

CALIFORNIA'S FIFTH
CLIMATE CHANGE
ASSESSMENT

Statewide Summary

California's Fifth Climate Change Assessment

Coordinating Agency

CA Governor's Office of
Land Use and
Climate Innovation

About California's Fifth Climate Change Assessment

California's Climate Change Assessments are a cornerstone of the state's efforts to understand and prepare for a changing climate. Since 2006, California has published four statewide assessments, each building the scientific foundation needed to understand climate risks and inform policies, investments, and resilience actions. California's Fifth Climate Change Assessment (Fifth Assessment) builds on this foundation while responding to new direction from Senate Bill 1320 (Stern, 2020), which requires the State to report the projected impacts and risks of climate change across California at least every five years. The Fifth Assessment offers new insights into California's climate future, with a dedicated focus on partnerships with California Native American tribes, public engagement, and communities most vulnerable to climate impacts.

The Fifth Assessment's research and tools are designed to fill critical knowledge gaps and support strategic climate action. Drawing on research priorities identified by state and local leaders, community representatives, and subject matter experts, the Fifth Assessment provides information to help decision-makers understand potential climate futures, the challenges they may present, and opportunities to build resilience. Its findings are intended to inform planning, investments, and policies at the state, regional, and local levels.

The Statewide Summary provides a high-level overview of key findings from across the Fifth Assessment's research and data, and other relevant sources. It serves as an entry point to understanding the breadth of climate impacts across California, and potential paths to build resilience based on the best available science and information.

For the full suite of Fifth Assessment research products, please visit: www.ClimateAssessment.ca.gov.

Climate Modeling, Scenarios, & Time Periods

The Fifth Assessment primarily considers the following climate models, greenhouse gas (GHG) emissions scenarios, and time periods:

- **CMIP6** (Coupled Model Intercomparison Project Phase 6) is the most recent version of a global collaboration that standardizes and combines the most advanced climate models to project how Earth's systems will react to our changing atmosphere. With CMIP6, we can see the most likely climate trends and the less likely, but still possible, extremes.
- **Greenhouse Gas Emissions Scenarios:** Current international climate models integrate two kinds of scenarios: Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). The SSPs model how global society might evolve over the next century, including changes in population, policy, technology, and economic growth, while tracking the amount of heat trapped in the atmosphere. The RCPs correspond to GHG emissions and capture a quantifiable range of emissions and warming—how much do we expect the world will continue to emit, and the associated warming, throughout the century? Combined, these describe how global social conditions (e.g., population, technological, and economic growth) affect emission trajectories. This shift offers a more nuanced understanding of how our collective decisions today will shape the climate of tomorrow. The Fifth Assessment research primarily focuses on two RCP/SSP combinations:
  - **SSP 2–4.5** (i.e., utilizing the second SSP narrative and RCP 4.5) describes an intermediate scenario indicating improvements toward meeting mitigation commitments. This scenario shows carbon dioxide equivalent (CO_2e) emissions initially hover at current levels, then start to fall by mid-century.
  - **SSP 3–7.0** articulates a high emissions scenario and less optimistic pathway, assuming current emission levels continue throughout the year 2100. This scenario shows CO_2e emissions doubling by 2100.
- The Fifth Assessment also references a more aggressive emissions scenario (**SSP 5–8.5**), which describes a very high and unlikely emissions pathway that shows CO_2e emissions tripling by 2075. The Assessment includes this scenario as a reference tool for a worst-case emissions outcome for informational and planning purposes rather than a plausible climate change future.
- **Global Warming Levels** (GWLs) ask "What happens to California once the world reaches a certain level of warming?" The focus is on adapting to a change in the expected climate, such as a 2°C (3.6°F) increase. While these models identify a range of years when these thresholds might be reached, the emphasis is on the intensity of the impact rather than the calendar date. This is a different and complementary approach to the previously used *date-based approach*.
- **Downscaling with Localized Constructed Analogues (LOCA) and Weather Research and Forecasting (WRF):** To make global climate models (GCMs) useful for local planning, scientists use a technique called downscaling. While global models provide a *big picture* view of the planet, the Fifth Assessment uses the LOCA2 statistical and WRF dynamical downscaling techniques and a hybridized version of these techniques, LOCA2-Hybrid, to focus on California's particular climate future.
- **Time Periods:** The Fifth Assessment uses a 30-year timeframe for analyses, as shown in the table below, alongside historical projections to draw comparisons between current and future time periods.

Descriptive Term	Time Range
Historical	1981–2010
Mid-Century	2041–2070
Late-Century	2071–2100



Figure 1: *Map of California depicting nine Climate Change Assessment Regions: North Coast, San Francisco Bay Area, Central Coast, Los Angeles, San Diego, Sacramento Valley, San Joaquin Valley, Sierra Nevada, and Inland Deserts. Figure by Symsoft Solutions.*

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Disclaimer

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Any references in this Assessment to the lingering and compounding effects of racism and discrimination are drawn from academic literature and are not factual findings of, or legal determinations by, the State of California or any agencies of the State, of prohibited discrimination in any particular instance. Similarly, any descriptions of potential future harms are not findings of or admissions by the State of California or any agencies of the State.

The research was reviewed by expert reviewers, Tribal Advisory Group members, and approved by an external editorial board to ensure scientific rigor as well as appropriate representation of the practitioners and partners to whom each report applies.

Use of Artificial Intelligence (AI):

AI tools were used sparingly in the preparation of this report to refine language, generate preliminary code for data analysis, and summarize cited documents. All AI information was carefully reviewed and edited to ensure accuracy. The authors take full responsibility for the correctness of the contents of this report.

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Key Messages

Climate change science and research have advanced substantially in recent years. These key messages highlight selected findings from California's Fifth Climate Change Assessment and illustrate how the latest climate science can inform decisions about California's future. More detail on these key messages, including citations, can be found in the sections below. Additional context about these climate issues can be found throughout the Assessment portfolio of research and data.

- **California will experience rising temperatures across the century.** Average temperatures in California are increasing at an unprecedented rate, projected to rise by 3.5–4.3°F (1.9–2.4°C) by 2050 relative to the 1981–2010 baseline. By 2100, projected temperature increases range between 5.7°F (3.2°C) under an intermediate emission scenario to 8°F (4.4°C) under a high emission scenario.
- **California will experience greater precipitation variability and more "climate whiplash."** California's weather will feature greater swings between wet and dry extremes. Storms are expected to intensify and deliver a greater share of total precipitation.
- **California's snowpack will decline substantially, affecting downstream water systems, local economies, and ecosystems.** Early April snowpack is projected to decrease by approximately 40% by mid-century (2041–2070) and approximately 60% by the end of the century (2071–2100) compared to the 1981–2010 average. Snowpack decline is due to rising temperatures and a greater amount of precipitation falling as rain.
- **Climate change is reshaping California's seasons, altering the timing, duration, and intensity of seasonal conditions.** As summer periods lengthen, winters shorten, and seasonal conditions become more variable, natural and human systems that depend on the reliability of seasonal patterns will be affected and forced to adapt.
- **Wildfire smoke exposure and associated health risks are increasing.** Models project that California will experience the highest increase in annual excess deaths from wildfire smoke of any US state by 2050, reaching over 5,000 excess deaths per year compared to 2011–2020. Farmworkers alone are projected to experience a 190% increase in smoke exposure days considered "unhealthy for sensitive groups" by mid-century.
- **Extreme heat events are growing longer and more frequent,** resulting in prolonged heat waves and more days above important temperature thresholds. By end-of-century, the average longest heat wave of the year is projected to lengthen across all regions of the state, with durations ranging from six days in the Bay Area to as long as 19 days across the Sierra Nevada under a high emissions scenario.
- **Climate risks are not distributed equally across California communities.** Communities differ in their exposure, sensitivity, and capacity to prepare for, respond to, and recover from climate impacts. For example, people living unsheltered (0.5% of California's population) make up 13% of all hospitalizations for heat-related illness. Many disadvantaged communities are particularly sensitive to place-based risks, ranging from drying of domestic wells during droughts to exposure to toxic substances from sea level rise near contaminated sites.

- **Marine and coastal ecosystems are being reshaped by marine heat waves, ocean acidification, and hypoxia.** Ocean acidification along the California coast is occurring at twice the global rate due to upwelling. Combined with severe marine heat waves and low oxygen levels in California coastal waters, marine ecosystems and wildlife are facing devastating threats.
- **With 3.3 feet of sea level rise $78 billion worth of property and 201,000 people could be exposed to coastal flooding by 2100.** This means five times the exposure expected in 2050. A 100-year storm could raise these estimates to 310,000 people and $122 billion in property exposed by 2100.
- **California Native American tribes face disproportionate impacts from climate change yet are leading effective climate adaptation solutions.** Historical land dispossession and criminalization of traditional practices have heightened tribal vulnerability to shifting seasons and climate-related hazards. Nonetheless, California Native American tribes are implementing strategies such as ecocultural restoration and cultural burning which can reduce the likelihood of catastrophic wildfires by up to 92% for a decade post-treatment. These practices strengthen ecosystems, communities, and California's overall adaptive capacity.
- **Climate hazards are increasingly interconnected, creating cascading and compounding risks.** Major climate hazards in California are most destructive when they occur sequentially or simultaneously. For example, an exceptionally hot summer and fall in 2024 exacerbated fire conditions leading into the 2025 Los Angeles Fires, one of the most expensive natural disasters in US history. Multi-benefit solutions can help address the complex and intersecting nature of climate hazards.
- **Climate change will have significant economic impacts across California,** particularly through the effects on health and labor. For example, recent extreme heat events have led to billions of dollars in losses through premature death, lost work hours, and more, while rising global temperatures are increasing the pace of inflation.
- **The future is not predetermined.** The decisions made today can help California adapt to a changing climate and strengthen resilience for generations to come.

Chapter 1.

Introduction



Climate change is affecting every region of California. Changing precipitation patterns, rising temperatures, devastating heat waves, declining snowpack, and unprecedented fluctuations in weather patterns are creating new challenges for communities, ecosystems, and infrastructure. The science points to a clear conclusion: While California's climate challenges will continue to grow throughout this century, today's decisions can still set the course for a resilient and thriving future.

Clear and reliable information about California's future climate conditions is an essential first step in strengthening infrastructure, increasing emergency preparedness, and furthering natural resources conservation and restoration, all of which support long-term community and ecosystem well-being. California's Fifth Climate Change Assessment (the Fifth Assessment) presents an updated state-of-the-science and foundation to support California's ability to prepare for and recover from future climate change events and disasters, so that all Californians have the opportunity to thrive amid a changing climate. The Fifth Assessment builds on the research of four consecutive climate assessments, including the latest in 2018, by generating new research and data about expected climate futures in California, matching analyses of risk and vulnerability with examples of adaptation, and elevating the latest climate science and information into regional and statewide reports to help guide decision-making.

California's commitment to science-informed policy, tribal partnerships, and participatory decision-making contributes to the state's global leadership in climate action. The forward-looking research of California's Climate Change Assessments complements other key State efforts to address climate change, including an evaluation of human health indicators of climate change across time in the Office of Environmental Health Hazard Assessment's Indicators of Climate Change Report (2026), California's framework to build resilience to climate impacts in the California Climate Adaptation Strategy (2026), and the state's Climate Change Scoping Plan (2022), which established a comprehensive framework for reducing greenhouse gas emissions.

While the Fifth Assessment provides valuable information about the state's climate future, it is not a strategic plan, regulatory document, or investment strategy. Responding to the information presented throughout the Assessment will require further action by state and local entities, such as building new strategic partnerships, making adjustments to permitting and planning processes, securing adequate funding, strengthening technical and institutional capacity, and identifying opportunities to integrate climate science into policies, programs, and investments.

1.1 California's Climate Change Assessments

The State of California has been investing in cutting-edge science to answer some of the most pressing questions about climate change for decades.

Since 2006, the State has published a series of Climate Change Assessments each building upon the last to expand current understanding of climate change, impacts, risks, and possible adaptation pathways. Through new research, modeling, and topic-specific reports, the Assessments have helped inform some of California's most significant climate policies, laws, and programs.

With new statutory direction in Senate Bill 1320 (Stern, 2020), the California Governor's Office of Land Use and Climate Innovation now leads the development to produce California's Climate Change Assessments at least every five years in partnership with the California Natural Resources Agency, California Energy Commission, and California Strategic Growth Council.

Assessments have evolved over the years to feature original research, hybrid climate modeling, tribally led research, and a community-driven research model, and the Fifth Assessment builds on this strong foundation.

Combined with investments in high resolution climate projections specific to California (see **Box 3**), original research, regional and topical synthesis reports, and tribal and community engagement, the Fifth Assessment represents a significant evolution in how climate science is generated, reviewed, and applied. As is often the case, new research inspired new questions. These new questions are captured within Fifth Assessment materials to advance future climate research both within and beyond California and provide a roadmap for future Climate Change Assessments.

Box 1: *Participatory Research*

The Strategic Growth Council's Participatory Research to Policy Model shaped and inspired the Fifth Assessment research process, which emphasizes community engagement to inform all phases of the research process—from scoping to development to dissemination of findings. The model has helped foster a more inclusive and actionable climate assessment by bringing together interdisciplinary teams of climate researchers and scientists, tribal environmental professionals, community members, and practitioners, and uplifting diverse perspectives in the research process. Acey et al. (2026) and Hatch et al. (2026) exemplify the benefits of this model, as they engaged grassroots leaders of frontline communities and vulnerable populations as experts on climate impacts or co-authors of their report alongside academic researchers. The Research to Policy Model has helped the Assessment to feature a stronger foundation for climate adaptation action that is scientifically rigorous, regionally relevant, and responsive to the needs of California's diverse communities.

Fifth Assessment Products

California's Fifth Climate Change Assessment involves:

- **New downscaled climate projections and scenarios** showing trends in precipitation, temperature, wind, and other conditions through 2100 for three emissions scenarios.
- **Original Climate Research Reports:**
  - **Energy Research** supporting development of climate projections, wildfire and hydrologic scenarios, quality-controlled historical weather data, and analyses that contribute to a resilient transition to a 100% clean energy system.
  - **Core Climate Research** addressing priority climate hazard, vulnerability, and resilience questions identified by state, tribal, local, research, community, and other partners.
  - **Tribal Research** that uplifts tribal sovereignty, Traditional Ecological Knowledges (TEK), and community priorities to ensure tribes and California Native American communities shape and benefit from California's climate science.
- **Regional Reports** summarizing climate risks, vulnerabilities, and adaptation opportunities across California's diverse regions.

- **Statewide Reports:**
  - **Statewide Topical Reports** examining cross-cutting priority issues, including racial equity and climate justice, impacts to the economy, human displacement and migration, and tribal communities.
  - **State Agency Reports** voluntarily contributed by California state agencies on progress, opportunities, and gaps in climate science and its application within the jurisdiction and expertise of select state agencies and departments.
  - **Statewide Summary** synthesizing key messages from across the Assessment portfolio of research and data, with a focus on climate-related hazards that affect climate vulnerability of California's natural, built, and social systems, and related adaptation approaches.

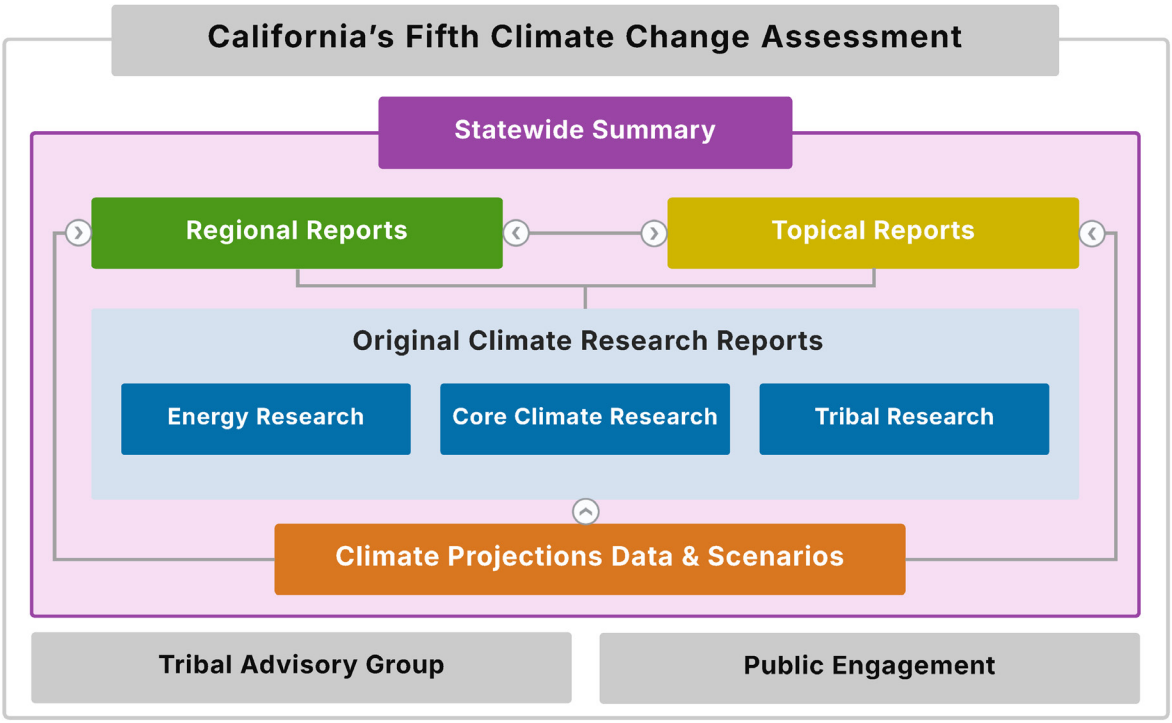


Figure 2: *Fifth Assessment project types and how they relate to each other. Lines and arrows indicate where one project informed another.*

Together, these diverse informational resources make the Fifth Assessment a primary resource for understanding future changes to California's climate and supporting informed climate adaptation across regions and communities. Whether a practitioner, technical expert, decision-maker, student, business representative, or community member, there are takeaways in the Assessment for all readers.

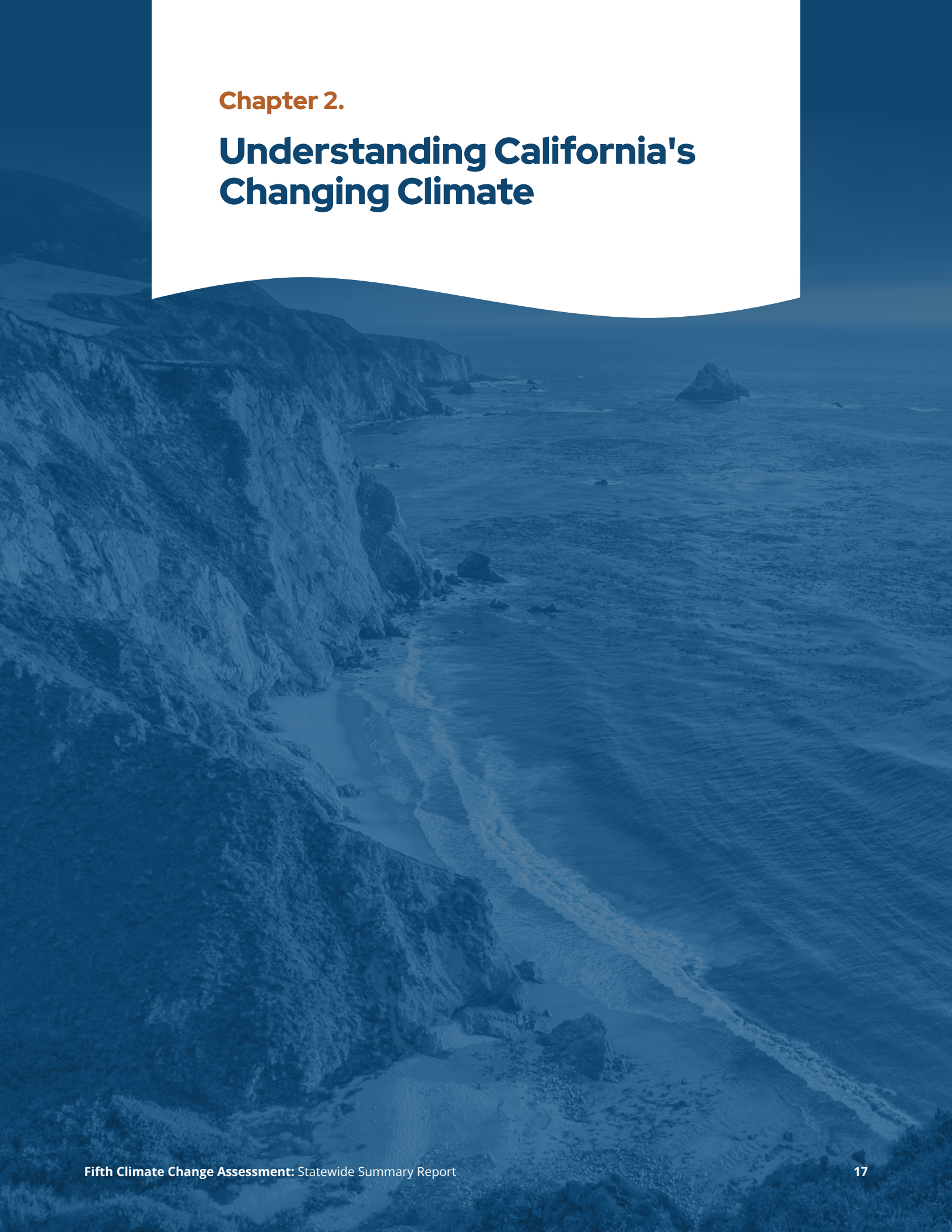
Box 2: *Understanding Climate Terms*

Climate change amplifies the frequency and intensity of extreme weather patterns and temperature changes, which can exacerbate five main hazards in California: extreme heat, drought, flooding, wildfire, and sea level rise. These are definitions of common terms used throughout the Assessment to describe varying levels of climate-related disruption and adaptation responses:

- **Climate Adaptation:** Adaptation is an action or effort, or set of actions or efforts, that reduce the impacts of climate change on communities, economies, and ecosystems (State of California, 2024). Adaptation refers to adjustments in natural or human systems in response to actual or expected climatic stimuli [external factors contributing to climate change] or their effects, which moderates harm or exploits beneficial opportunities (Bedsworth et al., 2018).
- **Climate Hazard:** The potential occurrence of a natural or human-induced physical event or trend, such as extreme heat waves, rising sea levels, catastrophic wildfire, or changes in precipitation resulting in flooding and droughts that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provisions, ecosystems, and environmental resources (Adapted from IPCC, 2023).
- **Climate Impact:** The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health, and well-being; ecosystems and species; economic, social, and cultural assets; services; and infrastructure (IPCC, 2023).
- **Climate Refugia:** Geographic areas that have had a stable climate on evolutionary time scales, or that are projected to have a stable climate into the future (IPCC, 2023).
- **Climate Resilience:** Resilience describes a state of readiness to face climate risks (State of California, 2024). It includes the capability to prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.
- **Climate Risk:** The potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change impacts, risks can arise from potential impacts of climate change as well as human responses to climate change (IPCC, 2023).
- **Climate Vulnerability:** Climate vulnerability describes the degree to which natural, built, and human systems are at risk of exposure to climate change impacts (ICARP, 2025) (see **Box 5** for more information).

Chapter 2.

Understanding California's Changing Climate



Climate science helps explain how changes in climate trends and patterns are expected to unfold across timescales and geographies. Though scientists have agreed for decades that global temperatures are rising at faster rates, today's climate models and projections provide increasingly detailed information about where, when, and to what extent climate change is likely to affect different regions. Understanding the nuanced conditions that communities are facing in different areas of the state is essential to effectively manage future risks and address vulnerabilities.

The Fifth Assessment relies on data from high-resolution climate projections that portray future temperature trends, precipitation patterns, and associated hazards across California's diverse communities and ecosystems (Kalansky et al., 2026). These projections are based on a select range of possible scenarios (see **Box 3**). Across each scenario, two distinct and consistent patterns emerge: 1) temperatures are projected to increase throughout the century, and 2) precipitation patterns in California are projected to become even more variable (**Figure 3**; see *Section 2.2 Precipitation: High Variability* below). These patterns form the basis for the Assessment's research and analysis, as highlighted in the sections below and throughout the broader Fifth Assessment portfolio.

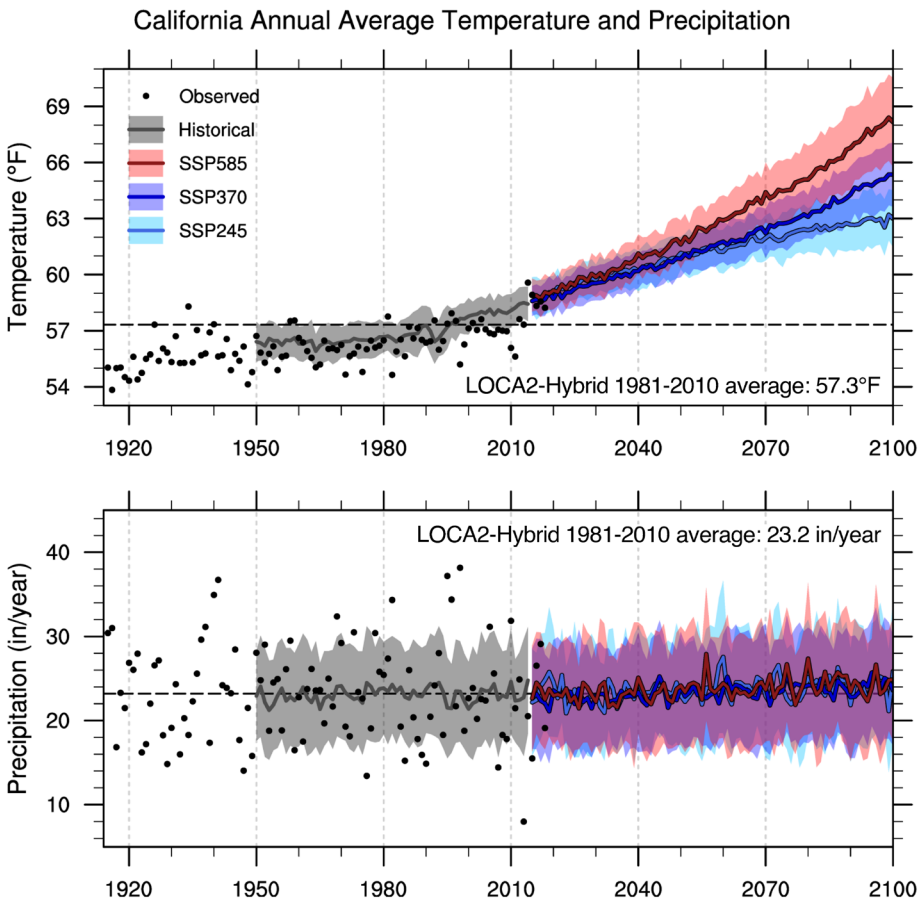


Figure 3: *California average annual temperature and precipitation over time combining observations (black dots; Livneh et al., 2013), simulated past climate (gray), and projections for three climate scenarios (cyan, blue, red). Simulated and projected climate is from the LOCA2-Hybrid dataset (see* **Box 3***). The thick line represents the mean across a group of climate models, and the shaded region represents one standard deviation from the mean. The dashed line denotes the average over the 1981–2010 period from simulated past climate. Figure by Paul Ullrich, UC Davis.*

Box 3: *Climate Modeling, Scenarios, and Time Periods*

Climate projections leveraged by the Fifth Assessment to portray California's future climate begin with the Coupled Model Intercomparison Project Phase 6, or CMIP6, a global collaboration that brings together climate models from research institutions around the world using common experiments and scenarios. These models show how Earth's systems will react to changing greenhouse gas levels in the atmosphere.

