Upland Ecosystem Science to Action Plan:

Integrated Research to Inform Greater Resilience in the Lake Tahoe Basin Uplands

Tahoe Science Advisory Committee Work Order #015

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Introduction and Need

The 63 watersheds that feed Lake Tahoe span a diversity of ecotypes that transition from Sierran to Great Basin, montane to alpine, and aquatic to terrestrial. Lake Tahoe is at the heart of all these systems and its health is highly dependent on the upland ecosystems.

Effective conservation and restoration investments are dependent upon a robust scientific foundation. Improving resilience of the Basin's upland ecosystems to climate change and disturbance (e.g. wildfire, introduction of species) is a broadly shared objective among Basin agencies. Decades of work in the Tahoe Basin suggest that improving management of upland ecosystems requires a holistic, coordinated framework that evaluates progress toward expected outcomes with monitoring, identifies undesirable conditions to inform resource decision making, and engages stakeholders and the public.

It is clear that scientific research has an increasingly important role in anticipating and adapting to environmental changes that are projected to occur as a result of climate change through a coordinated system of monitoring and adaptive management to conserve upland ecosystems. This document proposes a process by which the TSAC will outline specific investments in science to action over the next three years, during which future, longer-term high priority investments over the next decade will be identified.

The objective of the Upland S2A Plan is to develop a bold vision for the contribution that near-term and long-term research can make to promoting resilience to disturbance and climate change, adapting to environmental change, and enhancing the sustainability of environmental quality, ecosystem services and societal benefits.

Toward this end, this document broadly identifies important climate change impacts on upland ecosystems, outlines the critical need for research and management partnerships, describes the state of the science and critical research needs, and identifies a set of research tenets that transcend individual projects and that we feel will serve as a solid foundation for guiding the development of an innovative, scientific foundation for upland ecosystem management in the Lake Tahoe basin. The document outlines the process we will use to develop robust research agenda for the next 10 years that will leverage latest technological advances to gather and analyze data to increase our capacity to model, predict, and project when and where changes in conditions, capacities, and benefits are likely to be gained, and similarly where and how risks to valued resources can be minimized. Based on this foundation, high priority research questions and experimental designs that are designed to advance our ability to manage for multiple benefits

in coupled terrestrial-aquatic systems will be identified and ranked by importance for implementation.

Looking to the Future: Anticipated Climate Change Impacts

The high elevation of the Lake Tahoe basin might lead one to believe that it will be less impacted by climate change. Climate change modeling is suggesting just the opposite, largely because of the significance of precipitation shifting from predominantly snow to an increasing proportion as rain. Improved downscaled climate modeling efforts are making it possible to study and understand potential fine-scale responses to climate at the scale of the Lake Tahoe basin. The results of some recent efforts to downscale climate change at the scale of the basin are summarized below - more are underway.

Average temperatures in both air and water of the Lake Tahoe Basin (LTB) have increased steadily in recent decades (UCDTERC 2019). The LTB spans several terrestrial ecosystem types and microclimates, making projections of future conditions challenging. Not all of these environments will change at the same rate, or even in the same direction, for a given climate parameter. In addition, multiple climate trajectories could occur (e.g., warmer and wetter versus warmer and dryer). Despite these uncertainties, recent downscaling efforts have produced several outcomes specific to the LTB (CTC 2019):

- *Temperature*: Models project annual average minimum and maximum temperatures increasing by 2-5°C by the end of this century, with smallest increases in the winter (0.39°C per decade) and greatest decadal increases in the summer (0.68°C.)
- *Precipitation*: Precipitation variability is projected with some certainty to increase (e.g., wetter wet periods and drier dry periods), with less precipitation falling as snow. Projections show more precipitation in summer, suggesting a more monsoonal pattern.
- *Snowpack*: The snowpack in the LTB is projected to decline due to higher snowlines, more precipitation as rain, warmer springs, earlier and more episodic snow melt, and more frequent rain-on-snow events. Due to increased variability in precipitation, years of high or low snowfall/rainfall will also become more frequent.
- *Streamflow and Flooding*: Projections indicate small increases in overall streamflow discharge in LTB, but with potentially large changes in seasonal timing. Increased stream discharge, driven primarily by the shift in precipitation from snow to rain and earlier snowmelt, will generate larger runoff, turbidity, and winter floods.
- *Climatic Water Deficit*: Projections of this measure of excess evaporative demand versus precipitation are somewhat alarming, showing increases near the lake and large increases (e.g., doubling) at higher elevations on the north and east sides of LTB, where soils have less water holding capacity. This suggests increased drought stress and fire severity.

- *Kinetic Energy of Raindrops*: Due to shifts from snow to rain, projections indicate that the probability of intense rainfall on soil will increase. The increased kinetic energy may double to quadruple, depending on the emissions scenario. These changes could increase the potential for erosion and soil loss causing lake clarity degradation.

The net effects of a changing climate on upland ecosystems will be complex, but there are general trends that are fairly certain. Carbon stocks of coniferous forests, including those encroaching into riparian areas, will likely be threatened by increased vulnerability to fire and beetles. However, through careful management, forests and soils have the capacity to sequester carbon following fires. Lower groundwater levels will exacerbate existing trends in tree establishment in herbaceous plant-dominated ecosystems and loss of wetlands and wet meadow habitats. Riparian areas could experience more extreme floods and lower flows. High severity fires and floods may also facilitate regeneration of riparian areas and the migration and establishment of aspen. Invasive species will increase under climate change, particularly those that thrive in warmer and dryer conditions. The loss of habitat and increases in invasive species will lead to an overall reduction in native biodiversity, which reduces the adaptive capacity of the flora and fauna of the LTB. Upward range shifts are generally expected in warming environments, so it is possible that species in lower elevation ecosystems could be able to progress upslope and track their suitable climates. In the lake and river ecosystems, the resulting drought, low flow conditions may yield conditions that promote excessive algal growth including harmful toxins (Fletscher et al. 2015). Making predictions of trajectories for these critical management concerns and potential resilience strategies under a changing climate will require balancing different restoration outcomes to maximize mutual benefits.

