Preparing for Climate Change in the Klamath Basin

National Center for Conservation Science & Policy

The Climate Leadership Initiative

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(The Climate Leadership Initiative is a research collaborative between The Resource Innovation Group, a 501(c)(3) nonprofit, and the University of Oregon's Institute for a Sustainable Environment)

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Executive Summary

THE KLAMATH BASIN of southern Oregon and northern California is rich in history, culture, and natural resources. This report explores how the local communities and natural resources of the Klamath Basin are expected to be affected by climate change and identifies approaches to preparing for such changes. Many of the impacts from climate change are already becoming apparent, such as an increasing average global temperature, rising sea levels, earlier snow melt, loss of snow pack, and changing precipitation patterns and storm frequency. Without severe cuts in greenhouse-gas emissions, these impacts and others will continue to accelerate and negatively affect local communities and natural resources. While efforts to reduce emissions of greenhouse gases are essential to prevent the most severe impacts, we must also take steps to prepare for the impacts of climate change already inevitable due to emissions that have previously been released.

This project is the result of a collaborative effort. The USDA Forest Service Pacific Northwest Research Station developed projections for the potential future climate of the Klamath Basin. The University of Oregon's Climate Leadership Initiative and the National Center for Conservation Science and Policy presented these projections to local leaders and experts in the Klamath Basin through a series of workshops. Leaders and experts used these climate projections to identify likely changes to natural (aquatic and terrestrial species and habitats), built (infrastructure), economic (agriculture, forestry, business), human (health, education, emergency services), and tribal (resources of cultural and indigenous community importance) systems. Finally, recommended strategies and actions were developed to prepare communities and natural resources for those changes.

Future Climate of the Klamath Basin

Three global climate models–CSIRO, MIROC, and HADCM–and a vegetation model (MC1) were used to project future temperature, precipitation, vegetation, runoff, and wildfire in the Klamath Basin. The three climate models projected an increase in annual average temperatures compared to baseline temperatures (2.1°F to 3.6°F [1.1°C to 2.0°C] increase by mid-century and 4.6°F to 7.2°F [2.5°C to 4.6°C] by late century). Summer warming was projected to be greater than warming during other seasons.

Projections for annual average precipitation ranged from an overall reduction of 11% to an increase of 24%. All three models agreed that future summers are likely to be drier (a decrease of 3-37%) than past summers.

Vegetation model results indicated a shift in growing conditions in the Upper Basin that could favor grasslands in areas currently suitable for sagebrush and juniper. In the Lower Basin, conditions are projected to favor oaks and madrone over maritime conifer forest (redwood, Douglas fir, and Sitka spruce), which are projected to decline. The vegetation model also projects 11-22% greater area burned by wildfire by late century.

Recommended Actions for Preparation Across Systems

Through a series of workshops in the Klamath Basin, participants made recommendations for how to prepare for the changes expected under climate change. While recommendations were made for each specific system, many recommendations provide co-benefits across multiple systems and sectors. The strategies and actions suggested by workshop participants are likely to increase the resilience and resistance of local communities and natural resources to climate change. A summary of recommendations includes the following:

Natural Systems

- Protect areas with cooler water as air and water temperatures rise. These include stream and lake areas with groundwater-fed springs and well-developed bank vegetation.
- Decommission and re-contour nonessential roads to reduce the overall impact of erosion and sedimentation during severe storm events.
- Reconnect rivers with floodplains, restore wetlands, and restore streamside areas to hold more water during floods and increase groundwater recharge.
- Protect intact habitats such as roadless areas that provide strongholds for many native species.
- Reseed areas after disturbance with locally collected native seeds to reestablish plants that occur in the area and limit the spread of invading species.
- Develop new partnerships across agencies, tribes, and landowners to encourage landscape scale planning across jurisdictional boundaries.

Built Systems

- Increase reliability of water supply and decrease the likelihood of flooding by restoring wetlands, constructing bioswales (landscape elements designed to remove silt and pollution from surface runoff water), and restoring floodplains and streamside areas.
- Provide water conservation incentives to reduce demand and increase natural water storage.

- Provide homeowners with assistance in lowering their energy use to reduce reliance on services that may be interrupted.
- Replace undersized culverts to prevent road-stream crossing failures during floods.
- Expand rail use to increase energy efficiency of local and regional transportation and decrease reliance on the road network.
- Reduce the building of homes in fire-prone and flood-prone areas to keep communities safe and decrease the demand on emergency services.

Economic Systems

- Retain resiliency of natural systems so they continue to provide ecosystem services such as clean water supply, flood buffering, and timber production so the communities and industries they support are maintained.
- Identify and take advantage of new renewable-energy markets to reduce reliance on energy systems that may be disrupted and to build a local energy economy.
- Support the growth of small farms that provide local produce to improve food security and nutrition within communities.
- Retain large tracts of forestlands through carbon credits or limits on subdivisions as a means to reduce the risk of fire and the costs of emergency services as well as develop a carbon sequestration program.
- Promote tourism for activities like birding and cycling to expand the local economy while other industries, such as forestry, may decline due to climate change.
- Increase size and resiliency of commercially harvested fish populations through stream and watershed restoration activities to reestablish this sector of the economy.

Human Systems

- Improve detection of, and response to, new diseases and disease vectors to quickly protect communities from emerging health threats that occur due to warmer temperatures.
- Provide incentives for more efficient homes that would reduce the impacts of severe heat on local populations.
- Increase passive cooling and air conditioning in public places to minimize the impacts of severe heat on the health of community members.
- Update emergency plans to reflect increased likelihood of severe weather, floods, and wildfires.
- Engage with and communicate among community groups (faith-based organizations, nonprofit groups) to assist governments in emergency response (e.g., distributing supplies in response to flooding events and identifying and assisting people at risk from severe heat).

Tribal Systems

- Improve communication among state and federal agencies and tribes to allow for tribal input to planning processes and broaden community buy-in.
- Investigate feasibility of carbon credits for preserving tribal land forests to increase carbon sequestration and improve the local economy.
- Provide incentives for private landowners to cultivate culturally important species of plants and wildlife and allow for tribal use.
- Acknowledge the value of traditional ecological knowledge in managing natural ecosystems and protect such knowledge from misuse.

Heat waves, severe precipitation events, and prolonged drought are all expected to increase as a result of climate change. The recommendations made by local leaders and experts represent a sample of potential actions and strategies that could be taken in the Klamath Basin to prepare for climate change. By increasing the resilience of local communities in the Klamath Basin to changes brought on by climate change, the potential negative impacts of climate change would be reduced, thereby increasing the potential for maintaining current quality-of-life in the Basin.

Purpose and Overview

This report is part of the Climate Futures Forum project undertaken by the National Center for Conservation Science and Policy and the University of Oregon's Climate Leadership Initiative. The purpose of the project is to encourage the development of basin-wide planning in Oregon and California to prepare for the anticipated risks and impacts brought about by changing climate conditions. Taking steps to anticipate and prepare for the likely consequences of climate change can build resistance and resilience to the range of stresses expected to occur over the next century.

The Climate Futures Forum helps local stakeholders from a variety of systems and sectors to assess climate change projections for their region, identify likely impacts, and propose management strategies to prepare for them. The forum purposefully integrates strategies or recommendations across different systems and sectors within these systems (see box) to ensure that climate change preparation actions produce complementary benefits.

The climate change projections, likely impacts, and proposed recommendations within this report are the result of a climate modeling process and a series of workshops held in the Klamath Basin. Workshop participants represented a broad cross-section of expertise and knowledge from individuals within each of the affected systems. The strategies for addressing climate change-related impacts suggested in this report are intended to build resilience (i.e., the ability to recover from impacts) in human and natural communities, reduce short- and long-term risks, and capitalize on resource management opportunities. Many of these strategies are likely to reduce the costs of responding to climate change as well.

SECTORS WITHIN SYSTEMS

Throughout this report, we discuss Systems and Sectors. Our convention is that each system is made up of a number of sectors. For example:

Natural Systems: aquatic and terrestrial species and habitats, water quality and quality, invasive plants, etc.

Built Systems: transportation infrastructure, homes, buildings, water and power supply, etc.

Economic Systems: agriculture, forestry, retail, tourism, commercial fishing, health care, etc.

Human Systems: social services, public health, education, emergency services, etc.

Tribal Systems: communities, species, places and artifacts of cultural importance

See page 5 for an overview of each system.

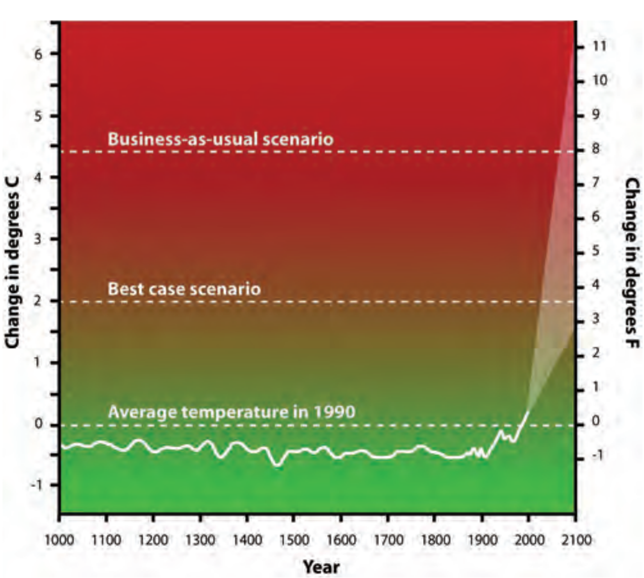


FIGURE 1. *The last 1000 years of global mean temperature, in comparison to projected temperature for 2100. Drastic cuts in greenhouse gas emissions would lead to an increase of about 2ºC by 2100 while the current trajectory will lead to an increase closer to 4.5ºC and as high as 6ºC (adapted from IPCC 2007).*

Evidence of Global Change

Experts agree that the earth is warming (Fig. 1) and that the primary causes are greenhouse-gas emissions and deforestation (IPCC 2007, USGCRP 2009). As global temperatures rise, there are likely to be changes to climate patterns that will affect land and water resources and the plant, animal, and human communities that rely on them.

Global average temperature has increased 1.4°F (0.7°C) since 1900 (National Research Council 2006). Carbon dioxide (CO_2) is a major atmospheric greenhouse gas and is primarily responsible for this

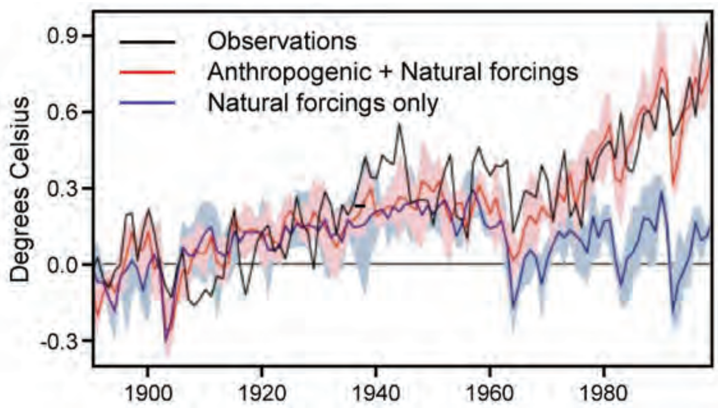


FIGURE 2. *Only models that include anthropogenic components of the climate system, such as greenhouse gases and land use, match the observed warming trend since 1960 (from Meehl et al. 2004).*

increase. Ice-core data indicate that atmospheric CO_2 levels are 30% above peak levels experienced over the last 800,000 years. Concentrations of this gas have risen 37.5% over the past 150 years (from pre-industrial peak levels of 280 parts per million [ppm] to current levels of 385 ppm [IPCC 2007, NOAA 2009]). This rise in CO_2 and other greenhouse gases has also triggered the following changes around the globe:

- Changes in seasonal precipitation, reduced snowpack, earlier snow melt, and increased storm severity (USGCRP 2009);
- An increase of 0.2°F (0.1°C) in sea surface temperature since 1961, and substantial ocean acidification (USGCRP 2009);
- An 8-inch (203 mm) rise in sea level (USGCRP 2009), following 2,000 years of little change;
- A decline in the amount of Arctic sea ice of about 20% since the 1950s (Curran et al. 2003).

The Earth's climate system is influenced by many natural and human-caused components, including volcanic eruptions, ocean dynamics, vegetation growth, fossil-fuel combustion, and deforestation. Until the 1980s, it was difficult to determine which variables had more influence—natural or human-caused. Since then, however, the climate has veered in a trajectory that scientists agree is primarily due to human-caused influences (Fig.2). More information on the causes of climate change is available in the reference section.

Expected Future Change

By the end of this century, CO_2 concentrations could reach levels two to three times those of peak levels over the past 800,000 years. Other greenhouse gases (e.g., methane, nitrous oxide, ozone, and water vapor) are also expected to rise. If the current trend in emissions remains unchanged, global projections for the coming century include the following:

- An increase of 2-11.5°F (1.1°C-6.4°C) in average global surface temperatures (USGCRP 2009)
- A sea-level rise of 3.3 to 9.8 feet (1 to 3 meters), with greater rise (20 to 200 feet) possible depending on ice-sheet stability (IPCC 2007, USGCRP 2009)
- Storm events, wildfire (Krawchuk et al. 2009), and heat waves (USGCRP 2009) likely to become more extreme.

