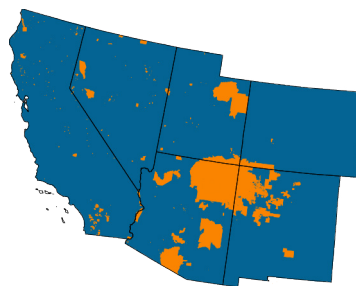


Southwest



Chapter 28. Southwest

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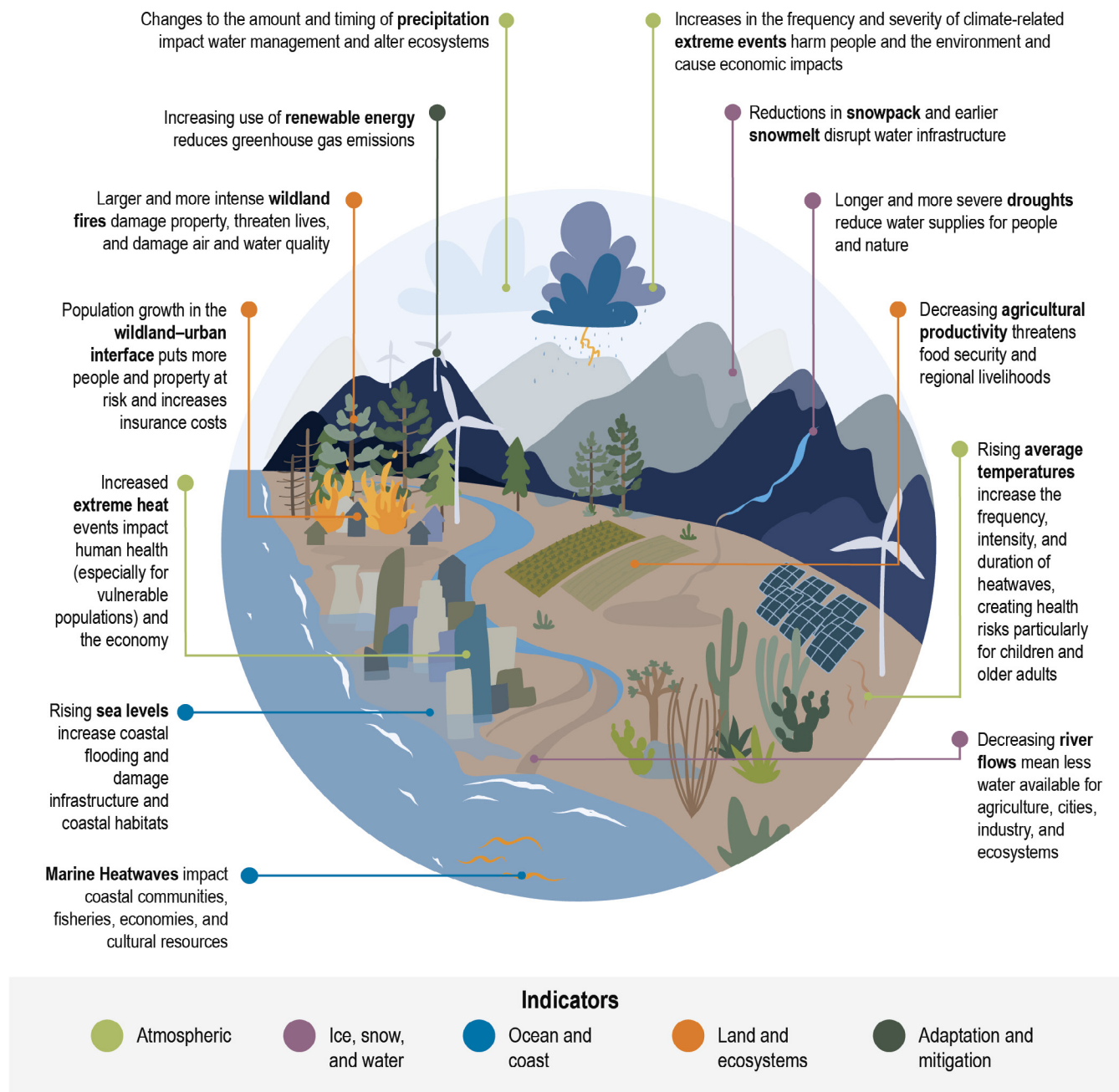
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Introduction

The Southwest encompasses diverse natural ecosystems, vibrant cultures, and productive economies. This vast region spans nearly 700,000 square miles, or 18% of the US land area.¹ The Southwest is home to more than 60 million people and is among the fastest growing and most economically productive areas of the country. Southwest ecosystems provide society with food, energy, and water; regulate climate; protect against disasters and disturbances; and offer the settings and inspiration for meaningful social, cultural, recreational, and spiritual experiences (Figure 8.17).

Climate change is negatively impacting human health and well-being (KM 15.1), cultural heritage, property, built infrastructure, economic prosperity, natural capital, and ecosystem services across the Southwest (Figure 28.1). Impacts include rising air temperatures² and sea surface temperatures, both attributable in part to human activities;³ changes to the timing, form, and amount of precipitation;^{4,5,6} sea level rise and associated flooding events;⁷ increases in extreme heat events;⁸ summertime heat stress^{9,10} and heat-related mortality;¹¹ surface and groundwater reductions;^{12,13,14,15,16} increased wildfire risks;^{17,18,19,20,21} and changes to ocean chemistry. These impacts pose heightened risks to overburdened and frontline communities and to Indigenous Peoples (KMs 4.2, 15.2, 16.1).

Climate Change Indicators, Impacts, and Responses in the Southwest



Indicators highlight important climate impacts and adaptation and mitigation efforts.

Figure 28.1. Indicators track the impacts of climate change on the atmosphere; ice, snow, and water; ocean and coast; and land and ecosystems, as well as adaptation and mitigation efforts. Monitoring these indicators helps us understand how impacts are experienced and how to adapt to risks. See Appendix 4 for more Indicators. Figure credit: Arizona State University. See figure metadata for additional contributors.

Southwest ecosystems transition from deserts and grasslands in hotter and lower elevations to forests and alpine meadows in cooler, higher elevations. The region supports important terrestrial and marine biodiversity and ecosystems, including the Sonoran Desert, the Sierra Nevada, and the Pacific Coast. The southern deserts commonly see temperatures between 105° and 115°F, and Phoenix has the hottest climate of all major US cities. The California coast stretches 3,400 miles (5,500 km), and its coastal wetlands provide critical habitat for fish and wildlife, protect water quality, and buffer against storms and floods.

The region is heavily urbanized, with 9 out of 10 people living in cities such as Albuquerque, Denver, Las Vegas, Los Angeles, Phoenix, Salt Lake City, and San Francisco. The region is also a major hub for software innovation, information technology, and semiconductor manufacturing. California's economy alone contributed more than \$3.21 trillion (in 2022 dollars) to the US GDP in 2021, about 12% of the total US economy.²² The region also encompasses expansive rural areas with livelihoods centered on ranching, mining, agriculture, and tourism.

Indigenous Peoples and Tribal lands are essential to the social, cultural, and geographic identity of the region. The Southwest is home to 182 Federally Recognized Tribes,²³ as well as numerous state-recognized Tribes and Tribes seeking state or federal recognition. California has the largest number of Federally Recognized Tribes (109) and the largest Indigenous population of any state.²³ Arizona, New Mexico, Colorado, and Utah are home to seven of the most populous Tribes, ranging from 10,000 to more than 300,000 members. Nine Tribes in the Southwest are considered “large land-holding Tribes,” five of which are among the ten largest reservations in the US, ranging in size from 600,000 to 16 million acres. The largest US federal Indian reservation—the 16-million-acre Navajo Nation Reservation—occupies portions of Arizona, New Mexico, and Utah.

The Federal Government manages nearly half of the total land area of the region through national parks, forests, fish and wildlife reserves, military installations, and public lands.²⁴ In Nevada, the Federal Government is responsible for managing more than 80% of the total acreage of the state.²⁴ Thus, the Federal Government is central to adaptation and mitigation in the Southwest.

Over the past five years, climate change impacts in the Southwest have become increasingly apparent and widespread.²⁵ At the same time, understanding and modeling of how these impacts affect specific sectors and processes have improved. For instance, advances have been made in understanding and modeling of water,^{26,27,28} food and agriculture,²⁹ wildfire,¹⁹ invasive species, biodiversity loss (KM 8.2), ecosystem transformations, human health,³⁰ and human migration across the Southwest.^{31,32} Furthermore, research has advanced understanding and modeling of interdependencies, feedbacks, and cascading risks for interconnected systems (KM 18.1) such as the food–energy–water nexus (KM 18.3).^{33,34}

To address these climate change impacts, governments, nongovernmental organizations, and private enterprises are increasingly responding with planning and actions to reduce current and future risks and increase adaptive capacity. Adaptation efforts that are effective, feasible, and just—including nature-based solutions such as green infrastructure for flood mitigation—have been shown to reduce climate risk, increase resilience, and provide co-benefits to related societal goals (KM 8.3).³⁵ There is an awareness of new approaches to equity and environmental justice for frontline communities, as well as Indigenous Peoples (KM 16.2) across the Southwest. These approaches recognize, protect, and apply diverse knowledge systems, including Indigenous Knowledges (KM 16.3). Social science has also improved our understanding of inclusive, participatory, and collaborative decision-making to solve problems in this region and beyond.^{36,37,38}

While this chapter focuses on climate impacts, risks, and adaptation actions in the Southwest, it also recognizes efforts underway to mitigate greenhouse gas emissions (Figure 32.20) throughout the region at multiple scales. California, Colorado, and New Mexico are members of the US Climate Alliance, committed to reducing net greenhouse gas (GHG) emissions in line with the Paris Agreement (KM 32.5). California has committed to carbon neutrality by 2045^{39,40} and released a detailed plan with targets to achieve this goal,⁴¹ as well as augmenting funding across sectors.⁴² Both Colorado and New Mexico have statewide greenhouse gas reduction goals.^{43,44} At the local level, dozens of cities in all Southwest states are committed to emissions reductions in line with the Paris Agreement through the bipartisan Climate Mayors network (KM 32.5). For example, the Phoenix Climate Action Plan states that the city is on track to meet its goal of 50% reduction in GHG emissions (below its 2018 baseline) by 2030 and is committed to carbon neutrality by 2050.

Key Message 28.1

Drought and Increasing Aridity Threaten Water Resources

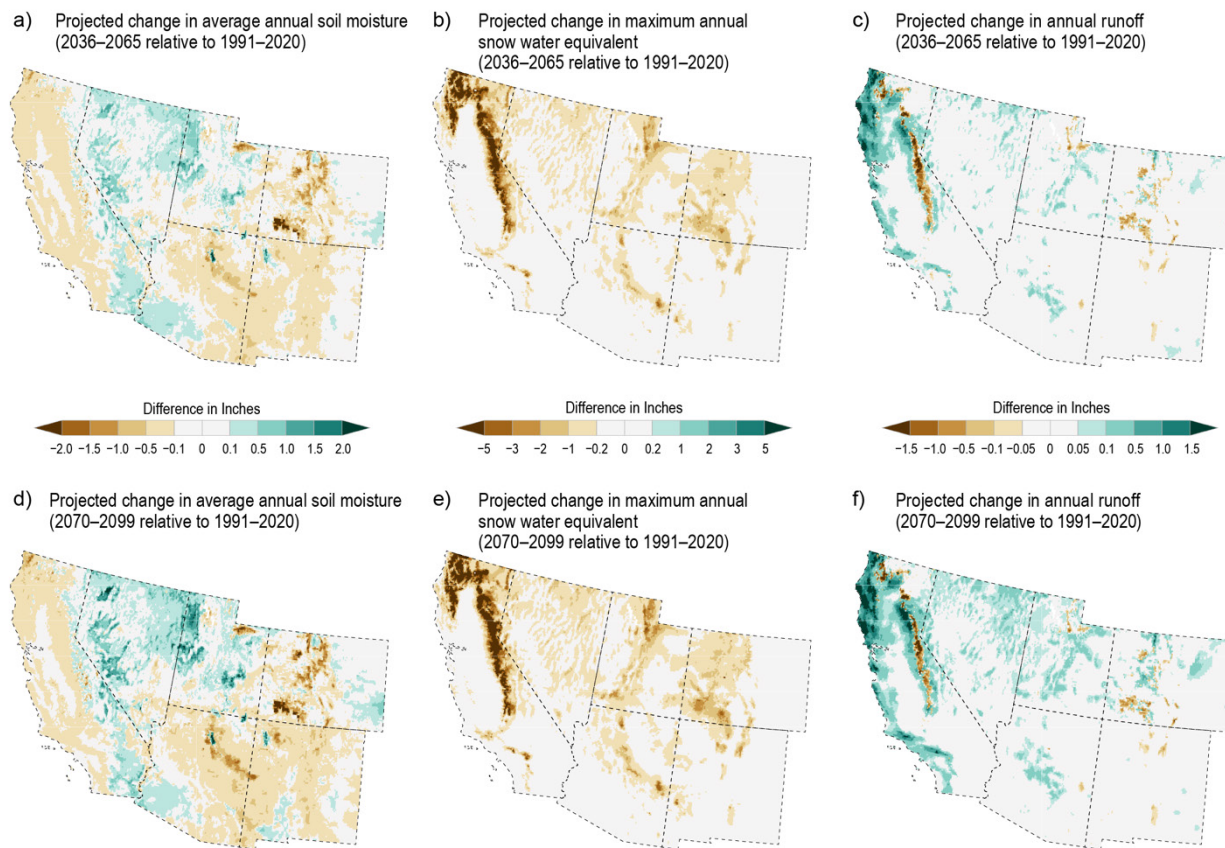
Climate change has reduced surface water and groundwater availability for people and nature in the Southwest (*very high confidence*), and there are inequities in how these impacts are experienced (*high confidence*). Higher temperatures have intensified drought and will lead to a more arid future (*very likely, high confidence*); without adaptation, these changes will exacerbate existing water supply–demand imbalances (*likely, high confidence*). At the same time, the region is experiencing more intense precipitation events, including atmospheric rivers, which contribute to increased flooding (*high confidence*). Flexible and adaptive approaches to water management have the potential to mitigate the impacts of these changes on people, the environment, and the economy (*medium confidence*).