Current international scenarios have two parts: Shared Socioeconomic Pathways (SSPs), which describe how global society might change, including population, policy, and economic growth, and Representative Concentration Pathways (RCPs), which correspond to quantifiable emission levels through the end of the century. Combined, these emission scenarios describe how global social conditions affect global emission trajectories. Out of multiple scenarios, the Fifth Assessment primarily focuses on two RCP/SSP combinations that provide a useful range of conditions for long-term adaptation planning:

- **SSP2–4.5** is an intermediate scenario where global CO2e emissions initially plateau at current levels, then start to fall after 2050.
- **SSP3–7.0** is a less optimistic high emissions scenario that shows CO2e emissions doubling by 2100.
- The Fifth Assessment also references a more aggressive emissions scenario (**SSP5–8.5**), which describes a very high and unlikely emissions pathway that shows CO2e emissions tripling by 2075. The Assessment includes this scenario as a reference tool for a worst-case emissions outcome for informational and planning purposes rather than a plausible climate change future.

Global climate models have very low spatial resolution to enable global coverage. To make these models helpful for regional and local uses, the Fifth Assessment uses a method called downscaling that creates higher resolution climate data for a smaller area and enables finer analysis. The two downscaling techniques used are called WRF and LOCA2-Hybrid; see the paper "Development of Climate Projections for California and Identification of General Use Projections" (Kalansky et al., 2026) for more.

Most Fifth Assessment analyses are based on three 30-year time periods: a historical baseline, a mid-century period, and a late-century period to draw comparisons between past and projected future conditions (**Table 1**).

Table 1: *Fifth Assessment time periods based on the available projections data*

Descriptive Term	Time Range
Historical	1981–2010
Mid-Century	2041–2070
Late-Century	2071–2100

2.1 Temperature: A Clear Signal

Average temperatures have increased and will continue to increase, both globally and in California. Current warming in California is unprecedented compared to measurements over the past century and estimates for the past millennium (Salzer et al., 2014; Stevens et al., 2008). Climate change projections show this trend continuing, with average temperatures increasing 3.5–4.3°F (1.9–2.4°C) by 2050 across climate scenarios relative to the 1981–2010 mean. By 2100, the two scenarios diverge, projecting mean temperature increases of 5.7°F (3.2°C; SSP2–4.5) and 8.0°F (4.4°C; SSP3–7.0). While unlikely, the very high scenario (SSP5–8.5) projects an increase of 10.8°F (6.0°C). Though temperatures are somewhat variable year over year, the overall signal of rapidly rising temperatures is unmistakable. This has dangerous consequences for California's public health, ecosystems, economy, and more (see *Section 4.3 Rising Temperatures and Extreme Heat*).

2.2 Precipitation: High Variability

California's precipitation (rain, snow, hail, etc.) is naturally highly variable due to its Mediterranean climate, with some years much wetter or drier than the historical average. Projections show this variability increasing. During high precipitation events, the biggest storms will carry even more rainfall, and a greater proportion of rain is likely to fall in extreme atmospheric rivers (**Figure 4**). During low precipitation periods, rising temperatures will exacerbate dryness (**Figure 5**).

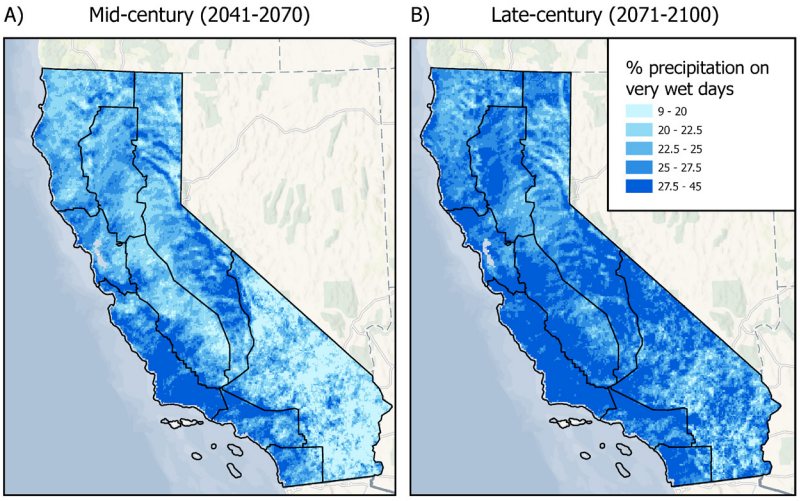


Figure 4: *Projected percent of total 30-year precipitation arriving on very wet days under the SSP3–7.0 scenario a) from 2041–2070 and b) from 2071–2100. Very wet days are defined as days with precipitation over the 95th percentile of precipitation (1950–2014) at that location. Figure by LCI Climate Services.*

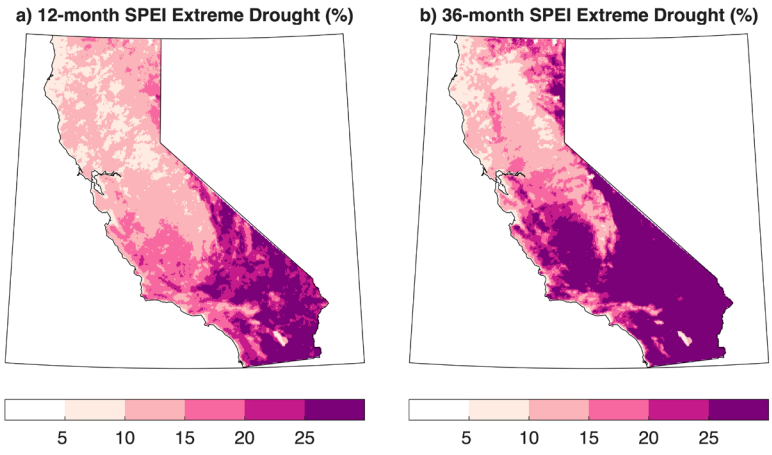


Figure 5: *The likelihood of a) single-year extreme drought and b) three-year extreme drought for mid-century (2041–2070) under SSP2–4.5. Extreme drought is defined as an event that would occur on average once every 20 years (5% likelihood) in the period 1951–2000. A 10% likelihood above signals a doubling of historical likelihood. The Standardized Precipitation-Evapotranspiration Index (SPEI) represents the balance of water supply (precipitation) and water demand (evapotranspiration). Figure by John Abatzoglou, UC Merced.*

2.3 Co-Occurring Climate Impacts and Overlapping Risks

Climate impacts rarely happen in isolation. While individual variables like temperature or rainfall provide a necessary baseline for understanding climate risk, a major challenge for long-term planning lies in how these hazards overlap and amplify one another. As climate change progresses, California is likely to experience more frequent and complex combinations of climate hazards, increasing the potential for impacts that are greater than those associated with any single hazard. These phenomena are often described as either compound events, where two or more climate hazards happen at the same time or in succession (see **Figure 6**), or as cascading impacts, a cause-and-effect sequence where one event triggers a series of secondary impacts across different systems (see **Box 4**). For example:

- Drought can dry vegetation and increase wildfire risk (cascading);

Box 4: *Cascading Impacts: Increasing Valley Fever*

Valley Fever is a disease caused by inhaling spores from certain *Coccidioides* fungi which are endemic to the US Southwest. Spores can become airborne when soil is disturbed by wind, dust storms, agricultural activities, construction, and other activities. Common symptoms include cough, fever, and fatigue, while rare but serious complications can include pneumonia and meningitis.

Emerging research suggests that Valley Fever transmission is sensitive to shifts between wet and dry conditions. Wetter conditions promote fungal growth, while subsequent dry summers, wind events, and dust-producing activities can increase spore dispersal (Camponuri et al., 2025; Head et al., 2022). As climate change intensifies climate whiplash between wet and dry extremes, Valley Fever risks may increase, with potential changes in the timing and geographic range across California (P. S. Lee et al., 2025). Valley Fever cases have increased recently in California, with the most cases seen in the San Joaquin Valley (CDPH, 2025) and disproportionate impacts to farmworkers and incarcerated people (Acey et al., 2026).

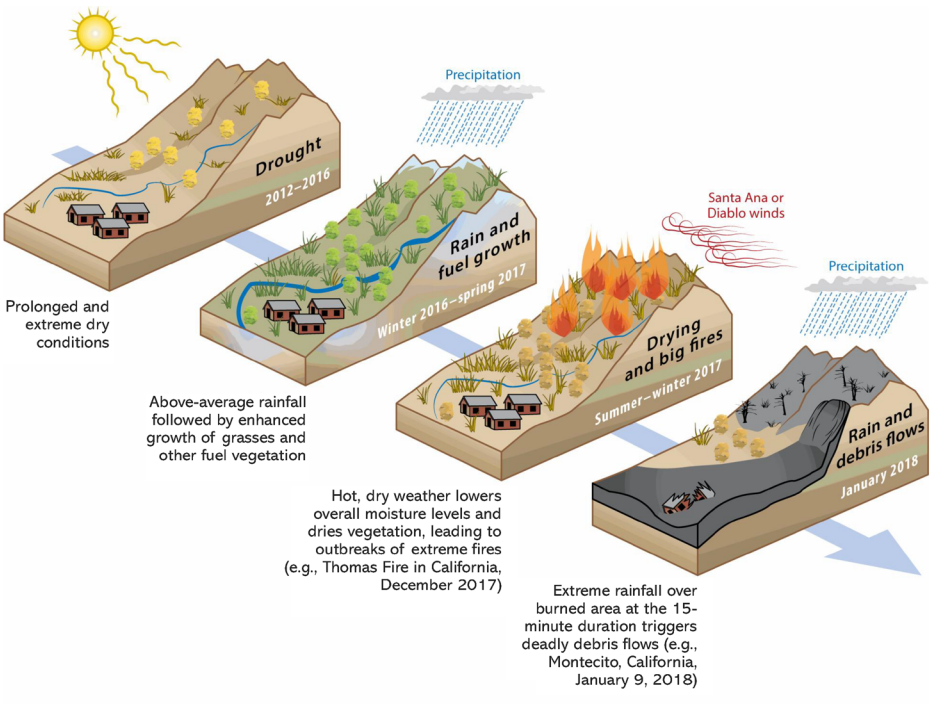


Figure 6: *An example of consecutive events that resulted in significant human health, economic, and ecological impacts in California. Adapted from AghaKouchak et al. (2020).*

- Wildfire can remove vegetation and change soil properties on hillsides and slopes, worsening flooding and debris flow (cascading);
- Extreme heat can co-occur with drought and worsen air quality (compounding); and
- Sea level rise can intensify coastal flooding (compounding).

Varying combinations of these extremes can impact cultural resources, social and economic dynamics, reliability of critical infrastructure, and health of natural systems and resources. Adaptation planning that focuses on only one risk at a time may miss these complex and interconnected realities of most climate extremes. Therefore, cross-cutting and multi-benefit strategies are key to reducing harm across multiple intersecting hazards or human populations at once (Acey et al., 2026).

2.4 Climate Whiplash

Scientists anticipate more frequent and intense annual "swings" between wet and dry extremes, often referred to as "climate whiplash" (**Figure 7**). Whiplash amplifies flash floods, wildfires, landslides, and disease outbreaks (see *Section 2.3 Co-Occurring Climate Impacts and Overlapping Risks*), and there is an increasing need to co-manage droughts and floods.

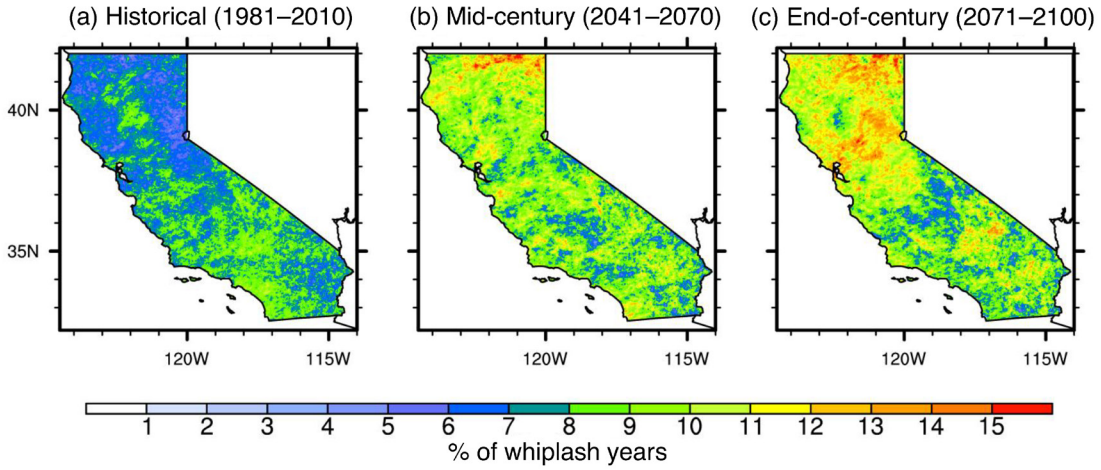


Figure 7: *Projected change in the percent of whiplash years under the SSP3–7.0 scenario by mid-century (b, 2041–2070) and end-of-century (c, 2071–2100) compared to a historical timeframe (a, 1981–2010). Whiplash years are defined as consecutive wet and dry years, where wet years are above the 80th percentile of historical 1981–2010 precipitation and dry years are below the 20th percentile of historical 1981–2010 precipitation. Figure by Jesse Norris, UCLA.*

2.5 Declining Snowpack

Snowpack is projected to decline over time. This stems from both projected warming temperatures and altered precipitation patterns, which can compound when they overlap. Warm temperatures and high or low precipitation events can lead to less snow, faster snowmelt,

precipitation falling as rain rather than snow, or rain-on-snow events that can produce rapid snowmelt and dangerous flooding. Increasing temperatures also play a role in the changing seasonality of snowpack and runoff (OEHHA, 2026). Under a warming climate, less snow is expected to remain in the Sierra Nevada during spring, leading to a shorter period of snowpack to replenish surface water reservoirs. This leads to long-term considerations for how water is managed in areas fed by snowmelt and runoff (Lynn et al., 2020; Mote et al., 2018; Shukla et al., 2015). Because winter snowpack functions as California's largest reservoir, declining snowpack can have a catastrophic effect on California's water supply, ecosystems, and public safety (see *Section 4.4 Drought* and *Section 4.5 Flood*).

Projected snowpack changes vary somewhat by analysis method but overall show a clear downward trend. For example, compared to 1981–2010, average snowpack in early April is projected to decline around 40% by mid-century (2041–2070) and 60% by end-of-century (2071–2100) across California (**Figure 8**). Similarly, a review by Siirila-Woodburn et al., (2021) found that across a number of studies, snowpack in the Sierra Nevada could be reduced by an average of around 50% by 2050–2074 and 65% by 2075–2099. By the second half of the century (2051–2100), snow lines (the elevation where snow cover begins) in the Sierra Nevada and Southern Cascades are projected to rise by 450–500 meters (0.2–0.3 miles) on average compared to 1951–2000 (Shulgina et al., 2023).

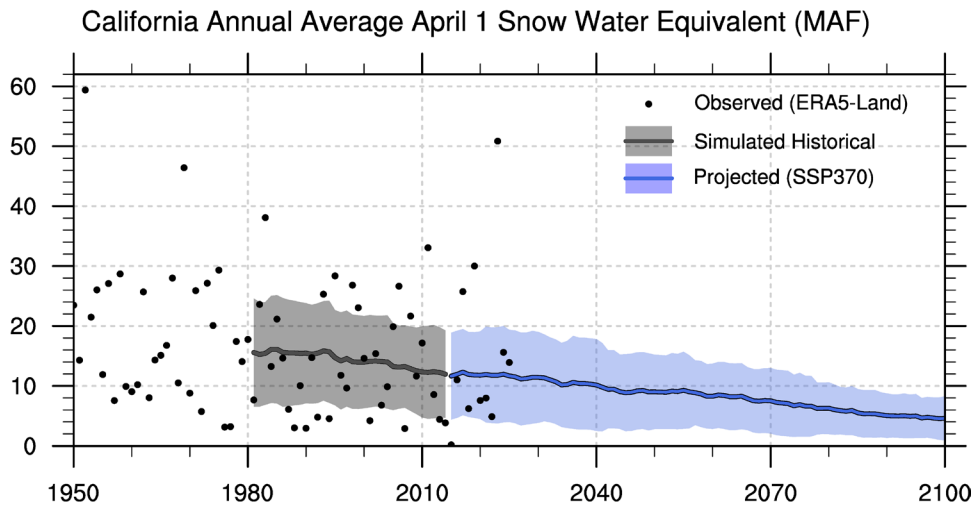


Figure 8: *Observed (ERA5-Land dataset), simulated, and projected (WUS-D3 dataset) annual April 1 snow water equivalent across California in millions of acre-feet (MAF). Snow water equivalent is the amount of water contained in snowpack, showing a clearly declining long-term trend. Figure by Paul Ullrich, UC Davis.*

The Colorado River, a critical water source for Southern California, gets its water from snowpack accumulating in the Rocky Mountains. Its natural streamflow has already dropped around 30% over the last century, and further reductions of about 0.5–0.8 million acre-feet (MAF) per year in California's share of Colorado River water are estimated in the coming decades (Lund et al., 2025; Schmidt et al., 2023).

2.6 Seasonal Shifts

Climate change is reshaping California's seasons, altering the timing, duration, and intensity of seasonal conditions. Warmer temperatures are arriving earlier in the year, persisting later into the fall, and contributing to longer periods of late-season dryness. At the same time, precipitation is becoming more concentrated, with similar annual totals falling over fewer days and in more intense storms. These changes are expected to continue and intensify, with summer periods projected to grow longer and winter periods shorter in the decades ahead (**Figure 9**).



Figure 9: *Conceptual diagram of seasonal shifts in California due to climate change, illustrating that summers are projected to grow longer while other seasons grow shorter. Preliminary estimates of average projected summer lengths under SSP 3–7.0 are shown for each 30-year time period to demonstrate the magnitude of the change.*

These seasonal shifts will increasingly affect the many natural and human systems that depend on the timing of seasonal patterns. For example:

- Plants and animals may experience increasing imbalance between seasonal cues and the availability of food, habitat, or other resources, affecting flowering, migration, reproduction, and survival.
- California Native American tribes may experience disruptions to seasonal indicators that guide cultural responsibilities, including the timing of harvesting traditional foods, ceremony, cultural burning, and other stewardship practices.
- Farmers may face changing temperature and precipitation patterns that can affect planting and harvesting windows, crop viability, water availability, and agricultural productivity.
- Tourism and recreational industries may face increasingly variable and less predictable seasonal conditions including reduced snowpack and shorter winter seasons, as well as changes in summer temperatures and water availability that affect recreational activities and local economies.

Seasonal shifts are also expected to affect water resources, conditions that contribute to wildfire risk, the length and intensity of pollen seasons, the distribution of disease vectors, and other natural and human systems. As these changes continue, understanding how the timing of seasonal conditions will shift and how those shifts interact with other climate hazards, will become increasingly important for adaptation planning, resource management, and long-term investments. Accounting for these impacts and dependencies in adaptation planning will become increasingly important as trends continue.

2.7 Climate Change and the Ocean

The ocean is a critical driver of global climate patterns through the influence of currents on winds and precipitation. It is also a pillar of California's economy, supporting $51.3 billion in gross domestic product and over 500,000 jobs in 2021 (NOAA, 2024). Climate change is already affecting the temperature and chemistry of the ocean, and these changes are expected to continue, with increasing consequences for marine and coastal ecosystems and the people and communities that benefit from them.

The California Current System is characterized by upwelling, which brings cold, acidic, low-oxygen, nutrient-rich water to the surface along the coast. Upwelling patterns are influenced by El Niño events (which bring warmer water, weaker upwelling, and increased chance of above average precipitation) or La Niña events (which bring cooler water, stronger upwelling, and lower precipitation). These events occur within the context of longer-term warm and cool phases (the Pacific Decadal Oscillation) which can last several years to several decades. These oscillating events and phases cause acceleration and deceleration of sea level rise on multi-year to decadal timescales, but do not change the overall rising trend (Hamlington et al., 2013). Future warming may cause changes in these interacting climate patterns (Cai et al., 2023; Klavans et al., 2025), contributing to increasing variability in rainfall (Cai et al., 2022) and coastal conditions.

Warming: Ocean warming has progressed at about 1.8°F (1.0°C) per century off the coast of California (Harris et al., 2026), with higher rates of warming in Southern California than the rest of the coast (OEHHA, 2026). Marine heat waves, which can bring temperatures 7°F (3.9°C) higher than average in some years (NOAA, 2019), are increasing in frequency and intensity (Capotondi et al., 2024; Oliver et al., 2019a). As ocean temperatures continue to rise, marine heat waves are expected to become more frequent and intense, increasing stress on marine ecosystems and creating additional challenges for coastal communities and ocean dependent economies (see *Ecosystems* under *Section 4.3 Rising Temperatures and Extreme Heat*).

Acidification: As atmospheric CO2 levels rise, the ocean absorbs increasing amounts of CO2. This increased uptake lowers the ocean's pH and increases acidity, a process known as ocean acidification. Acidification along California's coast is proceeding at twice the global rate because the water is naturally more acidic due to upwelling (Osborne et al., 2020; Stoll et al., 2025). Continued increases in atmospheric CO2 are expected to drive further ocean acidification, particularly in combination with California's naturally acidic upwelled waters. Acidic water can threaten marine life in a variety of ways, including by disrupting shell formation, with effects reverberating up the food chain and impacting seafood-reliant coastal economies (OEHHA, 2026).

Deoxygenation: Compared to the global average, California's coastal waters already have relatively low oxygen levels. Deep ocean waters, which are lower in oxygen, are becoming even less oxygenated over time, and these low-oxygen waters spread to shallower depths on the California coast due to upwelling (Barth et al., 2024). Low-oxygen conditions are projected to become more prevalent and intense along the California coast due to climate change, including an increase in hypoxia (Shi et al., 2023), a condition where dissolved oxygen levels in the water are too low to support most marine life.

Chapter 3.

California Native American Tribes and Climate Change



Since colonization, California Native American tribes have experienced violent land dispossession, forced removal, exploitation, and exclusion from land use and climate governance decision-making. Historical and ongoing land and water management practices and policies have limited tribal access to and authority over their ancestral lands, increasing the exposure of California Native American communities to climate hazards (Farrell et al., 2021). Climate change is inseparable from these broader social, political, and ecological histories and climate hazards interact with disruptions to tribal stewardship capacity to compound climate risks, limit tribal adaptive capacity, and weaken climate resilience across California (Hankins et al., 2026). As a result of these intersecting effects, California Native American communities face disproportionate impacts from climate change. For example:

- Climate change reduces access to traditional gathering sites as the seasonality and distribution of traditional foods and medicines shift (Campo Kumeyaay Nation, 2018; Tom et al., 2018). Limited access to gathering sites and cultural resources can diminish opportunities for intergenerational knowledge sharing, potentially affecting the continuation of traditional stewardship practices (Status of Tribes and Climate Change Working Group, 2021, 2025).
- Disproportionate rates of asthma, diabetes, and cardiovascular diseases among California Native Americans (CDC, 2024; HHS OMH, 2021, 2026) combined with heightened exposure to wildfire smoke (Casey et al., 2024) can increase susceptibility to climate-related respiratory illness, cardiovascular complications, hospitalizations, and other adverse health outcomes.

Despite the compounding challenges of climate change and colonization, California Native American tribes are drawing upon Traditional Knowledge developed over millennia to strengthen ecosystem resilience, support cultural continuity, and increase adaptive capacity in the face of a changing climate. Key resilience efforts include, but are not limited to:

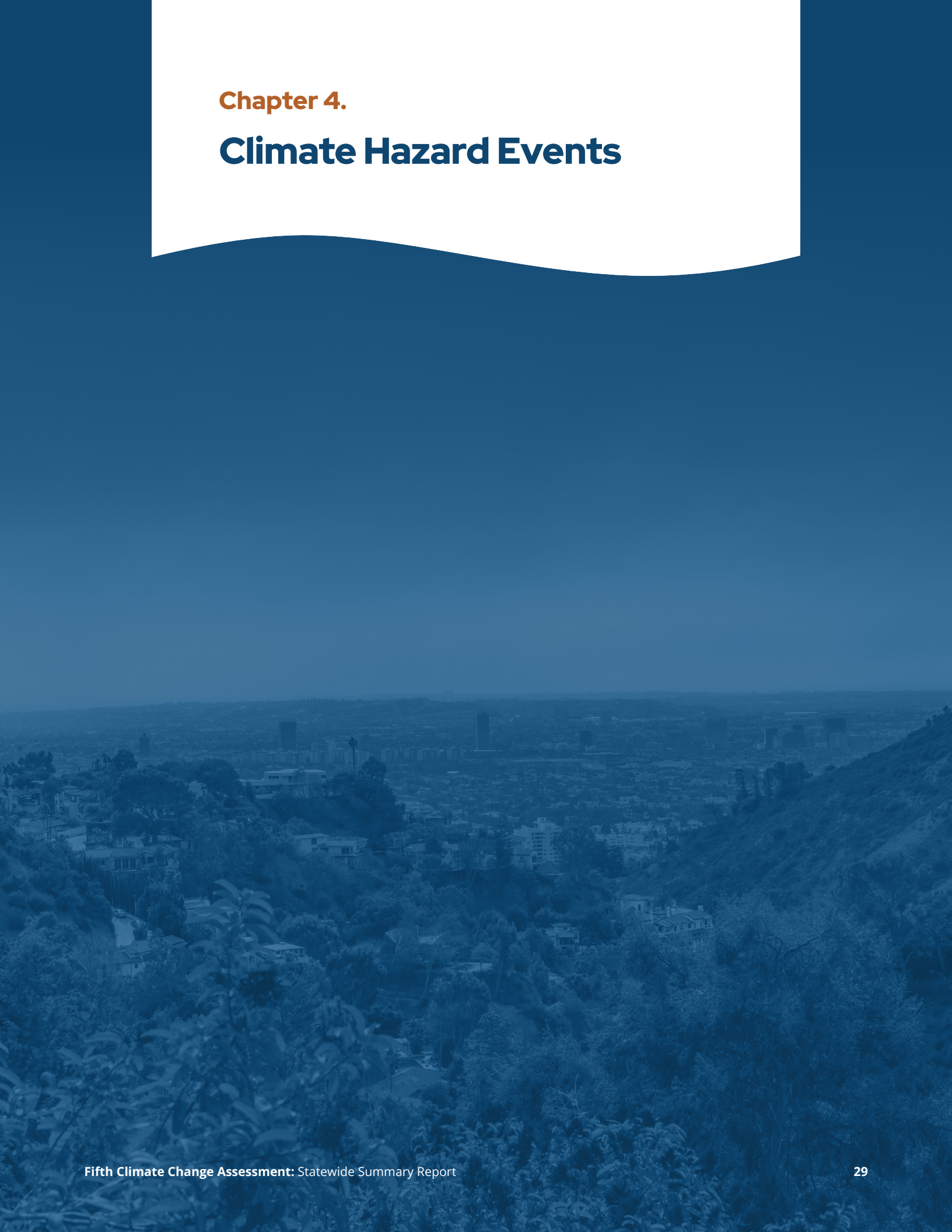
- Bringing cultural fire back to the land; restoring rivers, wetlands, forests, meadows, and coastal ecosystems; and reintroducing culturally significant species such as salmon, beavers, and condors to strengthen ecosystem resilience and cultural continuity.
- Returning ancestral lands to tribal ownership and developing co-management, co-governance, collaborative stewardship, and access agreements which restore tribal authority and strengthen the resilience of California's lands and waters.
- Developing place-based climate adaptation and emergency preparedness plans, renewable energy and microgrid projects, and other long-term resilience strategies that reduce tribal vulnerability to climate hazards.
- Supporting tribal elders, youth, and emerging tribal environmental professionals in sustaining Tribal Knowledges, languages, cultural practices, stewardship, and climate leadership across generations.

