Sierra Nevada Adaptive Management Project

Water-Team Update

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Executive Summary

This report is an update of results from the original documentation of the water component of the Sierra Nevada Adaptive Management Project (SNAMP), dated July 2012, which covered water years 2008-2011. The results presented here cover water years 2012 and 2013, the remaining 2 measurement years of the 7-year SNAMP study, with this current. This current and final year are focused on data analysis, hydrologic-modeling results (for both the catchment scale and upscaled to the fireshed), and integrating the hydrology results with the other components of SNAMP (including a 30-year hydrologic simulation). The background and methods from the original report are still current and are in Appendix C.

SNAMP is an integrated effort designed to study forest management from an ecosystem perspective - more specifically, to assess the effects of Strategically Placed Landscaped Treatments (SPLATs) in the mixed-conifer zone of the Sierra Nevada. In addition to water, investigations of forest health, forest fire, wildlife, and spatial processes is being conducted simultaneously in the same region. The hydrology (water) component focuses on detecting and predicting changes in the movement and timing of water flowing through these mountain catchments as a result of vegetation management, and on detecting changes to water quality. We hypothesize that the tree thinning and prescribed burning implemented with SPLATs will alter the timing of streamflow, increase water yields, and increase sediment movement within the stream channel due to the increased water yield.

The two SNAMP study areas are Last Chance, in the Tahoe National Forest, and Sugar Pine, in the Sierra National Forest. Within each study area, two headwater catchments were chosen for intensive monitoring, providing a treated and untreated watershed in both areas

The implementation of the Strategically Placed Landscape Treatments (SPLATs) were initiated in autumn 2011, and were completed in autumn 2012, a year later than scheduled. As a result, there is only one post-treatment water year (2013) instead of the two that were in the original study design. This delay in completion of SPLATs has led to a number of adjustments to the study timeline, with the delay in LiDAR analyses affecting interpretation of the hydrologic results. We require spatial information regarding the quantity of vegetation removed in the study sites, expected in fall 2014, in order to move forward with the final analysis and hydrologic modeling of the treatment effects on the water balance. In August 2013, the American River Fire burned through our treatment catchment, Bear Trap Creek. This complicates post-treatment analysis, but it also provides an opportunity to look at the effect of a low to medium-severity wildfire event.

Water years 2012 and 2013 were both dry years, with precipitation below average during both winters. Last Chance (Tahoe NF) recorded 146 and 154 cm while Sugar Pine (Sierra NF) recorded 97 and 128 cm of precipitation for 2012 and 2013, respectively. Annual stream discharge for both years was about 50 cm for the Last Chance headwater catchments and about 27 cm for the Sugar Pine headwater catchments. This resulted in a specific yield (discharge divided by precipitation) of approximately 0.37 in Last Chance and 0.24 in Sugar Pine for both years, which were lower yields than in the average and high precipitation years of 2010 (0.55 Last Chance, 0.41 Sugar Pine) and 2011 (0.58 Last Chance, 0.49 Sugar Pine). The dry conditions post-treatment also muted any hydrologic response to the treatments.

The Regional Hydro-Ecological Simulation System (RHESSys) has been set up to model the effects of the completed treatments, as well as the effects of further forest management and wildfire. The snow, soil-moisture, and streamflow data in this report are used to constrain the modeling, and preliminary calibrations are presented here. Finalization of the model, parameter calibration, and treatment results will be produced after the LiDAR vegetation layers are available.

Introduction

The Sierra Nevada Adaptive Management Project (SNAMP) is a joint effort by the University of California, state and federal agencies, and the public to study management of forest lands in the Sierra Nevada. The SNAMP team is assessing how forest vegetation treatments to prevent wildfire affect fire risk, wildlife, forest health and water. The USDA Forest Service's 2004 Sierra Nevada Forest Plan Amendment calls for managing the forest using the best information available to protect forests and homes. Vegetation management treatments are planned or being conducted in several places in the Sierra Nevada where fire risk is high. Millions of acres of Sierra Nevada forest are endangered by wildfire.

This report is summarizes the water quantity and quality monitoring for the Sierra Adaptive Management Project (SNAMP) for the water years 2012 and 2013. These results are an update to the July 2012 report on the period 2008-2011. The text of that report is appended. Figures 1-23 are incorporated into this report to provide a complete data record for the SNAMP. Data for water years 2012 and 2013 start at Figure 24. Additionally, analysis of water chemistry samples was incomplete at the time of the original report, but has since been completed and is included in this update.

This year the water team is focused on data analysis, hydrologic-modeling results (for both the catchment scale and upscaled to the fireshed), and integrating the hydrology results with the other components of SNAMP. In order to produce effective recommendations for land managers regarding the implemented forest treatments, it was decided to model the effects of these treatments on forest health, wildfire, water, and spotted owl habitat over 30 years. It has been estimated by previous studies that fire risk returns to pre-treatment levels within two to three decades. However, an integrated product over the extended timeline also required a new vegetation map that could be used for multiple analyses: forest growth and fire modeling, hydrology modeling, and spotted owl habitat assessment. This new spatial vegetation information was derived from a combination of lidar and forest plot data to produce more detailed information on forest community types, canopy cover, and vegetation density.

Methods

Methods described in the original 2012 data report are still current and are not repeated in this updated report. Presented here are some updates and additional information on data-collection and additional methods for analysis. In August 2013, the American River fire burned our treated catchment, Bear Trap, and some instrumentation was lost and some data records were interrupted.

Snow Depth

Additional snow-depth measurements (2012-2013) were distributed around the meteorological stations and the stream instrument clusters at the northern site to measure variability across the landscape. These installations were part of the wireless sensor network testbed for the American River Project but relevant data collected at the SNAMP instrument locations are presented here. Snow depth was gap filled from adjacent measurements prior to spatial averaging.

Stream Water Quality

The water-quality attributes of water temperature, conductivity, dissolved oxygen, turbidity, and stage continued to be collected in all study catchments using multi-parameter continuously running sondes. Water-quality attributes and stream stage are reported here in 15-minute time intervals. The meteorological attributes of air temperature, precipitation, and snow depth, plotted on the following graphs for reference to the water-quality data, are reported in daily time intervals. Air temperature was recorded at the study-site met stations. In the original data report, we reported precipitation measurements from our study sites. Because the study-site rain gages were unheated and unshielded, there was concern over their accuracy. In the data report update, precipitation reported are from the nearby stations Blue Canyon (for Last Chance) and Westfall (for Sugar Pine). As the precipitation data are provided for explaining trends, we opted for the more accurate data set. The plotted snow-depth values represent means of all snow-depth measurements at a given site.

Starting in WY 2012 a second multiparameter sonde co-located with the original sondes was installed in all catchments except Frazier Creek. These sondes measured water temperature, conductivity, and turbidity for data redundancy. Data from all the multiparameter sondes were manually checked to remove any erroneous spikes due to maintenance of sensors, sampling in the stream, or (for turbidity and dissolved oxygen) periods when the sonde was buried in sediment. To reduce sensor background noise, the turbidity data were filtered to remove any values less than 5 NTU. The remaining values were considered actual turbidity events and were used in analysis. Gaps after the WY 2012 installation were filled using the secondary sonde. When data from the secondary sonde were unavailable, only water temperature and stage could be gap filled using data from the stand alone stage recorders.

Turbidity events were classified according to seasons, with fall defined as first fall rain event to before the beginning of snow accumulation, early/mid-winter as beginning of snow accumulation to peak accumulation, snowmelt as peak accumulation to complete melt out, and base flow as full melt out to first fall rains. Intensity values of storm events were analyzed by subtracting peak discharge values from background discharge values defined by a 15-day running average.

Adjacent to the multiparameter sondes, automated water samplers were installed to collect suspended sediment samples. These samplers were tied to the sonde turbidity measurements and programmed to increase sampling frequency during turbidity events. Manual grab samples for suspended sediment, major ions, and stable isotopes were also collected on a monthly to bi-monthly basis. Manual and automated suspended-sediment samples were filtered using 0.45-micron filters, dried, and weighed to determine suspended-sediment concentrations. Major-ion samples were filtered, then split in half for ion-chromatography analysis of major cation and anions as well as titration analysis for acid neutralization capacity (ANC). Isotope samples were processed using integrated-cavity laser spectroscopy to determine the delta D and delta ^{18}O of samples.

Load-cell pressure sensors were placed near the water-quality instrumentation to measure bedload movement and channel-bed-elevation changes. Bank pins were installed (6-9 locations per stream) at the southern site to measure streambank erosion according to the methods outlined in Martin (2009). Attempts were made to install them at the northern site, but due to the high cobble and boulder content of the stream banks, the rebar pins could not be set. Cross-sections at the scour-pan locations and bank surveys at the bank-pin locations were completed several times throughout the study, typically during late-summer/early-fall low flows. Additional data on particle-size distribution, and localized gradient were also collected.

Stream Water Quantity

Stage values measured by the two pressure-recording instruments within each stream showed good agreement, so the record with greater confidence (i.e. fewer relocations, fewer malfunctions, more stable cross-section, etc) was chosen as the primary record for calculating discharge. Where gap filling was necessary, it was performed using the record from the secondary stage instrument.

Results

Meteorological Data

Hourly meteorological data continued to be recorded at the four stations, capturing the range of environmental conditions present within the four study basins. Figures 24 and 25 show the daily observations of solar radiation, precipitation, temperature, relative humidity, and wind speed, as well as net radiation for observing energy exchanges between the ecosystem and atmosphere. The upper and lower elevations at Last Chance showed greater differences in the meteorological observations than the Sugar Pine stations.

Precipitation measured in Last Chance was 146 cm in 2012 versus 154 cm in 2013; while Sugar Pine had 97 and 128 cm in the same years (Figures 24-25). Spatial differences in precipitation showed the northern study area of Last Chance, located within the American River basin, had about 40-cm higher levels annually than the southern study area of Sugar Pine, located within the Merced River basin. Precipitation at the higher-elevation stations of Duncan Peak and Fresno Dome (elevation >2100 m) is dominated by snowfall, while the lower elevation stations of Bear Trap and Big Sandy (1500-1800 m elevation) recorded similar levels of rain and snow.

Temperatures at Bear Trap averaged 10.4^{o}C (ranging -12.3 to 34.0) and Duncan Peak averaged 8.3^{o}C (-13.7 to 33.2) at Last Chance, while Big Sandy averaged 7.1^{o}C (-17.0 to 30.8) and Fresno Dome averaged 8.5^{o}C (-13.6 to 29.3) at Sugar Pine for WY 2012 and 2013 (Figures 24-25). This reflects a temperature difference of only 1.2 ^{o}C per 300 m elevation for Last Chance, and 1.0 ^{o}C for Sugar Pine. Daily maximum temperatures between the two sites differ by about 1.8 ^{o}C, versus 1.0 ^{o}C for daily minimum temperatures.

Higher relative-humidity values were recorded at the lower-elevation sites, with mean-daily wind speeds around 2 m s^{-1}, and the major wind direction being S-SE for all sites for WY 2012 and 2013 (Figure 24-25). Wind speed and direction were not able to be gap filled, due to the individual nature of wind conditions at each site.