Drought and Aridification

The Southwest region is historically arid and marked by episodes of intense drought and precipitation (KM 4.1).^{45,46} Climate change is exacerbating these conditions, as increasing temperatures are leading to hotter extreme heat events, drier soils, greater atmospheric evaporative demand, and reduced flows in major river basins such as the Colorado and Rio Grande.^{14,47,48,49,50} For example, between 1913 and 2017, annual average discharge from the Colorado River decreased by 9.3% for each degree Celsius of warming (Box 28.1).⁴⁹ Additionally, since 2000 the Southwest has experienced an exceptional “megadrought”—defined as an episode of intense aridity that persists for multiple decades—that is recognized as the driest 22-year period in 1,200 years.⁵¹

Mountain snowpack is one of the most important sources of water in the Southwest, serving as a natural reservoir to supply water to drier, lower elevations for irrigated agricultural, municipal and industrial uses, and ecosystems (KM 4.1). Observed declines in western snowpack over the last century have been predominantly driven by warming trends,⁴ leading to smaller snowpack volumes, higher-elevation snow lines, and earlier snowmelt (KM 3.4).^{6,52} These processes are exacerbated by the deposition of dust and other light-absorbing particles on snowpack, which accelerates snowmelt.⁵³ The resulting decrease in snow cover also reduces the albedo, or reflectivity, of the land surface, resulting in a positive feedback cycle that further increases solar radiation absorption, warming, and snowmelt.^{49,54,55} These changing snowpack dynamics are expected to have different influences on the timing and volume of snowmelt-driven streamflow in different basins,⁵⁶ potentially disrupting the ability of existing water infrastructure, including hydropower, to meet the region’s needs^{5,49} and altering ecosystem dynamics. Persistent low-snow years are projected to occur in the next half century if climate change continues unabated (Figure 28.2).⁵

Projected Changes in Soil Moisture, Snow Water Equivalent, and Runoff



Climate change is projected to reduce snow water equivalent and alter trends in soil moisture and annual runoff.

Figure 28.2. These maps show projected average mid-21st-century (2036–2065; top row) and late-21st-century (2070–2099; bottom row) differences in annual soil moisture, snow water equivalent (the amount of water contained within the snowpack), and runoff over the Southwest region relative to the baseline period, 1991–2020. The data in these maps come from a land-surface hydrological model that simulates different parts of the water and energy balance. The model takes temperature and precipitation data from an ensemble of downscaled Coupled Model Intercomparison Project, Phase 5 (CMIP5) global climate models using an intermediate scenario (RCP4.5)⁵⁷ to create future projections of soil moisture, snow water equivalent, and runoff.⁵⁸ Warming temperatures and precipitation variability are expected to reduce snow water equivalent and alter trends in soil moisture and annual runoff (KM 4.1). The historical record shows that the climatology of 1991–2020 was substantially warmer than the climatology of preceding 30-year periods. Thus, the areas of projected lower soil moisture, snow water equivalent, and runoff in this figure, especially at higher elevations, present marked deficits in comparison to 30-year periods in the 20th century. There are also areas of projected increases in soil moisture and runoff. Some CMIP5 global climate models project increased precipitation over parts of the Southwest, and when these are included in calculating average soil moisture or runoff, the result indicates wetter conditions in some locations, predominantly in Nevada, Utah, southwest Arizona, and southeast California. For more detail on variability, Figures 4.5, 4.6, and 4.7 show data from the same source that illustrate the wet to dry range of projections for the mid-21st century. Figure credit: New Mexico State University; Arizona State University; University of Nevada, Reno; NOAA NCEI; and CISESS NC.

In addition to extended periods of record-low precipitation, higher temperatures driven by climate change have increased evapotranspiration and reduced soil moisture, which can reduce the volume of runoff produced from a given amount of precipitation.^{16,47,50,59} These trends have negatively impacted natural resource management and agricultural production (KM 11.1) by increasing stress on vegetation.⁶⁰ Coupled with increases in demand and subsequent water withdrawals, reduced streamflow has caused many

of the region's lakes and reservoirs, such as the Great Salt Lake, to reach historically low water levels.⁶¹ Furthermore, greater variability in streamflow threatens the region's ability to consistently produce and use hydropower, impacting a typically reliable and low-carbon source of energy.⁶²

Climate warming will also reduce groundwater recharge from rainfall, snowmelt, and runoff in some areas, thereby reducing groundwater storage.^{63,64} These effects are exacerbated by groundwater pumping to satisfy the needs of agricultural irrigation,^{65,66} which is the biggest consumer of fresh water in the region. The Central Valley aquifer of California is one of the most stressed aquifers in the world; during the 2012–2016 drought, about two-thirds of the valley's surface water deficit was due to groundwater pumping, which caused land subsidence (the gradual sinking of land) in some areas⁶⁷ and declines in groundwater quality.

Flooding

Despite the region's increasing aridity, flooding from extreme precipitation events (KM 3.5) and snowmelt conditions (KM 4.1) also poses a threat to life and property, as well as to freshwater ecosystems.^{68,69} Due to climate change, snowmelt-driven flooding is expected to occur earlier in the year due to earlier runoff.⁷⁰ Moreover, atmospheric rivers, which have driven much of historical flooding in the region, are expected to intensify under a warming climate.^{71,72} Flooding from sea level rise may also threaten water infrastructure and supplies in areas such as the Sacramento–San Joaquin Bay Delta region.^{73,74}

Disproportionate Impacts

Critically, the impacts of these climate-driven changes are experienced disproportionately by certain communities in the region, including Indigenous communities (KM 16.1). A lack of clean water and sanitation services in Indigenous communities came to national light in 2020 due to COVID-19, which spread 3.5 times faster among Indigenous than non-Indigenous communities in the initial stage of the pandemic,⁷⁵ due in part to the lack of access to potable water in some Indigenous communities. A major impediment to water access is the cost of water infrastructure, which averages \$600 per acre-foot of water for non-Indigenous families with piped delivery, compared to \$43,000 per acre-foot of water for Navajo families relying on hauled water (no dollar year available).^{76,77} Furthermore, many Tribes in the region continue to lack access to water because their water rights have not been adjudicated through settlements or other processes, which could further exacerbate water shortages for other users.⁷⁸

Other examples of overburdened communities experiencing disproportionate water-related impacts of climate change include certain Black communities, which face disproportionately higher flood risk in Los Angeles,⁷⁹ and Hispanic and low-wealth communities, which receive lower-quality drinking water⁸⁰ and may be systematically excluded from water management processes (KM 4.3).⁸¹

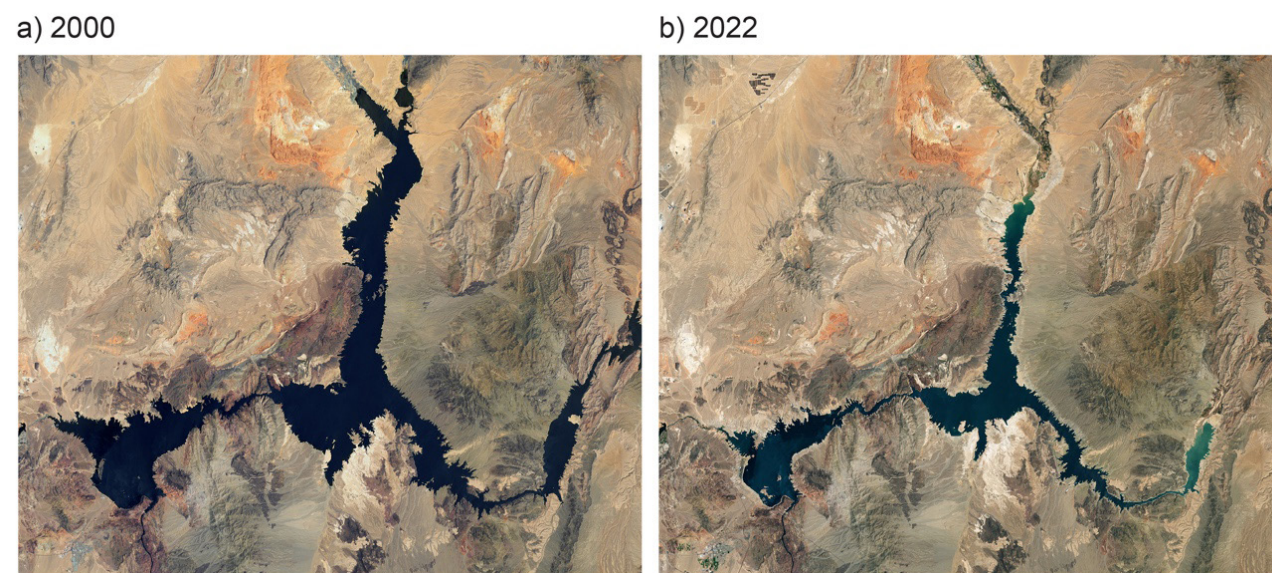
Adaptation Pathways

In response to these interrelated climate challenges, people across the Southwest have implemented adaptive water governance and management approaches. Examples include California's Sustainable Groundwater Management Act⁸² and various conservation and drought response measures in the Colorado River basin,^{37,38,83} which incentivize collaboration among diverse participants to develop innovative solutions (KM 12.4). Transitions toward more sustainable water management under climate change also include innovative infrastructure (e.g., enhanced aquifer storage, recharge, and recovery) and institutional practices (e.g., integrative land and water management practices, changes in rate structures, water sharing agreements, and reservoir operations).^{84,85,86,87} Social science studies in Southwest cities such as Denver, Phoenix, and Las Vegas indicate widespread support for innovative management strategies for urban water sustainability⁸⁸ and opportunities for targeted educational interventions for demand management strategies based on residents' attitudes toward climate change.⁸⁹ The extent to which these adaptation actions mitigate changes in water availability depends on interacting climate and social dynamics (KM 3.4).

Box 28.1. First Water Shortage Declaration on the Colorado River

In response to more than 22 years of historic drought exacerbated by climate change and a growing imbalance between water supply and demand in the Southwest, the US Bureau of Reclamation declared the first-ever water shortage on the Colorado River in August 2021 (Figure 4.18).⁹⁰ The decision came after the agency projected that the water level in Lake Mead, the Nation's largest reservoir, would fall to 1,066 feet above sea level, or just 36% of capacity, by the end of 2021, the lowest level since the reservoir was initially filled in the 1930s (Figure 28.3). In addition to impacting water supply reliability for all users, low reservoir levels could disrupt hydropower generation, which provides electricity to several communities in the region. The initial round of water supply cuts implemented under the declaration, following previously negotiated policies, affected Arizona, Nevada, and Mexico, with Arizona farmers taking the biggest cuts. Since then, deeper and more widespread cuts, as well as calls for additional conservation measures, have been made and are expected to expand as climate change impacts continue. In response, the federal governments of the United States and Mexico, the seven US Colorado River basin states, and Indigenous Peoples are developing a range of adaptation pathways and solutions to enhance long-standing collaboration on the Colorado River (KM 16.3), including modeling the impact of more extreme climate change scenarios on water resources in the basin. Multisector conservation and demand management is seen by many as a major solution. Farms can reduce agricultural consumption by increasing water-use efficiency using technologies such as drip irrigation and alternative crop choice. Urban and industrial water conservation, recycling, and reuse improvements could support “water-smart” and economically productive industries in the Southwest. Through a partnership with Mexico on coastal water desalination, the region could free up Colorado River water for the United States while providing Mexico with a secure new supply.⁹¹ Desalination proposals, however, have raised concerns about carbon-intensive energy demands, cost, brine management, and inequitable impacts on Mexico, including environmental impacts from brine disposal. Innovative, decentralized water treatment facilities could directly benefit communities in both countries, including those on Tribal lands.

Satellite Images of Lake Mead



Lake Mead water levels have declined, with potential water supply implications for millions of people.

Figure 28.3. Lake Mead, the largest reservoir in the US, supplies water to tens of millions of people across the Southwest; irrigates millions of acres of agricultural land; supports biodiversity, cultural heritage, ecosystems, and ecosystem services; and provides recreational opportunities. From 2000 (a) to 2022 (b), the water levels in Lake Mead declined from 98% to just 27% of its capacity, as shown in these satellite images. Satellite images: NASA Earth Observatory.

Key Message 28.2

Adaptation Efforts Increase to Address Accelerating Impacts to the Region's Coast and Ocean

Large-scale marine heatwaves and harmful algal blooms have caused profound and cascading impacts on marine coastal ecosystems and economies (*high confidence*). Without implementation of adaptation or emissions-reductions measures, human-caused warming will drive more frequent and longer marine heatwaves (*very likely, very high confidence*), amplifying negative coastal effects (*medium confidence*). Sea level rise, along with associated impacts such as flooding and saltwater intrusion, will have severe and disproportionate effects on infrastructure, communities, and natural resources (*likely, very high confidence*). The California State Government has applied climate science to planning and decision-making for sea level rise, and multiple regions are moving toward climate-informed and adaptive strategies for fisheries (*high confidence*). However, climate planning and adaptation solutions for aquaculture are less clear (*high confidence*).

The coastal region of the Southwest encompasses approximately 3,400 miles of coastline and nearly 70% of the state's 39.4 million people. California's 19 coastal counties employ more than 12 million people⁹² and in 2012 accounted for 80% of the state's GDP (\$57.25 billion in 2022 dollars).⁹³ Furthermore, California is showing leadership through adaptation actions nationally.

