Annual Report for Period: 09/2008 - 08/2009
Submitted on: 07/09/2009
Principal Investigator: Bales, Roger C.
Award ID: 0725097
Organization: U of Cal - Merced
Submitted By:
Bales, Roger - Principal Investigator

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

Project Participants

Senior Personnel

Name: Bales, Roger
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Kirchner, James
Worked for more than 160 Hours: Yes
Contribution to Project:
Co-PI signal analysis, physical weathering

Name: Boyer, Elizabeth
Worked for more than 160 Hours: Yes
Contribution to Project:
Organic carbon in stream water

Name: Tague, Christina
Worked for more than 160 Hours: Yes
Contribution to Project:
Co-PI modeling water and nutrient cycles

Name: Conklin, Martha
Worked for more than 160 Hours: Yes
Contribution to Project:
Co-PI surface-groundwater interaction

Name: Goulden, Mike
Worked for more than 160 Hours: Yes
Contribution to Project:
Flux tower Co-PI, CZO support.

Name: Johnson, Dale
Worked for more than 160 Hours: Yes
Contribution to Project:
Soil nutrients Co-PI. Soil carbon and nutrient analyses, nutrient fluxes, nutrient cycling.

Name: Molotch, Noah
Worked for more than 160 Hours: Yes
Contribution to Project:
Snow surveys and mapping

Name: Houlton, Ben
Worked for more than 160 Hours: Yes
Contribution to Project:

Nitrogen isotopes in streams - planning

Name: Hopmans, Jan
Worked for more than 160 Hours: Yes
Contribution to Project:
Co-PI for soil moisture

Name: Riebe, Clifford
Worked for more than 160 Hours: Yes
Contribution to Project:
Physical weathering rates

Name: Hart, Steven
Worked for more than 160 Hours: No
Contribution to Project:
Forest Ecology

Name: Berhe, Asmeret
Worked for more than 160 Hours: No
Contribution to Project:
Soil biogeochemistry

Post-doc

Name: Hartsough, Peter
Worked for more than 160 Hours: Yes
Contribution to Project:
Experimental design, implementation and ongoing maintenance

Name: Liu, Fengjing
Worked for more than 160 Hours: No
Contribution to Project:
Geochemical analysis

Graduate Student

Name: Malazian, Armen
Worked for more than 160 Hours: Yes
Contribution to Project:
Field installation and instrument calibration

Name: Palucis, Marisa
Worked for more than 160 Hours: Yes
Contribution to Project:
In preparation for Ph.D. qualifying exam, used stream and suction lysimeter data from the CZO to test a theoretical model for concentration-discharge relationships in porewaters and streams

Name: Alvarez, Otto
Worked for more than 160 Hours: No
Contribution to Project:
Data management

Name: Kelly, Anne
Worked for more than 160 Hours: Yes
Contribution to Project:
Evapotranspiration and water balance in forest

Name: Musselman, Keith
Worked for more than 160 Hours: Yes
Contribution to Project:
Snow surveys and mapping

Name: Kirchner, Peter
Worked for more than 160 Hours: Yes
Contribution to Project:
Water cycle, soil moisture

Name: Lucas, Ryan
Worked for more than 160 Hours: Yes
Contribution to Project:
water cycle and meadow research

Name: Kamai, Timir
Worked for more than 160 Hours: No
Contribution to Project:
Datalogger programming and instrument calibration

Name: Swarowsky, Alex
Worked for more than 160 Hours: Yes
Contribution to Project:
Manufacture, calibration and installation of field instruments

Name: Kerkez, Branko
Worked for more than 160 Hours: Yes
Contribution to Project:
Installation, monitoring, and maintenance of DUST wireless network

Name: Fellows, Aaron
Worked for more than 160 Hours: No
Contribution to Project:
Eddie covariance tower field work

Name: Anderson, Ray
Worked for more than 160 Hours: No
Contribution to Project:
Eddie covariance tower field work

Name: Godsey, Sarah
Worked for more than 160 Hours: Yes
Contribution to Project:
geomorphology, the extensions and contraction of the stream network at the CZO in response to snowmelt

Undergraduate Student

Name: Baumgartner, Thomas
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with field installations

Name: Melendez, Denise
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with field installations and data analysis

Name: Kelly, Sean
Worked for more than 160 Hours: No
Contribution to Project:
Field research and data analysis

Name: Rojas, Adrian
Worked for more than 160 Hours: No
Contribution to Project:
Field research and data analysis

Name: Loy, Garrett
Worked for more than 160 Hours: No
Contribution to Project:
Field research and data analysis

Name: Mukin, Brandy
Worked for more than 160 Hours: No
Contribution to Project:
Field research and data analysis

Name: Pendleton, John-Marc
Worked for more than 160 Hours: No
Contribution to Project:
Field research and data analysis

Name: Xochihua, Ruth
Worked for more than 160 Hours: No
Contribution to Project:
Field research and data analysis

Technician, Programmer

Name: Meadows, Matt
Worked for more than 160 Hours: Yes
Contribution to Project:
Research hydrologist in charge of continuing CZO field program

Name: Winston, Greg
Worked for more than 160 Hours: Yes
Contribution to Project:
Flux tower instrumentation

Name: Phelps, Gary
Worked for more than 160 Hours: No
Contribution to Project:
Website Manager

Name: Tuli, Atac
Worked for more than 160 Hours: No
Contribution to Project:
Field installation of soil moisture instrumentation

Other Participant

Research Experience for Undergraduates

Name: Holling, Timothy

Worked for more than 160 Hours: No

Contribution to Project:

Undergraduate research project (Summer 2009)

Years of schooling completed: Junior

Home Institution: Other than Research Site

Home Institution if Other: California State University, Stannislaus

Home Institution Highest Degree Granted(in fields supported by NSF): Master's Degree

Fiscal year(s) REU Participant supported: 2009

REU Funding: No Info

Organizational Partners

Pacific SW Research Station, USFS

The CZO is located at the Kings River Experimental watersheds, a set of research catchments operated by the Pacific Southwest Research Station (PSW), U.S. Forest Service.

Lawrence Livermore National Laboratory

Jean Moran and Brad Esser collected samples for isotope analysis as part of the meadow experiment in summer 2008. Initial analysis has been completed; further sampling and analysis may be conducted in order to obtain adequate data for collaboration on papers.

Other Collaborators or Contacts

Decagon Inc. Contact: Colin Campbell

Crossbow Technologies; deployed a prototype wireless sensor network system in Wolverton.

Scott Tyler, UNR; summer 2008 deployed DTS system for meadow water cycle experiment, has provide input and insight on meadow deployment data processing and interpretation

Center for Information Technology Research in the Interest of Society (CITRIS)
The installation, maintenance, and utilization of the Dust Networks wireless sensor platform in the P301 ground-based water balance instrumentation is a collaboration with Steve Glaser and the Civil Systems group at UC Berkeley. This interdisciplinary, and inter-campus collaboration is the first of its kind as part of the newly established CITRUS.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

See attached

Findings: (See PDF version submitted by PI at the end of the report)

See attached

Training and Development:

We are developing instrument clusters for mountain water cycle measurements, which is a great learning experience for all. This sort of integrated measurement network across a catchment has not been done before in the mountains of the Western U.S., at the rain-snow transition. Students, postdocs and research scientists are learning strategies that will need to be replicated much more widely in the future.

Outreach Activities:

We have provided press releases, done newspaper interviews and did a radio interview with the California Report, and a PBS TV interview. We are sharing technology with colleagues in research and operational agencies. Educational outreach with the Yosemite Institute will begin this coming school year.

Journal Publications

Johnson, D.W., W.W. Miller, R.B. Susfalk, R.A. Dahlgren, and D.W. Glass, "Biogeochemical Cycling in Forest Soils of the Eastern Sierra Nevada Mountains", Forest Ecology and Management, p. , vol. , (2009). Published, 10.1016/j.foreco.2009.01.018

Anderson, S. A.; R. C. Bales; C. J. Duffy, "Critical Zone Observatories: Building a network to advance interdisciplinary study of Earth surface processes", Mineralogical Magazine, p. 7, vol. 72(1), (2008). Published,

Books or Other One-time Publications

Johnson, D.W., W.W. Miller, R.B. Susfalk, R.A. Dahlgren, N. Matsuyama and D.W. Glass, "How will a warmer climate affect nutrient cycling in forests of the eastern Sierra Nevada Mountains?", (2008). Conference poster paper, Published
Collection: Fourth Biennial Tahoe Basin Science Conference
Science as a Tool in Lake Tahoe Basin Management: Making Sense of Complexity
Bibliography: Incline Village, Nevada March 17-18, 2008.

Johnson, D.W., W.W. Miller, R.B. Susfalk, R.A. Dahlgren, N. Matsuyama and D.W. Glass, "Biogeochemical Cycling in Forest Soils of the Eastern Sierra Nevada Mountains, USA", (2008). Conference poster presentation, Published
Collection: North American Forest Soils Conference
Bibliography: Blacksburg, VA June 22-26 2008

Tague, C, "Spatial modeling of coupled hydrologic-biogeochemical
processes for the Southern Sierra Critical Zone Observatory", (2007). Conference presentation and abstract, Published
Collection: Eos Trans. AGU
Bibliography: 88(52), Fall Meet. Suppl., Abstract H53A-0957

Bales, R; Boyer, B; Conklin, M;
Goulden, M; Hopmans, J;
Hunsaker, C; Johnson, D; Kirchner, J; Tague, C, "Southern Sierra Critical Zone Observatory: integrating water cycle and biogeochemical processes across the rain-snow transition", (2007). Conference presentation and abstract, Published
Collection: Eos Trans. AGU
Bibliography: 88(52), Fall Meet. Suppl., Abstract H13A-0962

Bales, R; Hunsaker, C; Conklin, M; Kirchner, J; Boyer, B; Kirchner, P, " Southern Sierra Critical Zone Observatory (CZO): hydrochemical characteristics, science and measurement strategy", (2007). Conference presentationa nd abstract, Published
Collection: Eos Trans. AGU
Bibliography: 88(52), Fall Meet. Suppl., Abstract H51K-02

Bales, R; Meadows, M; Hopmans,
J; Hartsough, P; Kirchner, P, "Snow and Soil Moisture
Response Across Elevation,
Aspect and Canopy Variables in

a Mixed-conifer Forest,
Southern Sierra Nevada", (2008). Conference presentation and abstract, Published
Collection: Eos Trans. AGU
Bibliography: 89(53), Fall Meet. Suppl.,
Abstract C21A-0496

Bales, R; Hunsaker, C; Kirchner,
P; Conklin, M; Lucas, R, "Hydroclimate, ecosystem links &
the Southern Sierra Critical
Zone Observatory", (2008). Conference presentation and abstract, Published
Bibliography: Southern Sierra Science
Symposium

Hartsough, P; Malazian, A; Tuli,
A; Kamai, T; Kizito, F; Bales,
R; Broad, A; Hopmans, J, "Remote Environmental Monitoring
of Hydrologic/Biotic Interaction
in a Mountain Environment", (2008). Conference presentation and abstract, Published
Collection: Eos Trans. AGU
Bibliography: 89(53), Fall Meet. Suppl.,
Abstract H51H-0974

Hunsaker, C; Bales, R, "Water Yield and Runoff Timing
Across the Rain-snow
Transition at the Kings River
Experimental Watersheds in
California?s Southern Sierra
Nevada", (2008). Conference presentation and abstract, Published
Collection: Eos Trans. AGU
Bibliography: 89(53), Fall Meet. Suppl., Abstract 13C-0933

Kirchner, P; Bales, R; North, M;
Small, E, "Snowmelt infiltration and
evapotranspiration in Red Fir
forest ecosystems of the
Sierra Nevada", (2008). Conference presentation and abstract, Published
Collection: Eos Trans. AGU
Bibliography: 89(53), Fall Meet. Suppl.,
Abstract C21C-0572

Lucas, R; Conklin, M; Tyler, S;
Esser, B, "Investigating Meadow Hydrology
and Hyporeic Exhange", (2008). Conference presentation and abstract, Published
Collection: Eos Trans. AGU
Bibliography: 89(53), Fall Meet. Suppl.,
Abstract H21L-06

Bales, R., "Southern Sierra Critical Zone
Observatory: Integrating water
cycle & biogeochemical
processes across the rain-snow
transition", (2008). Conference presentation, Published
Bibliography: Poster presentations by Roger
Bales at the fall meeting,
AGU, San Francisco, CA and

WATERS testbed meeting,
Baltimore, Md

Web/Internet Site

URL(s):
https://snri.ucmerced.edu/CZO
https://eng.ucmerced.edu/snsjho

Description:
The first is our main CZO url.
The second url is our digital library

Other Specific Products

Contributions

Contributions within Discipline:

The CZO provides a multi-disciplinary platform for research. Many of the CZO data are available to the community, and other data to CZO cooperators who agree to data-sharing protocols.