Role of Research in Promoting Resilience in Upland Ecosystems

Research contributes to achieving land management objectives by expanding our understanding of likely future conditions, identifying which ecological conditions are likely to be resilient to expected disturbances, establishing the capacity of sites to meet various target conditions, informing and facilitating adjustments to future changes that are not gradual or under our control (e.g., extreme events), and developing tools to maximize mutual benefits from management actions over the long term.
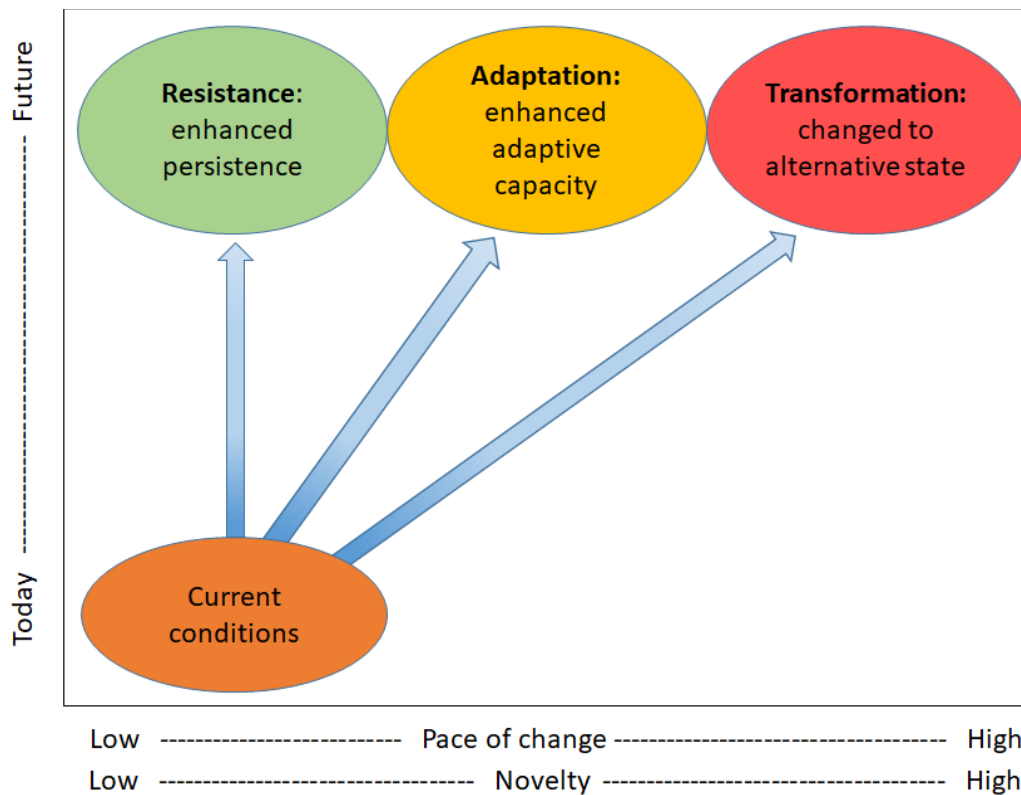
Figure 1. Three strategies for increasing resilience are distinguished by their intended degree and pace of change: resistance, adaptation, and transition. (*Manley et al. 2020*)

Resilience is a concept that pertains to the behavior of ecosystems, notably how ecosystems respond to disturbance and the degree to which they maintain their character and functions. As ecosystem engineers, managers are challenged with making decisions about desired conditions, and what management strategies will result in achieving desired conditions across landscapes and over time. Resilience strategies are defined by the intended type and degree of change, and include resistance, adaptation, and transformation (Figure 1). The management objectives of a resistance strategy are intended to protect resources against impacts to maintain current conditions for as long as possible, but in some cases for some fixed duration of time. Aspects of the ecosystem that are high value and difficult to replace, and for which mitigation measures can be effective, will warrant a 'resistance' strategy. In an 'adaptation' strategy, the objective is to create conditions that are better adapted to current or future climate and hydrological conditions, and enhance the ability of systems to respond to future disturbances. This strategy is generally focused on systems that are largely intact in terms of their characteristics and functions, such as the bulk of forest ecosystems in the basin, but their current resilience is deemed to be low, and management intervention is expected to have a positive effect on increasing resilience to future climate and disturbances. In a 'transformation' strategy, the intention is to change the current and

future condition to one that is novel for that place, and potentially novel for that landscape and beyond. This strategy is a type of triage, in that it is used either when loss of integrity has

already occurred, such as following a significant and unprecedented disturbance event (e.g., tree mortality in the southern Sierra Nevada, 2019 fires in Australia), or when the degradation or loss of some aspects of system (composition, structure, or function) are expected regardless of management actions. In a transformation strategy, although some integrity will be lost, more will be preserved, along with associated services, through targeted intervention (e.g., transmigration of species to avoid extinction, planting novel tree communities to improve performance in future climates) than would be possible without intervention.

It is now incumbent upon scientists and managers to understand what target conditions are likely to be most resilient to future climates in different landscapes around the LTB, what options exist for maintaining and restoring target conditions, and what role management may play in shaping conditions to provide essential services and multiple benefits into the future. Likewise, it is necessary to understand and quantify the connections among ecosystems in a region, because the resilience of one ecosystem may depend on the resilience or management of a different ecosystem.

State of Knowledge of Upland Ecosystems in Lake Tahoe

Where We Have Been

Research designed to provide a strong scientific foundation for management has been recognized as essential for over 50 years in the Lake Tahoe Basin. Research efforts have become more coordinated over time to address increasingly pressing issues facing environmental quality at the Lake. Over the past 20 years, research has been coordinated through formally recognized science organizations, first the Tahoe Science Consortium (TSC; 2005-2016) and now the Tahoe Bi-State Science Council (2016 to present). The Presidential Forum in 1997, along with the Lake Tahoe Restoration Act (2000), were primary catalysts for research advancements in the LTB.

The Lake Tahoe Watershed Assessment (hereafter Watershed Assessment; Murphy and Knopp 2000) was the first comprehensive review of the status of terrestrial, aquatic, and socioeconomic systems in the LTB. The Watershed Assessment developed a set of key findings that identified areas of resource concern and research needs. Based on this work, a set of key management questions was developed, which served to guide investments in capital projects and research. In 2010, the newly formed TSC developed and published an Integrated Science Plan for the Lake Tahoe basin (ISP, Hymanson and Collopy 2010), which developed a comprehensive list of research questions that has been the primary guidance on key research needs and priorities in the

LTB, as well as the foundation of a targeted review of research related to the LTB upland ecosystems.