Effective climate adaptation requires moving beyond extractive practices that incorporate Tribal Knowledges or data without consent or meaningful partnership or exclude tribes from decision-making authority altogether (Hankins et al., 2026). While state agencies and research institutions increasingly engage with tribal communities and Traditional Knowledges, many still position western science and institutions as the arbiter of truth while treating Traditional Knowledges and knowledge holders as auxiliary or additive (Ban et al., 2026).

Expanded tribal consultation policies, tribal affairs infrastructure, tribal-led research programs, and co-management initiatives represent important steps toward more equitable climate governance. However, remaining barriers to sustainable funding structures, lack of adequate recognition of tribal sovereignty, and the continuation of extractive practices constrain tribal leadership and limit the capacity of California Native American tribes to steward their ancestral lands, access adaptation resources, and exercise decision-making authority, perpetuating inequities in climate governance. Without addressing these challenges as a core part of California's climate resilience, the risks of climate change and the underlying and historic inequities will continue to compound.

Chapter 4.

Climate Hazard Events



4.1 Introduction: Vulnerability to Climate Hazards

Climate change is increasing the frequency, intensity, duration, and impacts of climate related events in California (Kalansky et al., 2026), including short- or long-term hazard events like wildfire, extreme heat, drought, flooding, and sea level rise. The impacts and risks brought on by these extremes vary across regions, communities, and ecosystems because exposure is not evenly distributed throughout the state. Further, because different populations or people are particularly vulnerable to the effects of climate change depending on various social, political, and/or economic factors, the ability of a community to prepare for, respond to, and recover from a hazard event is not uniform from one community to the next. Understanding these nuanced differences in potential exposure, vulnerability, and adaptive capacity is essential for effective emergency management and long-term climate adaptation planning that addresses hazards and reflects the realities communities are already facing. The sections below demonstrate how climate change is contributing to more frequent and severe instances of wildfire, extreme heat, drought, flooding, and sea level rise; how communities are responding to the associated risks; and how adaptation interventions can be implemented to prepare California for the inevitable challenges ahead.

Box 5: *Defining Climate Vulnerability*

While climate hazards affect all regions of California, their impacts are not evenly experienced. Climate vulnerability describes the degree to which natural, built, and human systems are exposed to climate impacts as well as their capacity to prepare for, respond to, and recover from those impacts. Vulnerability is shaped by physical (built and environmental), social, political, and/or economic factors, such as race, ethnicity, class, gender, sexual orientation, national origin, income inequality, and disability. People and communities facing multiple forms of marginalization often experience climate impacts more intensely and face greater barriers to recovery (ICARP, 2025).

Climate vulnerability also includes risks to cultural landscapes, sacred sites, and place-based stewardship practices. Climate change can threaten traditional gathering sites, burial grounds, sacred springs, and other places that sustain the cultural identity of California Native Americans. For example, historic Chumash coastal village sites are particularly vulnerable to sea level rise, coastal erosion, and storm surges along the Central Coast (Santa Ynez Band of Chumash Indians, 2026), whereas droughts and decreased snowpack in the Eastern Sierra contribute to the loss of sacred springs for the Bishop Paiute Tribe (Bishop Paiute Tribe, 2022). Loss of access to these sacred sites and of the ability to participate in cultural practices negatively impact the psychological, physical, and spiritual well-being of California Native Americans (OEHHA, 2026).

4.2 Wildfire

Introduction

In the last decade, the state has experienced a surge in extreme wildfires: fires that burn unusually large areas, cause severe damage to communities and ecosystems, and result in major public health, economic, and infrastructure impacts. This includes an increase in megafires, fires that burn more than 25,000 acres (Linley et al., 2022). Twelve of the 20 largest, 11 of the 20 most destructive (measured by structures lost), and six of the 20 deadliest fires in recorded California

history have occurred since the last Climate Assessment in 2018 (**Figure 10**) (CAL FIRE, 2024, 2025b, 2025c). These fires are incredibly costly, as exemplified by the 2025 Los Angeles wildfires, which generated the largest wildfire insurance claims ever on a global scale (Munich Re Group, 2025). The smoke produced by wildfires also exposes Californians to harmful air pollutants (OEHHA, 2026). Smoke from several large wildfires during the 2020 fire season impacted air quality across the state, with hazardous levels of fine particulate matter (PM2.5) persisting for weeks in several areas of California (CARB, 2021).

While the factors influencing wildfire are complex, a growing body of evidence indicates that climate change has increased wildfire risk across California, through intensifications in fuel aridity (dryness level), longer fire seasons, and more frequent fire weather conditions (Ostoja & Battles, 2026). These factors play out on a landscape that has been transformed by people, first by tribal land management, including application of cultural fire, and then by later settlement and land-use practices such as grazing, road building, agricultural expansion, development, intensive timber removal, and fire suppression. Decisions about land management today will help determine the consequences of climate change-driven wildfire risk in the future.

Complex Causes

Wildfires are influenced by many interacting factors, including fuel availability and aridity, weather patterns, ignition sources, topography, and land management practices. Some of these factors are further amplified by climate change, including increasing aridity driven by rising temperatures and the potential for more intense Santa Ana wind events. Understanding the complex causes of wildfire is necessary for evaluating California's risk to wildfire.

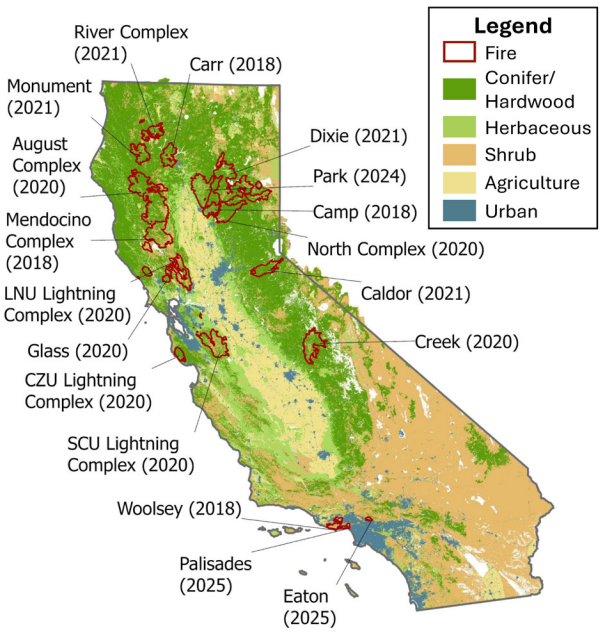


Figure 10: *Fires since 2018 which are among California's 20 largest, deadliest, or most destructive fires* (CAL FIRE, 2024, 2025b, 2025c) *shown over vegetation type* (CAL FIRE, 2025a)*. Figure by LCI Climate Services.*

Box 6: *The 2025 Los Angeles Fires*

In January 2025, multiple risk factors coincided, leading to highly destructive fires in the Los Angeles region. Two consecutive wetter-than-normal winters led to extensive herbaceous vegetation growth. This vegetation subsequently dried out during an exceptionally warm summer, while conditions remained dry due to the delayed arrival of fall and winter rain (Barnes et al., 2025; Madakumbura et al., 2025). During a strong Santa Ana wind event in January, multiple fires ignited in rapid succession across the region. Dry vegetation, strong winds, and the number of simultaneous fires limited suppression capacity and contributed to rapid fire spread (Guirguis et al., 2025). The Palisades Fire, which was ignited by arson, and Eaton Fire together destroyed more than 16,000 structures, burned more than 37,000 acres of land, and caused an estimated $250 billion in damage and economic loss in one of the most expensive natural disasters in US history (Chang et al., 2025). The 2025 Los Angeles fires resulted in 31 direct fatalities (Paglino et al., 2025).

HEAT AND DROUGHT

In montane conifer forests, climate change has increased the frequency and extent of damage caused by wildfires through increasing aridity of fuel, driven by rising temperatures and related vapor pressure deficit (VPD); (how much additional moisture the air could hold) as well as longer dry seasons (Prein et al., 2022; Swain, 2021; Turco et al., 2023; Westerling, 2016). At higher VPD, the air can remove more water from plants and soils more quickly, drying them out. As a result, small increases in VPD can drive disproportionately large increases in area burned (Juang et al., 2022; Westerling, 2016). In non-forested ecosystems such as shrublands, chaparral and grasslands, the increase in climate whiplash, such as back-to-back extreme precipitation and extreme drought due to climate change, can result in fast-growing, dying, and drying fuels. Drought and climate whiplash also interact with invasive species (see *Invasive Species and Wildfire* below).

IGNITIONS

In the last 30 years, 67% of California wildfires have been ignited by human activity or infrastructure, for example, via electricity transmission infrastructure, out of control campfires, sparks flying from vehicles, and arson (Ostoja & Battles, 2026; Short, 2026). Human ignitions can occur any time of the year, and when they coincide with hot, dry, and windy conditions, they can lead to extremely destructive fires. Throughout the deadly 2018 Camp Fire, the Diablo winds exacerbated flames sparked by poorly maintained powerlines. The fire was fueled by a buildup of extremely dry vegetative materials accumulated due to a previous unusually wet winter (Mass & Ovens, 2021). The Camp Fire burned 153,336 acres, destroyed more than 18,000 structures, and took 85 lives (CalOES, 2025).

Natural ignitions are caused by lightning. Such ignitions are most common in high-elevation mountainous regions and have started extremely large fires (Keeley & Syphard, 2018). For example, the 2020 August Complex Fire was the first fire that burned more than one million acres in recorded state history; it took three months to fully contain. Climate impacts on lightning itself are subtle; summer lightning may increase slightly in Northern California by 2031–2060 compared to 1995–2022 (Kalashnikov et al., 2025). If forest resilience does not keep pace with climate change, the effects of climate change on fuel aridity and land management on fuel availability will make each lightning strike more likely to cause destructive wildfire.

WINDS

Santa Ana, Diablo, and other downslope winds can amplify the extent of wildfire in California, expanding the perimeter dramatically by propelling embers and firebrands. The Eaton and Palisades fires were propelled by wind gusts reaching 90 miles per hour or more, driving embers two miles beyond the fire line (McChrystal Group, 2025). Santa Ana wind events, which occur in Southern California, may become more intense with climate change; they may also become less frequent in fall and spring and more frequent during winter (Guirguis et al., 2023; Guzman-Morales et al., 2016). In addition, climate models show that temperatures will be higher and fuel will be drier during Santa Ana events, increasing fire risk (Abatzoglou et al., 2023; Gershunov et al., 2021). In Southern California, if sufficient rainfall occurs before high winds begin, moist vegetation can decrease wildfire risk and size (Cayan et al., 2022). However, the average timing of strong winds relative to precipitation onset is not likely to change much in the next century (Taylor et al., 2025). Therefore, as in current conditions, some years will see significant precipitation arriving too late to reduce wildfire risk.

LAND MANAGEMENT

A century of fire suppression policies has fundamentally altered many California forests. Historic fire suppression reduced natural wildfires and tribal led cultural burns by more than 90% in some regions (Marks-Block & Tripp, 2021), assisting in fuel accumulation. In addition, 20th century logging in the Sierra Nevada range preferentially removed large, old, and more fire-resilient trees (MacDonald et al., 2023). These policies contributed to stands that are significantly denser and more susceptible to fire than pre-colonial conditions (Dolanc et al., 2014; McIntyre et al., 2015; North et al., 2022). Denser forests increase competition for water, making trees more vulnerable to drought stress and bark beetle outbreaks. These compounding conditions can contribute to widespread tree mortality events, the accumulation of additional fuels, and unusually large, intense, and long-lasting wildfires, including "mass fire" events such as the 2020 Creek Fire in the southern Sierra Nevada (Goodwin et al., 2021; Stephens et al., 2022). Unlike historical fires that typically burned most California forests in more patchy patterns and at lower severity, mass fire events can sustain extreme fire behavior across large continuous areas for days at a time.

INVASIVE SPECIES AND WILDFIRE

Human land use and transportation corridors can create pathways for the spread of invasive species and climate change hazards like wildfire can help to accelerate that spread (Keeley et al., 2011). Many invasive grasses and other non-native plants produce highly flammable fuels that dry earlier in the season than native vegetation, increasing wildfire frequency, size, and intensity (Wang et al., 2025). Following extreme wildfire, invasive species can rapidly establish in burn areas, outcompeting native plants and creating a self-reinforcing cycle in which invasive species promote future fires while impeding ecosystem recovery (Hopkins & Sendejas, 2026).

These impacts are concerning across California grasslands, shrublands, deserts, and forests as invasive species alter ecosystem processes, reduce biodiversity, and increase management costs. The spread of highly flammable non-native grasses, such as red brome, cheatgrass, and Mediterranean split grass in the Inland Desert region, has increased the continuity of fine fuels (fast-drying, thin, readily burned material like grass) across desert landscapes, contributing to heightened wildfire risks in an ecosystem that historically experienced infrequent wildfires (Hopkins & Sendejas, 2026). As these desert plant communities tend not to be fire adapted, this novel threat could be especially devastating for populations of species like the Joshua Tree which already faces climate-related challenges (Hopkins & Sendejas, 2026; **Figure 11**). A similar dynamic occurs in Southern California chaparral despite adaptation to high-intensity fire, as these ecosystems evolved with low-frequency fires. Increasing droughts and fire frequency have led to higher prevalence of non-native grasses, entrenching the "grass-fire cycle" (Ostoja & Battles, 2026).



Figure 11: *Eastern Joshua tree stands within an area of predicted climate refugia in Mojave National Preserve (C. I. Smith et al., 2023). 25% of this Joshua tree forest burned in the 2020 Dome Fire (National Parks Service, 2020). Photo by Lynn Sweet, September 2021.*

THE WILDLAND-URBAN INTERFACE

The wildland-urban interface (WUI) refers to areas where human-built structures meet or intermix with flammable wildland vegetation. More than three-quarters of the 20 largest, most destructive, or deadliest wildfires in California originated in close proximity to the WUI (Kumar et al., 2025). Many communities in the WUI were built decades ago, meaning they were not subject to standards of wildfire resilience set by California's current building codes. Structures built to these codes are significantly more likely to survive wildfires (Hedayati et al., 2023), and applying and retrofitting to these building standards is an important risk-reduction measure, relevant across the WUI but increasingly relevant in many adjacent areas.

High costs and barriers to development in urban areas contribute to ongoing development in the WUI. While more affordable housing can be found in some fire-prone areas (Greenberg et al., 2024), climate change can worsen wildfire risk in these same areas (Rao et al., 2022). According to the California Wildfire & Forest Resilience Task Force, WUI development and settlement increases exposure to wildfire "by exposing more communities to wildland vegetation, expanding the footprint of human-caused ignitions, and complicating firefighting efforts" (Ostoja & Battles, 2026). Promotion of infill development and increasing affordable housing in urban areas can reduce new development in these exposed areas, and interventions such as home hardening, defensible space, and restoring resilience in adjacent ecosystems can further mitigate the existing risk across wildfire-exposed communities and regions.

Box 7: *Groups Vulnerable to Wildfire*

Some groups of Californians are especially vulnerable to wildfire and wildfire smoke, often due to prolonged exposure to smoke or obstacles to evacuation. It is important to know and prioritize the needs of these groups when adapting to wildfire. For example:

- Unhoused populations are disproportionately exposed to wildfire smoke without adequate protection, proper air filtration, or clear emergency communication (Acey et al., 2026). For example, a study that surveyed people living unsheltered who had been near a specific wildfire smoke-affected area found that over half of respondents reported trouble breathing and accessing clean air during wildfire smoke events (Charan et al., 2026). Respondents also described asthma flare-ups, headaches, burning eyes, and the need to repeatedly wipe ash from their faces.
- Communities near freeways or industrial corridors, particularly Black communities, already experience air quality burdens due to historically discriminatory land use decisions. Wildfire smoke compounds these existing burdens (Acey et al., 2026), which can lead to disproportionate adverse health outcomes for Black residents (Liu et al., 2017).
- California census tracts with higher proportions of Native Americans have greater wildfire risk, experienced more wildfires from 2000–2020, and have low adaptive capacity (Davies et al., 2018; Masri et al., 2021). Heightened exposure to wildfire smoke and disproportionate rates of underlying health conditions increase susceptibility to air pollution-related illnesses amongst California Native Americans (Casey et al., 2024; Wiecks et al., 2020).
- For farmworkers, wildfire smoke reduces income and hours worked and can lead to health problems due to prolonged exposure (Acey et al., 2026). Farmworkers are projected to experience a 190% increase in smoke exposure days considered "unhealthy for sensitive groups" by mid-century (Marlier et al., 2022). Farmworkers, especially migrant farmworkers, are subject to higher income insecurity and health risks due to smoke exposure which compounds with exposure to heat, pesticides, and contaminated drinking water.
- Immigrant communities are vulnerable to evacuation failures and language-inaccessible emergency responses (Acey et al., 2026). Limited eligibility for relief programs among immigrants and undocumented residents has deepened inequities following wildfires and other disasters.
- People with disabilities may require additional assistance responding to emergencies, including evacuation orders (Ermagun et al., 2025). Emergency managers in California report gaps in communication and lack of transportation access.
- Children, pregnant people, and older adults face elevated health risks from wildfire smoke compared to the general population (Aguilera et al., 2021; Syed & Basu, 2025; Wardle et al., 2026).

Impacts

PUBLIC HEALTH

Wildfire exposure leads to adverse physical and mental health effects with significant public health implications. Wildfire smoke contains fine particulate matter (PM2.5) which can penetrate the lungs and enter the bloodstream (CDPH, 2026). Smoke can also include heavy metals (such as lead), carcinogens, and other toxic chemicals from the combustion of buildings, vehicles, and other synthetic materials, particularly if they extend into the WUI. Exposure to pollutants in wildfire smoke has been linked to respiratory illnesses such as asthma, as well as cardiovascular impacts including heart attacks and stroke (A. I. Chen et al., 2023; Heaney et al., 2022). The health consequences of wildfires extend beyond physical illness as evacuation, displacement, property loss, and smoke exposure are associated with increased rates of anxiety, depression, and post-traumatic stress disorder (R. Lee et al., 2025; Silveira et al., 2021; Wettstein & Vaidyanathan, 2024).

As climate change increases the frequency, intensity, and duration of wildfire activity, these combined physical and mental health impacts are expected to place growing burdens on California communities, particularly those facing repeated smoke exposure, displacement, or barriers to healthcare access. The impacts of wildfires are anticipated to worsen, with recent models projecting California to have the highest increase of all US states in annual excess deaths from wildfire smoke by 2050, with more than 5,000 excess deaths per year compared to 2011–2020 (Qiu et al., 2025). Public health interventions and programs that promote climate resilience such as community resilience centers, and promoting protective behaviors such as using HEPA air filters and sealing homes from smoke infiltration, may help reduce the health impacts during and after wildfire events (R. Lee et al., 2026).

HOUSING

Especially severe wildfires can cause displacement; for example, over 27,000 people were displaced in the wake of the 2018 Camp Fire in Paradise, California (CalOES, 2025). As older homes and rental properties are most likely to be destroyed, this can lead to a process of community displacement with lower-income residents less likely to return and rebuild (Lambrou et al., 2025). While some WUI development has reflected a search for affordability (Greenberg et al., 2024), increased wildfire risk has made home insurance in such areas increasingly unaffordable. Insurance premiums for single-family homes increased by 85% on average (45% adjusted for inflation) between 2020–2026, rising most sharply in wildfire-prone areas, and more homeowners are turning to the FAIR (Fair Access to Insurance Requirements) plan, California's insurer of last resort (Nguyen et al., 2026). Even if they can obtain coverage, up to 60% of Californians are underinsured, leading to rebuilding delays and increased financial distress especially for low- and middle-income households (CEA, 2025). Measures to protect homes by building resilient structures and creating defensible space can help combat rising insurance prices (see *Home Hardening and Defensible Space* below).

ENERGY AFFORDABILITY

Wildfire risk is increasingly affecting energy affordability in California. From 2019–2024, electricity costs rose by about 6.2 cents per kilowatt-hour (kWh) statewide, with about 5 of those cents

attributed to wildfire-related costs (Wiser et al., 2025). These costs include mitigation measures, such as undergrounding power lines and vegetation management around utility infrastructure, as well as rising utility insurance rates and payments for damages from utility-caused wildfires. The California Earthquake Authority report in response to Senate Bill 254, details the factors that connect wildfire risk, utilities, and electricity bills and outlines pathways to balance goals of reducing wildfire risk and affordable energy. Without action, the costs of preventing, insuring against, and recovering from wildfires will be passed on to electricity customers as climate change increases wildfire risk (Wiser et al., 2025). Damage to energy infrastructure during wildfires also results in reduced service capacity and increased outages (Vahedi et al., 2025).

WATER

Large wildfires with moderate to high burn severity can degrade water quality and negatively impact associated habitat, drinking water supplies, and recreation (Feather River Watershed Working Group, 2024). Common changes in water quality after a wildfire include increases in nutrient levels, metals, polycyclic aromatic hydrocarbons, and water temperatures from loss of vegetative cover. Debris flows and flooding pose the most obvious threats, but fertilizers, herbicides, and other chemicals in fire-ravaged areas that might be washed into stormwater systems or flow into waterways also threaten water quality, public health, and the environment (Feather River Watershed Working Group, 2024; SWRCB, 2025). Depending on the extent of the damage to infrastructure during a fire, drinking water systems can take weeks to months to recover fully (SWRCB, 2025). For example, wildfire is a critical threat to the Feather River Watershed which provides drinking water for millions of Californians and irrigation for thousands of acres of farmland (DWR, 2025c). Wildfires occurring between 2018–2022 changed the timing and amount of runoff from this watershed into Lake Oroville (Abolafia-Rosenzweig et al., 2024). This demonstrates that wildfires are another hazard requiring adaptive management of watersheds, reservoirs, and water provisioning systems in California.

AGRICULTURE

Crops and livestock can be directly and indirectly affected by wildfire through losses and smoke impacts. Smoke can slow photosynthesis, delay ripening, and ultimately reduce crop yields. Studies have shown reduced yields and damage in almonds, pistachios, walnuts, rice, and wine grapes due to wildfire smoke (Kennison et al., 2011; Orozco, Guzmán-Delgado, et al., 2024; Orozco, Lauterman, et al., 2024). While wildfire affects a relatively small portion of rangelands, their consequences for individual producers can still be significant and devastating (Medellín-Azuara et al., 2026). Surveys of 70 livestock producers (cattle, sheep, and goat) across California, Oregon, and Nevada revealed that the 2020 wildfire season forced 26% of producers to evacuate their herds and resulted in loss of pastures for 19% of producers (O'Hara et al., 2021). Respondents also reported decreased dairy production and an increase in negative health impacts like pneumonia. While reports of direct livestock deaths due to wildfire were minimal, there is a need to further quantify the impacts of wildfire on the livestock industry in the future.

Wildfire can also contaminate agricultural water sources (see *Water* above), which are also stressed by the other climate hazards discussed in this report.

ECOSYSTEMS

While many California ecosystems are adapted to low-severity or low-frequency fires, climate change is contributing to alteration of the state's historic fire regime by increasing fire severity, extending fire seasons, and shortening fire return intervals (Parks & Abatzoglou, 2020; Williams et al., 2019). These shifts have degraded ecosystem functioning and led to ecosystem type conversion (Ostoja & Battles, 2026). For example, without adequate reforestation, high-severity fires can convert forests to shrublands or grasslands (Coop et al., 2020). Under future climate regimes and without substantial fire resilience management, about 80% of forest burned at high severity could fail to regenerate (DeLyser et al., 2025). Native shrublands are vulnerable as well; although chaparral is adapted to high-severity fire, an increase in fire frequency in chaparral can allow invasive species such as black mustard and non-native grasses to replace native vegetation and increase future fire risk (Syphard et al., 2022).

Severe, unusually frequent, and/or large wildfires can also destroy, degrade, and fragment habitat that many plants and animals rely on. High-severity fires can eliminate native vegetation, reduce food and shelter, and weaken and disrupt ecological structures, functions, and services communities rely on, such as water supply protection, clean air, durable carbon storage, sediment retention, flood risk, and recreational opportunities. Intense heat from wildfires can alter soil microbial communities, burn protective organic matter, and create a water-resistant crust (Wilson et al., 2026; Wohlgemuth & Lilley, 2018). These impacts can persist long after a fire as post-fire erosion, vegetation loss, and the introduction of invasive plants alter habitat conditions and limit the recovery of native species. Fire-related habitat loss can also lead to an increase in human-wildlife conflict as displaced animals search for food and shelter (Blakey et al., 2022). For example, the presence of a massive black bear who found refuge from the 2025 Eaton Fire in an Altadena crawlspace delayed SoCalGas crews from restoring the homeowner's gas service after the fire (Lin, 2025).



Figure 12: *A large black bear was found under an Altadena, California home after the Eaton Fire, wildlife officials said. Photo by California Department of Fish and Wildlife via Byers (2025).*

Increased sedimentation, erosion, and flooding affect fish and amphibians (e.g., frogs, salamanders, newts) in watersheds affected by fire. Even coastal and marine ecosystems can be harmed through accumulation of sediment and toxic materials in ashes, fire retardants, and debris. Runoff can trigger harmful algal blooms. Harmful algal blooms, known as HABs, occur when toxin-producing microscopic algae and cyanobacteria grow excessively in a body of water and cause harmful effects on people and marine life (Oh et al., 2023). These changes can work their way through the food chain, even affecting marine mammals through loss of prey (OPC, 2025).

Carbon stocks can be used to help assess the health of the environment as well as the services they provide to communities, including the environment's ability to help fight climate change (CARB, 2025). They are also used within wildfire risk, wildlife habitat, and water storage metrics (e.g., Flint et al., 2018). Increasing droughts, extreme heat, and catastrophic wildfire conditions, among other factors, all threaten the ability of the environment to fight climate change and provide the basis for safe and healthy communities. Proactive nature-based solutions can help the environment withstand these climate impacts and increase their capacity to fight climate change (CNRA, 2022). Further, reducing emissions from fossil fuels that lead to droughts, extreme heat, and catastrophic wildfire conditions remains one of the most powerful ways Californians can help protect these lands.

Adaptation and Resilience

Wildfire adaptation and resilience efforts can take many forms, including fuel reduction, home and infrastructure hardening, defensible space, community scale coordination and planning, and emergency management. However, these strategies are most effective when designed in response to complex local community needs and environmental conditions such as ecology, topography, and infrastructure.



Figure 13: *An intergenerational cultural burn led by members of the Miwok community at the Lockeford Plant Materials Center in 2022 to increase productivity and diversity of native grasses and forbs, among other objectives. Photo by Sydney Hankins. B) A CAL FIRE firefighter uses a drip torch to light a prescribed fire on Pole Mountain in 2025. Source: CAL FIRE. C) A California Conservation Corps (CCC) corpsmember removes overgrown vegetation during a defensible space project on Angel Island in February 2026. Source: CCC.*

FUEL REDUCTION AS WILDFIRE RESILIENCE

In California, state, tribal, regional, and local governments; industrial and non-industrial timber owners and managers; and other non-governmental organizations are utilizing nature-based solutions to remove fuels to reduce wildfire risk (**Figure 13**). For example:

- **Prescribed fire** is one of the most effective tools for reducing fuel-dominated wildfire risk in many forested ecosystems (Chung et al., 2025; Fallon et al., 2025; X. Wu et al., 2023). These intentionally ignited, carefully managed fires consume surface and understory fuels and can reduce the likelihood of future catastrophic wildfires by up to 92% for a decade following treatment (Higuera-Mendieta & Burke, 2026).