Preparation Is Vital

Due to the buildup of greenhouse gases in the atmosphere, the climate system will take decades or possibly centuries before it stabilizes, even with considerable reductions in emissions. If emissions worldwide are not quickly and substantially reduced in the immediate future, we will lose the opportunity to reduce or mitigate the overall magnitude of climate change. In addition, communities can take action now to reduce their risk from the inevitable changes triggered by greenhouse gases already present in the atmosphere. With well-developed preparation strategies, it may be possible to reduce the severity of many near- and long-term hardships, if emissions are also reduced to limit the extent of climate change.

EMISSIONS SCENARIOS AND CLIMATE MODELS

Please see the companion report, "Projected Future Conditions in the Klamath Basin of Southern Oregon and Northern California," for more information on the models, modeling assumptions, and projections.

The interactions that affect the Earth's climate are complex. We rely on climate scientists and global climate models to project how temperature and precipitation might change by mid- and late century, given what is known about relationships between chemical, physical, and ecological systems. To test the models, climate scientists compare model results with observed temperature and precipitation information. In this way, the scientists can assess how well the models "predict" the past to determine how confident they are in projecting the future.

For this project, three global climate models (CSIRO, MIROC, and HADCM) were used to project a range of potential future conditions in the Klamath Basin.[1] While the models have the same inputs, they interpret interactions between these inputs in slightly different ways. This results in some variation among models. Despite their differences, all three models have been reviewed by the Intergovernmental Panel on Climate Change (IPCC; the leading scientific organization assessing climate change and the risks to environmental and socioeconomic resources) and have proven their ability to accurately reflect past climate patterns and conditions. Model projections are never free of uncertainty (they are simplified representations of complex processes), but they do provide the best available scientific information for assessing risks, identifying preparation opportunities, and building management strategies. When compared to other models available through the IPCC, two of the three models used in this report result in higher-than-average temperature projections for the Pacific Northwest while the third results in lower-than-average temperature projections, providing a range of future temperatures for the Klamath Basin.

Climate projections discussed in this report are based on the "business as usual" emission scenario (IPCC 2007), which closely follows the global emissions path of the late 1990s. A sharp rise in emissions in the decade since means that actual emissions have exceeded those used in the modeling for this report. Consequently, the report's climate projections may underestimate actual climate change impacts.

1 For a thorough description of the global climate models and their assumptions, see D. A. Randall, R. A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R. J. Stouffer, A. Sumi, and K. E. Taylor. Climate Models and Their Evaluation. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller, eds.]. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA. 2007.

Current Conditions of the Klamath Basin

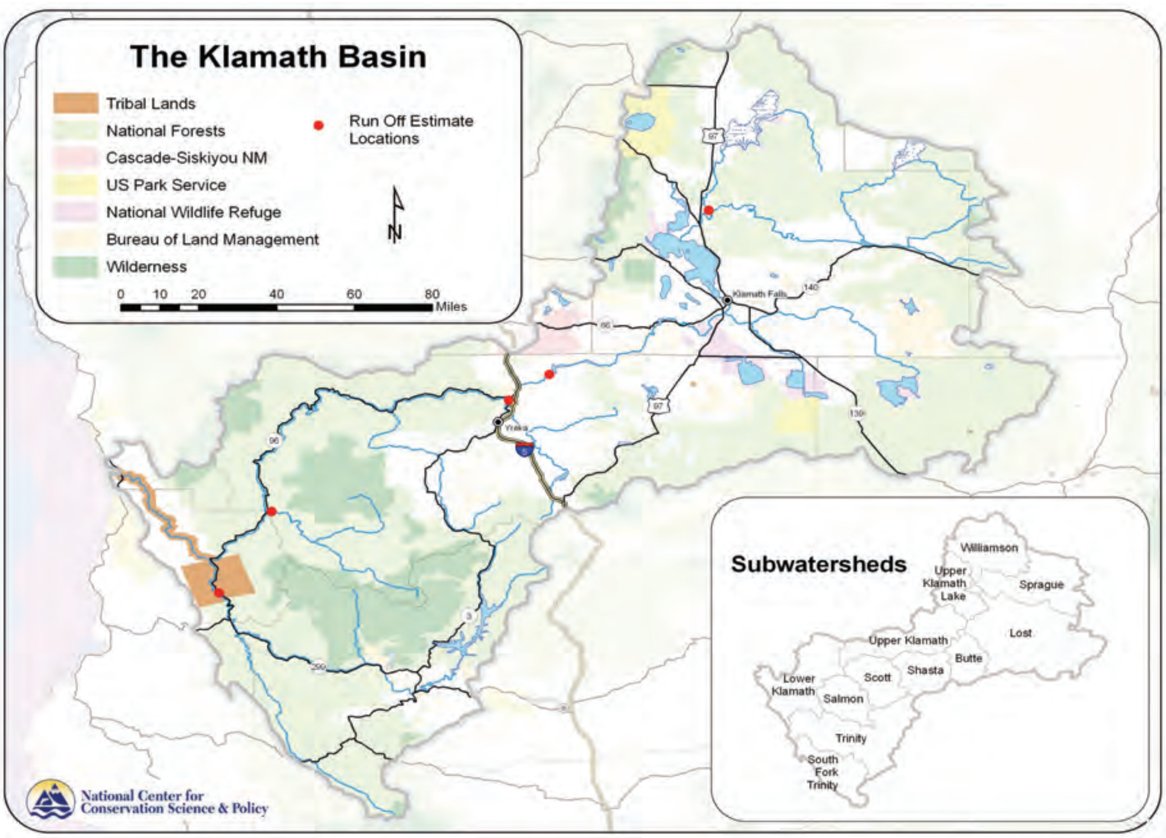
The Klamath Basin (Fig. 3) is rich in history, culture, biological diversity, and natural resources. Upper Klamath Lake, the largest natural lake in Oregon, is fed primarily by the Sprague, Williamson, and Wood rivers as well as numerous springs that flow directly into the lake. Water flowing out of Upper Klamath Lake forms the Klamath River, which cuts through the Cascades and coastal mountain ranges and flows 263 miles to the Pacific Ocean. The Basin drains 15,571 square miles and encompasses parts of three Oregon and five California counties.

Temperature and precipitation patterns vary widely across the Klamth Basin. In Klamath Falls, in the Upper Basin, annual average high temperature is 61°F and the average low is 35°F. Average January temperatures range between 21 and 38°F while July temperatures range between 51 and 86°F. Klamath Falls receives about 13.5 inches of precipitation each year. January and December are the wettest months (averaging 2 inches per month) and July is the driest (0.3 inches). Precipitation frequently falls as snow, particularly at higher elevations.

In Klamath, California, near the mouth of the Klamath River, annual average high temperature is also 61°F, but the average low is 45°F. Average minimum and maximum January temperatures are 38°F and 54°F, while July averages are 52°F and 66°F. The months of December and January each receive about 14 inches of precipitation; in contrast, July is very dry, getting about 0.4 inches. Most precipitation, except at the highest elevations, falls as rain, with an annual total of 80 inches.

Orleans, California, approximately seventy miles upstream of the mouth, has an annual average high temperature of 71°F and annual average low of 44°F. Average January minimum and maximum temperatures are 35°F and 51°F, while average July temperatures are 54°F and 93°F. Orleans gets about 51 inches of precipitation per year, mostly falling as rain, with around 9 inches in January and 0.2 inches in July. (Climate data from the National Oceanic and Atmospheric Administration.)

FIGURE 3. Land ownership and major highways of the Klamath Basin



Systems of the Klamath Basin

Natural Systems

At the turn of the century, the Klamath River was the West Coast's third-largest producer of salmon. A small fraction of the Basin's historic runs of Chinook salmon, coho salmon, and steelhead trout remain today. These fish are still very important to native peoples, commercial fisherman, and sport anglers. These migrating fish are restricted to the Lower Basin but were historically present upstream of Upper Klamath Lake. Black-tailed and mule deer, elk, pronghorn, black bear, river otter, coyote, and mountain lion are found throughout the Basin as are numerous small mammals, reptiles, and birds.

The Upper Klamath Basin, which lies upstream of Keno, Oregon, and includes the Lost River, is predominantly high desert with vegetation like sagebrush, deer brush, rabbitbrush, Idaho fescue, and the nonnative cheatgrass along with juniper predominating throughout the lower elevations. At higher elevations, mixed conifer forests are common with ponderosa pine, lodgepole pine, whitebark pine, Douglas fir, white fir, grand fir, Shasta red fir, and mountain hemlock. Trembling aspen and black cottonwood are the only common hardwoods found in the Upper Basin.

The Upper Basin is home to a number of relict species (i.e., species that have survived in place over the last 20,000 years), notably several sucker and lamprey species unique to the Basin that are staple resources for native cultures. Small populations of bull trout occur in several cold Upper Basin streams. Upper Klamath Basin marshes and wetlands are among the largest in the western United States. They attract nearly 80% of the waterfowl that migrate along the West Coast and support the largest over-wintering population of bald eagles in the lower forty-eight states. Approximately 300 species of birds are recorded from the Upper Klamath Basin. The region's only known breeding populations of yellow rail and red-necked grebes are found here. Mammals unique to this portion of the Basin include black-tailed jackrabbit and pronghorn. The Oregon spotted frog is found in high-elevation wetland complexes and many unique aquatic snails are found in springs throughout the Upper Basin.

The Lower Basin is dominated by temperate rainforest and mixed conifer forests (redwood, Sitka spruce, Douglas fir, ponderosa pine, sugar pine, white fir, grand fir, red fir, western red cedar, western hemlock, and Pacific yew), with subalpine and alpine zones at higher elevations in the Marble, Salmon, and Trinity mountains. Hardwood trees found in the Lower Basin include Oregon white oak, black oak, tan oak, and madrone.

It also supports native populations of lamprey, green sturgeon, eulachon, and coastal cutthroat and rainbow trout. Several unique, recently described amphibians are found including the Siskiyou Mountain and Scott Bar salamanders. Foothill yellow-legged frogs, southern torrent salamanders, and Pacific giant salamanders are also found throughout the Lower Basin. Fishers, large, tree-dwelling mammals in the weasel family that have largely disappeared from the rest of California, are still present in the mixed conifer forests of the Lower Basin.

Built Systems

PacifiCorp is the main utility provider in southern Oregon and northern California, producing most of the electricity from hydropower and a natural gas plant inside the Basin, while also drawing from coal plants located outside the Basin. Hydropower, as well as water storage and irrigation diversion, come from the nineteen large dams within the Basin—ten of which are located in Oregon and nine in California. The primary source for heating homes varies throughout the Basin. For instance, in Klamath County, the majority of households use utility gas for heating, while in Siskiyou County, fuel oil and wood are primary heating sources, and in Del Norte County, the majority of households use electricity or wood (City Data 2009).

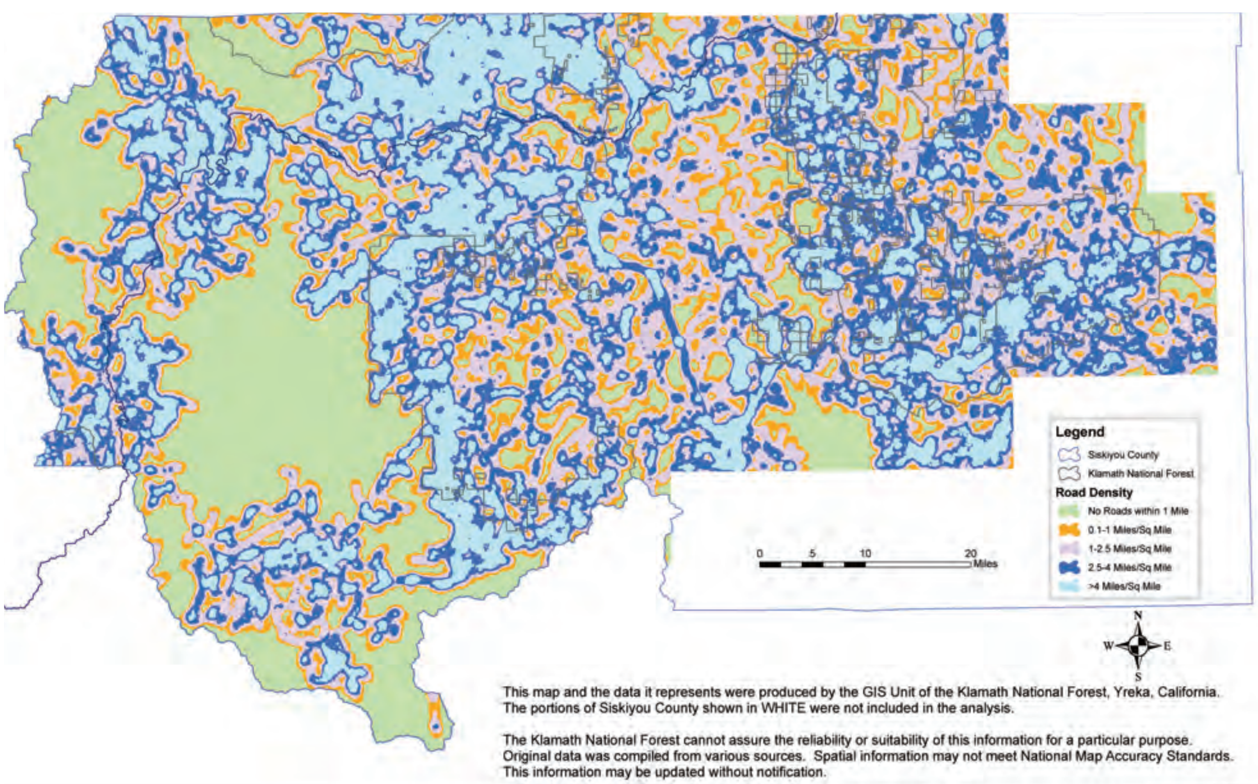
With the exception of Highway 101, much of the Lower Basin is accessible only by Highways 299 and 96, difficult-to-maintain roads that narrowly wind through mountainous terrain and connect the Lower Basin to the Interstate 5 corridor (a major north-south roadway). In the Upper Basin, Highways 97 and 140 are major arteries of the transportation network. On average, there is approximately one mile of road for every 0.4 square miles in the forested areas of the Basin (USFS 2007). Localized road densities are much higher (Fig. 4), however, and sparsely roaded wilderness areas are extensive in many portions of the Basin.

