Abstracts

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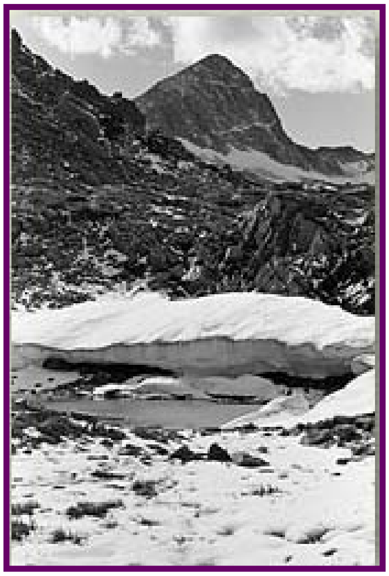

A Symposium on Coping with Climate Change in Sierran Systems: Incorporating Climate into Land and Resource Management and Developing Adaptation Strategies

Tuesday & Wednesday, March 17 -18, 2009, 8:00am to 5:00pm,

Tahoe Center for Environmental Sciences Building, 291 Country Club Drive, Incline Village, NV 89451

This symposium is sponsored by:

- Tahoe Science Consortium
- US Forest Service, Pacific Southwest Research Station
- University of California Cooperative Extension, El Dorado County
- California Tahoe Conservancy
- University of Nevada, Reno, Academy for the Environment
- University of California, Davis, Tahoe Environmental Research Center

Symposium Purpose:

The measurable effects of climate change have been documented in numerous montane systems throughout the world, including the Sierra Nevada Ecoregion. Although uncertainty remains in predicting how much change will occur and what the ultimate outcomes will be, scientists have begun to move beyond documenting and predicting the effects of climate change. Scientists are now working to develop methods and approaches to incorporate climate into land and resource planning and management. Scientists also have begun to think about the kinds of adaptation strategies land and resource managers could apply in response to the future likely effects of climate change. This symposium will present information relevant to the Lake Tahoe Basin forest and Lake Tahoe. Symposium objectives are to:

- Summarize current information about the documented and predicted effects of climate change in the Sierra Nevada Ecoregion.
- Explore the strategic and conceptual framework for incorporating climate into land and resource management.
- Present and discuss plausible adaptation strategies to cope with climate change.

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Day One - March 17, 2009

8:45 - 10:00 Summarizing the Likely Effects of Climate Change on Sierra Nevada Meteorology and Hydrology

The Tahoe Basin and Climate Change – Kelly Redmond (Desert Research Institute)

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Climate projections for the central Sierra call for a warming during the 21st Century. This warming should have already been under way for the past 3-4 decades. The same sets of climate models indicate a little more warming in summer, a little less warming in winter. Precipitation is now projected by these models to remain near present values, but to become more concentrated in winter months, and less frequent and in lesser amounts in spring and summer, and also in autumn. The recent history of surface based and upper-air based temperatures show evidence of warming on an annual basis, primarily in spring, and of late in summer. Daytime temperatures have changed less than nighttime temperatures. Precipitation is inherently so variable that it appears unlikely that a modest change in the mean could be detected anytime soon. Precipitation may change in character: more intense rates, and more in the form of rain instead of snow. Paradoxically, both floods and droughts may become more frequent. Lake Tahoe itself has warmed, but the interpretation of lake temperature records is somewhat complicated. The current and recent winters will be discussed in the context of potential changes in climate. Tools that assist users in accessing this information will be illustrated. Sources of climate change, and of uncertainty in the projections, will be presented.

Sierra Hydrology in Response to a Changing Climate - Noah Knowles (U.S. Geological Survey)

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In the last half-century, observed hydrologic changes in California have included a shift in precipitation form from snowfall to rainfall as well as earlier snowmelt runoff, both associated with a concurrent warming attributable in large part to anthropogenic climate change. Climate models project a continuation and acceleration of anthropogenic warming, with most estimates for California ranging from +2 to +6 degrees Celsius over the 21st century. Most models project only small precipitation changes, with an overall tendency for a slight drying. Driven by downscaled outputs from these climate models, hydrologic model projections show a loss of 61% to 95% of the April 1 snowpack (measured by liquid volume equivalent) in the northern Sierra and a loss of 33% to 58% in the southern Sierra by 2100, depending on the scenario considered. As a result of less snow accumulation and earlier melting of the snowpacks, 10-21% of total annual northern Sierra runoff and 14-34% of southern Sierra runoff would shift from post- to pre-April 1, increasing winter flood risks. Higher snowlines and warmer temperatures may also have important ecological impacts in the Sierra, as soils dry earlier in the year while potential evapotranspiration increases.

10:30 - 12:30 Forest Ecosystem Management: Conservation Strategies for Adapting to Climate Change

Natural Resource Management; Reframing Strategies for Climate Change - Connie Millar (USFS Pacific Southwest Research Station)

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Issues: Incorporating climate change, either natural variability or human-driven, into resource management forces a rethinking of basic frameworks and guidelines. Uncertainty yet certain change becomes the context in which managers will act.

Options for Management: Environmental changes that unfold as a result of changing climate differ in different parts of the country, state, and even local areas, and will affect ecosystems complexly. Thus, management implications must vary accordingly and be flexible. Key concepts include:

- Embrace and work with change
- Accept uncertainty as a premise for decision-making
- Recognize that some existing management paradigms have limited value
- Manage for future processes and ecosystem services rather than desired future conditions

Overall Strategy: Adopt a Toolbox Approach
No single solution or individual management approach will be appropriate to all or even most situations. Now and later, tools should be mixed and combined to best match the management context under consideration. At the highest level in the toolbox are two broad climate-change strategies: *adaptation and mitigation*. Adaptation includes actions taken to assist species, ecosystems, and resources to accommodate changes imposed by climate; mitigation includes actions taken to reduce and reverse the human influence on the climate system. Approaches to adaptation and mitigation will often be complementary; however, conflicts are likely to arise. Thus, evaluating pros and cons of short- and long-term choices becomes important. Five broad sub-strategies within the adaptation-mitigation toolbox are summarized below.

Increase Resistance to Change. Defending high- value resources against change is an appropriate and defensible, if short-term, approach for resource managers under certain circumstances of high value and limited risk. This action may be extremely expensive, take much time, resource, and staff effort, and be possible only for the short term. Important as it is in some cases, resisting change might become over time a “paddling upstream” option.

