CALIFORNIA'S FOURTH
CLIMATE CHANGE
ASSESSMENT

California's Changing Climate 2018

A Summary of Key Findings from California's Fourth Climate Change Assessment

Coordinating Agencies:

GOVERNOR'S OFFICE OF PLANNING AND RESEARCH · STATE OF CALIFORNIA ·

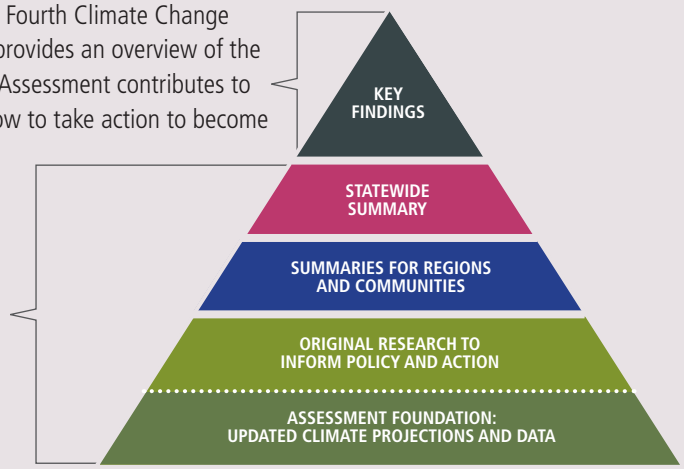
STATE OF CALIFORNIA ENERGY COMMISSION

CALIFORNIA natural resources AGENCY

Introduction to California's Fourth Climate Change Assessment

California is a global leader in using, investing in, and advancing research to set proactive climate change policy, and its Climate Change Assessments provide the scientific foundation for understanding climate-related vulnerability at the local scale and informing resilience actions. The Climate Change Assessments directly inform State policies, plans, programs, and guidance to promote effective and integrated action to safeguard California from climate change.

This capstone report presents key findings from California's Fourth Climate Change Assessment (also referred to as the Fourth Assessment). It provides an overview of the state of climate science while pointing out how the Fourth Assessment contributes to better understanding the impacts of climate change and how to take action to become more resilient.



To find out more about the other components of the Fourth Assessment, please visit: www.ClimateAssessment.ca.gov

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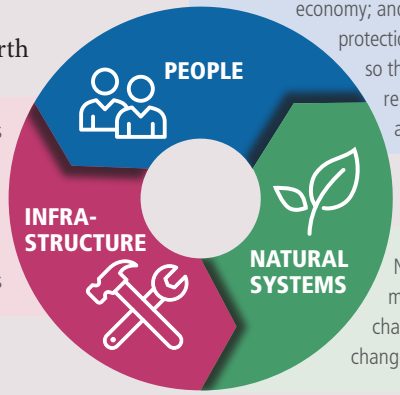
CALIFORNIA'S CLIMATE CHANGE POLICY AND THE FOURTH ASSESSMENT

While California is leading efforts to reduce greenhouse gas emissions, the State must also proactively address current and future impacts of climate change. The Fourth Assessment is part of California's comprehensive strategy to take action based on cutting-edge climate research. The Fourth Assessment addresses critical information gaps that decision-makers at the state, regional, and local levels need addressed in order to protect California's people, infrastructure, natural systems, working lands, and waters.



People and communities can respond to changing average conditions, shocks, and stresses in a manner that minimizes risks to public health, safety, and the economy; and maximizes equity and protection of the most vulnerable so that they both survive climate-related events and thrive despite and after these events.

Built infrastructure systems can withstand changing conditions and shocks, including changes in climate conditions, while continuing to provide critical services

Natural systems adjust and maintain desirable ecosystem characteristics in the face of change.

The Fourth Assessment provides critical information that will enable more ambitious efforts to support a climate-resilient California.

Why Study Climate Change in California?

California is one of the most "climate-challenged" regions of North America; its historical climate is extremely variable, and climate change is making extreme conditions more frequent and severe. California's temperatures are already warming, heat waves are more frequent, and precipitation continues to be highly variable. Since its Third Climate Change Assessment in 2012, California has experienced several of the most extreme natural events in its recorded history: a severe drought from 2012-2016, an almost non-existent Sierra Nevada winter snowpack in 2014-2015, increasingly large and severe wildfires, and back-to-back years of the warmest average temperatures.

California and the world need to rapidly reduce climate pollution to avoid the worst effects of climate change. We must also prepare for the continued acceleration of climate impacts in the future. The Fourth Assessment has prepared information needed to reach these goals.

The Fourth Assessment includes 33 State-funded research projects and contributions from 11 externally-funded researchers. The State-funded projects include the development of cutting-edge climate projections for California. The projections use a broader range of climate models, emission scenarios, and simulations than previous assessments, and included:

- The development and use of a new technique that provides spatial climate data that can be used at the local to regional level.
- Improved understanding of additional climate variables, including relative humidity and wind speed, and extremes like drought, heat waves, and heavy precipitation events.
- More extensive simulations of wildfire to help visualize increases in area burned.
- A more detailed set of sea-level rise projections that incorporate recent research on ice sheet collapse in West Antarctica.

These projections are critical tools necessary to understand and plan for climate impacts. They also inform research into critical actions for resilience.

CATALYZING ACTION THROUGH NEW ONLINE RESOURCES

The Fourth Assessment supported the development and expansion of new and existing resources to directly support climate action. Examples include:

cal-adapt

www.Cal-Adapt.org

Cal-Adapt is the State's portal for the climate projections produced for the Fourth Assessment, enabling data downloading and visualizations of climate scenarios at the local level and wildfire projections for the entire state.

°CHAT

www.Cal-Heat.org

Cal-Heat is a new tool funded by the Fourth Assessment to inform local public health officials' initiatives to protect the public during climate-exacerbated extreme heat events.

CoSMoS Coastal Storm Modeling System USGS

COASTAL STORM MODELING SYSTEM (COSMOS)

The CoSMoS model, partly funded by the Fourth Assessment, provides information about the complex interplay of coastal dynamics and climate change for California's coast.