Upper-elevation stations received slightly higher total daily solar radiation inputs during the summer than lower elevations due to the lower horizon, and the southern study site received more than the northern study site (Figure 24-25). Approximate maximum radiation values for WY 2012 and 2013 were 32 MJ m^{-2} day^{-1} at Fresno Dome, 30 MJ m^{-2} day^{-1} at Big Sandy, 30 MJ m^{-2} day^{-1} at Duncan Peak, and 25 MJ m^{-2} day^{-1} at Bear Trap. Absolute radiation values cannot be obtained due to the limitations of the LI-COR pyranometer used.

Maximum summer net radiation followed a similar stratification with values of 23, 23, 18, and 15 MJ m^{-2} day^{-1} at Fresno Dome, Big Sandy, Duncan Peak, and Bear Trap respectively. Net solar radiation was small, and in many cases close to zero for water year days 60 to 150 for all sites. The Duncan Peak station (higher elevation) also showed greater variability in net radiation than did Bear Trap (lower elevation).

Snow Depth

Site-averaged snow depth peaked at 53 cm for WY 2012 and 18 cm for WY 2013 at Last Chance (Figure 26-27). Site averaged snow depth peaks were 48 cm and 58 cm for WY 2012 and 2013 respectively at Sugar Pine. The data show snow cover durations of 5 and 7 months for Last Chance and Sugar Pine respectively in 2012, with both sites having about 4 months in 2013. Snow in 2012 came during the later months of January-March, while in WY 2013 most of the snow fell in the earlier months of December and January. Many instrument locations had low or intermittent snow cover in both years, but some maintained some snow cover all winter. Open snow-depth measurements tended to maintain more snow cover, while under canopy were more likely to be intermittent; canopy edges generally showed intermediate values between open and under canopy sites.

Upper-elevation meteorological stations recorded the highest snow depths and latest snowmelt dates. Last Chance snow depth showed greater variability than did Sugar Pine, with Duncan Peak having the highest snow accumulations and Bear Trap showing intermittent snow cover throughout the two winter periods. Snow depths measured above the banks of the streams varied from intermittent patterns to high accumulation and late melt out. Mean snow depths in WY 2012 and WY 2013 in Last Chance were around 75 cm and 30 cm. In Sugar Pine, snow depth values were around 15 cm and 20 cm in WY 2012 and WY 2013 respectively. Last Chance showed greater variability among measurement locations while Sugar Pine showed more daily variability over the winter seasons.

Soil Moisture

Soil-moisture values were more variable in WY 2012-2013 than in WY 2010-2011. The dry water years led to more variability in precipitation and snow cover, resulting in the higher soil moisture variability. The sites surrounding the meteorological stations continued to exhibit more variability than the sites adjacent to the streams in these dry periods (Figures 28-29). Monitoring soil moisture at Duncan Peak continued to be challenging, as the sensors exhibited behavior that could not be reconciled with measurements recorded at the other sites, limiting observations at the upper elevations. The failure rate of soil-moisture sensors (Decagon EC-TM) overall was relatively high, about 20% over the 4-

year record. The Duncan Peak north-facing site had all soil-moisture sensors fail by 2013, and the sensors at the south-facing site were damaged following the American Fire in August 2013 (Figure 28).

Temperature

Average water temperature for WY 2012 and WY 2013 ranged from 0 to 15.0 ^{o}C in Frazier, 0 to 13.6 ^{o}C in Bear Trap, 0 to 18.0 ^{o}C in Big Sandy, and 0 to 13.0 ^{o}C in Speckerman (Figures 30-33). Of the two years, WY 2013 showed slightly warmer water temperatures in all catchments except Big Sandy where WY 2012 had roughly 1 ^{o}C higher maximum water temperature. Yearly means were 5.8 and 6.6 ^{o}C for Frazier, 5.8 and 6.8 ^{o}C for Bear Trap, 5.6 and 6.3 ^{o}C for Speckerman, 5.8 and 6.3 ^{o}C for Big Sandy, for WY 2012 and WY 2013 respectively. Water temperature patterns were similar in both water years and trended with air temperature, reaching lowest values in early winter and gradually rising through the season.

Conductivity

At both Sugar Pine catchments, manual and continuous measurements of conductivity show low, relatively stable values with little seasonal variation (Figures 30-33). Mean specific conductivity values for WY 2012 and WY 2013 are 18 µS and 17 µS at Speckerman, and 45 µS and 44 µS at Big Sandy respectively. Mean conductivity values for the Last Chance catchments were 46 µS and 44 µS for Frazier for WY 2012 and WY 2013. For Bear Trap the mean value for WY 2012 was 48 µS. Bear Trap's WY 2013 mean was found to be 43 µS. These values are higher than those in WY 2010 and WY 2011, as would be expected due to WY 2012 and WY 2013 being low water years with proportionally less low-conductivity rain/snow entering the stream.

The highest conductivity values in this period are seen during baseflow conditions and the lowest during peak spring snowmelt. Big Sandy, Frazier, and Bear Trap show a much more-pronounced seasonal trend in conductivity than did Speckerman. The higher mean conductivities and high seasonal variation imply that the groundwater input at Big Sandy and the Last Chance catchments may be older or that the soil/rock the water is in contact with is more easily reacted. Both explanations are plausible for the Last Chance sites given that Sugar Pine has predominantly granitic bedrock that is slow to weather, whereas the Last Chance catchments have a mixture of granitic and metamorphic rock types.

Dissolved Oxygen

Dissolved oxygen data in both Last Chance catchments showed percent saturation values that remained in the 75% and 95% saturation range for all four water years (Figures 30-33). The WY 2012

A depletion of sediment was seen at the seasonal and at the event scale (for multi-rise events). Figure 34 shows a series of discharge and turbidity events during the fall 2011 season at Speckerman Creek. The largest turbidity signal was seen early in the season, with a gradual decrease in turbidity signal values even though the peak discharges for events increased. This suggests that there may have been stores of sediment that had accumulated during the previous low-flow season and that were gradually depleted as the season progressed. Mechanisms for low-flow sediment accumulation may be physical weathering of channel banks as they dry and crumble, or bioturbation. Multi-rise events also showed a shift in hysteresis patterns indicative of depletion of sediments. Figure 35 shows a multi-rise discharge event in Big Sandy Creek that progresses from strongly clock-wise to a weakly clock-wise pattern and finally, to a linear pattern. This indicates a progressive lag in sediment transport that likely results from a depletion in localized stores and a shift from nearby, easy-to-transport sediments to more distant sediment sources or to more consolidated sources (consolidated banks or armored beds) that require greater flow energy to entrain. Snow cover did not appear to factor into fall having higher turbidity values than winter and spring due to the sediment sources being localized, and no differences in turbidity patterns between the seasons (Martin *et al.*, 2014).

Major Ions

Analysis of major cation and anions from streamwater samples and comparison of those ion concentrations with stream conductivity showed the general trends of Speckerman having the lowest concentrations and conductivities of the four watersheds (Figure 36). Big Sandy had intermediary concentrations and conductivities while Frazier and Bear Trap showed the highest concentrations and/or conductivity depending on the ion in question. Also the Last Chance samples showed a much larger spread of sample points than did the Sugar Pine sites.

For the cations Na^+ and K^+, Speckerman, Big Sandy, and Frazier had increases in concentration that were proportional to increases in conductivity, while Bear Trap did not exhibit an increase in concentration with increasing conductivity. For Mg^{+2}, Speckerman did not show a concentration increase with increased conductivity and Bear Trap had only a slight increase (less steep slope) in concentration with increased conductivity. Big Sandy and Frazier had proportional increases similar to that for Na^+ and K^+. For Ca^{+2} all streams except Speckerman showed higher concentrations associated with increased conductivities.

The F^- anion showed considerable spread in the data along with relatively low concentrations. For Cl^- and SO_4^{-2}, Bear Trap showed increasing ion concentrations with increasing conductivity, but the other three streams had relatively stable ion concentrations even with increased conductivity. All four streams had proportional increases between ion concentration and conductivity for HCO_3^-.

These trends indicates that for Speckerman Na^+, K^+, and HCO_3^- are important constituents affecting stream conductivity, while Mg^{+2}, Ca^{+2}, and SO_4^{-2} play little role in that streams conductivity. The same constituent make-up seems to be the case for Big Sandy, however there is more scatter in the data. The similarities are likely due to very similar rock types and source waters between the two paired watersheds.

The Last Chance sites have very different constituent make-ups between the two watersheds. Ca^{+2}, Cl^-, and SO_4^{-2}, and HCO_3^- seem to be the most important constituents for stream conductivity (Mg^{+2} to a lesser degree) for Bear Trap, while Na^+ and K^+ seem to be unimportant. Frazier has a nearly opposite trend, with Na^+, K^+, Mg^{+2}, and HCO_3^- being the more important constituents (Ca^{+2} to a lesser degree) and Cl^- and SO_4^{-2} not contributing significantly to conductivity. These differences are likely due to variations in the bedrock chemistry between these two streams.

Stable Isotopes

Stable isotopes from stream samples showed slightly more negative δD and δO18 values for the Big Sandy and Speckerman samples as would be expected due to the southern catchments higher altitudes (Figure 37). Paired catchments showed similar values with the northern catchments showing a smaller range than the southern catchments. The isotopic signatures of the samples form a local meteoric water line (LMWL) that sits slightly to the left of the global meteoric water line (GMWL) in Figure 37 and fits well with samples from other Sierra Nevada sites.

Discharge

In Speckerman and Big Sandy Creeks, WY 2012 had a large rain event in early fall that was roughly equal to peak snowmelt discharge and a late fall event that exceeded peak snowmelt for the year (Figure 38). WY 2013 also had a late fall event that exceeded peak snowmelt for the year, representing the year's peak discharge. Big Sandy showed another significant event that exceeded peak snowmelt discharge prior to the late-fall annual peak event, but the same storm event led to less significant discharges in Speckerman. In Frazier and Bear Trap the WY 2012 fall rain events were much less significant and did not approach the peak discharge levels for the year. The highest discharge event for WY 2012 in Bear Trap was a mid-winter peak that corresponded to the highest daily precipitation for the year, while the second highest peak corresponded to a medium size precipitation peak during spring snowmelt. Frazier's largest peak discharge corresponded to the same medium-sized snowmelt-season precipitation peak as in Bear Trap. The second largest discharge peak was during late winter and corresponded to a medium-sized precipitation event that occurred after the storm event with the largest daily precipitation. In WY 2013, the largest discharge peaks for both Last Chance catchments occurred in late fall, concurrent with the largest daily total precipitation. This late-fall event was 2-3 times the peak snowmelt discharge for that year.

The yearly peak discharges in Bear Trap are proportionally higher than snowmelt and baseflow compared to the other watersheds (Figure 38). This is likely due to limited site access during times of peak flow, resulting in the rating curve being less well constrained for the higher discharges. We believe that the peak-flow values may be slightly over estimated for this catchment, but the mid-range and lower flows are accurately represented. Additionally, due to the short duration of the peak flows, they do not significantly affect annual discharge estimations used in modeling.