Promote Resilience to Change. Promoting resilience is the most commonly advocated adaptation strategy. Management actions to promote resilience are those that improve the capacity to return to desired prior conditions after climate-induced disturbance. As in resistance options, strategies to promote resilience are likely only successful in the relatively short-term, in that eventually changed climates will force new environmental conditions such that ecological re-setting rather than resilience will be more effective.

Enable Ecosystems and Resources to Respond to Change. Responding to and managing change is the most proactive approach. This assumes that a decision-maker acknowledges the inevitability of change and accepts a limited capacity to understand what change will happen at the scales important to managers. Many types of actions can assist species, ecosystems, or resources to move to new and adapted conditions and processes, such as:

- Assist species and resources to follow changing environments
- Anticipate and plan for associated risks
- Experiment creatively and learn from experiments
- Use redundancy
- Relax genetic-management guidelines
- Experiment with refugia
- Increase diversity
- Promote connected landscapes

Realign Conditions to Current and Future Dynamics. For systems that have been disturbed far out of range of natural variability, actions that promote alignment with current and future processes may be the best approaches for restoration rather than returning to historic conditions. Using historic range of variability and returning habitats to pre-disturbance conditions will often be inappropriate because much change has occurred since pre-disturbance times. Re-aligning or tuning to current and anticipated environments and processes is more likely to be successful.

Reduce Greenhouse Gases and Reduce Non-Renewable Energy Use. The forestry sector has an enormous opportunity to mitigate and reduce human influences on the climate system, but accounting challenges through the lifecycle remain carbon remain daunting.

Setting Priorities: Evaluation of options and setting priorities will be increasingly important. At an overall level, decision-makers have three options for engaging climate-management, each defensible under different contexts. They can deliberately delay action, react after disturbance or extreme events, or act proactively in advance. Tiered approaches such as no-regrets, low regrets, win-win; employing low- to high-technology approaches judiciously; and formal triage approaches are employed. Evaluating vulnerabilities is an essential first step in all approaches.

Case Studies: We can best learn the range of needs and tool-box strategies by drilling down to specifics through diverse case-studies and sharing tools that are generally applicable. The USFS Westwide Climate Initiative engages case studies in the Pacific Northwest, Rocky Mountain Region, and Pacific Southwest. In California our work has been with the Tahoe National Forest, Inyo National Forest, and Devils Postpile National Monument. A sample of lessons learned from those efforts and plans for further work will be introduced in this talk and outlined further in subsequent presentations.

Climate toolkit project: Summary from the Tahoe National Forest Case Study – Sharon Yeh (USFS– Region 5/ Pacific Southwest Research Station and Region) and Nikola Smith (USFS-Washington Office / Pacific Southwest Research Station)

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Problem: Existing decision making guidelines coupled with coarse scale climate models and their related uncertainties pose a challenge for resource managers when incorporating climate change into future projects and plans. Forest management also often assumes long term climate stability. While adaptive management is recognized as a tool to react and adjust management decisions, neither climate information nor adaptation options have been scaled for application to operational aspects of national forest management and planning.

Approach: To explore how adaptation options might be applied on the forest level, the Westwide Climate Initiative (WWCI) engaged case studies in the Pacific Northwest, Rocky Mountain Region, and Pacific Southwest Region. Tahoe National Forest (NF) was selected to represent the Pacific Southwest area, and they were an early participant in the US Climate Change Science Program Synthesis and Adaptation Product 4.4 (SAP 4.4).

Decision support tools were drafted in collaboration with TNF staff, and include:

1. *Climate Project Screening Tool* - Designed for use at the project proposal stage, this tool presents typical projects, related climate trends, and a series of broad questions that address the implications of these trends for project design. It seeks to provide discussion points for interdisciplinary teams and provide a framework to incorporate climate change considerations in project development.
2. *Evaluation of the compatibility of current resource management approaches with climate change adaptation* – Existing paradigms supported by the Sierra Nevada Forest Plan Amendment having to do with wildlife, silviculture, and fuels management were analyzed with regard to climate change.
3. *Addressing Uncertainty and Risk* – The Tahoe NF is about to embark upon its Land Management Plan (LMP) revision process. Issues of uncertainty in the LMP and project planning were explored.

Results

Climate Project Screening Tool: This tool was successfully developed and tested with Tahoe NF staff. It was concluded that this tool could be useful in recording climate change impacts that were considered for NEPA documentation, providing rationale for any modifications to project design.

Evaluation of the compatibility of current resource management approaches with climate change adaptation: Existing management guidelines and frameworks were originally developed for other purposes, such as the protection of the spotted owl. However, these management approaches assumed long term climate stability, and might need to be revisited to account for changing climate conditions. For example, limits on size of tree harvesting might need to be increased to account for greater fire frequency, intensity, and severity. Designation of protected sites for sensitive species may also need to shift as habitat conditions change.

Addressing Uncertainty and Risk: Although current models and projections carry uncertainty with them, forest planners are being advised to address climate change with the best available science through the LMP revision process. While it remains difficult to address uncertainty in a plan that provides guidance for only the next 15-20 years, LMPs are the most appropriate temporal and geographic scales to consider climate change. In most cases it's imprudent or inaccurate for planners to apply broad landscape scale models to specific project areas and watersheds.

Monitoring and adaptive management are key for addressing uncertainty and risk in long term planning. In actuality, however, both monitoring and adaptive management have been difficult to implement given lack of funding. Strategies for dealing with uncertainty require financial support in order to be operational.

What Can We Do so that Sierra Yellow-Legged Frogs Are More Resilient to Climate Change? - Kathleen Matthews (USFS - Pacific Southwest Research Station)

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The Sierra yellow-legged frog, *Rana sierrae (*formerly mountain yellow-legged frog *Rana muscosa*), was once common in Sierra Nevada high-elevation lakes and slow-moving streams at elevations ranging from 4,500 to 12,000 feet, but its range has decreased more than 80 percent in the last 90 years. The frog was found warranted for ESA listing and is the subject of much controversy because the stocking of exotic trout into the once fishless High Sierra lakes is one important factor in the frog's decline. Restoration projects by the National Park Service, National Forest Service, and California Department of Fish & Game have been initiated throughout the Sierra Nevada to remove exotic trout and restore native species.