View updated CoSMoS results on these websites:

- Hazard Exposure Reporting and Analytics (HERA) https://www.usgs.gov/apps/hera/
- Our Coast Our Future Flood Map www.OurCoastOurFuture.org

The full suite of Fourth Assessment projects and other tools can be found at: www.ClimateAssessment.ca.gov

How is California's climate projected to change?

The Fourth Assessment produced updated climate projections that provide state-of-the-art understanding of different possible climate futures for California. The science is highly certain that California (and the world) will continue to warm and experience greater impacts from climate change in the future. While the Intergovernmental Panel on Climate Change and the National Climate Assessment have released descriptions of scientific consensus on climate change for the world and the United States, respectively, the Fourth Assessment summarizes the current understanding of climate impacts and adaptation options in California. The greater detail provided by the Fourth Assessment supports efforts by individuals, businesses and communities to prepare for and reduce the impacts of climate change.

	CLIMATE IMPACT	DIRECTION	SCIENTIFIC CONFIDENCE FOR FUTURE CHANGE
	TEMPERATURE	WARMING ↗	Very High
	SEA LEVELS	RISING ↗	Very High
	SNOWPACK	DECLINING ↘	Very High
	HEAVY PRECIPITATION EVENTS	INCREASING ↗	Medium-High
	DROUGHT	INCREASING ↗	Medium-High
	AREA BURNED BY WILDFIRE	INCREASING ↗	Medium High

While most of these trends have been generally understood and expected since before California's First Climate Change Assessment in 2006, the Fourth Assessment provides new quantitative tools to understand and address these impacts. The updated results from the suite of Fourth Assessment models and analyses demonstrate the importance of achieving global reductions in greenhouse gas emissions. [1]

1 The phrase "if greenhouse gas emissions continue at current rates" refers to the Representative Concentration Pathway (RCP) 8.5. The phrase "if greenhouse gas emissions are reduced at a moderate rate" refers to RCP4.5. The RCP4.5 emissions level represents reduced emissions, but those reductions are not sufficient to achieve the targets called for in the Paris Agreement. However, the RCP4.5 emissions scenario was used in many of the Fourth Assessment's studies.

If greenhouse gas emissions…	are reduced at a moderate rate…	**then California will experience average daily high temperatures that are warmer than the historical average by…**	**2.5°F** from 2006 to 2039.	**4.4°F** from 2040 to 2069.	**5.6°F** from 2070 to 2100.
	continue at current rates…		**2.7°F** from 2006 to 2039.	**5.8°F** from 2040 to 2069.	**8.8°F** from 2070 to 2100.

While the averages of daily maximum temperatures over an entire year are easily understood, in many ways this indicator obscures the risks from extreme weather events due to changing climate. For example, the number of extreme heat days will increase exponentially in many areas.

Projections developed for the Fourth Assessment do not show a consensus in the overall trend in yearly precipitation, but they do have increasing variability in precipitation. However, across all the simulations, higher temperatures lead to dryer conditions because of increasing evaporation and plant stress. With increased numbers of dry days, several of the models indicated an increased occurrence of dry years and strings of dry years resulting in more frequent and more intense droughts. At the same time that most of the simulations had more dry days, there was also a tendency for increased precipitation on very wet days, so that the risk of floods caused by large storms will increase, sometimes occurring in bursts over several weeks.

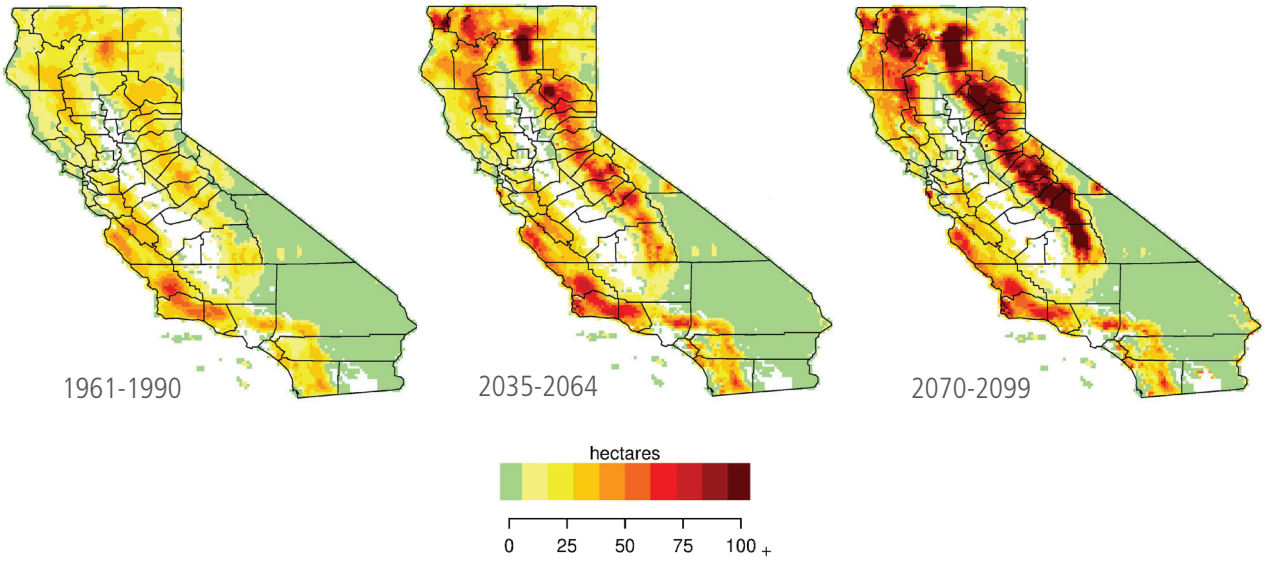
By 2050, the average water supply from snowpack is projected to decline to 2/3 from historical levels. If emissions reductions do not occur, water from snowpack could fall to less than 1/3 of historical levels by 2100.

The Paris Agreement brought, for the first time, all nations of the world together around the common cause of limiting global average temperature warming to 2°C [3.6°F] or less (1.5°C [2.7°F]) above pre-industrial levels. A Fourth Assessment study reports estimated climate impacts to California assuming global compliance with the Paris goals, finding that impacts in California would be substantially reduced. However, California still needs to prepare, at a minimum, for significant unavoidable impacts that would occur even if global average temperate rise is limited to 1.5°C, and adopt precautionary adaptation policy to protect against impacts from higher emissions scenarios.