- **Prescribed grazing and mowing** introduce livestock and machinery to remove grasses, shrubs, and other fine fuels which can carry fire quickly across a landscape. These practices are especially useful along roads and strategically in communities where prescribed fire may not be feasible or appropriate.
- **Mechanical and hand thinning** removes small trees, denser understory vegetation, and accumulated woody material that can carry fire from the forest floor into the canopy. These treatments can help reduce fire intensity and make prescribed burns safer and more effective. Hand thinning can be especially important in sensitive areas, areas with steep terrain, and landscapes where heavy machinery may damage soils, cultural resources, or sensitive habitat.
- **Invasive species removal** can help reduce fire spread, support native plant recovery, and help disrupt the feedback loop in which fire promotes invasive species which fuel future fires.
- **Selective timber harvesting** is the removal of individual trees or groups of trees to better mimic the structure and composition of forests prior to Euro-American colonization to reduce overcrowding, improve forest health, and lower the risk of wildfire.
- **Managing fire for resource benefit,** or "managed wildfire," is the strategic choice to manage natural ignitions to achieve management objectives, such as ecosystem restoration or hazard reduction. Managed fire is typically deployed in wilderness areas, national parks, and other areas of public ownership under specific conditions or circumstances.
- **Biofuels and biochar** can be produced from fuel reduction and restoration residue biomass as ways of contributing to California's carbon neutrality goals while producing more resilient ecosystems (Baker et al., 2020; Davison et al., 2024; DeLyser et al., 2025).

Across the western US, these fuel treatments have reduced wildfire spread and severity, avoiding an estimated $2.8 billion in damages from 2017–2023. The estimated return on investment was $3.73 for each dollar spent (Strabo et al., 2026).

TRADITIONAL FIRE STEWARDSHIP AND CULTURAL BURNS

California has a long and rich history of fire stewardship, with California Native American tribes practicing cultural burning since time immemorial (Anderson, 2005; Hankins et al., 2026). Cultural burning is the practice of intentionally setting low-intensity fires for cultural, ceremonial, subsistence, and ecological purposes. This fire stewardship practice has multiple benefits, including maintaining habitat for traditional foods, fibers, and medicines; removing underbrush; and hardening the landscape against devastating wildfires (Connor et al., 2022). Developed over thousands of years, this place-based practice varies among tribes, and each has its own specific cultural, spiritual, and environmental protocols. As tribes continue to reclaim their traditional practices, cultural burning is increasingly recognized as an essential climate adaptation strategy, nature-based solution, and exercise of tribal sovereignty, stewardship, and religious freedom.

Box 8: *Revitalizing Cultural Burns: Exercising Tribal Sovereignty as Climate Action*

Tribal land management and cultural practices, including cultural burns, were criminalized and suppressed for more than a century, beginning with California's 1850 Act for the Government and Protection of Indians and reinforced by subsequent state and federal fire suppression policies that disrupted tribal stewardship, contributed to fuel accumulation, and increased wildfire vulnerability across the state. Despite these discriminatory policies, cultural practitioners continued to carry the teachings of their elders in private, preserving fire knowledge and passing it on to future generations.

Today, tribes are increasingly returning cultural fire and prescribed fire to their traditional homelands. Across California, many tribes are revitalizing their traditional practices and strengthening wildfire resilience through tribal-led burn programs, cultural fire training, intergenerational knowledge sharing and workforce development, and partnerships with state, federal, and regional land managers. Examples include:

- **Cultural Burn Trainings:** Tribes and cultural practitioners are leading cultural burn trainings that bring together intertribal partners and allies to restore fire teachings and demonstrate the ecological benefits of good fire (Adlam et al., 2022; Buono, 2020; Tamien Nation, 2026).
- **Bark Beetle Management:** In response to severe oak mortality from the goldspotted oak borer, the La Jolla Band of Luiseño Indians is exploring prescribed fire as a landscape-level management tool (Tamm, n.d.). These efforts are restoring tribal stewardship practices and strengthening wildfire resilience at a time when the state is becoming increasingly interested in prescribed burns and partnering with tribes. While state policies that advance tribal sovereignty with respect to cultural burning (e.g., SB 310 [Dodd, 2024]) work to remove barriers for tribes to practice cultural burns, significant barriers remain (Simmons & Hacker, 2026).

POST-WILDFIRE REFORESTATION

Post-wildfire reforestation is an essential nature-based solution to reduce post-wildfire forest loss and the risk of repeated high-severity burns (DeLyser et al., 2025; Ostoja & Battles, 2026). While fires have historically been beneficial to ecosystems, the large size and intensity of modern extreme wildfires can prevent seeds from reaching interiors of burn regions or regrowing from destroyed seedbanks. Natural regrowth is further challenged by increased severity and frequency of drought and heat. Active reforestation can help avoid the worst impacts of high-severity wildfire and habitat type conversion while restoring the ecosystem services provided by forests, including water supply protection, wildlife habitat, carbon storage, snowpack regulation, timber provisioning, and recreation (DeLyser et al., 2025; Ostoja & Battles, 2026).

GRID HARDENING

Grid hardening includes actions utilities are testing and implementing to reduce ignition and wildfire risk, particularly during extreme weather events. These include burying electrical lines to avoid interaction with nearby vegetation, insulating the conductors, installing fault detectors that can rapidly de-energize the line (fast trip settings), and initiating Public Safety Power Shutoffs (PSPS) that de-energize lines during extreme fire weather events.

Innovations such as fast trip settings have emerged as a more finely targeted way to reduce wildfires (relative to PSPS). These settings have reduced vegetation-caused ignitions by approximately 80% in areas serviced by Pacific Gas & Electric (PG&E). Researchers also found that PG&E grid-hardening measures since 2020 have reduced wildfire risk along powerlines in recent years (Warner et al., 2025) (**Figure 14**).

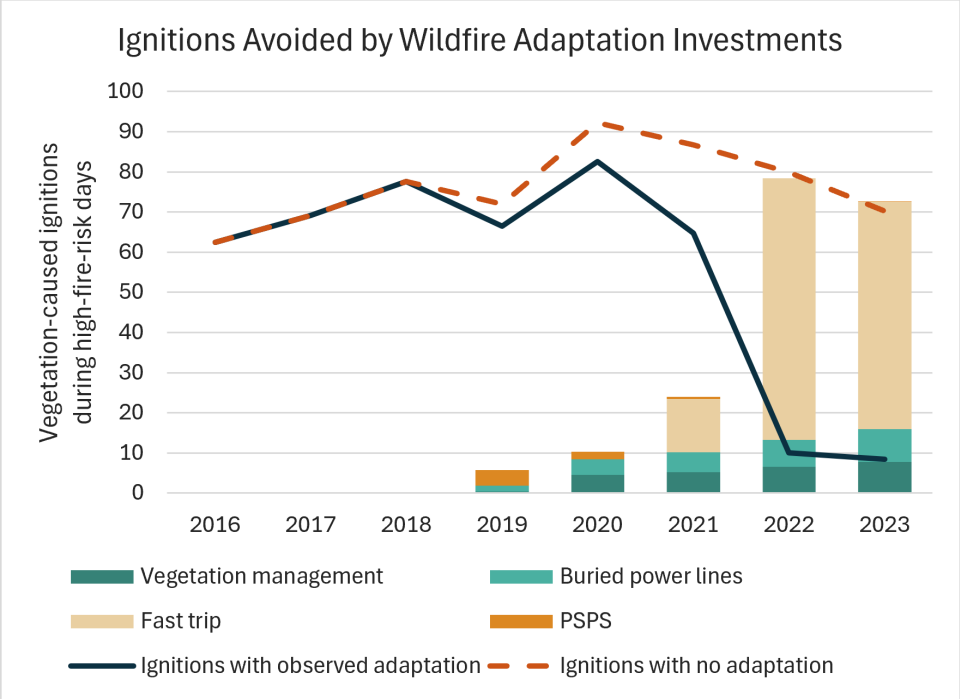


Figure 14: *Ignitions avoided due to wildfire adaptation investments, modeled using weather and vegetation data for 25,000 miles of PG&E power lines in high fire-risk areas. The stacked columns show the estimated number of ignitions avoided by each intervention type in that year based on both the amount implemented and its effectiveness. Note that these add up to more than the actual number of avoided ignitions because sometimes any one of multiple interventions would prevent the same ignition. Adapted from Warner et al. (2025).*

Box 9: *Microgrids in Tribal Communities*

Microgrids provide energy generation and storage at small local scales and can operate either connected to or separately from the regional electrical grid. The Tribal Energy Resilience and Sovereignty project is partnering with Blue Lake Rancheria, which has operated a highly successful microgrid since 2017. They are planning to create three nested microgrids covering 142 miles in Humboldt County (Schatz Energy Research Center, 2024). This initiative's goals include 20 megawatts of renewable energy resources and a 90% reduction in outage hours, such as those caused by PSPS, compared to conventional grid dependence. This will provide key energy resilience to a rural area with the longest and most frequent power outages in the state (Sherriff et al., 2026).

In Southern California, UC San Diego, the port of San Diego's Tenth Avenue Marine Terminal, and the Pala Band of Mission Indians have undertaken microgrid projects as well. The Pala Band's Community Microgrid project will offset 102% of the Tribe's electricity use at eight key facilities, saving approximately $6.4 million in net energy costs and displacing over 930,000 pounds of CO2 over the project's expected 25-year lifetime (US DOE, 2024).

These efforts are supported by California's comprehensive utility wildfire risk management system, including the nation's first mandatory Wildfire Mitigation Plans (WMPs), dedicated oversight through the Office of Energy Infrastructure Safety (OEIS), and continued regulation by the California Public Utilities Commission (CPUC). SB 901 and AB 1054 strengthened requirements for asset awareness, vegetation management, situational awareness, and risk modeling. Recent legislation, including SB 254 (2025) and SB 742 (2026), has further expanded utility mitigation and accountability requirements.

HOME HARDENING AND DEFENSIBLE SPACE

Because many homes ignite from wind-driven embers or nearby structures (Manzello et al., 2020), WUI wildfire resilience depends on reducing flammable materials on and around structures. Home hardening refers to the building or retrofitting of homes with fire-resistant materials and design features, such as ember-resistant vents, noncombustible roofing and siding, and tempered glass windows. Defensible space complements these efforts by managing vegetation and other flammable materials around buildings, including clearing dead vegetation, pruning trees, spacing plants, and keeping the area closest to structures free from combustible materials. Together, these strategies can reduce the likelihood of building combustion and slow the spread of fire between structures, especially when completed at the community level (Syphard & Keeley, 2019; Zamanialaei et al., 2025).

To enhance wildfire mitigation efforts in WUI communities, the Governor recently signed legislation (SB 894, Allen) that established the California Wildfire Resilience Loan Program. This low interest loan program will provide financial assistance for projects and activities that reduce wildfire related risks and losses, including home hardening and defensible space improvements. In addition to this legislation, among a larger package of wildfire prevention bills, the Governor also signed AB 1934 (Bennett) which creates a home hardening certification program implementation plan at Cal Fire, as well as AB 1934 (Bennett) which requires Cal Fire to document which homes in the WUI were built prior to 2008 and are not up to current WUI building codes (Title 24, Part 7). Furthermore, insurers in California must include some coverage (at least 10% of the policy limit) for upgrades to meet new building codes, increasing home resilience (California Insurance Code section 10103[c]). Insurers also must provide the same payout for a "total loss" regardless of the cost of building or purchasing a home in a new area (California Insurance Code section 2051.5[c][1]). This can facilitate movement to lower wildfire exposure areas.

4.3 Rising Temperatures and Extreme Heat

Introduction

Average annual temperatures in California have increased substantially in the past decades and will continue to rise (OEHHA, 2026).

From 1981–2010, California's average annual temperature was 58.2°F (14.6°C). Since 2010, all but two years have exceeded this threshold, most by over 1.5°F (0.8°C) (**Figure 15**). This rise in temperature is not uniform: the amount of observed warming varies by region, season, and even time of day. For example, future warming will be more pronounced in the summer than in the winter, making the hottest times of year even hotter.

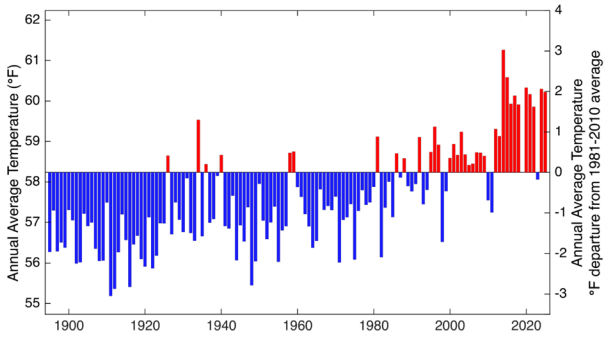


Figure 15: *Observed average annual temperature over California from 1895–2025 compared to the 1981–2010 average temperature of 58.2°F (14.6°C). Data from NOAA's monthly NClimGrid* (Vose et al., 2014)*, updated monthly since publication. Figure by John Abatzoglou, UC Merced.*

One of the most consequential impacts of rising temperatures is longer and more frequent extreme heat events. All California residents have experienced the impacts of extreme heat events in some way, especially within the past decade, and it is the leading cause of weather-related deaths in the US (NOAA, 2025a). An extreme heat event is often described as an unusually hot day or night that exceeds a relative threshold for a location compared to its average temperatures (EHAP, 2026; OEHHA, 2026). These thresholds can range from 85th to 98th percentile of historical values (OEHHA, 2026).

Extreme heat manifests differently location by location (**Figure 16**). For example, a community on California's North Coast where many buildings lack air conditioning might use a lower threshold to measure extreme heat than a community in the Coachella Valley, where days over 100°F (37.8°C) are common and air conditioning use is prevalent.

Though there is no universal definition of heat waves, they can be characterized as a type of extreme heat event consisting of a series of consecutive abnormally hot days and nights. Climate models project that heat waves will grow significantly longer in the coming decades. Analysis conducted for the Fifth Assessment shows that under a high emissions scenario, the average length of the longest heat wave per year, defined as consecutive days with temperatures above the 98th percentile of the 1981–2010 period, will grow from around three days across the state, to six days in the Bay Area region at the lowest, and 19 days across the Sierra Nevada region at the highest (Stevenson, 2026). Other regions with substantial projected increases are Inland Deserts (to 17 days), the Sacramento Valley (to 14 days), and the North Coast (to 12 days).

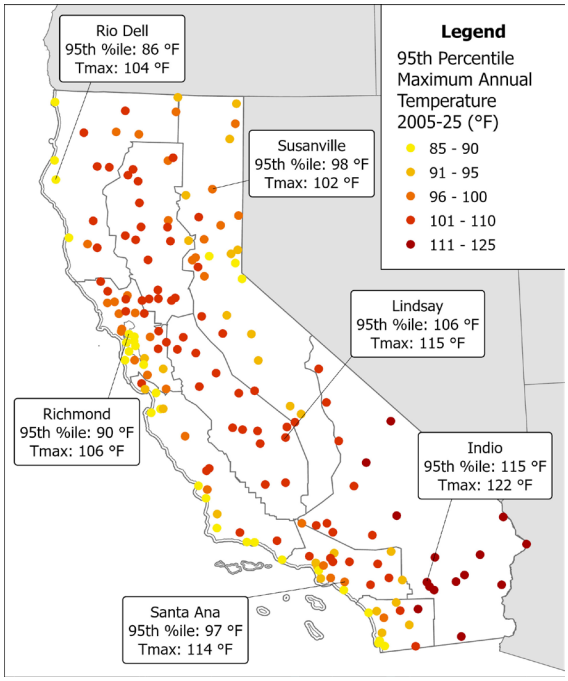


Figure 16: *95th percentile maximum annual temperature (2005–2025) at weather stations across California, representing one possible threshold for measuring extreme heat. To demonstrate what an extreme heat event looks like under these thresholds, callouts show the highest recent recorded temperature (Tmax; 2005–2025) at six example locations that have high social vulnerability to extreme heat according to the Vulnerable Communities Platform. Data from NWS; figure by LCI Climate Services.*

Box 10: *Groups Vulnerable to Extreme Heat*

Many groups are at elevated risk from extreme heat compared to the average population for biological, environmental, or socio-economic reasons. To curb the health impacts of extreme heat, it is important to consider the needs of these vulnerable groups. Examples include:

- Farmworkers are at a 35 times greater risk of heat-related mortality than the general workforce (Gubernot et al., 2015). Extreme heat also causes income insecurity for farmworkers and intensifies other common exposures, such as wildfire smoke, pesticides, and contaminated drinking water (Acey et al., 2026). Over 90% of farmworkers are immigrants, and it is estimated over half are undocumented, leading to exclusion from unemployment insurance and many disaster-relief and health aid programs (Cha, 2022). Fear of retaliation, deportation, and detention suppresses reporting of unsafe conditions (Acey et al., 2026).
- Older adults experience worse outcomes from extreme heat because cardiovascular function worsens with age (Kenney et al., 2014).
- Young children and infants less than 4 years of age may have an increased risk based on physiology to extreme heat events and rely on adults for hydration and cooling (C. J. Smith, 2019). Heat also negatively impacts children's school performance, with disproportionate impacts on students of color (Park et al., 2020; Postell et al., 2025). California schools are also not prepared for the impacts of extreme heat. An estimated 15–20% of California's TK-12 public schools have no mechanical HVAC systems, and up to another 10% of schools require major HVAC repair or replacement (Patel et al., 2023).
- Pregnant people and newborns are at risk, as extreme heat leads to higher rates of preterm births and other adverse pregnancy outcomes (Basu et al., 2017; Darrow et al., 2024; Ha et al., 2024; Teyton et al., 2023).
- Colonization and the forced relocation of California Native American tribes have increased tribal vulnerability to extreme heat and limited tribal adaptive capacity (Farrell et al., 2021). This vulnerability leads to further erosion of tribal culture and language, as high electricity costs, limited infrastructure, and extreme heat cause tribal members to relocate to cities (Flavelle, 2021).
- Black communities across income levels face disproportionate risks to extreme heat from historic policies such as redlining, urban renewal, and exclusion from planning (Acey et al., 2026). These have contributed to hotter neighborhoods with less tree canopy and vegetation, intensifying urban heat island effects, and exacerbating health risks (Estien et al., 2024; Hoffman et al., 2020; McDonald et al., 2021).
- People living unsheltered make up only 0.5% (~180,000) of California's population but account for 13% of all hospitalizations due to heat-related illness (Pocock et al., 2025). Constant outdoor exposure, underlying health conditions, urban heat island effects, and limited access to cooling and healthcare all magnify heat risk for this group (Acey et al., 2026). In several Continuums of Care (regional bodies responsible for coordinating homelessness response) where more than 80% of people living unsheltered reside, the number of days with a heat index above 100°F (37.8°C) is projected to at least double by the end of the century (Charan et al., 2026).
- Urban Native Americans and Alaska Natives may face heightened risk to extreme heat due to disproportionate rates of houselessness, elevated burdens of diabetes, and other chronic health conditions which limit thermoregulation and increase the risk of heat-related illnesses (CDC, 2024; County of Los Angeles, 2025; HHS OMH, 2021).
- About 168,000 people are incarcerated in local, county, state, and federal facilities in California (Prison Policy Initiative, 2026), and nearly 40,000 people work at these facilities (Sklar et al., 2026). These groups face unique impacts due to limited cooling and shade, aging infrastructure, and heat-absorbing concrete design (CDCR, 2025; Noth et al., 2026).

Impacts

PUBLIC HEALTH

When ambient heat rises, the human body works harder to stay within its normal temperature range. This leads to bodily responses such as increased heart rate, blood pressure changes, and increased sweating and breathing rates. Such stress responses can provoke cardiac events, strain the lungs and kidneys, and lead to heat-related illnesses such as heat cramps, heat exhaustion, or even heat stroke, which is life-threatening. Extreme heat is also associated with adverse impacts on pregnancy, with negative mental health outcomes, and increased risk for hospitalizations and emergency room (ER) visits (Basu, Gavin, et al., 2018; Basu, Rau, et al., 2018; Riley et al., 2018).

Box 11: *Compounding Effects of Extreme Heat and Wildfire Smoke*

Californians are increasingly exposed to extreme heat and wildfire smoke at the same time, particularly from July to September (Jones-Ngo, Ludwick, et al., 2025). In 2020 alone, about 68% of the state's land and 42% of the population, experienced both extreme heat and wildfire smoke at the same time (Rosenthal et al., 2022). Co-exposure to heat and smoke has synergistic effects, leading to more hospitalizations than each hazard individually (Jones-Ngo, Schmidt, et al., 2025). Areas across California experience high numbers of combined extreme heat and wildfire smoke days, but the Central Valley experiences them most consistently year to year (**Figure 17**) (Jones-Ngo, Ludwick, et al., 2025). Vulnerable groups such as people of color, pregnant individuals, children, as well as those with lower income, educational attainment, health insurance coverage, and tree canopy coverage experience stronger interconnected effects (C. Chen et al., 2024; Ha et al., 2024; Syed et al., 2026). Higher temperatures and increased sunlight raise ambient ozone on their own. When combined with additional ozone from wildfire smoke and urban pollution, these conditions can exacerbate respiratory problems, placing already vulnerable communities at greater risk from these combined effects (Schwarz et al., 2021). These compounded events are expected to increase with climate change and should be considered in public health planning.

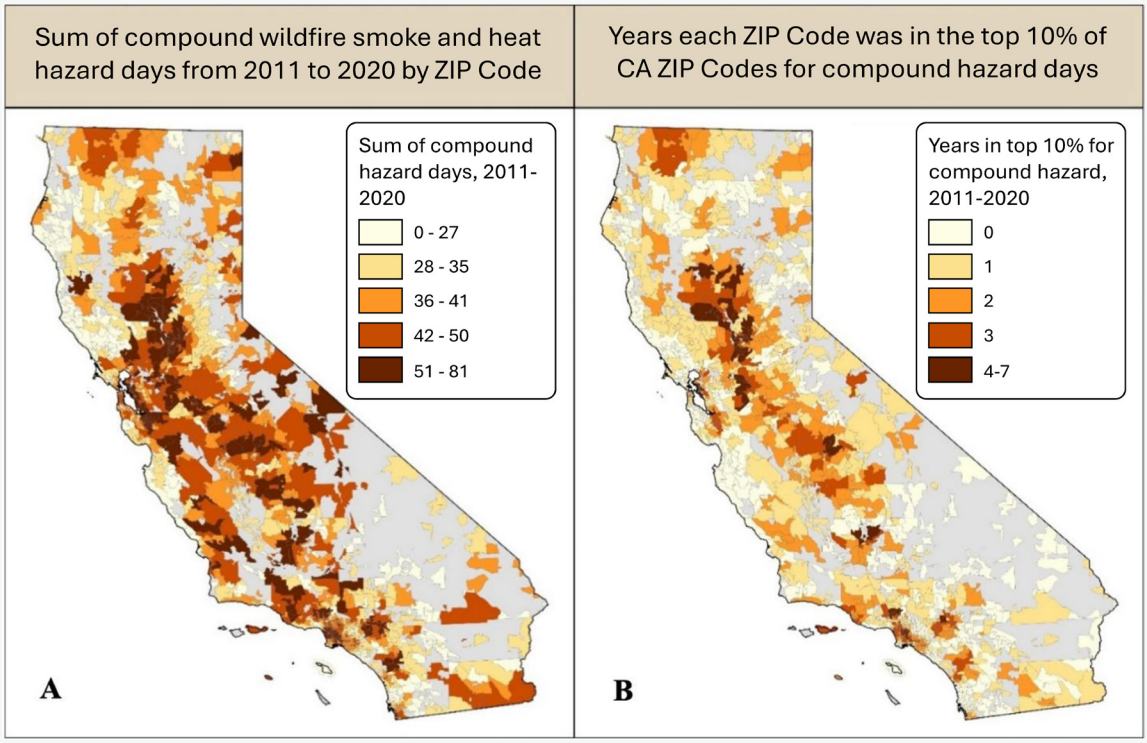


Figure 17: *Combined wildfire smoke and heat exposure by ZIP code tabulated area (ZCTA) over 10 years, 2011–2020. A) The total number of days of combined wildfire smoke exposure and extreme heat for each ZCTA from 2011–2020, and B) the number of years a ZCTA was in the top 10% of California ZCTAs in terms of compound wildfire smoke and extreme heat exposure days. Adapted from Jones-Ngo et al., 2025.*

From 2013–2022, seven major heat events in California led to an estimated 460 deaths, more than 5,000 hospitalizations, about 10,600 ER visits, and nearly 350 adverse birth outcomes (CDI, 2024). The number of deaths from an extreme heat event can be difficult to quantify, since heat can cause death directly or exacerbate existing cardiovascular, respiratory, and other conditions. For example, the number of deaths attributed to the 10-day record-breaking California heat wave in September 2022 ranges from 200 (CDI, 2024) to 395 (Milet et al., 2023), depending on analysis

methods. It is projected under an intermediate warming scenario that by 2050, extreme heat could contribute to an additional 15–20 annual deaths per 100,000 residents in some densely populated coastal cities and inland desert regions of the state (Carleton et al., 2022). Mortality alone does not capture the full burden: extreme heat increases emergency room visits and hospitalizations even when mortality effects are modest (Carleton et al., 2022).

ECONOMY & LABOR

Extreme heat events have broad and interconnected impacts across California's economy. A California Department of Insurance analysis of seven major heat events in California between 2013 and 2022 estimated approximately $7.7 billion in cumulative quantified losses (CDI, 2024). Premature death was the most significant portion of this cost (see *Public Health* above), but other cumulative losses across these events included more than $530 million in lost work hours, $740 million in manufacturing output, $580 million in losses from power outages, and $110 million in infrastructure damages to roads and rails (CDI, 2024). Importantly, these are conservative estimates because many heat-related costs and impacts cannot be fully quantified (CDI, 2024).

Future warming is expected to increase heat-related health risks, but the effects on California communities are more complex than an increase in heat-related deaths. By 2050, extreme heat is projected to cause about 560 additional deaths per year in California under an intermediate emissions scenario, rising to 703 additional deaths by 2100 (Gould et al., 2025). When valued using a 13.7 million value of a statistical life, these heat-related mortality increases correspond to approximately $7.7 billion in economic losses annually by 2050 and $9.9 billion annually by 2100 (McCord et al., 2026). Importantly, Gould et al. (2025) also project that reductions in cold-related mortality will exceed increases in heat-related mortality, resulting in a net decline in temperature-related mortality statewide. By contrast, Carleton et al. (2022) project that mortality will rise across most of the state as temperatures increase, with cold-related reductions limited to northern and high-elevation areas. This shows that heat impacts on mortality may vary geographically, underscoring a need to further quantify temperature-related mortality across all regions.

Measures of mortality do not capture the full health or economic burden of warming. Gould et al. (2025) project increases in temperature-related emergency department visits of approximately 0.46% by 2050 and 0.76% by 2100, equivalent to approximately 1.5 million cumulative excess emergency department visits by 2050. Thus, even where reductions in cold-related mortality outweigh increases in heat-related illness, associated health care demand is projected to increase.

Extreme heat also decreases workplace safety (LOHP, 2025). Heat exposure can reduce physical work capacity and productivity and increase occupational injury and heat-related illness. In California, workers in agriculture, fishing, and forestry industries have the highest rates of heat-related illness (Heinzerling et al., 2020). In the Pajaro Valley, approximately 74% of surveyed agricultural workers reported experiencing effects of extreme heat at work, including fainting or dehydration (Langridge, Von Schmidt, et al., 2026). In this study, nearly half of the agricultural workers reported never receiving extreme heat safety training (Brown et al., 2022). Reductions in crop yields due to rising temperatures can also impact employment opportunities for farmworkers (Kroeger, 2023).

Heat exposure is not limited to outdoor workers. Increasing temperatures can also create risks in warehouses, processing facilities, transportation, and other indoor workplaces. Emerging research

indicates that heat stress illness risk at California correctional facilities is projected to increase (Noth et al., 2026). While incarcerated workers are covered by existing Cal/OSHA workplace protections, they are not currently covered by California's newer prescriptive indoor heat standard, which requires certain action to be taken by employers when indoor working conditions reach specific temperatures (H. Smith, 2024). In response to these emerging risks, Cal/OSHA has begun the process to develop an indoor heat standard for correctional facilities.