Climate change models suggest one of the principal effects on Sierra Nevada water balance will be a decreased snow pack, with more than half of the current snow water equivalent gone by 2090. A decline in snowpack will likely exacerbate the frog declines by increased summer drying of the shallow, fishless ponds where most *R. sierrae* breeding and tadpole development (requiring 3- 4 years) occurs today. Our recent study published in Herpetological Conservation and Biology showed how the combination of breeding lakes drying up in summer and predation by introduced trout in larger lakes severely limits the amphibian's breeding habitat, and could ultimately result in its extinction. In our study basin in Kings Canyon National Park, most breeding currently occurs in shallow water bodies prone to drying in low snowpack years; when lakes dry all tadpoles die. No successful breeding occurs in larger, deeper lakes resistant to drying because they are inhabited with exotic trout. Historically, frogs could breed in any lake because their native habitat in the High Sierra Nevada was fishless. Experiments have showed that when fish are removed from the larger lakes then frogs return.

Following Millar's 5 R strategy (Reduce, Resist, Resilience, Respond, tRiage) for adapting to climate change, we must plan to have resilient populations of amphibians. For species that are already imperiled, what can be done? One way frogs could become more resilient to climate warming is to have access to larger deeper fish-free lakes. These amphibians are closely tied to water and all life history stages need permanent water for survival. Unlike most frogs and toads that have single-year tadpole stages, the frogs need permanent summer water for 3-4 years, and the adults also stay near or in water year round. Thus, restoration strategies for this imperiled frog need to account for further stress from climate warming, and allow access to water bodies not prone to drying. To ensure that Sierra yellow-legged frogs become resilient to climate warming, managers will need to restore many basins to their natural fish-free status so that breeding can be sustained even in low snowpack years. The survival and viability of Sierra yellow-legged frogs require a Sierra wide strategy that seeks to balance native species and recreational fisheries.

2:00 - 4:30 Forest Management Strategies for Adapting to Wildfire Risk under Climate Change

Effects of Climate Change on Wildfire Risks –Tony Westerling (University of California, Merced)

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The climate system interacts with various factors such as soils, topography, available plant species, and sources of ignition to give rise to both natural ecosystems and their fire regimes. Long-term patterns of temperature and precipitation determine the moisture available to grow the vegetation that fuels wildfires (Stephenson 1998). Climatic variability on interannual and shorter scales governs the flammability of these fuels (e.g., Westerling 2003; Heyerdahl et al. 2001; Kipfmueller and Swetnam 2000; Veblen et al. 2000; Swetnam and Betancourt 1998; Balling et al. 1992). Flammability and fire frequency in turn affect the amount and continuity of available fuels. Consequently, long-term trends in climate can have profound implications for the location, frequency, extent, and severity of wildfires and for the character of the ecosystems that support them.

Human-induced climatic change may, over a relatively short time period (< 100 years), give rise to climates outside anything experienced in California since the establishment of an industrial civilization currently sustaining a state population that has increased approximately 41,000% since 1850.1[1] Changes in wildfire regimes driven by climate change are likely to impact ecosystem services that California citizens rely on, including carbon sequestration in California forests; quality, quantity and timing of water runoff; air quality; wildlife habitat; viewsheds and recreational opportunities. They may also impact the ability of homeowners and federal, state, and local authorities to secure homes in the wildland-urban interface from damage by wildfires (Westerling and Bryant 2008).

In addition to climate change, the continued growth of California's population and the spatial pattern of development that accompanies that growth are likely to directly affect wildfire regimes

1[1] Calculated from population statistics obtained from the U.S. Census online at www.census.gov/.

through their effects on the availability and continuity of fuels and the availability of ignitions. They are also likely to impact both wildfire and property losses due to wildfire through their effects on the extent and value of development in California's wildland-urban interface, both through their effects on the number of structures proximate to wildfire risks and their effects on fire suppression strategies and effectiveness.

The combined effects of climate change and development on California's future large wildfire occurrence and burned area are the focus of the research presented here. Our modeling projects California's fire regimes *as they are currently managed* onto scenarios for future climate, population, and development. The methodology we employ can incorporate the effects of spatial variations in current management strategies on average fire risks. However, the monthly and interannual variations in large wildfire occurrence and burned area that we estimate do not reflect changes in management strategies over time, although our modeling does have the capacity to reflect changes in the effectiveness of current management strategies to the extent that these changes currently tend to correlate with climate and land surface characteristics. Thus, hypothetical effects of future changes in management in response to the impacts of climate and development on wildfire are not considered in this work.

The metrics we model here—large fire occurrence and burned area—are not the only metrics we would wish to employ to assess the full range of impacts of wildfire on the services and sectors detailed above. In particular, metrics of fire severity (e.g., the percent of available biomass consumed, characteristics of ecological impacts) would be highly desirable as well. These metrics are likely to change in response to climate. They may also be influenced by future management decisions, and are key components for estimating many wildfire impacts due to climate change. The work reported here does not consider changes in fire severity, which are the target of multiple ongoing research efforts. However, in interpreting our results, it would be a mistake to assume a linear correspondence between increased burned area and fire severity. Fire severity is likely to increase in some ecosystems and decrease in others alongside increases in burned area. Furthermore, severity might decrease in some ecosystems for reasons that many California residents would find undesirable.

This work extends an analysis by Westerling and Bryant (2008) that considered the effects of climate change on California large wildfire occurrence and wildfire-related damages holding development fixed at the 2000 census. In this analysis we statistically model large (>200 and >8500 hectares [ha]) wildfire occurrence as a product of both future climate scenarios and a future population and development scenario, using nonlinear logistic regression techniques developed for seasonal wildfire forecasting in California and the western United States (Preisler and Westerling 2007). We model the expected burned area using Generalized Pareto Distributions fit to observed wildfires >200 and >8500 ha. Large wildfire occurrence and burned area are modeled using hydroclimate and land surface characteristics under a range of future climate and development scenarios. The range of uncertainty for future wildfire regimes is analyzed over two emissions pathways (the *Special Report on Emissions Scenarios* [SRES] A2 and B1 scenarios); three global climate models (Centre National de Recherches Météorologiques CM3, Geophysical Fluid Dynamics Laboratory CM21 and National Center for Atmospheric Research PCM2); a mid-range scenario for future population growth and development footprint; two model specifications related to the uncertainty over the speed and timing with which vegetation characteristics will shift their spatial distributions in response to trends in climate and disturbance; and two thresholds for defining the wildland-urban interface relative to housing density. Results were assessed for three 30-year time periods centered on 2020, 2050, and 2085, relative to a 30-year reference period centered on 1975.

