**Proposed Scope of Work for Task 1**

**Assessment of Climate Change Effects and Impacts on the Hydrology of Southern Sierra Nevada Basins**

**Summary**

The Southern Sierra Regional Water Management Group, in partnership with UC Merced, proposes to develop a first-order assessment of climate change effects and impacts on the water supplies and quality of the southern Sierra Nevada watersheds – beginning with the Kings River Watershed. Building on our group’s past and ongoing efforts we will synthesize the existing ground-based and remotely sensed data and use these data to carryout a spatially distributed forest-vulnerability assessment. We will then conduct a pilot integrated hydrology, ecosystem, and socio-economic modeling in the Kings River Watershed to evaluate the vulnerability of region’s water supply to changes in vegetation and climate and explore adaptive solutions and capacities in terms of forest management. The products in the form of data, maps, and models from this assessment are specially designed to inform the southern Sierra IRWMP.

Water supplies in California depend on snowmelt runoff from the Sierra Nevada. As the climate continues to warm, much of the region’s precipitation will shift from snow to rain and snowpacks will melt earlier. These changes in snowpacks are not only expected to alter the flow timing, but warmer temperatures, longer growing season, and a shift in precipitation from snow to rain may result in more water use by forest vegetation and reduced streamflow. Reduced and earlier snowmelt is directly linked to enhanced forest growth, change in forest composition, forest fires, and increased forest stress and mortality. Changes in vegetation, in turn, can potentially alter snow accumulation and melt regimes, shift the timing of evapotranspiration losses, recharge and storage in the subsurface, and thereby feedback on regional water resources.

Previous research and ecohydrologic modeling by UC Merced group demonstrates that the changes in vegetation (both enhanced greening/expansion and mortality) are primarily driven by the interplay between atmospheric water demand, water storage (both in the form of snow and soil moisture), and forest density. Forest in the mid-elevations (3000-6000 ft) of the Sierra Nevada coincide with optimal precipitation and temperature, and enjoys a year-round growing season, supporting the highest net primary productivity. As a result, the forest density is much higher in this elevation range as compared to low and high elevations that are either water limited or cold limited. However, the same mid-elevations are experiencing greater impacts of climate change (reduced snow and higher atmospheric water demand in the winter with rising temperatures) than the other part of the Sierra Nevada and may have reached a tipping point with ongoing and massive tree mortality. As temperature continues to warm, presently stable forests in snow-dominated elevations may cross intrinsic instability thresholds in the future. These ongoing and additional changes in vegetation under future climate will have major water resources management implications for the region.

**Introduction**

The ongoing drought in California has resulted in unprecedented tree mortality and insect infestations across the Sierra Nevada. According to recent estimates from the US Forest Service, there are as much as 66 million dead trees − a number that will continue to grow as the drought persists. This rapid and massive loss of forest structure has the potential to alter a variety of hydrologic and ecosystem processes, including water and carbon fluxes. Unfortunately, the scale and actual effects of tree mortality on hydrologic and ecosystem function and fluxes are still not well understood or at least not placed in a context that produces useful and actionable information for amount of water resources and the health of forest that supply California’s water. In theory, runoff is inversely related to the amount of forest cover because of expected declines in interception and transpiration following tree mortality (Figure 1). Over time, gross and net primary productivity will recover to pre-mortality levels and gains in runoff will dissipate. The magnitudes of runoff increase as well as recovery time are very site specific and can vary by several orders of magnitudes depending on the climate and subsurface properties.

 Research on tree mortality, and forested experimental watersheds in general, have often produced results that contradict the theoretical framework linking the runoff with forest cover. Not all studies confirm runoff gain following tree mortality (e.g. Adams et al., 2012; Biederman et al. 2014; 2015). In fact several studies in the western US show a decline in runoff by up to 50% following tree mortality (Adams et al., 2012). This indicates that the underlying mechanism depends on multiple attributes of the forestland and climate (Troendle et al., 2010), and competing hydrologic processes (e.g. interception, transpiration, evaporation, and sublimation) may limit the runoff response (Biederman et al. 2014; 2015; Saksa, 2015). For example, the excess water available due to reduction in interception after tree mortality can be taken-up by sublimation, transpiration from remaining trees and understory vegetation, and increase in direct soil evaporation. Also, the hydrologic response to tree mortality are scale dependent and may differ from a patch, hillslope, to basin scales.