Communication services and accessibility vary throughout the Basin, with land lines, internet, and cellular services available in most cities, but sporadic in rural areas.

Potable water infrastructure is available to communities near larger cities, but many rural citizens rely on wells for drinking water. In larger communities, municipal sewage treatment plants are available, while the majority of households in rural communities rely on septic systems. New systems need permits from state environmental-quality agencies to ensure they are up to standard, but older systems occasionally fail, leaking waste into ground and surface water.

In general, communities in the Basin outside of the major cities (Klamath Falls, Weaverville, Yreka) are often self-reliant when it comes to road maintenance, septic, water, and even extension of

FIGURE 4. Road density (miles per acre) in part of Siskiyou County.



power lines to their homes. This infrastructure frequently fails during major weather events, during which rural communities are often reliant on gas or oil generators.

Economic Systems

The Upper and Lower Basin are dominated by agriculture and forestry; 75% of the land is forested and 20% is used for agriculture or range (USDA-NRCS 2002). Other major economic sectors vary amongst the counties within the Basin. In terms of number of employees, education, health and social services, manufacturing, and retail trade are major contributors to the economy in Klamath County. The lakes, mountains, and natural resources of counties in the Upper Basin draw tourists and support recreation, fishing, hunting, and mining (U.S. Census Bureau 2000). In Siskiyou County, education, health, and social services make up the largest economic sectors, with retail, recreation, food services, and forest products also major employers. While fishing and timber production historically were the main employers in Humboldt and Del Norte counties, government and education are now the major employers. In Trinity County, government employment dominates, with tourism, education, health services, natural resources (which includes forestry, hunting, mining, and subsistence and commercial fishing), and construction providing minor economic inputs.

Human Systems

Access to public health, safety, and social services varies across the Basin. For example, Klamath Falls residents and those along the Interstate 5 corridor near Yreka and Mount Shasta City enjoy the benefits of nearby regional hospitals, an established government and nonprofit social service support network, and robust police and fire protection. Residents in the Basin's most rural areas, such as western Siskiyou County and portions of Del Norte, Humboldt, Klamath, Modoc, and Trinity counties, are located far from organized medical, fire, law enforcement, and other services.

The Oregon Institute of Technology is located in Klamath Falls and Humboldt State University is just outside the Basin, about fifty miles south of the mouth of the Klamath River. In addition, Klamath Community College and the College of the Siskiyous are located in the Basin and the University of California and Oregon State University have extension services offices in Yreka, California, and Klamath Falls, Oregon, respectively.

Tribal Systems

Native Americans have occupied the Klamath region for at least 10,000 years. Historically, many tribes depended heavily on salmon (throughout most of the Basin), suckers, and an aquatic plant known as wocus (in the Upper Klamath Basin), shellfish (along the coast), acorns (in drier portions of the Basin), and deer and elk (throughout the Basin). The Hoopa Valley Tribe, Karuk Tribe, Klamath Tribes, Quartz Valley Tribe, Resighni Rancheria, Shasta Indian Nation, and Yurok Tribe continue to depend on these and other natural resources. The Hoopa Valley Tribe, Quartz Valley Tribe, Resighini Rancheria, and Yurok Tribe have reservations within the Klamath Basin.

Climate Change Projections for the Klamath Basin

Global climate models used in this report were adjusted to local scales by the Mapped Atmosphere-Plant-Soil System (MAPSS) team at the USDA Forest Service's Pacific Northwest Research Station. Workshop participants used the projected trends in temperature, precipitation, and other parameters to determine likely impacts to natural and community systems.

The projections agree, with high certainty, on a warmer future for the Klamath Basin (Fig. 5, Table 1). Precipitation projections, on the other hand, were more variable. The range of projections on precipitation should be kept in mind throughout this report as they relate to stream-flow projections, vegetation change projections, and stakeholder-projected impacts. Despite the range of precipitation projections overall, the three models used for this report all agree that summers will be drier. Soil moisture and water levels in lakes and rivers are both expected to decrease as temperatures and evaporation rates rise.

The MAPSS team vegetation model (MC1) provided projections for predominant vegetation types (Fig. 6, p. 10) and the proportion of the area burned annually by wildfire. Conditions in the Upper Basin are projected to favor grasslands in areas currently suitable for sagebrush and juniper. In the Lower Basin, conditions suitable for oaks and madrone may expand while those suitable for maritime conifer forest (redwood, Douglas fir, and Sitka spruce) could contract. Even when the suitable climate changes, however, vegetation can take decades or centuries to adjust. Mechanisms driving vegetation change are likely to be drought, fire, logging, insects, and disease. The percentage of the Basin burned by wildfire is expected to increase 11-22% from current levels of 2.7% to 3.0-3.3% per year by 2075-85, resulting in as much as 330,000 acres burned, on average, each year.

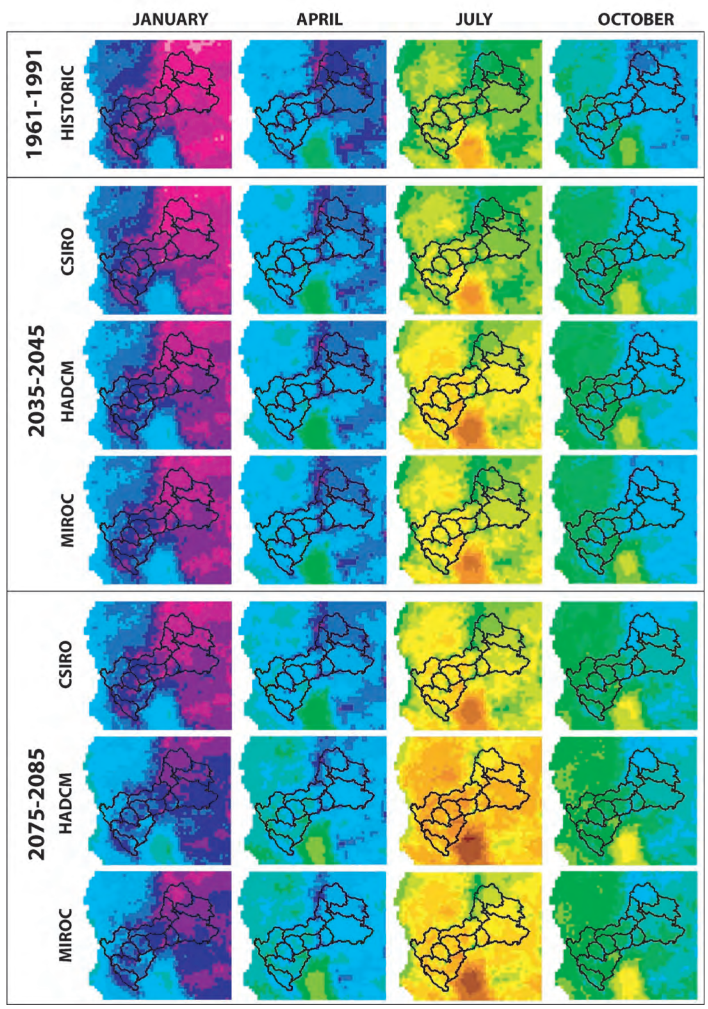


FIGURE 5. Average monthly temperature across the Klamath Basin for three time periods: historical (1961-1991), 2035-45, and 2075-85, based on projections from three global climate models (CSIRO HADCM, and MIROC).

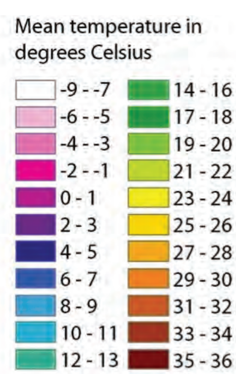


TABLE 1. The range of projected changes to the climate (including temperature and precipitation) and ecology (dominant vegetation types, fire regime) of the Klamath Basin from three global climate models and a vegetation model. Baseline conditions are based on data from 1961 to 1990. Snowpack projections are based on results from supporting studies (Hayhoe et al. 2004; Goodstein and Matson 2004).

	2035–45	2075–85
Projected Average Annual and Seasonal Temperature Increase from Baseline		
Annual	+2.1 to +3.6ºF (+1.1 to +2.0ºC)	+4.6 to +7.2ºF (+2.5 to +4.6ºC)
June–August	+2.2 to +4.8ºF (+1.2 to +2.7ºC)	+5.8 to +11.8ºF (+3.2 to +6.6ºC)
December–February	+1.7 to +3.6ºF (+1.0 to +2.0ºC)	+3.8 to +6.5ºF (+2.1 to +3.6ºC)
Projected Average Annual and Seasonal Change in Precipitation from Baseline		
Annual	–0.27 to +0.07 inch (–9 to +2%)	–0.33 to +0.74 inch (–11 to +24%)
June–August	–0.16 to +0.11 inch (–15 to –23%)	–0.25 to +0.01 inch (–37 to –3%)
December–February	+0.06 to +0.57 inch (+1 to +10%)	–0.28 to +1.59 inch (–5 to +27%)
Projected Percent Change in Area Burned on Annual Basis Compared to Baseline		
Area burned	+13 to +18%	+11 to +22%
Projected Changes in Vegetation Growing Conditions from Baseline		
Vegetation growing conditions	Complete loss of subalpine Partial loss of maritime conifer (redwood, Douglas fir, spruce) Expansion of oak and madrone	Partial to complete loss of maritime conifer Expansion of oak and madrone Possible replacement of sagebrush and juniper with grassland
Projected Change in Snowpack from Baseline		
Snowpack	Loss of 37 to 65%[1]	Loss of 73 to 90%[1]

[1] Estimates from Hayhoe et al. (2004) are for the Sierra Nevada range and estimates from Goodstein and Matson (2004) for Oregon and Washington, including Klamath region.

Future annual stream flow was calculated based on the relationship between model-derived runoff estimates and actual stream-flow measurements at four gauging stations in the Basin (Klamath River at Iron Gate, Sprague River, Shasta River, and Salmon River). Projected annual stream flows at each station were similar to past records with respect to the frequency of particularly high and low yearly flows. Two models project generally lower annual stream flows compared to the past fifty to eighty years. These annual runoff projections were within the historic range of variability. The other model projects slightly higher flows, with numerous yearly values at each gauging station higher than past records.

For more specific information about the models used in this report and additional modeling results, please see our companion report, "Projected Future Conditions in the Klamath Basin of Southern Oregon and Northern California."

