

Southwest Climate Adaptation Science Center

Science Needs Assessment



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Southwest
Climate Adaptation
Science Center

Southwest Climate Adaptation Science Center: Science Needs Assessment

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U.S. Geological Survey

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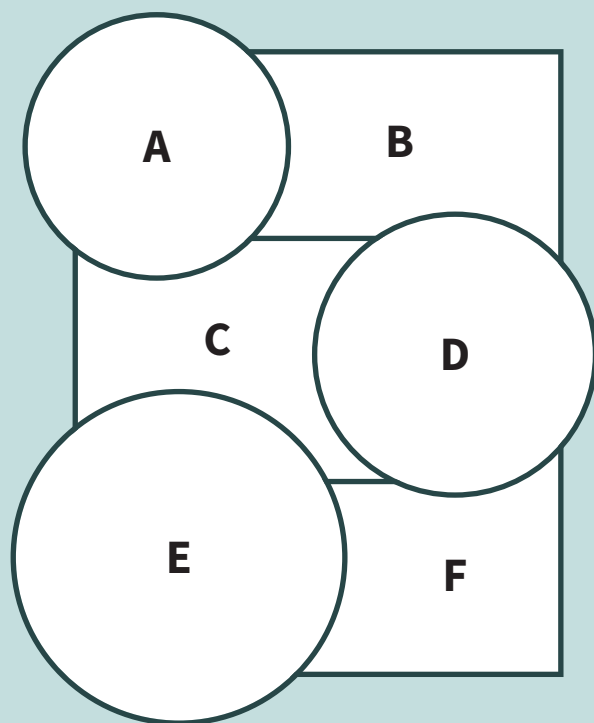
Outline

Acknowledgements	4
I. Introduction	5
Our Partnership Approach	6
Determining Science Needs	7
II. Management Challenges	9
Summary of Management Challenges	10
Water Availability and Long-Term Drought	11
Altered Fire Regimes	14
High Impact Events	17
Changing Ecosystems	20
Changing Coastal Environments	23
Adaptation Obstacles and Opportunities	26
III. Conclusions	29
IV. References	30

Image (left), Utah Drylands. Source: John Bradford, USGS

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I. Introduction

The mission of the Department of the Interior's **Climate Adaptation Science Center (CASC)** network is to deliver science to help fish, wildlife, water, land, and people adapt to a changing climate.

As part of this network, the [Southwest Climate Adaptation Science Center](#) (SW CASC) was established in 2011 to support independent, collaborative, and regionally relevant research on climate vulnerability and adaptation for resource managers and communities across Arizona, California, Nevada, and Utah ([fig. 1](#)).

Our role at the SW CASC is to develop actionable adaptation information, tools, and solutions in partnership with natural and cultural resource managers, policy makers, Native Nations, and researchers across the region. This ensures that the scientific approach, data collection, resulting information products, and tools are relevant and usable for practitioners and decision-makers. The SW CASC views science-based

management as essential to addressing climate change trends and impacts and improve resiliency. To accomplish our mission, the SW CASC consulted with regional resource managers to create the Science Needs Assessment, outlining existing resource management

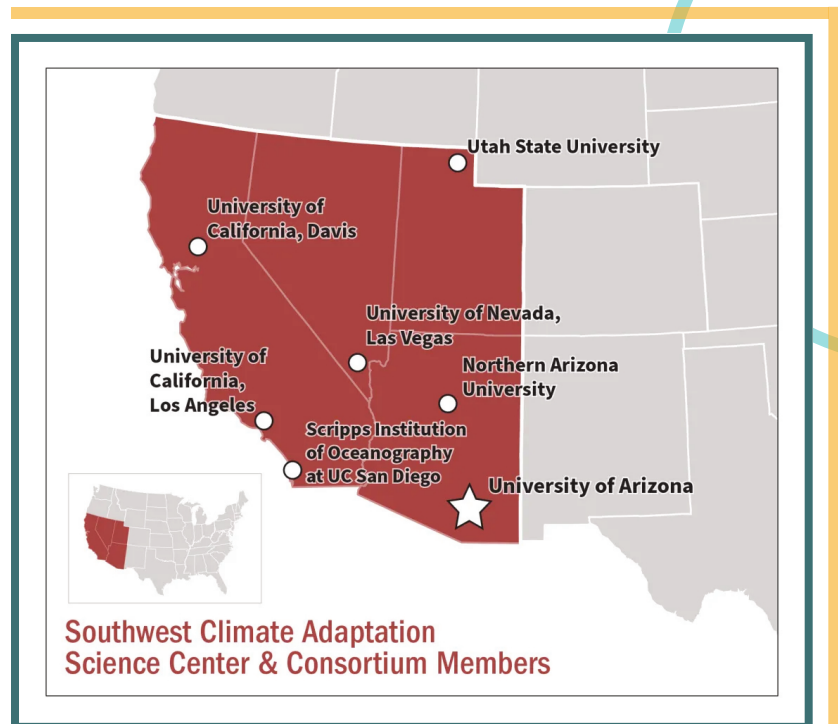


Figure 1. Geographic extent of the Southwest Climate Adaptation Science Center, including our University Consortium partners (open circles) and our current host institution (open star).

challenges and the information gaps associated with each. By identifying these science information needs, the SW CASC can better align with our research partners to produce actionable information and tools, improving science-informed management response to these challenges.

Our Partnership Approach

The SW CASC is a partnership between U.S. Geological Survey (USGS) CASC staff, SW CASC University Consortium partners, the American Indian Higher Education Consortium (AIHEC), and the SW CASC Advisory Committee.