Contributions to Other Disciplines:

The CZO fosters multi-disciplinary research. The site is also a candidate for a NEON investment, which could significantly enhance some of our CZO activities.

Contributions to Human Resource Development:

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, and modeling.

Contributions to Resources for Research and Education:

The CZO is a research platform, i.e. infrastructure for multidisciplinary research.

Contributions Beyond Science and Engineering:

The high profile of our CZO helps communicate water and other critical zone issues to the public, and helps educate agencies about the need to modernize measurement and decision-making infrastructure.

Conference Proceedings

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Product

Any Conference

Findings

The following presents findings associated with the various activities in the work plan. Refer to the section in the work plan of the same title for a description of activities.

Core CZO measurements, data management and integration. See the Activities pdf included with the annual report for a summary of activities corresponding to Core CZO measurements, data management and integration. Findings associated with core measurements are described in the following sections.

C**ore KREW measurements and data management.** The first of series of papers involving USFS and CZO personnel is undergoing final revisions in preparation for journal submittal. This paper utilizes streamflow, meteorological, and topographic data collected by the KREW field team at PSW. Streamflow data trends show greater discharge and water yield from higher elevation watersheds—the trend for annual discharge is stronger in wet years. Fifty percent discharge occurs later from higher elevation watersheds and is delayed in wet years (Figure 1). The spring transition in discharge from being snowmelt dominated to evapotranspiration (ET) dominated lags by 1-2 months from the lowest (D102) to highest (B204) elevations. When discharge is

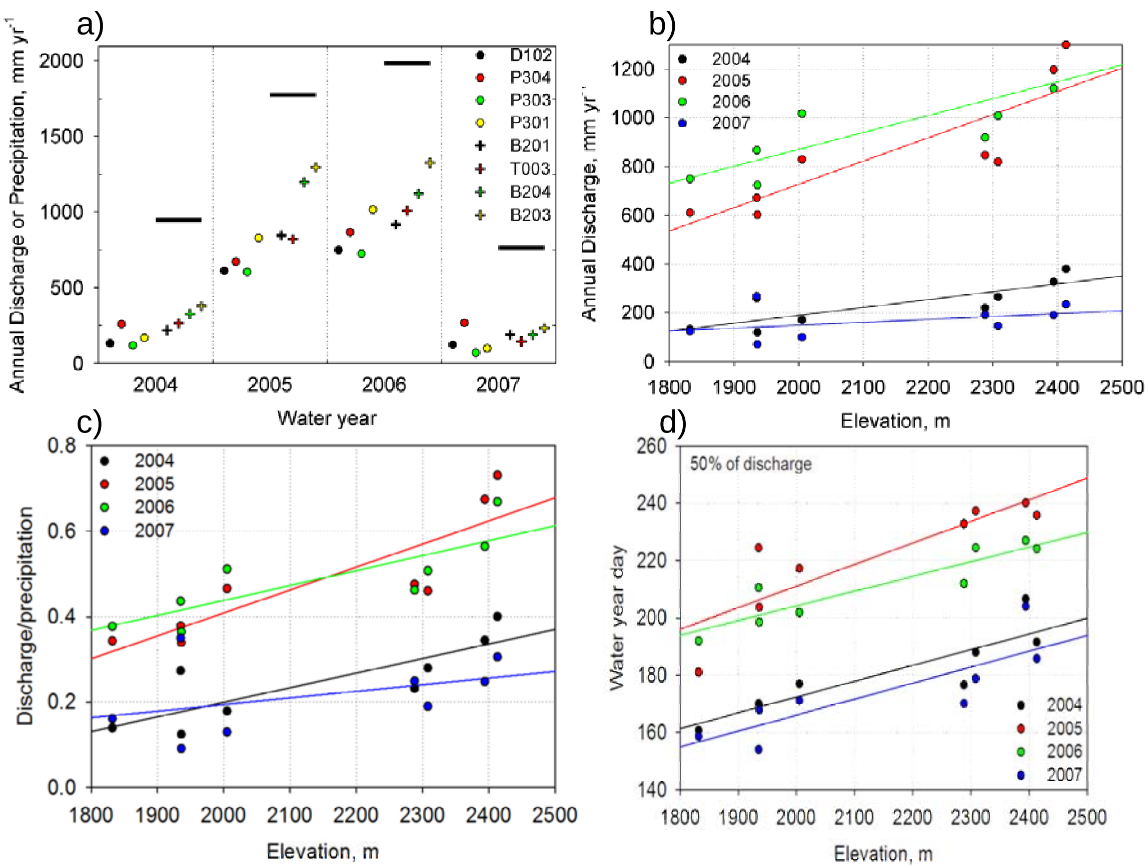


Figure 1—Annual discharge for each of the KREW watersheds for water years 2004 through 2007 (a); annual discharge (b), annual water yield—discharge minus precipitation—(c), and day of water year at 50% discharge plotted against mean watershed elevations.

dominated by snowmelt, peak discharge occurs in the late evening with minima in the morning. When discharge is dominated by ET, peak discharge occurs in the morning and minima occur after noon (Figure 2).

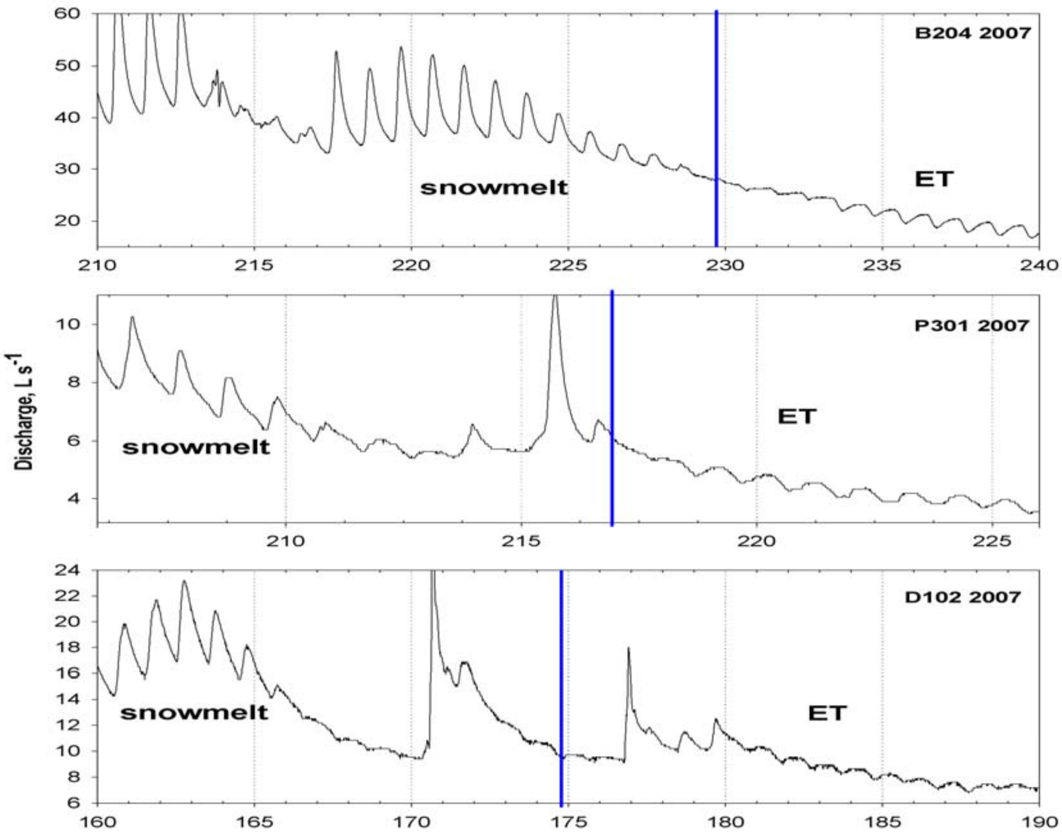


Figure 2—Stream discharge for three KREW watersheds showing the transition from being snowmelt dominated to ET dominated.

Modeling of water and nutrient cycles. The RHESSys hydrologic model was calibrated for 4 sub-watersheds in the Southern Sierra CZO. Model results show reasonable performance for 2004 and 2005 water years and capture distinctions between more rain dominated and more snow dominated watersheds (Figure 3). This set of hydrologic simulations forms a baseline set of model runs. Preliminary simulations, applying a uniform 2 °C warming scenario to simulations (Figure 4) show expected reductions in SWE and associated reductions in summer streamflow particularly for the more snow-dominated watershed (P301). This suggests that lower elevation watersheds (D102) will be less sensitive to warming. Spatial mapping of predicted peak annual SWE under baseline and 2 °C warming scenarios suggest that even with relatively moderate temperature increases (2 °C) the entire CZO site will lose most of winter snow accumulation and melt and become largely rain dominated (similar to D102) (Figure 5).

Near-surface soil-water processes. Data from the Critical zone tree show very dry soil conditions at summers end, typical of the conditions at the site. Winter precipitation arrived in December in the form of snow. Moisture conditions in the soil soon reached field capacity (Figure 6), after precipitation and snow melt events. The snowmelt patterns are captured in a time lapse video (http://hopmans.lawr.ucdavis.edu/nsf_czo_experiments.html). Soil temperature data show that the shallow (15cm) sensors are responding to diurnal fluctuations in air temperature (Fig. 7). Under dry soil moisture conditions, the soil temperature typically decreases with soil depth, whereas in the winter months the soil temperature profile is inverted with the highest temperatures at the greater soil depths. During short periods of snow melt, soil temperature is largely independent of soil depth because of infiltrating melt water.

Soil water storage was estimated by integrating soil moisture profile depth (Figure 8). Using total soil moisture storage (cm) values, tree transpiration rates for the initial 43 day dry period was estimated to be about 0.2mm/day, indicating severe soil moisture stress. The first precipitation of the season fell on 10/4/08, 3.3cm as measured at the NDAP site 2km away. Only approximately half of that amount made it to the sensors in the 1 m soil profile, with the remainder likely stored in the litter layer and in the dry shallow soil above the 15cm sensor. The next precipitation event of 3.7cm on 11/1/08 increased storage in the upper profile by 2.7cm, perhaps indicating that the lower soil profile was wetted, with changes in soil water storage reflecting precipitation amounts. The following large storm in mid-December falls mostly as snow and the water entering the profile is delayed until melting begins in early January. After the big storms in December and January, there is no net addition of water to the profile, because of soil water drainage after reaching field capacity. The receding limb in the soil water storage plot (Figure 8) is a measurement of the drainage rate out of the profile.

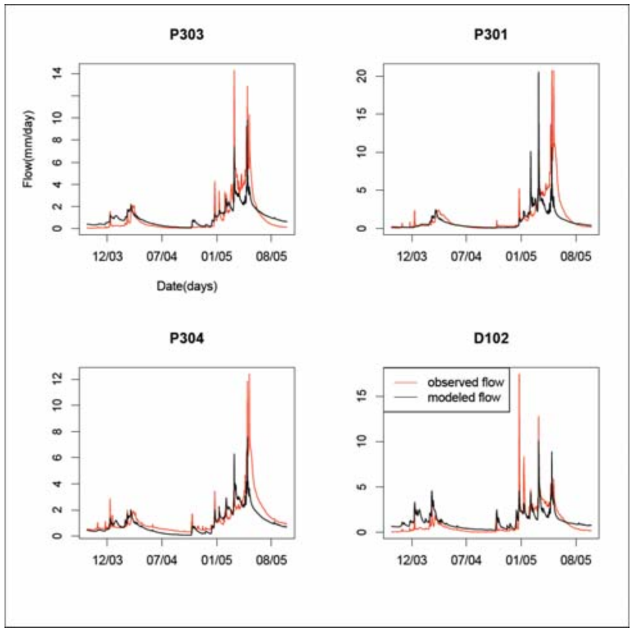


Figure 3—RHESSys simulation and modeled streamflow for 2004-2005 water years.

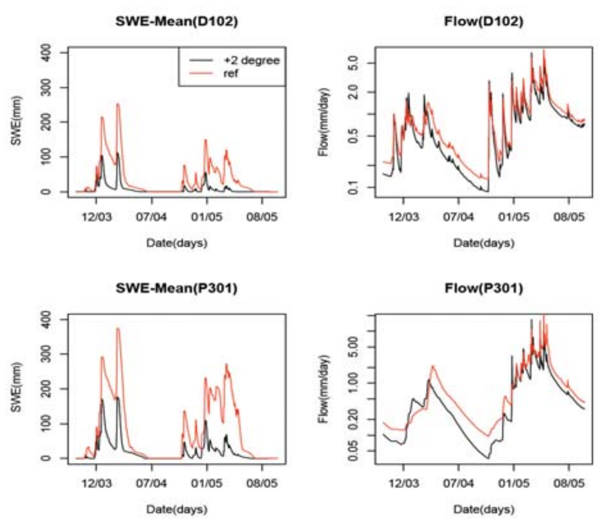


Figure 4—RHESSys estimates of changes in SWE and streamflow with uniform 2 C temperature increase applied to historic meteorological record.