Substantial increases in wildfire are anticipated for most scenarios, although the range of outcomes is large and increases with time. The increase in wildfire area burned associated with the higher emissions pathway (SRES A2) is substantial, with increases statewide ranging from 57 percent to 169 percent by 2085, and increases exceeding 100 percent in most of the forest areas of Northern California in *every* SRES A2 scenario by 2085. The spatial patterns associated with increased fire occurrence vary according to the speed with which the distribution of vegetation types shifts on the landscape in response to climate and disturbance, with greater increases in fire area burned tending to occur in coastal southern California, the Monterey Bay area and northern California Coast ranges in scenarios where vegetation types shift more rapidly.

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Forest Management Strategies to Avoid High Severity Fire and Reduce Carbon Emissions - Matt Hurteau (Northern Arizona University)

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Problem: Depending on management, forests can be an important sink or source of carbon. U.S. Forest carbon stocks have increased as a result of regrowth following land abandonment and in-growth due to fire suppression. Increasing carbon density and reducing emissions from disturbances (e.g. fire, pest outbreaks) are two potential strategies for using forests to slow the rise of atmospheric CO_2 (Figure 1). The recent increase in frequency of large and severe fires due to past fire suppression and ongoing climate change represents risk in forest carbon offset investment. Under current carbon accounting mechanisms, all forest carbon offset projects are equivalent provided they meet additionality and permanence standards. Risk of loss from disturbance is not incorporated into quantifying permanence, even though some forests are at greater risk than others. Many western forests are being treated to reduce the risk of catastrophic fire. Under current California Climate Action Registry (CCAR) guidelines, however, fuels treatments that reduce live tree biomass are considered a reduction in forest carbon stocks and landowners are penalized for removing or releasing carbon that could contribute to greenhouse gas emissions. We sought to determine if fuels reduction treatments could yield an avoided carbon emissions benefit and the effect that different forest structures have on wildfire emissions and post-fire carbon stocks.

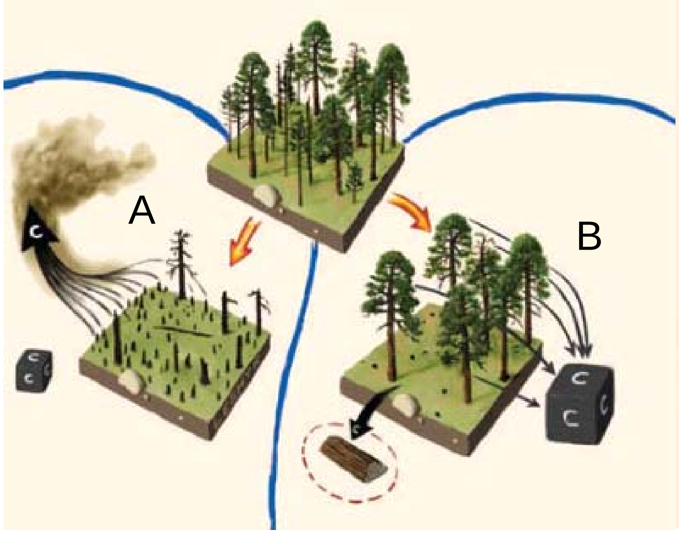

Figure 1. Postulated long-term consequences of managing overstocked forests in two ways (A or B). (A) Continued fire suppression in the absence of restoration thinning leads to catastrophic wildfires that release CO_2 to the atmosphere and greatly reduce carbon sequestration. (B) Fuel reduction treatments reduce the risk of catastrophic fire and protects a large stock of carbon in forest biomass.

The size of the cubes indicates the relative amount of carbon storage. (Figure from Hurteau, Koch, and Hungate, 2008).

Approach: To determine if fuels reduction treatments resulted in reduced emissions, we used a combination of plot data and characteristics from a representative modeled dry western forest type. We estimated the emissions and carbon stock loss of four of the largest fires in the western U.S. that burned during the 2002 wildfire season. To determine the effect that forest structure has on wildfire emissions and post-fire carbon stocks, we used data from the Teakettle Experimental Forest in the southern Sierra Nevada. We modeled stand growth and carbon stocks for a range of management actions over a 100-year period and simulated high severity wildfire at year 50 in the mixed-conifer forest using the Forest Vegetation Simulator and the Fire and Fuels Extension.

Results:

Fuels reduction treatments and fire emissions: During the 2002 fire season, four of the largest fires burned approximately half a million hectares of forest land, of which 92,000 ha was burned by high severity, stand replacing fire. These 92,000 hectares released approximately 4.2-6.1 Million Metric Tons of CO_2 ($MMTCO_2$) from live tree biomass. We estimated that had these areas been thinned prior to the fire events, the live tree carbon stock would have been reduced by approximately 3.9 $MMTCO_2$. However this reduction in the carbon stock would have reduced emissions by as much as 5.7 $MMTCO_2$.

Forest structure, carbon stocks, and emissions: Comparing modeled fuels treatments, we found the no-action control had the largest year 100 carbon stock in the absence of wildfire. However, when wildfire was simulated in year 50, the control had a significant drop in carbon stocks, the largest wildfire emissions, and a decrease in the ratio of live to dead trees. The fuels treatment that approximated the forest structure in 1865 resulted in the lowest wildfire and prescribed fire emissions. In year 100 this treatment also produced the best approximation of an active-fire, resilient forest structure and composition similar 1865 forest conditions.

Next Steps: Beginning this summer, we will collect data in the Lake Tahoe Basin to model tree species-specific growth response to a range of climate change scenarios. The goal of this work is to use the modeled changes in growth to assess the possible changes in forest composition and the influence of management actions on forest structure and wildfire risk.

Adaptation Strategies: Trees are long-lived organisms, and once established may survive likely near-term climate changes that are within the past range of variation. All models suggest greater inter-annual variability in climatic conditions, which may increase fire size and season length, in addition to increased drought-induced tree mortality. Implementing fuels reduction treatments that leave a low stem density dominated by large fire-resistant pine will reduce drought stress and fire severity, and may enable forests to persist in current locations for an extended period of time.

Forest Management Strategies for Fuels Reduction and Sensitive Species under Changing Climate Conditions - Malcolm North (USFS Sierra Nevada Research Center)

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Forest management often focuses on strategically placed fuels treatments as a first priority to reduce wildfire intensity and rate of spread. Outside of defensible fuel profile and threat zones, the remainder of the forest is managed for a desired condition, sometimes using past forest structure suggested by either a pre-European condition or a historic range of variability. With climate change, however, are restoring forests to these conditions even an appropriate goal? Does the past still have lessons for managing forests as climate shifts?