EXTREME HEAT DAYS PER YEAR IN DOWNTOWN FRESNO (Days exceeding 106.6°F)		
1961 – 2005	2050 – 2099	2050 – 2099
4	**26** if greenhouse gas emissions are reduced at a moderate rate	**43** if greenhouse gas emissions continue at current rates

Sea-level rise is virtually certain to increase beyond the 6 inches that much of California experienced in the past century, but there are important questions involving how fast and how extreme the rates of sea-level rise will be. The Fourth Assessment's projections underscore the dependence of sea levels upon greenhouse gas emissions and the associated melt and ice-loss from Greenland and Antarctica. If emissions continue at current rates, Fourth Assessment model results indicate that total sea-level rise by 2100 is expected to be 54 inches, almost twice the rise that would occur if greenhouse gas emissions are lowered to reduce risk.

Increasing acreage burned by wildfire is associated with increasing air temperatures. One Fourth Assessment model suggests large wildfires (greater than 25,000 acres) could become 50% more frequent by the end of century if emissions are not reduced. The model produces more years with extremely high areas burned, even compared to the historically destructive wildfires of 2017 and 2018.



This image shows the modeled area burned by wildfires from current time (modeled as 1961-1990), for mid-century (2035-2064), and for late century (2070-2099). By the end of the century, California could experience wildfires that burn up to a maximum of 178% more acres per year than current averages.

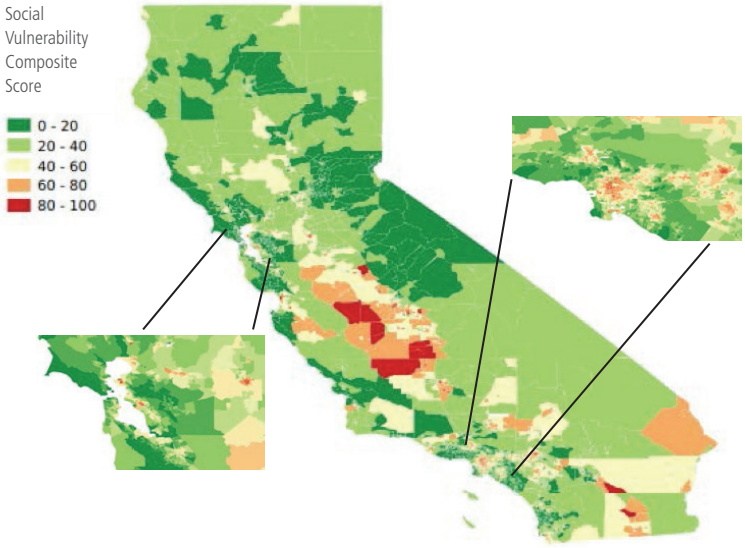
Impacts of Climate Change on People

While the impacts of climate change vary over time and place, each community will also experience these impacts in unique ways that will depend on social, economic, and demographic factors. The Fourth Assessment makes new strides at the intersection of social and physical sciences to understand how climate change will affect Californians – and how Californians can adapt and safeguard their communities from climate change.

PUBLIC HEALTH

Climate change will affect California's diverse people and communities differently, depending on their location and existing vulnerabilities. While research shows that all Californians will likely endure more illness and be at greater risk of early death because of climate change, vulnerable populations that already experience the greatest adverse health impacts will be disproportionately affected.

Heat waves, the natural disaster responsible for the most deaths in California over the last 30 years, are an example of the current and future risk climate change poses to people. The 2006 heat wave killed over 600 people, resulted in 16,000 emergency department visits, and led to nearly $5.4 billion in damages. The human cost of these events is already immense, but research suggests that mortality risk for those 65 or older could increase ten-fold by the 2090s because of climate change. Studies show that while air conditioning can reduce mortality and illness from heat, increased electrical demand for cooling due to hotter conditions could also drive up emissions. However, the state is rapidly moving to cleaner electricity generation. Greenhouse gas emissions from electricity generation in 2016 were about 37% lower than emissions in 1990.



A Fourth Assessment study produced this map of social vulnerability to heat by using 18 health, social, and environmental factors associated with heat vulnerability. The map highlights the relative heat vulnerability of 8,046 census tracts by synthesizing vulnerability indicators to render a clearer picture of overall heat vulnerability. In more detail, Map A illustrates the Bay Area and Map B shows greater Los Angeles area.

IMPACT FROM CLIMATE CHANGE: Heat-Health Events (HHEs), which predict heat risk to local vulnerable populations, will worsen drastically throughout the state by mid-century. The Central Valley is projected to experience average HHEs that are up to two weeks long, and HHEs could occur four to ten times more often in the North Sierra region.

ACTION FOR RESILIENCE: The Fourth Assessment supported the development of a prototype heat warning system known as the California Heat Assessment Tool (CHAT), which was designed to provide information about heat events most likely to result in adverse health outcomes. It will support public health departments taking action to reduce heat-related morbidity and mortality outcomes.

A new study found that deep greenhouse gas emission reductions (80% below 1990 levels) in California could significantly improve health outcomes, and cost savings would be comparable to the cost of achieving those reductions by 2050. These savings are achieved because shifting from polluting technologies to clean technology improves air quality, saves lives, and improves overall public health.

In addition to heat, direct climate impacts like wildfire, drought, and coastal and inland flooding will negatively affect public health. However, there are also additional indirect effects of climate change on human health: wildfire smoke leads to increased respiratory illness, warmer temperatures lead to the spread of mosquito-borne diseases like Zika, and increased disasters lead to greater stress and mental trauma.

CLIMATE JUSTICE

The Fourth Assessment includes a report on climate justice in California, a new addition to the assessment process. Climate justice is the concept that no group of people should disproportionately bear the burden of climate impacts or the costs of mitigation and adaptation, and is a critical component of California's climate strategy.

Vulnerable communities include field workers, such as this person being given a protective N95 face mask who was exposed to poor air quality during the California wildfires in the fall/early winter of 2017/2018. Photo: CAUSE

This Fourth Assessment report highlights the importance of adaptation efforts to minimize climate impacts to disadvantaged communities, as well as case studies of innovative programs to increase the resiliency of vulnerable populations in California. The report identifies areas for additional research needed to improve climate adaptation for vulnerable populations and to promote climate justice in California. These include better tools, indices, maps, and metrics for identifying and quantifying resilience in vulnerable communities, research into achieving a just transition to a low carbon economy, and methods for ensuring community involvement in climate adaptation planning.