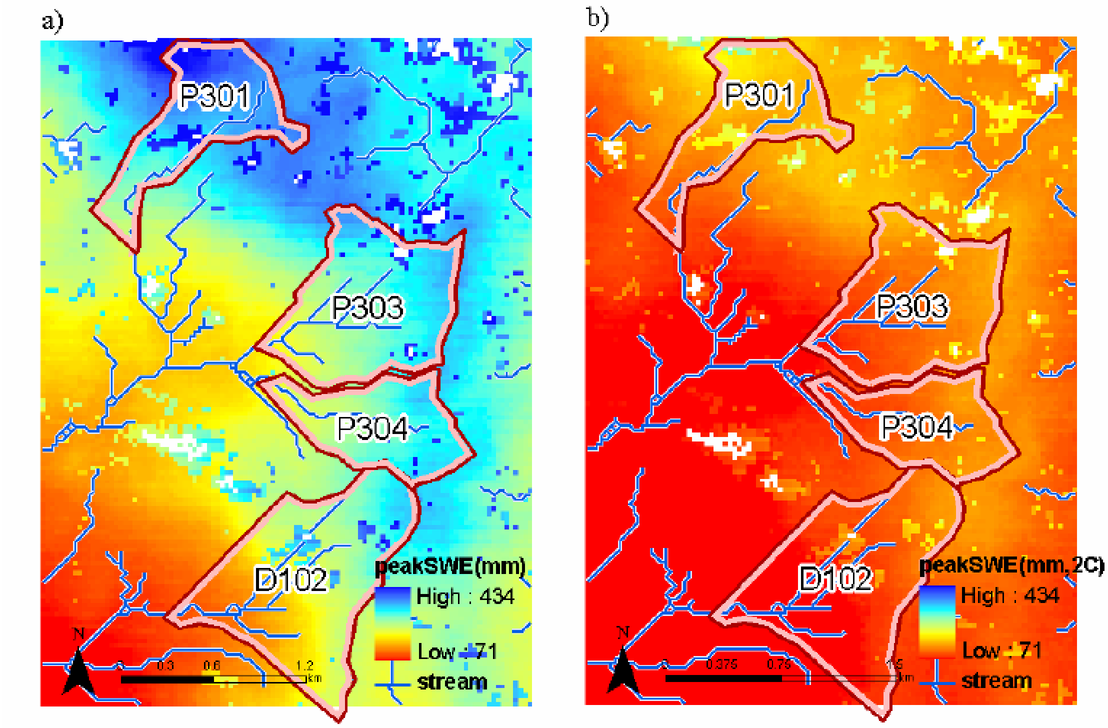


Figure 5—RHESSys estimates of spatial pattern of peak SWE for baseline and 2 °C warming scenario

Physical controls on water and carbon exchange and plant production. The P301 eddy flux tower has worked reasonably well, with a couple of notable gaps caused by low power during winter storms (labeled LP in Fig. 9) and the failure of a pair of data loggers during spring (labeled DL in Fig. 9). The gaps associated with low power will be difficult to improve on next winter – a much larger bank of batteries would be required to ensure operation during extended winter storms. The gaps associated with data logger failure are hopefully behind us – these failures were apparently caused by faulty multiplexer chips, and we believe the manufacturer has resolved this problem.

The most interesting finding so far has been the high rate of CO_2 uptake during the winter (Fig 9). The

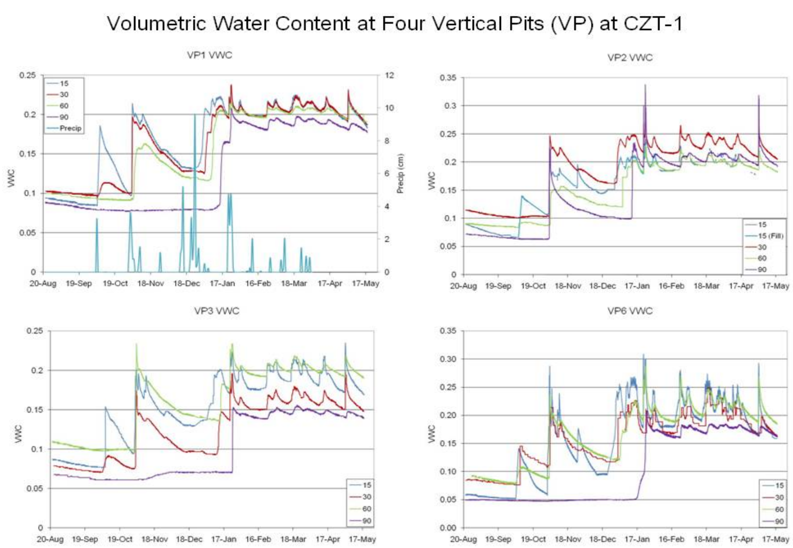


Figure 6—Distribution of soil moisture across four

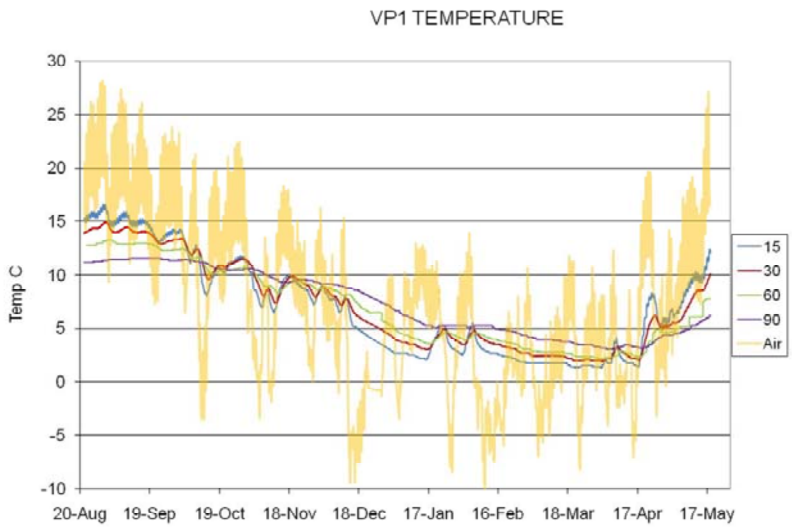


Figure 7—Soil Temperature profile in a representative vertical pit (VP-1).

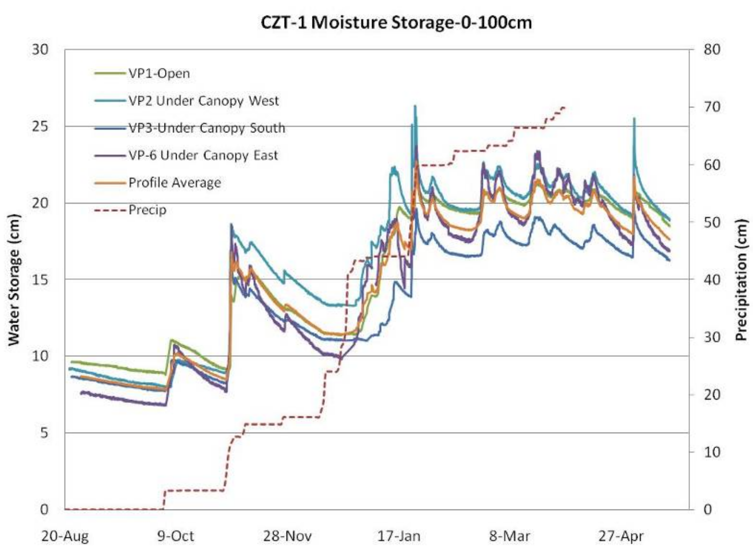


Figure 8—Soil Moisture Storage in the upper 1m surrounding the CZT-1.

photosynthetic capacity of the local vegetation is extraordinarily well adapted to cooler temperatures (Fig. 10). The forest is able to maintain peak CO_2 uptake down to an air temperature of 5^oC, and measurable CO_2 uptake to -4^oC. Both of these lower temperature thresholds are unusual, and lead to the interpretation that the vegetation is the result of heavy selection for year-round and winter photosynthesis, and that the distribution of these species is probably tightly controlled by daytime winter temperature. We predict the species found at P301 should drop out very abruptly at elevations and locations where the daytime winter air temperature is below 5^oC and significant winter photosynthesis is not possible.

Surface-groundwater interactions. Example longitudinal stream profile traces from the DTS are presented in Figure 11 a-c. The intermittence of the meadow stream combined with the frequently present willow shrubs hugging the stream channel in many locations proved it difficult to lay the fiber continuously in the stream. Large spikes in the afternoon and evening traces in Figure 11 a-c and large dips in the midnight trace are indicative of locations where the fiber was restricted from being placed in the meadow stream. The cable was placed in an ice bath at the bottom of the meadow and in a pool at the upper reach of the fiber. Dips in the trace in the afternoon and evening traces indicate locations where the fiber was placed in a meadow stream pool. All five meadow pools investigated exhibited diel temperature stratification to some degree. A one-day time series of a meadow pool exhibiting the diel pattern of temperature stratification and

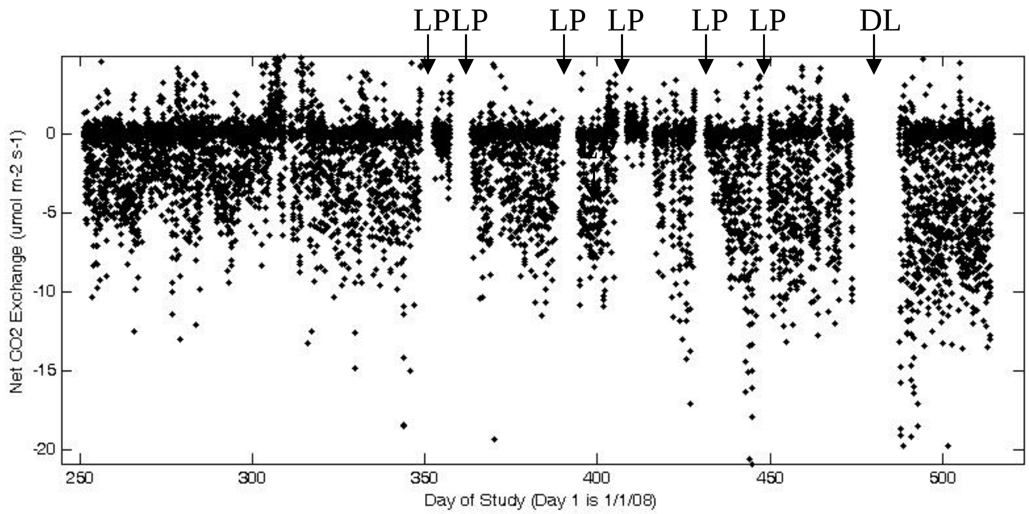


Figure 9—Net CO_2 Exchange measured at P301 tower from Sept 2008 to May 2009. Individual points are half hour covariances. Negative fluxes indicate net CO_2 uptake (photosynthesis; positive fluxes are CO_2 efflux (respiration).

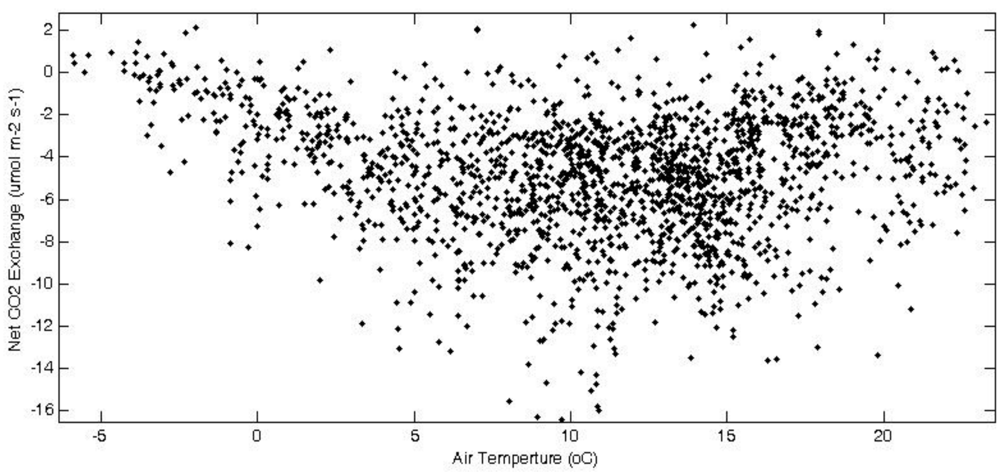


Figure 10—Relationship between Net CO_2 Exchange (y axis) and Air temperature (x axis) at P301 during sunny periods (incoming solar radiation > 250W m^{-2})

mixing is presented in Figure 12. Lengths in Figure 12 refer to height from the bottom of the pool, "DTS Up" refers to the DTS measured stream temperature upstream of the pool, and "DTS Pool" refers to the DTS measured pool temperature, which is integrated from a coil of the DTS fiber that intersected several depths of the pool.