Research Progress and Information Gaps

Several efforts have built on the ISP to develop comprehensive research questions for the Tahoe Basin, including the Tahoe Science Synthesis (TSS, Knopp et al 2016), the Sierra Nevada Region Report of the State of California's Fourth Climate Change Assessment (SNRR, Dettinger 2018), and the Integrated Vulnerability Assessment of Climate Change in the Lake Tahoe Basin (IVA, Catalyst Environmental Solutions 2020). We used these four primary documents (ISP, TSS, SNRR, and IVA) to assess where research needs specific to the upland ecosystems in the Tahoe Basin have been achieved and where important research needs remain outstanding.

The IVA synthesizes climate change predictions for the LTB in relation to natural resources and ecosystem health, providing a foundation for further research on system and resource response to predicted climate conditions. In terms of air quality modeling, the ISP questions primarily targeted atmospheric deposition and mobile source emissions, there have also been developments in understanding air quality impacts from wildfire and controlled burns (Zhang et al 2013, Koracin et al 2014, Chen et al 2010, Chen et al 2014, Brown et al 2013, Chen et al 2011, Green and Chen 2011, Bytnerowicz et al 2013). Research examining the question of how fuel treatments affect fire hazard includes the efficacy and implications of specific treatment methods (Hubbert et al 2013, Hubbert et al 2015), carbon sequestration (Loudermilk et al 2014), treatment effects on sediment and nutrient transport (Elliot 2017), soils (Busse et al 2013, Stubblefield et al 2012), and wildlife and habitat (Stephens et al 2016, Manley et al 2012). The Lake Tahoe West Project (LTWP, Long et al, in draft) summarizes a multi-system forest management model with numerous research successes that advance the ability to optimize forest management for multiple benefits, including landscape and fine-scale fire modeling (Scheller et al 2019, Hoffman et al in draft), forest management and climate change (Maxwell et al, in review), snow-forest processes (Harpold et al 2020, Krogh et al 2020), wildlife habitat (Slauson et al in draft), water quality, smoke impacts, and economics (Long et al in draft). There are numerous other successful research projects that met IRP research needs described in Appendix A.

 The SNRR provides the most recent synthesis of projected climate conditions, resource sensitivities, and research needs regarding future climate. Though important drivers of climate change on upland ecosystems are identified in the previous section, several research needs noted in the SNRR deserve attention here. For example, the lack of information about changing upland soil moisture, as well as upland and lowland groundwater response are key uncertainties to managing upland ecosystems. Groundwater connects spatially discrete environments such as forest, meadows, and streams and is not highlighted in the ISP. The SNRR report highlights

challenges to forest ecosystem dynamics from increased insect and disease outbreaks, invasive species, and changes in plant water-use. The TSS also highlighted climate change related questions, including future carbon dynamics in forests (Loudermilk 2012, Loudermilk 2013) and climate modeling of a montane peatland (Christensen 2013).

The Lake Tahoe West Project (LTW) answered some questions identified by the IRP and Tahoe Science Synthesis regarding forest resilience to climate change and application of a multi-system approach to forest management. LTW developed an Ecosystem Management Decision Support (EMDS) analysis that spanned 100-years and multiple projected climate scenarios. Results for 5 different management scenarios from a landscape scale LANDIS-II model were analyzed by specific process models to determine potential co-benefits and/or system feedbacks (Long et al. in draft, Abelson and Reynolds, in draft). LTW was also one of the first broad incorporations of water quantity considerations into forest management planning (Harpold et al. 2020, Krogh et al. 2020), rather than only on water quality and inputs to Lake Tahoe.

Tahoe basin research has historically been categorized by discipline; however management and research outcomes often overlap traditional disciplines, and many research areas and system processes have impacts across multiple, in some cases nearly all, disciplines. The upland ecosystems are interconnected, and the connected systems experience multiple feedbacks and high levels of physical mass and energy exchanges. It's imperative to approach future research with this understanding and to encourage interdisciplinary collaborations moving forward.

Defining Research Opportunities

The upland ecosystems of the LTB traditionally have not been studied with a systems approach. Tahoe Basin watersheds offer a natural gradient in climate from the wetter western shore to the drier eastern shore, as well as across elevation where orographic precipitation differences are large. Watersheds in LTB have a diversity of geology that affects their hydrological and nutrient properties, from low permeability granitic bedrock in the southern and eastern watersheds and more permeable volcanic in the north. The LTB has high biodiversity and a unique constellation of species, in part because it lies at the intersection of 4 bioregions, the Sierra Nevada range to the west, the Great Basin to the east, the central Sierra Nevada to the south and the Modoc Plateau to the north, and in part because of the diversity of steep elevation and precipitation gradients within the basin. The physical and biological interconnections of parts of the landscape through hydrology, topography, vegetation, wildlife, and disturbance (e.g., fire) has not been effectively researched nor understood. These interconnections of upland ecosystems may manifest as mutual benefits (or competition) among different management objectives. A systems-based framework that co-manages for resilience and multiple benefits has high potential to identify synergistic sustainable outcomes.

We used the Pillars of Resilience from the Tahoe Central Sierra Initiative's Framework for Resilience (Figure 2; Manley et al., in review) to quantify the multiple benefits associated with management-driven or research-focused questions compiled in Appendix A. This framework for socio-ecological resilience recognizes the interdependence of ecological systems, represented as environmental quality, and community well-being. The framework recognizes 10 pillars, but for this summary, we lumped economic diversity and social and cultural well-being together, and we lumped wetland integrity and water security together, resulting 8 pillars with which to associate questions and related benefits.

Questions were grouped as either scientific research focused (exploring specific processes or status) or management focused (exploring restoration activities or areas in which management interventions could alter or improve systems). In addition to the specific research questions, we identify cross-cutting themes to improve research impact for managers and stakeholders. Some of these key themes include defining baseline or restoration targets, quantifying restoration effectiveness, modeling responses to natural and/or anthropogenic disturbances, the need to translate research into decision support tools accessible to managers, and public outreach.