Figure 1: Expected changes in ecosystem fluxes of carbon (A) and water (B) during and following a tree mortality event. A dashed line indicates the beginning of the mortality event. Carbon fluxes include a decline in gross primary productivity (GPP) driven mostly by reductions in LAI (1), a decline in autotrophic respiration (Ra) due mostly to reductions in leaf area and growth rates (2), an increase in heterotrophic respiration (Rh) driven mostly by decomposition of dead leaves and roots (3), a decrease in net ecosystem productivity (NEP), and in some systems a second pulse of heterotrophic respiration driven mostly by decomposition of fallen stems and snags (4). Water fluxes include a decline in plant transpiration (Eplant) driven mostly by reductions in leaf area (1), increases in runoff (2), and in some systems a potential secondary increase in runoff due to increased surface water movement after snag fall (3) (Source: Anderegg et al., 2016)

Nonetheless, these conditions may provide a glimpse of the future ahead. As the region continues to experience altered hydrologic regimes mainly resulting from reduced precipitation, increased temperature, more winter precipitation falling as rain than snow, and snowpacks melting earlier, conditions of water scarcity and subsequent impact on the environment are expected to intensify (Barnett et al., 2005; Westerling et al.; 2006, Bentz et al., 2010; Dennison et al., 2014). Hence, a first-order forest vulnerability assessment and its potential impact on the region’s water supply are needed for developing future planning and green infrastructure management strategies, which are a fundamental part of the southern Sierra IRWMP.

The scope of the task 1 described in the main work plan consists five primary sub-tasks.

**Task 1a: Data Synthesis**

The Kings River Watershed is a home of National Science Foundation funded Southern Sierra Critical Zone Observatory (SSCZO), a platform for a wide variety of research that extends from bedrock to atmosphere. Since SSCZO was initiated in 2007, with the help of targeted measurements we have significantly improved our understanding of the amount and patterns of seasonal water storage in snowpack and soil along with ecosystem distribution and function in the southern Sierra Nevada. Headwaters of Kings River Watershed are also home to the US Forest Service funded Kings River Experimental Watersheds (KREW), a watershed-level, integrated ecosystem project for long-term research on nested headwater streams in the southern Sierra Nevada. Since 2002, researchers at KREW are collecting meteorological, discharge, soil, vegetation, sediment, and nutrient data to understand the functioning of the southern Sierra streams and evaluate effects of forest management (prescribed fire, small-group tree harvesting) on water quantity and quality. We propose to build on this body of new knowledge by combining the existing streamflow and field measurements of water storage and use (i.e. evapotranspiration) with remote sensing and GIS analyses to investigate the role of climate and water storage on the ecosystem functioning. This focus will help develop a predictive model to derive the sensitivity of ecosystem to climate change, including climate variability and extremes.

We have already acquired 800 m daily climate data from PRISM and downscaled future climate data will be obtained from University of Idaho (Abatzoglou and Brown, 2012). Following the global circulation model selection guidelines by the CA department of Water Resources (CA DWR, 2015), wewill synthesize climate scenarios at 4 km x 4 km spatial and daily temporal resolution, for near-term (up to about mid-century) and long-term (end of the twenty-first century). We will further downscale the climate scenarios obtained at 4 km x 4 km resolution to 800 m x 800 m resolution using PRISM data to drive the proposed forest vulnerability assessment and numerical modeling to examine the influence of climate change on water supply.

**Deliverables: (1) A predictive model of ecosystem sensitivity to climate change**

 **(2) Downscaled climate change scenario**

 **(3) Spatial map of water balance components for the study domain**

**Task 1b: Forest Vulnerability Analysis and Delineation**

**We define vulnerability as the degree to which forests are susceptible to the adverse effects of climate variability and change. Hence, the vulnerability assessment will be conducted by first performing a sensitivity analysis of region’s forests to climate and water storage. We will then combine the sensitivities with the climate exposure and adaptive capacities to derive vulnerabilities. We will develop GIS maps showing the most vulnerable areas in terms of forest health under various climate change scenarios.

