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Climate Change Vulnerability and Adaptation for Infrastructure and Recreation in the Sierra Nevada

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Cover Photo: Postfire mosaic along highway north of Wawona entrance inside Yosemite National Park, Ferguson Fire, 2018, by James D. Absher.

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Abstract

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A vulnerability assessment was conducted on the effects of climate change on infrastructure and outdoor recreation in the Sierra Nevada, including adaptation options that minimize negative impacts of climate change and facilitate a transition to a warmer climate. At vulnerable or flood-prone sites, resilience near stream crossings and in floodplains can be enhanced by designing infrastructure to withstand more frequent and severe flood events, and by upsizing or upgrading existing infrastructure to withstand flooding. Some roads and other infrastructure can be decommissioned or moved to mitigate risks. Following wildfires, managers can prioritize slope stabilization projects for infrastructure near unstable slopes and riverbanks, increase monitoring of soil and slope conditions, and restrict public access to sites where unstable soils create safety hazards. Increased recreation is projected for the Sierra Nevada, so adequate staffing and resources will be needed to aid delivery of recreation opportunities and to maintain visitor safety. Limits on visitation through determination of carrying and social capacity may be increasingly necessary, as will communication about alternative recreation areas, alternative activities, and warnings about potential crowding. Expanding partnerships among federal, state, and local agencies will increase the capacity of the U.S. Department of Agriculture Forest Service and other organizations to maintain functional ecosystems, water resources, and recreation and transportation infrastructure.

Keywords: Adaptation, climate change, disturbances, drought, extreme weather, infrastructure, recreation, resilience, roads, Sierra Nevada, wildfire.

Summary

The Sierra Nevada Infrastructure and Recreation Vulnerability Assessment and Adaptation Partnership was developed to identify climate change issues relevant for resource management on national forest units in the Sierra Nevada region of the U.S. Department of Agriculture, Forest Service (USFS) Pacific Southwest Region (Eldorado, Inyo, Lassen, Modoc, Plumas, Sequoia, Sierra, and Stanislaus National Forests and the Lake Tahoe Management Unit).

The 10 national forest units in the Sierra Nevada contain a combined 26,500 mi of roads, 9,300 mi of trails, 684 bridges, 169 dams, over 4,100 buildings and administrative sites, and over 50 campgrounds. Total infrastructure investments for facilities alone have an estimated value of $750 million. The combined effects of increasing use, aging infrastructure design, and changing climatic and hydrologic conditions are increasing the vulnerability of infrastructure and increasing risk for users. Water resource infrastructure, including dams and reservoirs, stores water, reduces flooding, and provides recreational opportunities. Future changes in timing, type (rain versus snow), and amount of precipitation will create challenges when storing and allocating water for irrigation, flood prevention, and energy production.

Outdoor recreation is a huge enterprise in the Sierra Nevada, providing diverse experiences, psychosocial value, and public health benefits to residents of California and beyond. Over 17 million people recreate in Sierra Nevada national forests each year, accounting for $1.6 billion in annual expenditures and $1.3 billion aggregate economic benefits to local businesses and communities. Warm-weather activities (hiking, viewing natural features, camping, etc.) account for the largest proportion of recreation, followed by winter activities (especially downhill skiing) and a broad range of other activities. Nearly all recreation is affected by weather conditions, which affect decisions about if, when, and where to recreate.

The Sierra Nevada is already experiencing the effects of human-caused climate change. Average annual temperature has increased 1.6 °F since 1901 and is projected to increase 6 to 10 °F by the end of the 21st century. Increases in temperature are expected to be higher at higher elevations (+9 °F at 3,000 ft compared to +9.5 °F at 10,000 ft). Precipitation is projected to change by -5 percent to +10 percent and to be more variable, although projections are uncertain.

Higher winter temperatures have resulted in more precipitation falling as rain rather than snow and reduced snowpack in many parts of the Sierra Nevada. Reduced snowpack and earlier snowmelt have led to earlier timing of streamflow, and peak flows are projected to occur 1 to 2 months earlier by the end of the 21st century. As precipitation regimes change from snow dominated to rain dominated, snowpack storage will decline, with the amount of water stored in snowpacks

projected to decrease by 60 percent by the end of the 21st century, with middle elevations experiencing the biggest losses.

Higher temperatures have also been associated with increased wildfire area burned and incidence of large fires. These effects are expected to become more pronounced in coming decades. Higher temperatures (and longer time periods between rain events) will likely increase drought stress in forests, potentially altering the distribution and abundance of dominant plant species over decades to centuries.