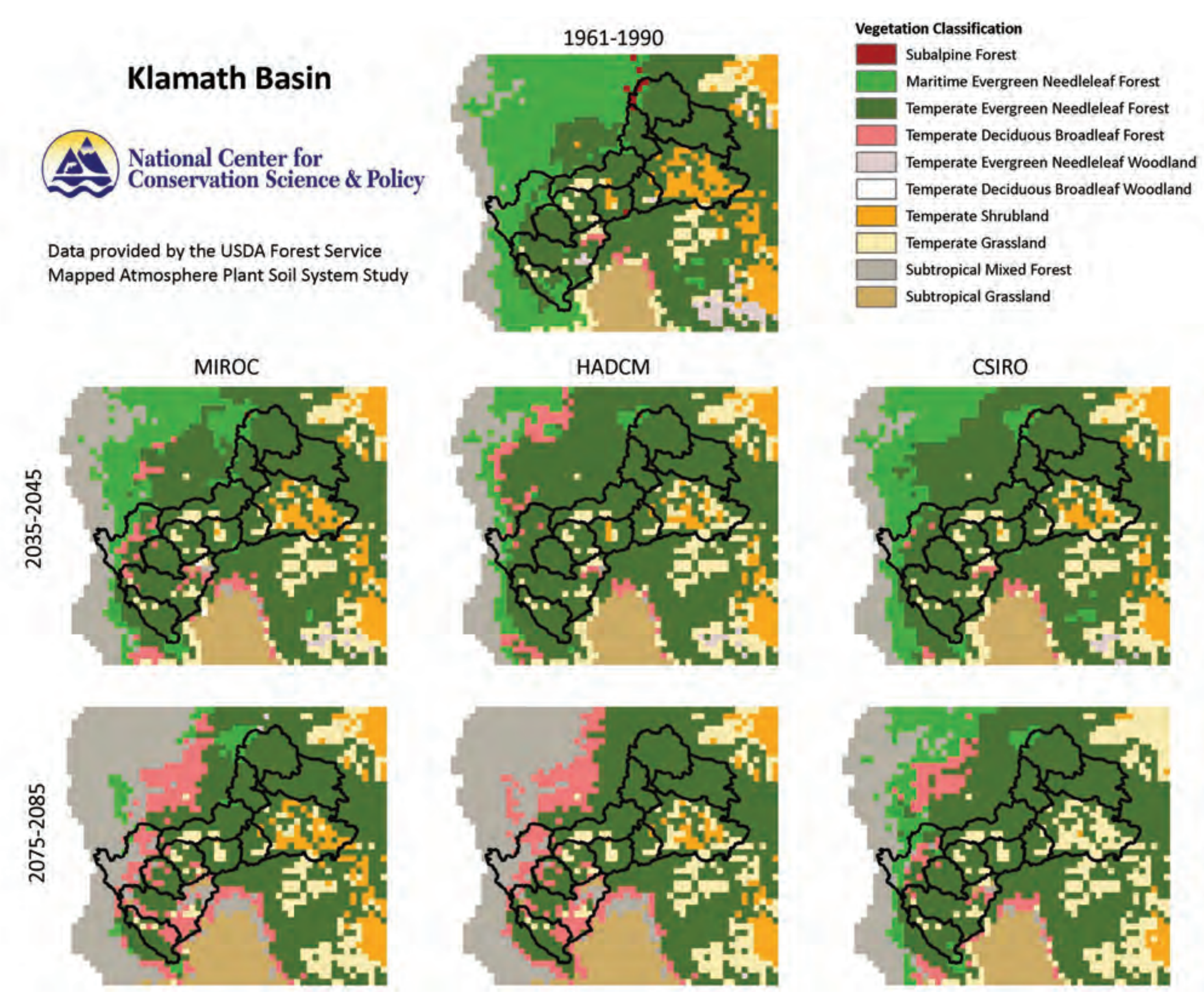


FIGURE 6. Projected suitable growing conditions for dominant types of vegetation, based on output from the MC1 vegetation model.

Projected Climate Change Impacts on Natural Systems and Recommendations for Preparation Strategies

The projected changes in climate will lead to many shifts in natural ecosystems and species in the Klamath Basin. Natural resource experts identified a variety of potential impacts to aquatic and terrestrial systems, as well as some potential benefits, during the workshop sessions. They also made recommendations for actions and strategies that can help natural ecosystems withstand the impacts of climate change over the next few decades. If emissions are not reduced, however, the actions and strategies will not be sufficient alone to maintain natural ecosystems beyond the next few decades. A summary of recommendations and how they benefit or affect other systems is provided in Appendix A.

Aquatic Habitats and Species

Projected Climate Change Impacts

Water quality. Water quality is currently poor in many areas of the Basin and is likely to decline in the future because of increasing water temperatures, more widely fluctuating dissolved-oxygen levels, and earlier, longer, and more intense algae blooms. Declining water-quality conditions will likely lead to increased disease outbreaks in aquatic animals. Areas that provide cool water during warm summer months will become more important.

Sediment delivery. Streams will receive more fine sediment because of more frequent intense storm events and higher likelihood of winter precipitation as rain. Increased erosion will result in negative impacts on the spawning of native fish such as lamprey, suckers, salmon, and trout that build their nests in areas of clean rocks and gravels. Greater levels of fine-sediment input will increase nutrient concentrations in aquatic systems and contribute to algae blooms.

Stream flow. Stream flow may increase in the winter and decrease during the rest of the year, reaching particularly low levels in late summer. As air temperatures increase, more precipitation is likely to fall as rain instead of snow, resulting in higher winter and lower spring-summer stream flows. If storm intensity increases during the November through April period, the frequency of flooding events is likely to increase. Shifting stream-flow patterns may alter timing of fish migration for adult and juvenile fish. The shorter duration of the snowpack melt season is likely to limit the period when side channel and floodplain habitats are inundated by water. These areas serve as nurseries for young fish and other aquatic animals. Decreased flows during late spring, summer, and early fall coupled with rising air temperatures are almost sure to increase water temperatures. Many streams that currently have low flows could be dry in some years in the future and shallow lakes will have more variable water levels and could go dry more frequently.

Groundwater. Flow from springs fed by groundwater is likely to decline, while flow from smaller springs could

KLAMATH BASIN RANGELAND TRUST

The Klamath Basin Rangeland Trust (KBRT) restores and conserves the quality and quantity of water flowing into Upper Klamath Lake, making water available for downstream agriculture and wildlife. The KBRT and its partners determine how to reach maximum agricultural productivity with minimum water use, often converting from flood irrigation to reduced irrigation or dry land grazing. The KBRT's priority area is the 50,000-acre Wood River Valley — significant because it supplies 25% of the water and 29% of the external phosphorous load, while making up just 6% of the watershed upstream of Upper Klamath Lake.

The KBRT's efforts focus on keeping cool, high-quality water in-stream, protecting against decreasing flows and declining water quality in Upper Klamath Lake and its tributaries. These actions will provide important refuge areas for native fish and other wildlife. In addition, it prepares ranchers to continue to be economically productive, even if faced with a decreasing water supply. As rancher Jim Popson stated, "We were excited to see water running in the creek year-round! It's just done wonders. It's been good for the fisheries and good for us."

become more variable and potentially cease in the driest years. These areas where groundwater flows to the surface offer important cool water refuge for many aquatic animals. Projected increases in water temperature may make these areas more important for fish survival throughout the Basin, and decreasing ground-water flows would likely reduce the amount of refuge these areas are capable of providing.

Climate Change Preparation Recommendations

Water quality and quantity. Higher quality water could be kept in-stream to protect species and river ecosystems by using low-quality water for agricultural purposes. This recommendation would also benefit human systems by protecting water for human consumption. Existing irrigation infrastructure would need to be adjusted, which could have a short-term negative impacts on agriculture, but would ensure that the sector was more efficient and resilient to changes over the long term. Other considerations for changes in agricultural water use include minimizing or eliminating out-of-Basin water transfers, shifting to more drought-tolerant crops, and expanding dry-land grazing, creating greater resiliency for the agricultural sector. Increasing the extent of wetlands, marshes, and meadows could filter sediment, nutrients, and pollutants from surface water and runoff. Wetlands in municipal areas can also slow the rate that stream flows increase and decrease and provide improved water quality through filtration.

Areas where there is cool water (e.g., stream reaches with extensive shading and springs fed by groundwater) should be considered for protection and should be connected to other cool water areas (e.g., by removing fish passage barriers and decreasing stream-road intersections). This will help ensure that aquatic animals dependent on these areas for reproduction and feeding are better able to survive water quality declines and have access to cold-water areas. This in turn will benefit water quality and quantity for human consumption, and protect commercial and tribal fisheries.

Sediment. Nonessential roads (e.g., logging or access roads that are no longer in use) that contribute substantial sediment to streams should be decommissioned. Road-stream crossing culverts should be assessed to make sure they can accommodate increased storm frequency and runoff. Improperly sized culverts should be replaced. This will benefit wildlife while building the resiliency of crossings toward climate impacts. Road networks and undersized road culverts at stream crossings contribute to erosion, which degrades water quality. Reducing these existing impacts will reduce future climate change-related increases in erosion. Stream bank and lakeside areas should be fenced to provide better grazing control as protection against erosion. This will help protect water quality for human consumption and both commercial and subsistence fishing.

Shifting stream flow patterns. Connections between streams and rivers and their side channels and floodplains could be restored so that fish and other aquatic animals can avoid the impacts from unusually high or unusually frequent winter storm flows. This would allow fine sediments from increased erosion to deposit in areas that are less likely to affect spawning fish and decrease costs of filtering water for human consumption.

High-elevation forest management practices may need to be modified to allow the snowpack to melt more slowly. One recommendation is to maintain or restore mature forests in high-elevation areas to reduce the rate that the ground warms on these slopes. Another somewhat-novel recommendation is to thin forests in specific areas to prevent snow from being captured in the canopy and evaporating before contributing to the snowpack. Protecting or promoting increased snowpack will lead to greater water storage for human consumption and more sustained runoff that will help fish and other aquatic resources.

To capture high winter flows and slowly release the water following storm and peak runoff events may require new off-channel water storage facilities. This could help protect infrastructure and communities from extreme flood events. Also, extensive meadow, marsh, wetland, and floodplain habitats should be restored and reconnected to lakes and rivers so that under certain stream-flow or lake-level conditions, water flows between these features freely.

Groundwater–fed springs. Areas that provide ground-water recharge should be considered for enhancement or expansion. This includes restoring meadows, marshes, and wetlands; increasing beaver populations in appropriate locations; and incorporating bioswales into urban developments. These measures will slow the flow of water through the Basin, filter silt, nutrients, and pollution from runoff, and increase ground-water recharge. While benefiting natural systems, this recommendation will also support resiliency of human and economic systems by increasing water storage.

Groundwater will become increasingly important for the survival of aquatic species. Therefore, aquifers and groundwater-fed springs should be protected. Measures to protect groundwater from withdrawals are needed in California. Existing ground-water regulations in Oregon may need to be more carefully enforced and new, more protective regulations should be considered. Protecting groundwater will increase the likelihood that it is available for domestic and other uses in emergencies.

Habitat and species resiliency. Stream reaches that currently provide good habitat for species should be identified and protected to the extent possible. Streams that have intact riparian habitats and floodplains with no development and infrequent or no grazing provide an important starting point on which restoration efforts can build. These streams and stream reaches are the most resistant and resilient to the impacts of climate change.

To ensure survival of species, it is important to protect genetic diversity. Animal populations with greater genetic diversity are more capable of resisting increasing environmental stress and adapting to environmental change. Increasing diversity in aquatic animal populations can be accomplished by expanding species distributions to new areas (e.g., by removing passage barriers or improving water quality).

Terrestrial Habitats and Species

Projected Climate Change Impacts

Range shifts. Although the coast constitutes a very small portion of the Klamath Basin overall, participants identified the coastal fog zone as being extremely important because it largely determines the range of the coastal redwood. A recent study demonstrates that fog conditions have become less favorable for coast redwood during the last century, and that this important species is experiencing drought stress due to changing conditions (Johnstone and Dawson 2010). Other scientists expect, however, that the increased temperature gradient due to greater inland warming will lead to increases in fog along the coast rather than decreases.

The shift in coastal fog, along with changes in precipitation and temperature throughout the Basin, may cause range shifts for vegetation. Alpine and subalpine vegetation communities and coastal redwood and spruce forests could decline to a large extent or disappear completely from the Klamath Basin. Vegetation shifts will likely be facilitated by insect and disease outbreaks and increased wildfire, which are expected to increase with warmer winters. Changes in dominant vegetation shifts may favor some wildlife species (e.g., black-tailed deer) while disfavoring others (e.g., marbled murrelet, northern spotted owl).

Noxious and invasive plants. Weeds and juniper are likely to expand their ranges and increase in abundance. Warmer temperatures could cause a loss of soil fungi, favoring juniper over sagebrush and bitter brush.

Riparian areas. Wetland and riparian habitats are likely to decrease as soil moisture and water availability decline, even under the wettest model projections, due to increased evaporation and plant transpiration (loss of water from leaves, flowers). As many of these habitats already are affected dramatically by development and pollution, further loss and degradation could have serious consequences for many birds, amphibians, and rare plants. Loss of habitat connectivity (undeveloped land that allows for movement of individuals among core areas) in riparian areas would further stress populations of many species.

Species loss. High-elevation species, including pika, mountain hemlock, and whitebark pine, may decrease in abundance to the point of elimination as their preferred habitat and temperature conditions become more rare in the Basin. Longer growing seasons and decreased soil moisture may convert small, high-elevation lakes to meadows, resulting in the loss of important breeding habitat for amphibians.

Species relationships. Relationships among plants and animals are likely to be disrupted because of earlier timing of plant flowering and fruiting, insect emergence, and plankton blooms. For example, some migrating birds may arrive too late to take advantage of peak food abundance, thereby lowering their breeding success. Disruption of the coordination between predator-prey or plant-pollinator life cycles may lead to declining populations of many native species.