Climate change can be an opportunity to re-examine Sierran forest management and identify where new thinking is needed. Certainly one crucial area is the need for a comprehensive strategy for sensitive species habitat within fuels treated landscapes. A recent national analysis of legal challenges to fuels treatments over the last 8 years found one of the most cited reasons was the lack of sufficient provisions for threatened and sensitive species (TES) habitat. One of the perceived conflicts is the association of some TES with forest conditions that have high surface and ladder fuel loads. Certainly in the Sierra Nevada this appears to be the preferred nesting and resting habitat for species such as the northern goshawk (*Accipiter gentilis*), the California spotted owl (*Strix occidentalis occidentalis*) and the Pacific fisher (*Martes pennanti*). In the Sierra Nevada and elsewhere in the western U.S., agency response is often to exclude TES core habitat from treatment, and than try to reduce fire severity in the landscape in the hope of maintaining TES core areas and their wider foraging habitat.

This approach fails to provide a comprehensive landscape plan for TES management or an overarching concept of how TES historically thrived in frequent-fire conditions. Part of the problem is that research has failed to provide such a concept. There are many studies of particular stand conditions or sometimes even landscape features associated with TES but no framework of how they fit together. Furthermore there are very few species that have been sufficiently studied to identify what would be an optimal habitat configuration for a forested landscape.

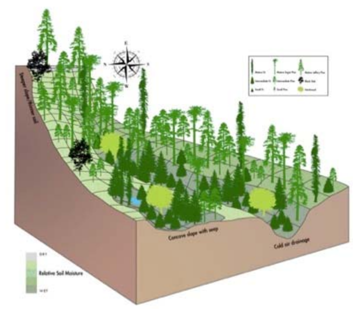

Figure 1: Stand-level schematic of how forest structure and composition would vary by small-scale topography after treatment. Cold air drainages and concave areas would have high stem densities, more fir and hardwoods. With increasing slope, stem density decreases and species composition becomes dominated by pines.

Here, the past can help. A central concept in restoration ecology is that ecosystems should be managed to best approximate the conditions under which species evolved. In mixed-conifer forests, fire was a keystone process fundamentally shaping its structure, composition, and function. Topography has a strong influence on fire frequency and intensity, which in turn shapes local forest structure and composition. Reconstruction studies are finding that nineteenth century frequent-fire landscapes had a variety of forest and habitat conditions, including areas of higher canopy cover and stem density. In collaboration with others, management guidelines have been developed[2] which are designed to balance fuels treatment with TES habitat needs, using topography as a template for varying fuel and forest conditions at two scales, within a stand and across a watershed. Within stands, mechanical fuels reduction in wetter areas, such as seeps, concave pockets, and cold air drainages would be limited to surface and small ladder fuels. These sites with their potentially higher productivity and cooler microclimate may have historically supported greater stem densities, higher canopy cover, and reduced fire effects. In contrast, sloping sites where soils may be shallower and drier, and where

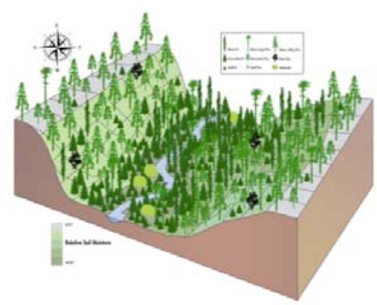

Figure 2: Landscape schematic of variable forest conditions produced by management treatments that vary by topographic factors such as slope, aspect, and slope position. Ridgetops have the lowest stem density and highest percentage of pine in contrast to riparian areas. Midslope forest density and composition varies with aspect: density and fir composition increase on more northern aspects and flatter slope angles

[2] North, M., P. Stine, K. O'Hara, W. Zielinski, and S. Stephens. In press. An ecosystem management strategy for Sierran mixed-conifer forests. USDA Forest Service, PSW General Technical Report.

fire can burn with greater intensity, would be thinned toward lower fuel loads and a more open condition. At the watershed scale, forest conditions would vary by slope position, aspect, and slope steepness reflecting how fire behavior and return interval may have topographically varied. In general, stem density and canopy cover would be highest in drainages and riparian areas, and then decrease over the mid slope and become lowest near and on ridge tops. Within a watershed, stem density and canopy cover would be higher on northeast aspects compared to southwest and would vary with slope becoming more open as slopes steepen. Riparian forests appear to provide exceptional habitat and movement corridors for many species, yet due to their productivity, also have some of the highest fuel loads in fire-suppressed landscapes. Similar to within stand moist microsites, riparian zones could be lightly treated for fuels reduction, removing surface and smaller ladder fuels while retaining their high canopy cover and modified microclimate habitat characteristics. In practice managers are already using many of these concepts, but often their use has not been clearly documented or coherently imbedded within a comprehensive management strategy.

Historically, Sierran mixed conifer forests have been remarkably resilient to episodic stresses such as prolonged La Niña droughts. Chronic moisture stress, however, resulting from fire suppression increases in stem densities, may be currently accelerating mortality, particularly of the large trees associated with many sensitive species. Perhaps the best means of providing TES habitat in fuels treated landscapes is to restore the variable, resilient forest structure that these species evolved with.

4:00 - 5:00 Adapting to Climate Change in Forest Management - Agency and Stakeholder Panel

Panelists: Eli llano (USFS/Lake Tahoe Basin Management Unit), Tina Carlsen (California Tahoe Conservancy), Roland Shaw (Nevada Division of Forestry), Susan Britting (Sierra Forest Legacy), Mike Vollmer (Tahoe Regional Planning Agency), Martin Goldberg (Lake Valley Fire Protection District)

Each panelist has been asked to answer the following questions:

1. What are the major challenges your agency or organization faces in using scientific data and information on climate change and its potential affects?
2. Was the information presented in the sessions today useful to your agency or organization? Specific examples are appreciated.
3. What kinds of information would you like to have and in what form(s) is that information most useful? Can you provide some specific examples of the information you need and how that information would be used?
4. How can your agency or organization cope with information on climate change that will inherently have high uncertainty?

