget.

## Budget Justification – CZO Award

### Senior Personnel

Two weeks of summer salary are planned for the PI for project management purposes. The PI serves as Director of the Eel River CZO, participates in CZO teleconferences, contributes to National CZO activities (such as writing basic documents), holds monthly meetings of the Eel River CZO community, contributes to outreach, gives lectures about the CZO, supervises budgetary matters, supervises staff, participates in National CZO meetings, mentors CZO students, and reports on Eel River CZO activities to NSF. One week of summer salary is included for the co-PIs who form the Executive Committee. This committee aids the PI in making administrative decisions, governing the research programs, and overseeing the progress of the CZO as a whole. The other senior personnel are faculty collaborators (Fung, Dawson, Firestone and Banfield) do not take on administrative duties. All the senior personnel contribute to management decisions concerning general operations and guiding the CZO toward its prescribed goals.

### Other Personnel

Our data manager, informatics specialist, and general field instrumentation support staff person, Collin Bode is supported 43% time through the CZO. He is responsible for the informatics infrastructure including, but not limited to the wireless network, operating and maintaining the sensor observatories, developing and maintaining the sensor observatory database and website for archiving and disseminating data, and performing spatial.

We will support a 20% time position for programming support to maintain the data flow and its accessibility. Virginia Ogle, the programmer who designed the original databases, will be employed to help avoid inherent data issues and structure problems, as well as improve data availability and accessibility.

Postdoctoral Scholars:

The modeling work will be accomplished by two postdoctoral scholar who will interact with each other and modelers at other CZOs. This work builds upon our field observations and requires advance knowledge and skills, hence the choice of postdoctoral scholar support.

Graduate student research assistants:

A group of five graduate student researchers (GSRs) will take the primary responsibility for the fieldwork, laboratory analyses, and some modeling associated with each of our four questions. Through rotation as graduate student instructors, fellowships, and other sources of funding we anticipate the graduate group working at the CZO will be much larger than that supported by this grant. Salary is for GSRs at 50% effort during the academic year and 100% effort during the summer period.

Undergraduate Assistants:

The intensive fieldwork associated with our proposed research will benefit from and will provide an excellent learning opportunity for undergraduate research assistants. We anticipate at least four to six undergraduates working part-time with CZO researchers, especially in the summer 2016 field season.

**Fringe Benefits**

Benefits for the PI and co-PIs is projected to be 18.10% of payroll. For the Specialist benefits have been calculated at 36.80%. For the programmer benefits are calculated at 44.60%. Postdoc benefits are calculated at 18.10% and graduate student and undergraduate research assistant benefits at 0.0%. In addition, funds are budgeted for the graduate students' fee remission (in-state fees), which is included in the fringe benefit line item. Graduate students who are supported at 45% or more time are eligible for the full fee remission (including non-resident tuition), which includes coverage of the SHIP fee plus campus fees. It is UC Berkeley's practice to similarly compensate students in non-sponsored as well as sponsored activities.

Travel

Travel funds for fieldwork will cost $36,139. This covers cost of car rental for graduate students, fuel, food, and lodging. All four of our research questions require extensive fieldwork. Three of the four questions entail focused research in the Angelo Coast Range Reserve, which is 360 miles of travel roundtrip from Berkeley. Fieldwork based at the Angelo Reserve requires a daily fee (includes being able to camp or stay in one of the buildings) of $12 per person. Fieldwork involves groups of graduate students, undergraduates and senior personnel. These researches will make frequent short trips all year long, but also spend significant periods of the summer in the field. Question (1) and Question (3) require extensive travel outside of the Reserve to monitor a site in mélange and to conduct two stream flow network surveys. Additional travel costs are included to support travel (including registration fees for CZO students) to the semi-annual face-to-face meetings with other CZO PIs held each fall at the American Geophysical Union meeting, and in conjunction with spring annual PI meetings.