TRIBAL AND INDIGENOUS COMMUNITIES

For the first time, the Fourth Assessment includes a Tribal and Indigenous Communities Summary Report. Tribes and Indigenous communities in California face unique challenges under a changing climate. Tribes maintain cultural lifeways and rely on traditional resources (like salmon fisheries) for both social and economic purposes. For many tribes in California, seasonal movement and camps were a part of living with the environment. Today, these nomadic options are not available or are limited. This is the result of Euro-American and U.S. policy and actions and underpins several climate vulnerabilities. Tribes with reservations, Rancherias, or allotments are vulnerable to climate change in a specific way: tribal lands are essentially locked into fixed geographic locations and land status. Only relatively few tribal members are still able to engage in their cultural traditions as livelihoods.

An example of how tribes use Traditional Ecological Knowledge can be seen in the use of prescribed burns. These are commonly deployed within a centuries-old cultural context to manage meadows, forests, and other areas within tribal lands.

Traditional Ecological Knowledge (TEK)-based methods are gaining a revitalized position within a larger statewide toolset to build resilience against climate change by tribal and non-tribal stakeholders alike. The importance of maintaining TEK is not isolated to environmental and ecological improvements. These ancient, traditional practices are closely linked to climate resilience across tribal cultural health, identity, and continuity. Cultural practices and traditional land management are also linked to improving physical and mental health among tribal members. These TEK techniques are increasingly incorporated by non-tribal land and resource managers as part of wildfire prevention and ecosystem management.

Impacts of Climate Change on Infrastructure

The Fourth Assessment provides in-depth assessments that support proactive steps to protect California's energy, transportation, and water infrastructure systems and the communities they serve. These systems face increasing risks from climate change as temperatures warm, sea levels rise, and other climate impacts worsen. These systems are interconnected, and disruption in one part can impact other connected parts with both direct and indirect economic effects.

ENERGY

Energy resources can be considered from both supply and demand perspectives. Fourth Assessment studies found infrastructure that supplies energy along the coast – particularly docks, terminals, and refineries – will increasingly be exposed to coastal flooding. Meanwhile, electrical power lines, rails, and roads are primarily at risk from increasing wildfire. Costs and impacts of wildfire to electricity transmission and distribution systems are expected to grow as climate change impacts increase.

IMPACT FROM CLIMATE CHANGE: Annual demand for residential electricity is projected to increase in inland and Southern California, with more moderate increases in cool coastal areas. Increases in peak hourly demand during the hot months of the year could be more pronounced. Even though reduced use of natural gas in warmer winter months will offset some of the total demand for energy, it will be critical to be able to meet higher peak loads while protecting infrastructure from climate impacts.

ACTION FOR RESILIENCE: Studies found that flexible adaptation pathways that allow for implementation of adaptation actions over time enable utilities to protect services to customers most effectively. The California Public Utilities Commission recently began a process to consider strategies and guidance for climate adaptation for electric and natural gas utilities, which will be informed by the Fourth Assessment.

IMPACT FROM CLIMATE CHANGE: Emerging findings for California show that direct climate impact costs by the middle of this century are dominated by human mortality, damages to coastal properties, and the potential for droughts and damaging floods. The costs have been estimated at tens of billions of dollars. The impacts after the middle of this century will be much lower if global greenhouse gas emissions are reduced substantially.

ACTION FOR RESILIENCE: California's Fourth Climate Assessment contributes information and tools that are needed from local to statewide levels to design and implement adaptation measures to lower economic impacts. In addition, the Climate-Safe Infrastructure Working Group, created in response to Assembly Bill 2800 (Quirk), is releasing recommendations that build on the Fourth Assessment findings to inform a robust, comprehensive, and equitable approach to building for the future.

Solar panels produce energy at the California Department of Water Resources Pearblossom Pumping Plant in Pearblossom, California. The Fourth Assessment considered climate risk to the electricity system in the context of the growth of renewable energy supply. Photo credit: Florence Low/California Department of Water Resources 2017.

TRANSPORTATION

California's roads, railroads, pipelines, waterways, ports, and airports are critical for the movement of people and goods. They will be significantly affected by climate change. A growing threat to California's transportation system is wildfire, which can also have cascading effects like landslides and mudslides that occur after rain falls on newly burned areas.

Increasing temperatures are also expected to increase road construction costs between 3 and 9%. Adapting roadway materials to withstand higher temperatures is needed to avoid potential costs of over $1 billion by 2070. 115 miles of railroad could be at risk of coastal flooding by 2040, with an additional 285 miles at risk by 2100.

IMPACT FROM CLIMATE CHANGE: Miles of highway at risk of flooding in a 100-year storm event will triple from current levels to 370 miles by 2100. Under that scenario, over 3,750 additional miles of highway will be exposed to temporary flooding.

ACTION FOR RESILIENCE: Based in part on its work with the Climate-Safe Infrastructure Working Group, Caltrans will update its Highway Design Manual to include the latest climate-informed data on precipitation and heat. Caltrans will also complete climate vulnerability assessments and develop climate adaptation strategies for each of its 12 districts.

The combination of the Thomas wildfire (281,893 acres) and a subsequent intense rainstorm caused heavy mud and debris flows in the towns of Carpinteria and Montecito, resulting in 21 fatalities, destroying at least 1,063 structures, causing over $2.176 billion in damages, and closing Highway 101 for two weeks.

Airports in major urban areas including San Francisco (SFO), Oakland, and San Diego will be susceptible to major flooding from a combination of sea-level rise and storm surge by 2040-2080, depending on location, without implementation of protective measures. SFO is already at risk of flooding from storm surge.

WATER INFRASTRUCTURE

The impacts of climate change on California's water infrastructure and management are especially profound and are causing shifts in the water cycle, greater risks to engineered systems, and threats to ecosystems and water quality. The complex network that stores and distributes water throughout the state was designed for historical hydrologic conditions that are now changing. The Fourth Assessment contributes critical knowledge to understand these new risks and to improve management.