Day Two: March 18, 2009

8:30 - 12:30 Climate Change and Adaptation Strategies for Lake Tahoe and its Watershed

What will Lake Tahoe look like in the 21st Century – Geoff Schladow (UC Davis Tahoe Environmental Research Center)

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Lakes have been described as integrators of all that takes place in their watershed. One of the largest changes expected to occur in the Tahoe Basin is the change in climate. Regardless of the precise trajectory that climate change will take, enough is now known to be able to say what climate variables are most likely to change, the approximate magnitude of that change and, with the application of some judicious assumptions, the likely physical response of the lake.

Three physical responses that Lake Tahoe is likely to exhibit in response to climate change are examined. These are future lake levels, future fine particle loading due to altered precipitation patterns, and future lake mixing. The methods and approach taken to explore each is different, and range from GIS for lake level, to extrapolation of statistical storm water data for urban particle loadings, and numerical modeling for exploring the changes in internal mixing processes.

Lake level is constrained at the upper end by the presence of the dam at Tahoe City. At the lower end, it is likely that the increasing severity of droughts will yield lake levels significantly below the natural rim more frequently in the coming decades. Likewise, the expected change in rain and snow patterns will likely increase the loading of fine particles from urban areas. Finally, increases in lake temperature combined with increased thermal stratification will yield a lake that will be prone to long periods without deep winter mixing.

These issues are all the focus of current research, in part to better quantify the expected changes, and in part to develop adaptation strategies.

Visible Impacts to Lake Tahoe's Invisible Biota in Response to Climate Change - Monika Winder (UC Davis Tahoe Environmental Research Center)

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Climate forcing strongly affects the mixing patterns in lakes and it is expected that these thermal changes alter species composition and the structure of phytoplankton. This microscopic plant community plays a fundamental role in the functioning of aquatic systems as they form the basis for energy production and largely control water clarity in Lake Tahoe. In this presentation I use a retrospective analysis of Lake Tahoe's long-term phytoplankton record and address the question how changes in mixing and stratification affected the community composition of these primary producers.

Climate warming increases the density gradient between upper and deeper water layers, which suppresses upward flux of nutrients and reduces nutrient availability for autotrophic organisms in the euphotic zone. Stronger stratification also suppresses the formation of turbulence, which increases sinking velocities of non-motile species. Consequently, climate warming is expected to enhance the competitive advantage of cell types that are better competitors for nutrients and that are able to maintain their vertical position in the euphotic zone. This will particularly affect diatoms, which have relatively high nutrient requirements and due to their heavy cell walls sink readily to deeper depth. Diatoms are an important group of phytoplankton species and many diatoms benefit from turbulent mixing to remain suspended in the upper illuminated water layer. Due to these characteristics diatoms are expected to decrease with climate warming because of reduced nutrient redistributions and increasing sinking velocities.

Diatoms contribute to a substantial portion of primary production in Lake Tahoe and this taxonomic group has collectively been able to maintain their biovolume in the presence of intensified stratification because species best adapted to changing mixing and nutrient regimes were able to flourish and expand. Increasing stratification and reduced nitrogen to phosphorus ratios selected for small-celled diatoms, particularly within the *Cyclotella* genus. And this shift in cell size was consistent within different depth strata. The increase in small-cell species was sufficient to decrease the average diatom size and thus sinking velocity.

An increase of small-sized cells was also observed within chrysophytes, another numerically dominant phytoplankton group in Lake Tahoe. Further, among the morphologically diverse chlorophytes, filamentous and coenobial forms were favored under intensified stratification. This shows that intensified stratification favor the expansion of small-sized species and species with the capability of buoyancy regulation. It remains to be shown how increasing water column stratification affects the smallest size fraction of primary producers, namely picophytoplankton, which are abundant in the upper water column of Lake Tahoe.

Change in phytoplankton species composition will alter the vertical positioning in the water column, primary productivity rates, and determines whether carbon and nutrients are recycled in the upper water column or transported to deeper water layers. It can be expected that large-sized non-motile algal cells sink more readily to deeper depth layers and facilitate downward transport of particles. Consequently a phytoplankton community consisting of small-sized cells may adversely affect lake clarity. As a next step it is important to understand how changes in phytoplankton size structure affect the fate and transport of carbon and nutrient in the lake.

A high water clarity will be important to allow larger cells to flourish because more transparent waters allows larger cells to remain in the euphotic zone for a sufficiently long period of time to proliferate. Thus improved water clarity and low nutrient concentration will be important to mitigate the effect of climate warming on Lake Tahoe's smallest biota.

Aquatic Invasive Species in a Warming Lake – Sudeep Chandra (University of Nevada Reno) and Marion Wittmann (UC Davis TERC)

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Problem: Global climate change is impacting the nearshore zones of lakes and associated biota (Sharma et al. 2007). Warming of the littoral zone has been tied to changes in biological composition, expansion of range, and changes to growth and reproductive seasons of established species. Global climate change induced disturbances have the potential to alter native biodiversity, weaken abiotic and biotic resistance to non-native species introductions, as well as promote the growth and spread of established aquatic invasive species (Ficke et al. 2007; Rahel and Olden 2008).

Lake Tahoe is a large montane, oligotrophic lake that is currently expressing a number of climate change induced impacts in its nearshore littoral zone. More specifically, the impacts to biodiversity can be attributed to a combination of factors including the disturbance to habitats, temperature warming, as well as increases in invasive species introductions. These pressures are impacting Lake Tahoe's littoral zone in recent decades as increases in the establishment, growth and spread of aquatic invasive species have been monitored.

In addition to facing existing forcing from climate change, the direct impacts from human influences outside of lake are of concern. For example, the lake receives high volumes of recreational trailered boater traffic travelling from multiple high-density city centers as well as other freshwater lakes, rivers and reservoirs in the Western United States. The movement of boats and fishermen between water ways increases the transport pressure of non-native aquatic species across landscapes (Johnson et al. 2006). These introductions can be intentional (i.e., fishes) or unintentional (quagga mussel, Eurasian watermilfoil, etc.) due to entrainment on boats or boating equipment. The introduction and establishment of these species increases as a result of this human movement, and are able to persist in novel ranges due to climate change (temperature warming) and immediate stressors (eutrophication).