Climate Change Preparation Recommendations

Range shifts. As species and habitats shift in response to changing conditions, restoring and protecting corridors of natural vegetation linking vital areas will increase the success of species movements. An incentive program to encourage private landowners to create and protect connections between areas that allow for species to migrate could be developed. Transplanting of species (e.g., moving them to a new area that they may not have previously occupied) to facilitate migration where corridors do not exist should be considered and, if used, should be very carefully and selectively implemented.

Both the Cascade and coastal mountain range portions of the Klamath Basin may become increasingly important for higher-elevation species; conservation measures taken to ensure that adequate habitat remains will be important. This may increase benefits for recreation as new parks or wilderness areas could draw additional tourists.

Noxious and invasive plants. As the range of juniper continues to expand, establishing new uses and markets for juniper would make juniper control more economically feasible. For instance, landowners could benefit from selling juniper for fence posts. Use of prescribed fire followed by reseeding of native grasses could be expanded to control invasive and noxious species. For reseeding, use of locally collected or harvested seeds could also provide benefits to the local economy.

Riparian areas. Streamside vegetation acts as a nursery for breeding birds, shades streams, supports breeding amphibians and fish, prevents erosion of stream banks, and improves water quality. These areas should be protected and restored to the extent possible. Managers of riparian-area restoration may need to consider shifting to flash grazing or cattle exclusion in critical areas to establish shrubs and trees. When adjoining areas are cultivated for potatoes or other crops, leaving a buffer between agriculture and waterways would be beneficial. Restoration measures under consideration should also include eliminating nonessential forest roads, improving stream crossings, removing dikes and berms (ridges of soil used to direct or contain flows) between bodies of water and their floodplains, relocating existing floodplain developments, and limiting future floodplain development. These recommendations can also reduce damage to infrastructure and reduce the need for emergency services to respond to flooding, but may limit economic development in some areas. Programs such as the Walking Wetlands program (see box) incorporate habitat restoration with sustainable, low-impact agricultural production.

Species loss. More funding for full implementation of existing conservation plans (e.g., Partners in Flight for migratory song birds) would likely improve the resiliency of species under climate change.

Conservation priorities. Conservation priorities should be reevaluated to ensure that they facilitate coordinated efforts across jurisdictions, regardless of land ownership, with a basinwide ecosystem perspective. This would likely result in new partnerships, especially among private landowners, state and federal agencies, and tribes, which will streamline the implementation of priority actions. Grants and programs across these jurisdictions should also be coordinated to leverage funding

WALKING WETLANDS

Measures that help prepare for climate change will need to be innovative and interdisciplinary. The Walking Wetlands program instituted by the U.S. Fish and Wildlife Service, the Bureau of Reclamation, and the University of California (among other partners) is one example. This program was initiated on two national wildlife refuges in the Klamath Basin with potentially conflicting legal mandates of providing wildlife habitat and allowing for 22,000 acres of commercial agricultural production. By rotating areas of agricultural production with areas of marsh on refuge lands, higher crop yields are maintained with lower inputs of fertilizers and pesticides. At the same time, high-quality wetlands are available for wildlife.

Though controversial due to the use of conservation lands for commercial agriculture, the Walking Wetlands program has motivated surrounding private landowners to manage their land in a new way that benefits both agriculture and wildlife. A similar program on private lands in the Sacramento Valley has proven extremely popular with both farmers and conservation organizations.

and increase broad-scale thinking. Collaboration among a variety of stakeholders on conservation projects is beneficial for all systems. It decreases the likelihood that decisions made for one sector will negatively affect another.

Forest management objectives. Forest management objectives should be reevaluated to address climate impacts. In high-elevation areas, maximizing snowpack and delaying snowmelt should be considered (e.g., through snow fences, forestry prescriptions). In some areas like south-facing slopes, retaining forest canopy may delay snowmelt. In other areas, removing some trees in strategic locations may actually increase snowpack. Drought stress and fire risk may be reduced by prescribed fire or by thinning in suitable areas (near residences, in tree plantations, away from riparian zones) using practices that do not disturb soils or bodies of water.

Public education. Programs at libraries or other public venues could be implemented to increase the public's understanding of the value of intact ecosystems in providing services that improve the quality of life of local residents (e.g., clean water provisioning, flood abatement, and reduced risk of extreme fire events).

Economic analysis. An analysis of the economic value of the Basin's ecosystem services could be conducted, as well as the costs of failing to prepare for climate change. Communicating such information widely may help provide an incentive for the public to support community preparation initiatives.

Projected Climate Change Impacts on Community Systems and Recommendations for Preparation Strategies

Changes to the climate are expected to lead to many shifts for built, economic, human, and tribal systems (collectively referred to as "community systems") in the Klamath Basin. Experts from various sectors, including forestry, agriculture, public works, education, emergency management, and Native American communities, identified many potential threats to these systems, as well as some potential opportunities that could arise from a changing climate.

They also made recommendations for actions and strategies that can be taken immediately to help these community systems withstand the impacts of climate change over the long term. A summary of recommendations and how they benefit or affect other systems is provided in Appendix A.

Built Systems

Projected Climate Change Impacts

Water. Projected increases in long-term, annual, and seasonal variability in precipitation are likely to result in less dependable water supplies, presenting a significant challenge for water managers and water infrastructure. Demand for dams, reservoirs, and wells is likely to intensify in response to declining groundwater availability and increasing seasonal flow variability. Increased runoff, intense storm events, and increased sedimentation may overwhelm drinking-water and wastewater treatment facilities, which could lead to increased municipal water pollution and higher treatment costs.

Power. Future electricity demand may rise due to increased population and needs for home cooling, refrigeration, water (which requires energy to transport), and power supplies for an ever-increasing number of small electronics. At the same time, efficiency and reliability of power transmission and delivery is likely to decline as power lines are stressed with higher ambient temperatures and increased risk from wildfires. As a result, more brownouts and blackouts are expected.

Roads. If the Basin experiences a greater frequency of floods, road and culvert repair and maintenance needs will increase. In addition, asphalt is likely to become more expensive and scarce as the availability of petroleum-based products declines. Maintenance of rural county roads may suffer as funding priorities shift to meet changing demands on local governments and the needs of growing urban areas.

OPPORTUNITIES PRESENTED BY A CHANGING CLIMATE

Although climate change could result in damage to our natural, built, human, economic, and tribal systems, it could also generate opportunities. Developing preparation strategies may help communities take advantage of opportunities such as the following:

- New opportunities for forestry and benefits for some species as a result of vegetation shifts
- New markets for juniper
- Reduced emissions (therefore supporting mitigation efforts) from switching to rail from air and freight
- New agricultural crop markets
- New incentives and tax credits for homeowners and businesses
- Innovation and creative thinking
- Increased local food economy, benefiting nutrition and health
- New and expanding markets for energy-efficient products
- Longer warm-weather tourism season
- Increased communication and collaboration across sectors and systems

Air and rail. If oil prices remain high or increase, the Basin will likely see reduced air service or a substantial and potentially dramatic increase in its cost. Rail service may become more competitive and experience an increase in demand. In addition, both rural and urban areas in the Pacific Northwest are likely to receive an increase in population of people that are displaced due to climate-related events—a trend that is likely to accelerate the demand for local and regional mass transit, including rail.

Homes and building design. Existing homes in floodplains and the urban-wildland interface may be lost to flooding and wildfire, while insurance coverage may become more expensive or less available. Increased costs of commuting and power delivery as well as increased vulnerability to fire and storm damage may make rural residential homes less affordable.

Climate Change Preparation Recommendations

Water. Water supply reliability could be increased by developing programs in cooperation with agricultural communities to store surplus high flows (i.e., storm runoff not needed to maintain ecological function) in groundwater aquifers, restore or create new recharge areas (e.g., wetlands, marshes, and meadows; bioswales to capture and slow storm-water runoff in more urban areas), and restore riparian zones and floodplains. This will benefit natural systems, reduce the likelihood of flooding in communities, and improve the reliability of water supply. Building new dams and increasing the use of groundwater should be considered only after water conservation measures have been implemented and only in areas and in a manner that will not cause ecological harm.

Incentives (such as tax credits) for domestic and urban water conservation, including bioswales and rainwater rooftop catchments, should be considered.

Water conservation measures on private lands to reduce water demand and increase natural water storage should be employed where possible. Developing groundwater regulation in the California part of the Basin and more consistent enforcement of groundwater regulations in Oregon are two places to start water conservation. A tax incentive such as conservation easements for rural landowners could facilitate these activities. Purchasing water from water-rights holders and keeping that flow in-stream is another mechanism for reducing demand on a short-term basis.

Drinking water and wastewater treatment facility capacity should be evaluated frequently and upgraded as necessary to meet new demands and more frequent extreme weather events.

Power. In areas along high-voltage transmission lines, vegetation should be managed to eliminate or decrease risk of contact to reduce wildfire risk.

Homeowners should be educated on energy-conservation strategies and assisted with implementation (e.g., sufficient insulation, proper hot water heater settings). Even simple practices such as using a clothesline rather than an electric dryer in the summer season, if adopted by thousands of households, can reduce electricity demand and utility costs for households. Incentives for businesses and households could be provided to reduce energy waste and increase energy efficiency. This will reduce dependency on power, reducing the likelihood of blackouts and brownouts.

Roads. Road culverts and other stream crossings should be resized and redesigned to accommodate increased runoff, more intense storm events, and increased sedimentation and debris flows. Opportunities for state and federal funding could be pursued for this purpose.

Rail. Passenger rail transportation may need to be expanded should population and demand increase. This includes increasing the frequency of trips and building new rail lines, although conflicts due to the interruption of wildlife migration corridors should be considered. Where adequate lines exist, rail transportation is more energy-efficient than air and highway transportation and helps reduce greenhouse-gas emissions, urban sprawl, and infrastructure service costs.

Opportunities to raise rail-system expansion capital could be explored by following the eastern seaboard Amtrak model (where Amtrak assumed ownership of lines).

The feasibility of double-tracking and reactivating spurs could be examined as a means for providing increased rail traffic along existing transportation corridors.

Homes and building design. Measures should be considered to reduce the likelihood that new homes will be constructed in fire- and flood-prone areas, either through zoning or by requiring that homeowners take responsibility for the cost of fire fighting and rebuilding after natural events. This may benefit natural systems by limiting development in sensitive areas. Existing homeowners in fire- and flood-prone areas should be educated on establishing defensible space and maintaining adequate access routes for fire fighters and other emergency services. Residents should have a thorough understanding of the risks of living in such areas and be provided with recommendations and solutions for minimizing these risks.

Planting native trees around homes and in urban landscapes and using whole-house fans to bring in cool night air would reduce the need for air conditioning and reduce power consumption during the warmer months. These measures would also reduce utility costs and provide more natural habitats for native wildlife in developed areas.

Economic Systems

Projected Climate Change Impacts

Agriculture. The agricultural industry is likely to face intensified competition for water from municipal and in-river users as a result of an increase in extended low-flow periods, higher temperatures (especially during summer), increasing human population size, and increasing need for measures to conserve imperiled species. The costs for irrigation power, machinery fuel, and fertilizer could rise. Economic margins will likely become tighter and may foster a shift in crop choices that force agricultural landowners to reevaluate investment in "lower-value" production, such as grazing and hay. Higher annual and summer temperatures may cause some temperature-sensitive potato and grain crop varieties to be less successful or even fail, and may foster a shift in livestock breeds raised within the Basin.

A longer growing season may expand the crops available for production, though water requirements of some high-value crops may be a limitation to this expansion. However, commodity prices will increase globally as water becomes more scarce, therefore making these high-value crops even more valuable in the future. Biofuel production may be hampered by water shortages, transportation costs, and reduced research budgets. The current shift from small to large farms may accelerate because economies of scale and generally greater capitalization means large farms typically have greater adaptive capacity.

Forestry. The forest products industry could face significant challenges as a changing climate affects growing conditions and triggers insect- and fire-mediated shifts in vegetation. Reforestation projects may also face difficulties in selecting the appropriate species and varieties for unknown and changing growing conditions. Managers will need to carefully consider the future climate conditions when making decisions about species to plant. Deciduous trees may be more favored in the Lower Basin at lower elevations under drier and more fire-prone conditions. Dramatic shifts in condition will likely favor companies within the forest products industry that are able to adapt.

OPPORTUNITIES

State and federal policy responses to climate change may create opportunities for carbon credits for agricultural production of biofuel crops. These crops are less sensitive to most direct climate change impacts, such as heat waves and heavy precipitation. However, potentially decreasing water availability in the Klamath Basin may affect the feasibility to expand biofuel crop production. Small local truck farms and large local gardens may benefit from increasing interest in locally grown food as community sensitivity toward greenhouse-gas emissions associated with food transportation rises. Grazing may benefit from a climate-driven vegetation shift from sagebrush to grass, although reduced moisture will lower productivity.