The list of questions was cross-referenced and scored by the number of pillars it benefited (see Appendix A). This initial scoring-and-screening effort resulted in a ranked list of questions. Questions that ranked high were the topics of forest management and fire, the need to develop performance measures and restoration metrics, climate change impacts, and watershed hydrology. The structure and scope of questions influenced pillar benefits, with broad questions scoring more pillars, and focused questions limiting cross pillar scoring (see Appendix A). The resilience pillar score was used to develop understanding of mutual benefit areas of research, while it is recognized that equally important targeted research is necessary to support those broad areas. Furthermore, it reinforced the philosophy of using integrated science and research to support multiple benefits from co-management of different objectives.
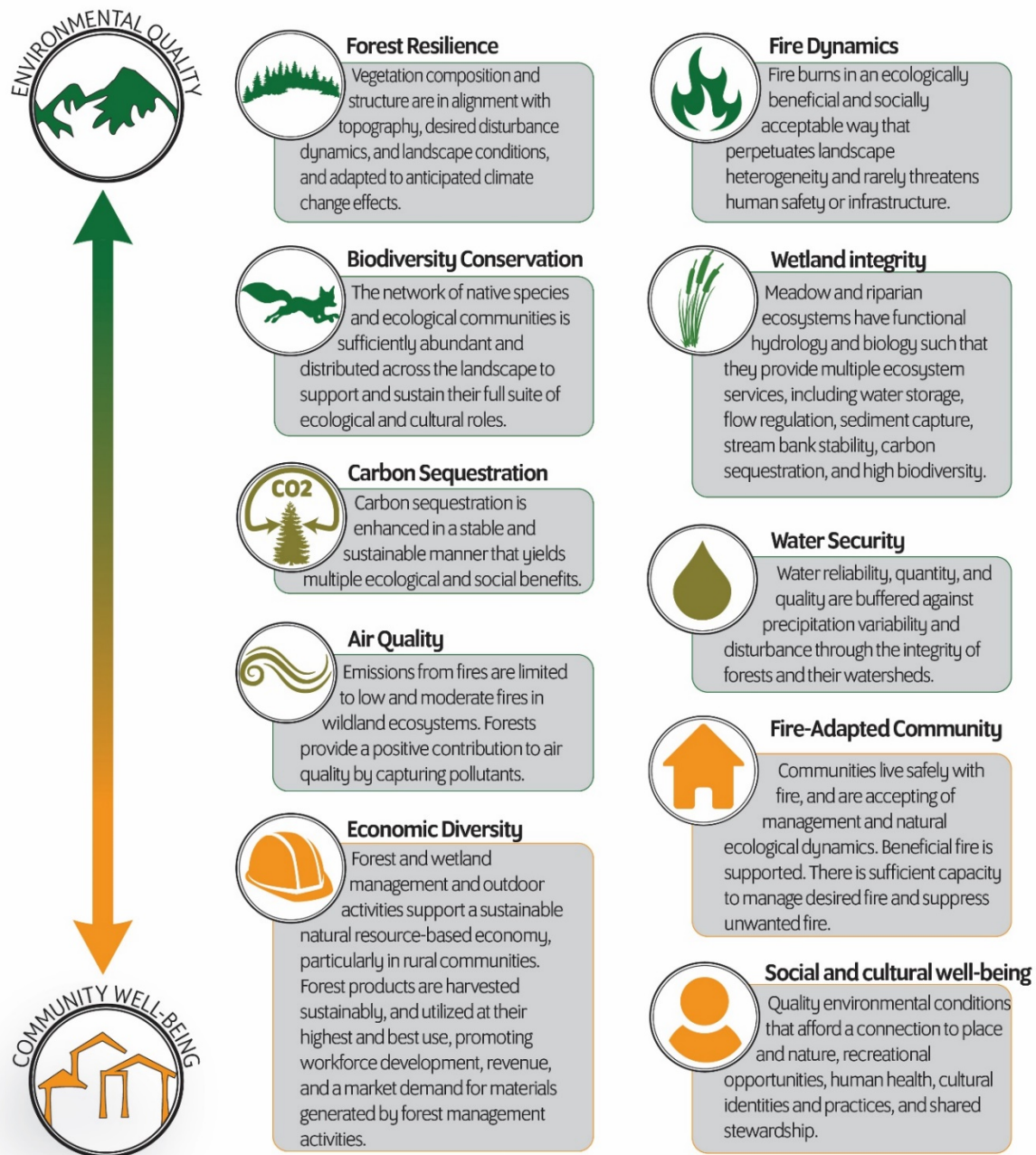
Figure 2. Ten pillars of socio-ecological resilience from the Tahoe Central Sierra Initiative Framework for Resilience (Manley et al 2020).

An Integrated Approach to 21st Century Upland Ecosystem Science

To meet the numerous challenges for managing upland ecosystems, we propose a short-term research investment strategy to support management action and the development of a longer-term integrated research agenda. Our approach seeks to enhance the ability of management to promote resilience and enhance ecosystem services (quality, quantity, sustainability) over time. Our vision is to expand the understanding of the dynamic nature of upland ecosystems and their potential tipping points and trajectories using observations and state-of-the-art models, and then apply that information to develop evaluation tools that can inform how and when management can make a positive contribution toward greater resilience and positive outcomes. We proposed to greatly improve the ability of managers to evaluate short- (in the next 1-10 years) and long-term (50+ years in the future) costs and benefits among different ecosystem services among watersheds across the LTB. Our intention is to position the LTB to be at the cutting-edge of Earth and natural resource science, and thereby enhance the management potential to develop upland ecosystem planning that contributes to the preservation of Lake Tahoe long into the future.

