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Assessing Environmental Justice Impacts and Social Learning of Integrated Regional Water Management Planning

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Project Summary

Water is arguably the highest-value ecosystem service associated with the conifer forests of California's Sierra Nevada. Yet the provision of this essential service is vulnerable to changes in the energy and water balance associated with climate warming. To date, we have observed more precipitation falling as rain versus snow, earlier snowmelt, and greater summer water deficits. Such climate forcing will impact the water balance for the foreseeable future. However there is the potential to manage the water balance in forest ecosystems.

The dominant vegetation (i.e., trees) is highly productive, forms dense canopies, and consequently, uses a great deal of water. There is a strong positive correlation between annual net primary productivity (the ultimate measure of the photosynthetic capacity of the ecosystem) and evapotranspiration (the primary cause of water loss). Any manipulation that reduces the productivity (i.e., removes trees) reduces evapotranspiration, shifts the balance of energy driving snowmelt, and thus may affect soil-water storage and streamflow. Water from the Sierra Nevada provides both hydropower and water supply to downstream users. Reducing and restructuring the forest vegetation density can also mitigate the negative impacts of wildfires as well as accomplishing some forest restoration objectives.

Forest management that specializes in high value and long-lived forest products can produce the greatest amount of total carbon sequestration benefits when energy use in the consumer sector is considered. Recreation-, conservation-, and biodiversity-related ecosystem values often pose competing aims relative to forest management but there are few mechanisms to evaluate the tradeoffs and complements related to different strategies. Open space easements and hunting leases are two examples of ecosystem services that could provide a model for translating expressed value for other ecosystem services into real financial mechanisms.

It is proposed to undertake a three-part, multi-year and multi-disciplinary research and assessment project that addresses issues related to climate warming, vegetation manipulation, and the forest water cycle. The three components are: i) measurements at sites of opportunity where fire or thinning treatments have taken place or are taking place, ii) meta-analysis and modeling using available data to interpret these results, and iii) evaluation of multiple ecosystem services and how multiple service providers (land and resource owners/managers) can effectively interact with service consumers (downstream and downhill residents).

Introduction:

Paired-catchment studies provide historical evidence regarding the effects of vegetation management on forest hydrology (NRC 2008). During the past 60 years, literally hundreds of studies have been conducted worldwide, with results summarized in a series of reviews (e.g., Bosch and Hewlett 1982, Hornbeck et al. 1993, Stednick 1996, Brown et al. 2005). However no paired-watershed study has been conducted in the conifer forests that dominate the west slope of the Sierra Nevada. Nor is the existing information sufficient to support process-based modeling of the causes of observed watershed responses.

Perhaps the most significant consideration is that past studies generally imposed a treatment once and then allowed the forest to regrow (Hornbeck et al. 1997). Reports of effects on water yield are typically based on the first five years following treatment (Brown et al. 2005). However the recovery of forest vegetation, ET and runoff to preharvest levels can be rapid unless regrowth is suppressed (Hornbeck et al. 1997). It is this rapid forest recovery that limits the practicality of managing the forest for water yield. Repeated entries into a watershed to maintain the vegetation structure takes time and money, an expense that is not always warranted by the value of the water (Hornbeck et al. 1997). Moreover, vegetation suppression has consequences to key ecosystem attributes such as productivity, nutrient cycling, diversity, wildlife habitat, and sediment transport.

Another important filter is to select studies done in similar forest types and comparable climates (Peel et al. 2010). The snow-dominated forests of the Sierra Nevada support temperate, evergreen, needle-leaved trees. They are productive forests that maintain large pools of live biomass with high leaf area. They also experience mild snowy winters and hot dry summers characteristic of Mediterranean regions. Based on generalizations from reviews of paired catchment studies, the Sierra Nevada conifer forest has ecological attributes that suggest a high potential for water-yield gains. First, forest catchments dominated by conifers consistently show greater per capita gains in water yield (mm of water yield/fraction of forest cover removed) than any other forest type. For example, Bosch and Hewlett (1982) found per capita water yield in temperate conifer forests was on average 60% greater than in temperate deciduous forests.

As shown by Zhang et al. (2001), changes in water yields depend on the amount of precipitation (ppt). In extremely dry ecosystems (< 500 mm yr-1 ppt) and extremely wet ecosystems (> 1500 mm yr-1 ppt) there is a limited ability to affect water yield by manipulating the vegetation. In the high Sierra, total annual precipitation ranges from a low of about 600 mm in the south to a high of over 1800 mm in the north (Bales et al. 2006). Thus in terms of input, the Sierra Nevada spans a range where there is a near-linear increase in water yield with reductions in forest cover (Zhang et al. 2001). Finally, in snow-dominated systems there is clear seasonality in the water-yield response to treatments, with the greatest absolute increases observed during snowmelt but the greatest proportional increases observed during the dry summer months (Brown et al. 2005). The duality in response suggests that upstream forest management can help fill downstream reservoirs in the spring as well as support baseflow during the summer. Thus from qualitative arguments, it seems that there is the potential to manage for water in the Sierra Nevada.