Modeling of reservoir operations show that Shasta and Oroville reservoirs, the two largest in the state, will have roughly one-third less water stored annually by the end of the century under current management practices. This reduced storage could limit water supplies and thus lower resilience to droughts. Changes in seasonal precipitation combined with the effects of sea level rise in the Delta may compound water supply reliability for

cities and farms that depend on imported water from the State Water Project and Central Valley Project, as exports from the Delta in future droughts could be reduced by as much as 50% more than during historical droughts. The Fourth Assessment also found that water rights administration and oversight practices from past droughts are ill-suited to the growing challenges for water management from climate change.

As temperatures increase, more precipitation will fall as rain rather than snow. With potentially larger storms, existing flood management practices and infrastructure will be challenged to meet the higher flows. Advances in monitoring systems, forecasts, and coordination, coupled with continuing modifications and repairs to flood management infrastructure, will enable more time to prepare for future large floods while increasing options to improve and maintain supply reliability.

The Shasta Dam is one of California's two largest, with a storage capacity of 4.55 million acre feet. Photo credit: Apaliwal 2009.

IMPACT FROM CLIMATE CHANGE: Current management practices for water supply and flood management in California may need to be revised for a changing climate. This is in part because such practices were designed for historical climatic conditions, which are changing and will continue to change during the rest of this century and beyond. As one example, the reduction in the Sierra Nevada snowpack, which provides natural water storage, has significant implications for California's water management system.

ACTION FOR RESILIENCE: Promising adaptation options such as the use of probabilistic hydrological forecasts, better measurements of the snowpack, and other improved ways to manage water can reduce these negative impacts. Increased groundwater storage is another promising option, which may include taking advantage of increased winter runoff to flood agricultural and natural areas to recharge aquifers. Institutional, regulatory, legal, and other barriers may need to be overcome to implement science-based solutions.

In addition to illuminating impacts from climate change to California's water infrastructure, the Fourth Assessment also presents potential solutions from around the state. One study shows how creative approaches from local water districts better prepared them for California's drought. While small water systems throughout the state currently struggle to incorporate climate change into their planning and management practices, the State could help disadvantaged communities most impacted by climate change by providing funding, technical assistance, and assistance consolidating these water providers.

Land subsidence and sea-level rise will impede the function of levees in the Sacramento-San Joaquin Delta, and by 2050-2080 some Delta levees may no longer meet federal standards.

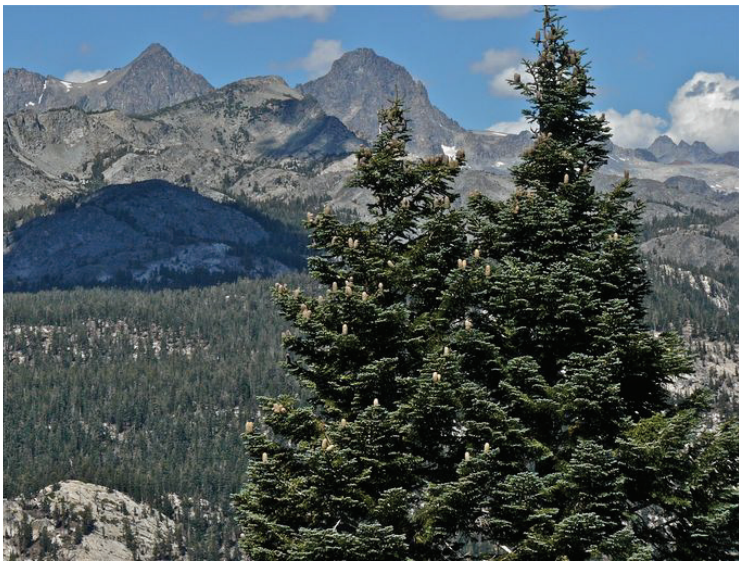
Impacts of Climate Change on Natural and Working Lands and Waters

Natural and working lands and waters include forests, rangelands, farmland, riparian areas, and California's ocean and coast. These lands contribute to the natural infrastructure of the state. They harbor the species and ecosystems of California, and are increasingly at risk of disruption due to climate change.

FORESTS

California's forests cover almost one-third of the state and provide important ecosystem services including water capture and filtration, wildlife habitat, recreation opportunities, and timber products. Climate change poses increased risk of wildfire and potential for insect infestations. California's forests have the potential to remove and store carbon from the atmosphere, and are an important element of the State's programs to reduce carbon in the atmosphere. However, more research is needed to understand the relationship between forest management practices to reduce wildfire risk and the effect on carbon storage. A Fourth Assessment study found that fuel treatments lowered the biomass stored in a forest, but that more of the remaining biomass survived a fire than in an untreated forest area. The study also developed a new method to track how much biomass is stored in living trees on large scales.

California's forests contain over 60 species of trees including red fir (Abies magnifica) and extends from coastal regions to high elevations in the Sierra Nevada and other mountain ranges. Photo: Jean Pawek



ACTION FOR RESILIENCE: A Fourth Assessment review of forest health literature provides further scientific backing to the State's Forest Carbon Plan to increase forest restoration and treatment such as prescribed fire to an average of 35,000 acres a year by 2020. Additionally, intensive thinning in highly productive forests reduced tree evapotranspiration, suggesting that forest thinning could result in increased base flows of up to 10% for dry years and 5% for all years.

This review found prescribed fire a suitable tool to lower extreme fire risk. However, under extreme fire weather conditions, fires may simply jump or burn through treated areas. With regards to sequestering carbon, a key question in California forests is whether fuel treatment data such as fire intensity, stand age, and extent of treatment can be used to predict the reduction of carbon lost in a subsequent wildfire.

A Fourth Assessment wildfire model suggests a 77% increase in mean and up to a 178% increase in maximum area burned by wildfires (compared to 1961-1990) by 2050, but the actual impacts could be substantially more severe because external factors such as wind are not yet incorporated. By the end of the century, if greenhouse gas emissions continue to rise, extreme wildfires burning over about 25,000 acres is projected to increase by nearly 50%. Reducing tree density and restoring beneficial, controlled fire can improve resilience of California's forests to wildfire. In the areas that have the highest fire risk, wildfire insurance is estimated to rise by 18% by 2055, and the fraction of property insured would decrease.