For WY's 2012 and 2013 there were considerable differences in the shape of the hydrographs between the Sugar Pine and the Last Chance sites (Figure 38). Interestingly, where WY 2013 had significantly less snow than in WY 2012 at the Last Chance sites, the annual discharge peaks and the snowmelt discharges were of similar magnitude. At the Sugar Pine sites the two years were more similar in amount of snow (though not in timing as previously discussed), and while Speckerman had very similar snowmelt discharges for the two years, Big Sandy had somewhat lower snowmelt discharges in WY 2013 possibly due to the earlier peak snow accumulation and slightly earlier melt out for the year.

Basin Discharge Comparison

For both water years, Big Sandy had a discharge that was more similar to Speckerman (Figures 38, 41), than during the first two years of record. The dry years clearly had an effect on flow levels, and may complicate interpretation of treatment effects (Big Sandy, treatment; Speckerman, control). Discharge at Frazier and Bear Trap are also more similar than 2010 and 2011 years, but have kept the trend of Frazier generally having higher discharges than Bear Trap during winter flow and spring snowmelt (with the exception of a few short-duration early winter events where Bear Trap has slightly higher peak event flows) (Figures 38, 41). That inverse relationship continued in the dry years where Bear Trap consistently showed higher discharges than Frazier during baseflow conditions. This may be due to the overestimations in the rating curve at higher discharges as discussed above or due to the bedrock channel at Bear Trap limiting channel bed infiltration or subsurface streamflow. Bear Trap may also have more flow from springs this time of year.

Cumulative discharge comparisons highlight the similarities between the two dry water years and between streams. Total annual flows for WY 2012 and WY 2013 were calculated for each stream (Figure 39). Total flow for Speckerman was 0.46 x10^6 m^3 (16.3x10^6 ft^3) for WY 2012 and 0.59 x10^6 m^3 (21.0x10^6 ft^3) for WY 2013. Annual totals at Big Sandy were 0.53 x10^6 m^3 (18.7x10^6 ft^3) and 0.67 x10^6 m3 (23.8x106 ft^3) in WY 2012 and 2013 respectively. Frazier had totals of 0.99 x10^6 m^3 (34.9x10^6 ft^3) and 0.88 x10^6 m^3 (31.1x10^6 ft^3) for WY 2012 and 2013. Bear Trap totaled 0.95 x10^6 m^3 (33.6x10^6 ft^3) and 0.96 x10^6 m^3 (33.9x10^6 ft^3) for WY 2012 and 2013.

When discharge values are normalized over the watershed areas, the similarities between streams become even more apparent (Figure 40). The normalized total cumulative discharge at Speckerman was 24 cm in WY 2012 and 31 cm in WY 2013. At Big Sandy, cumulative discharge was 23 cm in WY 2012 and 28 cm in WY 2013. Frazier's cumulative totals for WY 2010 were 53 cm for WY 2012 and 59 cm for WY 2013. Bear Trap cumulative flows were the same, 54 cm for both years. Annual stream discharge was the lowest during WY 2012 out of all four of the observation years.

Runoff coefficients, expressed as the fraction of precipitation leaving the basin as stream discharge, were associated more with precipitation levels than basin size (Table 3, Figure 40). As a result, Last Chance showed higher runoff coefficients than Sugar Pine, and values from both study sites were similar between 2012 and 2013. Speckerman Creek and Big Sandy Creek had respective coefficients of 0.24 and 0.23 in 2012 and 0.24 and 0.22 in 2013, respectively. Bear Trap Creek and Frazier Creek had respective coefficients of 0.41 and 0.37 in 2012 and 0.34 and 0.35 in 2013.

Table 3. Interannual variability of precipitation and water yield observed in the study watersheds.

Site	Year	Stream	Precipitation, cm	Water Yield, cm	Runoff Coefficient*
Last Chance	2012	Bear Trap	146	54	0.41
		Frazier	146	53	0.37
	2013	Bear Trap	154	54	0.34
		Frazier	154	59	0.35
Sugar Pine	2012	Speckerman	97	24	0.24
		Big Sandy	97	23	0.23
	2013	Speckerman	128	31	0.24
		Big Sandy	128	28	0.22

* Runoff coefficient is calculated as Water Yield divided by Precipitation

Regional Hydro-Ecological Simulation System (RHESSys)

RHESSys calibration and parameterization continues for the SNAMP basins, with final products dependent upon the LiDAR-derived vegetation layers that should be completed within the next few months. Preliminary parameterization results using modeled vegetation growth show reasonable agreement with snow, soil moisture, and streamflow observations (Figure 42).

In the original report, model results were obtained using observed temperatures and precipitation separated into rain and snow. Results are now being obtained using the model to split the precipitation into the different phases of rain and snow. The met station temperatures used initially were not representative of the regional temperature range recorded by the distributed snow depth sensors. Lowering the met stations temperatures by 1-2 degrees so that modeled snow matched observed snow levels allowed a better snow/rain representation than splitting the phases manually.

Upscaling RHESSys to the larger firesheds (10-25 km^2) is ongoing. The headwaters and firesheds have similar geology, with the streamflow from the closest available stream gauge also showing similar streamflow patterns. Similar studies using RHESSys have shown that parameters developed in headwater regions can be transferred to larger watersheds based on these physical characteristics, and we are using the same approach. The model output is also shown for water year 2010 from Bear Trap Creek (Figures 22-23).

Conclusions

The four years of continuous snow, soil moisture, and stream discharge observations have been achieved over a range of conditions (Figure 41). Water year 2010 showed average winter precipitation, 2011 was wetter than average, while 2012 and 2013 were both low precipitation years. Forest treatments were started in the fall of 2011 and were finished in the fall of 2012. Water-year 2013 is the only post-treatment measurement year, and will be the basis for evaluating any observed effects of thinning on the water balance in these watersheds. However, the dry conditions in the final two water years may mask any treatment effects in the single 2013 post-treatment year. The American Fire also burned through the Last Chance treatment catchment (Bear Trap Creek) in August 2013, complicating the evaluation of future effects of the forest treatments, but also providing an opportunity to look at further vegetation reduction from a low to medium-severity wildfire event.

Stream water quality showed similar seasonal trends to those seen in water years 2010 and 2011 with water quality parameters measuring within the acceptable range for water quality standards. For water years 2010-2012, turbidity was found to be episodic with distinct seasonal patterns. In-channel sources were shown to dominate sediment supply and those supplies underwent seasonal cycles of accumulation and depletion. Four years of stream water chemistry data showed that Speckerman generally had lower ion concentrations than Big Sandy, which fit with the comparatively low conductivity observed in Speckerman. Major ion constituents also differed greatly between Frazier and Bear Trap possibly due to differences in geology between the two basins. Stable isotope data showed elevational trends as expected and trends fit well with those of other Sierra Nevada sites. Due to changes in water quality being closely tied to changes in discharge the dry conditions post treatment are likely to also mask any potential treatment effects on water quality.

The water-quantity and energy-balance data assembled and presented in the preceding data report and this update provide better than usual observations to constrain and evaluate the modeling capability for the SNAMP catchments. A majority of models reported in the literature are calibrated on streamflow alone, while this model will be compared to snow and soil moisture levels as well. The initial two water years of meteorological measurements (2008-2009) will be use to stabilize the model environment. The range of precipitation conditions, while potentially masking treatment effects, will be very useful in calibrating the model over a range of possible winter climates.

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Appendix

A. Timeline of major field activities.

Year	Season	Activities
2007	Summer	2 Met station installed
	Fall	2 Met stations installed, Bear Trap Met moved**????**
2008	Winter	
	Spring	
	Summer	Streambank erosion pins installed at Sugarpine stream sites
	Fall	Snow depth sensors installed at all nodes
2009	Winter	Water quality sondes installed Solinst stream stage sensors installed Snow survey at Duncan Peak
	Spring	
	Summer	Soil moisture sensors installed at all nodes
	Fall	
2010	Winter	
	Spring	
	Summer	
	Fall	2 upstream scour sensors installed at Sugarpine stream sites DUST network partial installation 4 Culvert depth sensors installed
2011	Winter	Sugarpine TTS equipment installed
	Spring	YSI sonde calibrations (BTP creek, turbidity sondes)
	Summer	2 downstream scour sensors installed at Sugarpine stream sites 4 scour sensors installed at Last Chance stream sites YSI sonde calibrations Last Chance TTS equipment installed DUST network completion Stream reach cross-section surveys
	Fall	Speckerman Creek weir plate fabrication and fitting Turbidity sondes installed at Sugarpine sites
2012	Winter	Snow survey at Duncan Peak
	Spring	Turbidity sonde installed at Bear Trap Creek
	Summer	Instrument calibrations (Met Towers and YSI sondes) Stream reach cross-section surveys Longitudinal water chemistry surveys- all stream sites
	Fall	Tree fell on Fresno Dome north-facing node and was repaired
2013	Winter	
	Spring	
	Summer	The American Fire burns through the Last Chance study site, Duncan Peak south-facing site is removed by fire crews. YSI sondes recalibrated.
	Fall	Tree falls on Duncan Peak met station, which is destroyed.

B. Period of record by measurement type.

Site, measurement type	Period of record (water year)
METEOROLOGICAL STATIONS	
Big Sandy	
Meteorological Instrumentation	2008-2013
NF Snow Depth	2009-2013
NF Soil Moisture	2010-2013
SF Snow Depth	2009-2013
SF Soil Moisture	2010-2013
Bear Trap	
Meteorological Instrumentation	2008-2013
NF Snow Depth	2009-2013
NF Soil Moisture	2010-2013
SF Snow Depth	2009-2013
SF Soil Moisture	2010-2013
Duncan Peak	
Meteorological Instrumentation	2008-2013
NF Snow Depth	2009-2013
NF Soil Moisture	2010-2012
SF Snow Depth	2009-2013
SF Soil Moisture	2010-2013
DUST network	2011-2013
Fresno Dome	
Meteorological Instrumentation	2008-2013
NF Snow Depth	2009-2013
NF Soil Moisture	2010-2013
SF Snow Depth	2009-2013
SF Soil Moisture	2010-2013
STREAM SITES	
Big Sandy Creek	
NF Snow Depth	2009-2013
NF Soil Moisture	2010-2013
SF Snow Depth	2009-2013
SF Soil Moisture	2010-2013
Water Quality	2010-2013
Stage	2010-2013
Culvert Measurement	2011-2013

Site, Measurement Type	**Period of Record (Water Year)**
Big Sandy Creek (cont.)	
Scour Sensors	2011-2013
Bear Trap Creek	
NF Snow Depth	2009-2013
NF Soil Moisture	2010-2013
SF Snow Depth	2009-2013
SF Soil Moisture	2010-2013
Water Quality	2010-2013
Stage	2010-2013
Culvert Measurement	2011-2013
Scour Sensors	2011-2013
Frazier Creek	
NF Snow Depth	2008-2013
NF Soil Moisture	2009-2013
SF Snow Depth	2008-2013
SF Soil Moisture	2009-2013
Water Quality	2010-2013
Stage	2010-2013
Culvert Measurement	2011-2013
Scour Sensors	2011-2013
Speckerman Creek	
NF Snow Depth	2008-2013
NF Soil Moisture	2009-2013
SF Snow Depth	2008-2013
SF Soil Moisture	2009-2013
Water Quality	2010-2013
Stage	2010-2013
Culvert Measurement	2011-2013
Scour Sensors	2011-2013

C. Initial Report Text

Sierra Nevada Adaptive Management Project

Water-Team Field Activities, Methods and Results

Task Order #UC 10-6

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Executive Summary

This report is a review of the purpose, design, and installation of the water component of the Sierra Nevada Adaptive Management Project (SNAMP), and contains a summary of the data developed from the field measurement program over the first four years of the planned seven-year study. SNAMP is an integrated effort designed to study forest management from an ecosystem perspective - more specifically, to assess the effects of Strategically Placed Landscaped Treatments (SPLATs) in the mixed-conifer zone of the Sierra Nevada. In addition to water, investigations of forest health, forest fire, wildlife, and spatial processes are being conducted simultaneously in the same region. The hydrology (water) component focuses on detecting and predicting changes in the movement and timing of water flowing through these mountain catchments as a result of vegetation management, and on detecting changes to water quality. We hypothesize that the tree thinning and prescribed burning implemented with SPLATs will alter the timing of streamflow, increase water yields, and increase sediment movement within the stream channel due to the increased water yield.