Current transportation infrastructure, hydroelectric networks, and recreation resources in the Sierra Nevada are coupled with hydrologic processes and vegetation. Roads and other infrastructure on national forests provide access to recreation opportunities across all seasons. Recreation demand and outdoor recreation economies are increasing with growing populations in California. With projected warming temperatures and more intense precipitation events, higher demand for public access in national forests may coincide with increasing occurrence of floods, landslides, and wildfire. Earlier and larger spring streamflows will potentially lead to prolonged and lower summer low flows for streams that contribute to water supplies, support aquatic systems, and provide recreation opportunities.

Infrastructure

Climate change effects—

Infrastructure can be affected by direct climate change effects, increased climatic variability (e.g., precipitation timing, extreme temperatures, drought severity and duration) and indirect climate change effects such as increased fire and insect outbreaks. Infrastructure networks are interrelated with other resource management programs, and the vulnerability of infrastructure to climate change can influence access to and quality of other natural resources and ecosystem services (e.g., recreation).

Climate change will affect infrastructure over short and long time scales. Extreme events occurring over the course of several hours to several weeks often cause the most significant damage. Roads, bridges, and culverts are susceptible to increased runoff during storm events and failures owing to washouts, plugging, overtopping, stream diversion, and scour. Long-term climatic patterns that affect infrastructure over multiple decades—altered freeze-thaw cycle, timing and length of suitable construction weather, and snowmelt and stream hydrology—can also affect the sustainability of transportation, recreation, and water resource infrastructure.

By the end of the 21st century, streamflows that can lead to flooding (i.e., 50-year events) may increase 30 to 90 percent in the northern Sierra Nevada, and by 50 to 100 percent in the southern Sierra Nevada, particularly during the winter

months. Increased magnitude of peak streamflows in winter is expected to damage roads near perennial streams, ranging from minor erosion to complete loss of the road. Associated infrastructure such as bridges, culverts, campgrounds, and facilities near streams and floodplains will be especially vulnerable, potentially affecting public safety and reducing access for recreation and resource management.

Infrastructure can also be indirectly affected by climate-influenced disturbances such as wildfire. Area burned by wildfire has increased in California over the past 30 years, often destroying buildings and associated facilities and infrastructure. When heavy rains fall in areas where fire has removed vegetation, erosion and debris movement can plug culverts, cover roads, and damage downstream structures.

Adaptation options—

At vulnerable or flood-prone sites, resilience near stream crossings and in floodplains can be enhanced by designing future infrastructure to withstand more frequent and severe flood events, and by upsizing or upgrading existing infrastructure to withstand future flooding and erosion. In the most vulnerable locations, roads and other infrastructure can be decommissioned or moved to mitigate risks. Future maintenance and repair operations should occur during periods when weather conditions are optimum and risks to worker safety and site integrity are low.

Altered precipitation regimes will create challenges for dam and water resource managers who allocate water resources to support flood control, energy production, and irrigation. As streamflows become more variable, shifting the timing and amount of water releases from dams can maintain reservoir levels to minimize flood risk in the spring while maximizing water storage for longer periods. To supplement reservoir storage, managers can use off-stream water delivery infrastructure (canals, ditches, holding ponds) to increase water storage or divert excess streamflows.

Responding to changing hydrologic conditions may require investment in monitoring upstream snowpack, soil, and weather. In some locations, alternative monitoring techniques or protocols may be needed. Improving streamflow forecasting and expanding streamflow and snowpack monitoring networks will help managers respond to extreme events by ensuring water allocation for downstream uses. To improve forecasting and response times, managers can expand monitoring efforts to increase their capacity to respond to uncertain and rapidly changing weather, streamflow, and snowpack conditions.

To prevent wildfire damage to infrastructure, vegetation can be managed to reduce fuel loads and increase defensible space around facilities and transportation corridors in the wildland-urban interface. Following wildfires, managers can

prioritize slope stabilization projects around infrastructure near unstable slopes and riverbanks, increase monitoring of soil and slope conditions, and restrict public access to sites where unstable soils create safety hazards.

Collaborative adaptation efforts and an "all lands" approach are essential for effective responses to increasing disturbances. Expanding partnerships among federal, state, and local agencies will increase the capacity of the USFS and other organizations to maintain functional ecosystems, water resources, and recreation and transportation infrastructure. Public awareness of the connections among infrastructure, forest ecosystems, and disturbance can be promoted through outreach and education with local communities and stakeholders. This will also allow national forests to obtain feedback from the public, which can in turn help identify and prioritize vulnerable infrastructure and develop climate-smart actions.