The lack of continuous longitudinal stream temperature data made it difficult to separate out discrete groundwater inputs into the stream. In order to determine groundwater influence on the meadow, we solved a water balance for groundwater. In order for this to be successful, we assumed the change in storage was 0—this is a good assumption as the meadow sediment was completely saturated during the deployment—and measured evapotranspiration (ET), surface water inputs and outputs. ET was measured using a large geodesic dome for chamber measurements (Figure 13-14); measurements were validated by comparing the values to potential evapotranspiration

(PET) values calculated using the Penman-Monteith equation (Figure 13). These results indicate that at the time of the deployment the meadow ET as essentially at PET levels. Using measured ET and surface flow data, and by solving the water balance equation, a water balance was calculated for a 24 hour period during the experiment (Figure 15). The water balance shows that at the time of the experiment, groundwater discharge is a major source of water for the meadow system.

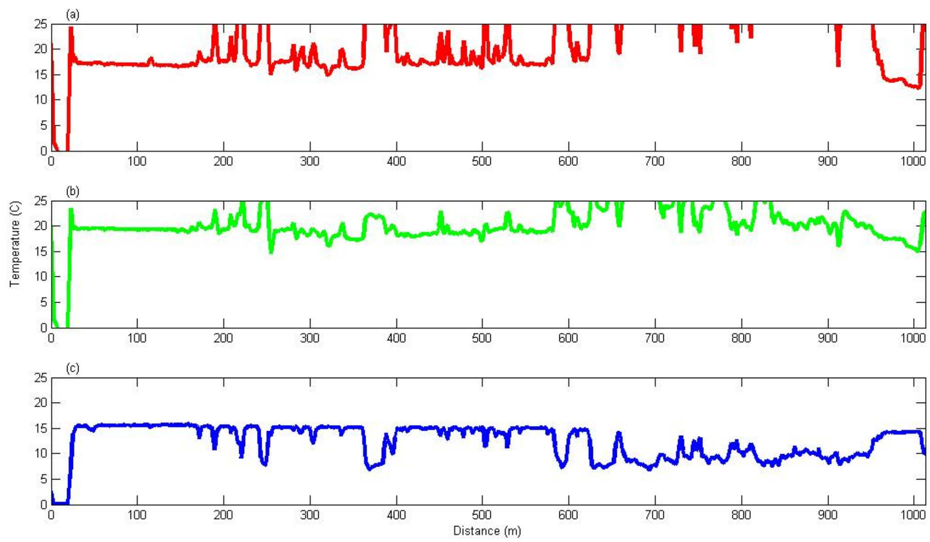


Figure 11—Longitudinal temperature profile traces of the meadow stream at 12:00 noon (a), 4:00 pm (b), and 12:00 am (c) on July 9, 2008.

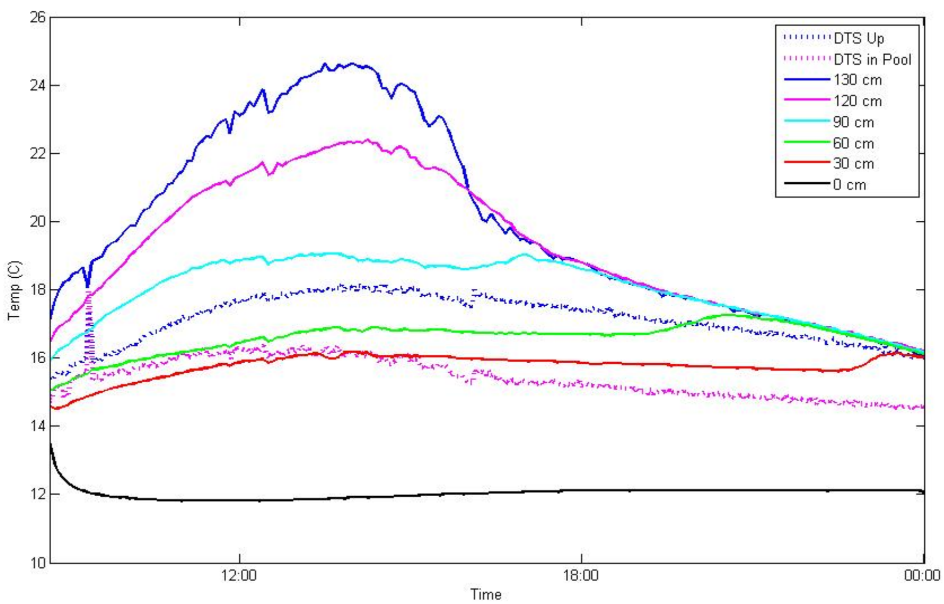


Figure 12—Vertical temperature profile of a meadow pool exhibiting string diel temperature stratification and mixing.

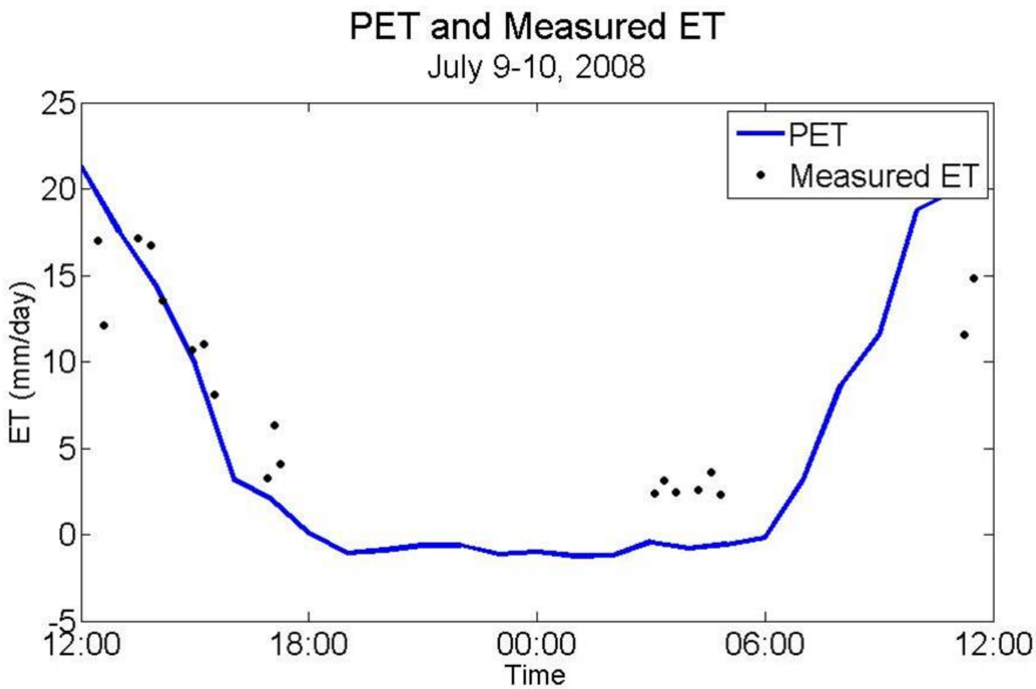


Figure 13—Measured ET plotted with calculated PET. Note: high ET values measured in the early morning may be artificially high due to high fan speed in the dome.

Figure 14—Measuring ET with the geodesic dome.

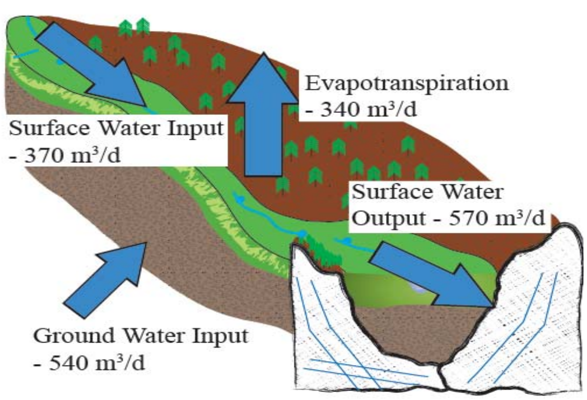
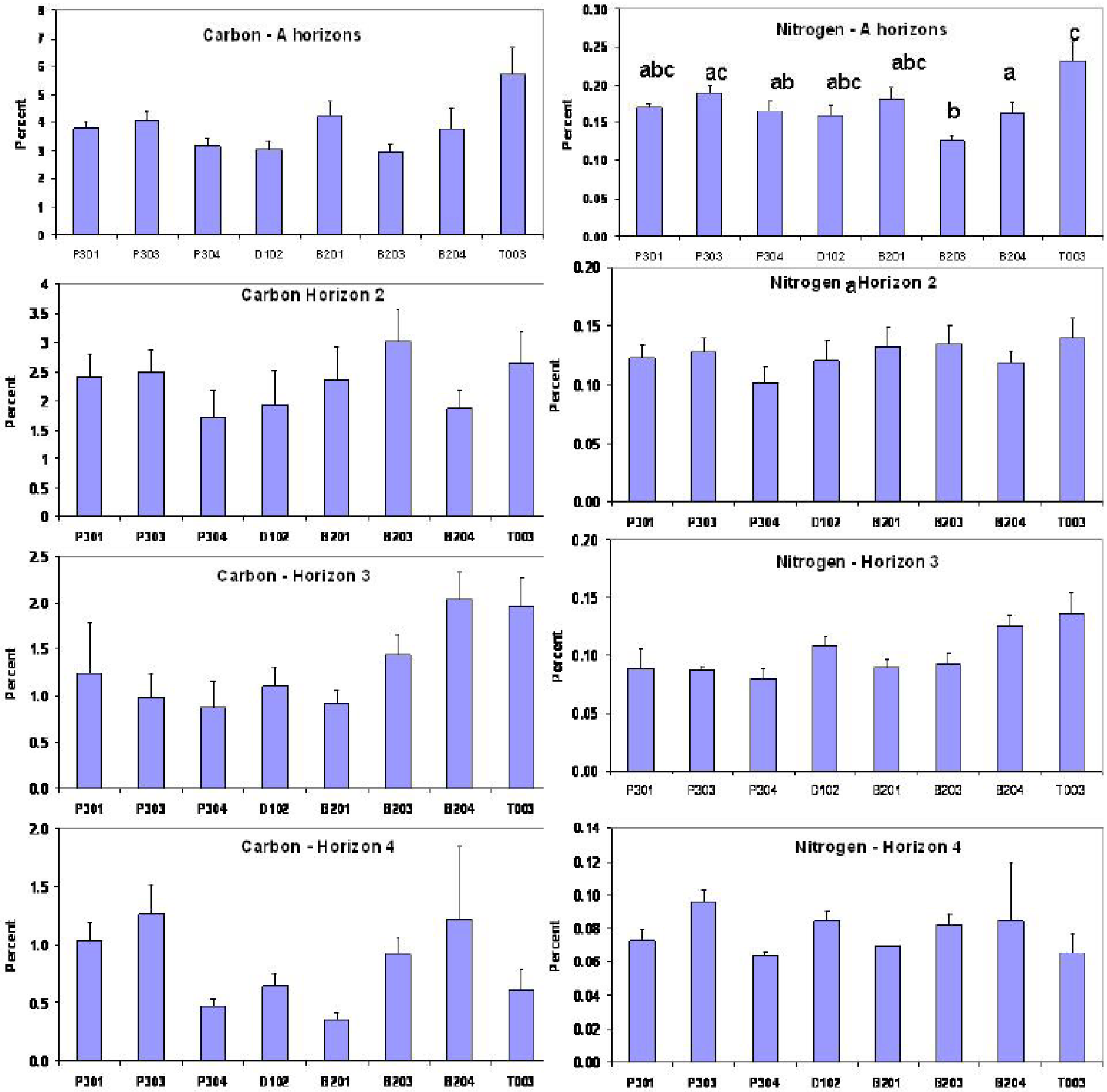


Figure 15—Calculated 24-hr water balance.