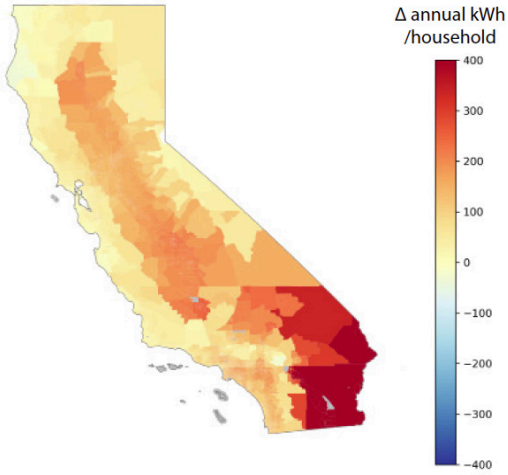


Figure 18: *Estimated change in annual electricity consumption in kilowatt-hours per household (kWh/household) in 2050 under a moderate emissions scenario, accounting for both increased air conditioning use and new air conditioning adoption* (Carleton et al., 2022).

Long-term electricity price estimates remain uncertain and will depend on regulations, grid investment and maintenance, energy demand, and investments in renewable energy, storage, and other infrastructure. Extreme heat can further increase electricity demand, particularly as households rely more on air conditioning to stay safe, with implications for both grid reliability and household energy costs. Median household electricity consumption in California is estimated to increase up to 55% by 2100, with the largest increases expected in the Central Valley and southeastern California (**Figure 18**) (Carleton et al., 2022). As temperatures rise, households with fewer financial resources may face greater difficulty balancing the cost of cooling with other essential expenses.

TRANSPORTATION INFRASTRUCTURE

Extreme heat can cause damage or failure for a variety of transportation infrastructure. It can accelerate and exacerbate wear and deformation of pavements and the buckling and expansion of railways (CDI, 2024). These failures increase risk of injury, and disrupt commutes, freight transportation, and supply chains, leading to economic losses. For example, a record-breaking 2022 extreme heat event in the Bay Area was the main cause for a rail deformation that led to the partial derailment of a BART (Bay Area Rapid Transit) train (Alvarez, 2022).

ENERGY

Extreme heat is known to drive peak energy demand due to the increase in air-conditioning cooling needs. Analysis of seven recent California extreme heat events found median household electricity consumption was 5.5% higher on days above 91°F (32.8°C) than on 65°F (18.3°C) days (CDI, 2024). At the same time, those high temperatures can reduce system efficiency and in severe cases, cause equipment to fail. Prolonged heat waves can strain the electrical grid and increase chances of rotating outages, which occurred in the mid-August 2020 extreme heat wave (CAISO et al., 2021). Since then, California has substantially expanded electricity procurement, adding more than 36,000 megawatts (MW) of new resources, including approximately 16,000 MW of utility-

scale battery storage in the CAISO territory. Battery storage is especially important for meeting peak demand during hot summer evenings, when solar generation declines while cooling demand remains high (CAISO, 2026).

AGRICULTURE

Rising temperatures impact not only agricultural workers (see *Vulnerable Groups* and *Economy & Labor* above) but also crops and livestock. Each crop has an optimal temperature range that supports its vegetative and reproductive growth. Both higher average temperatures and extreme heat events can negatively impact growth and yield, though not all crops are affected equally.

Overall, a 7.2ºF (4°C) increase in temperature may reduce yields from most fruits by more than 5%, and up to 40% in some regions of California (Zilberman & Kaplan, 2014). Many high-value perennial crops require a minimum number of chill hours (hours between 32–45°F [0–7.2°C]) to develop properly, and models project approximately a 20% decline in winter chill accumulation by mid-century across the San Joaquin Valley that may affect chill-dependent crops (L. E. Parker et al., 2025), especially those with high chilling requirements, like walnuts and pistachios (T. B. Pathak et al., 2018). Many crops will also be affected by expected decreases in pollinators due to warming temperatures (see *Ecosystems* below). Bee-dependent crops have grown eight times faster than non-bee-dependent crops since 2008 (Gaiarsa et al., 2026). For some crops, increased water can offset the deleterious effects of heat stress to some extent; however, there remains physiologic limits for heat exposure where no amount of water will prevent crop deficits or failures (CDFA, 2026).

Heat stress also impacts livestock. Heat can lead to impaired milk production, higher incidences of mastitis (inflammation of mammary gland), impaired reproductive processes, and premature deaths (Das et al., 2016). The combined economic impact of seven extreme heat events on dairy production between 2013–2022 totaled $89.1 million (CDI, 2024).

As warming increases, agricultural pests and diseases are expected to become more common because higher temperatures help them survive the winter, reproduce faster, and spread more easily, even to humans (Dietrich et al., 2023; Semenza et al., 2012). These effects are already present—for example, the life cycle of navel orange worm has sped up due to warming temperatures (T. Pathak & Zhang, 2022). Warmer temperatures also increase the risk of vector-borne diseases, such as by increasing the survival and activity period of ticks carrying Anaplasmosis (Bouchard et al., 2019), which can cause severe anemia, infertility, and sudden death in cattle (Young & Maier, 2020).

ECOSYSTEMS

Rising temperatures and extreme heat strain both terrestrial and aquatic ecosystems throughout California, threatening ecosystem structure, functions, and services.

Terrestrial Ecosystems

Warming from climate change is making California drier (Novick et al., 2024). This has already caused shifts in plant range, loss of large trees, changes to species composition (what species are present in ecosystems and how abundant they are) (e.g., Hill et al., 2023; Robinson et al.,

2023), shifts toward species with higher optimal temperatures (thermophilization) (Rosenblad et al., 2023), and changes to life cycles such as flowering times (Solakis-Tena et al., 2025). Pests and pathogens are expanding their host ranges or impacts due to climate change, including Sudden Oak Death (He et al., 2021), fungal pathogens (Garbelotto et al., 2025), goldspotted oak borer (Venette et al., 2015), and bark beetles (Hood et al., 2021; Robbins et al., 2022).

Rising temperatures and extreme heat also harm pollinators. For example, climate suitability for the wild Blue Orchard Mason Bee (*Osmia lignaria*), a key pollinator for native plants and California's food production, is expected to drop by over 54% in the next two decades and 69% to 83% by the end of the century due to rising temperatures (Gaiarsa et al., 2026).

Plant heat tolerance depends on both evolutionary history and daily weather (Hernández & Valliere, 2026). Many plants can acclimate to warming conditions over two weeks, boosting their heat tolerance by up to 18ºF (10ºC). However, a single day of extreme heat can lower tolerance, showing that even well-acclimated plants can be pushed past their limits during sudden hot temperatures. The study also showed wide variation in heat tolerance across California's vegetation types, suggesting conservation efforts should not assume plants are adapted based on location alone (Hernández & Valliere, 2026).

Freshwater Systems

In freshwater systems, elevated temperatures combined with declining groundwater and extended low water flows in the summer can raise the temperatures of rivers, streams, and lakes beyond bodily tolerance for certain species, such as salmonids, trout and other fish species (Shimabuku & Kammeyer, 2022b). Groundwater-fed cold water refugia become critical for survivability during times of extreme heat, but the quantity and connectivity of these refugia lessen when groundwater declines (Herbold et al., 2018). Climate refugia are geographic areas that have had a stable climate on evolutionary time scales or are projected to have a stable climate into the future (IPCC, 2023). Projects such as the return of over 47,000 acres encompassing Blue Creek to the Yurok Tribe demonstrate how ecocultural conservation efforts can protect and restore cold-water refugia as critical habitat for migrating salmon and steelhead (Yurok Tribe, 2025).

Marine Heat Waves

As well as gradual increases in ocean temperature, California has experienced a particular increase in marine heat waves near the coast. The most notorious is "The Blob," a heat mass of water that lasted from 2013–2016 and stretched from Alaska to Mexico that shut down most of the Pacific fishing industry and altered the marine food chain (Naranjo, 2021). This event contributed to the loss of 95% of bull kelp forest habitats in northern California, which has yet to recover past 10% of its pre-2014 baseline (McPherson et al., 2021; Woods Hole Oceanographic Institution & The Nature Conservancy, 2026). Since 2019, seven other large marine heat waves have occurred, six of which are among the largest since monitoring began in 1982 (Leising et al., 2025). Research has shown that marine heat wave events are likely to increase in frequency and intensity in California, which is a global hotspot of marine heat wave events (Capotondi et al., 2024; Oliver et al., 2019b, 2021).

Marine heat waves result in changes in nutrient availability and decreased plant and algal

growth, habitat loss, in negative impacts to fisheries, and even threats to public health through the increasing frequency of harmful algal blooms. Marine heat waves are also related to highly consequential marine infectious disease outbreaks, such as abalone withering syndrome and eelgrass wasting disease (Crosson et al., 2020; Groner et al., 2021; Peters et al., 2024). Marine impacts from warming and other climate impacts vary widely by species. While habitat could expand for some species, it will contract for others, pointing to the need for conservation efforts for these species in specific refugia that will remain habitable in the coming decades (Provost et al., 2026).

Adaptation and Resilience

A variety of strategies exist to adapt to climate impacts and risks, including interventions in the built environment and across social systems, and using nature-based solutions. The following section highlights several examples of extreme heat adaptation approaches.

HEAT RESILIENCE STRATEGIES

Alleviating the public health risks of heat requires action in homes, buildings and public spaces. At the individual level, public awareness and education of heat risks and strategies that support behavioral change also help—for example, being able to recognize the signs and symptoms of heat illness, and learning to hydrate often, seek shade, and check on neighbors.

At the building level, indoor air-conditioning (AC) is highly effective, having already reduced heat mortality by 10% since widespread adoption began in the 1960s (Barreca et al., 2016). In classrooms, AC can prevent heat-related drops in test performance and reduce the negative effect of heat on learning by 70% (Park et al., 2020). In addition to installing air-conditioning, other lower-cost strategies include installing passive cooling measures, such as window films, cool roofs, and cool walls, as well as increasing shade by using black out curtains, installing awnings, and planting shade trees, among others (CDPH, 2024).

At the neighborhood scale, increasing tree canopy cover and reflective surfaces can be highly effective. For example, in Los Angeles County, these adaptations could potentially reduce peak temperatures by 2–3°C (3.6–5.4°F) and prevent approximately 25% of heat-related deaths during an extreme heat event (Kalkstein et al., 2022; Sheridan et al., 2024). Neighborhood-scale interventions can include installing cool pavements and public shade structures, greening communities, and building green infrastructure for stormwater capture (Norris et al., 2026). Nature-based solutions can build extreme heat resilience in several important ways: plants, especially large-canopied trees, cool communities by providing shade; reflect more solar radiation than pavement, absorbing less heat; and release water vapor through leaves, cooling their surroundings.

Establishment of early warning systems and deployment of critical infrastructure can help protect communities during extreme heat. Interviews with people living unsheltered and practitioners who help them highlighted many short-term actions to improve well-being, including strategies for expanding shelter space and services during extreme heat events and providing timely information about available services (Charan et al., 2026). Ensuring that individuals have access to spaces such as resilience centers and cooling centers can help mitigate risks. Resilience and cooling centers provide essential social services such as food distribution and job training, and

they can also transition into emergency hubs and shelters for the community during events like heat waves and power outages.

WORKER PROTECTIONS

Since 2024, employers of indoor and outdoor workers are required to develop and implement a heat illness prevention program and provide workers with access to water, shade and cool-down areas. Senate Bill (SB) 1105, signed in 2024, requires that employers provide paid sick days to agricultural employees who want to avoid smoke, heat, or flooding conditions created by a local or state emergency. Potential measures to address climate-related burdens for incarcerated people, carceral workers, and warehouse workers include ensuring effective building-wide AC, providing breaks in cooled rooms, and temporary relocation or closure during extreme heat episodes (Noth et al., 2026).

Box 12: *Tribal Heat Resilience*

California Native American tribes are making concerted efforts to increase extreme heat resiliency. For example, the Fernandeño Tataviam Band of Mission Indians (FTBMI) published their Tribal Climate Resiliency Plan in 2024 and identified the following recommendations for extreme heat adaptation (FTBMI, 2024):

- Create cooling centers or other places with air-conditioning and resilience hubs where residents can get support, coordinate communication, find resources, and reduce carbon pollution while enhancing quality of life.
- Portable back-up power for critical residential loads to allow for residential cooling during extreme heat events (battery electric power generators are recommended over gas or diesel generators).
- Expand access to at-home heat adaptation resources like air-conditioning and insulation retrofits for homes.
- Install shade and water structures in high-use areas, protecting pedestrians from heat on streets and in other public places.
- Increase tree canopy coverage in streets, parks, and private property in neighborhoods and other high-traffic areas.

Since publication, FTBMI has been awarded funding from the California Strategic Growth Council's Community Resilience Centers grant program to plan for and implement cooling infrastructure to protect tribal members against extreme heat (SGC, 2024). Recognizing the cultural importance of elders as knowledge bearers, many tribes, including the Fort Mojave Indian Tribe, provide cooling stations, conduct emergency wellness checks, and provide assistance to elders during extreme heat events (Fadel, 2023).

CLIMATE REFUGIA

Heat-related adaptation strategies for ecosystems focus on establishing locations of climate refugia and increasing landscape connectivity—allowing species to move to more suitable habitat, though not all species are able to disperse or migrate well. Land managers must determine how fast local conditions are changing and whether to retain current vegetation, allow changes, or actively guide transition in different situations (Resist, Adapt, Direct) (Schuurman et al., 2020). Marine Protected Areas and other marine climate refugia can support healthy populations that are resistant to warming, as well as other climate stressors like ocean acidification and deoxygenation. By comparing the effectiveness of various management approaches and different refugia locations, decisions-makers can prepare actionable adaptive guidance for California's different climate refugia scenarios (Provost et al., 2026).

ADAPTIVE AGRICULTURE MANAGEMENT

Extreme heat and warmer temperatures throughout the year have been shown to significantly harm crop production (see *Agriculture* above). In the long run, it is likely that shifts are needed toward more heat-tolerant crops and cultivars, plants bred for specific desirable traits, such as lower chill requirements. Replacing crops is costly, so many strategies have been developed to help adapt to extreme heat and other climate hazards.

Some strategies include shifting to earlier planting dates to avoid summer heat stress, updating irrigation scheduling when there is an incoming extreme heat event, adding shade to modify the microclimate, and using crop residues to insulate the soil and roots from extreme heat (L. E. Parker et al., 2023). Kaolin clay, a naturally occurring mineral, is a useful physical barrier when coated on leaves and fruit. Spraying this film has been shown to reduce sunburn, deter pests, and even help increase chill portion accumulation by approximately 15% in certain crops (Doll et al., 2018). As more pests and pathogens survive warming winters, soil solarization, steam, and anaerobic soil disinfestation can help make the environment inhospitable to pests and disease and create habitats for beneficial insects that naturally prey on harmful pests (L. E. Parker et al., 2023).

Agrivoltaics, growing crops under or between solar panels, is also an emerging practice that can cool the vegetative understory. It has been found that agrivoltaics induce cooler daytime air temperatures by 1.0–1.6°C (1.8–2.8°F), which can reduce heat, decrease water evaporation, and increase crop yield (Barron-Gafford et al., 2019).

4.4 Drought

Introduction

Drought is one of California's most persistent and consequential climate hazards. Droughts are characterized by a deficiency in precipitation over an extended period (usually a season or more), resulting in water shortages and adverse impacts on communities, ecosystems, and the economy. Drought risk is difficult to project because it develops slowly and depends on many interacting climatic and water management factors.

Over the past quarter century, drought conditions have affected parts and sometimes nearly all of California (**Figure 19**), straining water supplies, ecosystems, agriculture, hydropower, public health, community resilience, and California's economy. These impacts are especially significant in a state where water availability depends on highly variable precipitation, seasonal snowpack, and complex water management systems.

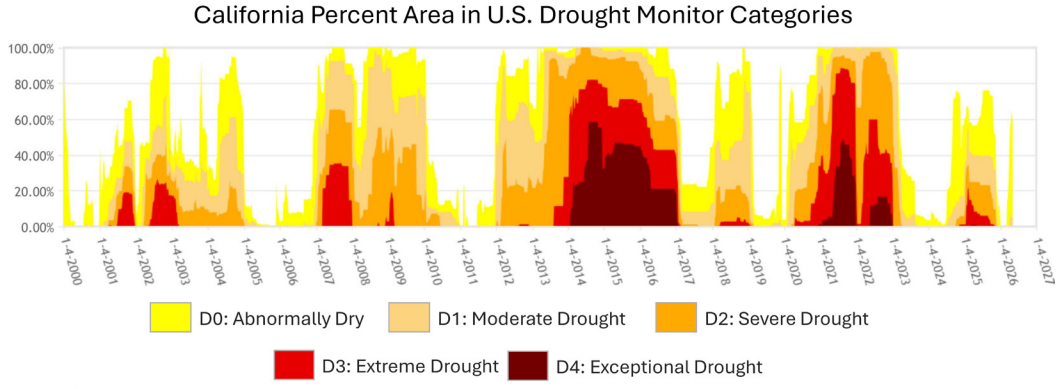


Figure 19: *Percent of California considered under drought by the US Drought Monitor (USDM) over time, 2000–2026. USDM uses six levels of drought: none, abnormally dry (D0), moderate (D1), severe (D2), extreme (D3), and exceptional (D4). Figure adapted from USDM.*

While California's future precipitation remains highly variable, rising temperatures are increasing atmospheric drying and evaporative demand, making drought impacts more severe. Atmospheric drying refers to how air pulls moisture out of soil, plants, and water bodies, while evaporative demand can be described as "atmospheric thirst," or how fast the atmosphere "wants" to evaporate water. This trend appears more clearly in metrics such as soil moisture (**Figure 20**). Warmer conditions increasingly pull more moisture from soils, vegetation, rivers, reservoirs, and snowpack, causing landscapes to dry out more quickly and increasing stress on water supplies, even when annual precipitation totals do not clearly decline.

Drought risk is described as both a climate hazard and a more complex coupled climate-human phenomenon that is dependent on both interacting climatic conditions along with water management and other societal factors (AghaKouchak et al., 2026). As a climatic hazard, low precipitation coupled with rising temperatures are significant factors, and observational analysis shows since around 2000, in the western United States, rising surface temperature and the resulting high evaporative demand have contributed more to drought severity than precipitation deficit (Zhuang et al., 2024). Increasing temperatures also play a role in the changing seasonality of snowpack and runoff (OEHHA, 2026). Under a warming climate, less snow is expected to remain in the Sierra Nevada during spring, leading to a shorter period of snowpack to replenish surface water reservoirs. This leads to long-term considerations for how water is managed in areas fed by snowmelt and runoff (Lynn et al., 2020; Mote et al., 2018; Shukla et al., 2015).

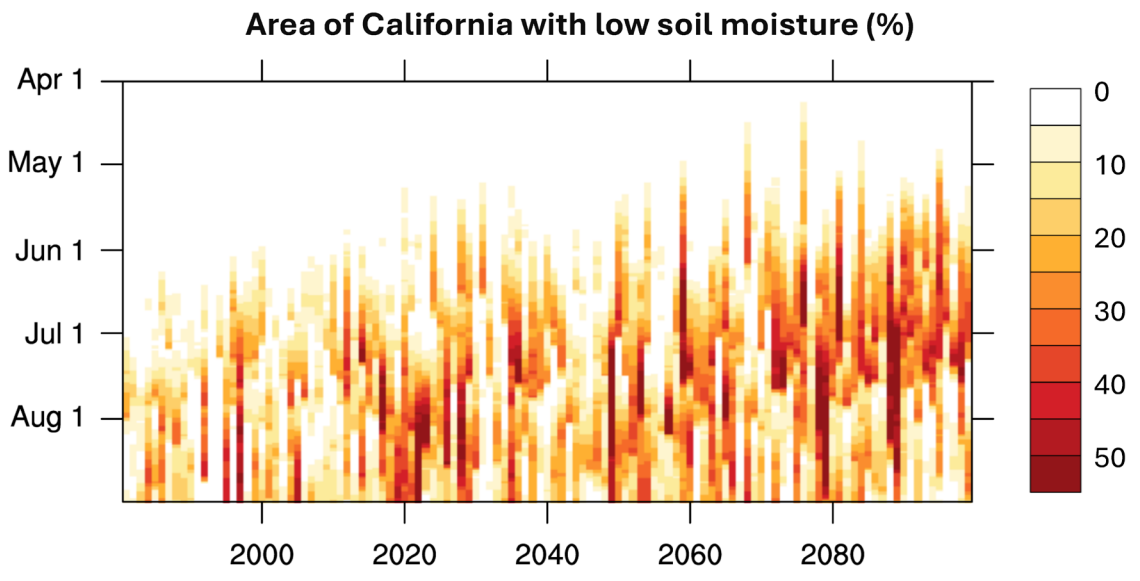


Figure 20: *An example simulation of California soil moisture over time. The y-axis shows how early in the year low soil moisture begins, while the x-axis shows the progression of conditions year to year. A darker red means a higher portion of California has low soil moisture. Low soil moisture is defined as moisture below the local 10th percentile of 1981–2010 conditions. Note: this figure only shows a single climate model, not an average of models. Figure by Paul Ullrich, UC Davis.*

In summary, California's future drought risk depends on precipitation amount and timing, how much water is captured as snowpack, and how quickly heat removes moisture from the landscape. Over the next 75 years, droughts are expected to become more severe, occur more often, and last longer on average (**Figure 21**).

Drought risk is also intensified by increased water demand during warmer and drier periods, and by management decisions, including groundwater pumping, reservoir operations, agricultural use, and urban water needs. Prolonged drought can strain reservoirs, reduce streamflow, require increased groundwater pumping, deplete domestic wells, and limit water availability for agriculture, ecosystems, hydropower, and community needs.

Recent extreme droughts, including those in 2012–2016 and 2020–2022 droughts (**Figure 19**), exemplify how droughts reduce surface water supplies, heavily impact the agricultural industry, and reduce ecosystems' resiliency and adaptive capacity. During the 2020–2022 drought, more than 2,000 domestic wells were reported dry statewide, predominantly affecting disadvantaged communities (Rodríguez-Flores et al., 2023).

Evaporative demand has increased over the decades, which makes it not only more difficult to recover from droughts but also widens the water deficit, which generally refers to conditions where water supply is unable to meet demands, especially during warmer and drier periods. This evaporative demand has intensified extreme multi-year droughts, such as the 2012–2016 drought in the San Joaquin Valley, which was the driest period in over 1,200 years in the region. Higher temperatures from climate change have led to greater evaporation rates and lower relative humidity and precipitation, increasing drought severity by 42% (A. P. Williams et al., 2022). These higher temperatures can increase evapotranspiration rates and can make even mild droughts more severe as the climate warms. Joint heat wave-drought events are likely to occur more frequently in the future, increasing by a factor of two to eight relative to a 1995–2014 baseline (Williams et al., 2022).

California has a highly engineered and managed water supply system that can help buffer

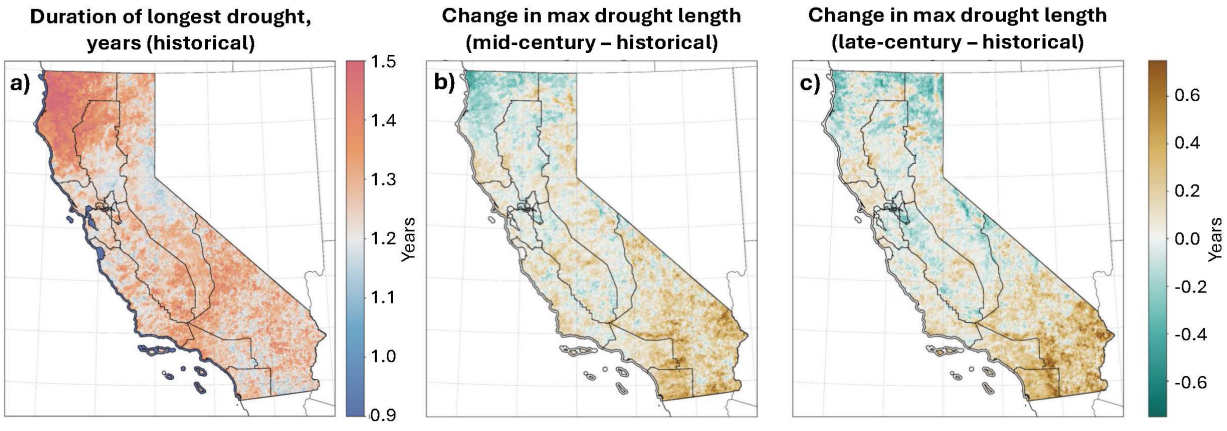


Figure 21: *a) the duration of the longest drought, in years, for the historical period (1981–2010). b-c) Change in the duration of the longest precipitation drought, in years, from the historical period to future periods (mid-century, 2041–2070; late-century, 2071–2100) as projected under the SSP3–7.0 scenario. Drought was defined as water year precipitation below the 10th percentile of the historical distribution. Figure by Samantha Stevenson, UC Santa Barbara.*

developed lands from the water shortage effects caused by these more intense droughts. However, over chronic multi-year droughts, regions of California can be at risk of surface water storage deficits and groundwater overdrafts. During the 2012–2016 drought in the Central Valley, one study found that between fall 2014–2015, the median groundwater level across the Central Valley fell by ~5 m (16.5 ft), and in some areas including Tulare, Kings, and Kern counties, the levels fell by tens of meters (Pauloo et al., 2020). This underscores the critical need to expand both surface and groundwater storage and reduce pressure on water supply.

Impacts

PUBLIC HEALTH

Drought can affect public health by reducing access to safe, reliable, and affordable water, while also worsening air quality through increased dust and particulate matter from dry soils and exposed lakebeds. Groundwater depletion can leach sedimentary heavy metals and concentrate high levels of other contaminants in groundwater supplies (Hausladen et al., 2018; Lopez et al., 2021; R. Smith et al., 2018). These risks are especially acute for rural communities that rely on small water systems or domestic wells, which often have fewer financial and technical resources to monitor, treat, or replace contaminated water supplies. Rural communities may also face increased competition for limited groundwater resources from large-scale agricultural users, further heightening water insecurity and drought vulnerability (Flores-Landeros et al., 2022).

Drought can also worsen respiratory health risks and allergies due to increased airborne dust and particulate matter. In places such as the Owens Valley and the Salton Sea, reduced water flows and exposed playa have contributed to severe dust pollution, driving negative public health implications for Californians with asthma, cardiovascular diseases, and other respiratory conditions (Hopkins & Sendejas, 2026; Johnston et al., 2019; National Academies, 2025). Agricultural runoff further worsens air quality in the Inland Deserts region as pesticides, fertilizers, and other contaminants accumulate in the shrinking Salton Sea (Abman et al., 2024; LAO, 2018). As the shoreline recedes and exposed playa expands, these contaminants can become part of the windblown dust, compounding respiratory health risks for

Box 13: *Groups Vulnerable to Drought*

Several groups of Californians are particularly vulnerable to the effects of drought due to their circumstances. For example:

- Many rural communities, particularly farmworker communities, rely on shallow household wells that can dry up when groundwater use increases during drought, leaving households without running water (Greene, 2018). Households in foothill and mountain regions that rely on domestic wells in fractured rock are also at high risk of water outages due to the nature of the geology and difficulties in monitoring that can contribute to a lack of early warning (DWR, 2024a, 2025b).
- Farmworkers are more likely to experience job instability during droughts, primarily due to land fallowing (Greene, 2018). Drought can also increase their exposure to dust containing pesticides or pathogens like Valley Fever (Felt et al., 2021).
- The above issues are more severe for Latine and Indigenous immigrants, especially those who are undocumented, due to lack of access to social services, safety net assistance, and healthcare (Acey et al., 2026).
- California Native American tribes in the Eastern Sierra, such as the Big Pine Paiute, Bishop Paiute, and Mono Lake Kootzaduka'a, face heightened drought vulnerability as climate-driven declines in snowpack and streamflow, compounded by more than a century of groundwater pumping, reduce water availability, degrade culturally important ecosystems, and threaten traditional foods (Big Pine Tribe, 2022; Bishop Paiute Tribe, 2020, 2022).

nearby communities already burdened by poor air quality and limited access to healthcare services. Droughts have also been linked to adverse mental health impacts on rural and agricultural communities. Water insecurity can increase stress, financial hardship, and uncertainty for rural households and agricultural communities that depend on small-scale water systems (Barreau et al., 2017). These impacts have been associated with increased calls to suicide hotlines by rural farmworkers during recent droughts, underscoring the mental health burden that drought can place on vulnerable communities (Dahlquist-Willard, 2021).