Materials and Supplies

The materials and supplies budget accounts for (1) further installation costs for monitoring system on the mélange bedrock (e.g. pressure transducers, weather monitors, moisture detection, data storage and batteries), (2) the annual maintenance of the Rivendell system (e.g. cables, monitoring equipment, radio replacement) (3) annual replacement costs of portable monitoring devices for the wetted channel surveys (based on experience this difficult work leads to the need to replace most of the instruments several times a season, which includes GPS, portable air and water thermometer, relative humidity, and digital camera) and (4) expendable supplies (e.g. pit tagging materials, nets, iButtons, balances, oxygen meters, and current meters) for stream field work.  Total for these four expenses is $37,399.

## Budget – LBNL Subaward

## SUMMARY PROPOSAL BUDGET

| | | | | | |
|---|---|---|---|---|---|
| | | | | FOR NSF USE ONLY | |
| ORGANIZATION **Lawrence Berkeley National Lab** | | | PROPOSAL NO. | DURATION (MONTHS) Proposed | Granted |
| PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR **Todd Wood** | | | AWARD NO. | | |

| A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets) | NSF-Funded Person-months CAL | AC | SUMR | Funds Requested By Proposer | Funds Granted by NSF (If |
|---|---|---|---|---|---|
| 1. **Todd Wood** | 0.0 | 0.0 | 0.0 | $**22,620** | $ |
| 2. | 0.0 | 0.0 | 0.0 | | |
| 3. | 0.0 | 0.0 | 0.0 | | |
| 4. | 0.0 | 0.0 | 0.0 | | |
| 5. | 0.0 | 0.0 | 0.0 | | |
| 6. ( **0**) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE) | 0.0 | 0.0 | 0.0 | **0** | |
| 7. ( **5**) TOTAL SENIOR PERSONNEL (1-6) | 0.0 | 0.0 | 1.50 | **22,620** | |
| B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS) | | | | | |
| 1. ( **0**) POSTDOCTORAL ASSOCIATES | 14.5 | 0.0 | 0.0 | **0** | |
| 2. ( **0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.) | 24.0 | 0.0 | 0.0 | **0** | |
| 3. ( **0**) GRADUATE STUDENTS | | | | **0** | |
| 4. ( **0**) UNDERGRADUATE STUDENTS | | | | **0** | |
| 5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY) | | | | **0** | |
| 6. ( ) OTHER | | | | **0** | |
| TOTAL SALARIES AND WAGES (A + B) | | | | **22,260** | |
| C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) | | | | **0** | |
| TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C) | | | | **22,260** | |
| D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) | | | | | |
| TOTAL EQUIPMENT | | | | **0** | |
| E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS) | | | | **1,800** | |
| 2. FOREIGN | | | | **0** | |
| F. PARTICIPANT SUPPORT<br>1. STIPENDS $ 0<br>2. TRAVEL 0<br>3. SUBSISTENCE 0<br>4. OTHER 0 | | | | | |
| TOTAL NUMBER OF PARTICIPANTS ( 0) TOTAL PARTICIPANT COSTS | | | | **0** | |
| G. OTHER DIRECT COSTS | | | | | |
| 1. MATERIALS AND SUPPLIES | | | | **0** | |
| 2. PUBLICATION/DOCUMENTATION/DISSEMINATION | | | | **0** | |
| 3. CONSULTANT SERVICES | | | | **0** | |
| 4. COMPUTER SERVICES | | | | **0** | |
| 5. SUBAWARDS | | | | **0** | |
| 6. OTHER | | | | **23,674** | |
| TOTAL OTHER DIRECT COSTS | | | | **23,674** | |
| H. TOTAL DIRECT COSTS (A THROUGH G) | | | | **48,094** | |
| I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)<br>**MTDC (Rate 54.6150%, Base: 48094)** | | | | | |
| TOTAL INDIRECT COSTS (F&A) | | | | **26,267** | |
| J. TOTAL DIRECT AND INDIRECT COSTS (H + I) | | | | **74,361** | |
| K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.) | | | | **0** | |
| L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K) | | | | $**74,361** | $ |
| M. COST SHARING: PROPOSED LEVEL $ 0 | AGREED LEVEL IF DIFFERENT: $ | | | | |

| PI/PD TYPED NAME AND SIGNATURE* | DATE | FOR NSF USE ONLY | | |
|---|---|---|---|---|
| Todd Wood | | INDIRECT COST RATE VERIFICATION | | |
| ORG. REP. TYPED NAME & SIGNATURE* | DATE | Date Checked | Date of Rate Sheet | Initials-ORG |