Content

Based on discussions and reviews of the previous research in the basin, we propose that upland ecosystem science and management can be summarized into three key facets of upland ecosystems: 1) biodiversity, 2) coupled forest and aquatic interactions, and 3) forest and fire dynamics (Figure 3). In addition, we recognize that as knowledge gaps are filled across these facets, it is essential to apply resulting improvements in understanding about system dynamics and interactions to tools and models to inform and support management.
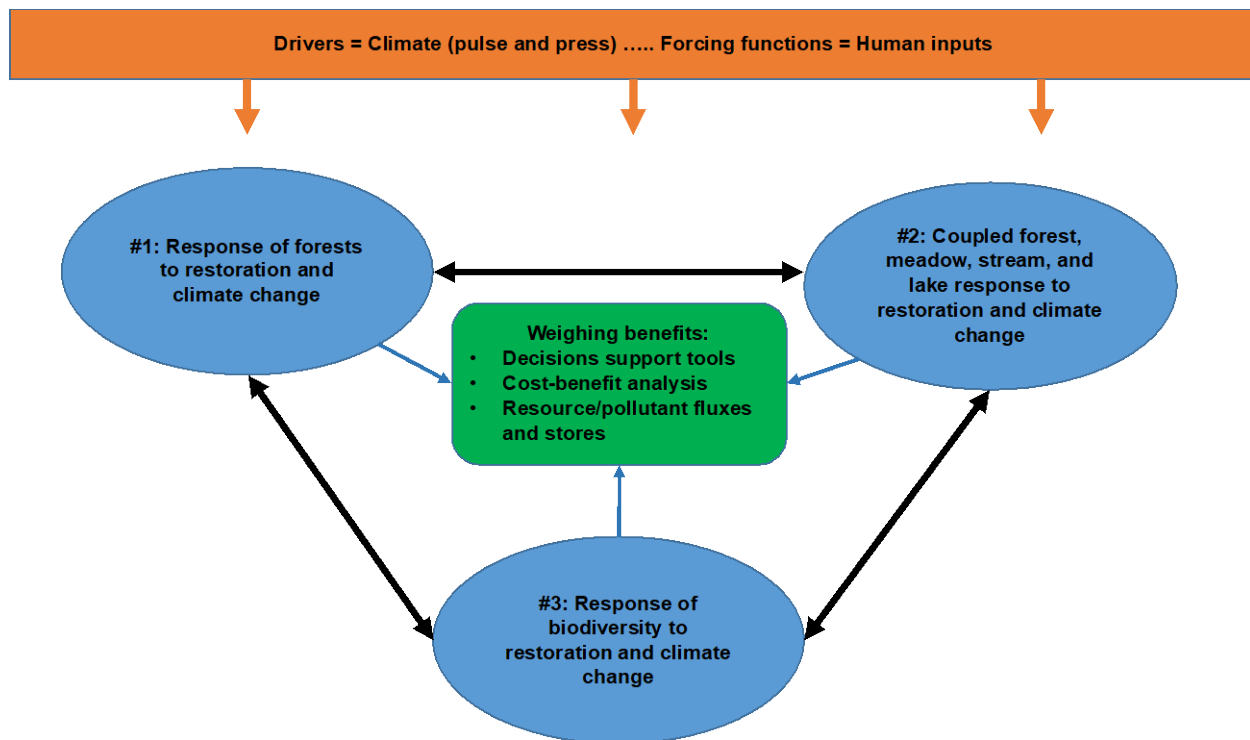
Figure 3. Three facets of upland ecosystems that must be coupled together (either with models or cost-benefit analyses) to quantify mutual benefits and outcomes. Current examples of models that address linkages between facets are noted.

Our authors have identified three tasks to be completed over the course of the next two years that will result in robust research to support management of upland ecosystems in the LTB: Task 1) launch a campaign to gather foundational empirical information needed to inform near-term management and research investments around three key facets (Figure 3); Task 2) develop a longer-term research agenda that can guide research investments over the next 10-20 years; and Task 3) develop ambitious integrated project proposals that reflect cutting-edge approaches to ecosystem research and management, with the intention of bringing substantial resources to the LTB to support research and science delivery to management.

Process

Our approach reflects the need to act in the most effective and efficient manner, in ways that are tempered by uncertainty regarding how to address known and unknown knowledge gaps. The three tasks are intended to be developed in parallel, to inform and support one over the next 2 years. The development and launch of the research plan will require a multidisciplinary team (i.e., forest and aquatic ecologists, hydrologists, soil scientists, biologists, climate scientists, fire ecologists) and a transdisciplinary approach that seeks to connect the physical and biological system to the socio-economic realities of management in the LTB. The development of the plan

will follow six tenets that transcend individual research projects and were found through synthesis of previous research projects.

1. <u>Develop robust management targets,</u> such as historic range of variability, contemporary reference conditions, and conditions expected to be robust to current and future stressors based ecosystem processes and functions.

2. <u>Develop and enhance performance metrics that can be used to evaluate status and monitor progress.</u> The need for quantitative tracking of restoration outcomes or reference conditions is fundamental to determining management actions and long-term planning.

3. <u>Develop decision support tools for a non-stationary world</u>. Decision support tools must function despite increasing departure from past precipitation and temperature regimes. New tools must be able to reliably extrapolate beyond historical conditions.

4. <u>Practice adaptive management between managers and researchers through co-production of priority information needs and project design</u>. Research projects are prioritized and designed alongside management priorities in ways with multiple potential scenarios and outcomes.

5. <u>Contribute to stakeholder engagement through living laboratories</u>. Engaging and educating local communities and tourists through 'place-based' knowledge is a key part of sustaining research and influencing public mindset about restoration efforts.

Stakeholder and scientific engagement is an integral component of all three tasks associated with the research strategy. Stakeholders include agencies and institutions that play a role in managing upland ecosystems in the basin, as well as residents, tourists, and other interested parties.

Task 1: Near-Term Investments to Support Research and Management Action

Task 1 addresses immediate information needs that can be accomplished in a 2-year timeframe, and are essential to support and inform the development of near term management tools and longer-term research plan. Key information needs are described below for each of the three facets of upland ecosystems. A base funding level is identified for each facet, however additional funding for any or all of the facets would serve to further strengthen the foundation of the research plan (Task 1), and improve the reach and strength of project proposals (Task 3).

Forests, Fire and Climate Change

Knowledge Gaps

Forests health and fire dynamics are a primary concern in the Lake Tahoe basin based on the significant influence they have on so many aspects of environmental quality and social well-being. Further, forest health and fire dynamics are affected by climate and climate change, so that introduces substantial uncertainty regarding the future of forests and fire, and impacts they may have on the basin as a whole.

Drought stress and beetle mortality are normal processes that operate in dry forests of the Sierra Nevada, but recent large-scale tree mortality in the southern Sierra Nevada (2018-2019), and past large areas of tree mortality in the Lake Tahoe basin (mid 1990s) provide able evidence that impacts to forest health and ultimately forest cover, structure, and composition can be dramatic and occur over short periods of time. Other impacts also exist, but they their consequences are less well understood, such as increased vulnerability to disease (e.g., white pine blister rust). Managing forests to reduce the vulnerability and risk of significant impacts to forests resulting from climate change requires an improved understanding of tolerances and tipping points of forests and elements that drive forest health. For example, drought stress is ultimately a function of water availability, so understanding options for reducing drought stress and associated target forest conditions will be important.