Approach: Our research group has intensely studied mechanisms related to aquatic invasive species establishment in the nearshore zone of Lake Tahoe. This includes the measurement of nearshore temperature changes, monitoring movements of invasive bass and bluegill fish species between marinas and the lake proper, and a boater-interview based study of the recreational boating connection between Lake Tahoe and other regional lakes, reservoirs and rivers that contain aquatic invasive species of concern to the Tahoe Basin. Additionally, a new nearshore bivalve, the Asian clam (*Corbicula fluminea*) has recently invaded the Southeast portion of Lake Tahoe. It has been implicated in causing filamentous green algal blooms and is causing an intensive management and research response. The global changes discussed above have a high probability of exacerbating the current Asian clam invasion in Tahoe.

Results: Non-native warmwater fish species are expanding ranges in Tahoe, which are largely determined by lake water temperatures that drive spawning and growth potentials (Shuter et al. 1983). Ngai (2008) showed that nearshore surface water temperatures has increased from 1910-2006, resulting in a longer growing season for invasive largemouth bass. As a result historically unfavorable areas of the lake nearshore zone are becoming suitable habitat. Furthermore, surface water temperature projections generated using regional climate model data suggest that the generally cooler waters that were unsuitable for largemouth bass will become more suitable in the future (2080-2099) (Ngai 2008). A recent study on movements of invasive bass and bluegill at Tahoe Keys has demonstrated that these fishes are potentially moving out of the marina. Wide spread warmwater fish invasion can have significant impacts on the native biota of Lake Tahoe. It is likely that they are competing with native fish for food resources (Kamerath et al. 2008) and may have significant predatory impacts on native fish (Kamerath and Chandra unpublished data).

Recreational boaters are moving between Lake Tahoe and western regional waterways that have established populations of aquatic invasive species (New Zealand mudsnail, quagga mussel) that threaten Lake Tahoe's waters (Wittmann 2008). These species have potential impacts to the nearshore ecosystem and benthic communities of Tahoe Basin water bodies. Recent laboratory studies on the potential survivability of these species under Lake Tahoe conditions show that New Zealand mudsnail show 5 to 40% survival (Kolosovich 2009 in press), and quagga mussel adults show 86% survival with potential for gamete production (Chandra et al. in prep). Other potential impacts due to quagga mussel introductions include the coupling between pelagic-benthic habitats as well as alterations to zoobenthic biodiversity and dominance (Ward & Ricciardi 2007).

Finally, these climate change induced temperature rises may also increase Asian clam growth and reproductive seasons which are also highly dependent on water temperature (Thorp and Kovich 1991). As Ngai (2008) showed for invasive largemouth bass, nearshore warming in Lake Tahoe has the potential to increase both the reproductive potential and survivability for Asian clam by impacting the temperature driven reproductive, growth and mortality limits.

Next steps: Due to the increased ecological impacts at Lake Tahoe as a result of increased boat traffic, disturbance, and climate warming, there has been a quick policy response to address invasion issues. A Lake Tahoe aquatic invasive species working group comprised of members of the scientific community, federal, state and regional agencies, as well as members of the public was formed in 2007 to protect Lake Tahoe via the prevention and control of AIS that are established or threaten the Lake. To protect Lake Tahoe from future AIS and impacts as a result of these species, the continued research regarding impacts to Lake Tahoe from climate related disturbances and species invasions should be a key objective for this working group.

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Facing Future Climate Change: A View from the Watersheds - Robert Coats (TERC and Hydroikos Ltd)

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This study quantifies the decadal-scale time trends in air temperature, precipitation form and intensity, spring snowmelt timing, and lake temperature in the Tahoe basin. Temperature data from six long-term weather stations in the Tahoe region were analyzed for trends in annual and monthly means of maximum and minimum daily temperature. Precipitation data (1910-2007) at Tahoe City were analyzed for trends in phase (rain versus snow), decadal standard deviation, and intensity of rainfall. Daily streamflow data for nine gaging stations in and around the Tahoe basin were examined for trends in snowmelt timing, by two methods, and an existing record for the temperature of Lake Tahoe was updated. The results for the Tahoe basin, which contrast somewhat with the surrounding region, indicate strong upward trends in air temperature, a shift from snow to rain, a shift in snowmelt timing to earlier dates, increased rainfall intensity, increased interannual variability, and continued increase in the temperature of Lake Tahoe. Two hypotheses (not mutually exclusive) are offered to explain why the Tahoe Basin may be warming faster than the surrounding region: 1) the 'lake climate change enhancement hypothesis'–that the lake itself may be enhancing the climate-warming effects of increasing greenhouse gas concentrations, and 2) the 'snow albedo perturbation hypothesis'—that high rate of soot deposition in the basin's snowpack decreases the snow's albedo, increases the temperature of the pack and overlying air, and accelerates spring snowmelt. Both of these hypotheses find support in the literature.

Continued warming in the Tahoe basin is likely to result in 1) increased tree mortality, and increased fuel loads; 2) increased wildfire frequency and intensity; 3) continued shift from snow to rain; 4) increased intensity of rainfall, with concomitant increases in surface soil erosion, flood peaks and channel erosion; 5) changes in the theoretical climax vegetation. Measures to address these changes must include 1) fuel load reductions, especially in developed areas; 2) modification of the precipitation depth-duration-frequency curves that are used to design culverts and water quality BMP structures; 3) modification of flood frequency curves used for design and flood insurance calculations; 4) experimental plantings of trees and shrubs that are currently

adapted for lower elevations; 5) modification of monitoring programs to emphasize variables (both independent and explanatory) that may be related to climate change.

Climate Impacts on Airborne Particle Concentrations in California: Implications for Atmospheric Deposition – Michael Kleeman (UC Davis)

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Atmospheric deposition of airborne particulate matter plays a critical role in ecosystem health. Climate change will modify weather patterns in California with unknown consequences for airborne particulate matter concentrations and deposition loads. Previous down-scaling exercises carried out for the entire United States have typically not resolved the details associated with California's mountain-valley topography and mixture of urban-rural emissions characteristics. Detailed studies carried out for California have identified strong effects acting in opposite directions on $PM_{2.5}$ concentrations making the net prediction for climate effects on airborne particle concentrations somewhat uncertain. More research is needed to reduce this uncertainty so that we can truly understand climate impacts on airborne particle concentrations and deposition.

The objective of this research is to predict climate change effects on annual average concentrations of airborne particulate matter and deposition in California with sufficient resolution to capture the details of California's air basins. Business-as-usual scenarios generated by the Parallel Climate Model (PCM) will be downscaled to 4km meteorology using the Weather Research Forecast (WRF) model. The CIT/UCD source-oriented photochemical air quality model will be employed to predict airborne particle concentrations and deposition loadings throughout the entire state of California. The modeled annual average total and speciated airborne particle concentrations for the future (2047-2049) and the present-day (2004-2006) periods will be compared to determine climate change effects. The results from this study will improve our understanding of global climate change effects on airborne particle concentrations and deposition in California.