Nitrogen cycling in soil . Soils from the KREW watersheds have been analyzed for total C, total N, NH_4^+ and NO_3^-; the data from this analysis are presented in Figure 16 a-d. Horizons 2, 3, and 4 are averages of genetic soil horizons that were not consistent from pit to pit – for example, B1, BA, etc were lumped for averaging here if such horizons occurred at the second sampling depth. Bars not sharing the same letters were significantly different, post-hoc LSD tests. These data indicate that there are significant differences in total nitrogen and mineral nitrogen, but not carbon, among the watersheds. The ammonium concentrations are very high—this may suggest that these systems are bordering on being nitrogen saturated.

Nitrogen fluxes from soil. Nothing to report.

Baseline hydrologic, sediment and geochemical characterization. See



a) **b)**

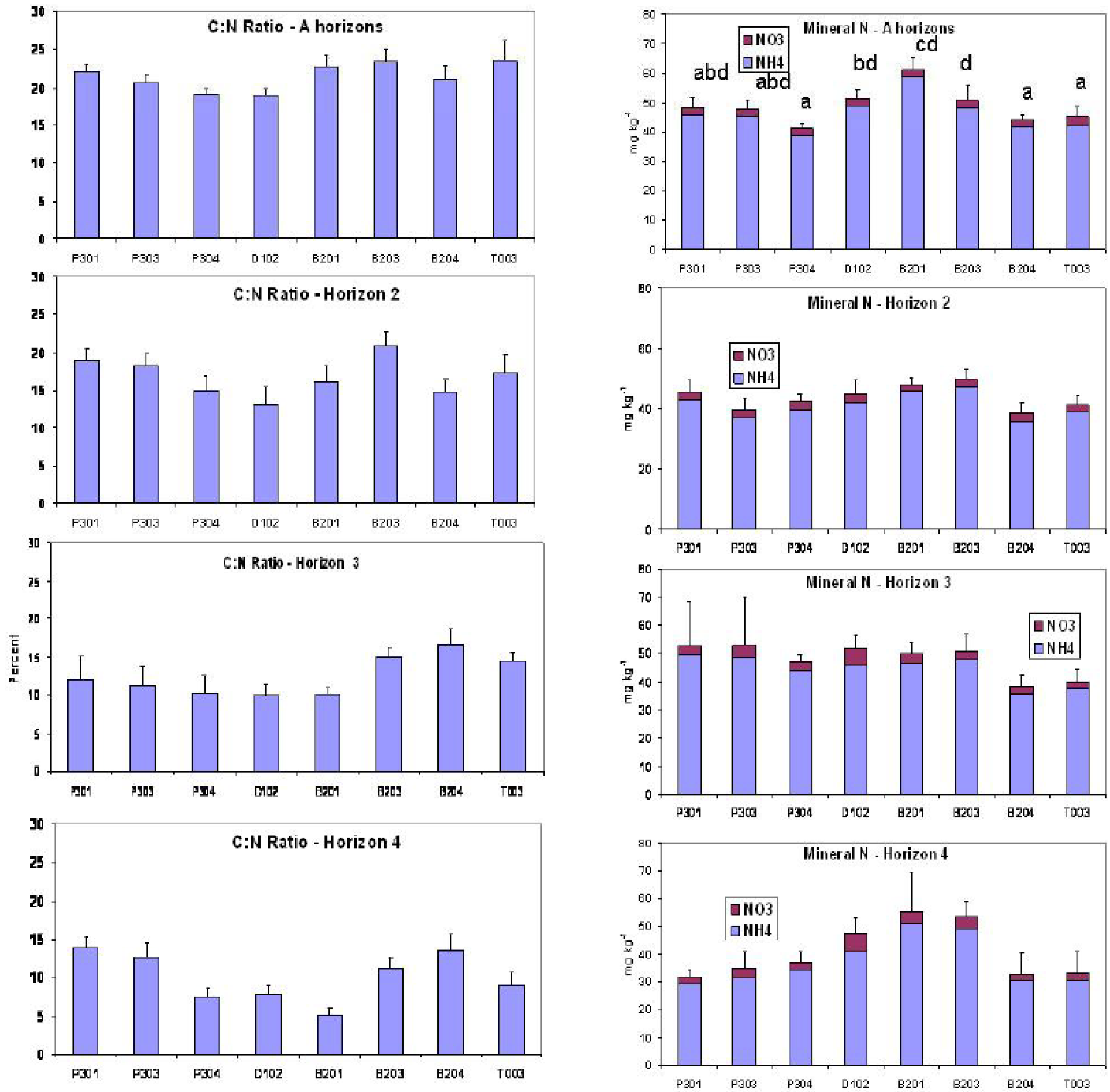
Figure 16—Average soil carbon (a) and nitrogen (b) concentrations in the KREW watersheds.

Figure 3 and "Core KREW measurements and data management" for annual-scale analysis of hydrologic data.

Initial findings from the analysis of PSW bi-weekly major ion samples are displayed in Figure 17 and described below. Annual mean ionic concentrations of major cations significantly decreased with an increase in the mean catchment elevations, with a slope of 0.33 $\mu eq\ L^{-1}\ m^{-1}$ for Ca^{2+} (n = 24, R^2 = 0.74, $p < 0.001$) and 0.20 $\mu eq\ L^{-1}\ m^{-1}$ for Na^{+} (n = 24, R^2 = 0.93, $p < 0.001$).

Change of the annual mean ionic concentrations of major anions with the mean catchment elevations was different from major cations. The annual mean concentrations of Cl^{-} slightly increased with an increase in the mean catchment elevations (n = 24, R^2 = 0.43, $p < 0.001$), but those of SO_4^{2-} slightly decreased (n = 24, R^2 = 0.43, $p < 0.001$).

The annual mean DIN (NH_4^{+} + NO_3^{-}) concentrations slightly increased with an increase in the mean basin elevations (n = 24, R^2 = 0.20, p = 0.03), but those of PO_4^{3-}



c) d)

Figure 16—Average soil C:N (c), NH_4+ and NO_3- (b) concentrations in the KREW watersheds.

significantly decreased. The correlation for PO_4^{3-} was significantly different for the water years 2006 from 2004 and 2005. Though the slope was about the same for all water years, the intercept was higher for 2006 than for 2004 and 205.

The inverse trends for DIN and PO_4^{3-} indicate that ecosystems in those catchments are still N-limited. If atmospheric deposition stays constant and current trends toward warmer temperatures and more rain than snow continue, N retention will increase and thus biomass production will increase (because P is still abundant).

Water, geochemical cycles, and upscaling of in-situ measurments. The mean snow water equivalent (SWE) for all measurements was 24.8 cm in 2007 and 88.4 cm in 2008 with a 14 and 32 percent difference, respectively, between the under canopy and open measurements. Spatial heterogeneity in SWE, snowmelt, and soil moisture timing are all influenced by orientation to and proximity with tree canopies (Figures 17-20).

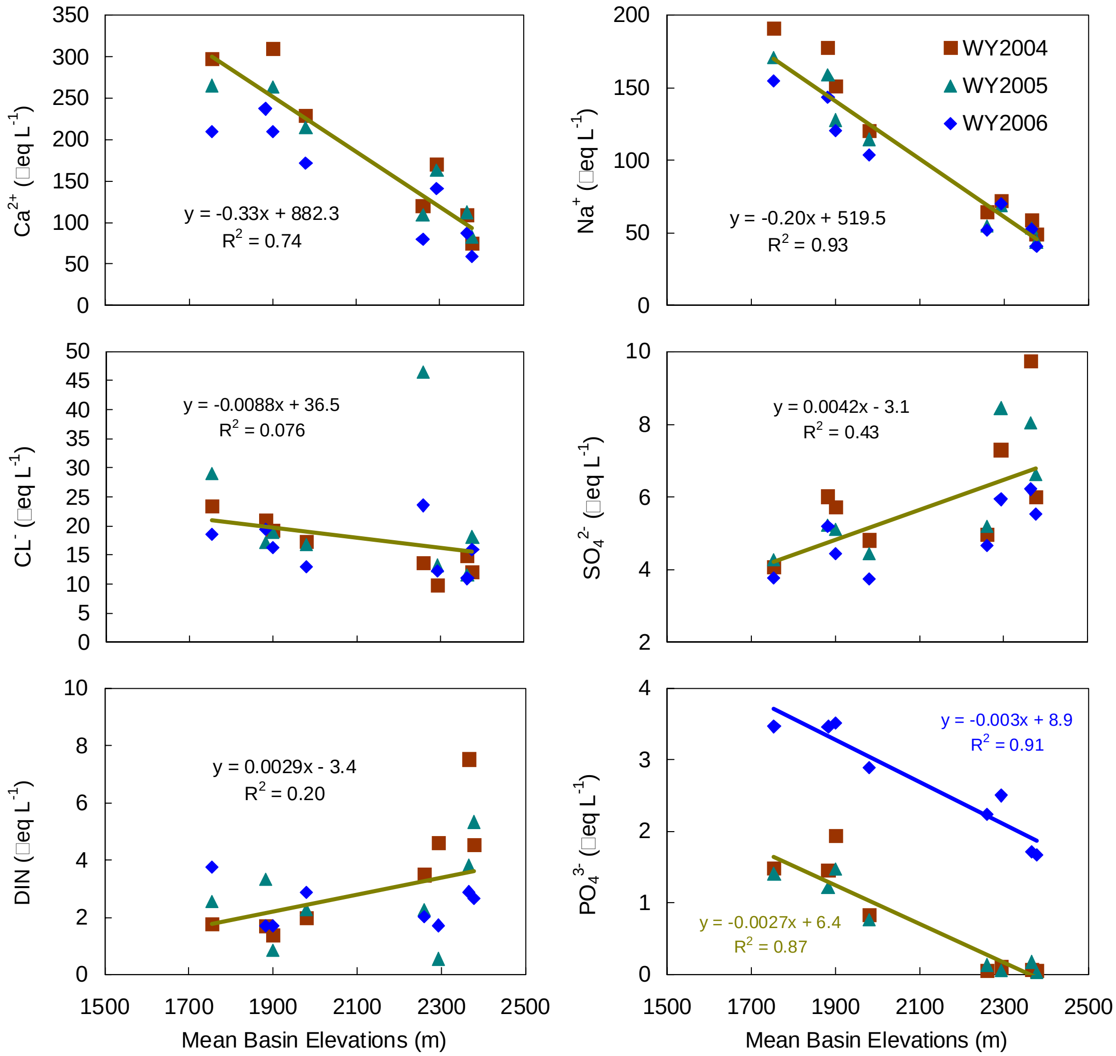


Figure 17—Correlation of annual mean ionic concentrations with mean catchment elevations at eight small catchments in a snow and rain transition in the central Sierra.

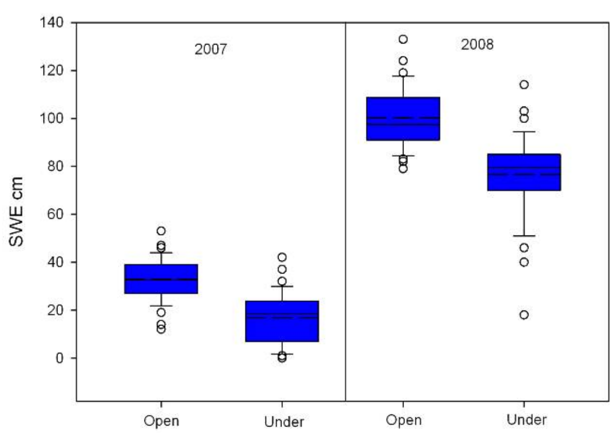


Figure 18—Box-plots of 496 measurements of open and under canopy SWE, at 36 locations for 2007 and 2008.

Differences between the open and under canopy are most prominent in locations that have high solar incidence during ablation (Figures 18-20). Similar patterns are observed in 2007 and 2008 despite large differences in total precipitation (Figure 20).

At the Wolverton baseline sites, infiltration from snowmelt occurred over a three month period starting in mid March and ending in late June during the 2008 water year (Figure 21a-b). At these locations snow melt-out occurred over a 4 week period depending on the relationship to the forest canopy with south facing under canopy sites melting out first and open canopy shaded sites melting out last. Soil moisture tracked the snowmelt pattern closely with diel fluctuations in saturated conditions, while the snow pack was melting. After melt-out saturated conditions ceased and there was an exponential dry-down to field capacity. This was followed by a prolonged summer drought punctuated by rain events that contributed less than 5% of total annual precipitation.

The differences in soil moisture amplitude are a function of heterogeneity in soil characteristics and litter depth. Rain events are also detectable at all sites but the those with deep litter, which becomes hydrophobic as it dries out, show a muted response and are more prone to preferential flow paths.