RANGELANDS

Conservation of California's grasslands, chaparral, and oak woodlands and improved management of their soils has strong potential to improve soil water-holding capacity, increase stream flows and aquifer recharge, reduce flooding and erosion, and reduce climate-related water deficits. Increasing organic matter in soils by 3% by applying compost could increase the soil's water holding capacity by up to 4.7 million acre-feet across all working lands in California, with hydrologic benefits greatest in locations with enough precipitation to fill increases in soil storage capacity.

Many of California's rangelands consist of nonnative grasses and oak woodlands including these blue oaks (Quercus douglasii) or chaparral. Photo: Neal Kramer

ACTION FOR RESILIENCE: Field experiments and modeling show that a single application of compost to rangelands in California can increase soil organic carbon sequestration for up to 30 years and enhance net primary productivity. The resulting increase in soil organic matter and increased vegetation also supports infiltration of water during storm events, contributing to recharge of aquifers. A lifecycle assessment of California's largest organic waste streams — food waste, yard waste, and cattle manure — showed that composting these feedstocks and applying the compost to California rangelands has lower net greenhouse gas emissions than other waste management approaches.

BIODIVERSITY AND HABITATS

California is a globally ranked biodiversity hotspot: only 25 regions in the world have as many species. These species live in the state's natural vegetation types: forests, chaparral, riparian areas, riverside and wetlands, as well as in its working landscapes, which include rangelands and agricultural lands. Under current emissions levels, between 45 to 56% of the natural vegetation in California becomes climatically stressed by 2100. The recent tree die-off during the drought of 2012-2016 shows how projected impacts are already having drastic effects.

Corridors can provide a means for plants and animals to migrate to more suitable areas as the climate changes. A Fourth Assessment study provides a framework for climate-wise corridor design and implementation for terrestrial plants and wildlife. It recommends starting with designs based on land use and land cover, to capture the connectivity needs of the majority of species. Corridors should be prioritized that connect habitat patches to sites where the future climate will be similar to the current climate in the habitat patch and incorporate climate refugia.

AGRICULTURE

California produces over half of the nation's specialty crops, including fruits, vegetables, nuts, flowers, and nursery crops. Many of these crops, including fruit and nut trees, are particularly vulnerable to climate change impacts such as altered temperatures and stress from warmth and dryness. Climate change impacts to California agriculture will add to ongoing challenges from conversion of agricultural land to urban areas and regulatory challenges. California agriculture is projected to experience lower crop yields due to extreme heat waves, heat stress and increased water needs of crops and livestock (particularly during dry and warm years), and changes in pest and disease threats. Many of these impacts can be lessened through on-farm management practices, technological advances, and incorporation of climate change risks in decision-making. A Fourth Assessment study suggests that climate-related crop losses will be less than impacts associated with the loss of water supply and conversion of agricultural lands to other uses.

An analysis of crops, dairies, and beef cattle in California based on historical and projected climate conditions suggests that agriculture will continue to thrive through 2050, although with a reduction of 5 to 15% in gross crop revenues, assuming reductions in irrigation water. When proper growing conditions exist, farms may rely on the production of higher value crops to cope with rising opportunity costs of water and land. The high demand for specialty crops means that production of these crops will continue, while field and grain crops may face more important decreases in irrigated area and associated loss of agricultural jobs.

IMPACT FROM CLIMATE CHANGE: A secondary, but large, effect of droughts is the increased extraction of groundwater from aquifers in the Central Valley, primarily for agricultural uses. The pumping can lead to subsidence of ground levels, which around the San Joaquin-Sacramento Delta has been measured at over three-quarters of an inch per year. This subsidence impacts the canals that deliver water across the region.

ACTION FOR RESILIENCE: Flooding of some types of agricultural fields during wet years can provide some additional groundwater recharge, which can be used to support agriculture through longer droughts. This could be an important adaptation option considering the loss of snowpack forecasted for the rest of this century. California's Sustainable Groundwater Management Act will also reduce groundwater overdraft, and guidance for incorporating climate change projections will increase resilience.

IMPACT FROM CLIMATE CHANGE: Agricultural production could face climate-related water shortages of up to 16% in certain regions. Regardless of whether California receives more or less annual precipitation in the future, the state will be dryer because hotter conditions will increase the loss of soil moisture.

ACTION FOR RESILIENCE: Increasing soil organic matter by 3% by applying a ¼ inch of compost could increase the soil water holding capacity by up to 4.7 million acre-feet if applied to all working lands in California.

California's agriculture produces a high diversity of crops, and depends on water that is frequently imported from other parts of the state or western US. Photo:Patrick Huber

Impacts of Climate Change on the Ocean and Coast

California's iconic shoreline is integral to the state's identity, but climate change is rapidly changing the ocean and coast. The coastal region, which stretches over 1,200 miles of shoreline, is an economic powerhouse that contributed $41.1 billion to the state's GDP, provided $19.3 billion in wages and salaries, and supplied 502,073 jobs in 2013. Rising sea levels, warming ocean waters, increasing acidity, and decreasing dissolved oxygen levels will have effects that ripple far beyond the three-quarters of Californians who live in coastal counties. The Fourth Assessment included a Coast and Ocean Summary Report for the first time; this report synthesizes the latest research – touched on below – about the challenges facing our coast and ocean because of climate change and what actions we can take to increase their resilience.

OCEAN WARMING

California has recently experienced unprecedented events along its coasts including a historic marine heat wave, record harmful algal blooms, fisheries closures, and a significant loss of northern kelp forests. These events increase concern that coastal and marine ecosystems are being transformed, degraded, or lost due to climate change impacts, particularly sea-level rise, ocean acidification, and warming. From 1900 to 2016, California's coastal oceans warmed by 1.26 °F. "The Blob," a very warm patch of ocean water off the coast of California from 2013-2016, demonstrated that anomalously warm ocean temperatures can produce unprecedented events, including the mass abandonment of sea lion pups and California's record-setting drought.