The two SNAMP study areas are Last Chance, in the Tahoe National Forest, and Sugar Pine, in the Sierra National Forest. Within each study area, two headwater catchments were chosen for intensive monitoring, providing a treated and untreated watershed in both areas. An upper and lower elevation meteorological station was installed in each study area to capture the range of conditions in each catchment. Stream instruments for monitoring water level and water quality were installed at the watershed outlets. Additional snow and soil moisture sensors were distributed on the landscape around the meteorological stations and watershed outlets to measure the variable conditions attributed to the heterogeneous nature of mountain terrain and vegetation.

Four years of meteorological data, three years of distributed snow depth data, and two years of distributed soil moisture, streamflow, and water quality data are reported here through water year 2011. These observations will be used in conjunction with the Regional Hydro-Ecological Simulation System (RHESSys), to assess the effect of forest treatments on water cycling. Preliminary model results are also displayed, though they are not yet complete. Operating continuously recording instruments that require access to a power source in remote mountain environments can be difficult, so a discussion of these challenges and lessons learned is also included. Forest treatments were started in the fall of 2011 and are expected to be finished in summer 2012.

The lower-elevation meteorological station at both the Last Chance (1590 m elevation) and Sugar Pine (1755 m) study sites had an annual average temperature of about 9.7-9.8^{o}C, and received

about an equal mix or rain and snow. The upper-elevation meteorological station in the north (2112 m) had an annual average temperature of about 7.1^{o}C, versus 8.1 ^{o}C in the south (2176 m).

The data show a snowcover duration of 5-7 months for Last Chance, and about 2 weeks shorter at Sugar Pine. Snow accumulates from approximately mid-December through mid-March or early April, then melts through May (2009) or July (2011). Many sites had winter melt periods in all three years, but maintained some snowcover all winter.

Soil-moisture values remained high from about November through May, dropped following snowmelt in June-July, and were at season-low values during August-September. Soil-moisture levels in the Sugar Pine study area were generally higher above the stream banks than around the meteorological stations.

Discharges for the two sets of paired catchments were comparable, with differences in both peak and baseflow attributed to the degree of subsurface flow. The total stream discharge at the Sugar Pine catchments was about 50 cm in WY 2010 and 100 cm in WY 2011. Specific-yield values (discharge divided by precipitation) were about 0.4 for both years. Stream discharge at the Last Chance catchments was estimated to be about 100 cm in WY 2010 and 150 cm in WY 2011. Respective specific-yield values were about 0.5 for both years.

Introduction

The Sierra Nevada Adaptive Management Project (SNAMP) is a joint effort by the University of California, state and federal agencies, and the public to study management of forest lands in the Sierra Nevada. The SNAMP team is assessing how forest vegetation treatments to prevent wildfire affect fire risk, wildlife, forest health and water. The USDA Forest Service's 2004 Sierra Nevada Forest Plan Amendment calls for managing the forest using the best information available to protect forests and homes. Vegetation management treatments are planned or being conducted in several places in the Sierra Nevada where fire risk is high. Millions of acres of Sierra Nevada forest are endangered by wildfire.

The overall SNAMP team includes university scientists acting as an independent third party to assess the effects of vegetation management treatments in the Sierra Nevada. Results will be used to improve forest management, with important implications for water yield, runoff timing and water quality. The goals of the Water Team are:

1) To better understand and predict the timing and movement of water through the catchments

2) To assess and predict the effects of forest treatments on the route and timing of the water; and
3) To quantify erosion and sediment movement caused by the water routing.

Our working hypothesis is that treatments will alter the timing of flows and increase water quantity and sediment movement in the streams. Any changes in water quality (such as turbidity) will be due to in-streamflow changes from the increased discharges. Results thus also provide process understanding that is important for improving predictions of runoff for water supply and other downstream uses.

Field sites for this study consist of two locations, a northern and southern site. The southern site (Sugar Pine) is located on the Sierra National Forest near Fish Camp while the northern site (Last Chance) is located on the Tahoe National Forest near Foresthill (Figure 1). Two headwater catchments were chosen in each site for intensive measurements based on the comparable size, gradient, discharge, aspect, and vegetation cover as locations for aquatic and terrestrial monitoring instrumentation. These instrument clusters were located along a relatively low-gradient response reach where sediment scour and deposition are likely to occur. One instrument cluster in each site is located in a catchment subject to treatment to study the effects of those treatments while the other is located in an untreated catchment as an experimental control.

In addition to the two stream instrument clusters, two meteorological stations were located in each site. One station is located at an elevation similar to the upper portion of the basins and the other at an elevation similar to the stream instrument clusters. Instrument clusters and meteorological sites are further divided into two nodes; one located on a south-facing slope and another on a north-facing slope (Table 1).

The two southern watersheds chosen are Big Sandy Creek and Speckerman North Creek. From the junction between Jackson Rd and CA-41, Speckerman Creek is approximately 5.5 km east while Big Sandy Creek is nearly 9 km east. The two northern watersheds chosen are Frazier Creek and Bear Trap Creek, both of which are located along Forest Route 44. Frazier Creek is approximately 9.5 km north of Forest Route 96 (Mosquito Ridge Rd) and Bear Trap Creek is another 4 km north of Frazier Creek.

In the southern site, the upper meteorological station, Fresno Dome, is approximately 3.25 km northeast of the Fresno Dome campground along Sky Ranch Rd (Forest Route 6S10). The lower meteorological station, Big Sandy, is located just west of the Big Sandy campground. The upper meteorological station in the northern site, Duncan Peak, is approximately 1 km west of Robinson Flat campground along Forest Route 43. The lower meteorological station, Bear Trap, is situated between the stream sites approximately 2.5 km from Frazier Creek along Forest Route 44.

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Table 1. Instrument nodes and watershed attributes

Forest (Site)	Instrument node	Area, km^2	Latitude, north	Longitude, west	Elevation, m
Sierra N.F. (Sugar Pine)	Speckerman Creek	1.62	37.4639	119.6051	1719
	Big Sandy Creek	2.47	37.4684	119.5819	1778
	Fresno Dome Met	--	37.4638	119.5362	2176
	Big Sandy Met	--	37.4684	119.5856	1755
Tahoe N.F. (Last Chance)	Bear Trap Creek	1.76	39.1067	120.5670	1560
	Frazier Creek	1.68	39.0851	120.5689	1605
	Duncan Peak Met	--	39.1546	120.5101	2112
	Bear Trap Met	--	39.0945	120.5769	1590

Methods

Field data collection started in late 2007 following the installation of the four meteorological stations. Snow-depth nodes were added in late 2008 to all sites and soil-moisture sensors were added to those nodes in the summer of 2009. Water quality and stage instrumentation was added to stream sites during the winter of 2009 (see Appendix A for timeline of major field activities). When not involved with installations, field personnel performed routine maintenance and repairs, stream sampling at regular intervals, data retrieval and processing, laboratory analysis, and public outreach as part of the SNAMP team.

Sampling

Water-quality samples were collected at stream sites year round at biweekly to bimonthly intervals. Samples were taken at or near the location of the water-quality instrumentation at each stream site in order to correlate sample results to stream conditions. Stream samples were analyzed for total suspended solids, major ions, and isotopes. Bottles and lids used during sampling were cleaned, triple rinsed with DI water prior to field work and then triple rinsed at the site with stream water. All samples were taken in the center of flow and bed sediment disturbance was avoided.

Snow samples were retrieved and analyzed for major ions and isotopes. Ion samples were taken at snow pit locations using a clean 10 cm diameter by 1-m long PVC pipe sampler inserted vertically near the edge of the pit. Snow from the samplers was placed in cleaned 4-L zip-top bags and once melted were combined and subsampled. Isotope samples were collected with a 500-mL snow cutter, placed in gallon zip-top bags, and once in the laboratory were melted put in isotope bottles.

Approximately 1 L of bulk soil was collected from each of the soil moisture sensor locations. Soil samples were air dried and sent to the University of California Analytical Laboratory (UC-ANL) in Davis, CA for texture analysis. At UC-ANL, the soil samples were ground in a Bico-Braun soil pulverizer until they were fine enough to pass through a 2 mm sieve. Soil particle size was then determined by measuring the settling rates of the sample in a sodium hexametaphosphate solution, using a hydrometer to record changes in suspension density (1% detection limit).

Total Suspended Solids

Total suspended solids (TSS) measurements were used to calculate the mass of all solids present in a volume of water. Total suspended solids samples were collected with a DH-48 depth integrated sampler, by dipping the bottle in the stream (referred to as grab samples), or with an automated water sampler. In all cases, labeled samples were stored in a refrigerator or out of the light to prevent algae growth prior to analysis. Filters (0.45 micron) were dried in a 60-70 °C oven for 24 hours and weighed prior to filtering to establish the initial mass of the filter. The volume of sample was measured and then filtered using a vacuum chamber. Filters were dried in an oven for 24 hours, and then weighed to determine the total mass (filter + sediment). Data are currently being reported by the laboratory and analyzed, and results will be forthcoming.

Major Ions

Ion chemistry in stream water can help to identify sources and flow paths of water in that system. Grab samples of 500 mL of stream water and 500 mL of total snowpack water were collected for major cation and anion analysis. Regularly collected stream samples were taken adjacent to water quality instrumentation, and snow samples from snow pits adjacent to the meteorological stations. Samples were brought back to the laboratory and filtered using a vacuum-filtration system with a 0.45-µm filter. If samples could not be filtered immediately they were frozen to preserve the samples until they could be processed. Samples were analyzed by the Environmental Analytical Laboratory at University of California, Merced on a Dionex ICS-2000 integrated ion chromatography system. Cations measured included Na, NH_4, K, Mg, and Ca. Anions measured included F, Cl, SO_4, and NO_3. Data are currently being processed and results will be forthcoming

Isotopes

Like major cations and anions, isotopes can give information about water sources and flow paths. Isotope samples were collected with 30-mL glass vials with septum lids. Bottles were capped such that no air was present in the bottle. Regularly collected stream samples were taken adjacent to water quality instrumentation and snow samples from snow pits adjacent to the meteorological stations. Additional single samples were collected at various locations of interest within the watersheds (ie. springs, seeps, confluences) to provide additional information on water sources and pathways. Samples were stored refrigerated until they could be analyzed to prevent algae growth. Aliquots of 1 mL from each sample were analyzed for $\delta^{18}O$ and δD on an LGR DLT-100 liquid-water-isotope analyzer. Data are currently being processed and results will be forthcoming.