Initial analysis of the synoptic soil moisture survey carried out in the Teakettle Expiremental Watershed indicates that measurements were taken disproportionately on West to South facing slopes with very few measurements acquired from northeast facing slopes (Figure 22). Soil moisture was consistently lower on steeper slopes than those with less slope in each survey, and decreased consistently through the water year with the exception of those conducted following a summer rain events (Figure 23). Soil moisture was consistently lower under canopy than in the open, with values converging in late season after dry-down (Figure 24).

Physical weathering rates. Analysis of preliminary samples is in progress.

Snow processes. Nothing to report.

Organic carbon in streams. Nothing to report.

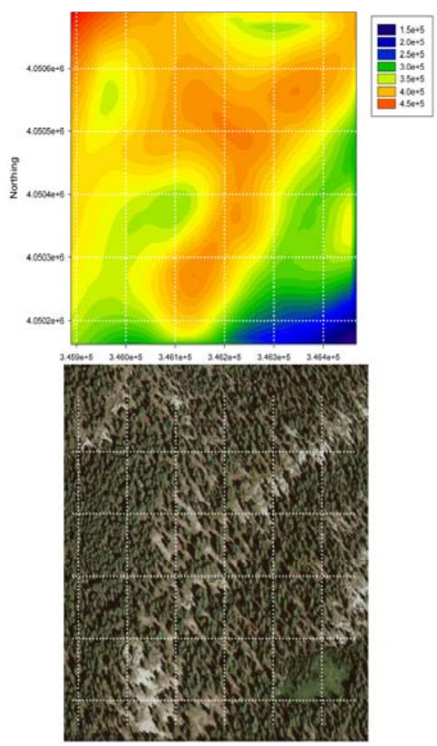
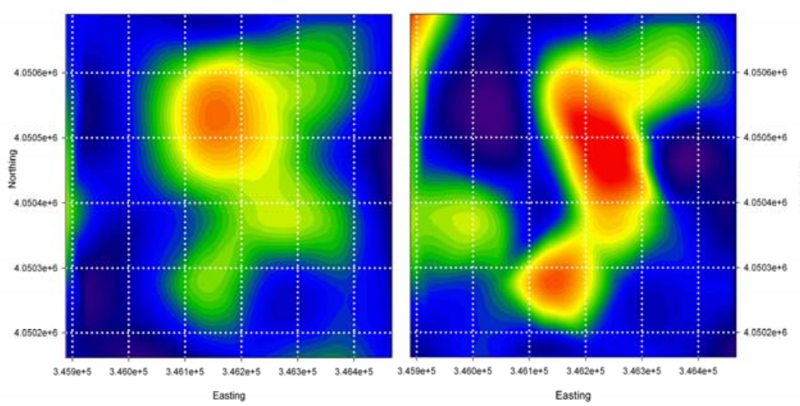


Figure 19—Top panel is clear-sky insolation in total Wh/m2 was modeled using a transmittivity of 0.7, to account for reduced air mass attenuation at higher altitudes, at ½ hour time steps. Bottom panel is an areal photograph



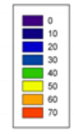


Figure 20—Percent differences between open and under canopy SWE measurements for April 1st (± 2 days) in 2007 (left) and 2008 (right) show consistent

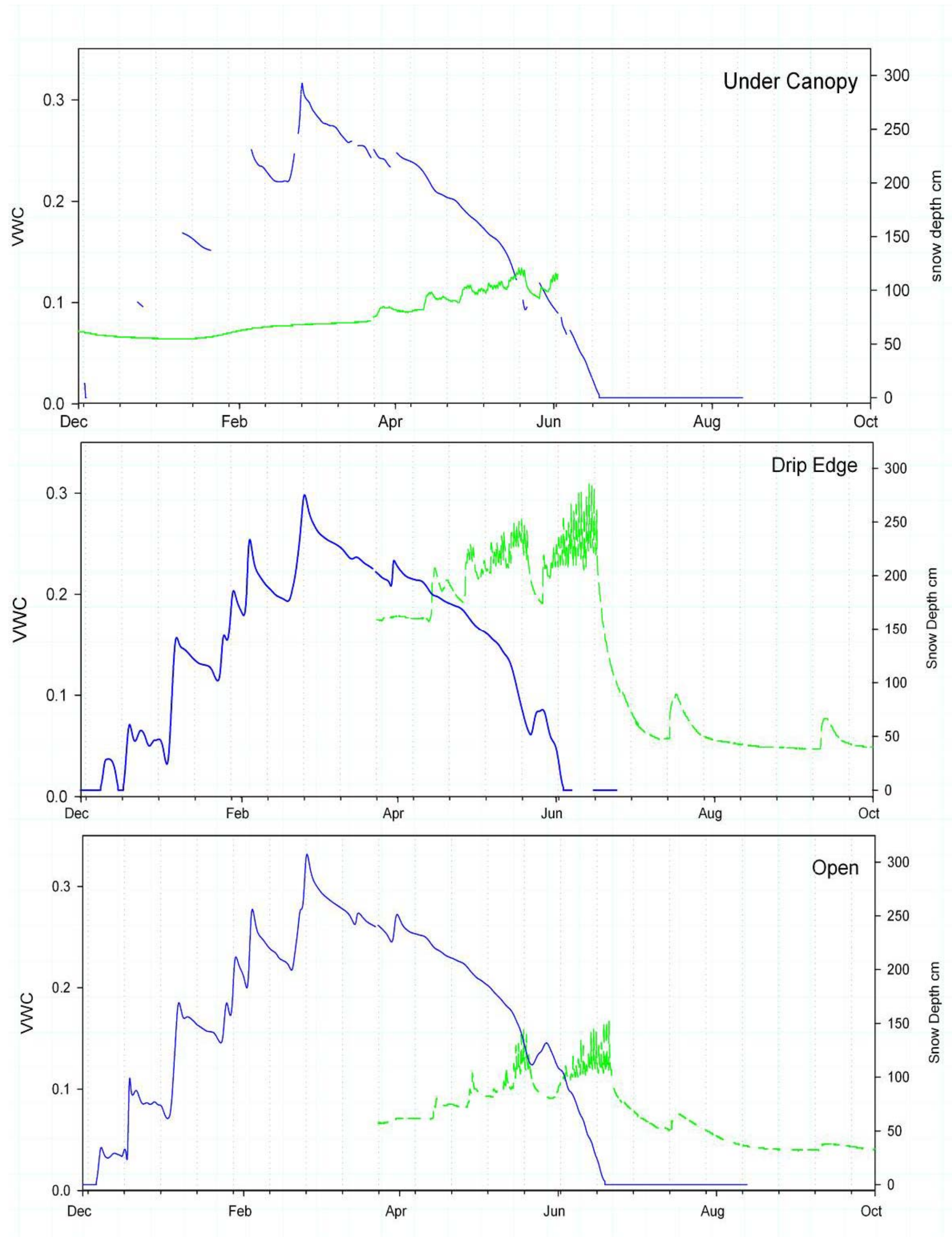


Figure 21a—Infiltration of snowmelt to soil at a north facing slope in the Wolverton baseline cluster. Blue line is the integrated top 20 cm soil moisture content and the green line is snow depth.

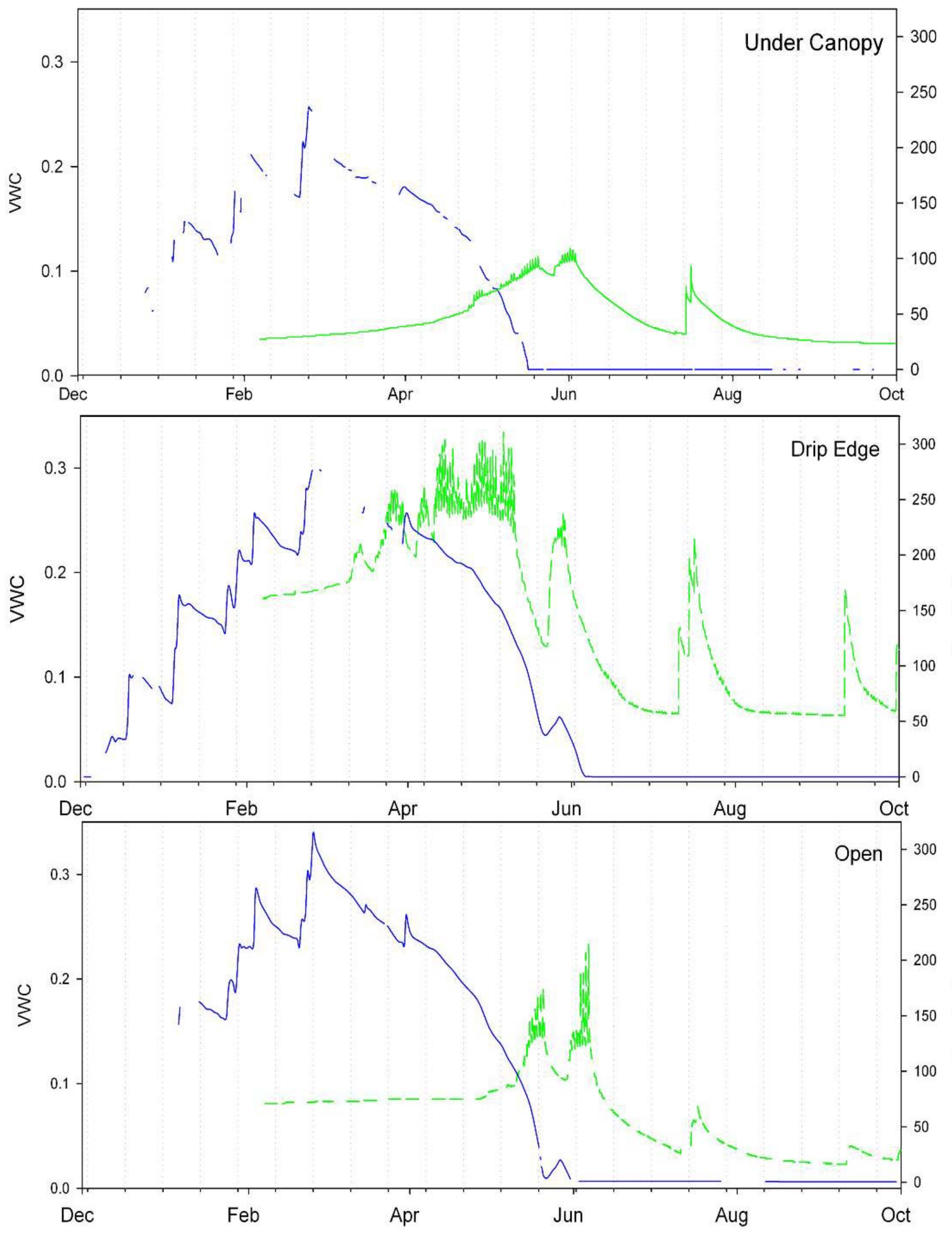


Figure 21b—Infiltration of snowmelt to soil at a north facing slope in the Wolverton baseline cluster. Blue line is the integrated top 20 cm soil moisture content and the green line is snow depth.