As a federal-consortium partnership, the SW CASC consortium is hosted by one institution within a larger consortium of universities, research entities, Tribal organizations, and/or non-governmental organizations ([fig. 1](#)). Host institutions and consortia are selected through a competitive proposal process and recompetes every five to seven years. In September 2024, the Phase III host was awarded to the University of Arizona and includes partners at the University of California, Davis, University of California, Los Angeles, Scripps Institution of Oceanography at University of California San Diego, University of Nevada, Las Vegas, Utah State University, and Northern Arizona University.

The SW CASC has hosted two Tribal Climate Resilience Liaisons funded by the Bureau of Indian Affairs Tribal Resilience Program and employed by AIHEC. Our Tribal Climate Resilience Liaisons have had a lead role in fostering dialogue, identifying needs, and ensuring strong working relationships with Tribal Nations and Tribal Colleges and Universities within the region.

The Advisory Committee is comprised of federal, state, and Tribal representatives and resource managers. They help identify regional management challenges and associated information needs, support the integration of SW CASC research into resource management,

and help develop and inform the Science Needs Assessment. Members include: Arizona 67 Department of Water Resources, Arizona Game and Fish Department, Bureau of Indian Affairs, Bureau of Land Management, Bureau of Ocean Energy Management, California Department of Water Resources, California Department of Fish and Wildlife, National Park Service, Nevada Department of Wildlife, Nevada Division of Water Resources, National Weather Service, Pascua Yaqui Tribal Council, Summit Lake Paiute, United States (U.S.) Department of Agriculture California Climate Hub, U.S. Department of Agriculture Southwest Climate Hub, U.S. Fish and Wildlife Service, U.S. Forest Service, USGS, Utah Division of Wildlife, and the Utah Division of Water Resources.



Red Rock Canyon National Conservation Area, Nevada. Source: Public Domain

Determining Science Needs

The goal of the SW CASC is to work with regional managers of land, water, fish, and wildlife, as well as nearshore, coastal, and cultural heritage resources, to identify high priority resource management and decision needs for which information on climate, climate change, impacts, or adaptation is needed. This partnership approach ensures the SW CASC can deliver effective scientific information and tools to assist resource managers in developing adaptation strategies, programs, and actions for responding to climate change. Through iterative

engagement and feedback sessions with the SW CASC Advisory Committee, the SW CASC gains a clearer understanding of the region's unique management challenges and where information gaps exist. From here, the SW CASC can work with research partners to generate appropriate science and decision support tools to fill these information gaps and more efficiently address these challenges.

This Science Needs Assessment reflects the current management challenges and near-term information needs identified by the natural and cultural resource managers on our SW CASC Advisory Committee. Overall, six primary management challenges in the Southwest were identified as well as the associated information needs to best address those challenges.



March 2021 cultural burn.
Source: Carolyn Enquist



Collecting bulk density samples at Seal Beach, CA. Source: Richard Ambrose



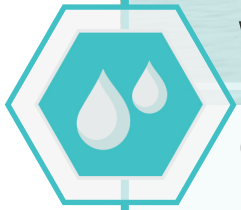
II. Management Challenges

The following section outlines the overarching management challenges identified through multiple listening sessions and meetings with the SW CASC Advisory Committee spanning 2024. The management challenges include: [1\) water availability and long-term drought](#), [2\) altered fire regimes](#), [3\) high-impact events](#), [4\) changing ecosystems](#), [5\) changing coastal environments](#), and [6\) adaptation obstacles and opportunities](#). For each management challenge, the Advisory Committee made recommendations on related information needs and knowledge gaps. The SW CASC staff then reviewed the literature and summarized the current state-of-the-science for each.

These management challenges have numerous overlaps and should not be considered standalone issues. Drought can lead to water stress and plant dieback, which can create fuels for wildfire, which, when severe, can lead to shifting or novel ecosystems. Floods can impact coastal processes and have cascading impacts on coastal ecosystems, as can post-wildfire runoff, which can contain higher sediment loads as well as contaminants from burned structures. Adaptation obstacles and opportunities exist for all management challenges.

A common theme across these challenges and information needs is the importance of integrating social science approaches. Adapting to climate change is likely to involve new management tools and strategies. Therefore, successful climate adaptation will require improved understanding of how people understand data and information, how they perceive risk, how they use climate information to make decisions, and the implications of climate change and adaptation actions across ecosystems and communities.

Summary of Management Challenges



Water Availability and Long-Term Drought

Changing water availability and long-term drought have cascading impacts across ecosystems and communities.

Altered Fire Regimes

Shifts in the timing, frequency, size, and impacts of wildfires are challenging existing resource management approaches.



High Impact Events

Environmental extreme events, from heat waves, flash drought, and algal blooms, to insect outbreaks, flooding, and fire are challenging ecosystem and community resilience.

Changing Ecosystems

Climate-driven shifts in vegetation can alter the landscape's ability to support endemic, high-priority, and at-risk wildlife and plant species.



Changing Coastal Environments

Sea level rise, increased storm surge, changing ocean temperatures, marine heatwaves, coastal erosion, and loss of wetlands are impacting coastal ecosystems and communities.

Adaptation Obstacles and Opportunities

Evaluating institutional, policy, and scientific opportunities and barriers to effective climate adaptation.



Figure 2. Graphic outlining the SW CASC's six overarching management challenges.