TTS program

Turbidity threshold sampling was used to observe how stream conditions change during turbid flows typical of precipitation or snowmelt events. Turbidity threshold sampling (TTS) stations consist of, at minimum, a water-quality sonde and an automated water sampler connected to and controlled by a datalogger. These stations also typically include instrumentation present at stream sites such as snow-depth sensors, scour pans, and soil-moisture sensors. The program uploaded to the datalogger executes in-stream and on-bank instrument measurements at 15-minute intervals. The automatic water sampler is triggered weekly or when turbidity values exceed a site-specific turbidity value set by the field personnel.

Instrument Cluster Configurations

All instrument clusters consist of Campbell Scientific dataloggers that were used to control and record sensor output at two nodes (north facing and south facing). All nodes collect data at 15 minute intervals and are in operation year round. Clusters were visited by field personnel on a monthly basis to download data and perform any maintenance or repairs required.

Stream clusters were located upstream of access roads and were reached on foot. North facing nodes at Speckerman operate snow-depth and soil-moisture sensors (Table 2). Included on the north-facing node at Big Sandy Creek is a scour sensor. At Speckerman, Big Sandy, and Bear Trap Creeks the south-facing node houses a datalogger running a turbidity threshold sampling (TTS) program that records water-quality readings and controls an automated water sampler. At Frazier Creek, the TTS program is run on a datalogger independent of the stream nodes.

Table 2. In-stream and terrestrial instruments present at each stream instrument cluster

Site	In-stream Instruments	Terrestrial Instruments
Big Sandy Creek	YSI 6920V2-2 sonde Solinst Levelogger Gold YSI 600 OMS sonde (2) Rickly Scour Sensors (1 attached to NF node)	(3) Judd Ultrasonic Depth Sensors (2 on SF node, 1 on NF node) (16) Decagon 5TM soil moisture sensors (8 per node)
Speckerman Creek	YSI 6920V2-2 sonde Solinst Levelogger Gold YSI 600 OMS sonde (2) Rickly Scour Sensors	(3) Judd Ultrasonic Depth Sensors (2 on SF node, 1 on NF node) (16) Decagon 5TM soil moisture sensors (8 per node)
Bear Trap Creek	YSI 6920V2-2 sonde Solinst Levelogger Gold YSI 600 OMS sonde (2) Rickly Scour Sensors	(3) Judd Ultrasonic Depth Sensors (2 on SF node, 1 on NF node) (16) Decagon 5TM soil moisture sensors (8 per node)
Frazier Creek	YSI 6920V2-2 sonde Solinst Levelogger Gold (2) Rickly Scour Sensors	(3) Judd Ultrasonic Depth Sensors (1 on SF node, 1 on NF node) (16) Decagon 5TM soil moisture sensors (8 per node)

NF= North facing; SF= South facing

Meteorological sites consist of a central tower with meteorological instrumentation in addition to two nodes on adjacent NF and SF slopes. Parameters measured on the tower include snow depth, rainfall, air temperature, relative humidity, incoming solar radiation, net solar radiation, wind speed and direction, and barometric pressure (Table 3). Data are transmitted from the tower hourly via an on-board GOES satellite transmission platform and posted on the California Data Exchange Center website (http://cdec.water.ca.gov/). After quality assurance and quality control, data are archived in the SNAMP digital library (https://eng.ucmerced.edu/snsjho).

Table 3. Tower and node instruments at each meteorological station

Met Site	Tower Instrumentation	Node Instrumentation
Big Sandy	Judd Ultrasonic Depth Sensor Handar 444B Tipping Bucket LI-COR LI200X Pyranometer Solinst Barologger Gold Kipp & Zonen NR Lite2 Vaisala HMP155C Temp/RH RM Young 05103 Wind Monitor	NF: (4) Judd Ultrasonic Depth Sensors (10) Decagon 5TM soil moisture sensors SF: (4) Judd Ultrasonic Depth Sensors (12) Decagon 5TM soil moisture sensors
Fresno Dome	Judd Ultrasonic Depth Sensor Handar 444B Tipping Bucket LI-COR LI200X Pyranometer Solinst Barologger Gold Kipp & Zonene NR Lite2 Vaisala HMP155C Temp/RH Vaisala WMT700 Wind Monitor	NF: (3) Judd Ultrasonic Depth Sensors (10) Decagon 5TM soil moisture sensors SF: (3) Judd Ultrasonic Depth Sensors (10) Decagon 5TM soil moisture sensors
Bear Trap	Judd Ultrasonic Depth Sensor Handar 444B Tipping Bucket LI-COR LI200X Pyranometer Solinst Barologger Gold Kipp & Zonene NR Lite Vaisala HMP45C Temp/RH Vaisala WMT700 Wind Monitor	NF: (3) Judd Ultrasonic Depth Sensors (10) Decagon 5TM soil moisture sensors SF: (3) Judd Ultrasonic Depth Sensors (9) Decagon 5TM soil moisture sensors
Duncan Peak	Judd Ultrasonic Depth Sensor Handar 444B Tipping Bucket LI-COR LI200X Pyranometer Solinst Barologger Gold Kipp & Zonene NR Lite Vaisala HMP45C Temp/RH Vaisala WMT700 Wind Monitor	NF: (2) Judd Ultrasonic Depth Sensors (8) Decagon 5TM soil moisture sensors SF: (4) Judd Ultrasonic Depth Sensors (14) Decagon 5TM soil moisture sensors

Instrument and Equipment Descriptions

Due to the remote locations, all instrumentation is solar powered. Panel size ranged from 10 to 50 watts, with panels mounted facing south to maximize their exposure to the sun. At instrument clusters panels were attached to the top of rigid metal conduit or up in trees, whichever gave the best sun exposure. Solar panels on the met towers were mounted directly to the tower.

Solar panels are used to charge batteries through use of a charge controller. Sealed lead-acid batteries were used to supply power to dataloggers and all attached instrumentation. Battery size varied from 7.5 AH to 50 AH and was based on size and amount of sun exposure the solar panel had, how much equipment was present, as well as trial and error. At met towers 100+ AH marine batteries were used due to the demands of the instrumentation on the towers. Two different 12-volt charge controllers were used in this study. At instrument nodes, a 6-Amp controller (Morningstar Sunsaver 6) was used while at the met towers a larger 15-Amp controller (Morningstar ProSaver 15) was used.

NEMA 4x certified fiberglass and steel enclosures were used in this study to provide protect dataloggers, batteries, and charge controllers from the elements. Refrigerator putty was used to further weather proof the enclosures and desiccant packs were used to control moisture levels inside. At many sites the enclosures fared well. However, in several cases, the pressure exerted on the boxes by snow creep often resulted in the enclosures being torn from the mounting poles, typically accompanied by severed instrument and power cables.

A 9-m Rohn Products tower is the primary mounting platform for all of the meteorological stations in this study. These towers are freestanding and climbable for instrument access. Three of the towers are set into poured concrete footings and one is set on a base bolted directly into bedrock (Fresno Dome Met). Towers meet the following specifications:

1) Survive 125 mph winds
2) No horizontal or vertical movement (sliding once installed)
3) Withstand snow loads of typical high mountain locations
4) Support technical personnel on the tower while servicing all sensors
5) Provide adequate mounting surface and locations to meet sensor requirements (NFDRS)

Galvanized rigid metal conduit pipe was used as the primary means to mount instrument enclosures and snow-depth sensors at all instrument clusters. Conduit pipe had a 4-cm inside diameter and 3-m length. Pipes were bolted to U-channel posts that were driven into the ground. Extensions 1.5-m in length were installed at the higher elevation meteorological stations where potential snow depth exceeds 3-m.

Programmable dataloggers such as the Campbell Scientific CR1000 and CR200x enable many types of sensors to be deployed and controlled at a site and allow a high degree of customization by users. Most instruments were wired into Campbell Scientific CR1000 dataloggers. An AM16/32B multiplexer was typically connected to the CR1000 to expand the instrument capacity at instrument clusters to control soil-moisture sensors. The CR200X dataloggers are used at culvert measurement locations and Bear Trap Creek NF node where fewer instruments are connected and differential ports were unnecessary.

GOES satellite telemetry was used to provide real-time updates on weather conditions at Met stations and alert personnel to issues that need addressing. Each GOES platform consists of a transmitter in the enclosure, a GPS antenna, and a satellite antenna. A CR1000 datalogger is used to upload data at 15-minute intervals into the Campbell Scientific TX-312 transmitter buffer that is then relayed once an hour to a GOES satellite. To ensure accurate transmission times, the transmitter uses a GPS antenna to synchronize the datalogger clock.

A Solinst Barologger was used to record barometric pressure at meteorological stations. Instruments were housed in perforated PVC capsules to protect them and allow sufficient pressure equalization. Housings were mounted directly to the meteorological towers. Barometric data were used to remove the effects of barometric pressure on stream level data.

Two types of precipitation were measured during this study: rainfall and snow depth. Rainfall was measured at meteorological stations using a Handar 444b tipping-bucket rain gage. Each tipping-bucket assembly was mounted on the meteorological tower 4.5 to 5 m above the ground. Rain gages were unshielded and unheated. Snow depth was measured at all instrument nodes and meteorological stations using Judd ultrasonic depth sensors. Each Judd was mounted on the end of a 5-foot section of ½" rigid metal conduit and positioned so that the surface of the transducer was parallel to the ground.

Scour sensors were installed to monitor sediment movement through the stream system. Two Rickly Hydrological load cell sensors were buried 30 to 50-cm below the stream bed at each stream reach. The sensors operate by measuring the pressure of the water column and the pressure exerted on a water-filled pan buried in the sediment at the same depth. The difference between the two readings is the weight of the sediment present on top of the pan. Sensors are co-located at Bear Trap, Frazier, and Speckerman Creeks to provide redundant measurements. At Big Sandy Creek, one sensor was installed adjacent to the water quality instrumentation and the other was installed approximately 15 m downstream.

Decagon Devices ECH_20 TM soil temperature and moisture sensors were installed in soil pits at depths ranging from 10 to 90-cm. At met station nodes, EC-TMs were installed under each Judd depth sensor to examine the relationship between snow depth and soil moisture. However, the deployment was changed when installing sensors at stream nodes to see how soil moisture was related to orientation. At these sites a tree was chosen and pits were dug approximately 1 meter from its base in the four cardinal directions. Installation depths vary but were generally confined to 30 and 60 cm due to the shallow nature of the soils.