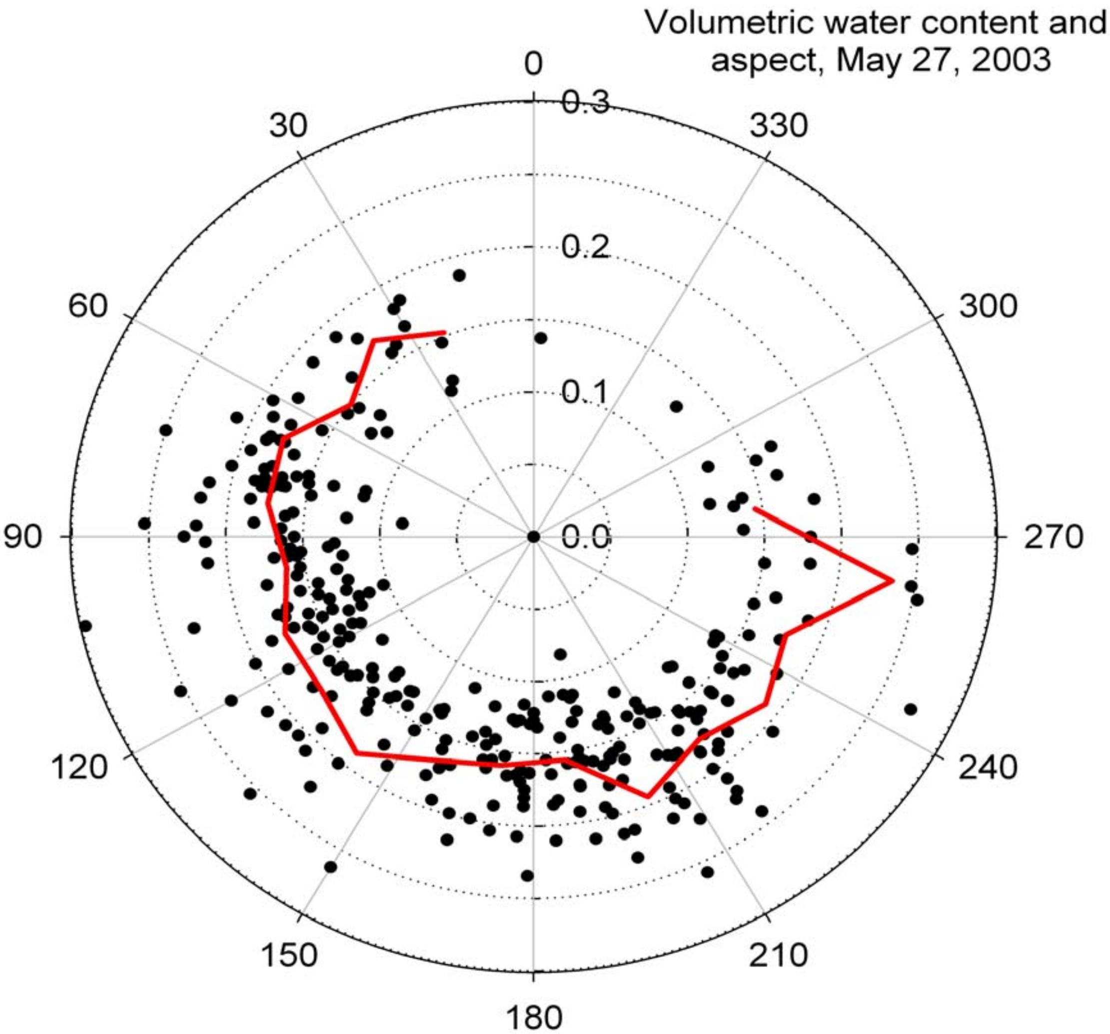


Figure 22—VWC and aspect of points where soil moisture was measured in the Teakettle Experimental Watershed

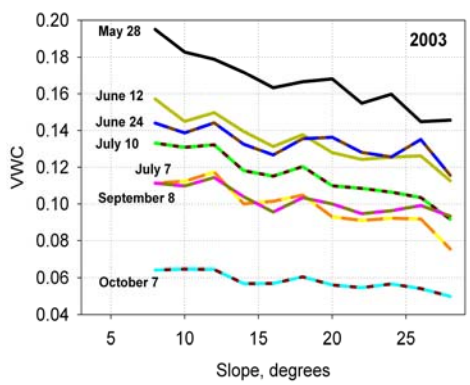


Figure 23—Soil moisture content and slope angle in the Teakettle Experimental Watershed.

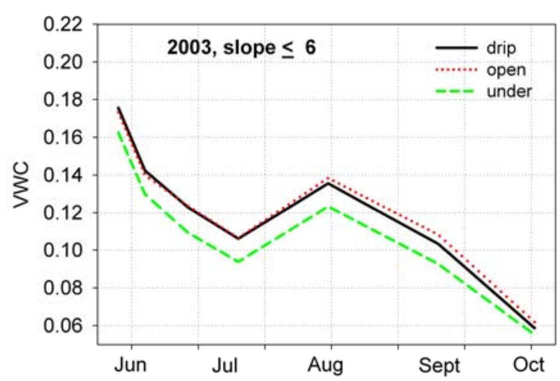


Figure 24—Mean soil moisture content during the 2003 growing season.

Photo credits. Figure 14: Margot Wholey (http://margotwholey.com/).

Activities

The following gives the status of various activities in the work plan. Refer to the section in the work plan of the same title for additional description of activities.

Core CZO measurements, data management and integration. The 50-m flux was instrumented in July-September, 2008. The flux tower is collecting consistent data, which is being telemetered via cellular connection. Most of the ground-based part of the water-balance instrument cluster installation at KREW was completed by summer-fall 2008; two soil moisture node transects remain to be installed in the meadow during summer 2009 (Figure 1). Ground-based water balance instrumentation is producing consistent data around 13 trees, in 3 meadow transects, at 3 aspects and 3 elevations (Figure 2). The Wolverton baseline instrument cluster has continued producing quality data. Otto Alvarez has continued part-time data management; supplemental data management has been conducted by Matt Meadows, Xiende Meng, Ryan Lucas, and Peter Kirchner. The digital library is functioning and is populated with data.

Wireless sensor platforms, or motes, have been deployed and integrated with the P301 ground-based water balance instrumentation over the past year. Dust Networks, an early offshoot resulting from research at UC Berkeley, originally designed the motes for highly demanding industrial applications. The mote platforms were expanded and equipped with sensors to measure snow depth, soil moisture, matric potential, humidity, temperature, and solar radiation. The resulting wireless network is distributed, self-

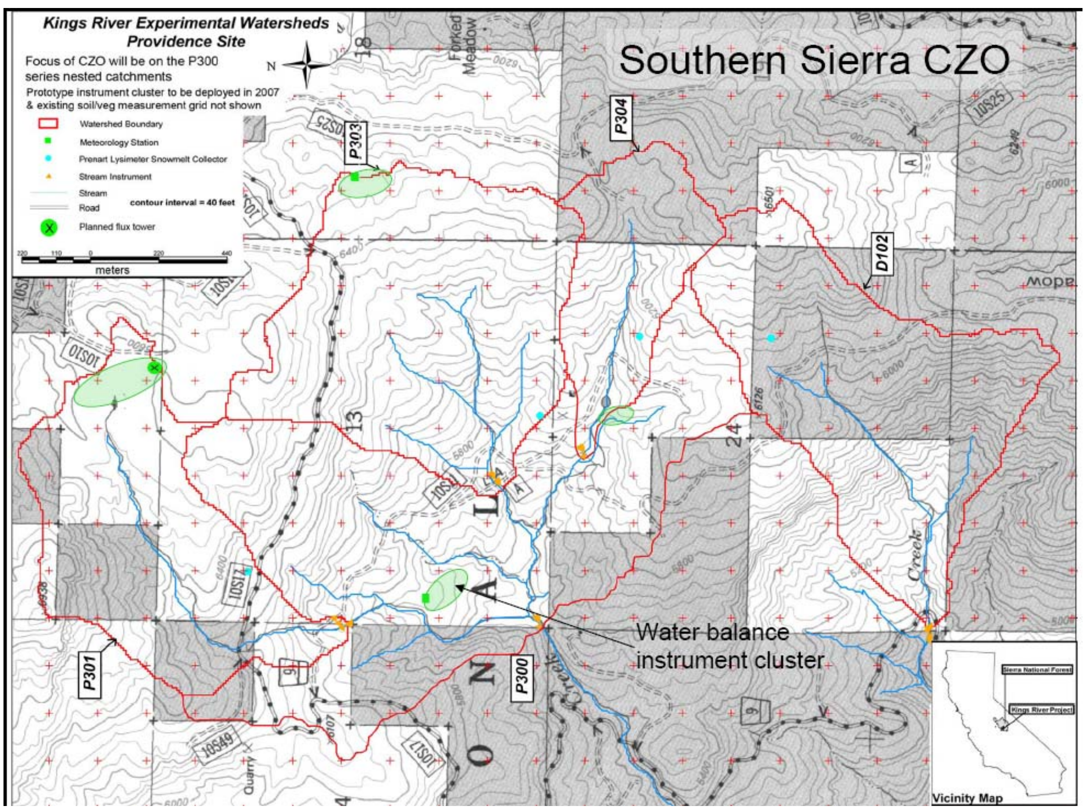


Figure 1—Instrument cluster design at KREW CZO site. Shaded green areas illustrate primary instrument node locations, strategically placed to capture variability in elevation, aspect ad vegetation properties.

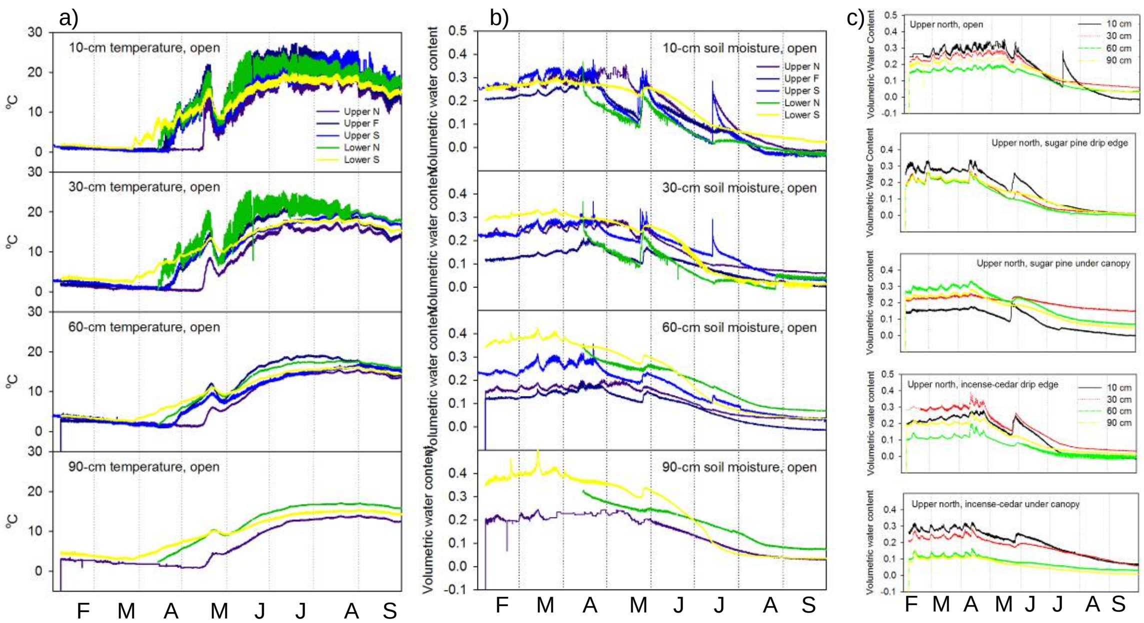


Figure 2—Soil temperature (a) and soil moisture (b) data collected around 11 trees at 3 aspects and 2 elevations. Vertical soil moisture profiles from nodes located at the upper elevation and north facing aspect (c).

assembling, and self-healing, meaning that if links in the network go down unexpectedly, alternative links form to ensure no data will be lost.

The overall system currently consists of 60 motes, and over 250 sensors, a central data hub (which can be connected to the Internet), and solar assembly for power. The wireless nature of the systems permits for data to be sampled at a large scale, and subsequently to be piped to a central location, and aggregated for easy collection, this would not have been possible with conventional wired setups (Figure 3).

Half of the motes are used as sensing platforms, while the remaining motes were employed for data-hopping purposes to reliably transfer data through the network. Each mote is able to run on a single 1.5V battery for two years without requiring a battery replacement. Linking the system to the Internet in the future will permit for the data to be available in real time, allowing decision makers to more accurately forecast runoff from snowmelt dominated catchments. The vast data set obtained through this system will ultimately be key in the development of a comprehensive understanding of the dynamic processes guiding snowmelt dominated regions.

The education and outreach position was filled in May 2009 (Ryan Lucas). In anticipation of taking on the position, Ryan gave a talk at a weekend seminar for the Institute for the Development for Emerging Area Leaders (IDEAL) associated with the Great Valley Center. The topic of the talk was climate change and much of it was focused on potential effects of climate change on hydrologic processes in the Sierra Nevada and the Central Valley. Ryan is currently in the process of outlining and developing the first educational module for our target audience, the Yosemite Institute. The first education module will be centered on the hydrologic cycle with specific focus on hydrological processes in the Southern Sierra.

C**ore KREW measurements and data management.** Streamflow, meteorological, turbidity, and sediment data analysis has continued. Collaboration between USFS and CZO personell is ongoing and will continue in the production of the series of manuscripts discussed in the included Workplan. See Figure 4ab for a typical stream control section in CZO/KREW catchments.