Tourist Industry. The tourist industry in the Klamath Basin is driven by birders, boaters, hikers, and other outdoor recreationists drawn by the region's lakes, mountains, and rivers. All of these resources are likely to be affected to a large degree by climate change. As noted above (see the "Natural Systems" discussion), wetland and riparian areas that support recreational fisheries and unique bird populations in the region are likely to face serious threats from the climate change impacts on water resources. Snow-dependent sports such as skiing and snowmobiling are expected to decline as well. Furthermore, as oil prices increase, tourism in the Basin may be reduced if discretionary driving declines.

Commercial and subsistence fishing. Chinook salmon, Lost River sucker, Pacific lamprey, and shortnose sucker have been the primary focus for commercial and subsistence fisheries. Populations of these fish currently are low and habitat conditions generally are poor; these circumstances are likely to deteriorate further with projected climate change. Additional declines in populations of these fish would exacerbate already reduced harvest (Lost River and shortnose suckers support only ceremonial harvest currently), further decreasing the availability of traditional and culturally important food sources and possibly leading to more restrictive fishing regulations.

Health-care industry. The projections for climate change in the Basin are likely to result in an increase and emergence of new health threats. As a result, an increase in patients may require additional health-care staffs, expanded services to more rural areas, and trainings adapted to cover projected new health risks. Health insurers may also be affected by changes in frequency of illnesses and new disease emergence. Their financial stability may be at risk without a consideration of the climate impacts.* (The impacts on human health are discussed in the "Human Systems" section.)

Education. University and community college infrastructure may face risks similar to those faced by other sectors within built systems, but may also be affected by enrollment numbers (reduced in areas of the Basin experiencing more extreme weather and increased in areas with more stable climates). Some curricula may become irrelevant, or faculty members may need to be hired to develop curricula that are more applicable to projected future scenarios.*

Immigration. The Klamath Basin may attract individuals and households moving to escape more severe climate change effects experienced elsewhere (see more discussion on this in the "Human Systems" section). Should this happen, it may favor the regional economy of the Klamath Basin in the long run, but only if the social, political, and built infrastructure is prepared to accommodate a population influx, and the capacity of the landscape to provide ecosystem services is not exceeded.

Climate Change Preparation Recommendations

Economic health. Maintaining and restoring the resiliency of the land should become a priority so that even under the projected climate conditions, the Basin's natural systems are capable of providing services on which the local economic systems depend (e.g., provision of clean water, support of healthy pollinator populations, buffering against drought and flood).

To support local economic health and resiliency of communities, it could also be valuable to expand economic opportunities across the Klamath Basin to more rural areas, such as developing small-scale biomass programs in forested areas near communities, expanding stream restoration activities, and further developing alternative energy (e.g., solar, wind, geothermal, or hydrokinetic-wave) installation and maintenance.

Financial incentives could help promote renewable energy development in the Basin to provide job opportunities in the future. Venture capital could also be used to identify and support new markets where new jobs, responsive to new climate conditions, could be created.

Agriculture. To the extent possible, there should be an increase in land-use policies that promote and clarify the benefits of small farms or family-owned large farms that grow a diversity of fruits and vegetables for local markets in an ecologically sustainable manner. This would help support the local economy, provide food security, and catalyze health and nutrition initiatives.

* *This topic was not discussed in detail by the workshop participants. Information provided is from author research.*

Education on the benefits of, and policies that support, restoring the natural water-storage capacity of riparian areas and floodplains—such as the Environmental Qualities Incentive Program (EQIP) and water conservation work under the Food, Conservation, and Energy Act of 2008—would benefit both the agricultural industry and natural systems. The Walking Wetlands program (see box, page 15) is a good example of one type of program that strives to meet this goal.

The Natural Resource Conservation Service (NRCS) should be encouraged to facilitate increased restoration work on private lands along waterways. The Conservation Reserve Enhancement Program (CREP) in California should be encouraged to support restoration of private land riparian areas.

An increase in crop and livestock research on the effects of climate change would also help; the capacity of Oregon State University Extension Service should be expanded to provide outreach on this topic to the agricultural community—information on alternative crop and breed selections that are less water-dependent and more tolerant of warmer temperatures, also benefiting wildlife habitat and protecting groundwater for human consumption.

Forestry. By further developing regulations and expanding education, or providing incentives to owners of large tracts of land, the likelihood that fire-prone forest lands will be sold in small plots to residential developers could be reduced. While this may limit economic development in some areas, infrastructure and wildlife habitat could be protected and become more resilient against projected changes. Carbon credits (i.e., emissions trading) should be sought for maintaining forest stands, and taxes deferred to prolong stand rotation and encourage forest management for carbon sequestration.

Tax incentives would be beneficial for thinning and other fire-prevention measures, consistent with the natural systems thinning recommendations. The Fuels for Schools and Beyond biomass program, using local wood biomass in rural areas as a cleaner energy source for schools, should be supported and further expanded.

Strategically located controlled burning should be applied to portions of the landscape with a history of suppression. For instance, tribes should be encouraged to burn areas of cultural importance carefully, to reduce the likelihood of burning beyond intended treatment areas. Clean Air Act regulations may need to be modified to accommodate more prescribed fire, and increased burning should not be pursued if the effect on public health is likely to be adverse.

Recreation and tourism. The Basin has an opportunity to be further marketed as a tourist and retirement destination on the model of the Running Y Ranch Resort near Klamath Falls, Oregon. However, the potential for visitors to move to the Basin, increasing the population and affecting existing residents, should be evaluated. Low-emission and low-impact recreational activities that could be worth pursuing include birding, camping, and cycling. As these markets are expanded, there should be open communication with the residents of the Basin to ensure that their lives are not negatively affected by an influx of tourists. In addition, the resiliency of wetlands, lakes, rivers, and other areas that support the resources on which the recreational industry depends should be protected as much as possible.

Commercial and subsistence fishing. Incentives for agricultural and other land-use practices could be implemented to support clean water and water conservation, particularly programs that increase in-stream water quantity and quality, decrease or limit increases of water temperature, and slow the runoff of precipitation. These actions should benefit both human health and aquatic species health.

Habitat restoration activities (e.g., removing fish passage barriers, protecting cold water sources, increasing cool water availability) should be encouraged through incentive programs to further support sustainability of the fishing industry. Such steps are important to recovering and sustaining the fish populations that support commercial and subsistence fisheries.

Monitoring of existing hatchery programs may need to be assessed and improved to increase reliability of hatchery return estimates. Monitoring should help build a better understanding of the how life histories vary within commercial and subsistence fisheries, as well as assess the impact the fishing industry has on these life histories.

The development of fishing regulations should be assessed to ensure that they are designed to provide adult salmon and Pacific lamprey returns well above "replacement" levels. Further, fishing regulations could be designed to promote and conserve genetic variability. These changes will help protect populations from acute effects and give fisheries their best opportunity to reestablish.

Health-care industry. The health-care industry in the Basin should prepare for the prevention and treatment of climate-related health problems. Health providers, particularly nurses, may also play a role in education of the community on climate change. Health-care insurers should assess how climate change and other events affect their practices and finances.*

Education. Community college programs should be expanded to pass on knowledge to new work force entrants about likely economic and employment implications of a changing climate. Curricula may need to be developed and appropriate faculty members hired to educate students on topics more relevant to future scenarios (e.g., different harvesting methods, green jobs). Universities and community colleges should continually assess their student loads to see if expansion or reduction of infrastructure or its curriculum is needed.*

Information regarding the economic impacts and implications of climate change should be shared among academic and governmental institutions. This will help create a common understanding of the economic situation that local communities are facing across the entire Basin and determine emerging employment opportunities in the region.

Human Systems

Projected Climate Change Impacts

Shifts in human population. The Pacific Northwest, including the entire Klamath Basin, is projected to initially experience less severe effects of climate change compared to other areas in North America. In areas where rural services (e.g., water treatment, road maintenance, emergency response) remain and landowners can afford to continue to pay for services, there may be an influx of people from more hard-hit areas. This is likely to cause strain on natural systems and social services. In rural areas where services cannot be afforded, there may be a migration of individuals and families within the Basin to more urban areas.

In addition, the more urban areas, such as Klamath Falls, are likely to receive climate refugees (individuals displaced by climate events) from other parts of North America and countries around the globe. An increase in population in urban areas could have negative consequences to social services and potentially to natural systems by increasing demand and further stressing the services.

Public health. Diseases currently uncommon in the Basin, including vector-borne diseases like Lyme disease and West Nile virus, are likely to become more pronounced. Rising temperatures also are likely to stimulate growth of blue-green algae, increasing the incidence of toxins that detrimentally affect the skin and may cause serious illness if ingested.

Most homes, buildings, and schools are not properly insulated and many do not have air conditioning adequate to protect occupants

* *This topic was not discussed in detail by the workshop participants. Information provided is from author research.*

from heat waves. This is likely to contribute to heightened susceptibility to heat-related illness and disrupt school and work schedules.

Respiratory illnesses likely will be exacerbated by increases in forest fires and ground ozone (due to increased air pollution), increased temperature, drought, and CO_2. Allergy sufferers will feel the impacts of increased vegetation growth and pollen counts, both of which are expected with increased temperature and levels of CO_2.

Climate change stress on top of existing stressors may lead to an increase in mental health cases. Although there is one well-equipped hospital serving most counties, the health sector may not understand or be prepared to respond to potentially emerging diseases and new climate change-related health risks.

Emergency management. Some counties have emergency operations plans that may not adequately address the potential impacts of climate change, especially related to flood and fire. Extreme weather events in the summer or winter may overload energy systems. Utility and emergency-service providers may not be equipped to manage the possible increased need for emergency response.

Public safety. Heat waves have been linked to increased street crime and domestic violence. Climate change is likely to produce additional stress (e.g., shutdown of industries, water restrictions, increasing population) on the residents of the Basin. This may further exacerbate crime, including heat-related unrest and gang activity (identified as a potential concern in the Upper Basin).

Social services. Climate change is likely to add stress to an already strained community, increasing the demand for low-income housing, food, and mental health treatment. Unless effective preparation measures are taken, there could be an increase in unemployment, poverty, and drug use.

People living in poorly constructed low-income housing may suffer more from heat waves (poor insulation) and other extreme weather events.

Although currently well-stocked, Klamath County's food bank may receive fewer donations from families that need to pay more for property or health insurance (due to increased risk of flood or fire), health care, or energy (due to increasing oil scarcity).

An influx of retirement-age people is expected in the Basin because of the projected milder winters and summers compared to other parts of Oregon and the country. This will shift community demographics and lead to the need for adequate housing accommodations, services, and resources in both rural and urban areas.

Vulnerable populations. As climate change raises summer temperatures, elderly and low-income families who are less able to bear the financial burden of air conditioning are likely to be more susceptible to heat-related illnesses. Migrant agricultural workers, construction workers, and others who work outside for extended periods also could be exposed to more heat stress.

Rural communities with limited road access for emergency vehicles could face increased risk during wildfires or extreme weather events that are projected to become more frequent. However, rural communities may enjoy greater food security as they already may produce much of their own food. Rural areas that are energy independent, such as along the lower Klamath River between Weitchpec and Klamath, may be better protected if energy infrastructure fails. However, rural areas on the grid may face more and longer electricity outages due to increased frequency of intense storm events. If groundwater levels decline, some wells are likely to go dry. This will limit the availability of domestic water and potentially affect the ability to maintain gardens for personal use.

Climate Change Preparation Recommendations

Shifts in human population. Services may need to be expanded or developed to support self-sufficiency of rural areas as they come under additional climate stress (e.g., local water treatment systems, providing off-the-grid energy options, local health clinics). In addition, urban areas will need to track population changes closely and potentially consider development of additional housing, employment, and expansion of services.

Public health. Processes to recognize and respond to emerging or climate-affected diseases should be developed and the existing capacity for preventative and crisis care expanded, including training focused on learning from past (e.g., polio) and current (e.g., H1N1) experiences with disease eradication.

Home construction standards for extreme weather events may need to be established to protect public health. For instance, communities could require new infrastructure to meet new insulation and cooling standards. This will also help reduce future utility costs. Financial incentives or tax credits could help people (beginning with the most vulnerable, such as the elderly) properly insulate existing homes and transition to efficient passive-cooling mechanisms to manage extreme heat (e.g., tree plantings and awnings). Inefficient cooling mechanisms (such as older, energy-intensive air conditioners) will need to be phased out and energy-efficient options (such as programmable thermostats) distributed.

Passive cooling (measures taken to cool buildings without using energy) at schools and work places should be provided by planting trees for shade. In some cases, buildings may need to be equipped with air conditioning to minimize schedule disruptions during extreme heat events. Cooling centers at schools, fairgrounds, libraries, senior centers, and other public buildings could be established to accommodate people during extreme heat days with backup generators to prevent air conditioning failures.

In decision-making processes for water management preparation, considerations for potential human health impacts should be incorporated to ensure actions taken to protect water resources do not negatively affect the population served.