Wildfires represent one of the greatest risks to human populations, property, and infrastructure of the Tahoe Basin, and constitute a significant threat to most of its ecosystems on both short and long time horizons. Although the threats and impacts from wildfires are broadly recognized, there remain areas where uncertainties remain that if addressed would aid managers in reducing risks and achieving the goal of increasing the positive role that fire can play in promoting resilience in the basin. Further, the desire and value of using fire as a management tool in the basin is great, but there are barriers that could be addressed at least to some degree with additional research.

Key Questions

1. What is the scientific foundation being used to determine target conditions for resilient forests (e.g., structure, composition, fire dynamics, disturbance dynamics)? What are the limitations of these data and what additional information is needed? ($100,000 minimum)
   a. Identify data sources currently being used to set tree density and basal area targets, and identify additional sources that could be applied or acquired to improve the scientific

foundation of target conditions and their expected benefits (e.g., wood supply, wildlife, water, fire).

b. Identify data sources currently being used to set seral stage amount and distribution targets, and identify additional sources that could be applied or acquired to improve the scientific foundation of target conditions, locations, and their expected benefits (e.g., wood supply, wildlife, water, fire). For example, where would having late seral forest make the greatest contribution to ecological objectives, and where is it most likely to be at the lowest risk of high severity fire?

c. Evaluate the status of our understanding of what qualifies as "old forest" of "old growth" and where it occurs in the basin. Are current definitions and location data in need of updating based on current scientific understanding and the availability of high resolution data?

d. Evaluate appropriate seed sources and species mixes for reforestation efforts that may be considered for use in the basin, and identify what concerns and risks that might need to be evaluated in order to apply new climate-smart criteria to species and seed selection.

e. Determine the degree to which more aspen is desired based on stakeholder engagement, and identify what modeling or forecasting capacity (and input data) would be needed to evaluate where and how an expanded and sustainable coverage of aspen could be achieved over time.

f. Evaluate the ability to generate spatially explicit representations of social and ecological benefits for every pixel/cell in the basin, such as wildlife habitat value, carbon value, large tree value, old forest value, recreation value, and fire management value that are based on current condition, potential future condition, and some measure of transition costs (time and effort).

2. What are the most pressing information and functional gaps that are limiting the ability of managers to use fire as a tool, and to reduce the threat of high intensity fire in the basin? ($100,000 minimum)

a. Identify current mechanisms used to identify and track primary ingress and egress routes, and what information gaps and analyses would improve the function of these routes and their ability to inform scenario planning. ($10,000)

b. Identify the potential for research to contribute to improving fuels characterization to in turn improve risk assessments and treatment type and prioritization, with particular emphasis on the potential for remote sensing from satellite and aircraft platforms to assess condition and change in fuels. ($20,000)

c. Identify potential climate refugia in the basin and evaluate the degree to which they could contribute to accomplishing resistance and adaptation strategies for various conditions and elements in the LTB. ($50,000)

d. Evaluate the potential to improve weather models in the past, specifically downscaled weather patterns and forecasts, with the objective of improving our understanding of how they may change with a changing climate. This will enable improved predictions of vegetation growth, change, and response to fire; movement and dispersal of smoke from wildfires and prescribed burns; and the spread and severity of wildfires should they occur. ($30,000)

e. Assess the ability of landscape locations to regenerate following fires under various fuel and weather conditions, to help plan future fuels reductions or prescribed burns and the most effective order in which to implement them. ($30,000)

f. Identify the availability of data and studies, or the need for data and studies, to address remaining uncertainties regarding how best to manage wildfire and to design and implement wide-spread prescribed fire, including optimal widths for fuel breaks, operational anchors for fire management, effects of fires in masticated fuelbeds on underlying soils and seedbanks, and the ecological effects of fire on habitat quality for wildlife. ($40,000)

g. Identify high value refinements to tools used by managers to plan and implement prescribed burns that would reduce the risks of escaped burns, and improve forecasts of smoke movements to allow better planning of prescribed fires to minimize smoke impacts to sensitive areas and groups. ($20,000)

h. Evaluate the degree to which smoke models could be improved to better support the ability of managers to forecast local and regional impacts from wildfires, and to inform potential impacts of smoke from wildfires and prescribed burning to local and regional populations. ($20,000)

3. What are the limitations of existing forest growth and fire models, what value would be gained by improving their performance, and what is needed (e.g., data inputs, sub-models, programming) to improve their performance? ($100,000 minimum)

a. Forest growth and dynamic models have been developed for the basin (e.g., Landis II) - what value do they have into the future and how can they be improved with data from recent studies conducted in the basin? How do they compare with other forest and hydrologic dynamic models (e.g. RHESSys)? ($20,000)

b. Identify the fuel and fire behavior models that are currently calibrated for use in the basin for restoration planning, particularly for managing prescribed fire. What are the strengths and weaknesses of these models for management needs? How do these models compare to the scientific state of the art? ($20,000)

c. Create a database of pre- and post-treatment forest structure, fuels, etc. using field measurements and the lidar dataset from 2010 and 2019. Consider how future thinning projects (e.g., Lake Tahoe West project) overlay with existing forest structure, and put

this in the context of current targets for forest structure, composition and distribution (e.g., restoration of historical conditions). ($50,000)
d. Gather information on state of the art physical modeling of upland hydrology, tree growth and disturbance, and fire behavior to support the next generation of management decisions. ($20,000)

4. What landscape information and climate projections, like topography, groundwater, etc., are necessary to understand terrestrial vegetation species distributions, vigor, and disturbance in the future? ($100,000 minimum)
a. Use recent LiDAR data to better describe forest structure and forest structure change since 2010. Overlay existing forest species mapping and identify potential for hyperspectral species mapping. ($50,000)
b. Create database of soil property and soil moisture datasets. Consider simple ways to develop soil moisture maps to inform forest and vegetation health, such as existing model output or topographic based regressions. ($10,000)
c. Relate soil, water availability, and topographic information to forest types and key management locations in the basin using multivariate statistical techniques. Work with stakeholders to determine the utility of this information for planning controlled burns, identifying micro-refugia for key species, and other stakeholder interests. ($40,000)

Stakeholder Engagement

Work with stakeholders to consider the value of new and more complex models for meeting short- and long-term planning challenges in the context of limited management resources and modeling capabilities. Engage with stakeholders to refine questions and utilize existing reports, databases, and data collection and analysis efforts. Preliminary list of stakeholders identified include US Forest Service, Tahoe Regional Planning Agency, Nevada State Parks, California State Parks, Nevada Department of Wildlife, California Department of Fish and Wildlife, CalFire, and US Forest Service.