Figure 2: Scheme of the approach followed to assess the climate change impacts and vulnerability in southern Sierra forests.

**Deliverables: Forest vulnerability data in terms of maps and GIS layers**

**Task 1c. Integrated Modeling of the Kings River Watershed and Alternative Futures Assessment**

 One of the key issues that planners face in evaluating climate-change impacts on water resources is the lack of consideration of many inter-related variables and pools. Many dependent processes like vegetation distribution (species, functional type), carbon stock (sequestration, forage), disturbance regime (fire, insect, die-offs), and hydrology (evapotranspiration, storage, runoff) are studied independently. There are very few numerical models (e.g. RHESSys, Community Land Model or CLM, Lund-Potsdam-Jena managed Land or LPJmL) that can integrate all of the aforementioned processes. However, none of these models are best suited for intermediate size basins. Hence, for the purpose of this pilot modeling assessment, we will integrate appropriate models of the KRB in a way that captures important elements of climate-vegetation- subsurface storage feedbacks and explicitly incorporates both climate and policy/management scenarios for adaptation. We will employ the *Envision* platform (Bolte et al, 2007), a robust and mature set of modeling, data-analysis and visualization tools and capabilities developed specifically to enable spatially and temporally explicit examination of strongly coupled human/natural systems using a model-based alternative-future-scenario approach that is ideally suited for IRWM planning. The *Envision* modeling frameworkincludes: 1) a geo-database that manages landscape-characteristic data through space and time; 2) a standard plug-in interface for water, ecosystem, and socio-economic models; 3) a multiagent modeling subsystem for representing human decision-making; and 4) a GIS based system for visualizing results. We will develop the *Envision* model for KRB by creating a spatial coverage of Integrated Decision Units (IDUs) and leading modeling integration efforts. Similar to a hydrologic response unit (HRU), a more commonly used term, an IDU is a hydrologic and management response unit upon which *Envision* runs. Each IDU is characterized by set of attributes that describe biophysical qualities (soil, land use /land cover, streams, roads etc.).

*Envision* allows a rich description of stakeholder and decision-maker behavior related to water and land management decision making through the three-way interactions of *actors* (individuals or institutions that have decision-making authority regarding land and water management), dynamic landscape changes resulting from biophysical and sociocultural processes, and the operative strategies and policies that guide and constrain decisions. Actors (e.g. reservoir operators, private timber companies etc.) balance a set of objectives reflecting their particular values, utility functions, mandates, constraints, and policy sets in force on the parcels they manage. As actors assess alternative forest management options within institutional contexts (*e.g.*, prescribed burn, forest thinning), they weigh the relative utility of available policies and strategies to determine which to select and apply at any point in time/space. Actors can thus both influence landscape dynamics and adaptively modify their behavior in response to these landscape signals.

**Deliverables: (1)** *Envision* **model for the Kings River Watershed**

 **(2) Water yield data (in the form of maps and tables) for the pine flat reservoir simulated under various climate and land management scenarios described earlier.**

**Task 1d. Meeting and Program Reports**

Quarterly meetings will be held to discuss the roadmap, products, and key findings. Also, we will work with the outreach plan described in the full work plan and seek community input in developing the alternative management scenario for the modeling work. UC Merced researchers will also explain the importance of the results to Regional Water Management Group stakeholders, and how it is relevant to the IRWMP and future project development.

**Deliverables: None**

**Task 1e. Prepare Final Report**

A technical report will be prepared, presenting the basic data and interpretation, maps, as well as recommendation for future implementation studies and monitoring programs. The stakeholders and other interested parties will have the opportunity to review the project report and provide comment. A final report will be prepared after addressing all the comments and concerns. The outcomes of this climate change assessment will be incorporated in the updated in the IRWMP as described under Task 14 in the main Work Plan.

**Deliverables: Final report to RWMG and incorporation of information and planning elements into the IRWMP**

**Conclusions**

The five sub-tasks will result in deliverables, which will each provide a critical foundation for the southern Sierra IRWMP update, including the Climate Change Chapter update, planning for water supply and quality as well as goals and objectives. These planning elements will aid in identifying future projects that directly benefit Disadvantaged Communities, agencies who manage lands, water purveyors, suppliers and water users downstream. The approach will be used to extrapolate to other watersheds to pursue a comprehensive climate-adapted water supply and quality approach in the southern Sierra Nevada.