Social services. Social services may need to be expanded to provide additional support and resources to rural areas. In urban areas, development of innovative partnerships could help with increased population and demand for services. For instance, partnerships across public health departments, retirement homes, food services, farmers, emergency managers, and the Department of Environmental Quality may allow for further expansion of services and improved ability to meet demand.*

Emergency management. Emergency operations plans for Klamath County and other jurisdictions should be reviewed and updated to include preparation for climate change risks (e.g., upgrade the probability of extreme weather events). In addition, existing hazard plans may need to be updated to cover climate change impacts and ensure that floodplain and other hazard maps reflect projected conditions. Emergency management capacity to handle the impacts of climate change on flooding, wildfire, and other disturbance events should be assessed and gaps filled where appropriate.

Nonprofits, such as the faith community and those that provide social services, could be employed to support counties during emergencies, by distributing supplies, shuttling people to cooling centers, and helping with cleanup after extreme weather events. This could reduce some of the strain on stressed emergency management systems.

Public safety. Public safety enforcement may need to be increased during periods of high stress such as floods, wildfire, or drought. Extreme weather events induced by projected climate change may challenge the capacity of rural police and emergency services in particular.*

Vulnerable populations. These populations, particularly in rural areas, should be assessed to identify their extent, distribution, and needs, and ensure they are adequately covered in preparation planning (e.g., access to emergency services, escape routes for flooding or wildfire, cooling mechanisms for extreme heat events).

Tribal Systems

Projected Climate Change Impacts

Vulnerability of tribal communities. Tribal communities are likely to be more heavily hit by climate change than other communities because of close cultural, economic, medical, and spiritual links to surrounding natural ecosystems.

Tribal identity and customs. Climate change may lead to loss of native species and fundamental shifts in ecosystems that have guided and formed the culture of many tribal communities. The link between future generations and their ancestors, formed by the area's species and ecosystems, may be weakened or lost—a circumstance that could cause future generations to lose interest in tribal culture and traditions. In addition, the loss of culturally

* *This topic was not discussed in detail by the workshop participants. Information provided is from author research.*

important species and ecosystems is likely to lead to economic and functionality losses. Ecological relationships, such as those between the flowering of specific plants and the running of eels, provide indicators for when to collect important resources.

Treaties. As species and habitats decline or ranges shift, the federal government may become less able to meet long-standing obligations to honor treaty rights. While traditional ecological knowledge could provide important information on how ecosystems should be functioning, the potential for misuse of such knowledge and lack of recognition provided to tribes that may share traditional ecological knowledge is likely to hamper state and local efforts to conserve culturally important species.

Tribal health and economics. Increases in wildfire could negatively affect tribal member health, tribal forestry practices, or the ability of tribal communities to hunt and gather food and ceremonial resources. Medicinal species may be lost with changes in temperature, shifting reliance to Western medicine or requiring longer travel to gather specific items.

Climate Change Preparation Recommendations

Communication. New relationships and communication avenues should be developed between tribal communities and federal and state governments to ensure that tribes are involved in the development and implementation of climate change preparation policies and practices that may affect them (e.g., state adaptation plans). Such improved communication may foster greater respect of treaty rights and tribal sovereignty and help reduce or avoid conflict and lawsuits. Improved communication can open up opportunities for co-management of areas shared between tribal communities and federal or state governments.

Carbon credits and cap and trade. An assessment should be conducted on the feasibility and implementation of effective incentives (perhaps via carbon credits) for preserving forests on tribal lands as opposed to harvesting them. A forest preservation program could help support carbon sequestration on tribal lands.

Incentives. Government incentives should be offered to encourage private landowners to cultivate culturally important species, restore and conserve habitat (especially for species that are declining on public and tribal lands), and allow harvest by tribes.

Incentives for small-scale biofuel development on tribal land could be established to offset some loss of economic opportunities from projected changes. A full understanding of the greenhouse-gas emission costs and benefits should be examined before organizing such a program.

Burning. Controlled burning where culturally and ecologically appropriate should be continued. Tribes will need to consider how burning will be affected by changes in vegetation, hotter temperatures, and more intense periods of drought as well as to assess the impacts of burning on human health.

Traditional ecological knowledge. Traditional ecological knowledge should be viewed as extremely valuable information about ecological relationships that is honored, respected, and protected from misuse. Tribes and others may use such knowledge to manage for functional ecosystems as climate change worsens, but the sharing of traditional ecological knowledge outside the tribal community will need to be arranged with the utmost care and respect.

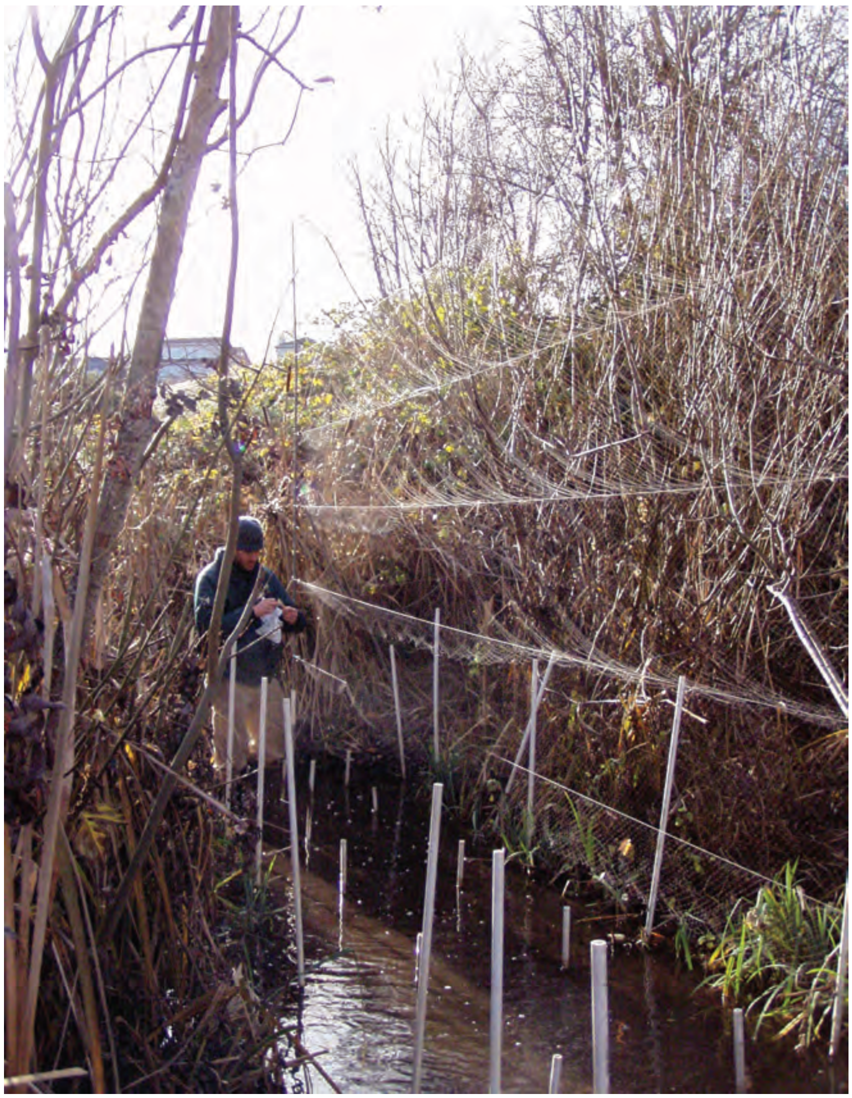
Research and Monitoring

Ecological and social changes resulting from shifting climate conditions could occur at various rates and are likely to be difficult to detect on a year-to-year basis. As well-grounded as climate models are, the effects of climate change at local scales may differ from model projections and the predictions of experts. This is due to uncertainty in how the entire climate system will react under different conditions and how natural and community systems respond to changes (and updating models and collecting data will continuously improve projections).

For these reasons, effective research and monitoring programs will be important to direct successful climate change preparation programs. Research and monitoring programs can help detect trends, prompt appropriate preparation actions or management responses, and evaluate the effectiveness of those actions in addressing climate impacts.

To accommodate these needs, participants of our discussions recommended an expansion of research and monitoring capacity in the Basin and improvements in data sharing. Monitoring efforts to date generally have been short term and limited to narrowly focused questions or a few parameters. To sustain more informative long-term efforts, administrative support is needed to coordinate focused, interdisciplinary, and interagency-government-organization programs. Monitoring and research data should be centrally housed in an objective and unbiased center committed to delivering useable and nonpartisan information to interested entities (such as a university). Agencies, governments, and organizations conducting investigations need to submit data to an identified clearinghouse (e.g., Klamath Waters Digital Library), allowing use of the information by a broad range of entities responsible for management decisions in the Basin.

Communication of research and monitoring results to the public and other resource managers is key to making the information applicable to on-the-ground management decisions. Monitoring and research must be relevant and credible, and results should apply directly to pressing management needs. Selecting effective messengers to deliver research and monitoring results will be essential to increase the likelihood of aiding future management and policy direction.



THE FOLLOWING EXAMPLES OF RESEARCH AND MONITORING ACTIVITIES WERE IDENTIFIED AS URGENT AND IMPORTANT BY WORKSHOP PARTICIPANTS.

Research Needs		
Impacts of water storage options on human health (toxic blue-green algae)		Crop alternatives for higher temperatures and increased drought conditions in Basin
Life-cycle analysis for predominant crops		Opportunity for rangelands and meadows to sequester carbon
Emerging markets for renewable energy		Cost-effectiveness of implementing preparation activities compared to taking no action
Results of local mitigation and preparation efforts to share lessons learned		Identification of human populations most vulnerable to projected climate change impacts (health, extreme events)
Effective communication tools and techniques for talking about climate change impacts and management strategies		Integration of projections with FEMA mapping to assess expansion of flood-prone areas
Monitoring Needs		
Stream-flow trends and effects to floodplains, groundwater, wetlands, and riparian habitats		Infrastructure risk to increased temperatures, more intense storms, increase in wildfire
Sequestration rates for a range of vegetation types		Effectiveness of preparation actions and innovative approaches
Effectiveness of water conservation activities		Disease incidence within Basin and in surrounding areas
Continued evaluation and refinement of preparation strategies		Continued evaluation and refinement of governance structures
Local economic activity and change in consumptive behavior over time (especially related to tourism)		Shift in human population, migration patterns, and demographics

Approaches to Preparedness

Climate change is a global phenomenon that has the potential to touch every individual, household, business, and community. Temperatures will increase and precipitation patterns will change. Demand for household water for drinking, washing clothes, and watering lawns and gardens will increase. Changes will affect forest, agricultural and fishery productivity. Repercussions will resonate through every community's infrastructure, health, and safety. Natural resources will be stressed and clean water, clean air, and the buffer against flood and drought may be affected unless action is taken to prepare for and mitigate the effects of climate change. A framework that functions across systems and sectors as well as across jurisdictional boundaries should be pursued.

Benefits of Integration

The risks from climate change are diverse, as are the preparations suggested by the participants in this process. The key to planning will be to embrace new ideas, honor different perspectives, and pinpoint actions that help reduce risks and provide benefits across all sectors and systems. The burden of preparing for climate change will fall on all the Basin's residents. Displacing risk from one sector to another does little good, but reducing overall risk will have wide-ranging benefits. Many preparation efforts, if properly developed and implemented, could provide benefits for both natural and community systems.

This project purposefully involved a cross-section of experts with varied knowledge including scientific professionals, tribal members, local decision-makers, business and industry representatives, and individuals from emergency management, social service, and public health sectors. Their task was to assess risks to natural, built, economic, human, and tribal systems posed by climate change, and propose strategies and actions to reduce those risks. These strategies, however, are just the starting point for an extended assessment of potential climate change impacts and preparation strategies needed in the Klamath Basin. The next step will be to integrate this information into a comprehensive and detailed strategic implementation framework that will need to be updated periodically.

Preparation actions that support strategies beneficial to the most stakeholders will enhance the resiliency of natural, built, economic, human, and tribal systems. The results from this effort provide a starting point for community planning discussions focused on identifying strategies that will comprehensively reduce climate change risks.

Effective Communication

To effectively reach the community and inspire action, participants acknowledged the importance of the right messenger to spearhead community discussions regarding the effects of climate change and the need for preparedness. Oregon State University Extension Service agents, business leaders, farmers, and members of the religious community, the Rotary Club, and chambers of commerce may be the most effective climate change communicators in the Klamath Basin. Government employees or members of the environmental community are less likely to be well received in many areas of the Basin.

When climate projections and potential effects are shared with the community, participants felt it was also important to provide information regarding the possible economic implications of climate change and the benefits of preparation. In addition, there is a need to address economic and energy security when talking about the impacts of climate change and the need for preparedness. There should be a particular emphasis on improving communication on climate preparation with farmers, foresters, fishermen, and individuals in other economic sectors by sending scientists and experts into the field. In many areas of the Basin, it was recommended that community discussions be focused on strategies to reduce and manage risk.

Another recommendation was to establish an oversight committee for climate preparation (e.g., a climate advisory council), headed by a community-based agency or organization and structured to anticipate changes in and facilitate planning across all sectors and systems. The committee would support integration of climate preparation efforts into existing planning exercises, rather than addressing them separately.