Management Challenge: Water Availability and Long-Term Drought



The Southwest is known for its region-wide water availability challenges, including aridity across its three desert ecosystems. Much of the region is arid, and dry summers are common. Across the region, precipitation can vary significantly from year to year, and long, sometimes severe, droughts are common. The region's rainfall patterns have become increasingly variable in recent decades¹, with rising temperatures driving increasing aridity² and declining snowpack^{3,4}. Changes in the seasonal cycle have also been documented with shifts to earlier snowmelt⁵, precipitation falling as rain versus snow^{6,7}, and variable summer monsoon rains⁸. Changes in climate have already impacted water availability and quality in the Southwest, including declines in groundwater storage⁹ and notable shortages on the Colorado River¹⁰. Recent droughts have been extreme even relative to droughts in the tree-ring record¹¹⁻¹⁴. Across the Southwest region, 2000-2021 was the driest 22-year period since the year 800¹⁵.

Future climate change is expected to continue these trends of increases in aridity², changing precipitation timing¹⁶, smaller snowpack^{17,18}, earlier snowmelt^{4,19}, increased evaporative demand^{6,20}, and reductions in surface water availability²¹ and groundwater recharge^{9,22}. Future projections indicate the possibility of longer, more intense and frequent droughts²³⁻²⁶. They also highlight the potential for continued variability in climate and uncertainty in future water availability²⁷.

Declining water availability for plants, fish, and wildlife will have far-reaching impacts across the Southwest. Increased water stress can lead to reductions in plant productivity²⁸ and changes in phenology²⁹ with cascading effects on fish and wildlife³⁰. Drought can also impact tree mortality³¹⁻³⁴. Long-term drought can contribute to the spread of invasive species³⁵ and fundamental changes in the composition and function of ecosystems³⁶.

Higher temperatures, changing snowpacks, variable rainfall, and drought also impact human communities and economies in the Southwest by exacerbating regional water supply shortages^{21,37}, groundwater depletion and well drying^{22,38,39}, increased crop water demand and lower crop yields^{12,40}, decreased soil moisture and increased extreme temperatures⁴¹, and increasing water scarcity^{42–44}. Declining water availability can also alter reservoir storage, impacting hydroelectric power generation⁴⁵. With population growth in the region twice as high as the rest of the United States, demand for limited water supplies will likely continue to grow^{46,47}.

Drought can also have cascading and compounding effects. For example, drier periods and related declines in surface water availability bring higher groundwater pumping for domestic and agricultural use and lower recharge^{37,48–50}. Increasing groundwater pumping has also been tied to lower water quality^{51,52}, with implications for groundwater-dependent ecosystems⁵³, and human use^{54–55}.

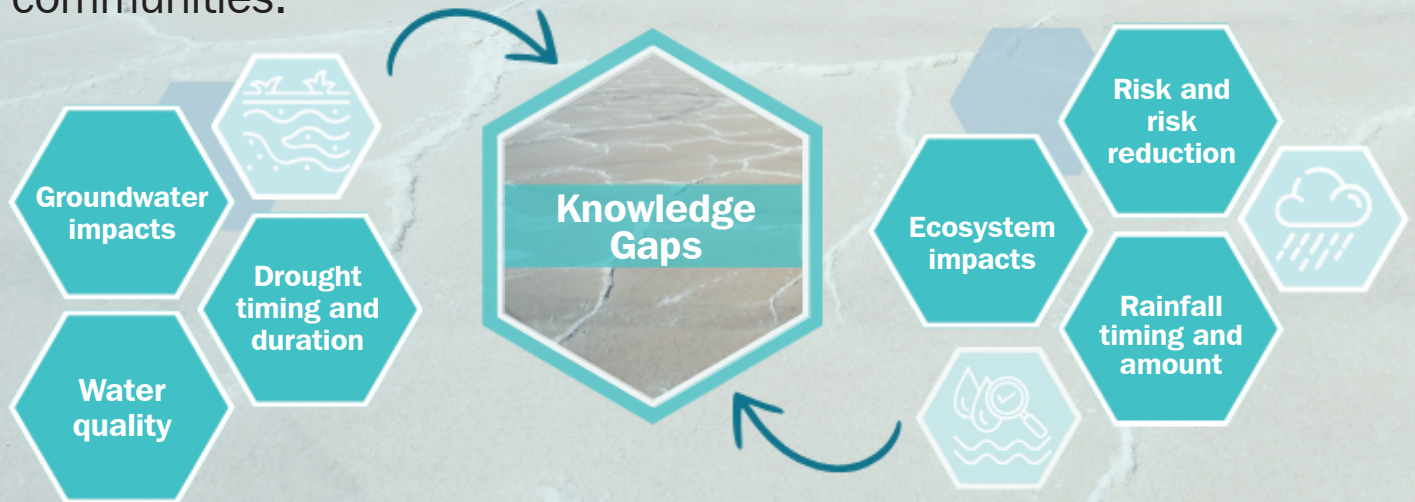
The potential impacts and uncertainty surrounding shifting water availability and drought in the Southwest will require widespread adaptation. Better understanding the drivers and impacts of historical variability⁵⁶ and regional drought vulnerability⁵⁷ will be needed to improve future adaptation approaches. Additional research into drought impacts and early indicators will also be needed to advance drought early warning and reduce drought risks through better drought management⁵⁸. Growing demands for water combined with the possibility of reduced supply increase the potential for conflict and highlight the need for innovative solutions for water management in the Southwest.

*Image on pg. 11: Elizabeth Lake, California.
Source: Jeffrey Lovich, USGS*



Water Availability and Long-Term Drought

Management Challenge: Changing water availability and long-term drought have cascading impacts across ecosystems and communities.