RISING SEA LEVELS

Building resilience to sea-level rise in California requires approaches tailored to communities' needs, climate impacts, and many other factors. Options to protect communities and ecosystems include combinations of armoring, natural infrastructure, and hybrid approaches. Decision-makers need tools to evaluate the economic and environmental costs and benefits of alternative strategies with more complete information. The Fourth Assessment contributed to this need

The CoSMoS tool permits assessment of flood risk for all parts of California. This image shows the San Diego Harbor with a 4.9 foot sea level rise and with or without a 100-Year storm.

IMPACT FROM CLIMATE CHANGE: A new model estimates that, under mid to high sea-level rise scenarios, 31 to 67% of Southern California beaches may completely erode by 2100 without large-scale human interventions. Damages in the state's major population areas could reach nearly $17.9 billion from inundation of residential and commercial buildings under 20 inches of sea-level rise, which is close to the 95th percentile of potential sea-level rise by the middle of this century. A 100-year coastal flood, on top of this level of sea-level rise, would almost double the costs.

ACTION FOR RESILIENCE: A Fourth Assessment study developed technical guidance on design and implementation of natural infrastructure for adaptation to sea-level rise, such as the use of vegetated dunes, marsh sills, and native oyster reefs. This research included case studies on existing natural shoreline infrastructure projects at five sites spanning from Humboldt to Los Angeles counties that show promising approaches to increase resilience to sea-level rise and other benefits.

This site in Ventura County showed severe coastal erosion in 1990. A managed retreat of infrastructure from the waterline provided adequate space for restoration using cobble, sand, and dune plantings. To learn more about this project and other case studies, see the brochure "Case Studies of Natural Shoreline Infrastructure in Coastal California" that was prepared as part of the Fourth Assessment.

A Fourth Assessment study found that sea-level rise has become the dominant concern for coastal managers, and most also face funding and financing barriers.

by supporting the expansion of CoSMoS – a tool that can simulate sea-level rise in combination with storm events and other coastal dynamics – to include Southern California.

Coastal protection strategies can include the restoration of tidal marshes, judiciously-placed coastal armoring, and beach renourishment for highly accessed urban locations (e.g., adding large volumes of sand, an expensive solution lasting only 1-2 years). However, by 2050, with increasing sea-level rise and coastal storms, localities may begin to consider retreat strategies.

The restoration of marine plants and seaweeds in coastal environments is a tactic that could increase dissolved oxygen levels, at least for local areas. Ocean and coastal vegetation including marshes also sequester carbon, and quantifying the locations and contributions that marine plants can make to reducing carbon dioxide in local waters is needed. Other actions include reducing nutrient runoff from sewage disposal and excess agricultural fertilizer.

OCEAN CONDITIONS

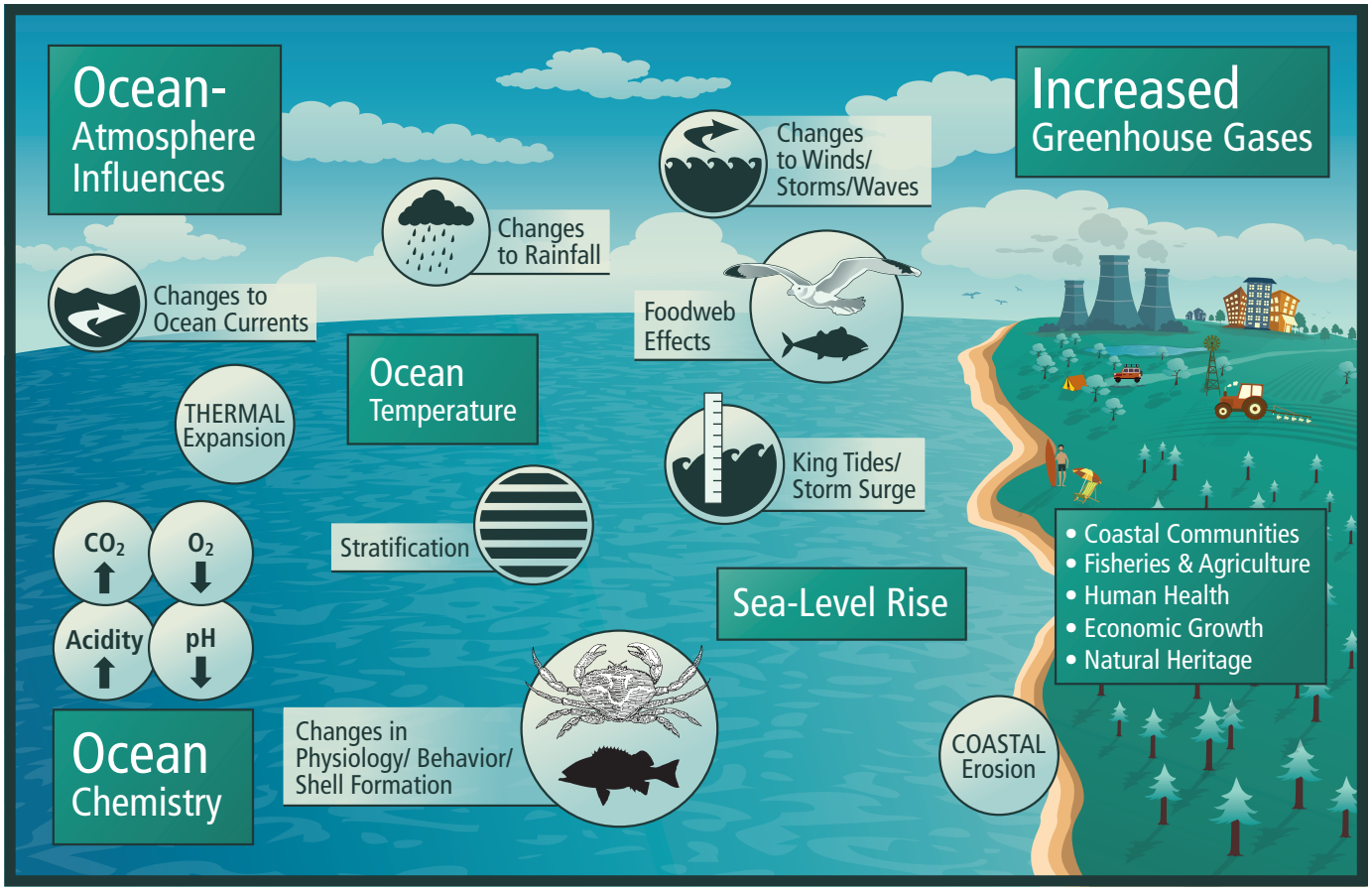
The ocean has been absorbing atmospheric carbon dioxide, which diminishes the amount of greenhouse gases in the atmosphere and slows the rate of climate warming but causes the ocean to become more acidic. However, its capacity to do so will decrease. Improving our understanding of the overlapping effects of rising

temperature, ocean acidification, and identifying potential survival thresholds for species or ecosystems will allow us to make better-informed decisions and improve management options to reduce future losses and impacts.