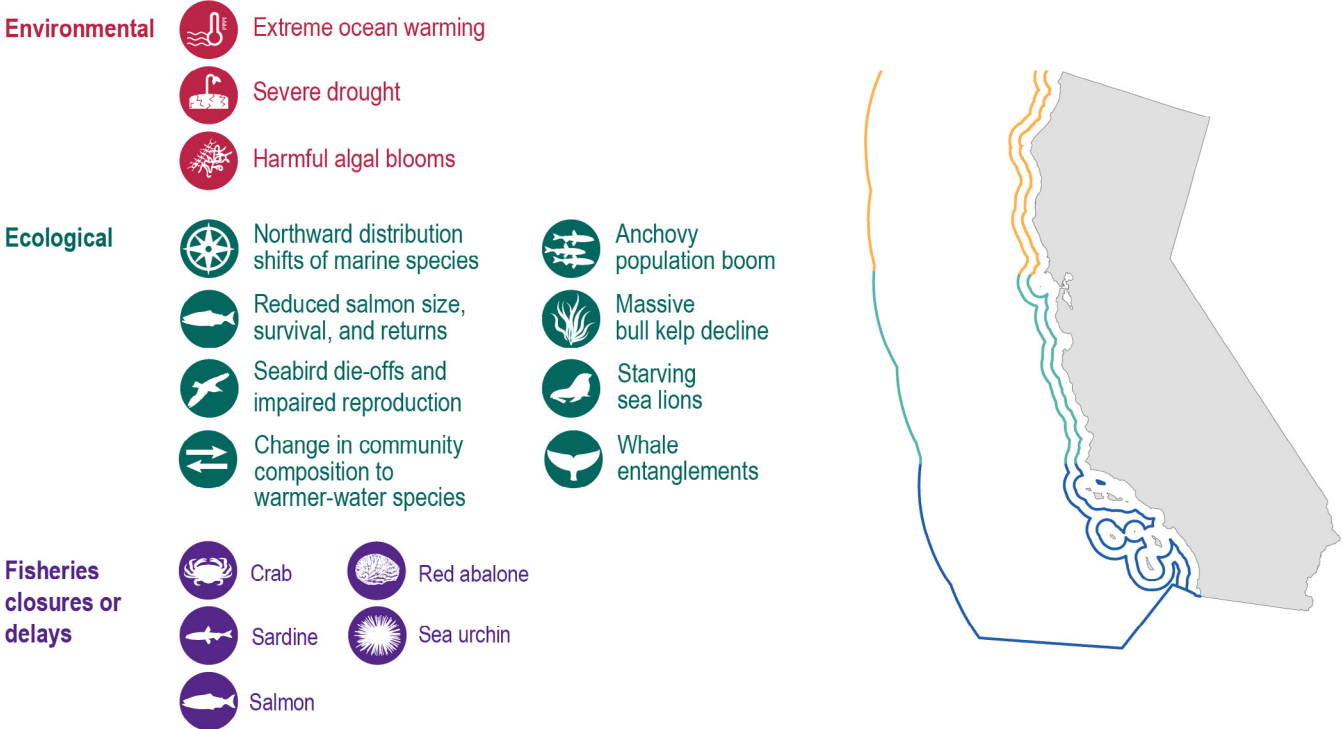
Ocean Extremes and Adaptation

California coastal sea surface temperature has increased an average of 0.4°–0.6°F per decade since the 1970s⁹⁴ and is projected to increase into the future under climate change (Ch. 2).^{95,96} Human-caused warming also contributes to marine heatwaves (MHWs; Figure 28.4), or incidences of exceptionally warm ocean temperatures, which have already had significant impacts on human and natural systems (Box 10.1).^{97,98,99,100} The change in average cumulative intensification of MHWs for the entire US coast is presented in Figure A4.11. As the ocean warms, including in California coastal waters, MHWs increasingly exceed thermal limits of ecosystems, amplifying impacts⁹⁹ including shifts in marine species composition,¹⁰¹ lower abundance and nutritional quality of important small prey fishes,^{102,103} and a potential influence on mass seabird mortalities and reproduction.^{104,105} Similarly, Tribal/Indigenous Traditional Knowledge demonstrates significant declines in five coastal species of cultural significance for the Tolowa Dee-ni' Nation, the Cher-Ae Heights Indian Community of the Trinidad Rancheria, the Wiyot Tribe, and the InterTribal Sinkyone Wilderness Council, a Tribal consortium of ten Tribal Nations.¹⁰⁶ Such ecological changes disproportionately impact coastal communities and economies (KM 9.3),^{107,108,109} including cultural resources for Indigenous Peoples (KM 15.2).^{106,110} The 2014–2016 Northeast Pacific marine heatwave was followed by others in 2018¹¹¹ and 2019–2020.¹¹² These MHWs can coincide with and contribute to other climate-related extremes such as drought¹⁰⁰ and harmful algal blooms (HABs).¹¹³

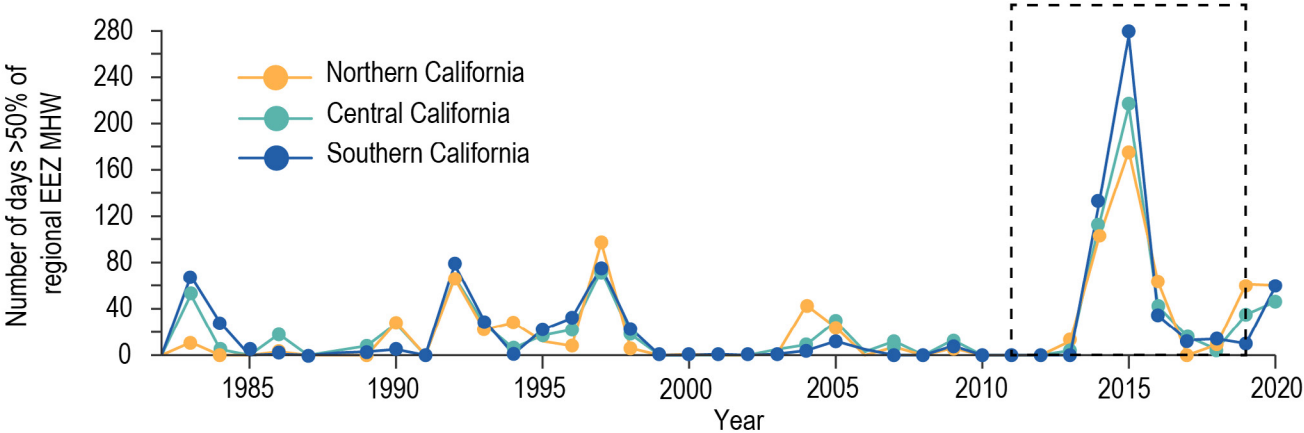
California Marine Heatwaves

a)

Coast-wide impacts



b)



Pacific marine heatwaves have had coast-wide impacts on ecosystems and fisheries.

Figure 28.4. The 2014–2016 Pacific marine heatwave (MHW) was unusually long and resulted in a variety of impacts for the southwest California coast (a). This MHW was followed by less extensive events in 2018 and 2019–2020 (b). While impacts like this can be expected to continue, they demonstrate the need and potential for adaptive management and mitigation through an integrated ecosystem approach to managing marine habitats and fisheries. EEZ refers to exclusive economic zone. Figure credit: University of California, Santa Barbara; California Department of Transportation; NOAA NCEI; and CISESS NC.

Commercial and recreational wild fisheries, as well as aquaculture (aquatic farming), will continue to be negatively affected by MHWs and HABs,¹⁰⁷ resulting in severe economic ramifications.^{113,114,115,116} Extreme ocean warming events also have compound effects: an MHW contributed to the loss of more than 90% of Northern

California's bull kelp, a foundational species for the ocean ecosystem, resulting in large economic losses in fisheries (Focus on Blue Carbon),^{117,118} including the red abalone, a species now listed as critically endangered by the International Union for Conservation of Nature. Further, extreme event-related delays and closures disproportionately impacted smaller-scale fishing operations.¹¹⁹

The widespread impacts of MHWs and HABs underscore the need for effective adaptive approaches to fisheries management. While fishers in California are coping with MHWs by fishing in different areas or for different species,¹⁰⁸ it will be challenging to manage fisheries in the long term under extreme warming events.¹¹⁵ Marine protected areas (MPAs), which are considered a management strategy for climate-driven ocean changes, may not buffer widespread effects of MHWs on species in southern California kelp forests.¹²⁰ Adopting an ecosystem approach that considers multiple management options instead of one species in isolation^{121,122} appears to improve management under climate change.¹²³ Applying a more coordinated disaster risk management approach to MHWs and extreme HAB events appears to correspond to better adaptive fisheries management, emphasizing the need for improving coordination and consistency across governing bodies, communities, and fishers on the frontlines (KM 10.3).^{124,125}

Human-caused ocean warming coincides with increasing ocean acidification (OA) and declining oxygen levels (hypoxia) of the deeper, more nutrient-rich upwelled coastal waters. Under a very high scenario (RCP8.5), sardines, a commercially and ecologically important species, are predicted to move poleward, resulting in substantial shifts in catch.^{109,126} Under the same scenario, increased acidity due to the ocean's chemical response to absorption of carbon dioxide is projected to increase the mortality of calcifying invertebrates (such as oysters and other bivalves), which are important to aquaculture and the food web, and result in a loss of food sources for some fishes and invertebrates.¹²⁷

Potential adaptation solutions include an ecosystem management approach to marine habitats and fisheries, as well as enforcing water and land-use regulations, which are expected to buffer some climate impacts.¹²⁸ Protection and restoration of foundational eelgrass and kelp forests in California waters provides essential habitat, and these ecosystems can also improve local pH and oxygen conditions.^{129,130} The Fishery Ecosystem Plan adopted by Pacific Fishery Management Council in 2013 includes guidance on OA and hypoxia,¹²⁸ but additional strategies—such as flexible permitting, better coordination with fishing communities, and adaptable control rules—may be needed to improve outcomes.¹³¹ Nature-based aquaculture solutions, such as conservation and restorative aquaculture, also have potential to mitigate local OA impacts^{132,133,134,135} but are just emerging in California.¹³⁶

Sea Level Rise Impacts and Adaptation Planning

Sea level rise (SLR) poses risks to the California coast through an increase in flooding, impacts from storm surges, and loss of coastal habitats and beaches (Figure 28.5; KM 9.1). Seas are projected to rise, on average, 0.79–1.25 feet for the California coastline by 2050, 3.10–6.63 feet by 2100, and 6.11–11.90 feet by 2150 (Intermediate to High scenario).⁷ California has more people living below 3.3 feet (1 m) of elevation than any other state except Louisiana;¹³⁷ the population living in the mapped 100- and 500-year coastal floodplains increased approximately 10% from 2010 to 2020.¹³⁷ SLR is also expected to exacerbate inequities in communities and result in compounding impacts, such as saltwater intrusion polluting groundwater.^{7,138,139,140,141,142,143} Furthermore, coastal Tribes in California are observing rising sea levels, which, when combined with the loss of kelp forests, are increasing the risk of coastal erosion, destruction of cultural artifacts, and limited access to traditional shoreline sites.¹¹⁰

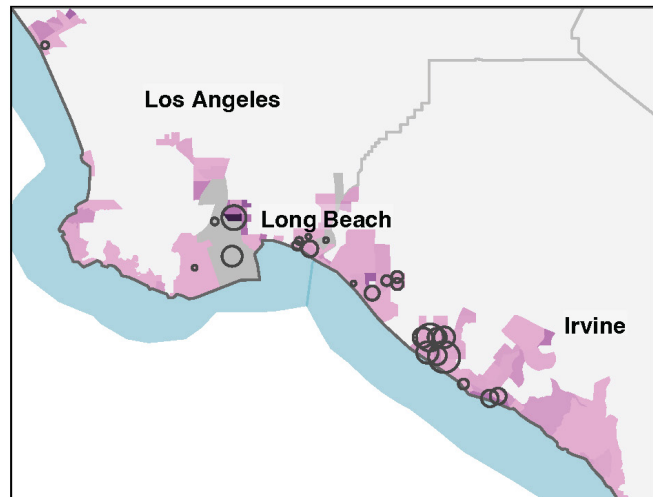
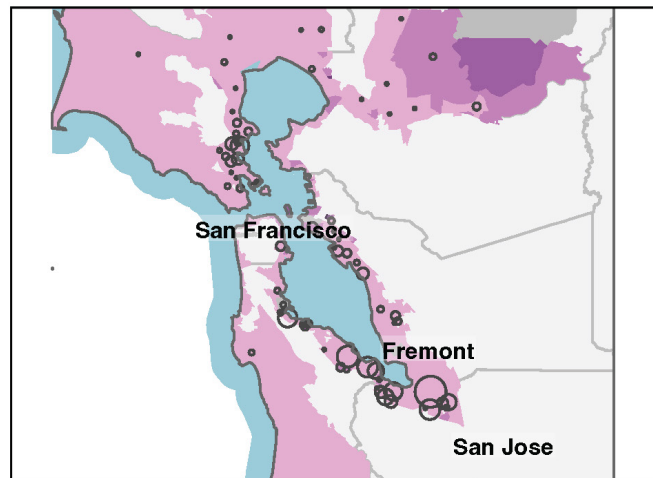
By 2050, for all emissions pathways, SLR effects on tide and storm surge are expected to cause more frequent moderate to major high tide flood events, and coastal communities are already experiencing minor to moderate high tide flooding (KM 9.1).⁷

Sea Level Rise Risks to Infrastructure and Communities

Transportation infrastructure



Low-income communities and hazardous facilities



3 ft. sea level rise

— Counties
— Highways
— Railways

● At-risk airports
● Open water
● Threatened by flooding

Poverty rate for census tracts
with flooding risk at 3 ft.
sea level rise

0.0 0.2 0.4 0.6 0.8 1.0 Missing

At-risk facilities in tract

○ ○ ○ ○
10 20 30 40

Flooding from sea level rise is expected to affect transportation infrastructure and communities along the California coast, with disproportionate impacts on lower-income communities.

Figure 28.5. These maps show the projected flood risk from 3 feet of sea level rise (SLR), as well as risks to critical infrastructure and surrounding communities, for the San Francisco Bay Area (**top row**) and the coastline from Los Angeles to San Diego (**bottom row**). Panels in the left column show transportation infrastructure threatened by flooding with 3 feet of SLR, while those in the right column show the number of hazardous facilities (indicated by circles) and census tracts at risk of flooding, with purple shading indicating the fraction of population in each census tract with income below the poverty level. Flooding from SLR will impact major transportation infrastructure along the coast; given the locations of hazardous facilities and their overlap with lower-income communities, this flooding will have disproportionate impacts on these communities. Flood risk from SLR is consistent with an Intermediate scenario in the year 2100.⁷ Transportation infrastructure includes major airports, highways, and railways. Hazardous facility categories defined by EPA include manufacturing plants, power transmission plants and substations, natural gas pipelines, refineries and oil and gas wells, waste management facilities, landfills and incinerators, and animal operations. Figure credit: Eagle Rock Analytics.