Information Needs

Improve understanding, observations, and estimates of changing precipitation type, seasonality, and variability, including snowpack and runoff measurements.

Characterize impacts of changing precipitation types, seasonality, and variability on natural and cultural resources, including identifying species and systems most vulnerable to changing precipitation and novel drought conditions.

Develop and evaluate drought risk assessment tools to support management actions.

Identify and evaluate methods and strategies to reduce the effects of long-term drought and water shortages, including economic evaluation, assessments of community preferences, and community impact analyses.

Assess the impacts of fluctuating water levels and changes in water quality on ecosystem, fish, and wildlife health.

Evaluate the impacts of climate change and drought on groundwater resources and groundwater-dependent ecosystems and communities.

Understand groundwater and surface water interactions and their associated impacts on lakes, rivers, streams, and aquatic systems.

Figure 3. Impacts and information needs of the 'Water Availability and Drought' management challenge.

Management Challenge: Altered Fire Regimes



Fire is an essential component of many healthy ecosystems in the Southwest and has long been an integral part of the region's natural disturbance regimes⁵⁹⁻⁶⁴. Many forest and shrubland species in the Southwest are fire-adapted⁶⁵. Traditional fire management techniques, sometimes referred to as cultural burning, that were in place for centuries also served to maintain healthy and productive ecosystems through frequent low-intensity surface fire^{63,66-68}. In forests, small pockets of managed fire introduced heterogeneity in forest structure that was maintained⁶⁹. The forced removal of Indigenous peoples, fire suppression policies, increased grazing, and other land uses since the late 19th century effectively reduced the frequency of these low-intensity fires in many forest-dominated parts of the Southwest^{68,70,71}. Clear cut logging also led to denser, even-aged forest stands that are less resilient to fire^{72,73}. The expansion of the wildland urban interface has led to an increase in human-caused fires⁷⁴ that contribute to increased fire activity, including in ecosystems not adapted to such frequent fire, such as chaparral^{75,76}. These 20th century policies and land-use practices, coupled with changing climate, have led to the dramatically altered fire regimes experienced today⁷⁷.

In recent decades, wildfires in the Southwest have grown in frequency, severity, and size⁷⁸⁻⁸³. These changes are the result of management practices⁷⁷ combined with shifts in the timing and amount of rainfall⁸⁴, earlier spring snowmelt⁸⁵, drought, and warming temperatures^{81,85-87}. Drought-driven declines in vegetation health have also contributed to changes in fire behavior⁸⁸⁻⁹⁰. The spread of invasive grasses has also changed fire risk and behavior in many southwestern ecosystems^{70,91-97}.

Novel fire regimes can hinder ecosystem recovery, alter species composition, and, in some cases, lead to a complete conversion of vegetation type, for example from forest to shrubland^{95,98-101}. These vegetation type conversions have consequences for wildlife, nutrient

and water cycling, carbon storage, and subsequent fire behavior and impacts. Changing fire behavior and the expansion of the wildland urban interface poses growing risks to people and communities^{102,103}. Wildfires, particularly large and severe fires, also contribute to declines in air quality^{104,105}, water quality¹⁰⁶, and recreational access¹⁰⁷. Landscape alteration and wildfire impacts can lead to higher risks of flooding, erosion, and debris flows and subsequent degradation of water quality¹⁰⁸⁻¹¹⁰. Climate change projections show many of these trends continuing¹¹¹⁻¹¹³.

Resource managers have used many diverse strategies to improve resilience in fire-prone landscapes¹¹⁴⁻¹¹⁶. These have included the reintroduction and restoration of frequent fire^{117,118}, with calls for expanding large-scale use of prescribed fire^{119,120} and Indigenous fire management practices at local and regional scales^{66,121}. Other strategies involve mechanical or manual thinning, removal of invasives, and managed wildfire to better replicate historical fire regimes, reduce fire risk, and promote ecological resilience¹²²⁻¹²⁴. Post-fire recovery efforts can involve mulching, re-seeding, invasive plant control, and transplanting^{116,125}. More information is needed as to the efficacy of these approaches, including long-term monitoring^{126,127}.