Further, using a simple quantitative method developed by Zhang et al. (2001) that is based on precipitation and vegetation cover, we estimated that a 30% reduction in forest cover (e.g. from 90% to 60%) for a Sierra Nevada watershed would increase water yield by 9%.Given the limitations of the data on which Zhang et al. (2001) had for developing their correlations, we feel that this number could be higher.

The seasonal snowpack in the Sierra Nevada is a critical component of this water balance. At lower elevations, the snowpack melts shortly after being deposited, but at higher elevations the snowpack typically accumulates from December until March or April, and then melts from April through May-July. Thus the lag between precipitation and discharge depends on elevation, and is about two months in catchments where only about 50% of the precipitation fell as snow (Hunsaker et al. submitted). In general, snow melts out about 20 days later for each 300-m increase in elevation (Bales et al. 2010). Stream discharge from these catchments varies from 10% of precipitation in a more rain-dominated catchment in a dry year, to over 60% in a snow dominated catchment in a wet year.

ET accounts for most of the precipitation not leaving the catchments as discharge. At least in the lower-elevation catchments, trees transpire year round, drawing water from both soil and deeper regolith during the dry summer when ET is highest (Bales et al. submitted). Forest treatments and climate warming will affect both the lag between precipitation and runoff, and the water yield. These changes will be mediated through shifts in the timing of snowmelt and the amount of water evaporated, transpired or sublimated.

Snowmelt is driven by temperature and vapor density gradients within the snowcover caused by heat exchange at the snow surface and at the snow–soil interface (Marks et al. 1999). Forest cover influences energy exchange to snow, effectively decoupling the above-canopy and sub canopy atmospheres and suppressing turbulent-energy fluxes (Link and Marks 1999). Thus the energy balance on sub-canopy snow is dominated by radiation. The canopy modifies shortwave irradiance through shading and longwave irradiance via thermal emissions (Link et al. 2004). Forest cover may also affect sub-canopy shortwave radiation by altering snow surface albedo through deposition of tree litter (e.g. twigs, leaves) on snow (Melloh et al. 2002).

The Sierra Nevada harbors globally distinctive forest resources that deliver a wide variety of benefits to the citizens of California and elsewhere. These benefits derived from natural ecosystems – also called ecosystem services – include recreation-, biodiversity-, conservation-, water-, and forest-product-related services. These ecosystem services often pose competing aims relative to forest management, but there are few mechanisms to evaluate the tradeoffs and complements related to different strategies.

Water is arguably the highest-value ecosystem service associated with the conifer forests of California's Sierra Nevada. Yet the provision of this essential service is vulnerable to changes in the energy and water balance associated with climate warming. To date, we have observed more precipitation falling as rain versus snow, earlier snowmelt, and greater summer water deficits. Such climate forcing will impact the water balance for the foreseeable future. However there is the potential to manage the water balance in forest ecosystems. The dominant vegetation (i.e., trees) is highly productive, forms dense canopies, and consequently, uses a great deal of water. There is a strong positive correlation between annual net primary productivity (the ultimate measure of the photosynthetic capacity of the ecosystem) and evapotranspiration (the primary cause of water loss). Any manipulation that reduces the productivity (i.e., removes trees) reduces evapotranspiration, shifts the balance of energy driving snowmelt, and thus may affect soil-water storage and streamflow. Water from the Sierra Nevada provides both hydropower and water supply to downstream users. Reducing and restructuring the forest vegetation density can also mitigate the negative impacts of wildfires as well as accomplishing important forest-restoration objectives.

Research Program

This research aims to build the information infrastructure for sustainable ecosystem management of Sierra Nevada forests, based on valuation and tradeoffs among complementary and competing ecosystem services. In particular, this research emphasizes high value water-related services, which have the potential to finance forest management for multiple benefits. The three main components of the project plan, their aims, and expected outcomes follow.

1. Field measurements. The aim is to collect the observational data needed to support the development of forest treatment/management scenarios through modeling and analysis. Expected outcomes are key improvements to the knowledge base of snow accumulation and melt, soil moisture, ET, stream discharge, LAI and the linkage of these attributes to climate, soils and physiographic features of the landscape. A further outcome will be a measurement framework to quantitatively enumerate ecosystem services to support potential future public and private investments.

2. Meta-analysis and modeling. The aim is to integrate data through analysis and modeling of how the forest vegetation and water cycle will respond to climate change and management actions. Expected outcomes are scientific findings around ET, water-use efficiency, water deficit, water storage, and water yield as a function of climate, vegetation and physiographic characteristics of the Sierra Nevada landscape, and a predictive ability that is relevant for forest management. A further outcome will be the design for a watershed treatment experiment designed to optimize water-based ecosystem services.