ENERGY

California relies substantially on hydropower (10–15% of total) for electricity generation, especially in summer when hot weather drives up demand. Low snowpack and reservoir levels associated with prolonged droughts significantly decrease hydropower generation (Forrest et al., 2018; Kern et al., 2020). The 2012–2016 drought reduced hydropower revenues by $1.9 billion and incurred an additional $3.8 billion in increased cooling demands (Kern et al., 2020). Higher temperatures and changing snowpack conditions could decrease hydropower generation overall, especially during summer peak usage (Yates et al., 2024).

WATER INFRASTRUCTURE AND SUPPLY RELIABILITY

California's water resources are foundational to the state's economy, ecosystems, and the lives of more than 39 million residents. California's highly engineered and managed water system helps buffer communities, farms, and developed lands from water year variability and some drought impacts by storing, moving, and delivering water across regions. However, climate change is placing growing stress on this infrastructure by altering the timing, amount, and reliability of water supplies, especially since they were designed under different operational requirements before the impacts of a changing climate. As warming temperatures reduce snowpack, shift snowmelt and mountain runoff earlier in the year, shorten the wet season, and increase evaporative demand, reservoirs, aqueducts, groundwater basins, and local water systems must operate under conditions that differ from those they were designed to manage.

These changes are especially important because much of California's water supply depends on mountain snowpack, groundwater management, and imported water. The Sierra Nevada functions as a natural reservoir, storing winter precipitation as snow and releasing it gradually during the spring and summer. As winters continue to warm, some precipitation falls as rain instead of snow, snow melts earlier in the year, and less water may be available during the dry season when demand is highest. At the same time, imported supplies, such as from the Colorado River, may become less reliable as drought, warming, and competing demands reduce water availability (DWR, 2024c).

Box 14: *Highlights from the Sacramento-San Joaquin Delta Report*

The Sacramento-San Joaquin Delta (Delta) serves as a central hub for the state's water supply. Much of the Sierra Nevada mountain's spring and summer runoff flows into the Sacramento-San Joaquin Delta (Delta Stewardship Council, 2021; J. Mount et al., 2022). Delta water is an important water supply for California, serving the needs of Delta communities and agriculture. Two-thirds of California's people and approximately one-third of its agricultural land receive some part of their water from the Delta. (Delta Stewardship Council, 2024; USBR, n.d.). The DWR 2023 State Water Project Delivery Capability Report highlighted the project's reduced export capability under a changing climate (DWR, 2024b).

During prolonged drought, reduced surface water availability can increase reliance on groundwater, contributing to overdraft, declining water tables, land subsidence, dry wells, and degraded water quality (DWR, 2025a). These impacts can strain water delivery systems, increase pumping costs, reduce hydropower generation, and heighten competition among agricultural, urban, ecological, and cultural water needs.

Miro et al. (2026) find that in three representative counties, San Bernardino, San Luis Obispo, and San Diego, water supplies are projected to remain sufficient to meet demand associated with housing growth through 2050. However, the study also notes areas of uncertainty and emphasizes a need for ongoing investments in adaptive management.

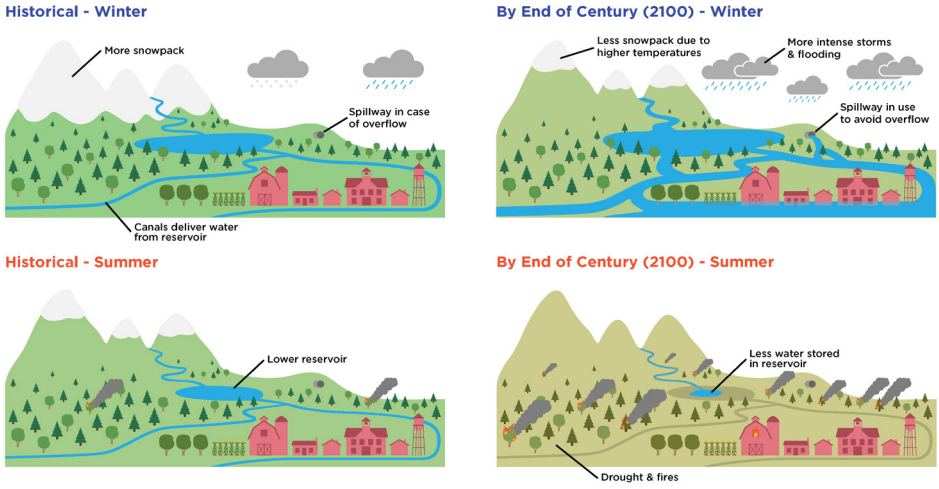


Figure 22: *Examples of expected climate change impacts on California water supplies by the end of the century. Figure by Nicholas Iannaco/UCS in Ortiz-Partida et al. (2020).*

AGRICULTURE

Climate change-related precipitation changes have resulted in immediate productivity losses for agriculture, as well as long-term instability due to variable water conditions. For example, the acute droughts of 2012–2016 and 2020–2022 resulted in crop revenue losses of $900 million–$1.2 billion per year and 2.6–5.9% income losses per year (Lund et al., 2018; Medellín-Azuara et al., 2022). As droughts diminish surface water supplies, groundwater can help meet crop demands, which account for up to 80% of the state's groundwater usage. However, groundwater overdraft, when more water is removed than can be replenished, can lead to water quality consequences (Levy et al., 2021) and subsidence. Subsidence is land sinking, which can increase flood risks and decrease transport capacity of canals (R. G. Smith et al., 2017),

Drought (along with heat) is likely to reshape the types of crops planted in the state due to changes in water allocation and local groundwater requirements. Irrigated acreage will decline under future climate projections (especially in the San Joaquin Valley, where declines of up to ~40% may occur), but revenues will not decline as steeply, reflecting economic reallocation toward higher value crops (Medellín-Azuara et al., 2026). This is due to reallocation of limited water resources toward fruits, nuts,

and vegetables, while feed crops experience reductions. This highlights the buffering role that economic adaptation can play but also signals structural shifts in crop composition.

ECOSYSTEMS

Drought affects California ecosystems by reducing the availability, timing, and reliability of water that plants, animals, and people rely on, also known as "ecological drought" (Crausbay et al., 2017). As rising temperatures increase evaporative demand, soils dry more quickly, streamflow declines, wetlands shrink, and plants experience greater water stress. These changes can reduce habitat quality, increase plant mortality, alter species distributions, and make ecosystems more vulnerable to invasive species, disease, pests, and wildfire.

In some landscapes, repeated or prolonged drought can push ecosystems past recovery thresholds. This has contributed to forest die-off, conversion of forests to shrublands or grasslands, and long-term biodiversity loss. For example, in the Sierra Nevada region, an estimated 30% of conifer forest areas transitioned to non-forested vegetation during 2011–2020 due to massive and interrelated drought, beetle, and fire disturbance (Steel et al., 2023). This loss of forest cover reduces habitat for forest-dependent plants and animals, causing some species distributions to shift upslope or face population decline, while also threatening ecosystem benefits such as carbon storage, water filtration, and outdoor recreation (Dettinger et al., 2018).

Montane wet meadows are another key ecosystem threatened by changing climatic conditions. These meadows form at high elevations where a depression or gently sloped valley holds shallow groundwater, maintaining relatively damp soils. While they only make up 3% of the Sierra Nevada's land, they contribute to 12–30% of the soil carbon (Norton et

Box 15: *Management of California's Groundwater Basins*

A Summary based on "Evaluation of Climate Change Adaptation Strategies for California's Adjudicated Groundwater Basins to Assess Impacts on Water Sustainability for Vulnerable Communities" (Langridge, Hall, et al., 2026).

Groundwater is a significant source of California's water supply during drought, providing 40% of the state's water supply in normal years and up to 60% in drought years (SWRCB, 2022). Many areas of California have become increasingly reliant on groundwater resources, and increased pumping during drought years resulted in many domestic wells going dry during drought (Jasechko & Perrone, 2020) as well as an increase in the amount and extent of subsidence, the sinking of the land surface. These and other impacts led to the 2014 passage of California's Sustainable Groundwater Management Act (SGMA). The act requires new local agencies, Groundwater Sustainability Agencies (GSAs), to develop Groundwater Sustainability Plans (GSPs) (by 2020 or 2040) that would avoid six undesirable results. SGMA also includes provisions to advance equity, requiring that GSAs take into account the interests of all beneficial users of groundwater. GSPs are required to plan 50 years into the future and incorporate potential climate conditions into assessments, making SGMA a significant climate change adaptation strategy supporting groundwater security and sustainability into the future.

A large group of groundwater basins, however, are exempt from SGMA core requirements. These court-adjudicated areas span over 8,000 square miles and are home to nearly 11 million people, more than 4 million of whom live in disadvantaged communities. They are managed under court judgments by court appointed "Watermasters." Predominantly located in Southern California, these basins encountered adverse conditions decades before SGMA, and major pumpers went to court to define groundwater rights in these areas. A review of adjudicated basin approaches to management, equity, climate change, and sustainability finds significant variation across these basins (Langridge, Hall, et al., 2026). Primarily located in regions projected to experience major stress to water supplies, many rely heavily on imported sources, yet climate change is under-addressed in planning for most of these areas. Furthermore, management decisions are dominated by large groundwater users and in practice, disadvantaged communities and small users generally have limited opportunities to participate (Langridge, Hall, et al., 2026). Highly fragmented information about sustainability and equity management practices, often absent in Watermaster documents while scattered across multiple other sites, leaves major gaps in understanding the physical condition of the adjudicated area. Watermasters are responding to challenges in some adjudicated areas and increasingly employing sustainable management approaches that could serve as positive models for other adjudications.

al., 2011, 2014), reduce the magnitude of flood events (Tague et al., 2008), and support high biodiversity. They provide critical habitat for breeding birds, native and endemic amphibians such as the endangered Yosemite toad (*Anaxyrus canorus*) (McIlroy et al., 2013), and insects. California's state fish, the California golden trout (*Oncorhynchus aguabonita*), relies on montane meadows for survival, it is currently a State Species of Special Concern (Moyle et al., 2015). Mining, grazing, and logging dating back to the 1800s have disrupted the natural function of these meadows, reducing their ability to store carbon, support native species, and prevent species invasion (Reed et al., 2026). Lower water tables due to drought and long-term snowpack decline further imperil these already precarious ecosystems, the ecosystem services they provide, and the species they support.

Watersheds and aquatic ecosystems are especially vulnerable to drought and changes to the timing and type of precipitation. As precipitation and snowpack decline and evapotranspiration increases, less water flows through rivers, streams, and creeks. Prolonged droughts can also affect rivers' and streams' baseflow from groundwater due to reduced infiltration and increased groundwater pumping and use. Reduced streamflow can increase water temperatures, lower dissolved oxygen levels, shrink aquatic habitat, and concentrate pollutants, creating stressful or lethal conditions for fish, amphibians, and other aquatic species. These conditions are especially harmful for salmon, steelhead, and trout, which depend on sufficient streamflow and cool water temperatures (Shimabuku & Kammeyer, 2022a). During severe droughts, low flows and warm water can delay migration, reduce spawning success, increase disease risk, and contribute to fish kills, causing cascading ecological, cultural, and economic impacts to the ecosystems and communities that rely on these fisheries.

Desert ecosystems are also especially vulnerable to drought because water is already limited and often concentrated in groundwater-fed springs, seeps, and oases. These hydrologic features function as climate refugia, sacred places for tribes, and biodiversity hotspots, supporting up to one-fifth of the region's vascular plant diversity despite making up only a fraction of the desert landscape (Hopkins & Sendejas, 2026). Many of these habitats depend on groundwater reserves that are slowly replenished by precipitation, mountain runoff, and snowmelt. As drought reduces recharge, groundwater levels can decline and threaten the spring and wetland habitats that sustain desert species, including riparian plants, desert bighorn sheep, amphibians, endemic fishes such as pupfish, and migratory birds (S. S. Parker et al., 2021). These risks are compounded by groundwater extraction and water management decisions that lower water tables faster than aquifers can recover, threatening biodiversity, sacred sites, and culturally important species associated with desert waters.

Adaptation and Resilience

California uses a range of adaptation strategies to increase drought resilience. These strategies include water conservation and efficiency measures, drought contingency planning, improved water storage operations and infrastructure, nature-based solutions, and ecocultural restoration. Agricultural and urban water users are also adapting through more efficient irrigation, demand reduction, water reuse, local supply diversification, healthy soils practices, and improved water quality and runoff management. The following section highlights several non-exhaustive drought resilience strategies currently used across California.

Box 16: *Ecocultural Watershed Restoration: Tribal Beaver Reintroductions*

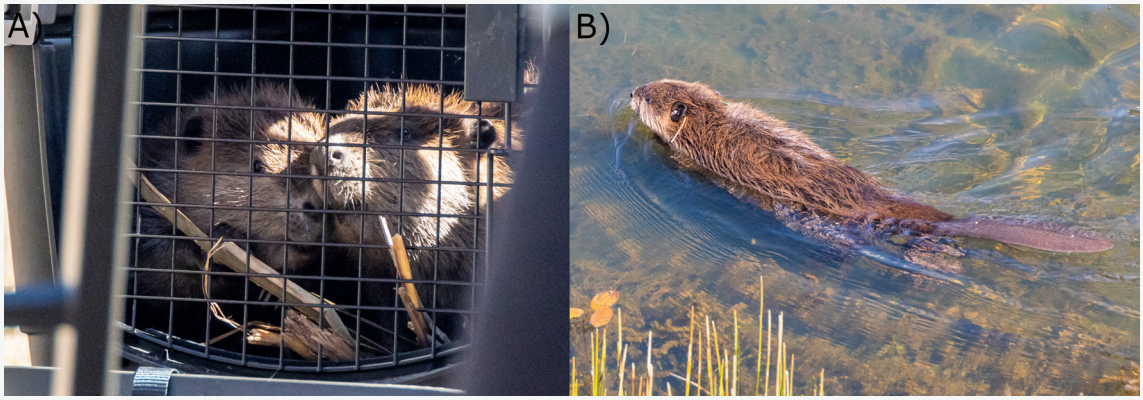


Figure 23: *Two different beaver reintroductions conducted in cooperation between California Department of Fish and Wildlife (CDFW) and the Tule River Tribe and CDFW and the Maidu Summit Consortium. Photo by CDFW.*

Ecocultural restoration is an approach to ecosystem restoration that recognizes the interdependence of ecological health, cultural continuity, and tribal stewardship (Hankins et al., 2026). Rather than restoring landscapes solely for ecological function, ecocultural restoration supports the renewal of relationships among people, plants, animals, waters, and places through tribal-led stewardship practices grounded in cultural responsibility and place-based knowledge. Tribes across California are practicing ecocultural watershed restoration and supporting ecosystem resilience against drought. For example, tribal leadership in two separate projects from the Maidu Summit Consortium and the Tule River Tribe partnered with California Department of Fish and Wildlife (CDFW) to conduct the state's first two beaver conservation releases in 75 years (CDFW, 2023). Beavers are a keystone species whose dams slow the flow of streams and rivers, storing water to create ponds and wetlands, increasing biodiversity, and bolstering ecosystem resilience to the impacts of drought and wildfire.

The reintroduction of beavers to the Tule River Reservation marks a return of an ecocultural species remembered by elders and depicted in 500- to 1,000-year-old pictographs along the Tule River (CDFW, 2024). Beavers were largely extirpated from California through intensive trapping during the fur trade and due to habitat loss as western land management practices altered rivers, streams, wetlands, and meadow ecosystems. By restoring a species once removed from the landscape, the project re-establishes natural water storage processes and climate resilience while reconnecting tribal communities with long-standing stewardship relationships and cultural traditions.

WATERSHED RESTORATION

Watershed restoration is an important nature-based solution and drought adaptation strategy because healthy watersheds help slow, sink, and filter water across the landscape. As rising temperatures, declining snowpack, and more variable precipitation alter the timing and availability of water across California, restoration can help retain water later into the dry season, improve habitat conditions and ecosystem functions, support biodiversity, and strengthen resilience to drought and climate change. Restoration strategies can increase drought resilience in many ways, including:

- Restoring wetlands and meadows to retain water later into the dry season, helping maintain soil moisture, reduce vegetation stress, and support post-fire recovery (Reed et al., 2026).
- Reconnecting rivers to their floodplains to slow floodwaters, increase groundwater recharge, improve water storage, and enhance habitat for native species.
- Restoring riparian vegetation to stabilize streambanks, reduce erosion, improve water quality, and provide shade that helps maintain cooler stream temperatures.
- Removing barriers to fish passage and restoring stream connectivity to improve access to critical habitat and support native fish populations during drought.
- Restoring forest health in headwaters to regulate water cycling and improve soil water storage and snowpack retention.

Box 17: *Klamath Dam Removals*

Two decades after the 2002 Klamath fish kill (an implication of low flow/high temperature climatic conditions), which left more than 60,000 salmon dead along the riverbank, and following decades of advocacy by the Yurok Tribe, Karuk Tribe, and Klamath Tribes, and assistance of California and Oregon state governments, four defunct dams were removed from the lower Klamath River, restoring connectivity to more than 420 miles of salmon habitat (NOAA, 2025b). One year following dam removal, the salmon population has rapidly rebounded, and water temperatures have returned to natural seasonal fluctuations (CDFW, 2025). As reservoir waters receded, tribes and restoration partners also seeded exposed lands with more than 17 billion native plant seeds to prevent the spread of invasive species and accelerate ecosystem recovery (The Yurok Tribe, 2024). This project demonstrates the interconnectedness of cultural revitalization, holistic habitat restoration, and climate resiliency, as dam removal restores river flow and seasonal water temperature fluctuations, increasing both the river's and salmon run's resiliency to extreme heat and harmful algal blooms.

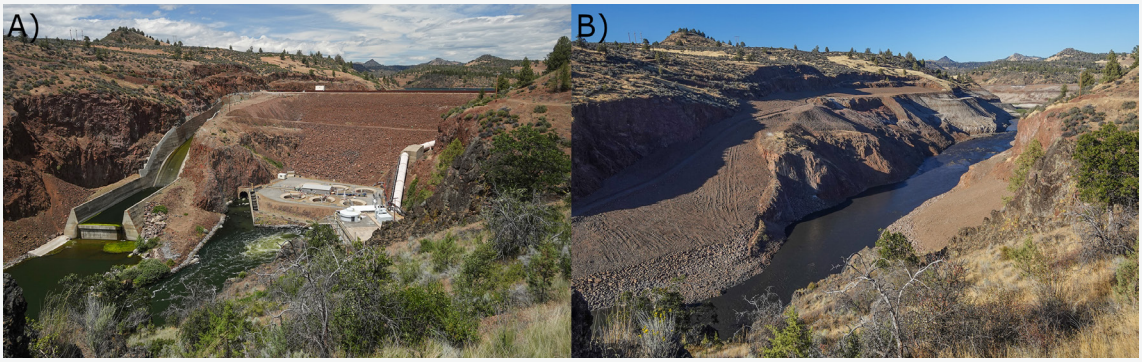


Figure 24: *Before and after photos of the rIron Gate Dam removal along the Klamath River. Photo by Swiftwater Films.*

Effective watershed restoration also depends on collaboration across jurisdictions, landownership, and governance systems. Tribal Beneficial Uses (developed by California Native American tribes, the State Water Resources Control Board, and other interested parties) recognize and honor Tribal Nations' unique and ongoing relationships with water and ensure that these uses are considered and safeguarded in water quality policies, planning, and permitting regulatory processes (SWRCB, 2026a). Tribal-led and tribally-partnered restoration efforts, including beaver reintroductions, salmon habitat restoration, dam removal, and protection of cold-water refuges, demonstrate how watershed restoration can strengthen ecosystem function while also supporting cultural continuity, food sovereignty, and tribal stewardship.

WATER SUPPLY ENHANCEMENT

Adapting California's water infrastructure to a warmer and more variable climate will require flexible management and modernized water infrastructure. It will also require additional groundwater recharge, stormwater capture, water recycling, desalination, conservation, and investments that improve resilience for small water systems, rural communities, tribes, and households that rely on domestic wells.

Water recycling treats wastewater to safe standards for use, whether that be for potable (drinking) or non-potable applications (SWRCB, 2026c), with a goal of providing 800,000 acre-feet (AF) of recycled water by 2030 and 1,800,000 AF by 2040 (State of California, 2022). Stormwater capture projects, which capitalize on high flows during storm events to store water, provide another drought resilience strategy. Similarly, groundwater recharge, which involves diverting water from high-flow events to underground storage can serve as an efficient and economical strategy to store water during periods of intense rain for upcoming dry periods (State of California, 2022).

Desalination of seawater or brackish groundwater can offer additional water supplies, as California's 14 desalination plants have the capacity to produce 89,000 AF per year (State of California, 2022). However, desalination can be costly, energy-intensive, involve lengthy permitting processes, and raise environmental concerns (Huang, 2025; Pezzetti et al., 2024). Expanding desalination locations where the plants can be cost effective and environmentally appropriate is an important intervention to address water supply issues during drought (State of California, 2022).

DEMAND MANAGEMENT

Even with intensive supply enhancement, demand management—such as, but not limited to, monitoring and evaluation, wastewater prevention policies, conservation pricing, and information sharing—will be necessary to achieve sustainable water management with climate change (Hanak et al., 2023). In California, urban water retail suppliers encourage customers to implement water efficiency measures to meet the retail suppliers' efficiency goals (SWRCB, 2024). Such measures can include replacing old and inefficient appliances, which they can get a rebate to do.

In the Inland Deserts region, water is mainly provided by the Colorado River, now facing historic drought. Consequently, Lake Mead and Powell could reach "deadpool" conditions, where water levels are too low to produce power or flow out to users. Immense strides in voluntary consumption reductions have been made to reduce the water deficits, leading to conservation of more than 1.2 million acre-feet (MAF) of water between 2022–2024 (Colorado River Board of California,

2024). However, participation in the usage reduction was supported by federal funding through the Inflation Reduction Act, so the future of this strategy is uncertain. Demand management is an important area for emphasis in the future to adequately complement supply enhancement strategies (Hanak et al., 2020).

AGRICULTURE

Issues of drought and water availability affect farmers' crop and irrigation decisions (Fan et al., 2023). Farmers' options to mitigate drought impacts include switching to crops that are more drought resilient, deciding to fallow the land for a season or more and potentially utilize that land for other purposes, or to try different crop and land management techniques (Morales et al., 2024). There are numerous land management practices that can increase drought resilience, including cover cropping, compost application, hedgerow planting, and reduced tillage (CDFA, 2026). One example in coastal rangelands showed that even a single application of compost was associated with higher soil moisture in the rooting zone after 15 years (CDFA, 2026). Another example is from farmers in the San Diego region who utilize agroforestry practices, based on potential to create cooler microclimates (Gomes et al., 2020), reduce water loss from leaves, protect crops from storms (Philpott et al., 2008), and increase soil nitrogen and carbon (Haskett et al., 2019). Multi-benefit land repurposing is used as a drought resilience strategy that repurposes retired agricultural land to reduce reliance on groundwater while providing numerous other benefits, including water supply, habitat, and climate benefits, among others (CDFA, 2026). Multibenefit land repurposing in the San Joaquin Valley's Capinero Creek is restoring previously irrigated agricultural land to native habitat to support San Joaquin Desert wildfire species (Tule Basin Land & Water Conservation Trust, n.d.).

Box 18: *Agroecology, Environmental Justice, and Nature-Based Solutions*

The community of Allensworth is a historically Black township in Tulare County facing compounding challenges due to disinvestment and discrimination. The Allensworth Progressive Association is organizing a community-led agricultural transformation oriented toward environmental justice through developing a 100-acre Agroecology Hub. The Hub will demonstrate regenerative agriculture, agrivoltaics for energy independence, beginning farmer training programs, and land access initiatives for farmers of color. Vermiculture composting, a rabbitry for cultural practices, and constructed wetlands for wastewater treatment are only a few of many projects that the Allensworth Hub will provide as a teaching center and example for other similarly challenged agricultural communities (Abatzoglou et al., 2026).

4.5 Flood

Introduction

The impacts of flooding are amplified by climate change, especially as extreme precipitation events become more frequent and intense (**Figure 25**). Most damage is caused by short-term "pulses" of excess rain that overwhelm already saturated soils or exceed infrastructural capacity, but the challenge of flooding extends beyond simply excess and extreme rainfall. Flooding is already a key priority in long-term planning and infrastructure investment strategies, however changes in California's climate affect long-term resilience capacity in the systems designed to withstand flooding risk. Systems that mitigate flood risks may not be designed for increased flood frequency and intensity. Additional challenges include aging infrastructure or neighborhoods and communities that were built in flood-affected areas. Many Californians have already experienced the effects of flooding through recent "billion-dollar floods" in 2017, 2021, and 2023, which include the 2017 Oroville Dam Spillway failure (NCEI, 2024), and the risk of further flooding disasters will only increase in the coming decades.

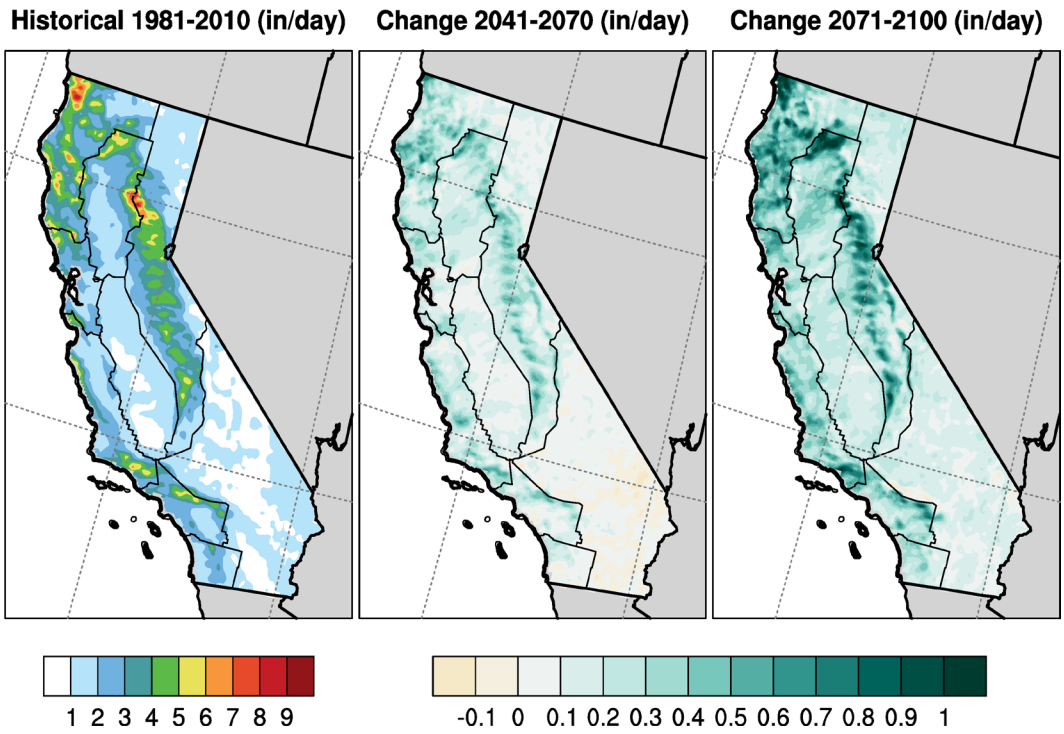


Figure 25: *Projected change in the amount of rain on the rainiest day of the year by mid-century (2041–2070) and end-of-century (2071–2100) compared to a 1981–2010 baseline under SSP3–7.0 (LOCA2-Hybrid). Figure by Paul Ullrich, UC Davis.*

Causes

California's most catastrophic floods are often driven by atmospheric rivers (ARs) and the occasional tropical storm. ARs are long, narrow corridors of high-water vapor transport in the atmosphere that can bring heavy rainfall to California. On average, they provide half of California's precipitation in just 120 hours per year (Lamjiri et al., 2018) but are also associated with some of the state's most acute and widespread and damaging flooding (Corringham et al., 2019). They can reach into the Central Valley and Sierra Nevada foothills, well away from coastal influences. ARs are projected to become more intense and clustered with climate change (**Figure 26**), resulting in concentrated midwinter precipitation (Gershunov et al., 2021; Rhoades et al., 2026; Shields et al., 2023).