Recreation

Climate change effects—

Altered temperature, precipitation, water resources, and seasonality of weather conditions will affect evolving recreation patterns in the Sierra Nevada over the course of the 21st century. Higher temperatures are expected to be a primary driver because most recreational activities are seasonal and vulnerable to changing seasonal conditions and extreme events. As temperatures continue to increase, communities near national forests will incur economic impacts, especially if those communities depend heavily on outdoor recreation.

Summer recreation will benefit from a longer period of suitable weather without snow, especially during the spring and autumn shoulder seasons. Winter recreation (skiing, snowmobiling) will be negatively affected by a warmer climate because of less and more transient snow. Ski areas and other facilities at lower elevations will be especially vulnerable. Hunting may be sensitive to temperature and timing and amount of snow during the designated hunting season. Fishing will be sensitive to streamflows and stream temperatures associated with target species; if summer flows are very low, some streams may be closed to fishing. Water-based recreation (swimming, boating, rafting) will be sensitive to lower water levels during drought years. Gathering forest products for personal and commercial use (e.g., huckleberries, mushrooms) may be somewhat sensitive to the climatic conditions that support the distribution and abundance of items being collected.

Nearly all recreation activities will be negatively affected by projected increases in extreme weather and disturbance events. Wildfire creates near-term (weeks to months) impacts by reducing visitor access to roads, trails, and recreation facilities, and pervasive smoke reduces air quality over large areas within and outside

national forests. Severe wildfires kill trees across thousands of acres, altering the aesthetic quality of recreation sites and vistas, and, in some cases, affecting plants and animals that are valued by recreationists. Dead and damaged trees, as well as postfire soil erosion, create significant hazards for recreationists that may last for decades.

Adaptation options—

Adaptation to climate-related events is already evident in the Sierra Nevada. For example, during 2017–18, the USFS issued messaging about air quality impacts from wildfires and smoke, and about closure of roads and recreation areas in response to damage from winter storms. Recreationists may benefit from searching information resources to plan forest visits and may need to develop alternative plans should unexpected events render an area or opportunity unavailable. Substitution of alternative locations and activities is complex and may be less inviting if there is a personal connection to a location or activity. Although recreationists are most likely to adapt to short-term patterns if the primary location is not available, long-term effects on recreation experiences are not well understood.

Increased recreation is projected for the Sierra Nevada because of California's increasing population. Consequently, adequate staffing and resources will be needed to aid delivery of recreation opportunities and maintain visitor safety. as well as protect and restore affected settings. Limits on visitation through determination of carrying and social capacity may be increasingly necessary, as will approaches that incorporate messaging around alternative areas and activities, and warnings about potential crowding. Communication via USFS websites, social media, and smartphone applications will enhance visitor awareness of specific seasons, closures, and limits to types of use. Partnerships and volunteer programs will continue to supplement management for diverse recreation opportunities and settings, supporting information needs and informing adaptive responses.

Specific adaptation strategies include:

- Increase resilience of recreation infrastructure to increasing disturbances.
- Adjust staffing and management during variable shoulder seasons to accommodate changes in seasonal access and recreation locations.
- Adjust visitor management policies and practices to increase management flexibility and facilitate transitions to meet user demands and expectations.
- Increase resilience of recreation sites to changing conditions or increased demand.
- Increase capacity to anticipate and respond to shifting seasonal recreation patterns.

- Increase management flexibility and anticipate fire-related effects at a regional scale.
- Reduce safety risks associated with hazard trees.
- Manage iconic places for resilience using an interdisciplinary approach to provide recreation opportunities.

The Sierra Nevada partnership achieved specific elements of national and regional climate change strategies for federal agencies, providing a scientific foundation for resource management and planning for infrastructure and outdoor recreation in national forests and beyond. First, the scientific basis for current and projected climate change effects on natural resources, infrastructure, and recreation is now well established. Second, a large number of adaptation options have been developed, many of which are a component of current management practice, providing a pathway for slowing the rate of deleterious change in resource conditions. Timely implementation of adaptation will help prevent the deterioration of infrastructure and the huge costs of repairs and replacement. It will also ensure sustainability of facilities, access, and opportunities for recreation. Long-term monitoring will help detect potential climate change effects, as well as evaluate the effectiveness of adaptation options.

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