1:30 – 2:30 Lake Tahoe and it Watershed - Agency and Stakeholder Panel

Panel members: Dan Sussman (Lahontan Regional Water Quality Control Board), Jason Kuchniki (Nevada Division of Environmental Protection), Jacques Landy (US Environmental Protection Agency), Tim Hagan (Tahoe Regional Planning Agency), Carl Young (League to Save Lake Tahoe)

Each panelist has been asked to answer the following questions:

1. What are the major challenges your agency or organization faces in using scientific data and information on climate change and its potential affects?
2. Was the information presented in the sessions today useful to your agency or organization? Specific examples are appreciated.

3. What kinds of information would you like to have and in what form(s) is that information most useful? Can you provide some specific examples of the information you need and how that information would be used?
4. How can your agency or organization cope with information on climate change that will inherently have high uncertainty?

2:30 - 4:00 California Climate Change Legislative Update, Climate Action Plans and Sustainability Frameworks

A New Climate for Land Use: SB 375 and the Future of Transportation and Land Use Planning in Lake Tahoe - Autumn Bernstein (ClimatePlan)

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Problem: Poorly planned development (urban sprawl) is one of the biggest causes of greenhouse gas emissions in California. Because so many new communities require a car for every trip, vehicle miles traveled (VMT) has increased at nearly twice the rate of California's population. 38% of California's GHG emissions are caused by transportation, and the vast majority of these emissions are from passenger cars and trucks. Unless we change our development and transportation patterns and build more walkable, transit-oriented communities, vehicle miles traveled (VMT) in California will increase 40 - 70% by 2030, canceling out the emissions benefits of improved fuel economy and low-carbon fuel options.

Approach: ClimatePlan is a partnership of environmental, civic and transportation organizations working together to ensure that California promotes smarter land use and transportation policies to meet the greenhouse gas reduction goals of AB 32 and SB 375. We work to promote land use policies and public investment to achieve greenhouse gas emission reduction targets, improve quality of life in California, and serve as a model for national action. Specifically, we:

- *Educate Stakeholders and Policymakers.* We work with key state agencies, local governments and stakeholders to ensure that implementation of AB 32 and SB 375 includes strategies for promoting sustainable land use and transportation.
- *Bring Diverse Constituencies to the Table.* Any new policy adopted by the State of California must work for our state's diverse regions and communities. ClimatePlan is reaching out to stakeholders and constituencies across California to foster their participation in designing AB 32 and SB 375.
- *Promote Innovations and Model Policies.* We have created a regional pilot program in the Bay Area to ensure the Regional Transportation Plan helps meet GHG reduction goals. We are also working with local government staff and organizations to create new, model general plans and other land use policies that help achieve AB 32 targets.

Next steps: With the passage of SB 375 in October 2008, California became the first state in the nation to recognize the linkage between land use patterns and greenhouse gas emissions. The new law takes effect in 2011, and the California Air Resources Board is currently in the process of developing protocols and establishing targets for implementation. Starting in 2011 regions across California, including Lake Tahoe, will need to develop a Sustainable Communities

Strategy (SCS), that identifies land use patterns, transportation programs, and affordable housing locations that will reduce Vehicle Miles Traveled (VMT) to comply with the new law.

Applying Climate Action Plans and Sustainability Frameworks: A New Approach for Tahoe - Darin Dinsmore (Regional Planning Partners)

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Problem: Twenty years ago Tahoe was at the forefront of environmental planning. Today, the region is struggling to make its communities and public lands more sustainable and preserve Lake Tahoe's famed blue waters, while facing threats from climate change. What would a Comprehensive Climate Action Framework look like for Lake Tahoe? What lessons can we learn from other approaches? Will an integrated approach help multiple stakeholders and agencies work together? Who are the partners and how do we work together?

Approach: Groundbreaking new laws in California (AB32 and SB 375) are now requiring regions to comprehensively address climate change and be implementing solutions by 2011. Basin managers need to find a way to implement the proposed changes and has an opportunity to start thinking about opportunities for implementation now to demonstrate early success and leadership.

Reducing GHG emissions is a shared responsibility involving both public land managers, local jurisdictions, transportation agencies, land use planning jurisdictions, residents and businesses working together to minimize impacts. The public and private sector will need to work together to take action and make appropriate investments and changes in behavior.

The City of South Lake Tahoe has already started to incorporate sustainability and climate change planning with their approved Sustainability Plan and new Sustainability Commission. What lessons can we learn from this process and other national approaches? What best practices in climate change and sustainability frameworks could be applied to the region?

We have developed a Draft integrated framework with concepts and actions for addressing climate change mitigation and adaptation. The Draft Regional Climate Action framework outlines nine concepts that provide a starting point for sustainable decision making:

1. Maintain healthy forests and prevent catastrophic wildfires
2. Restore watersheds and improve Stormwater Management with climate adaptation in mind
3. Implement adaptation strategies for Invasive Species and Vegetation Management
4. Redevelop existing communities and creating more compact, mixed-use and walkable places
5. Improve mobility and access with environmentally-friendly transit and improved efficient mobility options

6. Reduce energy and resource use by improving efficiency and providing more renewable energy sources
7. Invest and create green jobs and innovation to support a vibrant year-round economy
8. Implement Urban environmental improvements and Green Infrastructure reduce waste and improving recycling
9. Incentivize and invest in sustainable site design and green building

By implementing these concepts, the Region will increase its livability and prosperity, reduce the footprint of its residents and visitors, and improve human and ecological health. By working together the region may become a national leader in sustainability and proactive environmental planning.

Next steps: The next steps include exploring the option of creating a Tahoe Climate Collaborative, seeking funding and hiring a coordinator, and developing a detailed scope of work, timeline and action plan. Other steps may include:

- *Collaborate on an emissions inventory* to develop a baseline for the Region
- *Conduct a needs assessment* of the region, including an annual survey and analysis of current and proposed efforts to meet greenhouse gas emission reduction goals and begin the development of a regional climate change action plan to target for greenhouse gas emission reduction.
- *Develop an outreach strategy* to engage the public and build awareness and capacity. Website for information Exchange