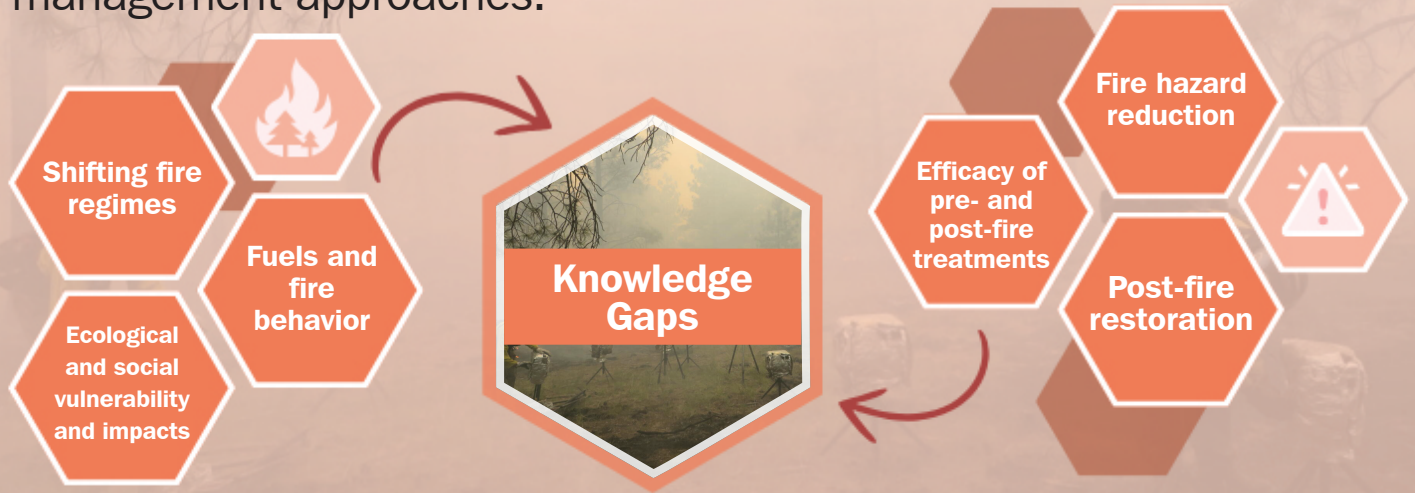
Continued research into the fire ecology of southwestern ecosystems will be needed to improve adaptive response, particularly in non-forested grassland, shrubland, and desert ecosystems. Questions remain about fire-climate relationships, species resilience, fuels and fire behavior, and long-term post-fire recovery. Indigenous knowledge, local knowledge, and western science are essential to inform best management practices for planned and unplanned fires¹²⁴. Better understanding the impacts and outcomes of prescribed burning, ideal pre-fire conditions and timing, and projections of fire risk to species, ecosystems, and human communities is also needed¹²⁸.

*Image on pg. 14: Deploying fire instruments.
Source: Rachel Loehman, USGS*



Altered Fire Regimes

Management Challenge: Shifts in the timing, frequency, size, and impacts of wildfires are challenging existing resource management approaches.



Information Needs

Further investigate climate change impacts on changing fire regimes, especially in non-forested ecosystems.

Assess the impacts of changing fire regimes on natural and cultural resources.

Identify and evaluate ecosystem and social vulnerabilities to wildfire.

Advance understanding of how pre- and post-wildfire conditions and treatments influence fire risk, spread, and behavior.

Determine the interacting effects of changing fuel loads and types, including invasive species spread, on altered fire regimes and ecosystem resilience.

Identify best practices for fuels reduction treatments, including siting, seasonality, and implementation for fire hazard reduction.

Evaluate the role of Indigenous fire management practices, prescribed fire, and other management activities in reducing fire risk and increasing resilience, including identifying barriers and opportunities to broaden practices.

Evaluate and assess post-wildfire restoration and adaptation approaches and monitoring.

Evaluate economic and social trade-offs and benefits of proactive versus reactive fire management strategies.

Figure 4. Impacts and information needs of the 'Altered Fire Regime' management challenge.

Management Challenge: High Impact Events



The Southwest is a land of high-impact climate-related events, from monsoonal rains and atmospheric rivers to extreme heat and drought, including flash droughts. These events are acute in nature and can require fast response by managers¹²⁹. Climate change has contributed to the increasing intensity, scale, and frequency of high-impact events¹³⁰⁻¹³². The number of days with excessive heat has increased over time¹³³ and hot extremes have become even hotter as humidity has declined¹³⁴. The frequency of atmospheric river events has been increasing, leading to a higher number of water management emergencies, triggering both landslides and downstream flooding of ecosystems and communities^{135,136}. While extreme precipitation events can contribute to groundwater recharge¹³⁷, heavy rains¹³⁸, rapid snowmelt, and rain-on-snow events^{6,139} can cause dangerous flooding. The size of these floods has grown as more precipitation is falling as rain versus snow¹⁴⁰. Acute declines in air quality from increasingly frequent dust storms¹⁴¹ and wildfires have cascading impacts on ecosystems and human health¹⁴²⁻¹⁴⁴. High-impact extreme events can also facilitate changes in ecosystem functioning by accelerating shifts in species composition and distribution¹⁴⁵.

The compounding stress from extreme climate-related events can make species and humans more vulnerable to insect, disease, and pest outbreaks. For example, climate-stressed forests are more susceptible to disease and insect outbreaks¹⁴⁶. Wildlife and livestock face greater exposure to tick-borne diseases given expansion in tick ranges¹⁴⁷. Extreme events can transport pathogens, such as waterborne bacteria in floodwaters¹⁴⁸ and dust-borne Valley fever¹⁴¹. Climate warming has contributed to episodic harmful algal blooms which can harm aquatic species and ecosystems^{149,150}.

Future climate change is projected to bring more excessive heat days and heat waves^{151,152}. Extreme heat can lead to lower plant primary productivity¹⁵³, declining avian abundance¹⁵⁴ and amphibian health¹⁵⁵, shifting plant phenology and wildlife response¹⁵⁶, and impacting

wildlife refuges in the Southwest¹⁵⁷. Precipitation extremes are projected to increase³⁹. With projected future climate warming, insect outbreaks are also expected to increase in magnitude¹⁵⁸. When high-impact events change in their frequency and duration, or are connected, broader scale compounding impacts can become a significant challenge for local resource managers¹⁵⁹.

An improved understanding of the causes and drivers of both individual high-impact events and their resulting compound disturbance and cascading hazards will be needed^{160,161}. Adaptation will require the identification and monitoring of vulnerable plant, animal, and human communities¹⁴⁸ and determining effective management approaches for these more acute events requiring more immediate response times^{129,162}.



*Image on pg. 17: Armoring the shore at Goleta Beach, California.
Source: Daniel Hoover, USGS Pacific Coastal and Marine Science Center*

High-Impact Events

Management Challenge: Environmental extreme events, from heat waves, flash drought, and algal blooms, to insect outbreaks, flooding, and fire.