Coastal energy and transportation infrastructure is expected to be negatively impacted by flooding from SLR. The projected inundation of energy substations in low-lying areas during storm events and from extreme SLR under a very high scenario (RCP8.5) is expected to cause electricity service interruptions to thousands of customers and increase maintenance and repair costs.¹³⁹ Analysis of California's transportation fuel network found that docks, terminals, and refineries are most exposed to coastal flooding.¹⁴³ The California Department of Transportation has begun adaptation planning efforts that consider a variety of strategies beyond hardening infrastructure, including nature-based strategies to limit the impacts of flooding (KM 8.3), as well as planning to avoid loss of coastal resources and access.¹⁴⁴

Sea level rise and increased coastal flooding will disproportionately impact frontline communities (KM 9.2).¹⁴⁵ The Toxic Tides project found that under a very high scenario (RCP8.5), SLR in California^{146,147} would result in increased flooding to over 400 industrial facilities and contaminated sites, including power plants, refineries, and hazardous waste sites, with 440 projected to be at risk of at least one flood event per year by 2100.¹⁴⁸ Any flooding of hazardous sites would increase risks of contamination in surrounding frontline communities.¹⁴⁹

Residents of affordable housing, typically low-income communities, are especially vulnerable to SLR, with a greater percentage of affordable housing exposed to SLR than the general housing stock in some coastal states.¹⁴⁰ California is in the top four states nationwide with the most units of affordable housing exposed at least four times per year to coastal flooding based on projected sea levels for the year 2050 under a very high scenario (RCP8.5).¹⁴⁰ By 2050, California is also projected to see a 40% increase in the number of units at risk of flooding, compared to 2000.¹⁴⁰ For affordable housing residents, flood risk is compounded by the threat of displacement due to rising property values and rents. Strategic city-level adaptation and resilience efforts, combined with community and infrastructure improvements, could protect these residents from potential displacement.^{140,150}

Higher seas are raising the coastal groundwater table, exposing communities to flooding from water that emerges from underground (KMs 9.1, 9.2).^{138,141} Communities in low-lying areas such as San Francisco Bay are most at risk, and areas with shallow coastal water tables are projected to see widespread flooding from groundwater emergence.^{138,141} Subsidence exacerbates this threat; coastal residents residing in subsiding locations experience an average relative sea level rise of up to four times faster than the global rate.^{142,151} These risks have not been well addressed in adaptation planning. Furthermore, the impacts and adaptation needs are expected to be higher than reported if only overland flooding due to SLR—which does not include flooding from subsidence or groundwater intrusion—is considered in community and infrastructure planning.¹⁴²

Adaptation planning for SLR as a field has advanced,¹⁵² as coastal managers have reported an increased concern regarding the threat of SLR and local, regional, and state governments in California apply climate science to decision-making (KM 9.3).¹⁵³ California has instituted policies requiring consideration of climate change in state and local government decision-making and infrastructure planning.^{154,155,156,157} Specifically for the coast, there is guidance on how to apply SLR risk assessment and projections into planning, including specific guidance for critical infrastructure.^{158,159} This landscape of statewide policy and guidance is directly informing local coastal adaptation planning. Of 19 coastal counties, 18 have completed a vulnerability assessment, developed an adaptation policy, and/or updated the state-mandated safety elements of their general plans to include climate adaptation.¹⁶⁰

While adaptation planning along the California coast has advanced significantly, many of these efforts have not yet been implemented.¹⁶⁰ This is partly because of financing and implementation challenges, especially for local governments that lack resources and must overcome institutional and governance issues (KM 31.5).^{152,161} Despite these challenges, California is ahead of many other parts of the US coast in employing adaptation strategies and appears to be well positioned for increased adaptation.¹⁵²

Key Message 28.3

Increasing Challenges Confront Food and Fiber Production in the Southwest

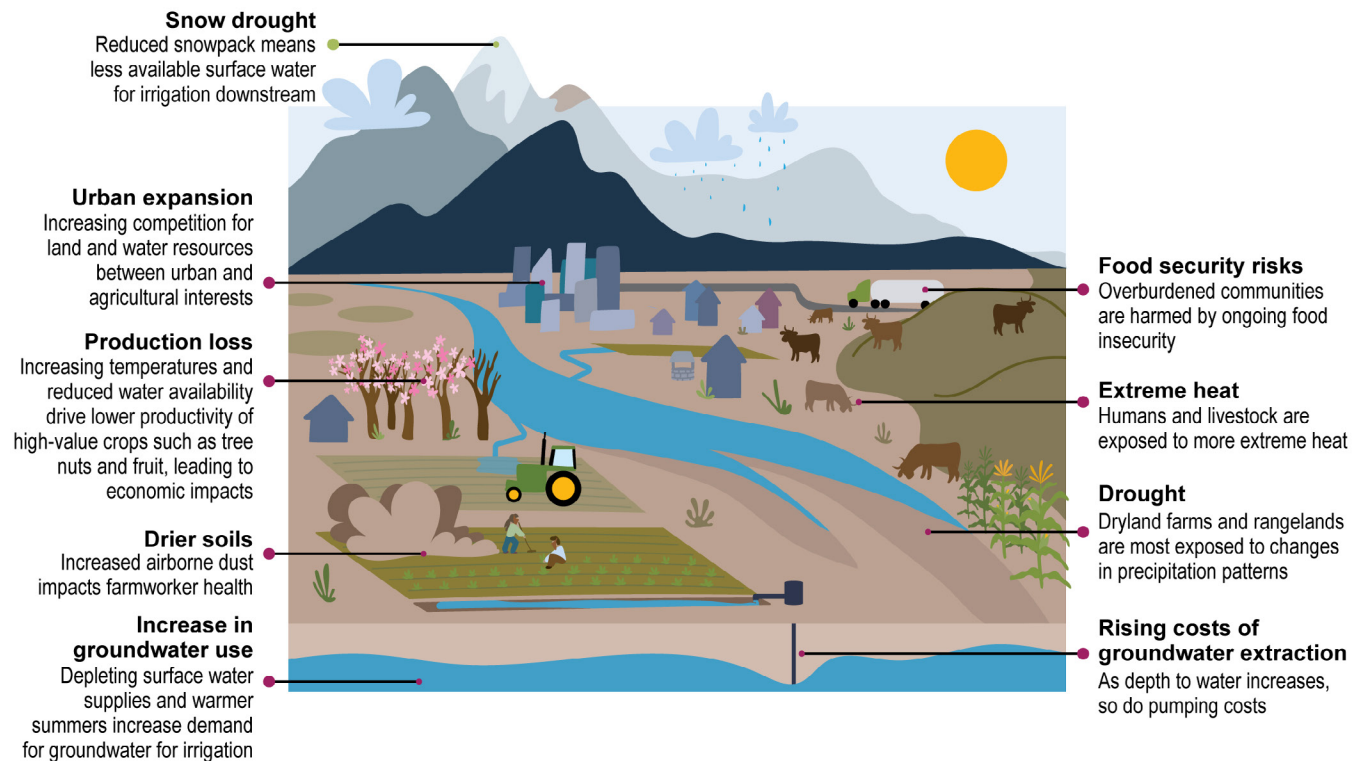
Continuing drought and water scarcity will make it more difficult to raise food and fiber in the Southwest without major shifts to new strategies and technologies (*high confidence*). Extreme heat events will increase animal stress and reduce crop quality and yield, thereby resulting in widespread economic impacts (*likely, high confidence*). Because people in the Southwest have adapted to drought impacts for millennia, incorporating Indigenous Knowledge with technological innovation can offer solutions to protect food security and sovereignty (*medium confidence*).

Across the Southwest, annual average minimum air temperatures, growing degree days, and average number of days above 86°F (the threshold used to define heat zones) are projected to increase due to climate change.¹⁶² By midcentury under intermediate (RCP4.5) and very high (RCP8.5) scenarios, projections show longer growing seasons, a northward shift in plant hardiness zones, and expanded areas of heat stress exposure to crops and livestock (KM 11.1).¹⁶² In California, increasing temperatures are expected to affect the timing of cool-season annual crops and the location of warm-season annual crops.¹⁶³ Warmer winters would be detrimental to the chilling requirements for orchard crops.¹⁶⁴ In California, fewer cold snaps are expected to reduce crop exposure to frost;¹⁶⁵ however, “false springs” in the intermountain West are expected to increase vulnerability to late-season freeze events.¹⁶⁶ During summer, a higher probability of heatwaves is expected (KM 2.2).¹⁶⁷ The productivity of some economically important crops, such as upland cotton in Arizona, has already declined because of heat stress.¹⁶⁸ While increased drought is the most prominent climate-driven risk to agriculture in the region, important farming areas such as California’s Central Valley also face damage from occasional large floods caused by atmospheric river events.¹⁶⁹

Impacts to Farming

Farmers and ranchers are particularly at risk from prolonged, severe drought (Figures 28.6, 8.6). Future temperature increases are expected to drive higher rates of evapotranspiration, increasing demand for fresh water for irrigation.¹⁶⁸ The producers most vulnerable to local precipitation deficits are dryland farmers growing rain-fed crops and producers raising livestock on rangelands. Community-based snow-fed irrigation systems in high-elevation watersheds of New Mexico and Colorado, known as *acequias*, are particularly exposed to the shortfalls in annual snowpack.¹⁷⁰ Under increasing aridity, agricultural practices such as fallowing and grazing on rangelands will need careful management to avoid increased wind erosion and dust production from exposed soils.¹⁷¹ Rising summer temperatures also degrade protective desert soil crusts formed by communities of algae, bacteria, lichens, fungi, or mosses, adding to airborne dust loads.¹⁷² The impacts of increasing aridity on agriculture are therefore twofold because dust deposits on mountain snowpack drive faster melting, depleting the snowpack¹⁷³ and resulting in reduced surface water for irrigation. While just 22 of the 216 counties in the region are classified as “farming-dependent” by the USDA,¹⁷⁴ agriculture is an important contributor to state and local economies and US food supply. California leads the Nation in agricultural cash receipts,¹⁷⁵ primarily from fruits, nuts, and vegetables; direct farm sales to consumers; and farm expenditures.¹⁷⁶ Climate change poses risks to both productivity and quality of fruit and vegetable products, requiring adaptations on farms and throughout the supply chain, including changes in crop calendars, nutrient and pest management strategies, post-harvest handling, and preservation methods.^{177,178}

Agriculture and Climate Change in the Southwest US



Monitoring indicators of climate impacts on agriculture can improve understanding and help with adaptation efforts.

Figure 28.6. Climate change impacts to the Southwest’s agriculture include longer growing seasons, a northward shift in plant hardiness zones, expanded areas of heat stress, and higher rates of evapotranspiration, increasing demand for fresh water for irrigation. Monitoring the indicators helps us understand how impacts are experienced and how to adapt to risks. Figure credit: New Mexico State University and Utah State University. See figure meta-data for additional contributors.

Reduced crop production due to climate change will carry major economic costs. Drought events have brought significant economic impacts on regional agriculture (KM 19.1); for example, the 2021 drought cost California farming sectors an estimated \$1.28 billion (in 2022 dollars) and led to the loss of 8,745 full- or part-time jobs (KM 11.3).¹⁷⁹ Modeling studies indicate that warming temperatures are expected to have a detrimental impact on the yields of almonds,¹⁶⁴ wine grapes,¹⁸⁰ and other high-value crops.¹⁶⁹ Localized adaptation strategies include crop- and locality-specific combinations of irrigation, site management (e.g., use of cover crops and increased fallowing), and cultivar selection.¹⁸¹ Fallowing as a response to water shortages can bring its own challenges, such as increased dust and weed production, but it can also enhance ecosystem services such as groundwater recharge and improved ecosystem health.¹⁸²

Climate warming is likely to lead to larger, more frequent, and more severe outbreaks of bark beetles, negatively affecting the quality and quantity of timber available to the region’s forestry and forest products industries.¹⁸³ While wood products are minor economic contributors to the region’s inland states, costs could be considerable in California, where the industry has been estimated to contribute \$44.8 billion (in 2022 dollars) and 177,000 jobs (KM 7.2).¹⁸⁴

Over time, agricultural income in the region has become more dependent on crops than livestock.¹⁸⁵ Because most Southwest croplands are irrigated, agriculture in the region had been thought to be less vulnerable to climate change than that in other parts of the country. However, future irrigation supply is

uncertain as it depends on dwindling ground and surface water supplies (KMs 28.1, 4.1). For example, Arizona allows up to 73% of its water to be used for crop production,¹⁸⁶ but the promise of continued irrigation water is less clear given the state's rapidly growing population and decreased flows in the Colorado River.¹⁸⁷ Crop irrigation, mainly of alfalfa, accounts for three-quarters of consumptive water use in the Great Salt Lake basin, where cuts to irrigation use are advocated as the state seeks to prevent total depletion of the lake and associated environmental and public health impacts.¹⁸⁸ Strategies to reduce irrigation water use include switching from gravity flow and sprinklers to more efficient systems,¹⁸⁶ but the costs of conversion can be difficult for farmers when climate change is already reducing yields.¹⁸⁵ Federal insurance programs can assist farmers after climate-related crop or forage loss, providing short-term economic relief from effects of extreme events.¹⁸⁹ However, some research suggests that federal insurance programs provide a disincentive for farmers to adapt to climate change impacts.¹⁸⁹ Non-climate-related stressors can influence the capacity of agricultural communities to adapt to climate impacts.²⁹ On the plains of Colorado and New Mexico, most rural counties are depopulating due to persistent out-migration of young adults, straining social services and reducing tax revenues.¹⁹⁰ Yet the Southwest also has some of the fastest-growing areas in the US, including high-amenity rural areas and cities expanding into agricultural zones.¹⁹¹ Urban expansion can increase cropland loss while simultaneously increasing the number of small farms focusing on specialty crops rather than basic commodities,^{192,193} placing greater pressure on the region's food supply as drought (KM 28.1)⁵¹ threatens agricultural production.¹⁹⁴

Livestock production is the dominant use of agricultural land in large areas of the Southwest where crop production is unprofitable or infeasible. Animal agriculture accounts for about one-third of agricultural revenue, with about 70% from cattle.¹⁹⁵ Climate change is expected to reduce the sustainability of cattle production that depends on rangeland ecosystems.^{195,196} Negative impacts are expected on the entire livestock food supply chain, affecting production and nutritional quality of forage, livestock health on rangelands and in transport due to heat stress and pest exposure, and shelf life of products during transport and storage.^{197,198} Forage from Bureau of Land Management rangelands is expected to decrease in Arizona and New Mexico, but it is less certain whether rangeland forage will hold steady in the central and northern portions of California, Colorado, Nevada, and Utah due to differences in moisture availability during the growing season.^{197,199}

Cascading Impacts of Climate Change to Agriculture

The cascading impacts of climate change in combination with urban population increases and other social and cultural factors pose an increasing threat to agriculture in the region.²⁹ Urban growth in the Southwest has led to competition for water between farms and cities, mirroring global trends.²⁰⁰ Water transfers from rural to urban areas have been a feature of the Southwest for decades, often with negative consequences for rural and low-income communities.^{201,202} To meet water demands for a growing metropolitan region while preserving irrigated croplands, Colorado is experimenting with water policy innovations designed to encourage rural-to-urban transfers while minimizing impacts in rural areas, but adoption has been slow due to distrust on the part of agricultural communities and uncertainty about trade-offs.²⁰² Market forces in California have encouraged growers to shift to crops with a high economic value but also a large water footprint, such as tree nuts^{203,204} and legal cannabis.²⁰⁵

Frontline Communities and Food Insecurity

Frontline communities including Hispanic populations, women farmers, migrant farmworkers, and Indigenous Peoples face challenges to water access in their homes as well as food security and health (KM 4.2).^{201,206,207} For example, the 2012–2016 drought in California's San Joaquin Valley disrupted farmworkers' employment and reduced food security, water security, and health.²⁰⁸ Mental health risks are also increasing as farmers and ranchers report moderate to severe levels of anxiety about climate change and the need

to adapt.²⁰⁹ First-generation and women ranchers are disproportionately vulnerable to climate impacts because of limited experience with drought and weaker connections to rancher networks.²¹⁰

Low-income urban communities are expected to be among the first to suffer food insecurity as climate change reduces the region's food production. Strategies have been proposed to produce more food in urban settings, but these foods often do not reach low-income consumers, who have less access to food distribution systems and often cannot afford to pay the higher prices such foods often command.²¹¹ Indigenous Knowledge has been proposed as a significant resource for climate change adaptation (KM 16.3).^{212,213} Because people in the Southwest have adapted to drought impacts for millennia, employing Indigenous Knowledge can allow the region to serve as a “laboratory” for future climate-adapted food systems²¹⁴ while enhancing food sovereignty.²¹⁵

Adaptation for Agriculture

Adaptation solutions exist for ranching operations,^{196,216} but social and economic barriers, such as distrust of experts, the financial costs and time commitments of innovation, and adherence to tradition, have slowed information uptake.¹⁹⁹ Climate change information is not routinely incorporated into ranchers' risk management decisions²¹⁷ and only recently has become a priority in federal agency rangeland management plans.¹⁹⁷

People across the Southwest are exploring technological adaptations to climate impacts (KM 31.3). Adaptive conservation management approaches that focus on minimizing soil disturbance while maximizing soil cover, biodiversity, and the presence of living roots have been gaining traction with farmers through practices such as cover cropping and reduced-tillage and no-till farming (KM 11.1).^{218,219} Combined with reduced tillage, cover cropping improves soil structure, organic carbon content, and infiltration and water-holding capacity in irrigated cropland²²⁰ and positively impacts nutrient cycling, crop yield, and soil water conservation in limited-irrigation, semiarid cropping systems.^{221,222} However, some farmers and ranchers, such as those who operate on small acreages, often find it hard to access the resources to transition practices or may perceive the risks of change to be too great, including financial expense and the perceived need to learn new skills.²²³

Irrigation efficiency can reduce risks to farming and ranching operations due to increasing temperatures, unreliable precipitation, and reduced water resources. However, access to these solutions can be complicated due to farm or ranch location, access to surface water and groundwater, water rights, current irrigation methods, and crop types.²²⁴ In the Verde Valley of Arizona, limited access to materials, equipment, and financial resources, especially for small-scale producers, inhibits their ability to respond to water-related challenges.²²⁴ Indigenous Peoples face barriers in accessing support from the Natural Resources Conservation Service (NRCS) related to land tenure, financial assistance, institutional mismatches, and complexities in incorporating Indigenous agricultural methods in applications for NRCS programs.^{225,226}

Key Message 28.4

Climate Change Compromises Human Health and Reshapes Demographics

Increases in extreme heat, drought, flooding, and wildfire activity are negatively impacting the physical health of Southwest residents (*high confidence*). Climate change is also shaping the demographics of the region by spurring the migration of people from Central America to the Southwest (*medium confidence*). Individuals particularly vulnerable to increasing climate change impacts include older adults, outdoor workers, and people with low income (*high confidence*). Local, state, and federal adaptation initiatives are working to respond to these impacts (*high confidence*).