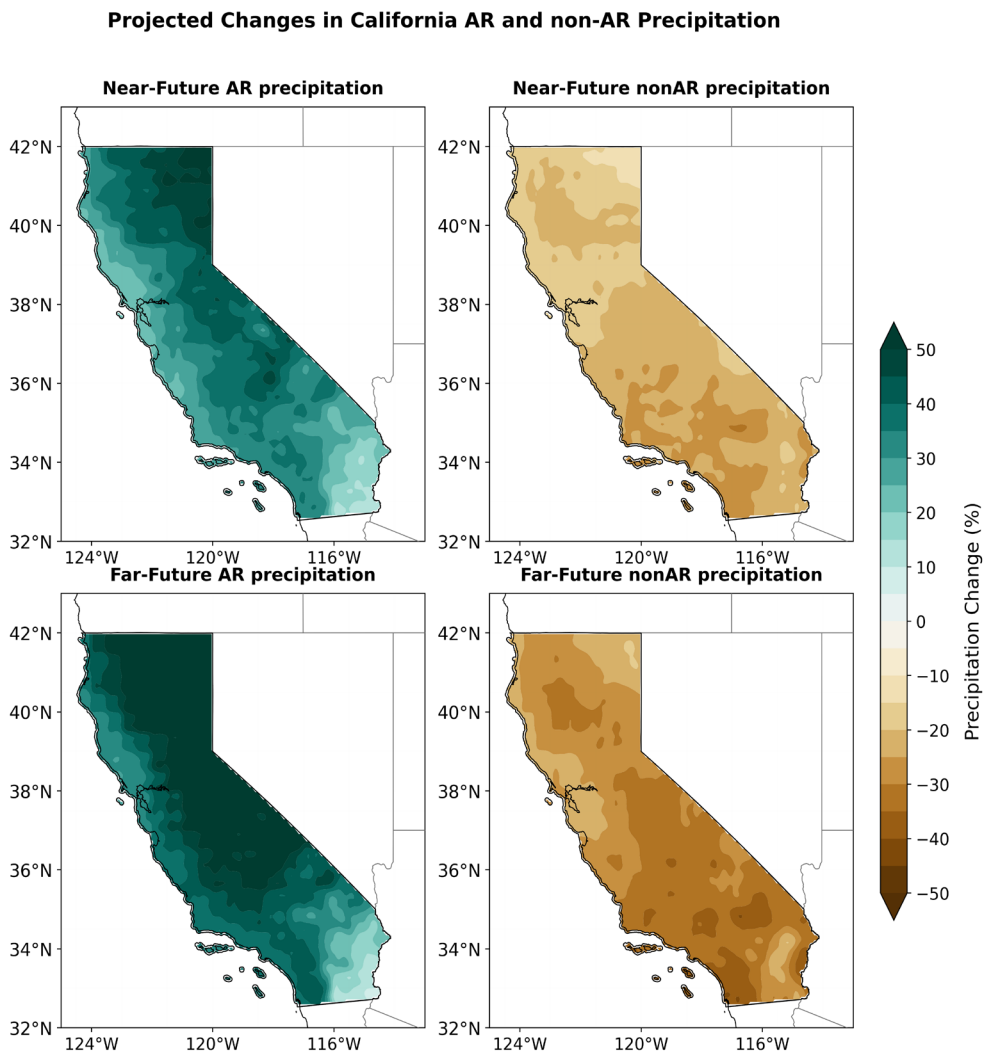


Figure 26: *Projected change in percent of October–April precipitation in California coming from Atmospheric Rivers (left column) and non-Atmospheric River storms (right column) by mid-century (top row, 2041–2070) and end of century (bottom row, 2071–2100). Figure by Rosa Luna-Niño, Scripps Institute of Oceanography at UC San Diego.*

Urban flooding where intense rainfall overwhelms local storm drainage systems is a significant and growing threat. This form of flooding is exacerbated by California's extensive urban footprints, where impermeable surfaces like roads and parking lots prevent natural infiltration and accelerate runoff. Urban flooding often has a disproportionate impact on low-income communities of color (Knighton et al., 2021a), frequently in areas with historic underinvestment in infrastructure.

Coastal environments face unique hazards where rainfall interacts with marine processes. These impacts are driven by:

- **Coastal Flooding:** Coastal flooding can occur when water levels are elevated from higher tides, large storms, large waves coinciding with high tides, or El Niño events (California Sea Level Rise Guidance, 2024). The frequency of coastal flooding events is expected to increase when sea level rise amplifies these already elevated water levels. Updated coastal storm monitoring includes the effect of tides, wave runup, peak river flows, and watershed hydrology and morphology which combined with storm timing are essential for understanding coastal flooding, especially when multiple impacts occur together. Storms with similar wave heights hit Santa Cruz in 2023 and 2024, but the 2023 storms caused much more coastal flooding since they arrived at a higher tide level relative to 2024 (Reguero et al., 2026).
- **Groundwater and Emergent Flooding:** Rising sea levels and heavy rain push the water table closer to, and in some cases above the ground surface, creating a compound impact that causes flooding even without visible surface runoff. This is especially hazardous when groundwater pollution is found.
- **Surface runoff and nutrient exchange** with groundwater, driven by sea level rise and altered recharge patterns, can contribute to harmful algal blooms (see *Marine Heat Waves* above for more) (Cheng et al., 2026).

These processes are discussed further below in *Sea Level Rise.*

Warming is also causing the Sierra Nevada snowpack to melt earlier in the year and leading to more precipitation in the Sierra Nevada falling as rain instead of snow. This increases flood potential, especially if rain-on-snow events cause rapid melting. The risk of rain-on-snow events will increase, expanding further southward in the Sierra Nevada (Rhoades et al., 2026). These shifts also underscore the need for flood hazard information and reservoir planning approaches that account for future climate conditions, not only historical hydrology.

Impacts

One in five Californians live in areas at risk of flooding (approximately 7 million residents) (Ayazi et al., 2026). A statewide megaflood brought on by major storms, like in the winter of 1861–62, could displace more than 1.5 million residents at present (J. F. Mount et al., 2024; Porter et al., 2011). Flooding can have devastating impacts on people, ecosystems, and property. Across the US, over 140 people died from floods in 2024, and at least 135 people died in a single flash flooding event in Texas in 2025 (Statista, 2025; Zhuang et al., 2025). Climate change makes these events more likely, including in California.

Box 19: *Groups Vulnerable to Flood*

Several groups, including those identified below, are especially vulnerable to flooding due to environmental and socioeconomic factors. Flood risk management efforts should be especially tailored to meet the needs of these groups.

- More intense storms, severe flooding, and increased erosion expose and damage cultural sites, degrade water quality, and threaten culturally important plants, animals, and gathering sites for California Native American tribes (Big Valley Band of Pomo Indians & Middletown Rancheria of Pomo Indians, 2021).
- For people living unsheltered, extreme rain and flooding can lead to infectious disease, property loss, social fragmentation, and reduced access to food, water, and hygiene resources (Acey et al., 2026). Flash flooding is especially dangerous for this group, since many live along riverbanks, the coastline, or within flood channels and are unable to evacuate quickly (Charan et al., 2026).
- Nationally, people of color are more likely to live in metropolitan areas with lower flood defenses, which can trap people in cycles of flooding and loss (Knighton et al., 2021b). This can also delay return from flood evacuation due to the high cost of damage repair and can lead to longer displacement (Ayazi et al., 2026).
- Rural communities relying on only one infrastructure system, or a single highway, are particularly at risk of flooding impacts to infrastructure (Sherriff et al., 2026).
- Communities experiencing repetitive loss may see neighborhoods lose social cohesion due to fragmentation or outmigration as families grapple with the costs and challenges of repeated flood events (Kick et al., 2011; Moftakhari et al., 2017; Nelson et al., 2022). Other factors which can increase vulnerability to flooding include poor housing quality, under-maintained drainage systems, and barriers to evacuation such as limited vehicle access (Acey et al., 2026). Such factors are particularly common in Black communities due to enduring patterns of discrimination and disinvestment, as well as among immigrant and low-income communities and renters.

PUBLIC HEALTH

Rains and flood events can produce standing water that creates ideal habitat for mosquitos, which can expand the area and populations affected by the diseases spread by them (Cal OES News, 2024). This includes established mosquito-transmitted diseases such as the West Nile Virus but could expand to include Dengue Hemorrhagic Fever or Chikungunya, which are typically associated with travel to areas with endemic infections (Fredericks & Fernandez-Sesma, 2014). Climate change can exacerbate conditions that support mosquito habitat (Capinha et al., 2014) and therefore the means for currently rare diseases to become established in California.

ECONOMY

Flooding presents substantial risk to California's economy, particularly in terms of property damage, and this risk is projected to increase due to climate change. McCord et al. (2026) find that "today, nearly 180,000 Californians have National Flood Insurance policies with approximately $54 billion in coverage (FEMA, 2025a, 2025b). However, FEMA's Flood Insurance Rate Maps are frequently cited as underestimating actual flood risk because they do not incorporate future climate-driven hazards such as sea level rise and more intense precipitation (Schubert et al., 2024; Wing et al., 2018). Independent analysis by the nonprofit research group First Street Foundation estimates that the actual number of properties at risk is much greater at 1.1 million, and an additional 150,000 properties will meet that threshold in the next 30 years (CDI, 2021). This suggests that currently, 920,000 properties statewide remain uninsured and vulnerable to significant flood-related losses (FEMA, 2025a; First Street Foundation, 2025)."

Box 20: *Case Study The Pajaro River Levee Breach*

Adapted from Eloy Ortiz (Langridge, Von Schmidt, et al., 2026).

In March 2023, a powerful atmospheric river storm system hit Monterey County, resulting in a levee breach that flooded the town of Pajaro. When the levee breached on March 11, residents were evacuated to shelters in the middle of the night and blocked from re-entering Pajaro for 10 days. Residents returned to a contaminated water system, damaged possessions and homes, odors, and mold. They faced burdensome financial expenses and experienced anxiety and depression.

The Pajaro recovery has been a struggle for residents, who largely speak Spanish or Central and South American Indigenous languages. The Federal Emergency Management Agency (FEMA) provided aid, but requirements for proof of legal status and for precise documentation of damaged property were significant barriers for many residents. The flood also had a lasting impact on agricultural work for laborers who lived in and outside of the area. Many farms closed through May 2023 as heavy rains continued, forcing local workers to choose whether to move, ask for loans from friends and family, use the little savings they had, or find work in other fields.

Many residents of Pajaro still have not fully recovered, but the community has found opportunities to improve their lives as they continue to heal:

- The headquarters for the only nonprofit organization in Pajaro focused on the town, Casa de la Cultura, has become a weekly gathering place for 20 to 50 residents and community leaders.
- The Pajaro Disaster Long Term Recovery Alliance continues to advocate and partner with other organizations to bring resources to Pajaro residents. The County of Monterey Sustainability Program and the local community organization Regeneración are leading a multi-jurisdictional planning process, engaging with the community on their needs related to greenhouse gas reduction.



Figure 27: *Aftermath of the Pajaro Levee Breach. a) A pile of damaged possessions; b) the American Red Cross and volunteers with the Hope Crisis Response Network provide disaster assistance; c) a sign in English and Spanish warning of hazardous materials, structural damage to buildings, and an active evacuation order. Photos by Eloy Ortiz, Regeneración Pajaro Valley Climate Action.*

Climate risk-informed floodplain mapping, such as DWR's Tuolumne River study, can help improve our understanding of flood risk by translating future precipitation and runoff changes into updated estimates of flood extent and exposure, supporting future updates to the Central Valley Flood Protection Plan and other long-term flood planning efforts (DWR, 2025e).

Flooding can also have significant impacts on the agricultural economy, including crop damage and loss, damaged infrastructure, and reduced agricultural productivity, in addition to effects on communities tied to agricultural activity (CDFA, 2026).

INFRASTRUCTURE

Major highways, bridges, and evacuation routes are increasingly at risk of storm-driven flooding. This risk was demonstrated by the 2023 flood events in Sacramento, which shut down key corridors and complicated emergency response (Pawley et al., 2023). Rural towns in California are particularly at risk when infrastructure is damaged, as they frequently rely on single highways and infrastructure systems that lack redundancy (Sherriff et al., 2026).

Atmospheric river events can also have severe repercussions for dams. The Oroville Dam spillway failure and concerns about potential additional risks occurred after back-to-back atmospheric river events that were exacerbated by climate change (Michaelis et al., 2022). This collapse forced the evacuation of 188,000 residents and threatened operations at the Feather River Fish Hatchery (Margolis, 2026).



Figure 28: *Intense rainfall from a thunderstorm in June 2022 triggered a debris flow on Murphy Creek, which was burned the previous year by the 2021 Dixie Fire. This deposit completely blocked Highway 70 and damaged the guardrail. Photo by Don Lindsay, California Geological Survey.*

Additionally, short-duration, high-intensity rainfall on recently burned landscapes can trigger high-volume debris flows and landslides and damage critical infrastructure, including roads, trails, culverts, and bridges (Keller et al., 2021; Oakley et al., 2025). For example, following the Dixie Fire in 2021, a thunderstorm produced intense rainfall and triggered debris flows in the burn area, destroying bridges, culverts, and trail networks and making Highway 70 impassable (**Figure 22**) (Sherriff et al., 2026; Thomas et al., 2023). The relationship between drought, fire, flood, and debris flows illustrates the destructive impact of cascading and compounding climate hazards.

WATER SUPPLY

Sierra Nevada snowpack accounts for about one-third of California's water supply, and agriculture and communities would be impacted by any decline in this resource (Soderquist & Luce, 2021). Snowmelt shifting to earlier in the year will increase flood risk at reservoirs designed for more gradual inflow. While major Northern California reservoirs (such as Folsom, New Bullards Bar, and Oroville) show resilience to potential future AR flood events, the events tested are not representative of all possible future flood events (Rhoades et al., 2026). These findings highlight the value of continued evaluation of reservoir operations under future climate conditions, including opportunities to use improved forecasts to support flood risk management, water supply, and downstream recharge objectives.

Adaptation and Resilience

The scale and urgent effects of flooding on built systems, ecosystems, agricultural lands, and public health in California requires improved flood risk information-sharing and multi-benefit

flood risk management approaches to proactively enhance community and regional resilience capacity and match the pace at which flooding can occur. The following section highlights several non-exhaustive flood adaptation approaches.

FLOOD-MANAGED AQUIFER RECHARGE

Flood-Managed Aquifer Recharge (Flood-MAR) redirects rain and snowmelt onto open fields and floodplains so that land managers can "bank" water underground. This strategy lowers the risk of downstream flooding while refilling depleted groundwater for use during droughts, thus creating a resilient "buffer" against a changing climate. This includes agriculture-managed aquifer recharge, which uses floodwater to help irrigate crops (CDFA, 2026). The San Joaquin River, San Francisco Bay, and Sacramento River hydrologic regions have expanded their recharge activity the most in recent years. Many agricultural regions (3.6 million acres) across the state have excellent or good potential for Flood-MAR (Marr et al., 2018; O'Geen et al., 2015), and technological advancements such as aerial electromagnetic surveys can target recharge efforts to maximize benefits (Knight et al., 2018). Flood-MAR can be evaluated alongside reservoir operations, conveyance, ecosystem benefits, and agricultural water management under more variable drought and flood conditions (DWR, 2025d).

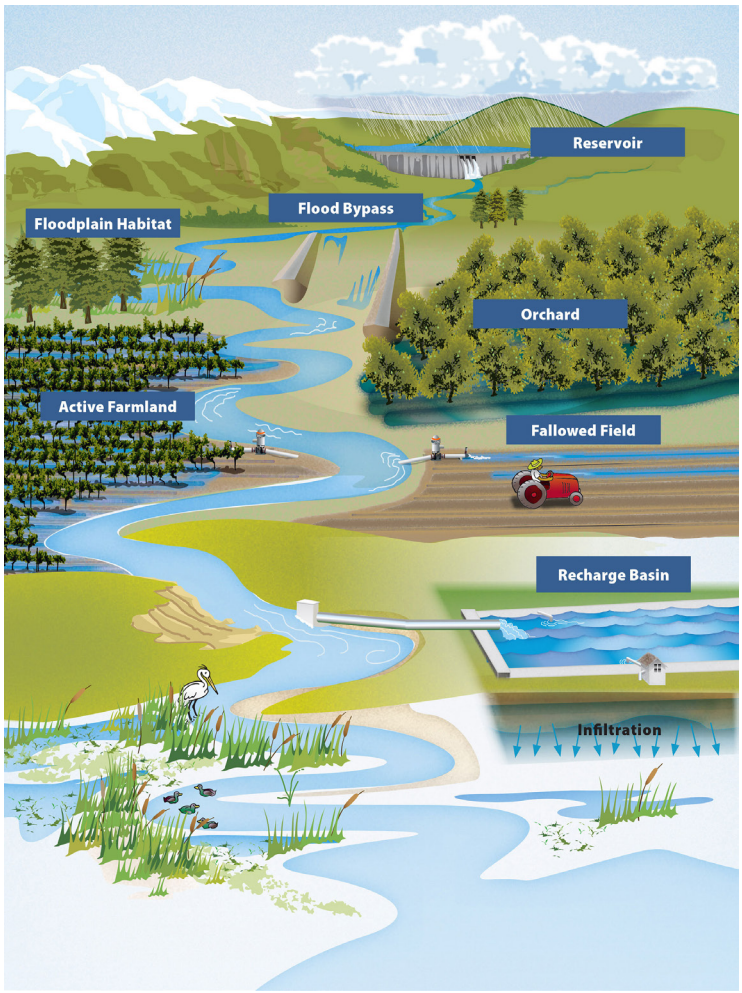


Figure 29: *Example elements and strategies for Flood-Managed Aquifer Recharge (Flood-MAR) Water Management* (DWR, n.d.).

MULTI-BENEFIT FLOODPLAIN RESTORATION

Rather than confining rivers to narrow channels with high levees, multi-benefit restoration efforts seek to expand floodplains and bypasses, thereby allowing rivers to spread out, and decreasing the pressure on levees, while providing habitat for sensitive species and opportunities for wildlife. In the Sacramento Valley, the Floodplain Forward Coalition works to reactivate the natural floodplain through dam removals, levee modification and operational shifts, and restoring river channels, among other actions. These actions can support wetland-dependent wildlife, farming of crops such as rice, and decrease risk of catastrophic floods (Margolis, 2026).

GREEN INFRASTRUCTURE

Green infrastructure harnesses the ability of plants and soil to store, filter, transport, and evaporate stormwater (US EPA, n.d.). Green infrastructure can include strategies like rain gardens, bioswales, and constructed wetlands to manage stormwater (US EPA, n.d.). Critically, green infrastructure can reduce flooding and prevent stormwater flows from overwhelming sewer systems (US EPA, n.d.). Counties in California are using green infrastructure strategies to manage their stormwater. For example, San Diego County has allocated funds to support "green street" projects through the Green Streets Clean Water Plan (Green Streets Clean Water Plan, n.d.) and the Waterscape Rebate Program (WRP) (County of San Diego, 2026). Green Streets have multiple co-benefits in addition to the management of stormwater, such as water conservation, increased access to green spaces, and higher water quality. Since 2021, the WRP has helped convert over 1.3 million square feet of turf to sustainable landscaping and implement water-saving best management practices on approximately 450,000 square feet of impermeable surfaces.

FORECAST-INFORMED RESERVOIR OPERATIONS

Flood-Managed Aquifer Recharge (Flood-MAR) is a management strategy that uses improved watershed observations, weather, atmospheric river, and runoff forecasts to inform reservoir operations. Previously, many reservoirs relied on rule curves (i.e., target water levels) and water control manuals developed from historical hydrology. By integrating modern atmospheric river forecasts, FIRO can help evaluate opportunities for operational flexibility while maintaining, and in many cases improving flood risk management, dam safety, water supply, and downstream public safety objectives. When coordinated with managed aquifer recharge (MAR), FIRO-MAR can also help evaluate opportunities to route or release water for downstream recharge when conditions allow (DWR, 2025d; Gershunov et al., 2025).

LEVEES

Levees are another adaptation intervention to address known flood exposure areas or manage anticipated future flood conditions. Levees are not unique to urban areas; they are often used to protect entire communities or urban areas subject to flooding within a larger metropolitan area. The Central Valley Flood Protection Plan (DWR, 2022) has numerous examples of these efforts, including levee protection for the Sutter Basin, levee improvement along Natomas and the American River in Sacramento, the Southport Setback Levee Project in West Sacramento, and updated levees in Lathrop as part of the River Islands Project. The report also highlights specific rural levee interventions such as repairs and improvements. Examples include the Knights Landing Levee Repair project and repairs of levee patrol roads throughout the Sacramento and San Joaquin river basins.

4.6 Sea Level Rise

Introduction

As rising temperatures melt glaciers and warm the ocean, the rate of sea level rise has accelerated globally. Based on the last thirty years of observations, the current rate of sea level rise is triple the 20th century rate (California Sea Level Rise Guidance, 2024). California's sea levels are influenced by regional variation, the impact of El Niño, and longer-term marine climate patterns, but nonetheless follow this global trend. Recent work has clarified the near-term and long-term trends, increasing hazards, and possibilities for adaptation to sea level rise in California.

Based on an *Intermediate* sea level rise scenario, California sea levels are most likely to rise 0.8 ft (0.3 m) by 2050 relative to sea level in 2000, with some local variation due to land movement (California Sea Level Rise Guidance, 2024). The high emissions scenario is approximately 1.2 ft (0.4 m) of sea level rise by 2050 (**Figure 30**), although greater amounts cannot be ruled out and are useful to consider for long-term planning. Over the long-term (toward 2100 and beyond), the range of sea level rise scenarios becomes increasingly large due to uncertainties associated with physical processes such as unexpectedly early ice sheet loss (**Figure 31**). These uncertainties, combined with greenhouse gas emissions pathways, make it more difficult to precisely project sea level rise at the end of the century and beyond. Statewide average sea levels are projected to rise by 3.1–6.6 ft (0.9–2.0 m) by 2100 and by 6.1–11.9 ft (1.9–3.6 m) by 2150 under *Intermediate* and *High* scenarios (California Sea Level Rise Guidance, 2024) (**Figure 31**).

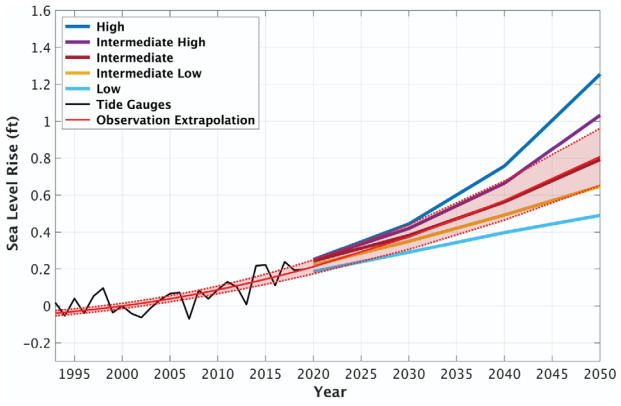


Figure 30: *Sea level rise scenarios for California, in feet, from 2020–2050 relative to sea level in 2000. The observation extrapolation line (red) derives a trajectory from the past statewide average tide gauge record (black) and serves as a comparison to the scenarios. The shaded region, bounded by the red dotted lines, represents the likely range for the observation-based extrapolation (California Sea Level Rise Guidance, 2024).*

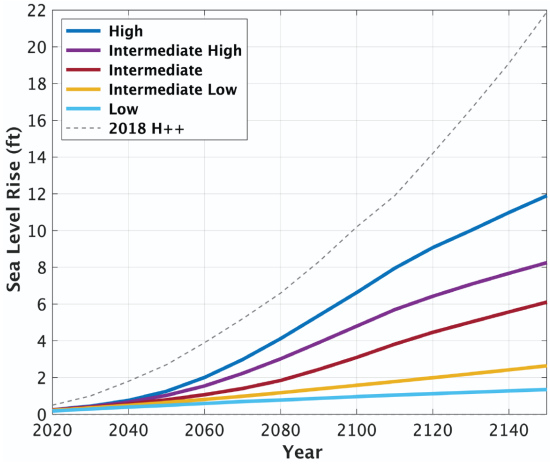


Figure 31: *Sea level rise scenarios for California, in feet, from 2020–2150 relative to sea level in 2000 (California Sea Level Rise Guidance, 2024). The H++ scenario from the 2018 California Sea Level Rise Guidance is no longer considered a plausible outcome but is included for comparison (Griggs et al., 2017).*

The rate of sea level rise varies across California due to differences in the rate of vertical land motion, for example from tectonic uplift or from subsidence due to removal of groundwater. While some locations in California are rising faster than the sea levels are, subsidence is more common, with between 4.3–8.7 million coastal residents exposed to subsidence (Waters et al., 2020). This process also threatens inland regions such as the Delta, where subsidence is leading to higher rates of sea level rise than along the coast (Baranes et al., 2023). Given this variation, it is critical for communities in different areas of the state to understand their unique sea level rise risks.

Box 21: *Sea Level Rise and Coastal Flooding*

Californians will see an increase in the frequency of coastal flooding from sea level rise in the 2030s and beyond due to the interaction between sea level rise and coastal storms (California Sea Level Rise Guidance, 2024). More extreme wave conditions will interact with rising sea levels, intensifying dangerous and damaging coastal flooding (Bromirski, 2023; Reguero et al., 2026). Given the interaction between sea level rise and coastal storms, researchers often analyze 100-year storm conditions under sea level rise scenarios to understand community, natural resource, and infrastructural vulnerability from sea level rise (California Sea Level Rise Guidance, 2024). Model projections from the USGS Coastal Storm Modeling System (CoSMoS) visualize the depth and extent of coastal floods for different sea level rise and storm scenarios. In addition, Fifth Assessment Sea Level Rise scenarios include hourly sea level rise projections for tidal stations along the California Coast (Cayan et al., 2023). This data helps identify hourly extremes in sea levels to capture potential flooding, particularly over the next 30 years.

Box 22: *Annual Return Periods*

Annual return periods are used to provide a sense of how often events like storms, floods, or tsunamis of a given intensity will occur. A 100-year event does not mean that the event will occur only once every 100 years. Rather, a 100-year annual return period event has a 1% chance of happening in any given year.