Information Needs

Analyze the cascading and compounding impacts from extreme events and opportunities for adaptation.

Identify social and economic vulnerabilities and evaluate management strategies to prepare for high-impact events.

Assess the climate-related factors contributing to insect and disease outbreaks.

Evaluate changing flood regimes and associated impacts, and potential adaptation strategies.

Assess post-wildfire hazards and strategies for adaptation in burned area emergency response and rehabilitation.

Figure 5. Impacts and information needs of the 'High-Impact Events' management challenge.

Management Challenge: Changing Ecosystems



Climate change impacts from changing rainfall patterns, warming temperatures, drought, wildfire, and the spread of invasives have altered ecological communities in the Southwest^{[35,163,164](#)}. Pushing ecosystems beyond critical physiological and ecological tipping points can result in wholesale shifts in ecosystem characteristics, composition, and functioning^{[165](#)}. A changing climate can also lead to changing habitat suitability and habitat compression^{[166–169](#)}, and changes in species refugia and habitat connectivity, which, in turn, can limit species dispersal pathways and movement^{[167,170,171](#)}. Changes in ecosystem functioning, composition, and spatial extent will likely impact management, conservation, and restoration decisions.

Observed ecosystem impacts from climate change in the Southwest include the spread of invasive grasses, shrubs, and trees^{[164,172–177](#)}, shrubland encroachment into grasslands^{[178–180](#)}, and changes in the distribution of woodland species^{[181](#)}, resulting in altered species composition generally^{[113,182](#)}. Climate-driven shifts in ecosystems and habitats are impacting endangered, priority, and at-risk wildlife populations^{[183–185](#)}, bird communities^{[186](#)}, and threatening habitat connectivity for fish^{[187–189](#)}. Widescale ecosystem changes are also reducing carbon sequestration capacity in some areas, causing a shift from historical carbon sinks to carbon sources to the atmosphere^{[190–192](#)}.

Future projections show recent climate-driven ecosystem changes persisting. Southwestern forests are expected to become increasingly vulnerable under future climate conditions^{[113](#)}. Forests in warmer and drier regions are already experiencing post-fire recovery to non-forest vegetation types^{[193](#)}. Declines in species richness in the high-elevation evergreen forests are also projected, along with a northward shift in Sonoran Desert biodiversity^{[194](#)}, a loss of one-third of the Sonora-Mojave Creosote bush-White Bursage Desert Scrub ecosystem^{[195](#)}, and a loss of nearly one-fifth of all reptile and amphibian taxa^{[170](#)}. Overall, climate change is expected

to alter the bioclimatic variables important for maintaining ecosystem suitability when compared against historical conditions¹⁹⁶.

Management approaches designed for ecosystem persistence will need to become more flexible in the face of shifting and novel ecosystems and potential changes in ecological continuity. Climate change may occur faster than many species can adapt¹⁹⁷. Vulnerability assessments will be needed to determine likely future conditions of ecosystems and species for prioritizing management actions^{198,199}. Managing for climate change refugia will be important to preserve species and populations as well as genetic diversity and evolutionary potential²⁰⁰. Climate-smart restoration practices will be needed, taking future climate change into consideration for restoration actions and to prevent maladaptation²⁰¹. Improving our understanding and application of climate change projections in determining habitat suitability will also be important as ecosystems change in extent^{196,202}. Forest restoration may help stabilize carbon sinks, when combined with restoration of fire regimes^{203,204}. An improved understanding of potential climate tipping points^{205–207} and how to successfully employ the Resist-Accept-Direct (RAD) framework may also be needed to help managers navigate ecological transformations of Southwest landscapes^{208,209}.

Continued climate adaptation research is needed to improve our understanding of climate-related shifts in ecosystems of the Southwest and identify best management approaches for adaptation. Such research investments can help managers make science-informed decisions to prioritize habitats and species for targeted management, conservation, and preservation actions²¹⁰. These can include identifying potential climate refugia, corridors, biodiversity hotspots, areas with high genetic diversity, priority seed bank populations, and opportunities to improve connectivity^{211–216}.



*Image on pg. 20: Tonto National Forest, Arizona.
Source: USDA*

Changing Ecosystems

Management Challenge: Climate-driven shifts in vegetation can alter the landscape’s ability to support endemic, high-priority, and at-risk wildlife and plant species.



Information Needs

Improve understanding of climate-driven species movements, population dynamics, range shifts, and connectivity.	Identify the extent, distribution, and persistence of climate refugia and corridors.
Identify climate tipping points for terrestrial and aquatic species and improve decision support for managing associated impacts.	Determine the climate-related factors contributing to the establishment and spread of non-native species, including invasive species.
Evaluate the efficacy of invasive species management approaches for climate adaptation.	Identify best approaches for habitat suitability modeling under a changing climate.
Better understand climate impacts on plant-pollinator relationships.	Identify the impacts of management activities on carbon sequestration.
Determine and evaluate management best practices for ecosystem and species conservation and restoration, given projected climate change.	Evaluate the efficacy of adaptation frameworks such as Resist-Accept-Direct, including identification of monitoring strategies and protocols.
Better understand the ecological and social implications of ecosystem change, including better understanding of acceptable levels of change.	Develop and evaluate strategies for climate-smart ecosystem restoration, including decision guidance for when and how to implement.
Develop frameworks for decision support in managing species movement and range shifts in response to climate change.	

Figure 6. Impacts and information needs of the ‘Changing Ecosystems’ management challenge.