Incoming solar and net all-wave radiation measurements were used to quantify the energy balance at meteorological sites for use in evapotranspiration calculations. Incoming solar radiation was measured using a LI-COR LI200X pyranometer that detects the spectral range of 400-1100 nm using a silicone photovoltaic diode. Net solar radiation was measured using a Kipp & Zonen NR Lite or NR Lite2 net radiometer. Both NR Lites report the difference between all incoming solar and far infrared radiation and the reflected radiation from the surface of the soil under the assumption that all wavelengths are absorbed (manufacturer specifications are identical for both NR Lite and NR Lite2 sensors). The LI200X and NR Lite sensors are mounted near the top of the meteorological towers facing south to get the best view of the sky and avoid shading from the tower and nearby trees.

Temperature and relative humidity were measured using two different instruments from Vaisala. The older HMP45 was installed at the two northern meteorological stations. It has a measurement range of -40°C to +60°C for temperature and 0% to 100% for relative humidity. Newer HMP155 sensors were installed at the two meteorological stations in the southern sites as replacements for HMP45 sensors that were malfunctioning. The HMP155 can read temperatures down to -80°C and has an updated version of the HUMICAP humidity sensor. Each of the sensors were mounted inside a 9- or 14-layer radiation shield manufactured by RM Young.

Two different sensor platforms manufactured by YSI were used to measure *in situ* water quality. The YSI 6920 V2-2 is a robust and flexible platform that contains 2 optical ports, 1 conductivity/temperature port, 1 pH/ORP port (not used in this study), 1 nutrient ion-selective-electrode (ISE) port (not used in this study), and an integrated unvented pressure transducer. The 600 OMSV2-1 sonde is a smaller unit and contains 1 optical port and an integrated conductivity/temperature sensor.

The two optical sensors used in this study are the YSI 6150 ROX® dissolved oxygen and YSI 6136 turbidity sensors. The 6920 sondes houses both of these sensors while the 600OMS sondes only house the turbidity sensor. The ROX DO sensor uses the luminescence lifetime method for detecting oxygen and does not require flow. The sensor is capable of measuring 0-100% dissolved oxygen with minimal drift. The turbidity sensor uses a near infrared LED to illuminate a sample and measures the light that is scattered with an adjacent photodiode. The range of the sensor is 0 to 1,000 NTU. Anti-fouling wipers are installed on both sensors to prevent buildup of sediment or algae on the optical ports.

The YSI 6560 conductivity/temperature sensor uses four nickel electrodes to measure conductivity and a thermistor to measure temperature. The temperature measurement range is -5 to 60°C and is used on-board by the sonde to calculate and output specific conductance. The range for conductivity measurements is 0 to 0.1 mS cm^{-1}.

Multiple in-stream sensors are employed at stream sites and in weir ponds to record changes in stream stage. Solinst Levelogger Gold pressure/temperature transducers are used near culverts and in weir ponds. The YSI sondes measure stage at the water quality instrument locations and Judd ultrasonic depth sensors measure stage inside the road culverts during high flow (winter/spring). Both the sonde and the Levelogger measure absolute pressure (barometric + water) and so data need to be processed after collection to reflect actual stage measurements. Rating curves developed from salt dilutions allow stage measurements to be converted into discharge values.

To better determine discharge during low flow times of the year, a v-notch weir was installed in the road culvert at the Speckerman outlet. The weir was constructed so that field personnel could easily remove it during high flow months to allow sediment and debris to move freely through the system. A Solinst Levelogger will be installed in the weir pond to log the stage of the pond during low flow. This will allow discharge to be calculated with standard engineering equations.

Two different wind monitors were used in this study: an RM Young 01503 and a Vaisala WINDCAP WMT700. On the 05103, wind speed is measured by a propeller and the direction is measured based on the orientation of the vane whereas on the WMT700, three ultrasonic transducers were used to measure both parameters. The 05103 sensors have a wind speed measurement range of 0-100 m s^{-1} and require a minimum of 1.1 m s^{-1} to accurately record wind direction. The WMT700 has a wind-speed measurement range of 0-75 m s^{-1} and require a minimum of 0.1 m s^{-1} to accurately measure wind direction. The 01503 is only used at Big Sandy meteorological station.

A wireless network prototype of snow depth nodes has been deployed around the Duncan Peak meteorological station. The goal of the network is to better capture terrain variability and reduce sensor downtime due to exposed wires that are susceptible to damage by rodents, bears and extreme weather conditions. This network consists of ten snow depth, temperature, and relative humidity measurements in a 1-km^2 area around Duncan Peak. Nodes are connected to a central computer via radio signals that stores data and is capable of on-demand transmissions through a cell phone modem. Off-site access to the network helps project personnel keep track of field conditions and the status of instrumentation.

Data Management and Processing

Continuous data are downloaded from all dataloggers at one-month intervals. These raw files are compiled by water year to a “level 0” file for processing and analysis. The raw data are then reviewed for anything considered an erroneous measurement by a combination of visual review and filtering algorithms to upgrade the file to “level 1”. The level 1 file has time periods with missing data due to measurement error or battery failure. These missing data are filled in using linear relationships with the same type of measurements collected at a nearby site, putting the file at “level 2”. Most of the data in this report are at level 2 or higher. Higher-level processing, including using the continuous stream-stage measurements with individual discharge measurements, creating a stage-discharge relationship for continuous discharge estimates, are files at “level 3”or “level 4”.

Results

Meteorological Data

Hourly meteorological data were recorded at the four stations beginning in water-year 2008, capturing the range of environmental conditions present within the four study basins. Figures 2 and 3 show the daily observations of solar radiation, precipitation, temperature, relative humidity, and wind speed, as well as net radiation for observing energy exchanges between the ecosystem and atmosphere. Note that net radiation was not measured at Big Sandy until water year 2012, and is therefore not shown on these figures. The upper and lower elevations at Last Chance showed greater differences in the meteorological observations than the Sugar Pine stations.

Precipitation measured in Last Chance was 120 cm in 2008 versus 255 cm in 2011; while Sugar Pine had 83 and 214 cm in the same years. Spatial differences in precipitation showed the northern study region of Last Chance, located within the American River basin, with about 40-cm higher levels annually than the southern study region of Sugar Pine, located within the Merced River basin. Precipitation at the higher elevation stations of Duncan Peak and Fresno Dome (elevation >2100 m) is dominated by snowfall, while the lower elevation stations of Bear Trap and Big Sandy (1500-1800 m elevation) record similar levels of rain and snow.

Temperatures at Bear Trap averaged 9.8^{o}C (ranging -12.5 to 35.2) and Duncan Peak averaged 7.1^{o}C (-16.7 to 31.8) at Last Chance, while Big Sandy averaged 9.7^{o}C (-15.4 to 32.7) and Fresno Dome averaged 8.1^{o}C (-15.0 to 30.8) at Sugar Pine. This reflects a temperature difference of only 1.5 ^{o}C per 300 m elevation for Last Chance, and 1.2 ^{o}C for Sugar Pine. A broader analysis of southern Sierra Nevada stations shows values of 1.8-2.0 ^{o}C per 300 m elevation. The cause of these relatively small differences is being evaluated using regional data. However, it is apparent that Duncan Peak has a lower day-night temperature difference than does Bear Trap. Also, daily maximum temperatures between the two sites differ by about 1.8 ^{o}C, versus 1.0 ^{o}C for daily minimum temperatures.

Higher relative-humidity values were recorded at the lower-elevation sites, with mean daily wind speeds around 2 m s^{-1}, and the major wind direction being S-SE for all sites. Wind speed and direction were not able to be gap filled, due to the individual nature of wind conditions at each site.

Upper-elevation stations received slightly higher total daily solar radiation inputs during the summer than lower elevations due to the lower horizon, and the southern study site received more than the northern study site. Approximate maximum radiation values were 35 MJ m^{-2} day^{-2} at Fresno Dome, 30 MJ m^{-2} day^{-2} at Big Sandy, 30 MJ m^{-2} day^{-2} at Duncan Peak, and 25 MJ m^{-2} day^{-2} at Bear Trap.

Maximum summer net radiation followed a similar stratification with values of 25, 20, and 12 MJ m^{-2} day^{-2} at Fresno Dome, Duncan Peak, and Bear Trap respectively. Net solar radiation was small, and in many cases close to zero for water year days 60 to 150 for all sites. The Duncan Peak station (higher elevation) also showed greater variability in net radiation than did Bear Trap (lower elevation).

Snow Depth

Additional snow-depth measurements (2009-2011) were distributed around the meteorological stations and the stream instrument clusters to measure variability around the landscape (Figures 4-5). The data show a snowcover duration of 5-7 months for Last Chance, and about 2 weeks shorter at Sugar Pine. Snow accumulates from approximately mid-December through mid-March or early April, then melts through May (2009) or July (2011). Many sites had winter melt periods in all three years, but maintained some snowcover all winter.

Upper-elevation meteorological stations recorded the highest snow depths and latest snowmelt dates. Last Chance snow depth showed greater variability than did Sugar Pine, with Duncan Peak having the highest snow accumulations and Bear Trap showing intermittent snowcover throughout the three winter periods. Snow depth measured above the banks of the streams varied from the intermittent patterns seen at the lower meteorological stations to the higher accumulation and later melt out of the upper-elevation stations. Due to the greater precipitation levels in Last Chance, snow depth was notably higher at the upper elevation, but similar at lower versus higher elevations in Sugar Pine. With the exception of the time period around day 180 in WY 2011, mean snow depths over the three years in Last Chance were around 100-cm. In Sugar Pine, snow depth values were closer to 75-cm, also excluding the time around day 180 in WY 2011. Last Chance showed greater variability among measurement locations while Sugar Pine showed more daily variability over the winter seasons.

Wireless snow-depth sensors were installed around Duncan Peak to cover a greater variety of terrain and capture a greater fraction of snow depth variability. A grid survey of 119 points with 75-m spacing was completed around Duncan Peak on March 23-26, 2009 and showed the 7 wired nodes represented 20% of the variability measured with the survey. A second survey on April 15 and 26, 2012 showed the wired sensors represented 24% of the variability, with 9 of the new wireless sensors improving that number to 61% (Figure 6). In both cases, the snow-depth sensors did adequately represent the mean spatial value of snow depth.

Soil Texture and Moisture

Soil samples were collected at moisture-sensors locations and analyzed for soil texture (Figure 7). The results show that all the soil samples were in one of four USDA texture classifications: loam, sandy loam, loamy sand, or sand. Almost all of the soils had greater than 50% sand, while they all had less than 50% silt and 30% clay. Soils in the Sugar Pine study area were sandier than in the Last Chance area, with textures showing more similarity by sample site location than by depth.

Soil-moisture values remained high from about November through May, dropped following snowmelt in June-July, and were at season-low values during August-September (Figures 8-9). Soil-moisture levels in the Sugar Pine study area were generally higher above the stream banks than around the meteorological stations (Figure 8). Measurements at the Big Sandy Creek south-facing node more likely represent mean moisture content than variability due to data gaps that were filled in using the north-facing site. At Last Chance, soil-moisture levels showed more similarity between the sites, with the greatest variability at the Bear Trap meteorological station south-facing node due to intermittent snowcover (Figure 9). Monitoring soil moisture at Duncan Peak proved to be challenging, as the sensors exhibited erratic behavior that could not be reconciled with measurements recorded at the other sites, limiting observations at the upper elevations. On average, soils in Sugar Pine maintained 20-30% Volumetric Water Content (VWC) during the wet winter season while Last Chance soils sustained approximately 30% VWC. This may be due to the lower sand content in Last Chance soils.