Box 23: *Groups Vulnerable to Sea Level Rise*

Many communities vulnerable to coastal flooding (see **Box 19**) are also vulnerable to sea level rise. Here are some examples of communities that are disproportionately vulnerable to sea level rise impacts:

- Communities of color and communities with high proportions of renters or people living in poverty are substantially more likely to be near hazardous facilities at risk of flooding (Cushing et al., 2023). Near the coast, these communities are increasingly threatened by sea level rise, especially where flood-prone areas overlap with hazardous sites or critical infrastructure (Acey et al., 2026).
- Coastal California Native American tribes are particularly vulnerable to sea level rise, as flooding, storm surges, and coastal erosion threaten ancestral village sites, cultural resources, and ecocultural habitats (Big Valley Band of Pomo Indians & Middletown Rancheria of Pomo Indians, 2021). Limited tribal jurisdiction over California's coastline constrains tribes' abilities to protect and steward these places (Santa Ynez Band of Chumash Indians, 2026).

PUBLIC HEALTH

Groundwater rise can have serious public health consequences driven by the interaction between seawater, groundwater, and infrastructure. When sea levels rise, they can push groundwater upwards, saturating contaminated sites from below. Materials such as heavy metals, pesticides and herbicides, per- and polyfluoroalkyl substances (PFAS), radioisotopes, unexploded military ordinance and volatile organic compounds (VOCs) can be released into the environment, especially affecting disadvantaged communities (Cushing et al., 2023; K. Hill et al., 2023). VOCs like benzene and tetrachloroethylene, which can threaten human health by increasing cancer risk and disrupting endocrine function (H. Wu et al., 2023), can create new exposure pathways (i.e., how people could contact the VOC) including vapor intrusion through sewers and building pipes (see **Box 24**).

ECONOMY

Similar to flood hazards, sea level rise causes large economic impacts through damage to property. Across estimates, it is clear that the cost of inaction in the face of sea level rise is high; however, cost estimates vary based on the sea level rise scenario chosen, type of hazard assessed, type of assets included, and whether adaptation is incorporated.

Without considering storms, coastal flooding exposure is expected to increase five-fold from 2050 (i.e., 0.8 ft [0.2 m] of sea level rise) to 2100 (i.e., 3.3 ft [1.0 m] of sea level rise), exposing 201,000 people and $78 billion in property (Barnard et al., 2019; Jones et al., 2017). However, coastal storms significantly raise coastal water levels primarily due to the combined effects of wave breaking and storm

Box 24: *Volatile Organic Compound Mobilization in the San Francisco Bay Area*

Movement of VOCs due to sea level rise is an emerging threat for the San Francisco Bay (BCDC, 2024). VOCs present a unique challenge because these contaminants can easily change state to become gases and move "uphill" or against the flow of sewer lines, so that they can enter homes and other buildings. In the San Francisco Bay Area, more than 1,500 active contaminated sites are potentially exposed to inundation from below with 3.3 ft (1.0 m) of sea level rise (K. Hill et al., 2023). A study with the goal of supporting public health efforts set out to characterize these sites based on criteria such as social vulnerability, contaminant toxicity, contaminant mobilization potential, and the potential for new exposure pathways (i.e., how people could contact the VOC) (Griggs et al., 2026). This labeling scheme allows users to sort sites by their chosen priorities for further investigation or remediation.

surge, therefore increasing coastal flood risk noticeably. For example, with just 0.25 m (0.82 ft) of sea level rise by mid-century, the present-day risk of flooding from a 100-year storm will increase by 2.5 times, exposing 166,000 people and $60 billion in property; this risk increases five-fold by end-century, exposing 310,000 people and $122 billion in property.

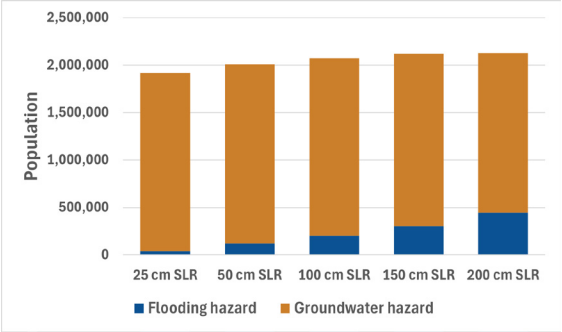


Figure 32: *California population at risk of exposure to the combined hazards of daily coastal flooding and shallow groundwater due to sea level rise. Figure by Patrick Barnard, US Geological Survey.*

An assessment of coastal groundwater hazards with respect to the California Ocean Protection Council (OPC) sea level rise scenarios found that exposure to groundwater affects many more people than coastal flooding alone (**Figure 32**) (Befus et al., 2020; Jones et al., 2017). For example, with 1 m (3.3 ft) of sea level rise by 2100 (*Intermediate* scenario), emerging and shallow groundwater would expose 1.9 million California coastal residents and $480 billion in property. This results in eight times more exposure than expected from tidal overland flooding.

In addition, coastal erosion threatens public access to beaches for recreation and tourism. Satellite imagery is being used to improve statewide projections of beach loss from sea level rise, waves, and currents, providing higher confidence in erosion estimates (Vitousek et al., 2023). These models suggest that without intervention, 24–75% of California's beaches could disappear seasonally or permanently by 2100, with highly developed areas of Southern California facing especially severe losses (Vitousek et al., 2023). The high end of this range reflects the *High* sea level rise scenario for 2130 (California Sea Level Rise Guidance, 2024).

The interactions between sea level rise and tsunami risk will cause significant mortality and structural damage, increasing drastically with higher sea level rise scenarios. Even 1.6 ft (0.5 m) of sea level rise significantly increases damage to structures during a 100-year annual return period tsunami (see **Box 22** on ARPs) (Patton et al., 2026). With 6.6 ft (2 m) sea level rise and a 100-year annual return period event, building losses increased from $123,000 (no sea level rise) to $16.5 million in models for Crescent City. At higher annual return periods, such as 2475- and 3000-year events, statewide damages reach billions of dollars (Patton et al., 2026).

INFRASTRUCTURE

Sea level rise will combine with increased storminess, including more extreme wave conditions (also caused by climate change) to overwhelm some coastal infrastructure. This includes roads, bridges, and railways as well as utilities. Rising groundwater associated with sea level rise can damage building and road foundations, septic systems, and public utilities as well.

TRANSPORTATION

Sea level rise contributes to cliff erosion and retreat, which can destabilize roads and railways built close to the coastline. For example, Highway 101 and the LOSSAN (Los Angeles–San Diego–San Luis Obispo) railway are transportation corridors commonly at risk. The 101 through Humboldt Bay and Crescent City is projected to flood regularly by 2050 (California Sea Level Rise Guidance, 2024; Sherriff et al., 2026). A stretch of highway south of Crescent City could be permanently closed, leading to $145 million in lost labor income, $456 million in lost business sales, and a 320-mile detour (Caltrans, 2018). In San Diego County, four bluff stabilization projects have been completed (and another began in 2025) to address dangerous erosion affecting the LOSSAN railway, but these efforts do not permanently address the issue. The regional government of San Diego County (SANDAG), US Department of Transportation (DOT), the California Department of Transportation (Caltrans), North County Transit District (NCTD), the California Coastal Commission, and other partners have worked to develop realignment options for the railway (SANDAG, 2025).

SEA LEVEL RISE IMPACTS ON EARTHQUAKE-INDUCED SOIL LIQUEFACTION

Soil liquefaction during earthquakes, when sediments that are loosely packaged and water-logged lose their strength, can cause landslides and adversely affect infrastructure. By raising groundwater levels, sea level rise can increase potential for soil liquefaction. As part of a project funded by the University of California Climate Action Initiative, researchers based at UCLA aim to thoroughly quantify the effects of sea level rise on liquefaction throughout the state and create a map of hazards to consider for coastal development. Initial findings from two simulations for Cardiff State Beach (San Diego County) project that the annual rate of liquefaction will increase by a factor of three for 1 m (3.3 ft) of sea level rise (Kota et al., 2025).

WATER SUPPLY AND AGRICULTURE

Saltwater intrusion harms water resources for consumption and agriculture, especially in low-lying areas like the Sacramento-San Joaquin Delta (Delta Stewardship Council, 2026). This region is sinking rapidly due to the decomposition of peat soil (carbon rich soil) when exposed to air, with some parts already approximately 20 feet (6 m) below sea level. As increasing sea levels overwhelm an aging levee system in the Delta, the region becomes vulnerable to the impacts of sea level rise and compound flooding, which occurs when multiple sources contribute to flooding (e.g., coastal storm surge and river overflow). Flooding in the Delta and associated saltwater intrusion threatens the water supply for 27 million Californians and six million acres of farmland (Delta Stewardship Council, 2026). Even at current water levels, a 100-year storm could overtop levees and lead to flooding and saltwater intrusion affecting 9,000 Delta residents and 41,000 acres of agricultural lands. 66,000 people and 148,000 acres of agricultural land could be exposed by one foot (0.3 m) of sea level rise with the same storm intensity (Delta Stewardship Council, 2026).

ECOSYSTEMS

Coastal, estuarine, and wetland ecosystems are threatened by erosion, flooding, inundation, and saltwater intrusion. Beach and dune loss threaten critical wildlife habitat, including nesting, breeding, and molting areas for protected species. For example, Northern elephant seals (*Mirounga angustirostris*) rely heavily on a small number of beaches for breeding and molting, making erosion and beach loss a growing threat to their long-term persistence in California (Heady et al., 2018).

Wetlands in California have already been reduced by 90% from their historical extent due to human activities (Bertoldi & Swain, 1999); in the Delta region, they have been reduced by 95% (Delta Stewardship Council, 2026). Sea level rise will further reduce ecosystem services such as carbon sequestration, flood dissipation, water filtration, habitat, and recreational access that wetlands provide. Flooding and saltwater intrusion in the Delta threaten 750 plant and animal species, including endangered bird species and salmon (Delta Stewardship Council, 2026).

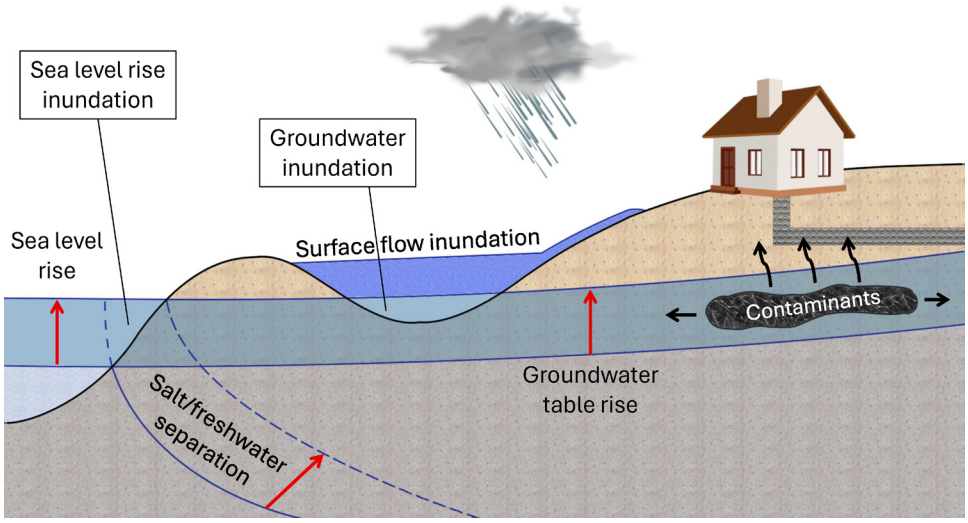


Figure 33: *A diagram showing how sea level rise can cause various coastal impacts, including sea level rise inundation, saltwater intrusion, a rising groundwater table, groundwater inundation, exacerbated inundation from surface flows, threats to underground infrastructure, and mobilized underground contaminants. Adapted from Rahimi et al.* (2020) *and Kane et al.* (2023).

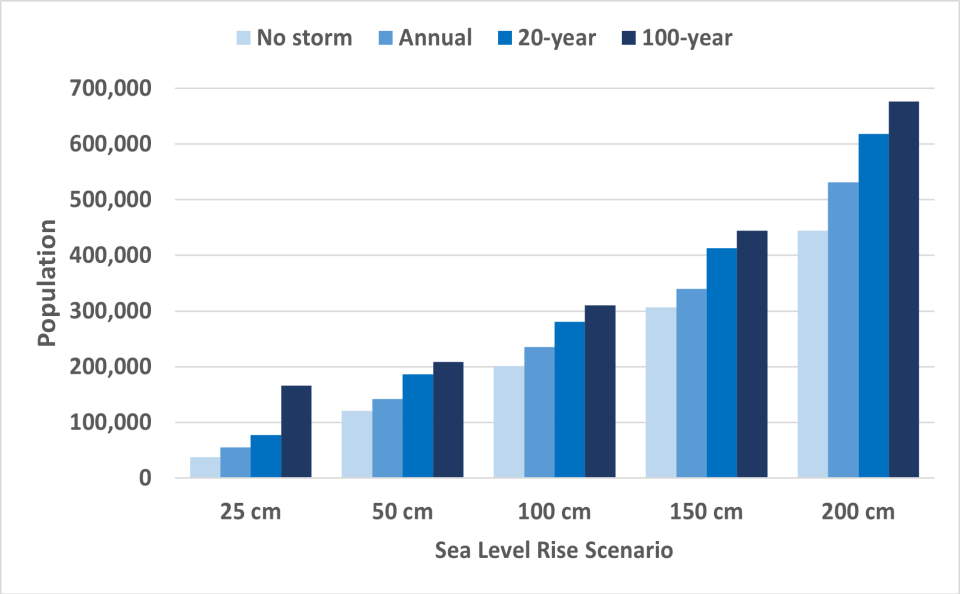


Figure 34: *California residents at risk of flooding for the plausible range of 21st century sea level rise (California Sea Level Rise Guidance, 2024) and storm scenarios based on projections from the Coastal Storm Modeling System (CoSMoS); (Barnard et al., 2019; Jones et al., 2017).*

California's beaches, dunes, and cliffs are increasingly threatened by coastal erosion driven by storms and accelerating sea level rise. These coastal ecosystems provide important cultural resources and ecosystem services, including cultural heritage (see **Box 25**), tourism and recreation, flood protection, and coastal habitat (Langridge, Van Schmidt, et al., 2026; Norris et al., 2026). Beaches naturally fluctuate over time; however, erosion risks are heightened where seawalls, roads, buildings, and other infrastructure prevent beaches and dunes from migrating landward, a process often described as coastal squeeze.

Box 25: *Coastal Chumash Village Areas at Risk from Sea Level Rise and Coastal Hazards: A Preliminary Review of Adaptation Measures by Chumash Tribes*

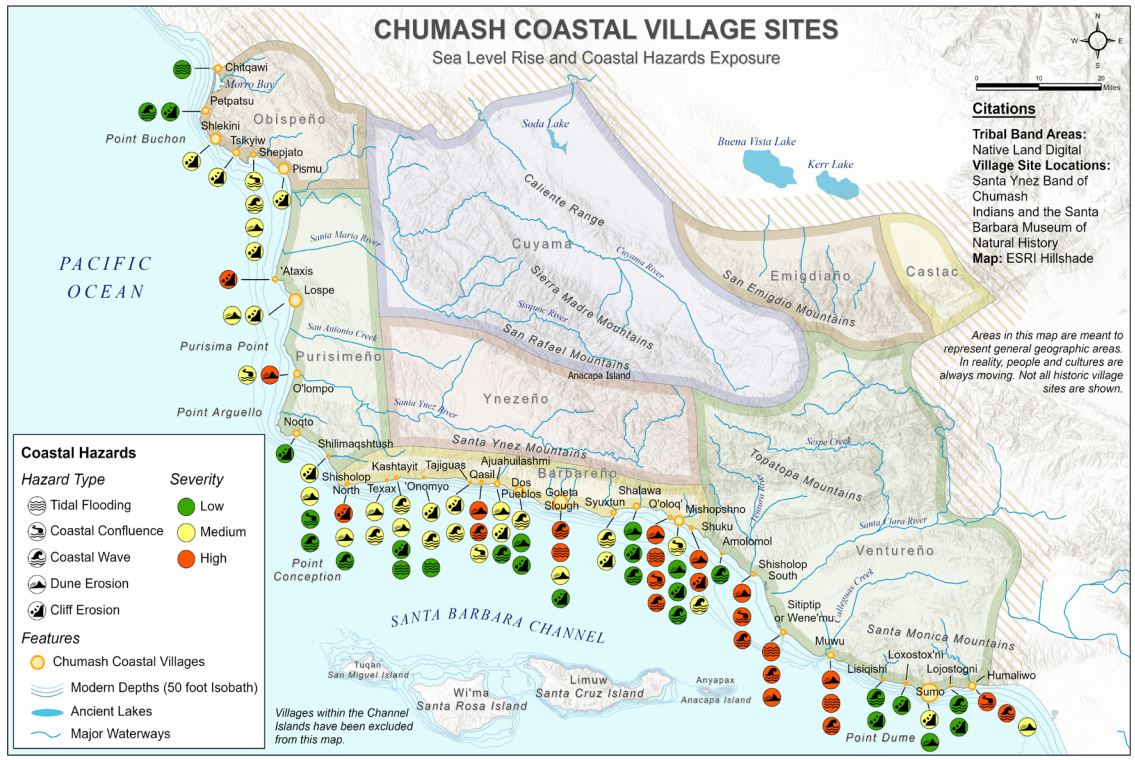


Figure 35: *Coastal Hazards and Chumash Village Site Exposure Highlights. Figure shared with California's Fifth Climate Change Assessment and reproduced with permission from the Santa Ynez Band of Chumash Indians (Santa Ynez Band of Chumash Indians, 2026).*

Sea level rise and coastal hazards threaten tribal cultural heritage sites. The Santa Ynez Band of Chumash Indians assessed 33 coastal Chumash village sites from Morro Bay to Malibu Point and found many are exposed to coastal dune and cliff erosion, storm wave flooding, compound flooding, and rising tides (**Figure 35**). These risks are intensified by colonization, which has limited tribal access to coastal places and excluded the Chumash from management authority over many of these sites. Protecting these places will require coastal adaptation planning that supports tribal access and treats tribes as governmental partners in coastal resilience (Santa Ynez Band of Chumash Indians, 2026).

Adaptation and Resilience

Many adaptation strategies can jointly bolster inland and coastal areas against rising water levels and address flooding impact, including upgrades to stormwater infrastructure and floodplain restoration, as discussed in *Section 4.5 Flood*. Other adaptation strategies include levee improvements and other hard infrastructure such as seawalls or nature-based approaches (managed foredunes, wetland and seagrass restoration, etc.). A combination of natural and built approaches is increasingly used and evaluated side by side. In areas at risk of long-term inundation, storm or tsunami damage, adaptation can include plans for strategic relocation, or natural and hard infrastructure interventions. The following section highlights several non-exhaustive sea level rise adaptation approaches.

COASTAL ARMORING

Historically, hard infrastructure such as concrete seawalls, rock revetments, sheet pile walls, and timber bulkheads has been the first line of defense for homes and infrastructure, as well as dunes or cliffs affected by sea level rise. These structures can also prevent human and ecological exposure to contaminated sediments and prevent erosion of caps built to contain contaminated sites (see *Public Health* section above). For example, the former Alameda Naval Air Station and former Hunter's Point Shipyard include rock revetments and seawalls designed to withstand coastal erosion (ERRG, 2014; NAVFAC, 2021); at other sites, structures are designed with the ability to be raised in the future to accommodate long-term sea level rise scenarios (ARCADIS, 2017). However, hard armoring can have unintended environmental consequences. Structures like seawalls can reduce intertidal and subtidal habitat complexity and prevent beaches from migrating inland, leading to beach loss and decreased biodiversity (Gittman et al., 2016; Griggs & Patsch, 2019).

BEACH NOURISHMENT

Beach nourishment involves placing additional sand on existing beaches to maintain the area in the face of erosion. This practice can be completed "opportunistically," when sand is removed as part of harbor dredging or construction projects and placed on beaches, or with deliberate offshore dredging and sand placement. This sediment management technique can support nature-based projects, such as dune restoration, or can simply involve replacing sand for recreational beach use.

LIVING SHORELINES AND HABITAT RESTORATION

Living shorelines are designed to harness natural materials and ecosystem services to prevent and manage flood damage. These approaches have shown promise both alone and in combination with hard armoring techniques. Living shorelines can include a diversity of habitat approaches, strategically sited and designed to increase habitat connectivity and shoreline protection. Approaches can include nearshore reefs, eelgrass and seaweed beds, coarse grain gravel and cobble beaches, rocky intertidal enhancements, low relief benches and sills made of mixtures of natural materials like cobble and shell, native revegetation in intertidal to upland ecotone zones, placement of woody debris, creation of higher elevation islands and mounds that support endangered species and other wildlife needing high tide refugia, and other methods. For example, salt marsh restoration can begin a positive feedback loop where the marsh accumulates sediment and confers more effective protection over time (Kirwan et al., 2016; Morris et al., 2002). Salt marsh restoration through the removal of invasive species

Box 26: *Giant Marsh Living Shorelines Project*

At the Giant Marsh Living Shorelines Project in Richmond, the placement of nearshore reefs in 2019 included comparison of different materials and methods at three tidal elevations, including clean recycled Pacific oyster shell and a combination of cement and native oyster shell, sand, and gravel termed "baycrete." These reef structures provided scaffolding for Olympia oysters and increased biodiversity of many species, as the offshore reefs supported 28 mobile and sessile taxa within two years. The project found that planting eelgrass adjacent to oyster reefs was beneficial, as there was evidence of greater eelgrass abundance on the shore side of oyster reefs and greater numbers of mobile invertebrates in eelgrass when adjacent to reefs (Boyer et al., 2025).

improved the ecosystem's potential to reduce wave impacts in Humboldt County (*Salt Marsh Project | Arcata, CA,* n.d.). These approaches require space for implementation and benefit from robust monitoring so they can be managed adaptively. They can be cost effective long-term solutions due to reduced overall installation and maintenance costs compared with hard armoring techniques (Huynh et al., 2024; Narayan et al., 2016; Reguero et al., 2026).

TOOLS FOR MODELING AND FORECASTING

CoSMoS Adapts

CoSMoS from USGS provides flood projections for multiple storm scenarios (daily conditions, annual storm, 20-year, and 100-year-return intervals) under a range of sea level rise increments from 0–9.8 ft (0–3.0 m) and an extreme 16.4 ft (5.0 m) scenario. The Fifth Assessment supported a new project, CoSMoS Adapts, led by UC Santa Cruz in partnership with USGS, to assess the costs and benefits of both nature-based and hardened solutions, such as dunes, artificial reefs, and seawalls for sea level rise in seven pilot localities (Reguero et al., 2026). While nature-based solutions like dune restoration were generally the most cost-effective, there was high variability across the study locations, suggesting that locally tailored adaptation strategies would be most effective. This tool can be expanded across the California coast and used to identify the highest benefit adaptation strategies grounded in the unique characteristics of a given locality.

Chapter 5.

Conclusion



Climate change is an urgent and ongoing challenge affecting the most cherished natural and human systems. As climate impacts intensify and become more frequent, preparing for the decades ahead will require proactive planning, sustained investment, and action at every scale. Decades of observations and research have made it possible to understand long-term climate trends and anticipate the increasingly complex conditions California may face throughout this century. But the future is not predetermined. Choices made today at the state, regional, and local levels will shape the conditions and opportunities available to communities tomorrow.

Building a resilient California for all means centering the communities facing the greatest climate risks and ensuring that resilience investments and long-term planning reflect the realities of the people and places they are intended to serve. It means elevating knowledge and leadership from across California's diverse regions, cultures, communities, and fields of practice, including the expertise of California Native American tribes and the lived experiences of those on the front lines of climate impacts. From infrastructure to ecosystems, from policy to community action, resilience must become part of how decisions are made at every level.

The Fifth Assessment is not a strategic plan, guidance document, nor prescription for specific policy action. It is not designed to identify a single "right" adaptation pathway for every community, nor does it eliminate the uncertainty inherent in projecting future climate conditions. The Fifth Assessment is designed to serve as a foundation for informed action—one that becomes most powerful when combined with local knowledge, lived experience, community priorities, and ongoing engagement.

California's Climate Change Assessments do not predict the future. They leverage collective knowledge to enable Californians to be better prepared for the future they may face and to be better positioned to shape the future they want.

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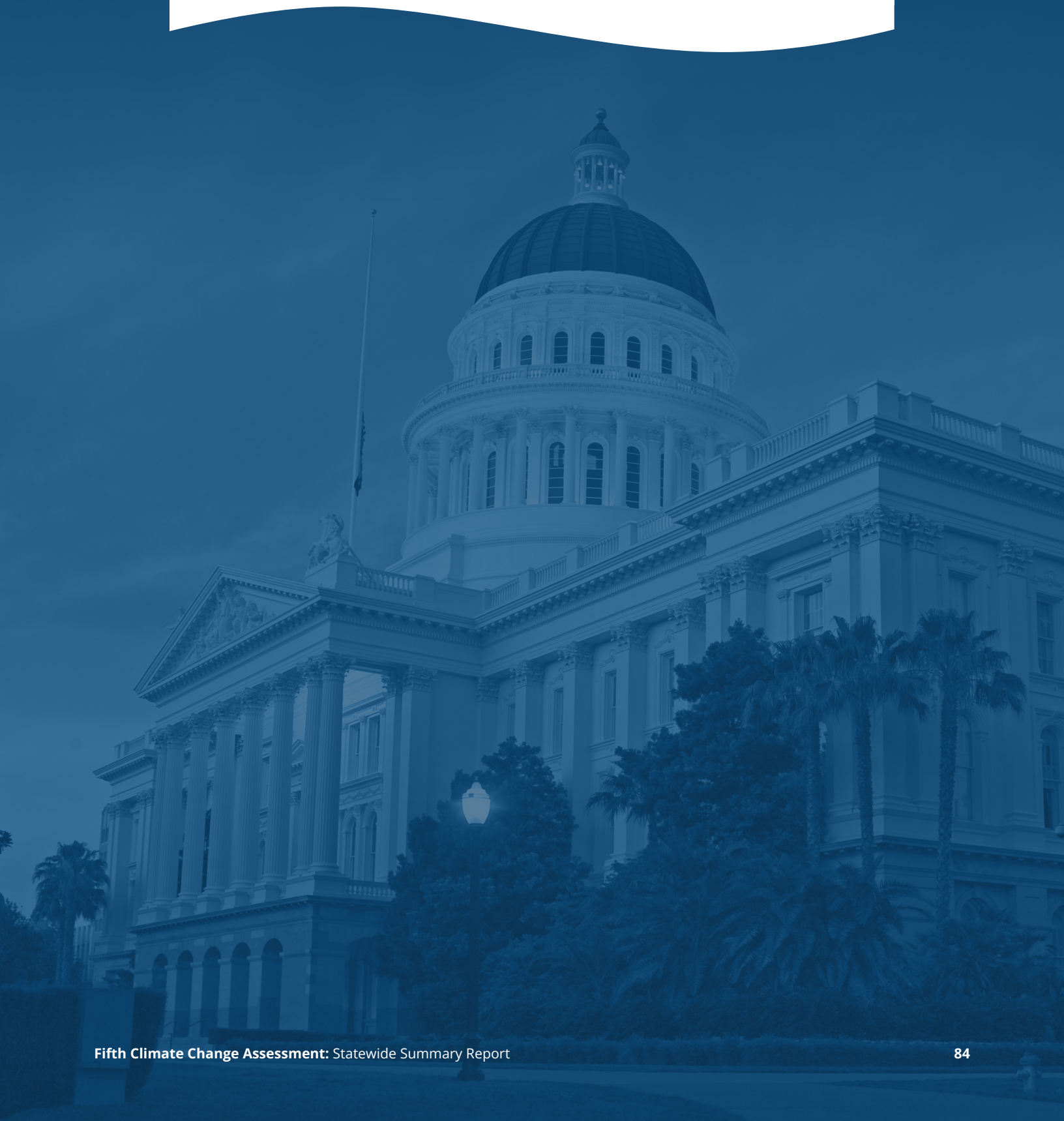

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