Cost

We suggest a minimum investment of $400,000 which includes data collection, spatial analyses and mapping, and model validation and calibration. Individual questions and topic areas could be pursued with partial funding, if agencies or entities were particularly interested in some subset of the topic areas listed.

Coupled Forest-Meadow-Stream Response to Disturbance

Knowledge Gaps

Aquatic habitat and hydrologic-mediated transport of pollutants are critical management concerns in the LTB, yet we have poorly quantified connectivity between terrestrial and aquatic systems in the Lake Tahoe Basin at the scale that management decisions are made. Terrestrial-aquatic linkages can occur, for example, from upland management actions or disturbances that translocate material to the stream channel (Figure 3). The linkages also work in the other direction, for example, when aquatic processes that regulate riparian vegetation can alter habitat and migration patterns of terrestrial species. These coupled processes are challenging to model and therefore, not included in management decision making and most models. Answering the questions below will require substantial scientific development and interfacing with managers and stakeholders, which will be accomplished over the course of this proposal.

Key Questions

We will combine information from existing research and monitoring with limited new data collection and analyses to answer a set of four inter-linked research questions:
1. How do upslope forest treatments, designed for fuel reduction and fire mitigation, impact meadow and riparian water, carbon, solute and nutrient fluxes across areas of the LTB with different properties?
2. How do integrated forest, meadow, stream, lake, and riparian restoration efforts combine to alter water and carbon budgets?
3. How transferable are recommendations at the basin-scale to targeted watershed-scale restoration approaches that involve meadow and riparian systems?
4. How will changing snowpack and rainfall patterns interact with watershed-scale restoration efforts to impact water availability, carbon sequestration, and nutrient fluxes, and how might these factors affect aquatic and terrestrial species, community interactions, and services?

Approaches to key questions:
- Catalog existing pre- and post-treatment datasets in the Basin. Identify areas for upcoming forest treatment that are located upstream of meadow and riparian systems. Prioritize sites where there may be the potential to have pre-treatment observations. Design data collection plans in key catchments identified with stakeholders. ($35,000)
- Work with stakeholders and TSAC to catalog relevant datasets, with a focus on meadow and riparian area water, carbon, and nutrient information. ($35,000)

Work with the Biodiversity team to identify potential linkages between measures of biodiversity and water availability, carbon, and nutrient fluxes, and data gaps needed to quantify these connections. ($25,000)

- Perform an analysis using remote sensing and existing datasets to investigate catchment forest structure and species, and identify the composition of key hydrologically connected forests (using existing hydrological modeling) to determine differences across catchments. ($100,000 over two years to support research student or associate)
- Work with experts to develop both statistically and physically-downscaled future climate predictions. Estimates of precipitation, temperature, humidity, radiation, and wind will be needed at <1 km scales to successfully model snowpack, streamflow, and evapotranspiration, which are need to answer many of these questions. Some of this hydroclimate modeling is already being done the Center for Western Water and Weather Extremes (CW3E) at UC San Diego. ($150,000 over two years to support researchers and collaboration with outside groups)
- Apply climate futures to predict how different catchment-scale restoration activities might fare. Identify how more accurate and finer spatial scale climate projections this might impact past or planned restoration actions. ($100,000 over two years to support a researcher)

Stakeholder Engagement

The key topics for stakeholder engagement are around refining the research questions, identifying existing and planned restoration treatments, identifying associated monitoring datasets, and determining the major management issues around water, carbon, and nutrient dynamics. Stakeholders include the US Forest Service, Tahoe Regional Planning Agency, Lahontan Water Control Board, Nevada State Parks, Truckee Meadows Water Authority, California State Parks, and the California Tahoe Conservancy.

Cost

We suggest investing a minimum of $400,000, which would accomplish some data collection, spatial analyses, and basic catchment predictions. Higher resolution climate modeling would require additional supplemental funding. Individual questions and approaches could be pursued with partial funding, if agencies or entities were particularly interested in some subset of the topic areas listed.

Biodiversity of Upland Forests, Lakes, Streams, and Wetlands

Knowledge Gaps

Basic occurrence, abundance, and distribution data are fundamental to understanding and modeling vulnerabilities and risks to biodiversity. Surveys of vegetation, terrestrial wildlife, and aquatic biota have been conducted for many decades. The Lake Tahoe Watershed Assessment (Murphy and Knopp 2000) was the last time a comprehensive synthesis of survey data was compiled. A wide array of biological studies and surveys have been conducted over the past 20 years, but some resources have received more attention than others, and no recent compilation of these data has been done. In addition, more recent data may present opportunities to improve or enhance distribution models, habitat relationship models, and other predictive models.

The terrestrial biota are the focus of some institutionalized monitoring programs. For example, the Forest Inventory and Analysis program samples a set of vegetation plots every 1-5 years in the basin. Individual agencies have monitoring programs that operate every year or periodically, such as project effectiveness monitoring (e.g., California State Parks prescribed fire program), and individual species monitoring (e.g., LTBMU California spotted owl, TRPA osprey). In addition, a number of recent studies and modeling efforts have shed new light on species responses to management that have not yet been incorporated into existing or new models. Finally, climate change responses could be readily interpreted based on downscaled climate data that have recently become available, which would greatly inform future vulnerabilities and risks to biodiversity.

The upland aquatic ecosystems (lakes, meadows, streams) of the Lake Tahoe basin and their biota are the least well surveyed and described systems in the basin, specifically in terms of their species and communities. They support native and federally listed (threatened or endangered) species (e.g. amphibians, willow flycatcher). In addition, some of the lakes (e.g. Marlette and Fallen Leaf) and larger creeks (Blackwood, Taylor, Upper Truckee) currently support or historically supported Lahontan Cutthroat Trout. The trout is a focus of recovery efforts in the basin and part of the Environmental Improvement program. There have been intermittent, biological surveys of selected creeks and small lakes in the Tahoe basin over time by the US Forest Service, California Department of Fish and Wildlife, and Nevada Department of Wildlife. However, there has been little contemporary, systematic effort to understand the basin level distribution of native species within aquatic ecosystems or focused efforts to link changes in hydrology (including water quality) to the persistence of species and their ecological function over time.