Stream Water Quality and Quantity

The water-quality parameters of water temperature, conductivity, dissolved oxygen, turbidity, and stage were collected in all study catchments using multi-parameter continuously running sondes (Figures 10-13). Water-quality parameters and stream stage were collected on a 15-minute time interval at the upstream instrument locations approximately 0.3 km above the outlet culvert at the Sugar Pine sites and 30 m above the culverts at the Last Chance sites. Downstream stage measurements were collected using a pressure transducer near the outlet culverts and was also collected on a 15 minute time interval. The meteorological parameters of air temperature and precipitation, plotted on the following graphs, were collected at the lower met stations at corresponding hourly time intervals. The snow depths plotted below were collected on fifteen minute and hourly time intervals, from which daily means were calculated. The plotted values represent means of all snow depth measurements at a given site.

Gap filling was conducted on water temperature and discharge using the upstream or downstream measurements from the same catchment. Snow depth was gap filled from adjacent measurements prior to spatial averaging. The remaining parameters were not gap filled and contain data gaps due to battery failures and burial of the sonde during sediment movement.

Turbidity measurements had considerable noise with background values ranging from -5 to +5 NTU. To compensate for this noise, all values under 5 NTU were removed so that only significant spikes of 5 NTU or more would be considered. That is, spikes exceeding 5 NTU were considered to be water-quality events of potential interest.

Manual measurements of discharge, conductivity, and dissolved oxygen were made on a bi-weekly to bi-monthly basis. Discharge was measured using the salt-dilution slug method and rating curves were created for the continuous stage data. Conductivity and dissolved-oxygen measurements were made with a separately calibrated multi-parameter sonde identical to the continuous running sondes.

Temperature

Water temperature ranged for the period of record from 0 to 11.9 ^{o}C in Speckerman, 0 to 15.6 ^{o}C in Big Sandy, 0 to 12.9 ^{o}C in Frazier and 0 to 11.8 ^{o}C in Bear Trap. Yearly means were 5.0 ^{o}C for Speckerman, 5.1 ^{o}C for Big Sandy, 5.4 ^{o}C for Frazier, and 5.5 ^{o}C for Bear Trap. For all four catchments, water temperatures in WY 2010 were lowest in early winter and gradually rose through the season. In WY 2011, temperatures stayed steady for much of the winter. The higher summer temperatures at Big Sandy compared to Speckerman may be due to Big Sandy having less groundwater input and/or less shading of the stream by vegetation.

Conductivity

At both the Sugar Pine catchments, manual and continuous measurements of conductivity show low, relatively stable values with little seasonal variation. Mean values for WY 2010 and WY 2011 are 12.5 µS and 12.4 µS at Speckerman, and 25.9 µS and 29.0 µS at Big Sandy respectively. The low seasonal variation suggests that the water in these streams is relatively new water. A greater seasonal change would be seen between rain/snowmelt and baseflow if older, higher-conductivity groundwater that has had more time to interact with soil and bedrock was feeding the stream during baseflow. The roughly double conductivity values at Big Sandy suggests the presence of at least some water that is older/higher conductivity than that at Speckerman or differences between the catchments in soils and rock that the event water comes in contact with.

A step-wise pattern is seen in the first part of the Speckerman conductivity record. This is due to the sonde's default setting not recording a sufficient number of significant figures, rather than to the physical functioning of the stream. The problem was remedied part way through WY 2011. Continuous conductivity and dissolved oxygen values at Big Sandy are not shown due to frequent battery failures and sediment burial.

Mean conductivity values for the Last Chance catchments were 33.3 µS and 28.8 µS for Frazier for WY 2010 and WY 2011. For Bear Trap the mean value for WY 2010 was 27.8 µS. Bear Trap's WY 2011 mean were not calculated due to the amount of missing data. Frazier and Bear Trap show a much more pronounced seasonal trend in conductivity. For both streams, the highest conductivity values are seen during baseflow conditions and the lowest during peak spring snowmelt. This is to be expected because baseflow consists of a higher proportion of groundwater, which generally has higher conductivity. In the spring, this groundwater input is diluted by relatively low conductivity snowmelt. The dilution effect can also be seen on a storm-by-storm basis. A good example is the large discharge spike from early season snowmelt centered on WY 2011 day 80 for Frazier Creek. The addition of low-conductivity melt water caused a dilution of the stream and a corresponding dip in conductivity is seen.

Higher mean conductivities and more seasonal variation imply that the groundwater input at Last Chance may be older or that the soil/rock the water is in contact with is more easily reacted. The latter is plausible given that Sugar Pine has predominantly granitic bedrock that is slow to react, whereas the Last Chance catchments have a mixture of granitic and metamorphic rock types.

Dissolved Oxygen

Dissolved oxygen data in all four catchments show percent saturation values that are fairly stable ranging between 75% and 95% saturation, with means for WY 2010 and WY 2011 of 88% and 87% saturation for Speckerman, 91% and 87% saturation for Big Sandy, 86% and 84% saturation for Frazier, and 89% and 86% saturation for Bear Trap. The concentration values in all catchments show a slight seasonal trend as would be expected with higher values in winter/spring when water temperatures are lower. For 85% saturation at sea level, dissolved oxygen values range from 12.2 mg L^{-1} at 0^{o} C to 8.5 mg L^{-1} at 15^{o} C. Values of 7.0 mg L^{-1} or higher are recommended for streams. All four streams have values that fall between 8.0 and 13.0 mg L^{-1}, a healthy range for aquatic life.

Turbidity

In Speckerman, the highest turbidity values tended to occur during snowmelt periods and did not necessarily correspond to the highest flow peaks. In WY 2010, the largest spike was during early snowmelt without any large discharge event associated with it. In WY 2011, the highest spikes were during the peak spring melt, but no spikes were associated with the largest discharge events in that year. An early spike in WY 2011 showed higher turbidity than the storm after it which was associated with a larger discharge event. Gaps in data make interpretation of Big Sandy turbidity difficult, but WY 2010 data shows spikes that correspond to winter and spring melt events as were seen in Speckerman.

Frazier has the most continuous turbidity record of the four catchments. In WY 2010, there is a significant peak that corresponds to the fall rain event, but the largest spikes for the water year were during small early winter snowmelt events and as in Speckerman did not seem to correspond to major discharge events. Two small spikes during spring snowmelt did correspond to some of the most significant discharge events of the year. Similar to Speckerman, one of the highest turbidity spikes in WY 2011 occurred during a rain fall that had a fairly small discharge peak associated with it. The following rainstorm had a much smaller turbidity spike, even thought it had a much larger discharge peak. This could imply a certain amount of sediment depletion occurring in early fall. The first event though smaller flushed out a large portion of the loose sediment leaving less material for the larger event following it to move. The Frazier data also showed a significant spike in turbidity in WY 2011 that in this case did correspond to the highest flow event of the year, an early season snowmelt.

Bear Trap had significant data gaps making interpretation difficult, but showed similar patterns to the other streams in that spikes were seen during snowmelt that did not necessarily correspond to large discharge event. There was also a similar pattern in the rain events in early WY 2011 where the earlier, smaller discharge event had the larger turbidity spike.

Another interesting pattern for all four streams was that significant spikes in turbidity occurred during baseflows when no discharge events were occurring. The exact reason for these spikes is unknown, but possible explanations may be wildlife using the stream or algae growth in the water column. Because the turbidity sensors are equipped with automatic wipers, biofilm buildup on the sensor is not a likely explanation for these spikes.

Discharge

In Speckerman and Big Sandy Creeks, WY 2010 had two fall rain events the first roughly equal to peak snowmelt discharge, the second significantly smaller. WY 2011 also had two fall rain events. In Speckerman, the second was the larger event and was roughly the same as spring snowmelt peaks. In Big Sandy, the second event was also larger, but was about 30% greater than spring snowmelt peaks. In Frazier and Bear Trap the early WY 2010 rain event had a discharge much smaller than that of peak snowmelt. The second of the two early WY 2011 rain events at Frazier was larger than the first, but unlike at Sugar Pine, was less than the peak snowmelt discharges.

The highest WY 2010 discharge events were peak spring snowmelt at the Sugar Pine sites and mid-season melt events at Frazier and Bear Trap. In WY 2011, the highest discharges at all four sites were associated with large early winter melt out events.

The Bear Trap WY 2011 data are problematic in that the downstream instrument read higher values than are reasonable for this stream. It's suspected that accumulation of woody debris near the sensor caused water to back up and artificially elevate stage readings. Because the downstream discharge data were suspect, it was not used to gap fill the upstream discharge values during the time the sonde was pulled for repairs. Bear Trap WY 2011 downstream discharge data were included in Figure 13 to show timing of events only. Discounting the questionable Bear Trap data, spring snowmelt peaks in the remaining three catchments were of similar magnitude in WY 2010 and WY 2011. However, WY 2010 tended to have distinct spring melt peaks, and WY 2011 was long and drawn out extending later into the spring.

Basin Discharge Comparison

For both water years, Big Sandy had higher discharges than Speckerman during rain events; winter flows and the snowmelt period (Figures 14-15). During summer baseflows, the relationship switched and Speckerman had slightly higher discharges. This may be indicative of a greater amount of subsurface streamflow at Big Sandy and/or a greater amount of groundwater input from springs in the Speckerman catchment during the baseflow period. Based on the WY 2010 and early WY 2011 data, Frazier seems to generally have higher discharges than Bear Trap during winter flow and spring snowmelt (with the exception of a few short-duration early winter events where Bear Trap has slightly higher peak event flows). Like at Sugar Pine, that relationship switches during baseflow conditions and Bear Trap showed higher discharges. This may be due to the bedrock channel at Bear Trap preventing any channel bed infiltration or subsurface streamflow. Bear Trap may also have more flow from springs this time of year.

Cumulative discharge comparisons highlight the differences between the two water years and between streams. Total annual flows for WY 2010 and WY 2011 were calculated for each discharge instrument and averaged by stream (Figure 16). Total flow for Speckerman averaged 0.76 $x10^6$ m^3 ($27x10^6$ ft^3) for WY 2010 and 1.50 $x10^6$ m^3 ($53x10^6$ ft^3) for WY 2011. Annual totals at Big Sandy were 1.21 $x10^6$ m^3 ($43X10^6$ ft^3) and 2.60 $x10^6$ m^3 ($92x10^6$ ft^3) in WY 2010 and 2011 respectively. Due to a faulty pressure transducer, the Big Sandy downstream data begins partway through WY 2011. To calculate the cumulative discharge for this instrument, the cumulative total for the downstream sensor at the time its record began was assumed to be equal to that of the cumulative total for the upstream sensor. Based on the discharge comparisons this may be a slight over estimation. Frazier had totals of 1.70 x10^6 m^3 (60x10^6 ft^3) and 2.58 x10^6 m^3 (91x10^6 ft^3) for WY 2010 and 2011. Bear Trap totaled 1.59 x10^6 m^3 (56x10^6 ft^3) for WY 2010. In both water years, Speckerman's total flows are about 60% of Big Sandy's and for both streams, the WY 2011 totals are roughly double that of WY 2010. For Last Chance, the differences are less drastic. Total flows for WY 2010 are tightly grouped and WY 2010 values are approximately 70% of WY 2011 values for Frazier. Bear Trap WY 2011 cumulative discharges were not included in the figure, but the downstream sensor measured a cumulative total of 4.56 x10^6 m^3 (161x10^6 ft^3), further indication that those data are suspect.