Extreme Heat Impacts

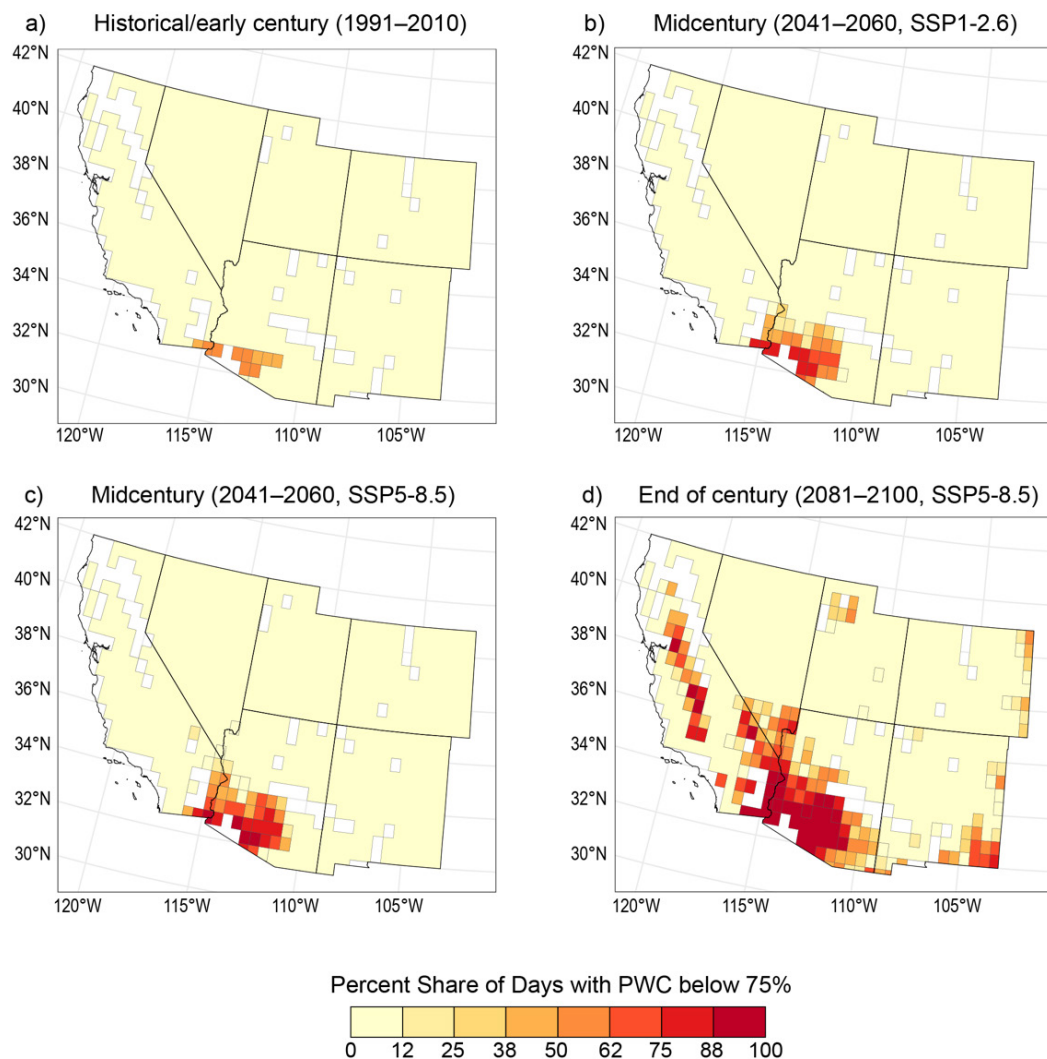
Since 2018, 31 large climate- and weather-related disasters have affected the Southwest, resulting in more than 700 fatalities and estimated damages totaling \$67.3 billion (in 2022 dollars).² Strong evidence indicates that extreme heat disproportionately impacts the health of frontline and overburdened communities in the region (KM 15.2), including the unhoused,^{227,228,229} outdoor workers, and migrant farmworkers (Figure 28.7; KM 11.2),^{230,231,232,233} as well as those with low income^{8,234} and older adults.²³⁵ Between 2016 and 2020, 7,687 hospitalizations in the Southwest were due to heat and heat-related illnesses, in comparison to 5,517 in the previous five years (2011 to 2015).²³⁶ Pre- and post-natal exposure to high heat and air pollution are shown to be particularly dangerous in the region.^{237,238,239,240}

Extreme heat and high-ozone days in the region are expected to increase under climate change (KMs 2.3, 3.5).²⁴¹ These changes are expected to increase heat and air-pollution exposure, illness, and premature death.²⁴² Intensified aridity from higher temperatures and drought is expected to lead to more dust storms²⁴³ and more than double the number of deaths attributed to fine dust by 2080–2099 under a very high scenario (RCP8.5), relative to 1986–2005 (KM 6.1),²⁴⁴ with increasing exposures for outdoor workers during the warm season. The incidence of coccidioidomycosis (Valley fever) in the region has increased (Figure 15.2)²⁴⁵ and is associated with higher air temperatures and drier soils,^{246,247} with greater risk to those whose job requires dirt disruption. The annual average cost to the US economy of Valley fever for the 2000–2015 baseline was \$4.8 billion per year (in 2022 dollars), which is projected to increase 390% by 2090 under a very high scenario (RCP8.5; Figure 15.2).²⁴⁸

Extreme heat exposure also affects the economy through decreased productivity and well-being in outdoor workers (Figure 28.7),^{249,250,251} especially among migrant agriculture workers in the region (KM 15.1).^{252,253} Impact estimates to productivity provided in Figure 28.7 are projected to result in a loss of 25% of the workday on all days in the third quarter (July–September) under a very high scenario (SSP5–8.5) by the end of century and cause important losses to the economy (KM 19.1). Dehydration due to working outdoors in extreme heat in California is linked to acute kidney illness even after a single day of exposure.²⁵⁴ Research into the mechanisms of chronic kidney disease related to climate change is ongoing, yet occupational heat exposure is a causal factor.²⁵⁵

Heat Impacts in the Southwest

Percent share of days (Jul–Sep) with physical work capacity below 75%



With extreme heat events expected to increase in frequency and severity, the ability to perform work outside is projected to decline across parts of the Southwest.

Figure 28.7. The ability to perform work outside—as measured by physical work capacity (PWC)—will decline across large swaths of the Southwest due to heat exposure throughout the century, with the greatest declines expected in southwest Arizona, southeast California, and California’s Central Valley. These impacts on outdoor work will affect agricultural output, as well as earning ability for workers. PWC has a range of 100% (no loss of work capacity) to 0% (complete loss). The maps display the proportion of days in the third quarter (July to September) in which PWC is less than 75%. In historical conditions (a), a few locations in southern Arizona had PWC values less than 75% for half of the quarter. (d) Under a very high scenario (SSP5-8.5) by end of century, most of southern Arizona, southeast California, and some of California’s Central Valley are projected to have less than 75% work capacity for all days in the third quarter. This daily labor loss is calculated based on a given heat load (temperature, humidity, and solar radiation) compared to temperate conditions where there is no thermal effect on work output. To provide a full range of potential impacts, maps are based on representative years for (a) historical/early century (1991–2010); (b) midcentury (2041–2060, SSP1-2.6 [low scenario]); (c) midcentury (2041–2060, SSP5-8.5 [very high scenario]); and (d) end of century (2081–2100, SSP5-8.5). Estimates are based on an individual performing moderate to heavy agricultural work outdoors over a daytime shift (about 7 hours). The PWC is an empirical estimate based on human physiological chamber studies quantifying how PWC changes with the environment heat load based on the wet-bulb globe temperature.^{256,257,258,259} Land areas in white had no crops in the early 21st century. Figure credit: University of Illinois–Urbana Champaign and Arizona State University.

Air Quality and Health Impacts

While the annual average level of fine particulate matter (PM_{2.5}) has seen decadal decline in the region due to strengthened air quality policies reducing emissions from controllable sources, disparities in PM_{2.5} exposure and related health concerns remain high in the region.²⁶⁰ Moreover, the frequency and severity of smoke events with PM_{2.5} exceedances of federal air quality standards have increased significantly due to wildfires (Figure 14.3). Since 2015 in Northern California, the annual average PM_{2.5} has increased because of wildfire events, which have taken over as the main source of PM_{2.5} exceedances.²⁶¹ PM_{2.5} in wildfire smoke contributes to adverse health effects for firefighters²⁶² and the public^{263,264} and can be more hazardous to health than similar levels of particulates from other sources.²⁶⁵ The costs of adverse respiratory and cardiovascular health outcomes can exceed the billions spent on wildfire suppression (KM 28.5).²⁶⁶ Chemicals in wildfire smoke also correlate with increased cancer risk.²⁶⁷ Direct exposure to the 2018 Camp Fire in California has been linked to mental health disorders such as depression and post-traumatic stress disorder.²⁶⁸ Wildfires can also cause other public health impacts, including water contamination when fires damage water distribution infrastructure,²⁶⁹ long-term loss of access to clean drinking water,²⁷⁰ and increased landslide risks (KM 28.5).

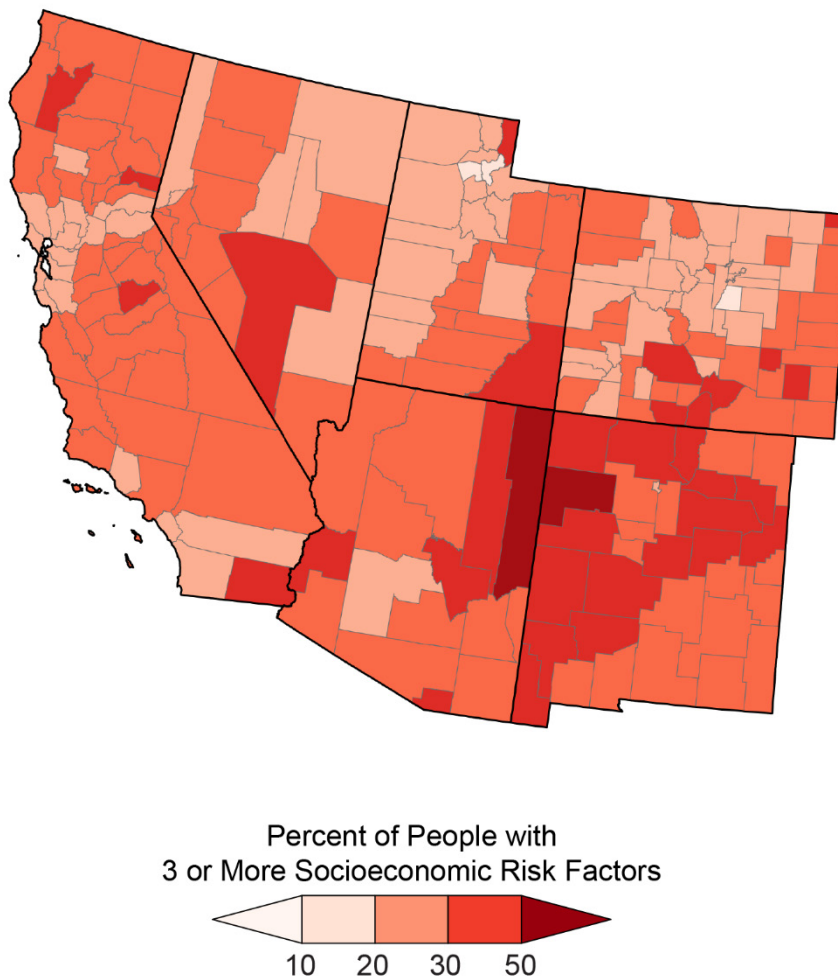
Flooding and Disease

Increases in flooding in the region are projected with continued warming.^{271,272} These changes increase risks of water-borne diseases and exposure to toxic hazards and place stress on food, energy, and water supplies, as well as farmworkers' health (including interconnected sectors) and their socioeconomic insecurity.³⁹ Flooding exposures may increase as a greater proportion of the population across the region, on average, is living on 100-year floodplains (e.g., in California, between 1990 and 2020, 25,000 more people lived on 100-year floodplains).¹³⁷ Flooding can also interrupt vector-control programs, such as for West Nile virus.²⁷³ The region is seeing challenges with West Nile virus, particularly in Arizona and California,²⁷⁴ with projected increases due to changes in the climate, human population, and mosquito distribution (KM 24.3).^{275,276}

Impacts to Outdoor Workers

Limited occupational health and safety standards for farmworkers and other outdoor workers are of key concern, as intensifying wildfires and heat collide with harvest season each year, particularly for undocumented Latino/a and Indigenous migrants.²³¹ The improvement of these standards at the state and national levels will be critical for health adaptation to climate impacts in the region. Moreover, the harm to farmworkers due to wildfire smoke is expected to be greater than previously thought, bolstering the argument for additional research and policies to help safeguard overburdened and stigmatized populations.²⁷⁷ Many Southwest cities experienced high rates of economic and population growth during the second half of the 20th century, particularly between 2015 and 2019.³¹ The region's flourishing economy and proximity to the Mexican border result in a high influx of migrants.^{278,279} Migrants from Central America, spurred to migrate due to climate change in addition to poverty and violence (KM 17.2), are drawn by the Southwest's strong economy and increase the number of vulnerable people and change the demographics in the region. Local, state, and federal efforts to both mitigate climate change and support essential human adaptation to increasing exposures will be vital in protecting the health of a growing and aging population and our most vulnerable communities (Figure 28.8; KM 15.1).²⁸⁰

Community Resilience Estimates for the Southwest



Communities with higher socioeconomic risk factors are expected to be less resilient in the event of climate and weather disasters.