**NSF Form 1030 (10/99)** ***Supersedes All Previous Editions*** *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

## Budget Justification – LBNL Subaward

The Year 3 subaward to the Lawrence Berkeley National Lab will be $74,361, which includes:

Senior Personnel

Todd Wood (Sr Scientific Eng Associate) (1.5 months) is responsible for modifying/designing and implementing electronics and firmware for automated water sampling at new Eel River sites. He deploys power/network infrastructure at 2 Eel River sites for real-time data acquisition and instrumentation control. He maintains instrumentation and datasets and supervises students performing water chemistry and trace metal analysis.

Travel

Estimated travel costs (car rental/gas) for a trip is approximately $300 per trip. It is anticipated that six trips will be required to maintain sampling activities. Total cost $1,800.

Additional Costs

Additional costs (Other) include: 1) support of existing ISCO controllers at Angelo Reserve well/creek sites; 2) analysis of trace metal and water chemistry of collected samples; 3) anticipated repair /replacement of system components such as pumps, electronics and tubing; and 4) data transmission charges for cellular or satellite modems. Total cost for these expenses are $23,674.

## Additional Funding

In our second year, ER CZO personnel have had tremendous success leveraging CZO support for additional funding. We have received the following new awards:

**Proposal Title:** Tree-driven diel microbial carbon dynamics in the vadose zone
**Investigators: J. Banfield, M. Firestone, J. Bishop, W. Dietrich, T. Dawson**
**Source of Support**: Joint Genomics Institute's Community Science Program
**Total Award Amount:** In kind support; 2TB for metagenomics and metastransciptomic analysis

**Proposal Title:** Water balance and plant ecophysiology in coastal California: Linking models and mechanisms to project winners and losers under future climate scenarios
**Investigators: T. Dawson**, D. Ackerly, **S. Thompson**
**Source of Support**: NSF
**Total Award Amount:** $726,511

**Proposal Title:** The application of the Vadose Zone Monitoring System in the weathered fracture bedrock of the Eel River Critical Zone Observatory
**Investigators: W. Dietrich, M. Power, J. Bishop, S. Thompson, S. Carlson**
**Source of Support**: NSF
**Total Award Amount:** $68,445

**Proposal Title:** Eel River CZO LiDAR Survey
**Investigators: W. Dietrich, M. Power, J. Bishop, S. Thompson, S. Carlson**
**Source of Support**: NSF
**Total Award Amount:** $88,426

**Proposal Title:** REU supplement for EAR–1331940
**Investigators: W. Dietrich, M. Power, J. Bishop, S. Thompson, S. Carlson**
**Source of Support**: NSF
**Total Award Amount:** $25,602

**Proposal Title:** Impacts of Marijuana cultivation on North Coast streams
**Investigators: M. Power**
**Source of Support**: The Nature Conservancy
**Total Award Amount:** $15,000

**Proposal Title:** Cracking the critical zone: Tree roots in fractures and a proposed mechanistic soil production function
**Investigators: J. Marshall**
**Source of Support**: NSF—Postdoctoral Award
**Total Award Amount:** $124,000

**Graduate Student Support this review period**:

EPA Star Fellowship (K. Bouma-Gregson) ($132, 000)
NSF Graduate Research Fellowship (D. Dralle) ($108,000)
NSF Graduate Research Fellowship (S. Kelson) ($108,000)
NSF Graduate Research Fellowship (E. Starr) ($108,000)
NSF Dissertation Improvement Grant (H.Uno) ($16,380)
UCNRS Mathias Grant (S. Kelson) ($3,000)
UCNRS Mathias Grant (P. Georgakakos) ($3,000)