Management Challenge: Changing Coastal Environments

The Southwest has the third longest coastline in the United States, spanning over 3,400 miles of California and its offshore islands, home to approximately 26.7 million people and several of the largest estuaries in the country including Humboldt Bay, the San Francisco Bay Delta system, and San Diego Bay²¹⁷. The nearshore, shoreline, grasslands, wetlands and estuaries are rich in biodiversity^{218–222}. Coastal and nearshore environments in California are experiencing numerous climate-related impacts and threats to both natural and human communities^{223–225}. Higher greenhouse gas concentrations have altered global atmospheric and ocean circulation processes and increased ocean acidity, leading to environmental changes from sea level rise, temperature stress, marine heatwaves, storm surge, saltwater intrusion, flooding, erosion, and wetland inundation^{226–230}. These changes can impact ecosystem function, marine life, coastline extent, habitat quality and quantity, recreation areas, and groundwater quality, and threaten coastal communities and property^{226,231}.

Marine heatwaves can drive shifts in coastal biota^{232,233}, lead to toxic and harmful algal blooms^{234,235}, and may facilitate the spread of invasives²³⁶. Increasing ocean acidity can challenge marine organism persistence and health²³⁷. High-tide flooding has increased in Southern California²³⁸. Many natural coastal systems, including marshes and wetlands act as effective storm buffers; however, their persistence will likely be compromised with sea level rise and a changing climate²³⁹. Climate projections show sea level rise continuing and accelerating in coming decades²⁴⁰, rising anywhere from 2 to 10 feet by century's end^{241,242}, leaving many coastal habitats vulnerable²²¹ and coastal communities at greater risk of displacement²⁴³.

Coastal adaptation planning is exceedingly challenging, given the uncertainty surrounding the rate of future sea level rise and other climate-driven coastal change. Resource managers and municipalities will need additional tools and resources to prepare for coastal management

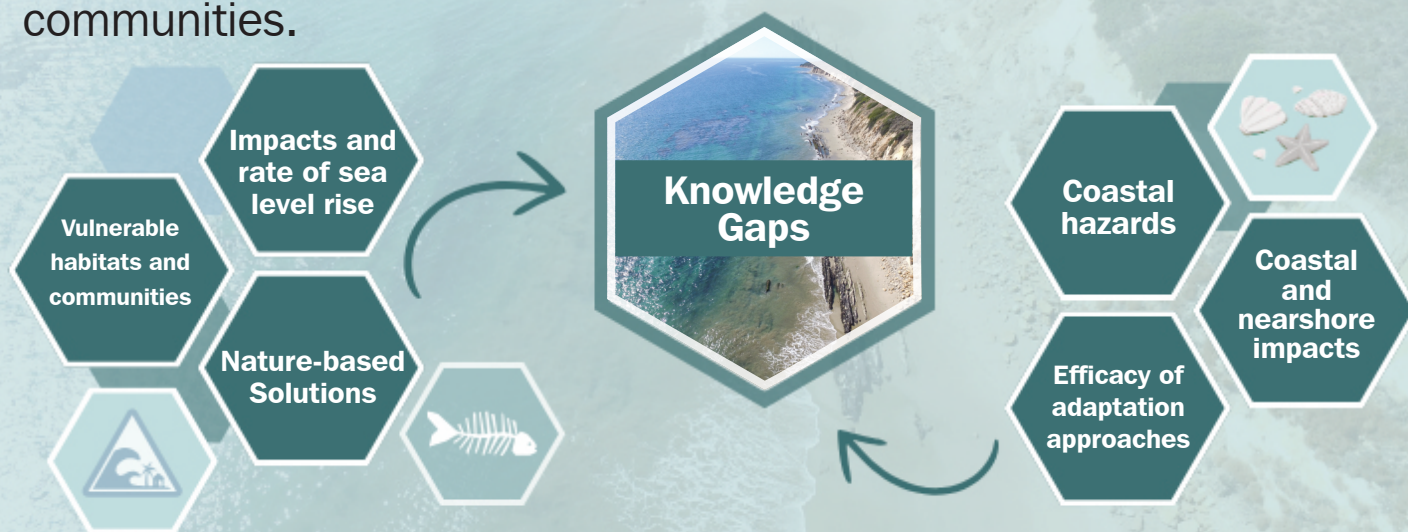
under a range of potential climate futures²²⁴. Tools to assess and evaluate the impacts of climate-driven coastal change impacts and related hazards will also be needed²⁴⁴. Adaptation planning should consider the value of coastal ecosystem services for hazard mitigation²⁴⁵ and biodiversity protection. Research into the efficacy of nature-based solutions for coastal systems is needed to quantify co-benefits to both nature and people and advance adoption of appropriate long-term solutions²⁴⁶. Efforts to protect and conserve coastal and shoreline systems under climate change will require foundational scientific evidence to identify best practices and approaches for targeted adaptation investments²⁴⁷. Improved sea level rise estimates are needed given future uncertainty²⁴⁸ and to inform coastal wetland vulnerability assessments and identify appropriate resiliency measures²⁴⁹.



*Image on pg. 23: Arroyo Hondo Preserve, California.
Source: Steve Lee*

Changing Coastal Environments

Management Challenge: Sea level rise, increased storm surge, changing ocean temperatures, marine heatwaves, coastal erosion, and loss of wetlands are impacting coastal ecosystems and communities.



Information Needs

Assess the impacts of climate change on coastal and nearshore ecosystems.