**References:**

Abatzoglou, J. T., & Brown, T. J. (2012). A comparison of statistical downscaling methods suited for wildfire applications. International Journal of Climatology, 32(5), 772-780.

Adams et al., 2011. Ecohydrological consequences of drought- and infestation-triggered tree die-off: insights and hypotheses. Ecohydrology, DOI: 10.1002/eco.233.

Anderegg et al. 2016. When a tree dies in the forest: scaling climate-driven tree mortality to ecosystem water and carbon fluxes. Ecosys., DOI: 10.1007/s10021-016-9982-1

Barnett, T. P., Adam, J. C., & Lettenmaier, D. P. (2005). Potential impacts of a warming climate on water availability in snow-dominated regions. Nature, 438(7066), 303-309.

Bentz, B. J., Régnière, J., Fettig, C. J., Hansen, E. M., Hayes, J. L., Hicke, J. A., ... & Seybold, S. J. (2010). Climate change and bark beetles of the western United States and Canada: direct and indirect effects. BioScience, 60(8), 602-613.

Biederman et al., 2014. Increased evaporation following widespread tree mortality limits streamflow response. Water Resources Research, DOI: 10.1002/2013WR014994.

Biederman et al., 2015. Recent tree die‐off has little effect on streamflow in contrast to expected increases from historical studies. Water Reso. Research 51(12) 9775-9789.

Bolte, J. P., Hulse, D. W., Gregory, S. V., & Smith, C. (2007). Modeling biocomplexity–actors, landscapes and alternative futures. Environmental Modelling & Software, 22(5), 570-579.

Dennison, P. E., Brewer, S. C., Arnold, J. D., & Moritz, M. A. (2014). Large wildfire trends in the western United States, 1984–2011. Geophysical Research Letters, 41(8), 2928-2933.

DWR, 2015, Perspectives and Guidance for Climate Change Analysis. <http://www.water.ca.gov/climatechange/docs/2015/Perspectives_Guidance_Climate_Change_Analysis.pdf>

Saksa, P (2015). Forest management, wildfire, and climate impacts on the hydrology of Sierra Nevada mixed-conifer watersheds, PhD dissertation, Uni. of California Merced.

Troendle et al., 2010. Fuel management and water yield. Cumulative watershed effects of fuel management in the western United States, edited by W. J. Elliot, I. S. Miller and L. Audin, Gen. Tech. Rep. RMRS-GTR-231, pp. 126–148, U.S. Dept. Agr., Forest Serv., Rocky Mountain Res. Stat., Fort Collins, Col.

Westerling, A. L., Hidalgo, H. G., Cayan, D. R., & Swetnam, T. W. (2006). Warming and earlier spring increase western US forest wildfire activity. science, 313(5789), 940-943.

**Budget:**

|  |  |  |  |
| --- | --- | --- | --- |
|   | Year 1 | Year 2 | **Sum** |
| Salary and Benefits: | $78,874 | $17,086 | **$95,960** |
| Supplies | $2,000 | $0 | **$2,000** |
| Travel | $1,000 | $500 | **$1,500** |
| Outreach and Education | $0 | $0 | **$0** |
| Tuition & Fees | $0 | $0 | **$0** |
| Indirect Cost (5%) | $4,094 | $879 | **$4,973** |
| Total | **$85,967** | **$18,466** | **$104,433** |

**Budget Justification:** Funds are requested to support one postdoc (level 3, 1.0 FTE @ $4,096/month) for 15 month along with two weeks salary (@ $22,556/month) of co-PI (R. Bales). The TBA postdoc will be responsible for data synthesis, producing forest vulnerability maps, and running the Envision model for the Kings River basin. The co-PI (R. Bales) will help coordinate the meetings with stakeholders and also supervise the postdoc.

**Supplies:** $2,000 requested for purchasing a personal computer and relevant software licenses for running the data synthesis and modeling.

**Travel:** A total of $1,500 requested for travel, for both field and stakeholder meetings.

**Indirect Cost:** Indirect costs are calculated based on the DWR allowable rate of 5%.