Call for Improved Governance

In the effort to develop a comprehensive strategy to prepare for climate change, the communities of the Basin will need to explore new governance structures better suited for responding to risks and impacts of changing conditions. This need is particularly acute in the Klamath Basin, which encompasses numerous, diverse, and widely separated communities and spans multiple governmental jurisdictions in two states. Workshop participants noted that current governance structures are not designed to efficiently gather and share information, secure funding, allocate resources, make decisions, or show accountability across the entire Basin. The presence of a Basinwide governance structure (such as an advisory council) could facilitate cost-effective climate change preparation planning. Cross-Basin governance is critical, especially for water, forest, and other resources that cut across multiple political boundaries.

Preparedness strategies should consider a regional approach, incorporating the needs and interests of both the Upper (left) and Lower (right) Klamath Basin.

Conclusion

Changing climate conditions (including higher temperatures, shifting precipitation patterns, reduced snowpack levels, and shifting species) will transform the natural systems of the Klamath Basin, stimulate considerable changes in the region's local economy and the ability of the built environment to support communities, increase risks to human health, and adversely affect the quality of life. Millions of dollars in costs could accrue if Basin communities do not manage foreseeable risks and prepare for change (Climate Leadership Initiative and EcoNorthwest 2009).

The people and institutions of the Klamath Basin have the capacity and innovation needed to effectively prepare for changing conditions and new risks and local planning that will best serve residents of the Basin. Taking steps now to prepare the natural, built, economic, human, and tribal systems for the likely consequences of climate change will help the people, communities, cultures, and ecosystems of the Basin prosper and thrive in the future.

While climate change is projected to cause damage to a variety of systems in the Klamath Basin, it may also provide opportunities. As climate change projections provide the impetus for change, for example, local communities could take this opportunity to increase their self-sufficiency, economic vitality, and local support networks for vulnerable populations. New industries and agricultural products can be developed that are more suitable to future climate conditions or more resilient to change.

The results of the workshops discussed in this report are a first step. Stakeholders of the Basin must assess these recommendations, develop additional recommendations, and prioritize activities based on costs, impacts, and feasibility. All sectors across the Basin should then work together to develop a regional, multisector framework for climate preparation in the Basin and develop strategies for effective implementation of the framework in a particular community or sector.

All households, communities, companies, organizations, agencies, and governments of the Basin are encouraged to use the information in this report to develop specific strategies and actions that build resiliency and resistance to climate change across resource sectors. With extensive community involvement, innovative climate preparation planning can be successfully developed and implemented to withstand and prepare for the coming changes.

APPENDIX A: Co-Benefits of Recommendations Across Systems

Natural Systems	Impacts on other systems (+ denotes positive impact, – denotes negative impact)			
	Built	Economic	Human	Tribal
Use low-quality water for agricultural purposes		– short-term expenses + long-term efficiency and reduced water costs	+ improves water quality for human consumption	+ supports recovery of culturally important species
Prevent out-of-Basin water transfer		+ improves reliability of water for industrial uses + supports recovery of commercially important species	+ improves water quality for human uses	+ supports recovery of culturally important species
Increase extent of wetlands	+ reduces flash-flooding events	+ increases reliability of groundwater for irrigation consumption	+ increases reliability of groundwater for human consumption	+ supports recovery of culturally important species
Protect and develop connections between cool water areas		+ supports recovery of commercially important species		+ supports recovery of culturally important species
Remove or replace culverts and roads that are not able to accommodate increased storm frequency and runoff	+ protects infrastructure from damage during extreme weather events		+ improves water quality for human consumption	
Limit or eliminate grazing in some areas		– may limit agricultural expansion	+ improves water quality for human consumption	
Promote accumulation of snowpack in higher elevation forests	+ reduces flash-flooding events	+ increases reliability of groundwater for irrigation consumption	+ increases reliability of groundwater for human consumption	
Protect and increase genetic diversity of species		+ supports recovery of commercially important species	+ maintains ecosystem services such as timber supply, fisheries, hunting, etc.	+ supports recovery of culturally important species
Protect and restore natural plant and animal movement corridors		+ supports recovery of and limits impacts to commercially important species + increases tourism		+ supports recovery of and limits impacts to culturally important species
Harvest juniper to reduce further spread		+ new markets for juniper such as fencing		
Limit floodplain development	+ reduces damage to infrastructure	– may limit economic growth in some areas	+ reduces risk of communities being affected by floods + limits need for emergency response	

Human Systems	Impacts on other systems (+ denotes positive impact, – denotes negative impact)			
	Tribal	Natural	Built	Economic
Improve infrastructure to protect from heat illness				+ reduce utility costs

APPENDIX A: Co-Benefits of Recommendations Across Systems

Built Systems	Impacts on other systems (+ denotes positive impact, – denotes negative impact)			
	Economic	Human	Tribal	Natural
Store surplus high flows during storms and promote water conservation	+ provides water for irrigation during drier periods + increases reliability of water supply	+ ensures adequate water quality and quantity for consumption		+ may include restoration of some natural areas
Update water and wastewater treatment facilities to withstand extreme weather events		+ protects natural water bodies from contamination		+ protects natural water bodies from contamination
Expansion of rail lines	+ improves trade connections			– may disrupt animal movement corridors
Reduce construction in fire and flood prone areas	– may limit expansion of developments into some areas	+ reduces need for emergency response for fire and flood damage		+ protects some environmentally sensitive areas from development
Plant native trees, and use air circulation for cooling	+ keeps energy costs low	+ protects human health from heat illness		

Economic Systems	Impacts on other systems (+ denotes positive impact, – denotes negative impact)			
	Human	Tribal	Natural	Built
Promotion of diverse crops on small or family-owned farms			+ promotes diversity of species + reduces impact to soils	
Promotion of drought-tolerant crops	+ increases reliability of groundwater for human consumption		+ increases reliability of groundwater for irrigation consumption	
Expand dry land grazing			+ leaves more water in the river for wildlife	
Maintain and restore land resiliency for local economic systems	+ water quality and access to nutritional food improves		+ reduces impact on wildlife habitats	+ reduces impact of flooding on infrastructure
Promote regional renewable energy projects			unknown consequences of some renewable energies on wildlife and ecosystems + may lead to dam removal, benefiting aquatic systems	

Tribal Systems	Impacts on other systems (+ denotes positive impact, – denotes negative impact)			
	Natural	Built	Economic	Human
Encourage cultivation of culturally important species and restoration of habitat	+ promotes biodiversity and native plant and animal abundance		+ supports recovery of commercially important species	
Controlled burning where culturally and ecologically appropriate				– smoke may have local health consequences

APPENDIX B: Literature Cited

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APPENDIX C: Resources

Climate Leadership Initiative: climlead.uoregon.edu

National Center for Conservation Science and Policy: www.nccsp.org

Intergovernmental Panel on Climate Change: www.ipcc.ch

Climate Crisis Coalition: www.climatecrisiscoalition.org

University of Washington Climate Impacts Group: Interdisciplinary research on climate change impacts on the Pacific Northwest: www.cses.washington.edu/cig

Oregon Climate Change Research Institute (OCCRI): A clearinghouse for climate information for Oregon and the Pacific Northwest as well as climate data providers: www.occri.coas.oregonstate.edu or occri.net

Real Climate: Climate change science blog: www.realclimate.org

Environmental Protection Agency: Glossary of climate change terms: www.epa.gov/climatechange/glossary.html

Setting the Record Straight: Responses to Common Challenges to Climate Science (Q and A for climate skeptics—answers to the most frequently stated concerns, edited by members of the Climate Leadership Initiative: climlead.uoregon.edu/sites/climlead.uoregon.edu/files/reports/Setting_record_Straight.pdf

APPENDIX D: List of Participants

Name	Agency	Workshop
Bill Adams	Klamath County Planning Department	C
Steve Adams	Climate Leadership Initiative	C
John Alexander	Klamath Bird Observatory	N
Brian Barr	National Center for Conservation Science and Policy	N, C
Mike Belchick	Yurok Tribe	N
Craig Bienz	The Nature Conservancy	N
Crystal Bowman	Quartz Valley Indian Tribe	N
Molly Boyter	Bureau of Land Management, Lakeview District	N
Tom Burns	Rancher, educator	C
Joyce E. Casey	U.S. Department of Agriculture, U.S. Forest Service	C
Damion Ciotti	U.S. Fish and Wildlife Service, Klamath Falls Fish and Wildlife Office	N
Ned Coe	California Farm Bureau	C
Angelina Cook	City of Mount Shasta	C
Ric Costales	Siskiyou County	C
Rob Cozens	Resighini Rancheria	N
Lyra Cressey	Salmon River Restoration Council	N
Cindy Deacon Williams	National Center for Conservation Science and Policy	N,C
Mike Deas	Watercourse Engineering	N
Bob Doppelt	Climate Leadership Initiative	C
Davy Dowd	Resighini Rancheria	N
Dennie Dunkeson	Klamath County Radio Amateur Civil Emergency Service	C
Larry Dunsmoor	Klamath Tribes	N
Mark DuPont	Mid-Klamath Watershed Council, Sandy Bar Ranch	C
Craig Ellsworth	U.S. Geological Survey	N
Chanda Engel	Oregon State University, Klamath Basin Research and Extension Center	N
Ken Fetcho	Yurok Tribe	N
Scott Foott	U.S. Fish and Wildlife Service, Nevada Fish Health Center	N
Shane Fryer	Lava Beds National Monument	N
Nick Goulette	Watershed Research and Training Center	C
Jon Grunbaum	U.S. Forest Service, Klamath National Forest, Happy Camp Resource District	N
Andy Hamilton	Bureau of Land Management, Lakeview District	N
Mark Hampton	California Department of Fish and Game	N
Roger Hamilton	Climate Leadership Initiative	N,C
Eric Haney	California Department of Fish and Game	C
Mark Henderson	South Valley Bank and Trust	C
Heather Hendrixson	The Nature Conservancy	N
Lani Hickey	Klamath County, Public Works Department	N
John Hicks	Bureau of Reclamation	C
Dave Hillemeier	Yurok Tribe	N
Susan Honea	Oregon State University, Klamath Basin Research and Extension Center	N
Joe Hostler	Yurok Tribe	N
Becky Hyde	Rancher, Upper Klamath Water Users	C
Nathan Jackson	Klamath Watershed Partnership	C
Carson Jeffres	University of California at Davis	N
Jacob Kann	Aquatic Ecosystem Sciences	N
Richard Kehr	Fremont-Winema National Forests	C
Steve Kirk	Oregon Department of Environmental Quality	N
Marni Koopman	National Center for Conservation Science and Policy	N,C
Ron Larson	U.S. Fish and Wildlife Service, Klamath Falls Fish and Wildlife Office	N, C
Cecil Lesley	Bureau of Reclamation	N

N = Attended Natural Systems Workshops
C = Attended Community Systems Workshops

APPENDIX D: List of Participants, continued

Name	Agency	Workshop
Jeffrey Lindsey	Hoopa Tribe, Forest Department	C
Tom Lisle	U.S. Forest Service, Pacific Southwest Research Station	N
Ned Livingston	Gerber Ranch	C
Brett Lutz	National Oceanic and Atmospheric Administration	C
Katie MacKendrick	Climate Leadership Initiative	N
Doug Markle	Oregon State University	N
Susan Mattenberger	U.S. Fish and Wildlife Service, Klamath Falls Fish and Wildlife Office	N
Tim Mayer	U.S. Fish and Wildlife Service	N
Terry Morton	Klamath Watershed Partnership	N
Marshal Moser	Lonesome Duck Ranch	N
Seth Naman	National Marine Fisheries Service	N
Richard Naumann	National Center for Conservation Science and Policy	N
Jim Patterson	National Resource Conservation Service, Yreka	N, C
William Patterson	Yurok Tribe	N
Shannon Peterson	Klamath Basin Rangeland Trust	N
Karen Pope	U.S. Forest Service, Pacific Southwest Research Station	N
Mark Radabaugh	Department of Land Conservation and Development	C
C.J. Ralph	U.S. Forest Service, Pacific Southwest Research Station	N
Stewart Reid	Western Fishes	N
Willie Riggs	Oregon State University Extension Service	C
Robert Roninger	Bureau of Land Management, Lakeview District	N
Dwight Russell	Klamath River Basin Compact Commission	C
Ryan Sander	NOAA National Weather Service	C
Daniel Sarr	National Park Service	N
Keith Schultz	Bureau of Reclamation	N
Kathleen Sloan	Yurok Tribe	N
Joshua Smith	Watershed Center	N
Roger Smith	Oregon Department of Fish and Wildlife	N
Shawn Thomas	Lava Beds National Monument	N
Bill Thompson	Klamath County Emergency Management	C
Mark Tompkins	CH2M Hill	N
Abby Topin	Lava Beds National Monument	N
Torrey Tyler	Bureau of Reclamation	N
Robert VanKirk	Humboldt State University	N
Stacy Vynne	Climate Leadership Initiative	N,C
Jeff Weber	Department of Land Conservation and Development	C
Jack Williams	Trout Unlimited	N

N = Attended Natural Systems Workshops
C = Attended Community Systems Workshops

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