Identify and assess regions, species, and habitats at greatest risk of climate-driven coastal hazards, including sea level rise, flooding, erosion, and storm surge.

Use climate change projections to identify potential future climate impacts on biotic and abiotic characteristics along the coast.

Identify opportunities for coastal habitat adaptation.

Evaluate sea level rise projections and uncertainty estimates to inform use in research and decision-making.

Identify and evaluate adaptation activities to increase resilience to sea level rise.

Identify and evaluate opportunities for nature-based solutions to changing coastlines.

Determine the impacts and extent of ocean acidification on coastal and nearshore ecosystem function.

Evaluate the social, cultural, and economic vulnerabilities of coastal regions and policies that constrain or advance adaptive capacity.

Figure 7. Impacts and information needs of the 'Changing Coastal Environments' management challenge.

Management Challenge: Adaptation Obstacles and Opportunities



Numerous obstacles hinder the planning and implementation of climate adaptation^{[250,251](#)}. Institutional barriers are often cited and challenging to overcome^{[252,253](#)}. To remove these obstacles, shifts in policies, practices, and mindsets will be needed^{[254](#)}.

Climate change will require new approaches to decision-making. Traditional management approaches may need to incorporate adaptive management practices as climate change alters existing ecosystem conditions and species composition^{[255](#)}. Conserving communities, species, biodiversity, and areas already protected may be more effective if climate change is considered in the planning process^{[256–258](#)}. Managing under conditions of uncertainty, such as environmental variability, non-stationarity, and where observations are sparse, also presents significant challenges for managers^{[259,260](#)}. Sometimes, adaptation strategies are poorly designed and can result in maladaptation, a result where vulnerability to climate impacts increases as a result of the action^{[261,262](#)}. Resource managers will need flexible adaptation strategies, which consider historical as well as potential future conditions to effectively manage given these uncertainties and to maximize adaptation investments over time^{[263,264](#)}.

Opportunities to improve climate adaptation planning are available. Including the appropriate decision makers, communities, and knowledge systems into the decision-making process can be effective^{[265,266](#)}. Successful adaptation approaches may also benefit from identifying climate scenarios for examining management and response actions^{[267–270](#)}. Developing robust frameworks for communicating risk and uncertainty can ensure climate adaptation science is properly incorporated into resource management decisions^{[271–273](#)}. Conservation and restoration activities which can generate multiple co-benefits for managers and stakeholders may also reduce risk and improve resilience^{[274](#)}. Greater incorporation of social science research is needed to understand the human dimensions of climate adaptation^{[275,276](#)}.

Climate adaptation decisions are made by people, understanding perspectives of decision-makers and impacted communities can help us understand why some strategies succeed and others fail. Understanding the links between human and non-human communities in socio-ecological systems increases the sustainability of climate solutions. Social science methods can elucidate the institutional, social, and governance structures that hinder climate adaptation to facilitate transformation and improve research approaches^{266,277}. Coproducing adaptation strategies with decision-makers and impacted communities and including diverse ways of knowing can increase the depth and breadth of our understanding of complex systems and create more successful adaptation strategies. Opportunities to strengthen regional coordination and support large landscape-based adaptation strategies also exist through shared learning, greater collaboration, and improved communications across jurisdictional and agency boundaries²⁷⁸.



Image on pg. 26: Colorado River, Arizona
Source: Public Domain

Adaptation Obstacles and Opportunities

Management Challenge: Evaluating institutional, policy, and scientific opportunities and barriers to effective climate adaptation.



Information Needs

Inform the design of effective monitoring programs and early warning systems to detect and respond to climate change and track the impacts of adaptation strategies.

Determine effective practices for adaptation to climate change and identify ways to detect and reduce the risk of maladaptation.

Evaluate laws, policies, regulations, and practices impeding or facilitating effective management of natural and cultural resources in a changing climate.

Assess how climate adaptation choices to protect natural and cultural resources are influenced by perceptions and values of decision makers, interested parties, and rightsholders.

Evaluate and identify appropriate climate projections to improve prioritization of conservation and restoration actions.

Evaluate strategies for identifying and filling data gaps.

Assess the efficacy of climate-informed decision science, scenarios, and frameworks in the selection, application, and siting of restoration, conservation, and nature-based solution management actions.

Develop and evaluate frameworks for effective risk communication and incorporation into decision-making.

Identify strategies for respectfully including and applying Indigenous and local knowledges into planning, while respecting data sovereignty and the principles of Free, Prior, and Informed Consent.

Develop strategies for assessing the relative value of additional data and/or reduced uncertainty for decision-making.

Identify co-benefits associated with climate adaptation practices.

Figure 8. Impacts and information needs of the 'Adaptation Obstacles and Opportunities' management challenge.



III. Conclusions

This Science Needs Assessment was informed by multiple engagements with the SW CASC Advisory Committee. Through virtual, in-person, and electronic communications, the Advisory Committee worked to define these six management challenges representing region-wide resource management issues. The information needs associated with each management challenge highlight where knowledge gaps exist which impede managers from effective, science-informed decision making. The Science Needs Assessment can be used to guide SW CASC scientists and our partners in selecting relevant and actionable research projects to help fill these information needs, ultimately improving regional resource management actions.

Using the Science Needs Assessment as a guidepost, the SW CASC can engage with USGS colleagues to determine how these information needs are aligned with current administration priorities. Aligning science needs with administration priorities can help improve efficiencies by streamlining research investments, improving collaborations, and leveraging existing resources and federal capacity.



Old growth coast redwood groves, Headwaters Forest Reserve, CA. Source: Public Domain



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