Figure 28.8. The map shows community resilience estimates (CREs) for the Southwest. Community resilience is the capacity of individuals and households to absorb, endure, and recover from the health, social, and economic impacts of a disaster. Individual and household characteristics from the 2019 American Community Survey were modeled, in combination with data from the Population Estimates Program, to create the CREs at the county level. Darker shading indicates a higher proportion of the population at risk. Adapted from US Census Bureau 2021.²⁸¹

Demographic Shifts Related to Climate

The effects of climate change on other regions of the world—especially Central America—are changing the Southwest’s demographics. Decreasing agricultural productivity, increasing levels of food insecurity, and adverse climate effects are among the main reasons why people emigrate from the Northern Triangle (Guatemala, Honduras, and El Salvador) to the US (KM 17.2).^{32,279} In 2021, 42% of Central American immigrants to the US lived in the Southwest region,²⁸² and about 43% of immigrants apprehended at the Southwest border in 2019 originated from the Northern Triangle.²⁷⁸ Many are poor, women, children, or Indigenous Peoples. Climate-related migration has been shown to affect people’s physical and mental health, resulting from exposure to weather extremes, disruption of social ties, and overcrowding of health systems in the host communities.²⁸³

Adaptation Efforts for Health

Several programs have been developed to address the health impacts of climate change in the region, but financial constraints and political support affect their implementation.²⁸⁴ Since 2010, the CDC's Building Resilience Against Climate Effects program in Arizona and California has developed and implemented strategies to protect communities from climate-sensitive hazards, including schools, healthcare facilities, and other at-risk populations.²⁸⁵ This program, currently in 10 cities across the country, has developed important resources and programs that can be scaled up for future climate resilience efforts. To protect the health and learning of school children, the Arizona Department of Health Services created new heat policy guidance, resulting in recommendations for school heat safety and adaptation strategies.^{286,287} In California, San Mateo County assessed asthma burden connected to local climate issues.²⁸⁸ Public health guidance in the region should focus on co-exposures to heat and wildfire smoke in adaptation efforts,²⁸⁹ particularly given the projected increase in childhood asthma due to wildfires.²⁹⁰ While data on private sector investment is limited, the private sector has historically lacked incentives to invest in adaptation (KM 31.6). Globally, in 2017–2018 only 1.6% of all adaptation financing came from the private sector.²⁹¹ In the Southwest, however, certain sectors, such as insurance, came under pressure from the local authorities to get involved in tackling climate change by divesting their fossil fuel-based investments.²⁹²

Key Message 28.5

Changes in Wildfire Patterns Pose Challenges for Southwest Residents and Ecosystems

In recent years, the Southwest has experienced unprecedented wildfire events, driven in part by climate change (*high confidence*). Fires in the region have become larger and more severe (*high confidence*). High-severity wildfires are expected to continue in coming years, placing the people, economies, ecosystems, and water resources of the region at considerable risk (*very likely, high confidence*). Opportunities for adaptation include pre- and postfire actions that reduce wildfire risk and facilitate ecosystem restoration and include traditional land stewardship practices (*high confidence*) and the application of Indigenous cultural fire (*medium confidence*).

Fire is a natural process in many ecosystems across the Southwest and is necessary for biodiversity, ecosystem services, and nature-based solutions (KM 8.2). Fire regimes associated with fire-dependent ecosystems are highly variable with elevation and across geographies.²⁹³ Long-standing policies and forest management—including fire suppression, widespread logging and livestock grazing, and elimination of Indigenous fire use—combined with the effects of a changing climate, have contributed to high tree densities, compromised ecosystem function, and the diversity, or heterogeneity, of forest attributes such as species, size classes, and geographic distributions.^{18,21,294,295,296} Consequently, many Southwest forests and fire-prone wildlands are susceptible to climate-mediated impacts including droughts, pests and disease (Box 7.1), and devastating wildfire.^{295,297} An abundance of scientific research strongly suggests that Southwest ecosystems, in the face of rapid climate change-induced transformation, will require active management interventions that increase forest heterogeneity and enhance ecosystem function and adaptive capacity (KM 7.3).^{298,299,300}

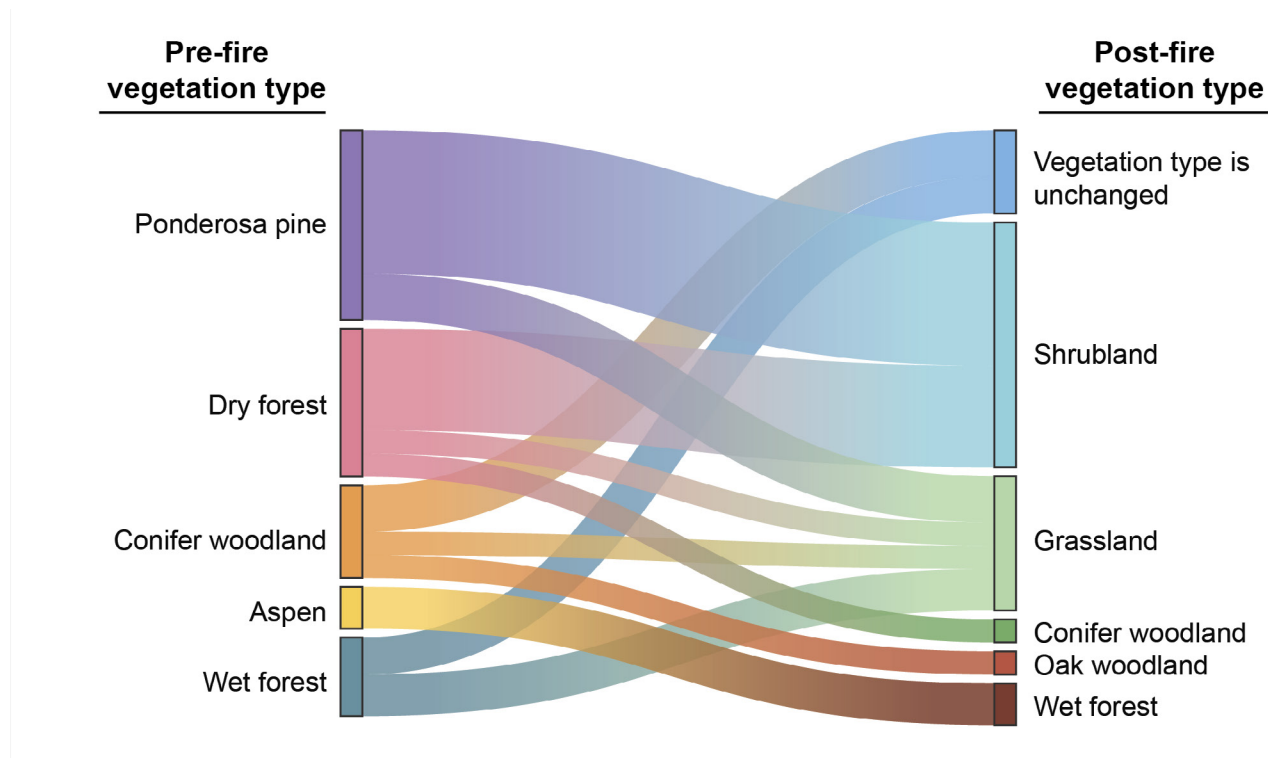
Human-induced warming temperature trends, changes in precipitation patterns, and increases in vapor pressure deficit have driven the desiccation of fuels that influence wildfire patterns and behavior across the western US (KM 7.1).^{17,18,19,20,21,301} In the Southwest, fires have become larger, more frequent, and, in many

areas, more severe (KM 7.1), with clear evidence of climate change as a major cause.^{302,303} Seven of the ten largest US wildfires in 2020–2021 occurred in the region. Of the 50 largest US wildfires in 2020, 22 occurred in California, and the 7 largest wildfires recorded in California have occurred since 2018.^{304,305,306} The three largest wildfires recorded in Colorado occurred in 2020; the largest fires in Nevada history burned in 2018;³⁰⁷ and the largest wildfires in Arizona, New Mexico, and Utah all occurred since 2007 (Figure 28.9; Focus on Western Wildfires). Large fires on non-forested western US rangelands also increased more than fivefold during the period 1984–2017.³⁰⁸ Much of this increase is driven by increases in invasive annual grass cover, caused partly by climate change and increased atmospheric carbon dioxide.³⁰⁹

Impacts on Ecosystems

Climate change causes cascading effects with other factors in Southwest ecosystems that are otherwise fire-adapted. For example, large areas of high-severity fire have driven ecosystem type conversions in many parts of the region.^{294,310} Semiarid to arid forest systems are particularly vulnerable to these effects and have experienced conversion to native grassland,³¹¹ shrubland, or non-native grassland (Figures 28.9, 8.6).²⁹⁴ The cumulative effects of fire-driven ecosystem changes continue to place ecosystems at high risk of vegetation type conversion (e.g., forests to shrublands), which can result in severe impacts on watersheds and aquatic resources.²⁹⁴ Effects include degradation of riparian systems; risks to riparian and riverine species, as well as to threatened and endangered species, from erosion caused by extreme precipitation events; and increased invasions by non-native species.³¹²

Wildfire and Vegetation Change in the Southwest



Climate change is leading to larger and hotter fires and resulting in shifts in vegetation.

Figure 28.9. Data from the states of California, Arizona, Colorado, and New Mexico show that approximately half (about 50%) of vegetation type change (e.g., forests transiting to shrublands or grasslands) is a function of high-severity fire. Adapted from Guiterman et al. 2022²⁹⁴ [CC BY 4.0].

Recent climate-induced aridification, including loss of snowpack, has also hindered postfire tree seedling and shrub establishment, limiting ecosystem recovery.^{313,314,315} This is particularly true of postfire conditions for water availability, quantity, and quality. Moreover, interactions between wildfire and natural drought variability are expected to increasingly exacerbate dry conditions that will further stress tree seedlings³¹⁶ and drive potential future shifts in species composition or vegetation type.^{314,317} Conversions of coastal shrublands driven by human development also have interacted with climate-induced drying of vegetative fuels to generate atypical fire conditions.³¹⁸

Projections of future climate change suggest that wildfire activity will continue to affect ecosystems and their services.^{298,319,320,321,322} Specific ecosystem responses to climatic changes will depend on interactions among vegetation type, moisture stress, disturbance regimes (e.g., pests, pathogens, and high-severity fire), and human land-use changes (KM 6.2).^{295,297,319} For example, climate change is predicted to lead to a loss of sagebrush ecosystems in the southern and eastern Great Basin because those ecosystems are less able to recover after fires in a warmer, drier climate.³²³

However, future wildfire trends are less certain in rangelands than in forests because fire size (measured by annual area burned) and severity (a shift from low-intensity fires to stand-replacing crown fires) depend on production of aboveground vegetation that varies annually with climatic conditions.³²⁴ Growth of the grasses that typically fuel wildfires is expected to decrease in Arizona and New Mexico,^{199,325} whereas elsewhere in the region, precipitation is projected to increase early in the growing season, which, when followed by hotter summers, will generate conditions ideal for fire ignitions.³²⁴

Impacts on People and Communities

Climate-related increases in the frequency, severity, and extent of wildfires in the Southwest are endangering lives and property (Focus on Western Wildfires).^{17,18,19,20,21,326} Complete data across the region on wildfire-caused fatalities are sparse,³²⁷ but three of the five deadliest fires on record in California have occurred since 2017, costing 122 lives.³⁰⁴ Further, loss of life can be attributed to wildfire smoke, which has also been linked to increases in COVID-19 fatalities in Northern California³²⁸ and postfire debris flows that can leave slopes bare of vegetation and vulnerable to rapid erosion (Ch. 7; Focus on Western Wildfires).³²⁹ The risk of postfire debris flows in coastal communities is expected to increase due to an increase in heavy precipitation typically delivered by atmospheric river events (KMs 28.1, 8.1).³³⁰

Property losses due to wildfire are greatest in the Southwest compared to other regions. In 2021, 3,363 structures burned due to wildfires in California, the highest number lost in any state, while the December 2021 Marshall Fire in Colorado, a fast-burning grassland fire, burned more than 1,000 homes in just a few hours.³⁰⁶ The 2022 Calf Canyon/Hermit's Peak Fire that burned 341,735 acres is New Mexico's largest fire. Secondary impacts of wildfire, such as postfire debris flows (Figures 3.13, 6.5) on recently burned slopes, impose additional hazards to property.³²⁹ The estimated cost of fighting the 10 largest California wildfires in 2021 exceeded \$2.25 billion (in 2022 dollars),³⁰⁶ with suppression costs representing only a fraction of a total economic impact that also includes loss of structures and infrastructure, increased medical costs, crop losses, water quality contamination, and other factors (KM 19.1).