3. Evaluation of ecosystem services. The aim is to use the American R. area as an informative case study for measuring and valuing water-based ecosystem services, assessing the impact and importance of those services to local stakeholders, and determining competition between services. Expected outcomes include approaches and metrics for valuing and assessing ecosystem services. A further outcome is stakeholder participation in subsequent pilot projects to manipulate forests to optimize for water storage and yield. In addition to these strategic aims, several scientific objectives will be addressed that contribute to our understanding of not only the Sierra Nevada forests, but forests in other semi-arid landscapes.

1. Determine rates of ET in Sierran mixed-conifer/true fir forests. It has recently become apparent that ET estimates based on ecological modeling versus those based on field measurements of hydrologic water balance differ by 50% or more. It is also apparent that the ET and net primary productivity (NPP) values for Sierran forests do not correspond to the well-established near-linear relationships between NPP and ET.

2. Determine water use efficiency of trees and shrubs in Sierran mixed-conifer and true fir forests. The carbon gained per unit of water transpired (i.e., water use efficiency) is an overarching silvicultural question. We need to learn how to protect species diversity and maintain a healthy forest given climate change, while also minimizing the use of in-forest water use and maximizing water yield. Essential to this task is quantifying differences in water use efficiency among the common forest species.

3. Determine the potential for forest management to delay snowmelt in Sierran forests. Storage of water in the snowpack attenuates streamflow. Delaying runoff later into the summer drought season has value to multiple ecosystem services. While it is well known that changes in the magnitude and distribution of LAI influence the forest energy balance and thus snowmelt, prescriptions specific to the heterogeneous landscape of the Sierra Nevada and their impact have yet to be quantitatively assessed with hydrologic modeling.

4. Determine potential economic tradeoffs of forest management treatments to affect water yield and ecosystem services. Forest management interventions designed to increase late season runoff and related environmental benefits will need to be substantial enough to produce measurable and predictable changes to justify the development and enforcement of contracts for the additional services. In addition to estimating the on-site costs and benefits, the contractual arrangements between the producers and willing buyers of variable quantities of goods and services will be characterized.

5. Involve stakeholders in decision-making regarding forest management and watershed effects. Over the past 2-4 years, stakeholders concerned with Sierra Nevada ecosystem services (primarily water- and wildlife-related services(, have become sensitized to the potential synergies and conflicts between these services, and the potentially large economic benefits to be gained from better information to support decision-making. For example, the investigators on this project have collectively given talks and attended meetings to address these issues an average of at least twice monthly and often several times a month over the past 2-4 years. It is expected that this project, which builds on the planning done under the SWEEP project, will spawn an on-the-ground set of forest treatments.

One output of our work will be a site-specific plan, supported by stakeholders, to carry out the thinning and associated assessments at the scale of headwater catchments (~1 km2). This project will provide the needed bridge between the SWEEP planning support and the expected distributed support from state and local sources for the treatment and follow-up research.

Information Transfer/Outreach Program

Anticipated outcomes:

Supporting science based decision making: The proposed project will support science based decision making by increasing understanding of the relationship of forest management to increasing water yield in the Sierra Nevada. Involving managers and policy makers in the research process allows for mutual learning that can enhance research outcomes and increase the likelihood of adoption of research results. Key stateholders will be involved through the formation of a technical advisory committee (TAC) developed to capture the expertise of stakeholders in the valuation case study area – the American River basin. This TAC, to be composed of crictial stakeholders including water agencies, environmental consultants, hydro-electric generators, forest residents, forest managers and downstream water users will be critical to development of the valuation case study.

These stakeholders must be engaged to identify how ecosystem services can be priced and allocated. The TAC will be formed by selecting critical American River basin stakeholders and asking them to commit to two project meetings a year as well as collaboration in committeees. At the start of the research project, the TAC will be used to review the valuation study plan and add any variables that are critical from their perspective. During the research phase, the TAC will be used to supply needed data for the case study and vet research findings. At the end of the study, the primary responsibility of the TAC will be to assist in dissemination of study results to appropriate audience and advise on any needed policy changes needed to develop ecosystem service markets based on project results. A primpary function of the TAC in the final year of the project will be to assist the research team in developing pilot project area where research results that based on modeling can be vetted through studies of actual forest management project across a range of canopy densities.

Delivery of useful findings to support policy and outreach efforts: The state critically needs to adopt new approaches to water and forest management that consider the changing climate and other pressures. Findings from this project will be used by a multitude of stakeholders who are keen on establishing closer links between headwaters and downstream users. Specifically, there is very strong interest in the development of methods for valuing the water yield augmentation due to forest management with the hope that income received from this ecosystem service would more accurately reflect the society-wide economic benefits of certain forest management actions. The team will participate with stakeholders wanting to pursue policy changes and collaborations to develop ecosystem service markets based on project results.