Key Questions

1. What are the current distribution (seasonal and annual) of native and nonnative species (vertebrates to invertebrates) within forests, lakes, streams, and meadows within the LTB, and how are they likely to be affected by changing climates?
   a. Utilize existing databases and reports from the agencies (e.g. US Forest Service, State Dept of Wildlife agencies) to develop a map of species distributions (presence absence) within aquatic ecosystems.
   b. Initiate a pilot resurvey of a subset of lakes, streams and meadows to confirm the species presence/ absence within aquatic ecosystems.
   c. Compile existing data on species occurrence and habitat relationships in upland vegetation types to build a contemporary species list and a co-occurrence matrix for the Lake Tahoe basin.
   d. Evaluate the degree to which terrestrial species are expected to shift or change their distributions based on simple interpretations of downscaled climate projections in the basin, to identify potential limitations, vulnerabilities, and risks.
   e. Identify monitoring systems that are in place and their strengths and weaknesses, as well as the potential for gaining efficiency and effectiveness by augmenting or changing monitoring designs.
   f. Evaluate the degree to which connectivity and corridors are likely to play a role in facilitating population persistence in the basin in the face of climate change, and what information may be lacking that would be valuable in determining where connectivity is most likely to be important and for what species.

2. What are the potential ecological functions/functional traits (feeding, size, life history characteristics) of native species and nonnative species within LTB upland ecosystems?
   a. Create a functional traits database for native invertebrate and fish species within the upland aquatic ecosystems of the LTB by examining existing data and information from the literature for each taxa level grouping.
   b. Create a functional traits database for native vertebrate and plant species within the forest ecosystems of the LTB by examining existing data and information from the literature for each taxa level grouping.
   c. Develop a first generation food web for upland ecosystems in the LTB based on species occurrence data, species probability of occurrence, and species food habits.

3. What environmental parameters of water quality and quantity correlate to aquatic species distributions within these systems?
   a. Classify system types by size and other ecosystem characteristics.
   b. Create a database of environmental characteristics of each ecosystem including temperature, oxygen, metals, major ions, nitrogen, phosphorus, and carbon.

c. Resurvey a subset of ecosystems to determine if the environmental characteristics are similar to previous measurements and to identify uncertainty in our correlation analysis.

d. Conduct statistical analyses to explore relationships between environment parameters and species distributions (presence/absence).

Stakeholder Engagement

Engage with stakeholders to refine questions and utilize existing reports, databases, and plan for resurvey efforts. Preliminary list of stakeholders identified include US Forest Service, Tahoe Regional Planning Agency, Nevada State Parks, California State Parks, Nevada Department of Wildlife, California Department of Fish and Wildlife, US Fish and Wildlife Service, and The Nature Conservancy.

Cost

We suggest a minimum investment of $400,000 which includes surveys, database creation, development of maps, statistical correlations, and food web development ($225k for aquatic work, $75k for terrestrial work, and $100k for food web development).

Task 2: Develop an Integrated Long-Term Research Agenda

Description

Our first objective is to develop an integrated plan that will highlight the fundamental linkages within and among the three facets we identified for upland ecosystems (Figure 3) and associated key information gaps where research is needed to better understand multiple benefits/paths available for management, given future uncertainties related to climate and other disturbances (e.g. wildfire, invasive species). Through our efforts over the last 2 months which includes a review of historical research in the basin (see State of the Knowledge Section above and Appendix A), understanding of future and current climate and disturbances to the region, as well initial feedback from our management stakeholder groups, the authors determined that a robust research plan was essential, and would require the next two years to develop. Although much progress has been made over the past 20 years, the authors believe it is important to take a step back and evaluate not only what gaps remain, but also how those interface with new resilience-adaptation-transition restoration strategies (Figure 1).

Cost

The development of a robust research plan will require some dedicated staff time. We suggest that staffing required to lead the development of a robust research plan that is coordinated and

integrated with the other tasks would require a 0.5 FTE research scientist and at least 0.25 FTE coordinator for 2 years, for a total of approximately $150,000. This staffing level would facilitate stakeholder and scientist engagement across the three groups outlined in Task 2, synthesis of existing information and new information generated by Tasks 2 and 3, and a document providing a detailed overview of research priorities and their relevance.

Task 3: New Research Proposal Development

Description

The objective of this task is to develop project proposals to agencies outside of the LTB that make substantial investments in furthering our understanding of linkages and dynamics that drive conditions and resilience of upland ecosystems, and our ability to move our enhanced understanding of system linkages and dynamics into models and decision support tools designed to address management needs. We anticipate that a primary goal will be to parameterize and develop state-of-the-art Earth systems models (e.g. Community Earth Systems Model, http://www.cesm.ucar.edu) scaled and tuned specifically for the environment and needs of the LTB. We will leverage the diversity of LTB environments (e.g., precipitation and temperature gradients, ecological gradients, species distributions, geological gradients, geomorphological features) to test and improve modeled dynamics and processes. Further, landscape-scale strategies to promote resilience could be evaluated over long time scales to inform management investments in resistance, adaptation, transition objectives (Figure 1) such that mutual benefits can be quantified as part of an integrated and robust manner. This type of next generation model would also provide the opportunity to model linkages between upland ecosystems and Lake Tahoe and would bring in new streams of research funding.

We envision these proposals will be developed by a range of experts not limited to the council or its member organizations, and that membership will be a natural outcome of the expert panels that we expect to convene to accomplish Tasks 1 and 2, and to scope Task 3. This effort will take all the information garnered from stakeholder engagements for Tasks 1 and 2, and new information gathered as part of Task 2, to inform key information gaps and priorities that will drive proposal development. We envision convening expert panels to discuss approaches to defining and modeling upland systems, breakthrough options for new approaches, and that a core set of individuals would convene to develop a few robust, coordinated and integrated proposals that would target significant funding from outside the basin.

Stakeholder Engagement

Engage with the scientific community as part of the scoping of proposal development, and engage agency stakeholders as the process progresses to observe and contribute to panel discussions, discuss directions and provide feedback.

Cost

The development of a robust set of research proposals that are competitive will take time and commitment of substantial time of at least a handful of individuals, primarily in the second year, and a capstone to Tasks 1 and 2. Target funding sources are likely to include National Science Foundation, USDA AFRI grants, and California State grant sources for water and forest research. We suggest that staffing required to lead the development of a robust set of research proposals that are coordinated and integrated with the other tasks would require a 0.50 FTE research scientist for one year, and 0.25 FTE coordinator for 2 years (to support Tasks 2 and 3) for a total of approximately $110,000.

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