The increase in structures and infrastructure lost can be linked to population growth in the wildland-urban interface (WUI; Figure A4.14), where houses are built close to forests and other natural areas.³³¹ The number of Americans living in the WUI doubled from 1990 to 2010, and the WUI population has risen fastest in areas such as the Southwest where wildfire risk is greatest.^{332,333} While migration to WUI counties shows modest reductions immediately after wildfire or extreme heat events,³³⁴ fires do not seem to drive current residents away; fewer than 6% of Sonoma County, California, residents who lost homes to wildfires in 2017 subsequently left the county.³³⁵

Impacts of fire on community livelihoods depend on exposure to wildfire risk and capacity to adapt (KM 7.3). Analysis of livelihood vulnerability in 14 fire-prone states found that New Mexico and Arizona residents were most vulnerable due to relatively high risk exposure and low to moderate access to resources needed to adapt to changing conditions.³³⁶ Low-income areas, communities of color, undocumented Indigenous migrants, sexual and gender minorities (KM 15.2),³³⁷ and unsheltered persons are most vulnerable to wildfire impacts,^{231,338} including water contamination from carcinogenic compounds.²⁶⁹ Populations with medical disabilities or limited mobility, older adults, and those who rely on medical equipment are also disproportionately at high risk during wildfires.³³⁹

Wildfires, moreover, often occur during farm harvest seasons, increasing health risks for workers.²⁷⁷ Southwest industries especially vulnerable to wildfires include wineries,³⁴⁰ tourism,^{341,342} forest products,¹⁸³ and legal cannabis cultivation.³⁴³ For example, in the 2020 fires, the economic impact of smoke taint is estimated to have cost the California wine industry \$4.2 billion (in 2022 dollars). Smoke taint occurs when smoke and ash permeate the skin of grapes and can affect the taste and smell of wine.³⁴⁴

Impacts of wildfire on natural environments can affect ecosystem services (KM 7.2) that people derive from those environments, including air quality (KM 28.4),²⁶⁶ water quality and availability,³⁴⁵ pollination,³⁴⁶ livestock forage and health,³⁴⁷ and outdoor recreation.³⁴⁸ Ecosystem service effects vary over time as short-term declines in services can be followed by improvement over a longer term as ecosystems recover.³⁴⁹ Wildfires in forested ecosystems chemically alter watersheds and can reduce drinking water quality,³⁵⁰ in some cases leading municipalities to issue drinking water advisories.³⁵¹ Postfire hazards such as floods and debris flows further threaten water security (Focus on Western Wildfires).³⁵² Smoke from the 2020 wildfires significantly reduced industrial solar energy production in Southern California.³⁵³

While high-severity wildfires (i.e., stand-replacing fire) generally have negative impacts, wildfires and prescribed fires that burn at low to moderate severities can have positive effects by reducing fuel loads, curtailing plant pests and diseases, and stimulating new vegetation growth.³⁵⁴ Prescribed burning, while an effective tool to reverse undesirable changes in forest vegetation structure due to fire suppression, can also reduce air quality in the short term.²⁶⁶

Ecosystem Management Challenges and Adaptation Solutions

Forest resilience may be enhanced by thinning trees, leveraging low- and moderate-severity wildfires with traditional forest management treatments that adjust fuels, and better incorporating managed wildfire.²⁹⁹ Using prescribed fire in conjunction with mechanical forest treatments, such as thinning or pruning, also reduces tree densities and fuels.³⁰⁰ Prescribed fire can increase forest resilience during periods of climate-related stress, such as sustained drought,³⁵⁵ and can reduce the extent and intensity of the wildfire regime.³⁵⁶ Cultural fire use to meet Indigenous and Tribal objectives can be compatible with traditional fire application and help advance increased resilience to climate change.^{296,357}

To decrease competition for water resources and increase forest resilience, reductions in tree density and fuels can lower the risk of high-severity wildfires and drought- and pest-induced mortality (KM 6.2).^{358,359} Recent evidence suggests that increasing these approaches can help adapt to the rapidly increasing risks.^{299,360} However, the implementation of prescribed fire may be curtailed due to public concerns about smoke and fires that escape management prescription.³⁶¹

Natural lands, including forests and associated woodlands, play a central role in mitigating climate change (KM 32.1).^{362,363} However, climate variability, drought- and pest-driven tree mortality, wildfire, and other disturbances suggest that the Southwest will see a continued decline in terrestrial carbon storage.^{362,364} As a result, securing or even increasing ecosystem carbon storage is often an objective for forest management investment.³⁶⁵ Forest management treatments differ in their short-term carbon losses relative to the

expected benefits of greater fire resistance, which leads to longer-term carbon stability (Box 7.2). In Southwest forests, reducing thinning area and increasing the area burned enhances the potential for a net carbon benefit when compared to no action.³⁶⁶ Reforesting areas where forest cover was lost due to mortality can help mitigate the effects of climate change,³⁶⁷ but planting additional trees that increase forest density would result in elevated fire risk and drought stress and therefore is not expected to be an effective adaptation solution.^{300,368}

Other adaptation solutions include power shutoff policies by utilities to reduce wildfire risk when extreme wind events are predicted to topple powerlines and telecommunications infrastructure.^{369,370,371} Power shutoffs are more likely in autumn due to a climate-related increase in the number of days with extreme fire weather.¹⁸ Power shutoffs may also increase homeowners' intention to adopt solar power³⁷² or fossil fuel-powered generators.³⁷³ Individuals who experienced shutoffs reported poorer physical and mental health immediately after the occurrence, yet they still supported the use of shutoffs as a wildfire risk-reduction strategy.³⁷⁴

Traceable Accounts

Process Description

Following their selection in August 2021, the chapter lead author, federal coordinating lead author, and agency chapter lead author developed a comprehensive list of author candidates based on an analysis of prior National Climate Assessments, published scientific literature, science communication outlets, and policy-relevant reports. The final chapter authors were then selected based on their depth of knowledge, diversity of expertise, and experience in issues critical to the Southwest. Furthermore, authors were selected to represent diverse perspectives in terms of race, ethnicity, and gender identity. The Southwest chapter public engagement workshop was held virtually on February 4, 2022, with more than 90 participants. The workshop included an overview, a series of breakout rooms where the participants provided feedback on key topics, and a final roundup discussion among all participants. The author team held a debriefing session on February 7, 2022, to reflect on the input provided during the workshop. The author team met weekly during the development of the chapter.

Based on discussions among the author team, input from stakeholders, and consideration of the Fourth National Climate Assessment, the authors developed five Key Messages representing the valued assets and unique characteristics of the region. These include water resources, the coast, food and agriculture, demographics and human health, and wildfire. The chapter details the observed and anticipated effects of climate change on human and natural systems across those topics and outcomes to be avoided in the absence of adaptation and mitigation.

For the scientific assessment, the authors conducted a systematic evaluation of the body of scientific and technical knowledge to synthesize published studies, data, models, and assumptions while applying best professional judgment to assess uncertainties and conflicting findings. The chapter pays specific attention to factors that make specific systems and groups more vulnerable. The chapter identifies intersections between topics, cascading risks, and paths to resilience. The chapter also addresses cross-cutting themes including adaptation solutions and challenges, climate change equity and environmental justice, Indigenous Peoples and Knowledges, economics, infrastructure, and ecosystems and ecosystem services.

Key Message 28.1

Drought and Increasing Aridity Threaten Water Resources

Description of Evidence Base

Instrumental data and paleoclimate data provide strong, abundant evidence that the early-21st-century drought in the Southwest is more severe than most, but not all, prior drought periods.^{28,45,46,375} Research has identified higher temperatures as being a major driver of drought severity through the mechanism of increased atmospheric demand.⁴⁷ Recent research builds on an already-substantial evidence base demonstrating the decline of southwestern snowpacks over the last century.^{5,6,49,50} Research has shown how drought-induced shortages in surface water have increased groundwater pumping in California's Central Valley,⁶⁷ which provides one example of how drought may reduce future water access, especially if aquifer recharge is also reduced.⁶³

Major Uncertainties and Research Gaps

Historical data supply insight into the potential impact of precipitation deficits on surface water, and various research studies demonstrate how precipitation deficit and higher rates of evapotranspiration feed into reduced soil moisture and infiltration, both in contemporary and future warmer climates. However, there is remaining uncertainty over the precise contribution of temperature to these declines in 20th-century

Upper Colorado streamflow,³⁷⁵ the impact of changing snowpack dynamics on streamflow in and across different southwestern river basins,⁵⁶ and the impacts of El Niño–Southern Oscillation on precipitation in the region.^{376,377}

There are also research gaps on the impacts of climate change on the full hydrologic cycle of the Southwest. From the biophysical perspective, there’s a lack of information about aquifer recharge, specifically regarding temporal variability of recharge rates and locations.⁶³ Another topic for further exploration is the relationship between drought, surface water supplies, and rates of groundwater pumping for agriculture in locations within the Southwest beyond California (e.g., Rio Grande and tributaries, Utah, Nevada). Further, there is limited research on climate change impacts on the dynamics of the North American Monsoon, including how to more effectively capture monsoon moisture to substitute for decreased winter precipitation, as well as on other extreme precipitation events such as atmospheric rivers.

Additionally, there are multiple paths for water adaptation in the Southwest for industry, agriculture, and communities to build resilience to a more water-scarce future. However, there are research gaps around the feasibility and long-term effects of these adaptation solutions.^{378,379} Moreover, the ability of different sectors and communities—including rural, low-income, Indigenous, and other frontline communities—to adapt to climate-induced water scarcity is highly variable across the Southwest.³⁸⁰ There is a gap in research on best practices to support these communities in adapting to current and future water scarcity.

Currently, Indigenous Peoples’ water rights are under-utilized, while water access remains a challenge for many Indigenous Peoples. As more Indigenous Peoples gain access to and use their water rights, there is limited research on how this might impact other water users and broader water management actions, especially under Colorado River drought policies.³⁸¹

Description of Confidence and Likelihood

Measurements of snowpack, streamflow, and groundwater over the last century support the observation, with *very high confidence*, that climate change has reduced surface water and groundwater availability for people and nature in the Southwest.^{4,14,56} Moreover, evidence from the peer-reviewed literature supports the assertion of *high confidence* that certain Indigenous and frontline communities, including agriculturalists, will experience disproportionate impacts from reduced water availability and that long-standing institutional frameworks drive these inequities.^{187,382,383,384}

The *high confidence* that higher temperatures have intensified drought and will *very likely* lead to a more arid future is based on recent evidence that shows that since the early 20th century higher temperatures have increased the proportion of precipitation being lost to evapotranspiration relative to its contribution to Colorado River flow—a trend that is expected to continue as the region warms.^{28,51}

Without extensive adaptation, which is challenging because human systems have developed under the historical water cycle patterns (KM 4.2), there is *high confidence* and it is *likely* that these dynamics will further stress existing water supply–demand imbalances. Water supply imbalances primarily refer to the over-allocation of surface water supplies in the region’s major rivers, such as the Colorado and Rio Grande, due to committing more water to what are legally known as “beneficial uses” than is currently available. Concurrently, longitudinal studies and climate models suggest that there is *high confidence* that increased flooding will occur due to more intense precipitation events, such as those caused by atmospheric rivers,^{71,72} in the region’s future.

There is *medium confidence* that flexible and adaptive approaches to water management have the potential to address changing climate risks and mitigate the impacts on people, the environment, and the economy (KM 4.3). While there are abundant examples of such approaches from around the world and in multiple water-use sectors, assessments of the feasibility of these examples in the Southwest are lacking.

Key Message 28.2

Adaptation Efforts Increase to Address Accelerating Impacts to the Region's Coast and Ocean

Description of Evidence Base

Recent research and observed events demonstrate that marine heatwave events will continue and increase in frequency alongside other stressors, impacting marine-resource dependent communities.^{35,95} Marine heatwaves and century-scale sea surface temperature warming trends near the coast of California have been attributed to human influence on climate.³⁸⁵ Adverse impacts to aquaculture and wild-capture fisheries have already been observed and are projected to worsen. Impacts are connected to the degradation of marine ecosystems from not only temperature effects but also ocean acidification, hypoxia, and harmful algal blooms. And while there is extensive literature on the California Current ecosystem and wild-capture fisheries, there are fewer studies on the long-term effects of extreme events and California aquaculture, and thus higher uncertainty.

Sea level rise impacts have been extensively modeled and compared with observed flooding. The most recent lines of evidence are synthesized with a large body of relevant literature included in the 2022 Interagency Task Force report on sea level rise⁷ and the Intergovernmental Panel on Climate Change Sixth Assessment Report from Working Group I.⁹⁵

The authors focused on findings on the impacts from sea level rise, which centered around new understandings of sea level rise impacts to groundwater and infrastructure and communities. Energy and transportation infrastructure will continue to be impacted by increased flooding. Furthermore, recent studies have shown that climate impacts will disproportionately impact overburdened communities, but additional research specific to California is lacking.

Adaptation for infrastructure and communities has been accelerating in California through state and local governments, as seen through the release of laws, executive orders, and state guidance documents, as well as an increase in state, Tribal, local, and regional vulnerability assessments and adaptation plans. Government planning requirements and guidance for different sectors are increasing. The State of California also invests in downscaled climate science to inform state and local climate decision-making; the state's climate change assessment has been codified in law. Less information on adaptive strategies for fisheries and aquaculture has been released.

Major Uncertainties and Research Gaps

Long-term, compound implications of greater extremes with other stressors and mitigation strategies are less certain. There is less research in California on combined, long-term impacts of marine heatwaves and multi-stressor effects on ecosystems, species, and aquaculture. However, multi-stressor research is advancing,³⁸⁶ including for the California Current,³⁸⁷ increasing our mechanistic understanding of climate change effects. Mitigation strategies of nature-based carbon dioxide removal are growing in interest and investment in the US (Ch. 32),³⁸⁸ including in California. While the emerging evidence suggests that ocean-based solutions, such as seaweed aquaculture carbon sequestration, are not a global “silver bullet” to mitigate carbon emissions, they may provide some local benefits.¹³³ However, who benefits from such interventions and the impacts to surrounding ecosystems require further investigation to ensure positive outcomes for nature and people.^{389,390,391}

There is a lack of research on the impacts of sea level rise on groundwater flooding, as well as the application of those findings to infrastructure and community analyses. These compounding threats

have not been included in most adaptation planning to date, which could result in less adaptive solutions being implemented.

As governments and communities begin building adaptation projects, uncertainties about their efficacy remain. There is limited research tracking adaptation implementation, including research identifying potential ramifications, such as displacement of overburdened communities, economic injustices in terms of resources available for adaptation, and methods to ensure communities are part of decision-making for eventual retreat or relocation. Additional work could help identify how existing funding tools can support adaptation and resilience efforts and how to develop a more robust understanding of adaptation costs and benefits.

Description of Confidence and Likelihood

There is *high confidence* that climate change will increase marine heatwaves and harmful algal blooms (HABs), resulting in impacts to coastal ecosystems and economies. There is *very high confidence* and it is *very likely* that marine heatwave frequency, intensity, and extent will increase. Laufkötter et al. (2020)³⁸⁵ found that heatwaves have already increased twentyfold because of human-caused global warming and that the probability of occurrences increases in frequency under progressively warmer scenarios. Linkages between HABs and thermal conditions of the oceans have been demonstrated, but frequency and extent are linked to climate and non-climate (e.g., runoff) drivers.³⁹² There is high agreement and evidence of negative impacts to marine ecosystems and resource-dependent communities in the literature, but under moderate to high climate mitigation scenarios, the severity of impacts will depend on adaptive interventions (e.g., nature-based solutions, adoption of ecosystem-based management).

Sea level rise will *likely* cause increased flooding on the Southwest coast, and there is *very high confidence* that those impacts will severely affect infrastructure and communities, with inequities in how these impacts are experienced. The latest climate models and sea level rise projections demonstrate increased confidence in relative sea level rise amounts by 2050. Sweet et al. (2022)⁷ state that relative sea level for the entire contiguous US coastline is expected to rise, on average, as much over the next 40 years (2020–2050) as it has over the last 100 years (1920–2020; 0.82–0.98 feet). Furthermore, by 2050 the expected relative sea level will impact tide and storm surge, leading to major and moderate high tide flood events occurring as frequently as minor high tide flood events occurred in 2022, which will impact infrastructure, communities, and ecosystems.⁷

Given the State of California's progress and leadership on climate science and adaptation planning for sea level rise, there is *high confidence* that adaptation planning and implementation will continue. As evidence, the state's fiscal year 2021–2022 budget included \$4 billion (in 2022 dollars) for climate resilience programs, with other new climate resilience programs created in fiscal year 2022–2023. State agencies continue to release adaptation planning guidance (e.g., State Agency Sea Level Rise Action Plan 2022;³⁹³ Extreme Heat Action Plan 2022;³⁹⁴ State Adaptation Strategy 2021³⁹⁵) and new funding programs (e.g., Adaptation Planning Grant Program 2022;³⁹⁶ Transportation Climate Adaptation Planning Grants 2022;³⁹⁷ Local Transportation Infrastructure Climate Adaptation Project [LTCAP] Program 2022;³⁹⁸ Regional Resilience Planning and Implementation Grant Program 2022³⁹⁹). There is limited to no inclusion of aquaculture in California state climate planning (e.g., Lester et al. 2022⁴⁰⁰), and comparatively less coverage overall in the scientific literature compared to wild capture and agriculture,⁴⁰¹ and thus there is *high confidence* that climate planning and adaptation solutions for aquaculture are less clear.