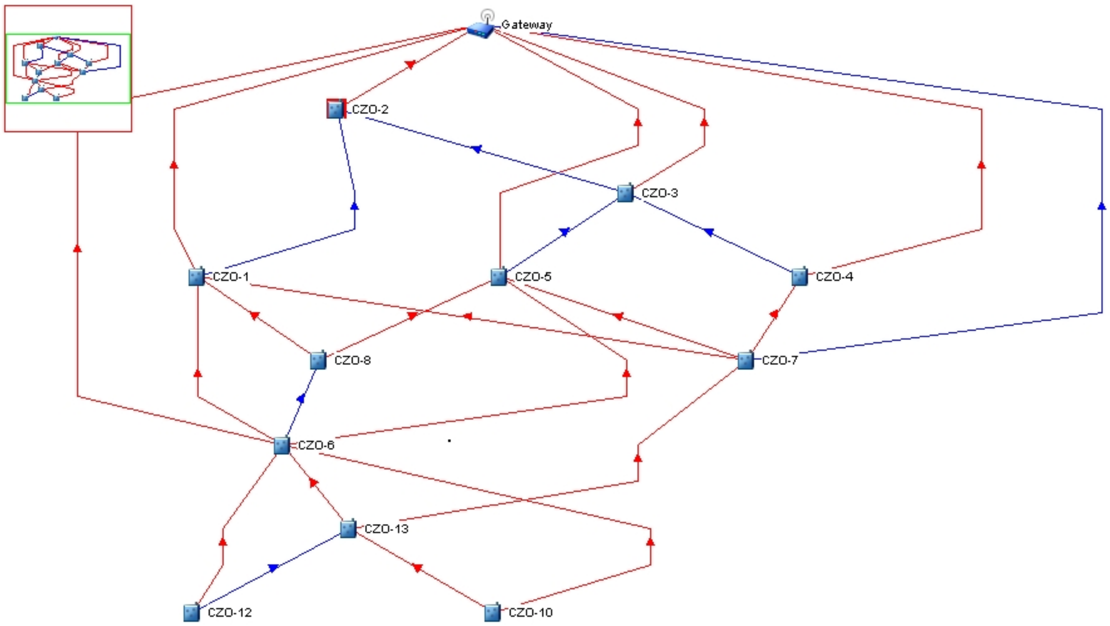


Figure 3—A schematic representations of the Dust wireless network. The motes can communicate with their neighbors and with the central data hub.

a) b)

Figure 4—Looking up (a) and down (b) stream of a typical stream control section in the CZO/KREW catchments.

Modeling of water and nutrient cycles. The RHESSys hydrologic model was calibrated for 4 sub-watersheds in the Southern Sierra CZO. This baseline will be used to examine model sensitivity to a) small scale variation in snow accumulation and melt and soil moisture as characterized by ongoing field measurements and b) climate variation and change will be assessed using the baseline set of model runs. The model will be refined to better simulate the watershed processes.

Near-surface soil-water processes. The soil moisture arrays at Wolverton continue to operate and have been providing data for 2-3 years. A Crossbow wireless network provides for telemetry of data to enable real-time access. Analysis of data is in progress. With the exception of two transects in the P301 watershed, the soil moisture/temperature network for the KREW site has been installed (Figures 1-2). The soil moisture/ temperature nodes at the upper and lower meteorological stations are hard-wired to loggers while the nodes around the flux tower utilize the DUST wireless network (Figure 3).

In August 2008 we instrumented a white fir (*Abies concolor*) tree (CZT-1) in the SSCZO with soil moisture, temperature, matric potential (MPS) sensors and tensiometers. We placed the sensors in a radial array around the tree to capture the changing dynamics of the water content across the growing season and through the winter season (Figure 5-6). The tree is located within the Kings River Experimental Watershed (KREW), at an elevation of 1900m. The tree itself was also instrumented with sap flux sensors and time domain reflectometry (TDR) for determination of changes in stem water content. Ninety soil sensors are spread over a spatial array at 30 cm depth and also distributed across 6 vertical pits to a depth of 90cm. Collocated within this plot are four water balance clusters (UCM pits) consisting of additional soil moisture measurements, snow depth and solar radiation. All sensors are autonomously powered (solar panels) and use radio transmission to the P301 Flux tower. From there, data is transmitted by cell modem to UC Davis. Also installed on the CZT-1 site was a camera to monitor changes in snow depth (Figure 6).

Ongoing research into summer 2009 will involve integrating

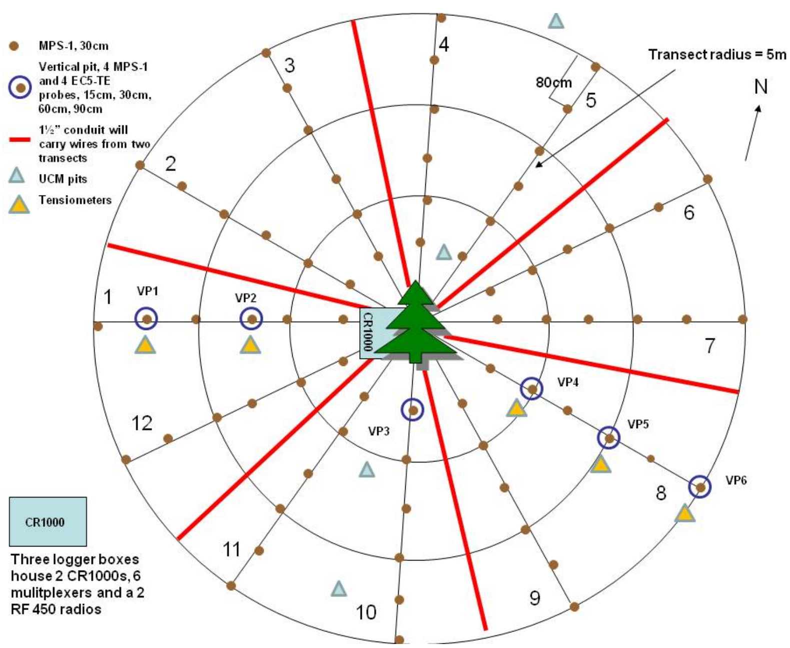


Figure 5—Site Layout showing radial array of soil sensors and locations of vertical pits and tensiometers.

measurements at the tree, stem water content, sap flux, and stem water potential, with measurements of changing conditions in the subsurface. A Ground Penetrating Radar (GPR) survey of the root structure is planned to better determine the point locations of moisture extraction by the tree. Moreover, we will calibrate the soil water potential sensors (MPS) with co-located tensiometers, thereby allowing evaluation of soil water stress and its spatial distribution on tree transpiration. Co-monitoring the tree and the soil across the developing moisture stress conditions of the Mediterranean summer will provide valuable data on the interaction of surface/subsurface water dynamics in a mid latitude alpine forest. Measurements taken at the tree can be scaled up to catchment scale using data from the 50m P301 flux tower adjacent to the plot.

Figure 6—CZT-1 instrumentation

Physical controls on water and carbon exchange and plant production. Our main accomplishment during the last year was the installation and operation of the eddy covariance tower at the top of the P301 watershed. A contractor installed the tower in early summer 2008, and we installed the power infrastructure in June 2008. We instrumented the tower in Sept 2008, and have operated it since then. The tower transmits a subset of observations hourly, which allows us to keep an eye on how the system is functioning. The complete data set is collected manually approximately every month and is transferred to UCI via the internet. These data are then processed, and posted on the digital library at Merced.

We expect to add towers at the Soaproot Saddle and Courtwright sites, and possibly also San Joaquin Range, in summer 2009. We also plan to begin periodic observations of litter-fall, stem increment using dendrometers, and LAI using a LiCor LAI-2000 at all sites. The Courtwright site is particularly interesting, since we suspect this site is too high for consistent winter photosynthesis. We are also very interested in comparing the summer drought stress at the sites, and expect to find the rates of late summer CO_2 uptake increase with elevation. We feel we are making significant progress to understanding the relationships between climate, water balance, plant physiology, ecosystem production, and the distribution of vegetation across the mountain front, and expect this progress will accelerate as we add more sites.

Surface-groundwater interactions. The intensive meadow water-balance experiment was carried out in July 2008, at Long Meadow, Wolverton. The distributed temperature sensor (DTS) fiber optic cable was laid in the meadow stream for a five day deployment in July 2008. Further evapotranspiration (ET) investigation of Long Meadow and the P301 meadow will commence upon completion of the construction of a small ET dome.

Meadow stream pools exhibiting anomalous temperature behavior were investigated by placing Hobo Tidbit temperature loggers in the pools. The Tidbits were placed at varying depth in order to capture meadow stream pool stratification. We utilized Fluent, a fluid mechanics modeling software, to simulate a 2-dimensional model of a "typical" meadow pool. Initial conditions were set to mirror observed conditions in the Lodgepole-33 pool and meteorological parameters were input from values measured at the micro-meteorological station. Simulations were run with varying input stream velocities. Analysis of the model results are in progress. Further investigation into the temperature stratification behavior of meadow pools is planned for summer 2009. A manuscript describing meadow pool behavior is in progress.

All but two meadow transects in the P301 watershed—comprised of soil moisture/temperature, snow depth, and shortwave solar radiation sensors paired with clustered groundwater monitoring wells/piezometers—were installed summer and fall 2008. The remaining two transects will be installed summer 2009.

Nitrogen cycling in soil . Soils from the KREW watersheds have been analyzed for total C, total N, NH_4^+ and NO_3^-. Further analysis of this data will entail calculating soil contents from bulk density and rock content data and correlating the soil content to watershed parameters like rock content, location, vegetation cover, elevation, aspect, etc.

Pre-treatment sampling for the hot spot study started during the summer 2008. Pre-treatment sampling included collecting litter layer O horizon inter-flow water samples and resin nutrient sampling as described in the workplan (see attached workplan). O horizon inter-flow water samples were collected starting summer 2008 through spring 2009. Resin nutrient collectors were deployed summer 2008 and retrieved spring 2009. O horizon inter-flow and resin samples are currently undergoing analysis.

Nitrogen fluxes from soil. Initiation of this project is underway.

Baseline hydrologic, sediment and geochemical characterization. Analysis of the water samples collected bi-weekly at the KREW watershed gauging stations has commenced. In cooperation with PSW, Fenjing Lui is conducting this analysis.

Water, geochemical cycles, and upscaling of in-situ measurments. Measurements from the Wolverton basin in Sequoia National Park and the Teakettle Experimental Forest in the Red Fir zone of the southern Sierra Nevada (2,300-2,600 m elevation) were used to evaluate our hypothesis that topography and vegetation cover are the most important variables affecting snowmelt and soil moisture. Our strategy is to combine synoptic surveys and instrumental data from both sites to describe these processes across broad temporal and spatial scales.

Synoptic snow surveys of a 0.6 sq km area in the Wolverton Basin were conducted in April 2007 and 2008. Annual precipitation was below average in 2007 and above in 2008. Depth and density were measured at 36 grid points, four times under the canopy of the nearest mature Red Fir tree and four times in the closest canopy gap.

Synoptic surveys of soil moisture were carried out in the Teakettle Experimental forest as part of a comprehensive study on forest management. Soil moisture was measured at buried probes at multiple locations seven times over the water year using time domain reflectometry. Initial analysis of the 2003 survey has been conducted. Further analysis of this data is in progress.

Physical weathering rates. In the first part of 2009, Cliff Riebe worked with CZO investigator Jim Kirchner and PI Roger Bales to assemble a work plan and budget for the measurement of long-term rates of physical erosion and chemical weathering in the CZO watersheds. Together, they defined a series of questions that are designed to improve understanding of long-term hillslope processes, while addressing as many as possible of the other research aspects of the overall CZO work plan and identifying potential collaborative linkages among the CZO investigators.

Riebe, Kirchner, and Bales also laid out rough plans for data collection and analysis. According to the plan, the main thrust of the fieldwork would begin in the summer of 2009. A set of preliminary samples was collected earlier by Kirchner and Riebe, in September 2008, immediately after the annual all-CZO meeting at Shaver Lake. These samples were transported by Riebe to the University of Wyoming. To assist in the preparation of these samples, Riebe has employed a recent graduate of Geology and Geophysics from the University of Wyoming. This student has made significant headway on preparing a series of soil and rock samples for XRF analysis; the goal is to measure the bulk chemical composition of each sample and quantify the chemical alterations that have occurred as the rock was converted to soil by weathering processes. The student has also cut a series of CZO rock samples (also collected by Riebe and Kirchner) for preparation of polished thin sections.

Riebe has recruited a graduate student to work on the CZO project. The student, Barbara Jessup, will be matriculated in Fall 2009 at the University of Wyoming as a candidate for an MS degree in Geology.

According to the plan, Riebe and Jessup will converge at the CZO late in the summer to begin sample collection and start the Ground Penetrating Radar survey. A contingency for additional work in the early fall is also in the plans.

Snow processes. A series of snow surveys was carried out in the Wolverton basin for the second consecutive year. Data analysis is in progress.

Organic carbon in streams. Sampling for organic carbon in the KREW streams commenced in April 2009. Samples have been collected monthly at the KREW gauging stations; sampling has coincided with the bi-weekly major ion sampling conducted by the PSW field team. Along with the organic carbon samples, water isotope samples have been collected. The collected organic carbon samples have been sent to Elizabeth Boyer at Pennsylvania State University for analysis. Water isotope samples are being stored for future analysis.

Photo credits. Figure 4: Ryan Lucas**.** Figure 6: Peter Hartsough.