Ocean warming, ocean chemistry changes, sea-level rise, and other greenhouse gas-driven changes to California's ocean and coast – those already occurring and projected – will have significant consequences for California's coastal economy, communities, ecosystems, culture, and heritage. Reducing greenhouse gas emissions is the most effective long-term solution to man-made climate change and ocean acidification.

IMPACT FROM CLIMATE CHANGE: Climate extremes and ocean acidification are already impacting shellfish in California. Acidification affects shell-building species by decreasing the carbonate ions available in the water that they need to build their shells, causing larvae to essentially dissolve at certain acidities.

ACTION FOR RESILIENCE: A Fourth Assessment study found a species of mussel can be an important "indicator species" for California to help us understand the biological and chemical processes altering ocean waters, potentially pointing the way to strategies that are more effective for mitigating the harmful effects of acidification.



Climate change can affect many parts of the ocean ecosystem including what species can live in the ocean, foodwebs, winds and storms, ocean currents, sea level rise, and ocean chemistry, particularly the acidity of the water and the level of dissolved oxygen held in the water.

Building Capacity to Address Local Impacts

For climate adaptation to be effective there is a need for action from all levels of government. Adaptation planning and actions at the community level will need regional and local context. The sector-specific analyses and advanced projections developed as part of the Fourth Assessment are key to increasing resilience against natural disasters and enabling effective local action.

EMERGENCY MANAGEMENT AND DISASTER PREVENTION

Climate change is making major disasters more frequent and destructive, and emergency managers are starting to ensure their capacity matches growing challenges. A Fourth Assessment study found that $1.7 billion of critical facilities for emergency response, like dispatch centers and fire stations, are at risk to wildfire or flood damage by 2100, and researchers developed a tool to assess emergency infrastructure vulnerability.

IMPACT FROM CLIMATE CHANGE: In the City of Los Angeles, eight days of power disruption due to a prolonged heat wave would pose critical threats to lifeline systems such as treated water, supplies, and access to air conditioning.

ACTION FOR RESILIENCE: Integrated maps of interconnected emergency services systems can help make practitioners more aware of the importance of cascading events and geographically-connected impacts (teleconnections) and can support effective efforts to prevent or otherwise mitigate them.

Another Fourth Assessment study shows that interconnected systems are vulnerable to disasters in ways that may be beyond the traditional jurisdictional scope of local emergency managers. Maps of interconnected lifeline systems will be needed to recognize and prepare for cascading effects of climate impacts.

Proactive planning for future urban growth will be particularly important to avoid loss of life and property in the future. Avoiding residential growth in areas at high risk of wildfire and other forms of "climate-smart development" will be critical to reducing vulnerability to climate change. Future research is needed on the interplay between climate risk and development patterns.

LOCAL AND REGIONAL GOVERNMENTS

In order to address the impacts of climate change, California's local and regional governments must build institutional capacity to ensure the resilience of individuals, communities, natural systems, and infrastructure. The Fourth Assessment explores the social aspects of preparing people and communities to grapple with and adapt to the imminent impacts of climate change, particularly in light of the high cost of natural disasters and other climate change-related events.

In addition to the social aspects of preparing communities for the impacts of natural disasters and recovery, local governments must identify strategies to deal with the financial burden estimated to be in the tens of billions of dollars. Given the potentially high cost of inaction, climate adaptation is a highly cost-effective option for governments to pursue.

A Fourth Assessment study found that models that can quantify risks to people's assets can help engage stakeholders who may be reluctant to participate in discussions of climate vulnerability and adaptation by allowing them to see how their communities will experience the impacts of extreme climate-related events.

While California's three prior climate change assessments were focused on developing climate models and assessing climate change impacts, the Fourth Assessment prioritized an additional focus: identifying actions for successful climate change adaptation across different sectors and regions.

IMPACT FROM CLIMATE CHANGE: A Fourth Assessment study found that funding and financing challenges are among the top barriers to adaptation, with these challenges exacerbated by a number of organizational barriers such as limited local government staff and lack of technical capacity, agency leadership, and stakeholder partnerships.

ACTION FOR RESILIENCE: As part of the Fourth Assessment, the Adaptation Capability Advancement Toolkit, termed Adapt-CA, was created to help local governments overcome common organizational barriers and advance their capability to implement climate change adaptation measures. The Toolkit can help local governments assess their existing capabilities for climate adaptation and identify concrete actions to advance their capabilities for more effective planning and implementation of climate change adaptation activities.

View the Adaptation Capability Advancement Toolkit (Adapt-CA) at:

www.arccacalifornia.org/adapt-ca

The Alliance of Regional Collaboratives for Climate Adaptation represents networks across California that are building resilience to regional impacts. It hosts the Adapt-CA Toolkit.

To support action at the local scale, the Fourth Assessment includes reports for 9 regions of the state. These summary reports were included for the first time as part of the State's assessment process in part because the vast majority of adaptation planning and implementation will happen at the local and regional scales. Each of these regional reports provides a summary of relevant climate impacts, adaptation solutions, and local initiatives. As previously mentioned, the Fourth Assessment also includes three summary reports on climate justice, tribal and indigenous communities, and the coast and ocean. Like the regional summary reports, each of these 3 reports was designed to catalyze discussions, planning, and actions to understand and address climate vulnerability.

The map on this page shows the regions and the icon for all 12 summary reports.

The Fourth Assessment produced nine regional reports and three topical reports to provide greater detail for the public on the climate change risks and potential adaptation strategies for California.

These reports, the statewide summary report, 44 technical research reports, and other resources are available on the Fourth Assessment website:

www.ClimateAssessment.ca.gov

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