Key Message 28.3

Increasing Challenges Confront Food and Fiber Production in the Southwest

Description of Evidence Base

Temperature and precipitation data clearly show that this century has been warmer and drier than the last.^{50,381,402} This drying and warming trend is already resulting in measurable impacts on rangeland forage production,⁴⁰³ dryland agriculture,⁴⁰⁴ and irrigated crop yields. A substantial literature exists showing the impact of climate change on livestock production through changes in food quantity and quality, pests and disease, and animal health and well-being.⁴⁰⁵ Evidence shows that climate is already affecting the distribution of livestock agriculture in the east of region. The Southern Plains (in New Mexico) and Central Plains (in Colorado) saw large decreases in cow numbers in the 2011–2014 drought.⁴⁰⁶ Increasingly the Southwest's agricultural economy relies on crop production, but research anticipates downward trends in the production of numerous high-value crops in California¹⁶⁹ and reduced or less reliable supply of irrigation water that supports crop production throughout the region. Numerous examples of adaptation strategies exist, such as improved irrigation technologies, soil protection strategies, and shifts to Indigenous practices and crops, although there are barriers that inhibit widespread adoption of many of these practices.

Major Uncertainties and Research Gaps

Southwestern food and fiber production is diverse, spanning rangeland livestock systems, irrigated croplands and orchards, dryland, and Indigenous farming. Each of these systems is nested within local, regional, and international contexts that can exacerbate or alleviate vulnerability to climate change. This diversity, combined with factors other than climate change (e.g., global pandemics, inflation, supply chains, access to financial support) contribute to the complexity of assessing the impacts of climate change on southwestern agriculture. There are therefore research gaps and some uncertainty on how the adaptation options described in the agronomic and range management literature can be applied in the real world.

Research gaps remain in our understanding of not only the biophysical and socioeconomic capacity to support change in southwestern agrosystems but also the will of farmers and policymakers to change the type of crops that are grown. For livestock producers who rely on forage from public lands, there is uncertainty about how climate change will affect the number of animals the land can support and how possible reductions in stocking rate will affect the viability of ranches and ranching-dependent communities.

Description of Confidence and Likelihood

There is *high confidence* that continuing drought and water scarcity will make it more difficult to raise food and fiber in the Southwest without major shifts to new strategies and technologies. Climate models agree that the Southwest will continue to warm. This impacts the thermal tolerance and chilling requirements for economically important crops. There are multiple indicators that the Southwest is undergoing aridification; as a consequence, it is expected that there will be less available water for irrigated agriculture in the future.

Given substantive evidence in the literature, there is *high confidence*, and it is *likely*, that extreme heat events will continue to occur and are expected to worsen in intensity and increase in frequency in the 21st century.¹⁶⁷ Extreme heat reduces crop quality and yield^{181,403} and affects livestock productivity (and in some cases survival), resulting in economic impacts.^{197,198,405} USDA Risk Management Agency indemnities data from 1989 to 2021 show that heat events are already driving crop production losses across the region.

There is a growing literature that advocates for greater inclusion of Indigenous Knowledge for informing adaptation solutions in Southwest agriculture. There is *medium confidence* that Indigenous Knowledge, along with technological innovation, has the potential to inform sustainable agricultural practice

regionwide, as well as increasing Indigenous food sovereignty, because there are few studies to date that demonstrate how Indigenous Knowledge can be drawn on to adapt larger acreages or commercial operations to climate change. It is also evident in the literature that technical innovations (e.g., agrivoltaics, internet of things) have yet to become more widely adopted or applied to larger acreage operations.

Key Message 28.4

Climate Change Compromises Human Health and Reshapes Demographics

Description of Evidence Base

Strong evidence and good agreement among multiple sources and lines of evidence show that extreme heat exposures already are leading to heat-associated deaths and illnesses across the region.^{228,233,407} Exposures to extreme heat for city dwellers are increasing, partly due to human-caused climate change and partly due to urban-induced warming.^{408,409} Regional-scale warming in the Southwest since 1901 exceeds what would be expected from natural variability and is partly attributable to human influence.³ Climate change has doubled the likelihood of an event capable of producing catastrophic flooding for California, and future increases to this risk are expected due to continued warming.^{271,272}

Multiple lines of evidence indicate current and future increases in human exposures and adverse health outcomes to wildfire smoke in the region.^{277,410,411} Good agreement exists among models that the intensified arid conditions in the region will result in more dust storms²⁴³ and thus a higher incidence of respiratory ailments, including Valley fever.^{246,248}

Evidence supports the need for increased investments in adaptive strategies that support social, physical, and health systems that enhance individual and community resilience to changes in climate, particularly extreme heat.^{288,412,413,414,415} Improving public health systems and community infrastructure in the region can reduce the health consequences of climate change.

Major Uncertainties and Research Gaps

Uncertainties exist in the attribution of changes in climate variables to specific health outcomes. The collection of and alignment of more environmental and health data will assist in understanding the long-term nature of how climate change affects specific health outcomes. Detecting direct relationships between climate change impacts and public health outcomes is also made more difficult due to confounding factors related to socioeconomic, vulnerability, exposure assessments, demographic shifts, migration, and community and individual characteristics. Detection and attribution studies are thus vital to the region for addressing multiple public health concerns (e.g., Ebi et al. 2020³⁰).

Related uncertainties in how regional changes in climate will affect public health exist due to variability in projections of extreme precipitation; uncertainties in the occurrence and intensity of climate-sensitive exposures that impact human health, including wildfire smoke exposures; and variability in local and regional ozone based on meteorological conditions and emissions-reduction targets achieved.

Uncertainties also exist in projecting climate-related changes to the abundance of vector-borne diseases and associated disruptions. While US rates of chikungunya and Zika dropped⁴¹⁶ with widespread travel restrictions due to COVID-19, issues with West Nile virus (WNV) remain due to the endemic nature of the virus in the region. The most common WNV vector in the region (*Culex quinquefasciatus*) is abundant in urban areas such as Los Angeles, Albuquerque, and Phoenix,⁴¹⁷ and certain water management structures (e.g., catch basins, storm drains, and retention ponds) provide favorable environments for *Cx. quinquefasciatus* reproduction.⁴¹⁸ There is also uncertainty around how heavy precipitation, as compared to drought

conditions, impacts the abundance and distribution of vector-borne diseases connected to human activity and management of water. Transmission of WNV is also projected to shift northward,⁴¹⁹ thus decreasing potential risks of transmission in parts of the Southwest.

Finally, considerable uncertainties exist in how individuals and communities will adapt to the effects of climate change in the region. Model projections of health impacts rarely account for adaptive capacity changes into the future. Improving adaptive capacity involves enhancing infrastructure, technologies, behavior, and the overall health of the population to cope with climate effects.

Description of Confidence and Likelihood

There is *high confidence* that increases in extreme heat, drought, flooding, and wildfire activity are negatively impacting the physical health of Southwest residents. Climate models agree that the Southwest is experiencing higher temperatures and more intense, longer, and more frequent heat events.^{3,8,375,420} Extreme heat exposure causes mortality, morbidity, and lost productivity if dangerous exposures occur (KM 15.2).^{235,421} Drier conditions lead to a greater risk of wildfires and particulate matter, which adversely affect human respiratory and cardiovascular health when exposed.^{265,290,422,423,424}

Climate change is also shaping the demographics of the region by spurring the migration of people to the Southwest, primarily from Central America (*medium confidence*). In 2021, about 13 million people (representing 21.3% of total population) living in the Southwest were foreign born; 21.1% of those foreign born entered the United States in the last 10 years.⁴²⁵ Decreasing agricultural productivity, increasing levels of food insecurity, and adverse climate effects are among the main reasons why people emigrate from the Northern Triangle (Guatemala, Honduras, and El Salvador) to the US (KM 17.2).^{32,279} About 43% of immigrants apprehended at the Southwest border in 2019 originated from the Northern Triangle.²⁷⁸

Individuals particularly vulnerable to increasing climate change impacts include older adults, outdoor workers, and people with low income (*high confidence*). Wildfires and the related smoke are affecting a higher number of people, with strong evidence pointing to the most vulnerable populations being at greatest risk.⁴²⁶ Strong evidence further connects rising particulate matter levels to higher risk in already-vulnerable populations, including individuals with low income, Indigenous Peoples, pregnant people, children, and outdoor workers.^{427,428,429,430,431} It has been well documented that extreme heat disproportionately impacts the health of the most vulnerable populations in the region, including the unhoused,^{227,228,229} outdoor workers, and migrant farmworkers,^{230,231,232,233} as well as people with low income,^{8,234} older adults,²³⁵ and pregnant people and babies (particularly with air pollution co-exposures).^{237,238,239,240}

There is *high confidence* that local, state, and federal initiatives can respond to these climatic and demographic changes by helping people and communities become healthier and more resilient. There is strong evidence that increasing adaptive capacity and resilience across communities, especially the most vulnerable, will reduce the human health impacts of climate change.⁴³² The relative importance of various adaptive strategies will differ across spatial and temporal scales, climatology, and social and behavioral contexts. Improving public health systems, overall health, community infrastructure, and education can reduce health risks that are being exacerbated in the Southwest due to climate change, as well as many health risks in general.⁴³¹

Key Message 28.5

Changes in Wildfire Patterns Pose Challenges for Southwest Residents and Ecosystems

Description of Evidence Base

Changing wildfire dynamics include increases in wildfire size and severity and changing and lengthening fire seasons.^{18,303,433,434} Extensive research has found that climate change is linked to increases in extreme fire weather,¹⁸ wildfire activity,^{20,303,326} wildfire severity,^{17,19,21,434} and acreage burned annually.³⁰² Unprecedented high-severity fires have driven ecosystem conversions in many parts of the region.^{294,311} Recent climate-induced aridification, including loss of snowpack, has also reduced postfire tree seedling and shrub establishment, limiting ecosystem recovery.^{313,314,315}

Projections suggest that future fire activity will continue to degrade ecosystems and alter their structure and function.^{294,298,319} Increased fire activity,^{320,321,322} further warming and drying that stress tree seedlings, and model projections of stand-replacing fires at the forest/non-forest boundary in the western US³¹⁶ have raised the possibility of shifts in species composition or vegetation type.^{294,317} These projections suggest high variability in ecosystem responses depending on interactions between vegetation type, moisture stress, disturbance regimes, and human alterations.^{314,319,435,436,437,438}

Increasing wildfire risk poses threats to lives and livelihoods in the region. Wildfire and accompanying smoke have led to fatalities caused by the fires themselves,^{304,327} by smoke from wildfires,³²⁸ and by debris flows that occur when heavy rains fall on recently burned slopes.³³⁰ Even if not fatal, wildfires have been linked to declines in physical health^{265,328,439} and mental health.²⁶⁸ Frontline communities, including low-income groups and populations of color, are especially vulnerable to these impacts.^{231,338} Exposure of people in the Southwest to wildfire risk is also increasing due to population growth in wildland-urban interface areas near fire-prone forests, shrublands, and grasslands.^{331,332,333} Economic costs to individual households come from structures burned and increased insurance and healthcare costs.^{440,441} Further costs come from income lost due to fires that affect energy, agriculture, and tourism.^{340,341,342,353}

Adaptation strategies include reduction in tree density and wildland fuels^{299,355,358,359} that can reduce the size and severity of fires when they occur. Integration of Indigenous burning practices with contemporary forest management can mitigate wildfire risk as well.²⁹⁶ Risk is expected to be reduced through public safety power shutoffs initiated by electric utilities when weather conditions suggest wildfire danger is especially high.³⁷⁰

Major Uncertainties and Research Gaps

The short-term likelihood of increasing wildfire risks and impacts is very high. What is less clear is the extent to which adaptation strategies such as increasing fuel-reduction treatments and adoption of climate-adapted silviculture will be able to mitigate those impacts. As yet, there has been no reliable way to quantify the degree to which increases in fire area and severity are due to climate change versus past management, non-native species invasions, urbanization, or other factors. To restore forest resilience (KM 7.3), the rate of thinning and fuel reduction needs to be greatly increased, and it is not known whether resources will be available to achieve such intensified management. Fire ecologists point to the need for increasing use of prescribed burning to reduce fuel loads, but it is not certain how much this increase can be achieved, considering the increasing risk of fire escape and public unease about the use of fire as a management tool.³⁶¹ Geographic factors, forest policies, and public attitudes toward forest management can constrain the rate at which risk-reduction actions can be implemented. Similarly, long-term attitudes toward public safety power shutoffs, restrictions on homebuilding in fire-prone landscapes, and other risk-reduction policies are uncertain.

Description of Confidence and Likelihood

There is *high confidence* that the Southwest region is experiencing unprecedented wildfire occurrence and that this change is linked to climate change. Contributing causes include land management policies that have led to high tree densities that increase fuel for fires,^{295,318} climate-mediated events such as insect and tree disease outbreaks (Box 7.1),³¹⁹ and increased human population at the forest's edge,³³¹ all of which interact with climate change in ways that increase wildfire risk and occurrence.^{18,21}

There is *high confidence* that fires in the region have become larger and more severe. Increased temperatures and changes to precipitation have combined to produce an increase in vapor pressure deficit.³³³ This, in conjunction with episodes of climatic extremes such as droughts and heatwaves, means it is *very likely* that these trends will continue in the region's forests.^{319,320,321,322} However, there is less certainty about future trends in non-forested areas because of high year-to-year variability in production of the grasses that fuel wildfires,³²⁴ with model projections suggesting that climate impacts on plant growth will vary across the region.³²⁵

There is *high confidence* that severe wildfires are placing people, economies, ecosystems, and water resources at risk, and it is *very likely* that severe wildfires will continue, partially because of climate change impacts. There is consensus among studies from climate models that the Southwest will continue to warm, and there are multiple indicators that the region is becoming more arid, increasing wildfire risk. There are many indicators of costs to human lives, health, and livelihoods due to wildfire, and as the risk of catastrophic wildfire increases, so do those costs.

There is *medium confidence* that adaptation pathways will reduce wildfire risk and promote ecosystem restoration through forest management and other adaptations such as the application of Indigenous Knowledges. While the adaptation opportunities are known, it is less clear whether society will have the capacity to embrace those opportunities.

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