When discharge values are normalized over the watershed areas, the differences between streams become less apparent (Figure 17). The normalized total cumulative flow at Speckerman was 51.4 cm (upstream) and 42 cm (downstream) in WY 2010 and 92 cm (upstream) and 93 cm (downstream) in WY 2011. At Big Sandy they were 49 cm (upstream) in WY 2010 and 108 cm (upstream) and 104 cm (downstream) in WY 2011. Frazier's cumulative totals for WY 2010 were 96 cm (upstream) and 107 cm (downstream). For WY 2011 they were 162 cm (upstream) and 143 cm (downstream). Bear Trap WY 2010 cumulative flows were 92 cm (upstream) and 88 cm (downstream). When normalized the paired watersheds group closer together, but there is still a significant difference between the two water years. WY 2010 had normalized total discharge values that were between 46% and 67% of WY 2011 with the greater differences seen at the Sugar Pine sites.

Runoff coefficients, expressed as the fraction of precipitation leaving the basin as stream discharge, were associated more with precipitation levels than basin size (Figure 17). As a result, Last Chance showed higher runoff than Sugar Pine, and both increased from 2010 to 2011. Speckerman Creek and Big Sandy Creek had respective coefficients of 0.40 and 0.42 in 2010 and 0.46 and 0.53 in 2011, respectively. Bear Trap Creek and Frazier Creek had respective coefficients of 0.51 and 0.58 in 2010 and 0.55 and 0.61 in 2011.

Seasonal Stream Diel Cycles

Water-quality data were plotted for select ten-day periods to explore any diel cycles of the water-quality parameters. Frazier Creek and Speckerman Creek WY 2010 were used since their records had the fewest data gaps (Figures 18-19). Snowmelt, spring-recession, and baseflow periods were selected for each stream. For each water-quality parameter in which a diel cycle was seen, the time of day of for the peak of each cycle was identified. Diel signals at Speckerman were seen in water temperature, dissolved oxygen, and discharge. For the Speckerman snowmelt period, a cold-air front drowned out the cycle around days 193-194, but it picked back up around day 195. Water temperature peaked at around 14:00, dissolved oxygen peaked at 12:30, and discharge peaked at 18:00. This reflects only a 4-hr lag between peak temperature, indicative of peak snowmelt, and peak discharge. The spring-recession period was identified as a time past peak snow accumulation along the recession limb of the yearly hydrograph. During this period, water temperature peaked at 15:00, dissolved oxygen peaked at 13:00, and discharge peaked at 14:30. During the baseflow period water temperature peaked at 15:30, dissolved oxygen peaked at 13:00, and discharge peaked at 11:45 (Table 4). A diel signal may also be present in conductivity, but was not visible due to data recording issue explained above.

As the melt season progressed peak temperature shifted to slightly later in the day, dissolved oxygen stayed relatively constant, and peak discharge shifted to earlier in the day. The results are as expected for discharge as early season discharge is dominated by snowmelt and typically peaks later in the day while late season discharge is dominated by evapotranspiration processes and tends to peak earlier in the day before ET reaches its peak. The somewhat unexpected results were in the temperature values. Typically during snowmelt, temperatures peaks are opposite those of discharge because during maximum snowmelt (max discharge) cold melt water is entering the stream dropping water temperature. The fact that these cycles are only slightly out of sync may be an indication that a piston-type flow model is occurring in this stream where snowmelt is immediately infiltrating into the soil, increasing the hydraulic head and pushing near stream soil water into the channel. Additional investigation will be necessary to confirm this conceptual model.

Table 4. Timing of diel cycles in Speckerman water quality data for three flow periods

	Snowmelt	Drawdown	Baseflow
Temperature, peak	14:00	15:00	15:30
Dissolved oxygen, peak	12:30	13:00	13:00
Discharge peak/minimum	18:00/04:00	14:30/04:00	11:45/00:00

At Frazier diel cycles were seen in water temperature, conductivity, and dissolved oxygen. No diel signal could be seen in the discharge for the time periods chosen. During the snowmelt period, temperature peaked at 13:45, conductivity peaked at 14:00, and dissolved oxygen peaked at 12:00. For the draw down period, temperature peaked at 14:14, conductivity peaked at 17:30, and dissolved oxygen peaked at 12:00. The baseflow period showed temperature peaking at 16:00, the conductivity peaking at 15:30, and the dissolved oxygen peaking at 10:30 (Table 5).

The diel water temperature peaks shifted toward slightly later in the day. Conductivity varied widely, but did not show any discernible trend. Dissolved oxygen as in Speckerman did not show any significant shift in the daily peaks.

Table 5. Timing of diel cycles in Frazier water quality data for three flow periods

	Snowmelt	Drawdown	Baseflow
Temperature, peak	13:45	14:15	16:00
Conductivity, peak	14:00	17:30	15:30
Dissolved oxygen,peak	12:00	12:00	11:00

Regional Hydro-Ecological Simulation System (RHESSys)

RHESSys calibration and parameterization continues for the SNAMP basins, with additional input from the Kings River Experimental Watershed – Critical Zone Observatory (KREW-CZO). KREW-CZO has longer, richer data sets than do the SNAMP catchments, and catchments lie at similar elevations and are of comparable areas. Thus the KREW-CZO catchments are being used as part of a meta-analysis for KREW. Further, parameterization developed for CZO-KREW catchments will guide efforts on the SNAMP catchments and larger study areas.

Model results were obtained using observed temperatures and precipitation separated into rain and snow. The separation of rain and snow, as opposed to a single precipitation input, provides a more-accurate daily calculation of evapotranspiration, soil moisture and streamflow. Results for one Providence Creek catchment (P303, KREW-CZO) for water year 2006 (wet year) are shown (Figures 20-21), though modeling has been carried out for two catchments for 6 years. The model simulation was also adjusted using additional observed input parameters such as relative humidity, vapor-pressure deficit and wind speed for water years from 2003 to 2008. The presented results show a good agreement between the daily observed streamflow and simulated streamflow. Moving forward, additional observed parameters such as daily soil moisture, evapotranspiration, and snow depth/snow water equivalent will be compared with the model estimates to finalize the calibrated model.

The same model output is also shown for water year 2010 from Bear Trap Creek (Figures 22-23). It is evident comparing the streamflow output between this watershed and P303, that the model is not as mature for this basin. Calibration and parameterization of the four headwater catchments is still ongoing, although model development of these basins has not yet reached the more advanced stage of P303. The KREW-CZO catchments have been useful for informing these model configurations, as they have provided a good starting point for parameter values, have a more extensive streamflow record for model testing, and have observed values not available at these sites: sapflow rates, fluxes of water vapor and carbon dioxide with the atmosphere, and chemical composition of wet and dry atmospheric deposition.

Project Challenges

Gaps are expected when collecting continuous datasets and were filled during post-processing. Gaps can be caused by many situations, some of which include instrument failure, power failure, damage, vandalism, and user error. Inclement weather and access difficulties occasionally prevented consistent site visits. This was especially prevalent during the fall and spring months when roads are only partially covered with snow. Under those conditions, access with either truck or snowmobile was difficult and often not possible. In these situations, sites were accessed on foot by personnel or field work was delayed until access by vehicle was possible. However, when large repairs were required the equipment needed couldn't always be carried and repairs had to be postponed.

Long stretches of cloud cover or accumulation of snow prevented solar panels from receiving enough incoming solar to keep batteries charged and resulted in station down time. It was expected that battery charge would drop during the winter months and so the initial approach was to replace batteries when they started getting low. Because the sites locations had poorer sun exposure than accounted for, batteries drained faster than could be replaced. Larger batteries helped solve power issues at some sites, however at sites with chronic power issues (typically north facing nodes) solar panels needed to be moved to locations with better sun exposure. This often required a professional tree climber to move the panels high enough in trees that ridgetops did not block low angle winter sun. The combination of increasing battery size and relocating solar panels largely resolved any power problems.

By far the most common damage to sites was from snow loads. The damage caused by snow creep on installations varied each season but common damage included: bent u-channels, mounting/instrument poles leaned downslope, enclosures torn from mounting poles, and cables ripped out of dataloggers. Damage was amplified during heavier snow years (e.g. WY 2011) and resulted in wide-spread power failures and instrument damage. Many of the snow depth sensors and instrument enclosures needed to be repaired or replaced during the life of this project. Duncan Peak was especially hard hit and required repairs to every instrument node following the 2010-2011 winter. Mitigating damage was difficult due to the constraints on field season length and budget. Sites were generally repaired with some minor modifications such as reinforcing connection, adding extensions, installing more robust hardware, and burying or using zip-ties to secure loose or exposed cables.

Two less-common forms of damage at sites were a result of vandalism and wildlife. Vandalism ranged from property destruction to theft and was usually confined to areas where summer recreation was popular (e.g. Big Sandy Campground). Solar panels became targets for both firearms and rocks but those incidents usually did not result in much, if any, instrument downtime. Theft occurred once during the summer of 2011 at the Speckerman Creek culvert installation and required the replacement of all site components. Wildlife damage was focused around enclosures and cables. The most common damage was from rodents chewing through exposed cables cutting power to instrumentation. Bears focused their efforts on fiberglass enclosures and flexible conduit, chewing through or ripping out cables running along mounting poles. Trenching and running cables through conduit were the best ways to prevent wildlife damage but made troubleshooting cable connections was difficult and time consuming.

Operating a network of 8 instrument clusters that, in some cases, produce upwards of 30 individual 15-minute data streams each, results in a massive amount of data accrued annually. Processing the incoming data is time consuming and was difficult to keep up with while concurrently performing installations, routine maintenance and repairs. To address this issue, a protocol for managing incoming data streams was established. Through use of the protocol, a clear division of responsibilities, and additional project support, data streams are being processed in a timely manner and routinely examined throughout the year. Prioritizing the installations, measurements and data processing was also necessary given the lag and eventual reduction in funding relative to the project's original scope of work and accompanying budget.

Conclusions

The 2-4 years of water-quantity and energy-balance data assembled and presented here provides an adequate basis for developing a pre-treatment modeling capability for the SNAMP catchments. Use of the CZO-KREW data is important to help guide the modeling effort, and extend it to large areas. Forest treatments were started in the fall of 2011 and are expected to be finished in summer 2012. Thus water-year 2012 data represent a transition year. Water-year 2013 will be a post-treatment measurement year, and will be the main measurement basis for evaluating the effects of thinning. Extending measurements through water-year 2014 would enhance detecting the post-treatment effects; but that would necessitate data analysis and modeling through spring-summer 2015.

While it has been necessary to somewhat reduce the water-quality measurements and scope, measurements to date do establish baseline conditions from which to compare effects of treatments. The adequacy of this data set will depend in part on precipitation and hydrologic conditions in water-year 2013.